A Global Survey of Deep Underground Facilities; Examples of Geotechnical and Engineering Capabilities, Achievements, Challenges

(Mines, Shafts, Tunnels, Deep Pits, Boreholes, Sites and Underground Facilities for Nuclear Waste and Physics R&D):
A Guide to Interactive Global Map Layers, Table Database, References and Notes – Revision 1

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Revision 01 April, 2018 INL/EXT-17-42285-Rev1 LA-UR-17-24967-Rev1	• Editorial corrections: text, references, and tables. • Modifications to report Sections 1-7 to accommodate addition of Table 5 (Deep open pit mines) and sections of report (Section 6, 6.1-6.4) describing open pits map layer, table, references and notes, and discussion. • Addition of Section 7 (Summary). • Changes to Tables 1- 4: minor content changes, site location adjustments, and editorial corrections; modification of some site descriptive text; some additional references. • Addition of references and notes for Tables 1-4. • Addition of Section 6, “Table 5 (Deep Open Pit mines)”, “Table 5 References and Notes”, and Table A1-5 data supporting incorporation of GIS map layer 5 (Table 5 database) in online interactive map suite at https://gis.inl.gov/GlobalSurvey . • Reflects change of GIS URL site for online map suite from http://gis.inl.gov/globalsites/ to https://gis.inl.gov/GlobalSurvey; added map layer for Table 5 • Addition of Appendix 2, user guide to http://gis.inl.gov/GlobalSurvey/ for online interactive map tool.

ABSTRACT:

This report presents tables, references, notes, and a synthesis of some notable geotechnical and engineering information that were applied in the creation of five interactive layer maps [http://gis.inl.gov/globalsites/ will redirect to 2018 update, http://gis.inl.gov/GlobalSurvey/] for selected: 1) deep mines and shafts; 2) existing, considered or planned radioactive waste management deep underground studies or disposal facilities 3) deep large diameter boreholes, 4) physics underground laboratories and facilities, and 5) deep open pit mines from around the world. These data are intended to facilitate user access to basic information and references regarding "deep underground" facilities, history, activities, and plans. In general, the interactive maps and database provide each facility's approximate site location, geology, and engineered features (e.g.: access, geometry, depth, diameter, year of operations, groundwater, lithology, host unit name and age, basin; operator, management organization, geographic data, nearby cultural features, other). Although the survey is not all encompassing, it is a comprehensive review of many of the significant existing and historical underground facilities discussed in the literature addressing radioactive waste management and deep mined geologic disposal safety systems. The interactive map suite allows for a better appreciation of site area geographic and cultural settings. The global survey is intended to be used as a communication tool to support and inform: 1) interested parties and decision makers; 2) radioactive waste disposal and siting option evaluations, and 3) safety case development applicable to any mined geologic disposal facility as a demonstration (examples) of historical and current engineering and geotechnical capabilities available for use in deep underground facility siting, planning, construction, operations and monitoring.

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SECTION 1: GLOBAL SURVEY

Section 1.1 – Introduction

The extraction and utilization of the Earth's natural resources through human activities has presented an ever increasing challenge for the species as culture and civilization evolved over the millennia. With changes in the nature of powering and sustaining the evolving civilizations, production and supply systems grew in complexity; concomitant with evolution of these systems was increased complexity in the management and removal of waste products from the areas of human habitation (Today, waste disposal may require not just removal of waste, but that the waste may be contained and isolated from the accessible environment for the long-term). Underground activities have progressed from shallow near-surface (e.g., pits) to intermediate depth excavations (e.g., shallow mine shaft construction, digging wells, and tunnels developed for military purposes or for underground "cities"); some of these latter "facilities" have lasted for thousands of years. More recently (years to centuries, not millennia) drilling and mining for deep resources (coal, oil, gas, water, and geothermal energy) became possible. Advances in engineering, technology and science, knowledge gained from deep underground mining, drilling technology advances, operation of underground R&D science laboratories, development of underground storage or disposal facilities (solids, liquids, or gas, super-critical fluids) have resulted in improved exploration and characterization processes with enhanced safety systems that are applicable to improvement of resource development and material storage or disposal systems. This report should help inform interested users and promote confidence in assuring feasibility of developing underground facilities by demonstrating capabilities (and limitations) of engineering and science to planning, construction, operation, and monitoring of existing underground facilities. Humans are exploring for and exploiting resources at deeper zones within the earth by mining and drilling. Large subsurface rooms (stable for generations) have been excavated for resource exploitation or science investigations within a large range of subsurface depths and in a variety of rock types. This survey of underground facilities and sites may help build confidence that the technologies, and engineering / science required for safe deep underground activities generally exist. Data for the included facilities and sites could be useful in a number of subsurface study applications (geothermal, seismic, waste management and disposal, carbon sequestration, oil and gas industry).

The report presents a synthesis of geotechnical and engineering information for selected notable underground facilities and sites that are used to create five interactive global map layers for: 1) deep mines and shafts; 2) existing, considered or planned nuclear waste management deep underground studies or disposal facilities 3) deep large diameter boreholes, 4) physics underground R&D laboratory facilities, and 5) deep open pit mines from around the world [original URL http://gis.inl.gov/globalsites/ will redirect user to a new platform developed to replace original, i.e., new site with Java Script presentation of interactive maps at http://gis.inl.gov/GlobalSurvey/ ; see *Appendix 2*, *User's Guide*]. The deepest mines and shafts of the world are included to show significant mining engineering capabilities and limitations; also featured are significant deep mining projects from the past or those currently planned for future development, with many of the ore zones located in crystalline rock (igneous and metamorphic). Historical and recent deep borehole drilling projects, in particular, deep large diameter boreholes and those penetrating significant sections of crystalline basement rock are included to demonstrate historical and existing drilling technology capabilities and challenges. Deep underground physics facilities and radioactive waste management disposal sites, proposed or existing site areas, and underground research laboratories and test sites are also tabulated for use with the associated interactive map tool. Deep open pit mines are incorporated to demonstrate the existence of large area surface pits excavated to equivalent depths of existing and planned underground disposal facilities. Many of the sites in this database are obtained from lists in the literature; source materials are identified in tables, references and in site locality map layer presentations. These data (Tables 1-5) and the map tool are intended to facilitate user access to basic information and references regarding "deep underground" facilities, activities, and plans. Interactive maps and database provide each facility's approximate site location, geology, and facility features (e.g.: access, geometry, year of operations, depth, groundwater, operator, lithology, host unit name and age, basin, related geographic data, type of testing, and other). The user may find it advantageous to examine the surveyed sites and data for a better understanding of geography and geology for underground facilities. The map layers and database may inform geotechnical investigations of high level radioactive waste disposal, carbon sequestration, geothermal projects, induced seismicity, evolution of sealing technologies, and development of deep underground monitoring and testing tools for the geosciences. Although the survey is not intended to be all inclusive, it is representative of many of the significant existing and historical underground facilities or sites discussed in the literature.

Improvements to the tabulated data are expected to be required as time passes given the scope of the exercise, changes introduced with evolving corporate site ownership and control, and international engineering, science, and governmental program management changes. Tabulated information was gathered over a period of several years. The first version of this document was produced in 2017; additional data and updates are incorporated in this revision. The report promotes what should be a useful approach (interactive map suite, information consolidation) in consideration of facility location, siting and safety case discussions and represents an initial attempt to help communicate technical issues in context of geographic and geologic settings. Comments are welcomed and others are encouraged to move the effort forward, possibly using these materials with an objective to improve the table content for future use.

Section 1.2 – Purpose

As a survey of deep underground "facilities", this study is intended to present an accessible online database of information, interactive map layers, tables, references, and links to online reference materials. This survey compiles some basic descriptive information in one place for each of the included localities for a variety of "facility" types:

1) For use by interested members of the public, decision makers, and students with online access; these interactive maps, databases, references, notes and links serve as a launching point for further study
2) To demonstrate global nature of underground science and engineering investigations
3) To highlight science and engineering capabilities and limitations, current and historic, for mined facilities and boreholes
4) For use by interested parties to facilitate study (introductory) or understanding of the geography, geology, design, testing, construction and operation of deep underground facilities and boreholes
5) To serve as a template for future updates, corrections, additions, or refinement of presentation format and content for tables and interactive map suite (e.g., refine location data, enhance geology description; tabulate information presented in database in more useable GIS-friendly format; incorporate new information such as database and interactive map projects (linking to geothermal investigations, carbon sequestration programs, global deep drilling projects, subsurface gas and liquid storage facilities, other)
6) To support and to inform nuclear waste disposal and siting option evaluations, and in support of safety case development as demonstration of engineering and geotechnical capabilities available for use in deep underground facility planning, construction, operations and monitoring.

Section 1.3 – Synopsis and Scope; Interactive Map Layers, Databases, and References / Notes

The content of the database of information (Tables 1-5) used for construction of the associated interactive maps (Map Layers 1-5; http://gis.inl.gov/GlobalSurvey/ and user guide, Appendix 2) was derived from literature sources (References and Notes supporting Tables 1-5), many containing lists of facilities or boreholes incorporated in this study. The reference section for each table and map layer contains numbered references identified in tables and map displays for specific sites. References are also grouped by "facility" type, general topics of interest. Site-specific numbered source reference with notes are provided for each site for each table. Every effort was made to use online source material and to provide links for ease of access by the user. Sources include online literature and websites (few exceptions) developed by government, industry, professional and international associations, and other R&D organizations. Site-specific information was obtained from existing compilations and enhanced with additional data from other sources as noted in tables. Precise location information was often difficult to obtain or to verify; approximate locations are used in many cases for a general area of interest (e.g., candidate site areas of the EU countries, Russian Federation sites, in particular, USSR era deep borehole sites; geothermal wells of Australia show general area within basin for sites). *Google Maps* and *Wikimapia.org* were often useful to cross-check location information; many locations were obtained from mining industry websites, corporate and R&D facility websites, and state databases. Database / table content (precise location and added technical information) could be enhanced with future revision and contributions from team members and users.

Table 1 (Mines) brings together data for deep mines and shafts, those currently in operation, historically significant ventures, and closed or planned mines. Information presented demonstrates operational capabilities exist for depth range of up to ~4 km. Table 1 also contains discussion and references for several groundwater residence time studies that indicate some deep mine crystalline formation pore waters have remained isolated for long periods (e.g., ~>1 billion years), while formation fracture water appear to have remained isolated for geologically shorter duration (e.g., 10s of millions of years). Table 2 (Repositories, URLs, Sites) presents a compilation of many of the globally distributed radioactive waste management underground research sites, some repository site locations, some current and former candidate sites or proposed testing locations, and existing disposal sites, repositories, and URLs. Table 3 (Boreholes) contains data on deep and large diameter boreholes from around the world to demonstrate drilling engineering capabilities, achievements, and limitations. In addition to the numerous onshore deep continental drilling projects included in Table 3, examples of "deep water" offshore drilling engineering capabilities are included as examples of challenging exploration and development boreholes (e.g., Gulf of Mexico deepest water drilling, horizontal extended reach; exploration and production record setting wells and platforms; well design features). Some offshore site data may be updated in later revisions to this study. Table 4 (Physics Facilities) compiles data for many physics underground science and engineering laboratories, and past and current candidate sites. Selected deep underground seismic investigations (e.g., in South Africa) are captured in Table 4 with redundant information found in Table 1 references and site information for deep mines. The geographic setting, geologic environment, depth, and seismic-related geophysical tests are the focus of Table 4, not the various astrophysics or particle physics testing programs. Table 4 could be better developed to describe the underground tests and facilities in future revisions to the report. Table 5 contains a selection of some of the world's larger and deepest open pit mines highlighting fact that these deep pits reach depths equivalent to or in excess of depth range considered for mined geologic repositories and URLs intended for nuclear waste studies or disposal.

Several recent and historical deep mines, boreholes, and underground test and research facilities identified in the database (Tables 1-5) have experienced problems during operations (some with disastrous outcome) likely due to bedrock (mechanical) or equipment problems, collapse, fire, flooding, induced seismicity, ventilation, other engineered component system failures, and human error. Although historical and recent disasters are not the focus of the study, examples and references are provided for the user to better understand technological and engineering capabilities, evolution, and limitations with exploration of / operations within deep underground geologic environments. Over time, safety measures have been implemented to reduce risk to workers from activities associated with the subsurface operations. Improvements in management, technology, engineering, continued R&D, monitoring, risk mitigation plans and improved warning systems lead to enhanced safety and health programs. These bode well for future advances in underground operational capabilities, and show promise for continued reduction of risk to worker safety and health.

An overview of each table with descriptions, database, references and notes supporting the 5 interactive map layers (deep shafts and mines; nuclear waste management repositories, URLs, sites; deep large diameter boreholes and drilling engineering; underground physics facilities; deep open pit mines) are presented below. "Topics for Discussion" are included for each table / map / reference suite (Sections 2.4, 3.4, 4.4, 5.4, and 6.4); these sections contain statements, assertions, and questions intended to encourage discussion, but no answers. These discussion topics for each map layer: 1) reflect several challenges and opportunities identified by the study; 2) are not representative of conclusions drawn by the U.S. Department of Energy nuclear waste management program., and 3) are intended to stimulate discussion concerning deep underground facility operations, R&D opportunities, and engineering and technical capabilities, limitations and challenges.

Notes are added to many references to assist user in the determination of the applicability to their needs for information contained in the reference document; supplemental data and notes are presented to identify source information and add to limited summary data contained in the tables. One or more links (weblink to source / URL) are provided for each reference; notes may include additional sources and related websites. Appendix 1 (Alphabetical Listings, Tables A1-1 to A1-5) incorporates elements (table number, item number, "facility" name, country, other) of the five tables (Mines; Repositories, URLs, Sites; Boreholes; Underground Physics Facilities; Deep Open Pit Mines) sorted in alphabetical order by "facility" name for each table to aid in the use of the GIS tool for each map layer and pop-up panel features associated with each site or facility available with use of the interactive map suite. Appendix 2 provides a user guide for the map tool (http://gis.inl.gov/GlobalSurvey/).

For each item / site, an attempt was made to provide lithology, geologic age / stage, and or rock unit names for host sequence and some important area geologic events or features. The reader is referred to the International Commission on Stratigraphy's (http://www.stratigraphy.org/index.php/ics-chart-timescale) *International Chronostratigraphic Chart, v2016* (http://www.stratigraphy.org/ICSchart/ChronostratChart2016-12.jpg) for absolute age correlation chart of the Phanerozoic and Precambrian time/rock systems, and additional time/rock references.

A number of studies describe technological, engineering, and science capabilities for exploring the deep subsurface rock environments, and are not limited to nuclear material disposal investigations. For example, an organization may be tasked with drilling a deep and / or a large-diameter borehole, or to excavate a mine shaft or tunnel, or challenged to develop a mined geologic repository, or to construct an underground research facility. A wealth of literature contains many examples of underground facilities and sites formerly considered or being considered for study. From examination of domestic and international literature (e.g., geothermal, carbon sequestration, waste management, oil and gas exploration, geochemistry of hydrocarbons and source rock, induced seismicity, economic geology and mining, characterization of sedimentary basins, geohydrology, groundwater residence time, and other), it was self-evident that accessible web-based site location survey maps could help tell a global story of (and applicable to) subsurface exploration and disposal R&D activities. Thus, it would be useful to have a variety of subsurface facility locations, geographic, geoscience, and historical information readily available for reference in one report and with online access to such basic information (GIS, map of sites and easy access to site data).

This study was initiated to develop an easily accessible interactive map suite and compilation of some of the available data in one place as a communication tool and resource. The intent was to include facilities and sites, current and historical, those commonly discussed in the literature and others that may prove helpful to the discussion of drilling and mining engineering capabilities (e.g., How deep could one drill or mine? How large a diameter borehole or excavation is possible for a given depth or rock type? What has been accomplished to demonstrate capabilities and limitations on facility design? Where is the site located? What is the geologic, cultural and geographic setting for the site area?). Several types of "facilities" seemed to provide information to address some of those questions: mines and shafts, underground geoscience or physics research facilities, deep boreholes, and deep open pit mines. For each type of subsurface facility, existing lists or compilations were identified and used to form the basis of this new compendium of "facilities" that would also include additional sites and facilities of interest. For example, online sources (e.g., domestic and international governmental, academic, private sector business / industry / websites and online publications) were identified that provided synthesis and listings of the deepest mines of the world, deepest or largest open pit mines of the world, the deepest gold mines in the world, the deepest mines in countries or on continents, the deepest boreholes, large diameter deep boreholes, drilling and mining engineering achievements described at professional annual meetings, compilations of radioactive waste disposal sites and characteristics, summary articles and listing of underground physics facilities. The survey also attempted to incorporate data in the report tables (information not captured in the online interactive site data) indicating status of international radioactive waste management programs for involved countries. The information is current to the extent practicable, but the majority of the data compilation occurred during 2014-2016.

In this survey, summary information and references are presented in the tables for each location by facility or site type. Tables and references are organized according to facility type to make presentation more user friendly. Several sites are included in two tables. References generally include website links for the operator, owner, or responsible party; notes on numerous references are included to assist the user seeking to perform a more thorough study of an aspect of interest. Users may also export tabulated data for mapping applications available through Google Earth or Google Maps.

SECTION 2: (Mines) DEEP MINES AND SHAFTS, MINING ENGINEERING

Section 2.1 - Map Layer 1 (Mines): Notable Deep Mines and Shafts, Deep / Large Diameter Shafts, Subsurface Mining Engineering Capabilities and Achievements

Interactive map Layer 1 (Mines) presents information from Table 1 of this report for the interested user to explore numerous deep mines and shafts of the world. Access interactive map Layer 1 (mines / deep mines and shafts) at http://gis.inl.gov/GlobalSurvey/ (User's Guide, Appendix 2, herein). As the user zooms in on the global map, site identifiers become evident. Currently, the GIS map system is set up to show deep mines and shafts sites first as the user zooms in on the world map. Site data associated with each layer must be activated for the site information to appear as pop-up panel when a site is selected / right-clicked on the map site symbol. This is described in Appendix 2; selection of the site on the GIS global map generates pop-up panel with associated data for the specified site derived from one of the 5 tables (five map layers) from this report. Appendix 1 Table A1-1 lists all deep mine sites (of Table 1) in alphabetical order with Item Number and country.

Section 2.2 - Table 1 (Mines): Notable Deep Mines and Shafts, Deep / Large Diameter Shafts, Subsurface Mining Engineering Capabilities and Achievements

Table 1 serves as input to development of map Layer 1 (mines, mines and shafts, deep mines) and presents the world's deepest mines and shafts and other selected deep mines of historical importance or those that help illustrate mining engineering capabilities and achievements, and mining technologies that now permit access to ore bodies in the depth range ~ 1-4 km+. Private industry, academics and government parties are currently conducting R&D to facilitate development of safe and cost effective mining technologies that will allow for operations at depths in excess of 4-5 km. The included mines commonly exploit mineral resources in "crystalline" (e.g., meta-sedimentary or granitic) rock. Several mining ventures in salt or other sedimentary units (e.g., coal, limestone) are included because they are of historical significance (e.g., depth record), or the underground workings are extensive (10s to hundreds km of tunnels). Others are included because shaft diameter, depth, or other subsurface engineered design features demonstrate engineering capabilities that may be of general interest in various programs. However, the purpose of this study (this report and interactive maps, http://gis.inl.gov/GlobalSurvey/) is to permit rapid examination of site summary information (e.g., location, geology, selected design features, groundwater residence time, access shaft depth and diameter) about the world's deepest mines, historically significant mines, and some more recent existing or planned deep mining ventures employing state-of-the-art mining technologies. Table 1 *explanation* includes key and acronyms used in table. Appendix 1 (Table A1-1) presents an alphabetical listing of deep mine sites of Table 1.

Section 2.3 - Table 1 References (#1-159) and Notes Supporting Map Layer 1 (Mines)

The reference section of this report **c**ontains numbered references and notes (#1-159) that are cited in Table 1 database and in each deep mine site pop-up data panel at http://gis.inl.gov/GlobalSurvey/.

Section 2.4 – Table 1 Topics for Discussion:

Mine shafts in "crystalline" hard rock included in Table 1 may reach depths of 2 to ~4km; several mining operations exploit ore at depths in excess of ~3 to > 4km. Literature review revealed deep shaft construction may be preceded by drilling of vertical deep (~7.5") relatively large diameter guide holes in preparation for (blind") vertical shaft and raised bore construction. Mine shafts to depths of 1-3km are often 10-18' in diameter; some have a larger diameter. Hoists for rock removal from deep mines and other activities show lift capacity could exist to move UNF/SNF and HLNW to and from great depth. Pioneering advances in engineering, drilling and shaft construction technology resulted from contributions of the U.S. AEC / DOE / National Laboratories, and engineering companies (e.g., AEC Plowshares program). Underground studies for waste management and disposal R&D could benefit from partnering with current mine operators in subsurface investigations, tool development, and other engineering, mining, and testing activities (e.g., LBNL studies at Homestake / Sanford Laboratory). Existing deep mines and other prospect excavations could be considered for SNF/HLW underground research (e.g., induced seismic investigations in South African mines; Sanford Laboratory geotechnical investigations). The feasibility of deeper disposal options (also see Table 2, URLs and Section 6.4) could be explored beyond current general <~500m depth limit often under consideration by various national mined geologic waste disposal programs (See Section 3.4, and 6.4). R&D could be conducted to examine multi-layer repository option in deep mines. What does successful operational activities for deep mines and shafts offer for building confidence in capabilities to successfully handle, emplace, and potentially retrieve nuclear waste for a deep geologic mined repository? A tendency to limit repository and test operations to 300-500m depth range may not be warranted given current deep mining capabilities.

SECTION 3: (Repositories, URLs, Sites) RADIOACTIVE WASTE MANAGEMENT AND UNDERGROUND DISPOSAL, RESEARCH LABORATORIES, SITES, R&D

Section 3.1 - Map Layer 2 (Repositories, URLs, Sites): Past, Planned, and Operating Underground Research Laboratories [URLs]

Map Layer 2 (Repositories, URLs, Sites) presents information from Table 2 as an interactive map for the interested user. Access interactive Map Layer 2 at http://gis.inl.gov/GlobalSurvey/. To examine map layer information for a site included in Table 2 "URLs and Repositories, Sites", see Section 2.1 and the *User Guide* in Appendix 2.

Section 3.2 - Table 2 (Repositories, URLs, Sites): Past, Planned, and Operating Underground Research Laboratories [URLs]; Past, Present, Selected, and Candidate URL and Repository Sites or Areas

Table 2 database presents an introduction to the current and historical international radioactive waste management community's underground research laboratories (URLs), historical underground test facilities, disposal sites, candidate sites, and considered sites. The table contains site name, identifying number, approximate location for the site, other facility location information, access (tunnel or shaft depth and diameter / geometry), depth and types of testing conducted, geology and age of the host unit. The national plan for URL or repository site development are indicated in Table 2 for those sites where the information may be readily obtained from web sources (e.g., Reference 167a) and online published government, academic, and corporate materials. NEA, IAEA and EDRAM and other source (References 160-167a; checked with Reference 167b) information on repositories and URLs around the world were used to develop the table along with other general sources of data (General references 167-189). Table 2 *explanation* includes key and acronyms used in table. The table is color coded for the geologic nature of the expected disposal or study host unit (salt = yellow; argillite = grey; crystalline = pink; other). Locations of example sites previously considered during a half century of the U.S. DOE and AEC siting and testing exercises are also incorporated in this survey (http://gis.inl.gov/GlobalSurvey/); for several DOE considered sites, the information is captured in the table, but are not included in map layer online. Similarly, Table 1 of this report captures information about international disposal programs not presented in the online interactive map site survey. See Appendix 1 (Table A1-2) for alphabetical listing of sites and a cross walk of items in table with chapters in Reference 167a.

Section 3.3 - Table 2 References (# 160 – 469f) and Notes Supporting Map Layer 2 (Repositories, URLs, Sites)

Numbered references and notes are cited in Table 2 database (Repositories, URLs, sites) reference column; access to Table 2 references is facilitated by including URL / online access links in each reference #160-469f. These numbered references are included within each site's data pop-up panel in map layer for repositories, URLs, and "sites" (map layer 2, at http://gis.inl.gov/GlobalSurvey/).

Section 3.4 – Table 2 Topics for discussion

Many countries are involved with siting deep underground geologic repositories and test facilities (URLs); an arduous site selection process continues in several countries, but was completed in others (e.g., Finland). The U.S. has conducted or considered underground studies for disposal of radioactive waste in salt, argillite, tuff, and crystalline rock; numerous sites were evaluated in the 1960s to 1980s. A tendency to limit repository and URL operations to 300-500m depth may not be warranted (see Section 2.4). Depth of planned repository operations could be increased (e.g., doubled, tripled) given current mining capabilities. Proper design and ground support will ensure safe operations at depths well beyond current practice of limiting repository operations and emplacement depth to shallower zones. Deeper URL and repository development may enhance long term safety, although potentially increasing risk to workers during construction. Consideration of deeper repositories and URLs may permit greater depth for disposal and alternative (e.g., layered) repository design. Many existing types of facilities may be used for conduct of geotechnical and geophysical testing programs (e.g., Table 1 and Table 4, South African Mines). Participation in international R&D projects is beneficial for the domestic SNF/HLW disposal program. Testing results from generic and site specific facilities may increase confidence in national disposal program safety cases around the globe.

Reference 167a (Faybishenko et al., 2016) supplies links that will direct the user to the most recent presentation of the international approaches for deep geological disposal of nuclear waste; it constitutes a key document summarizing international program status for disposal, R&D, and siting with a wealth of more detailed information available for discussion. For each site in Table 2, Appendix 1 (Table A1-2) presents an alphabetized list and a cross-walk of site or country with chapters in Reference 167a. Reference 167b (Apted and Ahn, 2017) provides a wealth of detailed information about international disposal programs also reflected in this survey.

SECTION 4: (Boreholes) DEEP LARGE DIAMETER BOREHOLES, DRILLING ENGINEERING

Section 4.1 - Map Layer 3 (Boreholes): Drilling Engineering Achievements and Examples

Access to interactive map Layer 3 (boreholes, deep large diameter boreholes) is at http://gis.inl.gov/GlobalSurvey/. Each facility or site on the global map for map Layer 3 (Boreholes) may be right-clicked in order to view associated site information from Table 3. To examine information for a site included in Table 3 "Boreholes, deep boreholes, large diameter boreholes", see Section 2.1 and Appendix 2 for interactive map layer *user guide*. The layer site data activation process is described in Appendix 2. This map layer includes many of the world's deepest and operationally challenging (in drilling and testing) industry and scientific boreholes, examples of deep water and directional drilling milestones, geothermal projects, and large diameter deep holes drilled for underground nuclear test related programs (e.g., AEC Plowshares program representing early efforts to drill large diameter deep boreholes for testing. Several of these boreholes represent early large scale fracturing / fracking testing programs designed to enhance permeability and flow in gas reservoirs).

Section 4.2 - Table 3 (Boreholes): Drilling Engineering Achievements and Examples: Deep and / or Large Diameter Boreholes, Crystalline / Granite Tests, Deep Continental Crust Drilling, Characterization, Exploration and Exploitation Boreholes

Table 3 (Boreholes) database reflects current and historical drilling engineering technologies and capabilities that illustrate some aspects of drilling engineering limitations and advances over the past 60 years. The presentation of selected historical and recent deep large diameter borehole drilling efforts displayed as map Layer 3 (Boreholes) is the focus of borehole information discussed in this global survey. Inclusion of boreholes drilled into basement crystalline rock was an important consideration; this resulted in the inclusion of several geothermal boreholes and projects from around the globe. Similarly, a number of international Continental Drilling Program wells are presented as examples of deep large diameter boreholes drilled in various lithologic types, but commonly are in basement crystalline units. Borehole depth, diameter, lithology, and location are presented for each site in this survey with some exceptions noted in table. Many of the deep large diameter boreholes discussed in the literature related to deep borehole (including disposal) projects are incorporated to provide interested parties an opportunity to locate such project areas and assist in facilitating better understanding of cultural, and geographic settings, and the evolving geotechnical and drilling engineering capabilities and challenges (e.g., feasibility of waste emplacement at 3-5 km depth in boreholes within crystalline basement rock). Several deep boreholes are included for the harsh environments encountered in drilling the well (e.g., thermal issues, well control problems, caustic water); several geothermal wells and projects are inluded. CO2 sequestration R&D drilling activities, underground liquid or gas storage, and other geothermal projects not examined in detail during this exercise could be added in future updates to the study (later may add to http://gis.inl.gov/GlobalSurvey/). Table 3 *explanation* includes key and acronyms used in table. See Appendix 1 (Table A1-3) for alphabetical listing of boreholes found on the interactive map derived from Table 3 data.

Section 4.3 - Table 3 References (# 470 – 609f) and Notes Supporting Map Layer 3 (Boreholes)

For access to Table 3 references and notes (boreholes), see numbered references 470-609f, herein; the reference numbers for each site are shown in each location pop-up panel found at http://gis.inl.gov/GlobalSurvey/.

Section 4.4 – Table 3 Topics for Discussion

Numerous large diameter deep boreholes (depths in excess of 5km) have been drilled in igneous and metamorphic units during the past ~50 years; thus, the technology appears to exist to drill deep large diameter holes to depths beyond 5km. Financial constraints and purpose of a project may determine borehole diameter rather than limitations in technical capability. Considerable advances in drilling (large diameter) and drilled “shaft” construction technology were developed by AEC / DOE / U.S. National Laboratories during weapons testing and Plowshares projects (1960s, 1970s; e.g. Amchitka Cannikin test, Rulison, Rio Blanco, Gnome in Table 3, herein). Radioactive waste retrieval from disposal sites appears to be possible with current drilling and mining operational technology, but may not yet have been demonstrated for a 3-5km deep crystalline rock disposal zone. The disposal package for a mined or drilled geologic disposal system should be designed for waste retrieval for a set period of time post-emplacement; sealing and spacer material may be designed for removal should it be necessary. If current drilling operations and technical capabilities appear to prove insufficient for recovery and removal of radioactive waste materials emplaced in a deep borehole or mined deep geologic repository system, recognize that technology may already exist that would potentially permit retrieval, e.g., 1) sinking blind shafts to >4km depths to recover waste as suggested by information in Table 1; 2) directional drilling advanced sufficiently to permit alternative access route to borehole or mine for retrieval purposes as suggested by borehole activities evident from information in Table 3, and 3) application of robotics and remote control in deep subsurface excavation operations as suggested by activities associated with operations at sites presented in Tables 1 and 3. Excavation of shafts to ~>3km depth has been proven, and industry is conducting R&D to accomplish safe mining to depths of 5km. Literature indicates shafts are much easier to stabilize than horizontal drifts. Technology advances permit better well control and stabilization than in past. Although retrieval from deep borehole or closed deep mine may be technologically possible, it constitutes an economic and technical challenge, is likely a high risk objective, but may not be an impossible venture (e.g., Climax SFT; Project Salt Vault). Deep borehole disposal may be accomplished with existing technology; retrieval may be possible with existing technologies from mining and drilling industries, although costly and somewhat risky. Precise vertical and directional drilling capabilities are evident from site activities described in Table 3 (e.g., Gulf of Mexico Tiber, Perdido, Macondo, Cardamom Field; San Jose rescue) and Table 1. These have implications not just for waste retrieval, but for operational and post closure system monitoring.

Reference 549b presents one of the best available general information summaries of a complex and challenging deepwater hydrocarbon production project, the Jack/St. Malo fields, Gulf of Mexico. That report is well illustrated and informative as an introduction to the engineering challenges faced and how they were addressed in the design and development process for deep water)and reservoir unit (e.g., 7000’ water depth; ~28,000’ total depth; high temperature and pressure environment; 1000’-1400’ pay interval).

SECTION 5: PHYSICS UNDERGROUND RESEARCH FACILITIES

Section 5.1 - Map Layer 4 (Physics Facilities): Selected Physics Underground Research Laboratories (URLs) and Facilities

Access interactive map Layer 4 (Underground physics facilities) at http://gis.inl.gov/GlobalSurvey/. Selected significant international, historical, candidate (former and existing) and current underground physics testing sites are included for examination by the user. Each facility or site on the global map for map Layer 4 (physics facilities) may be selected on the global interactive map in order to view associated site information in pop-up panel for data taken from Table 4, as discussed in Section 2.1, and in Appendix 2. The layer site data activation process is described in Appendix 2, *User Guide* for the Global Survey map tool.

Section 5.2 - Table 4: Selected Physics Underground Research Laboratories (URLs) and Facilities; Existing, Proposed, Candidate, Former R&D Facilities and Former Candidate Sites (Database)

Table 4 (Physics underground research laboratories / facilities / sites) database presents considered, planned, existing current and historical underground physics laboratories and test facilities, candidate sites and former candidate sites; many are hosted in crystalline basement units, while others are in sedimentary sequences (salt, argillite, limestone). These sites are included to indicate the existence of underground R&D programs not tied to radioactive waste management and disposal and to identify possible sources of geotechnical and engineering information that could be of use in radioactive waste management siting and characterization studies. Many of the important international science / physics / astrophysics RD&D sites of the past and present (or those proposed) are incorporated in this study although the list is not comprehensive. Data presented in Table 4 are the least developed for this global survey exercise. Content could be substantially improved in the future with additions to include those sites and other geologic information currently omitted in this survey. The focus of Table 4 compilation (map Layer 4, http://gis.inl.gov/GlobalSurvey/) is not the physics-related research conducted at an underground laboratory, but site characteristics and location / cultural setting, geology and geophysical studies. The interested party is directed to reference material as a launching point for detailed study of physics investigations. Table 4 *explanation* includes key and acronyms used in table. See Appendix 1 (Table A1-4) for alphabetical listing of sites in Table 4.

Section 5.3 - Table 4 References (#610-741a) and Notes Supporting Map Layer 4 (Physics Facilities)

For access to Table 4 references and notes (References 610-741), see below; reference numbers are included in pop-up information panel for individual sites included in Table 4 when using interactive map Layer 4 (Physics Facilities; http://gis.inl.gov/GlobalSurvey/).

Section 5.4 – Table 4 Topics for Discussion

Radioactive Waste Management and physics URLs / facilities are generally less than 500m deep (below ground level); several physics facilities and testing zones are 1-2+ km below ground level. Instrumented geophysical studies (monitoring; induced seismic; fault activity) in mines are located up to 3+km depth (e.g., South African mines; JAGUARS / NELSAM / DAFSAM / SATREPS, Table 4). It is common for physics and radioactive waste management underground test facilities to be constructed in association with an existing facility (e.g., rail or road tunnel, mine). Safe mining operations and testing are conducted at depths well beyond 1-2 km below ground level (bgl). Depths of 1-3 km or greater could be considered for generic radioactive waste mined geologic disposal option evaluations; use of existing deep mining facilities and partnering with industry could be considered for future testing (also see Map Layer 1). Underground physics testing facilities often include construction of very large test chambers and rooms to accommodate large test equipment. Like many mines, the rooms have remained stable for a generation or more (~25-50 years); complex large scale underground construction engineering and test activities are safely accomplished. Lessons learned in those facilities may apply to siting, characterization, construction, operation and monitoring of mined geologic disposal facilities.

SECTION 6: (Pits) LARGE DEEP OPEN PIT MINES

Table 5 and interactive map Layer 5 (open pit mines, http://gis.inl.gov/GlobalSurvey/) present a summary of some of the world's largest and deepest open pit mines constructed during the 20th and early 21st centuries. During the last century, it had become technically and economically feasible to develop large deep open pit mining operations to supply some of the most valuable commodities (e.g., Au, Ag, Cu, Mo, diamonds, and Fe) in order to support the modern world's technology-oriented industrial society and associated cultural practices. Pits have been excavated to depths >1 km (>3000'). Commonly, these pits are located in areas characterized by crystalline "basement" rock (igneous and metamorphic complexes; meta-volcanic, metasedimentary; hydrothermally altered) for exploiting either or both concentrated or disseminated mineral resources.

Background:

Mining, metals, rocks and minerals have played a crucial role in human cultural development. People have used lithic material for a variety of purposes since hominins began making stone tools about >2-2.5mya (very Early Stone Age). Ancient peoples mined surface pits and the shallow underground for pigments (e.g., red ochre, hematite) for 10s of thousands of years. Neolithic groups mined the subsurface using shafts and tunnels, and surface pit exploitation for mining flint / chert (Reference 850). The advancement out of the late or New Stone Age culture (Neolithic; the agricultural revolution, first farming settlements, pottery; initiated ~4000 to 10000 BCE / Before Common Era) to more complex cultures was transitional in nature and varied geographically and temporally around the globe. The "post-Stone Age" cultural transition generally progressed within a region in stages, and time boundaries between stages are blurred globally. Age ranges [generally expressed as i) *BCE*, Before the Common Era; ii) *CE*, the Common Era] provided below are for various regional stages found in the literature. Surface mining and trade played an important role as did advances in metallurgical technologies and other important cultural developments as humans advanced beyond the "simple" Stone Age culture:

1) *Chalcolithic culture* [copper / stone], evidence of heating and smelting copper initiated ~5500 BCE, ~4500-2300 BCE, 3000-1700BCE, varied geographically; the use of stone and metals (such as native copper or gold used 5000 -7000 BCE). Evidence of metallurgy and smelting of native metal ore for the production of tools, weapons, and decorative items, commonly cited as circa 4000-3000 BCE; some consider this part of the early Bronze Age.
2) *Bronze Age cultures* and technologies, initiated 4000-3000 BCE, ~3000-1200 BCE, 1500-800 BCE; extraction of metals [e.g., smelting tin oxides / cassiterite, and sulfides / chalcocite and "chalcopyrite" source minerals] from ore and the mixing these metals [e.g., tin / copper alloy] permitted use of metal alloys for casting bronze objects.
3) *Iron Age cultures*, initiated in Eurasia regionally ~800-700 BCE, 1200 to ~2200 BCE, 600 CE by geographic location; the transition culminated in development of the early Iron Age technologies with smelting of iron ores to generate ferrous metal / iron products (and early carbon steel alloys) for tools, weapons, and other products.

These cultural technological changes (References 848, 849, 851) required advanced understanding and control of heat (fire) energy, and use of the energy and metal ore for processing, refining, and product development. Stone Age cultures used surface mining methods to obtain clay and developed methods (firing of clay) for production of pottery and bricks (~4000-18000 BCE); firing of clay likely contributed heavily to the discovery and application of the Chalcolithic, Bronze and Iron Age smelting and glass making technologies. Proximity or access to natural resources (e.g., water) was critical to location of early centers of population in the Stone Age and "post-Stone Age" periods. Many early population centers developed in areas proximal to surface and shallow copper or tin mines, and along early Eurasian and African trade routes (also in the Americas). Early trade routes grew to supply non-local resources (e.g., chert / flint, and natural glass during the Neolithic; tin and copper in the Bronze Age) for growing population centers.

As cities and towns were established, large shallow stone quarries supplied building stone for construction. Extraction or mining of lithic materials (e.g., chert / flint, naturally occurring glass / obsidian, shale, building stone; native metals, metallic ore minerals) generally progressed from Stone Age and Chalcolithic age people's exploitation of surficial deposits to underground shallow shaft and tunnel excavations. Underground mining is as old as civilization itself, becoming better established during the Bronze Age. Mining techniques changed little over the millennia until the industrial revolution. By the 19th and early 20th centuries, construction of deeper underground mines (shafts, tunnels) became routine and shallow open pit mines extended over larger areas. During the last half of the 20th century, the economics of operating large deep open pit mines became competitive with underground mining as technological advances in transport, extraction, and processing ore permitted development of deeper or lower grade deposits from large deep open pits. More recently, some large open pits reach depths of over 1000m below the surface and extend over several square kilometers. However, there remain significant economic, technical, and safety limits and risks with extensive deep open pit mining ventures. Once economic or safety limits are reached for the deep open pit mine, a return to underground mining is common practice at the location as an option to the closing of the mine before the recoverable resource has been exhausted at depth.

The following sub-sections present information about the location (Section 6.1: interactive map Layer 5; http://gis.inl.gov/GlobalSurvey/) and characteristics (Section 6.2, Table 5) of some of the larger and deepest open pit mines. Associated online source material with notes on cited references (Section 6.3) along with topics for discussion (introductory topics for consideration) in Section 6.4 may be of use to researchers and other interested parties.

Section 6.1 - Map Layer 5 (Pits): Large Deep Open Pit Mines

Access to interactive map Layer 5 (Pits, deep large open pit mines, Table 5) is at http://gis.inl.gov/GlobalSurvey/. Information from Table 5 is presented as an interactive map for the user to explore some of the deeper open pit mines of the world. Each open pit mine site included in Table 5 and on Layer 5 of the global map (pits, deep large open pit mines) may be selected on the global interactive map in order to view associated site information from Table 5 as discussed in Section 2.1, and in *User Guide* in Appendix 2.

Section 6.2 - Table 5 (Pits): Large Deep Open Pit Mines

Table 5 database serves as input to development of interactive map Layer 5 and presents some of the world's deepest open pit mines, those of historical importance, or those that help illustrate mining engineering capabilities, limits, and engineering and operational achievements that permit open access to ore bodies in the depth range of up to ~ 1.2km below ground level. However, the purpose of this study (and http://gis.inl.gov/GlobalSurvey/) is to allow interested parties to examine summary information (e.g., location, geology, selected design features) about the world's larger or deepest open pit mines using the interactive map suite. Appendix 1 (Table A1-5) presents an alphabetical listing of sites in Table 5. Table 5 database includes the site number, name, country, pit depth, pit size (from reference sources, if available, or as estimated or measured from Google map), other site data, and references by number for each site. Table 5 *explanation* includes key and acronyms used in table.

Although the environmental degradation aspects associated with mining operations are not the focus of this report, it is noted that the excavation of such deep pits disturbs the surface and ambient subsurface environmental conditions (hydrologic, geochemical, and thermal characteristics) of the surrounding strata, the host rock, and ore-bearing units encountered for what had been a system in rough equilibrium with the surrounding subsurface environment, often for millions of years. Adverse environmental impacts may be minimized through application of controls, use of appropriate monitoring systems, and site remediation. The impact of deep pit excavation and ore processing operations on the local area can be minimal to quite substantial. The deep open pit examples are intended to show excavations to depths far in excess of many existing or planned underground mined geologic repositories and URLs.

Section 6.3 - Table 5 References (750-851) and Notes Supporting Map Layer 5 (Pits / Large Deep Open Pit Mines)

The reference section **c**ontains numbered references and notes (#750-851) that are cited in Table 5 database and introduction to Section 6. For access to Table 5 References and Notes, see this report and pop-up panels on interactive map for each site at http://gis.inl.gov/GlobalSurvey/ . Each site / facility number is found in Table 5 (first column), Appendix 1 (alphabetic list of sites), and site information popup on interactive map layer.

Section 6.4 – Table 5 Topics for Discussion:

Deep open pit mines included in Table 5 may reach depths of ~ 1.2 km. To what extent do the following statements contribute to the discussion and consideration of mined geologic disposal options for nuclear waste and spent nuclear fuel? Are the statements or conclusions verified from field testing or laboratory investigations? By economic / cost evaluations?

- Open pit mining may be cheaper and safer than underground mining operations.
- Existing deep open pit mines and failed prospect excavations could be considered for SNF/HLW underground disposal research.
- The feasibility of deeper disposal options (also see Table 2, URLs) in deep underground or open pit mines could be explored beyond current general <~500m depth limit often under consideration by various national mined geologic disposal programs (See Section 3.4).
- Shallow open pit sand and gravel mines and quarries (and alluvial deposits) have been used by many municipalities and other entities as waste disposal sites.
- Some have suggested that deep open pits could be utilized for disposal of solid wastes and or high level nuclear waste and spent fuel. The deep pit disposal site could be engineered to prevent or retard movement and ensure containment and isolation of material within the pit (within engineered system environment) preventing or reducing movement of contaminants into the surrounding subsurface or surface natural system environment.
- Engineered fill and seal systems could provide a degree of containment and isolation for the waste materials disposed of in the deep pit environment.
- An engineered backfill of the pit would be characterized by low permeability, minimal transmissivity or advective flow and transport of contaminant material, minimal vertical or lateral flow, and with diffusion-only transport of contaminants to the surrounding subsurface rock units, thus, limiting contaminant species from reaching the accessible environment.
- Backfill materials could be mixed or blended with substances to promote adsorption of radionuclides.
- The engineered litho-backfill barrier could be hundreds of feet thick, the waste at a depth of thousands of feet and physically isolated from the surrounding environment to the extent practicable and required.
- An engineered top, bottom, and lateral fill sequence could be emplaced. Multiple waste and seal layers could be designed, and a layered repository developed. Inter-waste layer seal units could be of variable thickness.
- A range of nuclear waste types could be accommodated.
- Canister design could be flexible to accommodate direct disposal of Dual Purpose Canisters / Containers / packages, and large or small packages.
- Depending on location, expected disposal site area and pit depth, the cost of using or constructing a deep open pit for disposal may be competitive with cost of a mined (tunnels) geologic repository. Mining companies may be willing to cost-share if mined in ore zone; possibly willing to cost-share for site remediation.

- Remote handling for emplacement of waste containers and system monitoring may be much less complex operationally over 100 to several hundred year time period.
- Emplacement layer zones within the repository disposal pit could be large enough to serve as an aging facility before overlying top or upper seal is emplaced on a given layer of waste packages.
- The repository host and deep pit fill sequence could consist of many lithologies (crystalline, argillite, alluvium, bentonite, selected mineral species…).

Other considerations:

- The pit itself may have little apparent effect on regional subsurface flow systems, since these deep pits are often constructed within low permeability rock. Deep open fractures present challenges.
- In these very deep pit areas, a number of aquifer and aquitard zones may be encountered.
- The ambient system's deeper formation waters are often non-potable, may be saline and density stratified.
- In general, vertical mixing is expected to be limited; however, if during or after excavation, shallower potable water, rain water, or pressurized transmissive permeable features (e.g., faults, fractures) are present or encountered, the pit may begin to flood and must be controlled. Arid environment and deep water table areas are best.
- If pumping is required to keep the pit open (not flooded), the waste water should be treated before release into the environment (e.g., evaporated).
- The rock material removed from the pit and stored or processed locally may present the greater threat to environmental quality in the surrounding areas if those aspects of the exploitation process are not properly managed by the owner/operator.
- Landslides and collapse features are of concern; reduction of risk requires quality management and planning, design controls, monitoring systems, and maintaining features and systems important to operational safety.

This revised Global Survey report and interactive map suite (http://gis.inl.gov/GlobalSurvey/) help tell a story of subsurface resource exploration and exploitation, history, evolving engineering and science technologies (R&D), economics, concepts to consider in waste disposal and facility siting, and lessons learned with human access to the "deep earth". Although deep pits are not "underground" facilities in a strict sense, they examine the deep geology in a similar manner to those facilities included in the first four tables of "underground" or sub-surface facilities. In general, strip mines and open pits developed for the extraction of resources (e.g., coal, sand and gravel, phosphate) other than diamonds and valuable metals (e.g., Au, Ag, Mo, Cu, and Fe) are not included in this survey table. Generally, larger and deeper operations are more economically viable for the higher-priced commodities. Geology and geometry of the ore deposit determine the design, geometry, and depth of the open pit operation area.

SECTION 7: SUMMARY AND CONCLUSION

The interactive maps, database, and references with notes representing a global survey of underground facilities (past, existing, proposed, considered) may contribute to a better understanding of current and historical geotechnical and engineering capabilities in subsurface exploration and investigations of crustal rock properties at depth. The study permits easy access to information on facility types, characteristics, testing, and locations. Many government and non-governmental organizations (e.g., IAEA, NEA, EDRAM, EURIDICE, NAS, AAPG, ACS, SAIMM) may offer geographic location compilations for some of the types of facilities referenced in this report, but it is not common for those compilations to include mines, shafts, open pits, deep boreholes, disposal sites, repositories, underground research laboratories, geothermal, seismic investigations, groundwater residence time R&D, and subsurface physics laboratory examples in an interactive map format accompanied by easily accessible database, linked references and other support information. With few exceptions, references used for the study are accessible on the internet; links are supplied for most references and notes in this report. Numbered references for each site are identified in the tables and map layer data, and details in the reference section for each of the five facility types (5 tables) included in this report.

The user may recognize a subtle bias (favoring deep basement, crystalline / granitic units; boreholes that are deep, hot, and in Precambrian age rock) in facility / borehole selection incorporated within this study. The deep borehole radioactive waste disposal option is being considered by several nations; waste emplacement is expected to be within crystalline basement rock (igneous, metamorphic) at depths of 3-5 km. A mined geologic disposal option within a crystalline rock environment is also being investigated by numerous countries. Many geothermal programs have focused on deep wells in crystalline units. Physics laboratories have sought to conduct experiments in units that are geo-mechanically stable and have low porosity and permeability, i.e., features characteristic of crystalline rock. Humans have mined, drilled and excavated in crystalline rock to >4 km depth to permit safe subsurface physical access and operation for both people and machines. Well drillers have penetrated the earth's crustal units to several times the depth of deep underground mines. International drilling programs promote deep crustal drilling, often in the older deep crystalline crustal terrain.

Future engineering advances (and advances in robotics) should permit safer and even greater depth of subsurface activities. Current and future engineering and operational capabilities evident from facilities described in this report suggest potential for improved safety assurance for waste disposal operations including emplacement and retrieval of solid radioactive waste at considerable depth. It is intended that these interactive maps and data would support and inform site evaluation or safety case development for any mined geologic disposal repository concept as part of a confidence building exercise and as a demonstration of historical and current engineering and geotechnical capabilities available for use in deep underground facility siting, planning, construction, operations and monitoring.

Interested members of the public, students, professionals, and decision makers may benefit from use of these introductory-level data and maps describing global underground facilities, testing, and sites. The survey is extensive but not all-inclusive. It is representative of many significant existing and historical underground facilities discussed in the literature addressing radioactive waste management and disposal safety systems.

These data, maps, tables, and references may serve as a communication tool for use by those (e.g., public; students for discussion as intended by Sections 2.4, 3.4, 4.4, 5.4, and 6.4, in discussion or seminar format) having an interest in deep underground geology and related subsurface exploration and exploitation activities including the disposal of nuclear waste. The material is intended to support safety case development, to inform decision makers, and as a communication tool to possibly be used to facilitate discussion of national and international subsurface site studies.

Comments and corrections are invited from the interested readers and users of the database and interactive maps. Additions, modifications, and updates may be made with future revisions or the information may be used by others for development of an improved and more detailed presentation of site, facility, or site project information.

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REFERENCES AND NOTES

Global Survey of Selected Deep Underground Facilities

Map Layer and Table Title / Number	Reference Numbers
Table 1: Mines and Shafts	1-159
Table 2: URLs, Repositories, Sites	160-469f
Table 3: Boreholes	470-609f
Table 4: Physics Facilities	610-741a
Table 5: Deep Open Pit Mines	750-851

Table 1 References (#1-159) and Notes Supporting Map Layer 1 (Mines)

Primary General References for Map Layer 1 and Table 1

1) *Mining-technology.com* (website). 2013. "The Top Ten Deepest Mines in the World", *Mining-technology.com, Feature Story*; Kable, UK; dated 9/11/2013**;** http://www.mining-technology.com/features/feature-top-ten-deepest-mines-world-south-africa/ ; accessed February 8, 2016 (NOTES: 8 of ten deep mines / shafts are in South Africa, in 2013/14)

2**)** Michaud, David. 2014. Top 10 deepest mines on the planet; *Mining Examiner, Metallurgist.com blog*, January 7, 2014. Via *Mining-Technology.com*, http://www.911metallurgist.com/blog/top-10-deepest-mines-on-the-planet ; accessed February 8, 2016

3) Carlos Andres. 2013. World's top 10 gold deposits; *Gold Miners Investment Newsletter*, August 7, 2013, Mining.com**,** http://www.mining.com/web/worlds-top-10-gold-deposits/ ; accessed February 8, 2016 (NOTE: Mponeng mine reaches 150ºF; AngloGold Ashanti)

4) Drilling Today House. 2013. The Top Ten Deepest Mines in the World, DTH Rotary *Drilling website, News*, September 24, 2013. http://www.dthrotarydrilling.com/News/24-September-2013/The_top_ten_deepest_mines_in_the_world.html ; February 8, 2016 (NOTE: Mponeng shaft 1, deepened to 120 level, which is some 3.4km below datum, 2013; the two mines not in SA are Creighton and Kidd Creek mines, Ontario, Canada)

5) Walker, Simon (Ed.). 2012. Deep Thinking: Shaft Design and Safety for a New Generation of Mines; *Engineering and Mining Journal (E&MJ) News*, August 1, 2012. Features. http://www.e-mj.com/features/2191-deep-thinking-shaft-design-and-safety-for-a-new-generation-of-mines.html, and http://www.e-mj.com/features/2191-deep-thinking-shaft-design-and-safety-for-a-new-generation-of-mines.html#.VaWlAtLF-_E , and http://emj.epubxp.com/i/74512-jul-2012/43 ; Accessed February 8, 2016 (NOTES: "German company, Herrenknecht, having introduced its SBS shaft-boring system in 2010… Rio Tinto's focus on this, as part of its 'Mine of the Future' technology-development program… Palabora also uses a 9.9-m-diameter service shaft, 1,272 m deep… Oyu Tolgoi in Mongolia/ Redpath states (shaft) measuring 10 m in diameter by 1,320 m (4,035 ft.) deep… Resolution Copper project in Arizona, where Cementation is currently sinking a 2,130 m-deep (7,000-ft) exploration shaft. Or South Deep in South Africa, where the new main shaft is 2,995 m deep… Kidd mine D No. 4 shaft and the Nickel Rim South twin shafts—without incurring a lost-time injury. Cementation's contract for the internal, 7.62-m-diameter Kidd D No. 4 involved sinking 1,651 m to reach shaft bottom at 3,014 m below surface… China's 1,000 m deep shaft sinking exercise… presented some information on over 40 shafts that have been sunk since 2000, all of which are close to, or more than, 1,000 m deep… Huaibei Coal Mining's Xinhu mine in Anhui province, at 1,037 m depth and 8.1 m diameter"; capabilities developed for accurate drilling to depth with "diameters of up to 13 m"); includes "A snapshot of China's coal progress"; p. 42; capability to drill to >1000m with 13m diameter drill shaft. See associated reference, *Institute of Materials, Minerals, and Mining; Third International Conference on Shaft Design and Construction*, 24-26 April, 2012, 2012; London, UK; agenda, http://maekonverentsid.blogspot.com/2012/03/third-international-conference-on-shaft.html . Beswick (2008), Reference 470, herein, also has extensive discussion of shafts and mines summarized in notes in the borehole reference section.)

6) Sherwood Lollar, B., T.C.Onstott, G. Lacrampe-Couloum, C.J. Ballentine. 2014. The contribution of the Precambrian continental lithosphere to global H_2 production. *Nature* 516: 379-382. http://www.nature.com/nature/journal/v516/n7531/full/nature14017.html ; abstract accessed February 8, 2016 (NOTE: estimated H2 production from Precambrian continental lithosphere; comparable to marine systems production rates.)

7) Holland, G., B Sherwood Lollar, L. Li, G. Lacrampe-Couloume, G. F. Slater, C. J. Ballentine. 2013. Deep fracture fluids isolated in the crust since the Precambrian era. *Nature* 05/2013; 497(7449):357-360; http://www.nature.com/nature/journal/v497/n7449/abs/nature12127.html and http://www.researchgate.net/publication/236911498_Deep_fracture_fluids_isolated_in_the_crust_since_the_Precambrian_era ; abstract accessed February 8, 2016 (NOTE: Timmins, Ontario mine water minimum residence time 1.5 billion years with evidence of up to 2.64 Ga; Kidd Creek Mine (Cu); later work reports Sudbury water to be old, ~ 2.7 Ga; noble gases show that ancient pockets of water can survive the crustal fracturing process and remain in the crust for billions of years. The Witwatersrand basin in South Africa is the most extensively studied among these crustal basement systems. There, radiogenic noble gases in the deepest fracture waters provide evidence for groundwater residence times of up to 25 million years (Myr); fluid inclusions, billion years; Timmons mine with ancient pockets fracture fluids at least a billion years old. Timmins mine fluids can be linked to xenon isotope changes in the ancient atmosphere and used to calculate a minimum mean residence time for this fluid of about 1.5 billion years. Noble gases age dating, Timmins mine Canada "noble gas residence times 1.1-1.6 billion years (Ga)… calculate a minimum mean residence time for this fluid of about 1.5 billion years… (radiogenic noble-gas, ^{4}He, ^{21}Ne, ^{40}Ar, ^{136}Xe) residence times… together, the different noble gases show that ancient pockets of water can survive the crustal fracturing process and remain in the crust for billions of years." See attached videos and file with abstract, Nature)

8) Association of Mine Managers South Africa (AMMSA) website. Knowledge Hub Presentations, and Technical Papers http://www.ammsa.org.za/knowledge-hub/presentation-archive/2014 {NOTES: Access to papers and presentations for SA mines; example, M. Bevan, http://www.ammsa.org.za/knowledge-hub/technical-papers ; example, http://www.ammsa.org.za/component/jdownloads/finish/1-technical-papers/115-south-deep-the-challenges?Itemid=0 South Deep: planned shaft 9m diameter to ~2,760mbgl}; accessed February 8, 2016

9) *Society of Mining Professors (SOMP*; online blog*)*. 2014. Mponeng - World deepest (4.1 km) mine, Mponeng Gold Mine, South Africa ; http://mineprofs.blogspot.com/2014/07/mponeng.html ; accessed February 8, 2016 (Note: provides links to mining groups and information resources; field excursion and facts, Mponeng.)

10) *Mining-Technology.com/Projects* (webpage). Mponeng Gold Mine, Gauteng, South Africa; Kable, UK http://www.mining-technology.com/projects/mponeng/ ; accessed February 8, 2016 (NOTES: AngloGold Ashanti's Mponeng mine, formerly the Western Deep Levels South Shaft, or Shaft No 1)

11) Hart, M. 2013. A Journey into the World's Deepest Gold Mine; *The Wall Street Journal*, December 13, 2013. http://www.wsj.com/news/articles/SB10001424052702304854804579236640793042718; accessed July 9, 2015; pay to view, without free access, February 8, 2016. (NOTE: Informative descriptive trip into deep mine, SA)

12) *Infomine-africa.com*. 2013. http://www.infomine-africa.com/WhatsNew.aspx . What's New, June 14, 2013 - Harmony and Department of Mining Engineering at University of Pretoria launch Mining Rock Engineering initiative , University of Pretoria, Harmony Gold Mining Company Limited (Harmony) ; accessed February 8, 2016 (NOTES: Original source: *http://www.harmony.co.za/investors/news-and-events/company-announcements-2/announcements-2013/719-harmony-and-department-of-mining-engineering-at-university-of-pretoria-launch-mining-rock-engineering-initiative* ; accessed February 8, 2016)

13) *Infomine-africa.com*. 2013. http://www.infomine-africa.com/WhatsNew.aspx . *What's New, June 14, 2013* - Rio Tinto announces new global Centre for Underground Mine Construction in Canada**;** accessed February 8, 2016. **{NOTE:** Source information for news item was from *Centre for Excellence in Mining Innovation (CEMI****), T****he Rio Tinto Centre for Underground Mine Construction* / RTC-UMC at CEMI; https://www.miningexcellence.ca/?p=1867 ; accessed February 8, 2016); RTC-UMC was created to undertake research in support of Rio Tinto's Mine of the Future™ program; CEMI is in Sudbury, Ontario, and will focus on innovative rapid mine construction and ground control for mining at depth (https://www.miningexcellence.ca/ ; accessed February 8, 2016) and CEMI relation with *Ultra deep Mining Network* (http://www.miningdeep.ca/), R&D for mining deeper than 2.5km ; accessed February 8, 2016}

14) *Infomine-africa.com*. 2013. http://www.infomine-africa.com/WhatsNew.aspx . June 14, 2013**.** Concargo now member of the heavy weights; accessed February 8, 2016 {NOTES: References to members of the Heavy Lift Group, THLG, http://www.theheavyliftgroup.com/ accessed February 8, 2016; The Heavy Lift Group was founded in 1987 by West European Heavy Lift Operators … a worldwide group having members in the U.S.A. Latin America, the CIS, the Middle East, Asia, South Africa}

15) *Centre for Mechanised Mining Systems (CMMS)* Website. University of the Witwatersrand; http://www.minemech.org.za/ ; accessed February 8, 2016 (NOTE: see presentations)

Site Specific and Topical References

Mponeng, Tau Tona / Savuka, AngloGold Ashanti. West Wits Operations: South Africa

16) Showers, B. 2012. It came from Africa. *Shaft Development;* Australia's Mining Monthly, February 2012; http://ftp2.bentley.com/dist/collateral/docs/corporate/AMM_Bentley_Shaft_Development_2-12.pdf ; accessed February 8, 2016 (NOTE: Savuka shaft restoration after 2009 flooding event; safety, seismic, rock falls)

17) *Mining-Technology* Website. 2015. Savuka Gold Mine, Gauteng, South Africa; http://www.mining-technology.com/projects/savuka-gold-mine-south-africa/ (West Wits Operations area); accessed February 8, 2016

18) Spence, R. 2014. The Deepest Underground Mines in the World (slideshow). *Mining Global* website, August 19, 2014; http://www.miningglobal.com/miningsites/1095/SLIDESHOW-The-Deepest-Underground-Mines-in-the-World; accessed February 8, 2016 (NOTE: AngloGold's West Wits Operations area; Savuka, Tau Tona, Mponeng video)

19) *AngloGold* Ashanti (website). 2006. Mponeng Mine Visit. http://www.anglogoldashanti.com/en/Media/Presentations/20Jan2006_MponengVisit.pdf ; accessed February 8, 2016

20) AngloGold Ashanti. 2014a. *Operational Profile, West Wits (Performance Review, Regional Review, South Africa*); http://www.aga-reports.com/14/ir/performance/regional-reviews#south-africa, accessed February 8, 2016 (NOTES: Operations areas and mines: 1] Vaal River Ops = Great Noligwa, Kopanang, Moab Khotsong; 2] West Wits Ops = Mponeng, Tau Tona / Savuka; Mponeng w twin shafts and 3900m bgl; Tau Tona, and Savuka mines combined in 2015._West Wits includes Mponeng, Tau Tona / Savuka exploiting VCR and CLR; Vaal River operations includes Great Noligwa, Kopanang and Moab Khotsong, exploiting Vaal Reef. By late 2017, AngloGold Ashanti was in the process of transitioning ownership of several of the SA mines; see References 30a-30c, below)

21) AngloGold Ashanti. 2014b. *West Wits, South Africa, Operational Profile*, 2014. http://www.aga-reports.com/14/download/AGA-OP14-sa-westwits.pdf ; accessed February 8, 2016

22) AngloGold Ashanti. 2014c. *South African Region Technology innovation Presentation*, AngloGold Ashanti; http://www.anglogoldashanti.com/en/Media/Presentations/20140131_AGA_SA_site_visit.pdf ; accessed February 8, 2016 (NOTE: excellent slide collection subsurface detail construction, seismic, rock bursts)

West Rand (South Deep, Kloof / Driefontein Complex {GoldFields}, Khotsong), Far West Rand (Elandsrand, Deelkraal and Western Deep Levels, West Wits Area; {AngloGold}): South Africa

23) Cousens, R.R., and W. Garrett. 1969. The Flooding at the West Driefontein Mine; *Journal of South African Institute of Mining and Metallurgy* (Johannesburg) and *9th Commonwealth Mining and Metallurgical Congress* (London), April/May, 1969, pp. 421-463; http://www.saimm.co.za/Journal/v069n09p421.pdf ; accessed February 8, 2016 (Note: flooding and control - Far West Rand; adjacent to the Western Deep Level Mines; important water control, mechanical hydro paper)

24) GoldFields. *Review of South African Operations: Driefontein Gold Mine*. http://www.onlinewebstudio.co.za/websites/goldfields/ops_driefontein.php ; accessed February 8, 2016 (Note: Witwatersrand Basin; exploits VCR and CL; lowest working level ~3300 m bgl; data current through 2008)

25) GoldFields. 2011. *KDC (Kloof-Driefontein Complex); Technical Short Form Report, 2011*. https://www.goldfields.co.za/reports/ar_dec_2011/minerals/pdf/kdc_mine.pdf ; accessed February 8, 2016. (NOTE: Kloof-Driefontein Complex (KDC; GoldFields); Cecil Rhodes, 1887, founder of GoldFields)

26) Winde, F., and E.J. Stoch. 2010. Threats and opportunities for post-closure development in dolomitic gold mining areas of the West Rand and Far West Rand (South Africa) – a hydraulic view, part 1: mining legacy and future threats; *Water SA* (Online) vol.36 no.1 Pretoria Jan. 2010; Water Resource Commission, South Africa (Pretoria.); http://www.scielo.org.za/scielo.php?pid=S1816-79502010000100008&script=sci_arttext; accessed February 8, 2016 (NOTES: Water problems, sinkholes, hydrology problems and solutions; history West/Far West Rand; Figure 1, Study Area; Far West Rand includes South Deep, Kloof, Driefontein, Khotsong mine areas; West Rand includes West Wits area. In "1998, Elandsrand, Deelkraal and Western Deep Levels were all incorporated into AngloGold, and the three mines now form the AngloGold West Wits Operations.")

Great Noligwa, Kopanang, Moab Khotsong; AngloGold Ashanti. Vaal River Operations, South Africa

27) *AngloGold Ashanti*. 2014. Operational Profile, Vaal River; http://www.aga-reports.com/14/download/AGA-OP14-sa-vaal-river.pdf ; accessed February 8, 2016 (Note: for related information, access http://www.aga-reports.com/14/ir/performance/regional-reviews#south-africa; http://wikimapia.org/19133596/AngloGold-Ashanti-Vaal-River-Operations ; accessed February 8, 2016; Vaal River includes Great Noligwa, Kopanang, Moab Khotsong; Kopanang w single shaft to 2600m bgl; use Wikimapia for mine location, identification.)

28) Brenchley, P. R., and J.D. Spies. 2006. Optimizing the life of ore passes in a deep-level gold mine; *The Journal of The South African Institute of Mining and Metallurgy* (106), p. 11-16; in http://www.phoenixhollo.com/en/Moab_Khotsong_mine_3.html ; accessed February 8, 2016

29) *AngloGold Ashanti* (website; accessed February 8, 2016). Event on August 5, 2014. AngloGold Ashanti update on earthquake at Vaal River operations – News http://www.anglogoldashanti.com/en/Media/news/Pages/20140508_Eartquake.aspx (NOTE: event Near Vaal River Operations area at ~8km depth; magnitude 5.3 quake, 2014; Moab / Khotsong with reel of 3,054 metres (10,020 ft.) in one uninterrupted four-minute journey)

30) *AngloGold Ashanti* (website; accessed February 8, 2016). August 6, 2014. AngloGold Ashanti further update on South Africa earthquake – News http://www.anglogoldashanti.com/en/Media/news/Pages/20140806_Earthquake_Update.aspx (NOTE: Great Noligwa and Moab Khotsong mines, 3,300 workers brought to surface; event on August 5, 2014 = 5.3 magnitude occurred near its Vaal River Operations in South Africa, at a depth of roughly 8km)

30a) Harmony Gold Mining Company Limited (website announcements), Oct. 19, 2017, *Harmony Gold Mining Company Limited News and Events: Proposed acquisition of AngloGold Ashanti's Moab Khotsong operations*; https://www.harmony.co.za/investors/news-and-events/company-announcements-2/announcements-2017 , and https://www.harmony.co.za/investors/news-and-events/company-announcements-2/announcements-2017/1043-proposed-acquisition-of-anglogold-ashanti-s-moab-khotsong-operations (Note: announced that it is planning to acquire AngloGold Ashanti's Moab Khotsong and Great Noligwa mines.)

30b) AngloGold Ashanti (website, announcements). News Release, October 19, 2017 - *AngloGold Ashanti announces the sale of various assets in the Vaal River Region*; https://thevault.exchange/?get_group_doc=143/1508388479-ANGLOGOLDASHANTIANNOUNCESTHESALEOFVARIOUSASSETSINTHEVAALRIVERREGIONINCLUDINGTHEMOABKHOTSONGMINETOHARMONY.pdf

30c) AngloGold Ashanti (website, announcements). October 19, 2017 - *AngloGold Ashanti announces the disposal of its Kopanang Mine, the West Gold Plant and related infrastructure*; https://thevault.exchange/?get_group_doc=143/1508389254-ANGLOGOLDASHANTIANNOUNCESTHEDISPOSALOFITSKOPANANGMINETHEWESTGOLDPLANTANDRELATEDINFRASTRUCTURE.pdf ;

Kusasalethu (Deelkraal, Elandsrand), Harmony Gold: South Africa

31) *Harmony Gold* (website; accessed February 8, 2016). Harmony Gold, Our Operations, Kusasalethu: West Rand Operations, Harmony; https://www.harmony.co.za/our-business/our-operations/kusasalethu (NOTE: Deelkraal mine and Elandsrand mines, bought from AngloGold in 2001 combined to form Kusasalethu

32) *Mining-technology.com* (website). February 23, 2015. 486 people rescued from fire at Harmony Gold's Kusasalethu gold mine; *mining-technology.com News*; http://www.mining-technology.com/news/news486-people-rescued-from-fire-at-harmony-golds-kusasalethu-gold-mine-4517825 accessed February 8, 2016 (Note: 2015 mine fire, ~Level 75, ~2300m bgl)

33) Handley, M. et al. 2000. A review of the sequential grid mining method employed at Elandsrand Gold Mine; *The Journal of The South African Institute of Mining and Metallurgy. The South African Institute of Mining and Metallurgy*, 2000; p. 157-168. http://www.saimm.co.za/Journal/v100n03p157.pdf ; accessed February 8, 2016 *(*NOTE: Thus, in 2000, Elandsrand ~2700m bgl; since "1998, Elandsrand, Deelkraal and Western Deep Levels were all incorporated into AngloGold, and the three mines now form the AngloGold West Wits Operations")

South Deep Gold Mine, GoldFields: South Africa

34) Gold Fields (website). Review of South African Operations: South Deep Gold Mine. http://www.onlinewebstudio.co.za/websites/goldfields/ops_south_deep.php ; accessed February 8, 2016 (Note: Gauteng Province; Witwatersrand Basin; twin shaft complex; main shaft single drop to 2995m bgl; second shaft and operations to 3250m bgl)

35) SiemagTecberg (Corporate Website). Accessed February 8, 2016. *Technical Information - Blair Multi-Rope Double-Drum Winder, Gold Fields, South Deep Gold Mines, Johannesburg, South Africa*; http://www.siemag-tecberg.com/infocentre/technical-information/ti_05-south-deep.html (NOTE: South Deep - multi-rope double drum winder)

36) Douglas, A., and K McLeod. 2005. Sinking contractor's close out presentation on completion of south deep shafts. *The South African Institute of Mining and Metallurgy, Third South African Conference on Base Metals.* Pp.455-470; http://www.saimm.co.za/Conferences/BM2005/455-470_Douglas.pdf; accessed February 9, 2016 (NOTE: "Placer Dome-Western Areas Joint Venture's South Deep Twin Shaft Complex"… 2991m deep shaft… 2759m ventilations shaft –included 6m drill)

Kidd Creek Copper / Zinc Mine: Timmins, Ontario, Canada

37) Werniuk, Jane. 2007. The Reno: First stage of Kidd Creek's Mine D project complete; *Canadian Mining Journal*. January 1, 2007; http://www.canadianminingjournal.com/news/the-reno/1000210304/?&er=NA ; accessed February 9, 2016 (Note: discussion of mine D at Kidd Creek; shaft 4; built by Cementation; winze from the collar on 47 level (1,432 m depth) down 1,580 m to a depth of 3,012 m bgl. The circular shaft with steel framing was excavated to 8.5 m diameter, with a 7.6-m-diameter concrete lining; the No.4 shaft at Kidd Creek Mine D, which is really a winze collared at 1,432 m depth, ends in a sump 3,012 m below surface; deepest mine in North America)

38) Fiscor, Steve (Ed.). 2008 (September). Xstrata Copper Launches Kidd Creek Expansion Project, The deepest base metal mine pursues operational efficiencies. *Womp* 08 Vol 7 (*Mining e-Journal*, Engineering and Mining Journal, online); www.womp-int.com and http://www.womp-int.com/story/2008vol7/story024.htm (NOTES: D mine shaft which extends to 9,889 ft. below surface; developed ore reserves now reach to a depth of 9,100 ft. It is presently the deepest mine with ramp access from the surface; Xstrata Copper Canada; disc 1964)

39) Lamour, A. 12/1/2008. Xstrata Copper's Kidd Mine goes even deeper; *Sudbury Mining Solutions Journal*, 12/1/2008; http://www.sudburyminingsolutions.com/xstrata-coppers-kidd-mine-goes-even-deeper.html ; accessed February 9, 2016 (Note: In 2008, internal shaft (No. 4) between the 4,700-foot level and the 9,889-foot level; shafts No. 2 and 4 are operational; No. 1 and 3 have been decommissioned. The installation of an internal shaft (No. 4) between the 4,700-foot level and the 9,889-foot level was completed in 2006.)

40) *Mining-Technology.com* (website; accessed February 9, 2016). Kidd Creek Copper and Zinc Mine, Ontario, Canada http://www.mining-technology.com/projects/kidd_creek/ (Industry Projects) (Note: volcanogenic sulphide deposit, Archaean Abitibi greenstone belt; owner, 2015, Xstrata)

41) Gibson, H., et al. 2003. The Kidd Creek volcanogenic massive sulfide deposit: a growing giant, after forty years of mining, exploration, and research**;** *The Gangue* (Geologic Society of Canada, Mineral Deposits Division), July 2003, Issue 78, p. 1, 5-7; http://www.gac.ca/wp/wp-content/uploads/2012/04/Gangue78.pdf ; accessed February 9, 2016 (NOTE: Kidd Volcanic Complex deposit occurs within the 2.710 to 2.717 Ga Kidd-Munro assemblage; deposit occurs within the Kidd Volcanic Complex, Kidd Creek volcanogenic massive sulfide (VMS) deposit; western Abitibi Subprovince; D Mine, the extension of the deposit from the 6800 level to the 10,000 level; The Kidd Volcanic Complex deposit occurs within the 2.710 to 2.717 Ga Kidd-Munro assemblage; Although unavailable online, see Walker, R. R., A. Matulich, A. Amos, J. Watkins,.& G. Mannard. 1975. The geology of the Kidd Creek mine. *Econ. Geol.* 70, 80–89 (1975))

41a) Kidd Operations, Glencore Company (websites; accessed March 8, 2016); http://www.kiddoperations.ca/EN/Pages/default.aspx (Note: Kidd Mine, the world's deepest base-metal mine below sea level, mining at 9600 feet with shaft bottom at 9889' depth. Related sites, http://www.kiddoperations.ca/EN/Pages/default.aspx ; Kidd Operations, A Glencore Company, http://www.glencore.com/)

42) *Cementation Inc*. (webpage; accessed February 9, 2016). Shaft Sinking, Xstrata Copper Kidd Mine D No. 4 Shaft (Cementation) Project; http://en.cementation.com/site/project-kidd-4d.php?p=1; index http://en.cementation.com/site/projects.php . (NOTES: 7.62 m internal diameter concrete lined winze to a total shaft depth of 1651 m. Once completed, the shaft bottom was 3014 m below surface;

43) Counter, D. (Glencore). 2014. Kidd Mine – dealing with the issues of deep and high stress mining – past, present and future; *In:* Hudyma, M., and Yves Potvin, (editors); *Deep Mining, 2014: ACG (Australian Center for Geomechanics) Seventh International Conference on Deep and High Stress Mining, Sudbury, Canada*; ACG, Perth, Australia; http://acg.uwa.edu.au/publications/details/underground_mining/deep_mining_2014; and http://acg.uwa.edu.au/__data/page/8367/D_Counter.pdf ; accessed February 9, 2016 (NOTE: See ACG "Deep and High Stress Mining 2012 and other Proceedings volumes; example papers presented Kidd / Kidd Creek mine; No.1 Shaft, 1969, 930m bgl; No.2 Shaft, 1974, 1556m bgl; No.3 Shaft reached 2,105m bgl in 1991; No.4 Shaft and D-mine reach to 2926m bgl in 2014; planned to 3,110m bgl. *Note Cementum reports that No.4 shaft by Cementum 1432m to 3012m bgl (~9882'), with 8.5m diameter shaft; Xstrata is owner of Kidd Creek Copper / Zinc Mine; Glencore and Xstrata merger in 2013.)

Creighton mine / SNOLAB, Sudbury, Ontario, Canada

44) Phaneuf, C., and J.C. Mareschal. 2014. Estimating concentrations of heat producing elements in the crust near the Sudbury Neutrino Observatory, Ontario, Canada; *Tectonophysics* 622, p. 135-144; Elsevier; http://www.sciencedirect.com/science/journal/00401951/622 and http://ac.els-cdn.com/S0040195114001280/1-s2.0-S0040195114001280-main.pdf?_tid=18edace8-cf7b-11e5-8d27-00000aacb35f&acdnat=1455056511_c1d8d126ab5cbbfb3234b4177373889f and http://ac.els-cdn.com/S0040195114001280/1-s2.0-S0040195114001280-main.pdf?_tid=18edace8-cf7b-11e5-8d27-00000aacb35f&acdnat=1455056511_c1d8d126ab5cbbfb3234b4177373889f ; accessed February 9, 2016 (NOTE: aka SNO, Sudbury Neutrino Observatory; thermal gradient; located at 46.475°N and 81.201°W on the south range of the Sudbury impact structure)

45) Faggart, B.E., A. Basu, and M Tatsumoto. 1985. Origin of the Sudbury Complex by Meteoritic Impact: Neodymium Isotopic Evidence; Reports; *Science* 230, p. 230-239 (October 25, 1985); http://ees.rochester.edu/tims/publications/Sudbury.pdf ; accessed February 9, 2016 (NOTE: propose basement is 2.5Ga, impact 1.84Ga; formerly was 2073m, ~6800'bgl /6000mwe; mineralization between norite / granite-gabbro; 2073; continuous shaft at Creighton Mine)

46) ESG Solutions (Website). Rockburst re-entry protocol at a deep underground Nickel mine in Sudbury, Ontario, a Case Study; *ESG Solutions*; 20 Hyperion Court, Kingston, Ontario, Canada; https://www.esgsolutions.com/sites/esgsolutions.com/files/rockburst_re-entry_v1.pdf and https://www.esgsolutions.com/technical-resources/case-studies/rockburst-re-entry-protocol-at-a-deep-underground-nickel-mine-in-sudbury-ontario ; accessed February 9, 2016 (Notes: Vale Inco Limited, Creighton nickel mine in Sudbury, Ontario; Canada's deepest mine; operations since 1901; Sudbury Igneous complex; microseismic monitoring system; safety)

Springhill Coal Mine: Cumberland County, Nova Scotia, Canada

47) Calder, J.H. et *al*. 1993. *One of the Greatest Treasures: The Geology & History of Coal in Nova Scotia*; Nova Scotia Department of Natural Resources Information Circular No. 25; Nova Scotia Department of Natural Resources; http://novascotia.ca/natr/meb/data/pubs/ic/ic25.pdf ; accessed July 16, 2015 (NOTES: Carboniferous coal measures within Cumberland Group; bituminous coal stage; Cumberland Basin with largest coal deposits in Nova Scotia; 1891, 1956, 1958 disasters occurred in different mines of the coalfield; Springhill mine closed after 1958 disaster)

48) Jessop, A. 1995. Geothermal Energy From Old Mines At Springhill, Nova Scotia, Canada; In *Proceedings of the World Geothermal Congress, Florence, Italy, May 13–31. Auckland, New Zealand: International Geothermal Association. pp. 463–468.* http://www.geothermal-energy.org/pdf/IGAstandard/WGC/1995/1-jessop.pdf ; accessed February 9, 2016 (NOTES: early coal mine, Nova Scotia; operations 1872-1958; 1350m depth bgl; International Geothermal Association; using mines for production of geothermal energy supply; Canada coal mine, Pennsylvanian age; mine disaster, 1956, 1958; began mining in 1873; mines closed during 1970s; No. 2 colliery is deepest, ~4000' or 1200m bgl with inclined ramp access / tunnels – see https://en.wikipedia.org/wiki/Springhill_mining_disaster).

Homestake Mine / DUSEL / Sanford URL / SURF: South Dakota, USA

49) Caddey, S.W. et al. 1991. The Homestake Goldmine: an early Proterozoic iron-formation-hosted gold deposit, Lawrence County, South Dakota (Chapter J, p. J1-J67); Chapter J, *In*: *Geology and Resources of Gold in the United States* (eds. D. Shawe et al.),U.S. Geol. Surv. Bull. 1857; http://homestake.sdsmt.edu/Protected/USGS%20Bulletin%201857-J.pdf (NOTES: Early Proterozoic; 2Ga; intruded and Metamorphosed through ~1.8 Ga to 1.7 Ga; Greenstone belt deposits iron formations as of world for that age and distribution.); accessed February 9, 2016

50) *Sanford Underground Research Facility / SURF* (website; accessed February 9, 2016). http://sanfordlab.org/ (NOTE: Yates and Ross Shafts important to current projects)

51) *Homestake -- Background material for DUSEL (Deep Underground Science and Engineering Laboratory)*: Resources (website; accessed February 10, 2016); http://homestake.sdsmt.edu/Resources.htm (Note: links to geology, Sanford URL)

52) Campbell, T. J. (website). *Homestake Reference Book: Geology*; http://homestake.sdsmt.edu/HRB/Refer.htm; accessed February 10, 2016

53) Campbell, T.J. (website). *Synopsis of Homestake Mine Geology*; http://homestake.sdsmt.edu/Geology/geology.htm ; accessed February 10, 2016 (NOTE: Poorman, Homestake, and Ellison formations; metavolcanics, metasediments, iron formations; gold mine closed, Lead area, Black Hills, SD)

Lucky Friday: Mullan, Idaho, USA

54) Bennett, E.H. 1984. *A Hypothesis concerning the Genesis of Ore Bodies in the Coeur d'Alene Mining District, Idaho*; Technical Report 84-7, Idaho Geological Survey, Moscow, Idaho; http://www.idahogeology.org/PDF/Technical_Reports_(T)/TR-84-7.pdf ; accessed February 10, 2016

55) Hecla Mining Company (website). Accessed February 10, 2016. *Lucky Friday, Mullan, Idaho*; http://www.hecla-mining.com/lucky-friday/; (Notes: lead, silver, zinc mine; Coeur d'Alene Mining District; #4 Shaft project should be completed in late 2016; Mullan, in Shoshone County, North Idaho; currently excavated to the 8244 level; initial mine area operations, 2001; LF expansion area first mined in 1997; tunnels 12ft high by 12ft wide; planned internal shaft descending from the 4900 level to 8800 level; #4 Shaft Project is a key growth project that is currently excavated to the 8244 level and expected to TD at 8800 level. See also corporate site for history, http://www.hecla-mining.com/history/ , and news examples)

56) Tapanila, L. and Paul Link. (webpage) *Mesoproterozoic Belt Supergroup (Module 2): Introduction to the Belt Supergroup Geology, Age and Extent of Belt Supergroup Geologic History of Belt Supergroup; Digital Geology of Idaho*; http://geology.isu.edu/Digital_Geology_Idaho/Module2/mod2.htm ; accessed February 10, 2016

57) Cementation (website accessed February 10, 2016). *Shaft Sinking: Heckla Mining Company Lucky Friday Shaft #4 project*; http://en.cementation.com/site/projects.php , and *Lucky Friday Mine Cementation shaft #4 Project*, http://en.cementation.com/site/project-lucky-friday-4-shaft.php?p=1 (Note: design and sinking of an 18 ft diameter shaft to a depth of 8800 ft below surface)

Lucky Friday Mine, Silver Shaft, Mullan Idaho, USA

58) McKinstry, B.A. 1983. Sinking the Silver Shaft; Chapter 31, pp.493-512; *In*: Sutcliffe, H., and J.W. Wilson (eds.), 1983. *Proceedings of the Rapid Excavation and Tunneling Conference, Volume 1, 1983 Rapid Excavation and Tunneling Conference*, Chicago, Illinois, June 12-16, 1983; American Institute of Mining, Metallurgical, and Petroleum Engineers, American Society of Civil Engineers; http://pbadupws.nrc.gov/docs/ML0404/ML040480468.pdf ; accessed February 10, 2016 (NOTE: Lucky Friday Mine is located at Mullan, Idaho, Couer d'Alene District; Ag, Pb, Zn mine; planned 5.5m / 18' diameter shaft to 2285m / 7500'; 47°28′20.5″N 115°46′45.4″W; 47.472361, -115.779278 ; Access to the underground workings of Lucky Friday is via the 18-foot diameter, concrete lined, Silver Shaft. File / pdf includes papers on Crownpoint, WIPP, Silver Shaft for Lucky Friday Hecla/Redpath activities)

Palobora: South Africa-

59) Heinrich, E.W. 1970. The Palabora Carbonatitic Complex - a unique copper deposit (Contribution No. 298 from the Mineralogical Laboratory, The University of Michigan); *Can. Mineralogist*, V10, No. 3, 585-598; http://rruff.info/doclib/cm/vol10/CM10_585.pdf ; accessed February 10, 2016 (NOTE: Cu mine; carbonitite intruded into Archean granite as a vertical ovoid pipe; also spelled Phalaborwa)

60) Kusehke, O.H., and M.J. H. Tonking. 1971. Geology and Mining operations at Palabora Mining Company limited, Phalaborwa, N-E Transvaal; *Journal of the South African Institute of Mining and Metallurgy*, August, 1971, pp. 12-22; http://www.saimm.co.za/Journal/v072n01p012.pdf ; accessed February 10, 2016

61) The Palabora Mining Company (website; accessed February 10, 2016). http://www.palabora.com/palabora.asp; http://www.palabora.com/underground_mining.asp; http://www.palabora.com/underground_mining.asp (NOTE: older workings, open pit; underground mine excavation shaft completed 2004; Palabora Igneous Complex)

Oyu Tolgoi Mine (Cu, Au): Mongolia

62) *Turquoise Hill Resources* (website; accessed February 11, 2016). Oyu Tolgoi (copper-gold), Mongolia: Project Website (NOTE: Rio Tinto, Mongolian Gov.); http://www.turquoisehill.com/s/Oyu_Tolgoi.asp; http://www.turquoisehill.com/i/maps/IVN_PropMongA_20121128.jpg; (NOTE: location map)

63) AMEC Minproc (for Ivanhoe Mines Ltd.). 2010. *Oyu Tolgoi Project* – Technical Report, June 2010, Rev 0, 4/6/2010; http://www.turquoisehill.com/i/pdf/IDP10_June062010.PDF ; accessed February 11, 2016 (NOTES: Omnogovi Aimag, Mongolia; developed by Oyu Tolgoi LLC; 2009, Ivanhoe Mines, OT LLC and Rio Tinto PLC signed an Investment Agreement (IA) with the government GOM; five areas with several shaft access points; Palaeozoic Gurvansayhan Terrane, which consists of highly-deformed accretionary complexes and oceanic island arc assemblages; of the Altaid orogenic collage, a continental-scale belt dominated by collisional tectonics related to Late Palaeozoic convergence and rotation of Neoproterozoic and pre-0.6 Ga cratonic blocks; also within the South Mongolia Volcanic Belt, island arc terrain, Upper Devonian Alagbayan Formation, and volcanic sedimentary sequence of the Carboniferous Sainshandhudag Formation. Oldest rocks are Devonian age. Devonian age intrusive bodies, granodiorite, other; porphyry copper deposits; 42 58' 30" N 106 47' 30" E, and 43 03' 00" N 106 55' 00" E two of 4 boundary coordinates)

64) AMC Consultants Pty Ltd. 2013. *2013 Oyu Tolgoi Technical Report*, *Turquoise Hill Resources Ltd.*; AMC Consultants, 492 pp. http://www.turquoisehill.com/i/pdf/2013-Oyu-Tolgoi-Technical-Report-March-25-2013.pdf ; accessed February 11, 2016 (NOTE: Developed by Oyu Tolgoi LLC; Rio Tinto, manager. Mine design projects access with: Shaft 1, 6.7m diameter, 1,385depth bgl; Shaft 2, 10m diameter; 1319 depth bgl; Shaft 3, 11 m diameter, 1,180depth bgl; Shaft 4, 11m diameter, 1,220depth bgl; Shaft 5, 6.7m diameter, 1,195depth bgl; construction phase, depths vary with conditions as built)

65) Haines, A., et al. 2006. Geotechnical design considerations for the proposed Oyu Tolgoi open pits, Southern Mongolia; *The South African Institute of Mining and Metallurgy International Symposium on Stability of Rock Slopes in Open Pit Mining and Civil Engineering; pp. 133-154* http://www.saimm.co.za/Conferences/RockSlopes/133-154_Haines_fin.pdf ; accessed February 11, 2016

66) *InfoMine / Intelligence Mine* (website; accessed February 11, 2016). Oyu Tolgoi; Global Mining Market Intelligence **http://www.infomine.com/minesite/minesite.asp?site=oyutolgoi**

66a) Porter, T.M. 2016. The geology, structure and mineralisation of the Oyu Tolgoi porphyry copper-gold-molybdenum deposits, Mongolia: A review; *Geoscience Frontiers*, Vol. 7(3), May 2016, pp. 375-407 (Research article); http://www.sciencedirect.com/science/article/pii/S1674987115000924 [Note: Oyu Tolgoi cluster of seven porphyry Cu-Au-Mo deposits in southern Mongolia, define a narrow, linear, 12 km long; deposits lie within the Gurvansayhan island-arc terrane, a fault bounded segment of the broader Silurian to Carboniferous Kazakh-Mongol arc; Oyu Tolgoi is associated with multiple, overlapping, intrusions of late Devonian (~372 to 370 Ma) quartz-monzodiorite intruding Devonian (or older) juvenile, probably intra-oceanic arc-related, basaltic lavas and lesser volcaniclastic rocks, unconformably overlain by late Devonian (~370 Ma) basaltic to dacitic pyroclastic and volcano sedimentary rocks. 43°01'40?N, 106°51'34?E]

Resolution Copper Mining Project: Superior, Arizona

67) Winant, A.R. 2010. *Sericitic and Advanced Argillic Mineral Assemblages and Their Relationship to Copper Mineralization, Resolution Porphyry Cu-(Mo) Deposit, Superior District, Pinal County, Arizona*; A Prepublication Manuscript Submitted to the Faculty of the Department Of Geosciences (Master Of Science), The University Of Arizona; http://www.geo.arizona.edu/Antevs/Theses/WinantARMS2010.pdf Accessed February 11, 2016 (NOTE: Prior production is from the Magma vein and from related materials that replace selected beds in the Paleozoic carbonate sequence; Resolution deposit occurs beneath the Apache Leap Tuff, largely south and east of the Magma vein; top of the ore body is ~1.5 km bgl; located in the Superior (Pioneer) district, Pinal County, Arizona; Porphyry-related deposits in the Superior mining district; formed within the Late Cretaceous to early Tertiary Laramide arc; Proterozoic Pinal Schist forms the local basement; overlain by Proterozoic Apache Group, sedimentary and volcanic units; Overlain by Paleozoic sedimentary sequence, and the later Mesozoic sedimentary and intermediate volcanic and volcaniclastic rocks; Mesozoic, Paleozoic, and Proterozoic rocks are intruded by felsic porphyry dikes and sills.)

68) Cementation (website; accessed February 11, 2016). Shaft Sinking, Resolution Copper Mining, Resolution Copper (Cementation) Project; http://en.cementation.com/site/project-resolution-copper.php?p=1 ; index and home, http://en.cementation.com/site/index.php ; http://en.cementation.com/ (NOTE: Cementation, Canada)

69) Resolution Copper Mining Home (website; accessed February 11, 2016). http://resolutioncopper.com/;

70) Resolution Copper Mining (website; accessed February 11, 2016). The Resolution Copper Project; http://resolutioncopper.com/the-project/

71) Resolution Copper Mining. 2013. *Resolution Mine Plan of Operations: Volume One, Environmental Setting and Project Description*, Section 4, Proposed Mine Plan, pages 103-193; http://resolutioncopper.com/the-project/mine-plan-of-operations/; http://49ghjw30ttw221aqro12vwhmu6s.wpengine.netdna-cdn.com/wp-content/uploads/2014/06/resolution-copper-plan-of-operations-volume-one-proposed-mine-plan-2.pdf ; accessed February 11, 2016 {NOTE: this is a three volume set with multiple sections. Rio Tinto, operator; Resolution project in porphyry copper deposit, Arizona mine, US deepest mine "sunk shaft" to 6943'; includes Magma mine properties associated vein deposit; Resolution project deposits rest 5000-7000'bgl; 6 shafts planned as operational; 2013, Shaft 10 ~ 7000' bgl, 28' diameter; Rio Tinto, BHP Billiton; footprint area Gila Conglomerate (Tcu – Miocene Conglomerate) and Pinal Schist (Xp – Early Proterozoic Pinal Formation); deposit is hosted by a thick sequence of Cretaceous volcaniclastic and siliciclastic sedimentary rocks; see Rio Tinto "Mine of the Future" project}

72) E&MJ News (website article). 2014. Resolution Completes Deepest Single Lift Shaft in North America. *Engineering and Mining Journal "News"*, 11/24/2014; http://www.e-mj.com/news/leading-deveopments/4703-resolution-completes-deepest-single-lift-shaft-in-north-america.html#.VZ7tXXnJAy4 ; accessed February 11, 2016 (NOTE: completed to total depth - Shaft 10 is 6943'/2116m bgl, 28' diameter; construction completed 11/18/2014)

73) MinDat.org (website; accessed February 11, 2016). Magma Mine (Resolution Copper). http://www.mindat.org/loc-3349.html (Eight shafts from Magma mine workings with depths up to 4800' bgl; Superior, Pinal County, Arizona; Shaft 9 deepening for Resolution project)

74) Manske, S. and A.H. Paul. 2002. Geology of a major new porphyry copper center in the Superior (Pioneer) District, Arizona; *Economic Geology*, V97, No.2, p. 197-220. http://economicgeology.org/content/97/2/197.abstract ; accessed abstract February 11, 2016

75) Cementation Inc. (webpage; accessed February 11, 2016). World Class Projects: Resolution Copper Mining, Resolution Copper Project. http://en.cementation.com/site/project-resolution-copper.php (construction of 28'diameter shaft to 1000'; shaft sinking planned to 7000' bgl; Resolution Copper Mining LLC, owned by BHP Billiton and Rio Tinto Group)

76) Fiscor, S. April 17, 2014. Sinking America's deepest shaft; *Engineering and Mining Journal*, News, April 17, 2014; http://www.e-mj.com/features/3899-sinking-america-s-deepest-shaft.html ; accessed February 11, 2016 (NOTES: Resolution Copper No10 shaft >5280'bgl with goal of 7000' bgl, 28' diameter shaft; in 2012, encountered hot water ~5200' and progress stalled until environmental adjustments made; later completed)

77) Resolution, LLC. (website accessed February 11, 2016). Developing an Arizona copper resource to benefit the world; http://resolutioncopper.com/ (NOTE: Located near Superior, AZ; near Manga Mine)

78) Resolution, LLC - Media Release. November 18, 2014. Resolution Copper Mining completes the deepest single lift shaft in America (completed 28 foot diameter shaft 10 to final depth of 6,943 feet (2116.2 m); http://49ghjw30ttw221aqro12vwhmu6s.wpengine.netdna-cdn.com/wp-content/uploads/2014/04/FINALShaft_10_depth_media-release.pdf ; accessed February 11, 2016

79) Cementation (website; accessed February 11, 2016). November 17, 2014. *Largest Mine Shaft in the USA Complete (News Release);* http://en.cementation.com/site/pdf/Cementation-Deepest_Single_Lift_Shaft_in_USA-20141126.pdf (NOTE / QUOTE: Cementation USA has completed sinking the deepest single lift shaft in the United States at the Resolution Copper Project in Superior, Arizona. With a finished diameter of 28 feet, the No. 10 shaft was sunk to a final depth of 6,943 feet below surface.)

80) Rio Tinto (website; accessed February 11, 2016). *Resolution Copper Mining completes deepest single mine shaft in America*; http://www.riotinto.com/ourcommitment/features-2932_13649.aspx ; (NOTE: "This 1.3 mile deep vertical shaft is truly unprecedented in North America," said Tom Goodell, General Manager of Shaft Development for the Resolution project.... final depth of 2116.2 metres... 6943' … 28' diameter shaft)

Xinhu mine, Huaibei Coal Mining Co., Anhui Province China (coal related information)

81) EPA (Environmental Protection Agency). 2015. Energy Markets in China and the Outlook for Coal Mine Methane Project development in Anhui, Chongquing, Henan, Inner Mongolia, and Guizhuo (http://epa.gov/cmop/international/china.html); accessed February 11, 2016. (NOTE: Example file, http://www.epa.gov/cmop/docs/chinamarkets/2014_CoalChinaEnergyMarket_Ch1_ExeSum.pdf ; accessed February 11, 2016)

82) Long, Zhiyang and Liangyu Gui. 2012. Current situation and development for China's 1000m deep shaft sinking; *Institute of Materials, Minerals, and Mining, Third International Conference on Shaft Design and Construction 2012*; http://maekonverentsid.blogspot.com/2012/03/third-international-conference-on-shaft.html ; not accessible (Note: presentation content described in Simon Walker, 2012, conference paper)

Pumpkin Hollow: Yerington, Nevada, USA

83) Nevada Copper (website; accessed February 11, 2016). Pumpkin Hollow, Map Gallery and Projects (links). http://www.nevadacopper.com/s/PumpkinHollow.asp?ReportID=614316&_Type=Pumpkin-Hollow&_Title=Map-Gallery

84) Nevada Copper (website; accessed February 11, 2016). Pumpkin Hollow Project. http://pumpkinhollowcopper.com/ (Note: Completed 1900' bgl shaft, 24' diameter; see Nevada Copper news release, 9/30/2015)

85) Nevada Copper Pumpkin Hollow Project, Press Release, May 28, 2015 (website; accessed February 11, 2016). Nevada Copper Announces Positive Feasibility Study Results; Nevada Copper, Pumpkin Hollow Mine; Category Archives: Press Releases. http://pumpkinhollowcopper.com/category/press-releases/ and http://pumpkinhollowcopper.com/category/press-releases/page/2/ (NOTE: a 24

foot diameter concrete lined shaft; the shaft is sunk to the 1,900 foot to primary production level from which lateral development is progressing towards the East ore zone; Yerington, NV, USA)

86) Nevada Copper (website; accessed February 11, 2016). *Pumpkin Hollow Geology*. http://www.nevadacopper.com/s/PumpkinHollow.asp?ReportID=614284&_Type=Pumpkin-Hollow&_Title=Geology

87) Mining-Technology.com Projects (website; accessed February 11, 2016). *Pumpkin Hollow Project, United States of America*. http://www.mining-technology.com/projects/pumpkin-hollow/ (NOTE: see list of other mining projects; Fe, Cu, Au; Mineralization flanks Yerington Batholith; Granodiorite / diorite of batholith cut the limestone belonging to the Triassic Mason Valley Formation and the calcareous argillites, siliceous shales, siltstones and limestone of the Gardnerville Formation; intrusion accompanied by development of large zones of skarn and copper and magnetite mineralisation; see http://www.mining-technology.com/projects/)

88) Cementation (website; accessed February 11, 2016). *Cementation, Projects, Shaft Sinking*: Nevada Copper, Inc., Pumpkin Hollow Mine East Shaft Project; http://en.cementation.com/site/projects.php ; http://en.cementation.com/site/project-pumpkin-hollow-shaft.php?p=1 (Pumpkin Hollow Mine Cementation Project: Cementation Projects listing, http://en.cementation.com/site/projects.php; Cementum target was 24' diameter shaft to 2160')

89) Schottenfeld, M. T. 2012. ***Structural Analysis and Reconstruction of the southern end of the Pumpkin Hollow deposit, Yerington District, Nevada;*** A Prepublication Manuscript submitted to the Faculty of the Department of Geosciences, in Partial Fulfillment of the Requirements for the Degree of Master of Science, in the Graduate College, The University of Arizona. 67 pages; http://www.geo.arizona.edu/Antevs/Theses/SchottenfeldMT_MS_2012.pdf ; accessed February 11, 2016. (NOTES: Identified as iron oxide-copper-gold (IOCG) / iron oxide-copper-(gold-silver) skarn with IOCG affiliations; Late Triassic; high grade IOCG chalcopyrite- magnetite skarn adjacent to Yerington Batholith; Mason Valley Limestone is the principal host of mineralization; main ore mineral is chalcopyrite)

McArthur River / Key Lake: Saskatchewan, Canada

90) Cameco (website; accessed February 11, 2016). McArthur River / Key Lake; Cameco Operations. http://www.cameco.com/businesses/uranium-operations/canada/mcarthur-river-key-lake (Note: Uranium mines; world's largest producer; northern Saskatchewan, Canada)

91) Bronkhorst, D., *et al*. 2012. *McArthur River Operation, Northern Saskatchewan, Canada*; NI 43-101 Technical Report. Prepared for Cameco Corporation; http://s3-us-west-2.amazonaws.com/assets-us-west-2/technical-report/cameco-2012-mcarthur-technical-report.pdf ; accessed February 11, 2016 (NOTE: Located Athabasca Basin, within the southwest part of the Churchill Structural Province of the Canadian Shield. The crystalline basement rocks underlying the deposit are members of the Aphebian Wollaston Domain, metasedimentary sequence. These rocks are overlain by flat lying sandstones and conglomerates of the Helikian Athabasca Group. These sediments consist of the A, B, C and D units of the Manitou Falls Formation. In the deposit area, the fault has thrust a sequence of Paleoproterozoic graphitic metasedimentary rocks into the overlying late Paleoproterozoic (Helikian) Athabasca Group sediments; ages of 1348 ± 16 and 1521 ± 8 Ma, the older being interpreted as the age of the primary uranium mineralization and the younger as the age of a remobilization event. SHAFTS = Shaft 1, aka Pollock Shaft, 5.5m diameter; Shaft 2 is ventilation shaft; Shaft 3 has 6.1m diameter lined shaft; mineralization occurs 500-640m bgl.)

91a) Cameco (website, announcement). November 8, 2017 - *Cameco to suspend production from McArthur River and Key Lake operations and reduce its dividend*; https://www.cameco.com/media/news/cameco-to-suspend-production-from-mcarthur-river-and-key-lake-operations-an (Note: Cameco announced the Mc Arthur River mine [largest producing uranium mine in the world] operations to be temporarily suspended by the end of January 2018)

LaRonde: Cadillac, Quebec, Canada

92) Agnico Eagle (website; accessed February 11, 2016). *LaRonde (Northern Operations).* http://www.agnicoeagle.com/en/Operations/Northern-Operations/LaRonde/Pages/default.aspx {NOTE: Geology - located in the Abitibi region of northwestern Quebec; LaRonde's Penna shaft (#3 shaft, 7217' bgl; reported in 2014 to be 2.246km deep) is believed to be the deepest single lift shaft in the Western Hemisphere. The new #4 shaft bottoms out at over 3,000 m (9,800 ft) down; currently mining to 3100m depth bgl. Gold mine with Ag, Zn, Cu; looking to extend production to 3.7 km bgl; Archean-age Abitibi volcanic belt, within the Bousquet Formation of the Blake River Group of volcanic rocks. Page contains links for technical report, Guy Gosselin, 2005; http://s1.q4cdn.com/150142668/files/doc_Technical_Reports/LaRonde/March23-LaRonde-TechnicalReport2005_v001_l7ba95.pdf }

92a) Werniuk, J. 2008. LaRonde Extension; *Canadian Mining Journal*, News, June 1, 2008; http://www.canadianminingjournal.com/features/laronde-extension/ (NOTE: Construction of the internal shaft (No. 4) has recently begun. It will be an 835-m-long, 5.5-m (inside diameter) concrete-lined circular winze from 2,030-m (level 203) to 2,865-m depth; services in No. 4 shaft will be nearly identical to the Penna shaft)

92b) Mercier-Langevin, F. 2011. LaRonde Extension – mine design at three kilometres. *Mining Technology: Transactions of the Institutions of Mining and Metallurgy: Section A*, Volume 120, Issue 2, 2011, p. 95-104; http://www.tandfonline.com/doi/abs/10.1179/037178411X12942393517417?journalCode=ymnt20 ; abstract accessed March 10, 2016 (Note: plans for 3.7km exploration, see http://minesqc.com/en/knowledge-base/fiche/laronde-mine/)

East Rand Goldfield (ERPM): South Africa

93) Mosoane, C. 2003. Ore reserve valuation of mined-out areas and remnants at East Rand Proprietary Mines (ERPM); *The Journal of The South African Institute of Mining and Metallurgy;* March, 2003; p. 87-92. http://www.saimm.co.za/Journal/v103n02p087.pdf ; accessed February 11, 2016 (NOTE: mined 3200m-3585m bgl; Witwatersrand Basin, Boksburg, SA; Far East Vertical (FEV) Shaft Area mined at depths of between 2600 and 3200 m below surface; mine Composite Reef in the FEV Area;)

94) DRDGold Ltd. http://www.drd.co.za/; website accessed February 11, 2016 (NOTE: 2014, asset sale as owner of East Rand Proprietary Mines Limited / ERPM; http://www.drdgold.com/investors-and-media/media-releases/2008/underground-operations-of-east-rand-proprietary-mines-limited-erpm-to-be-placed-on-care-and-maintenance-section-189a-consultation-process-to-begin-2008-11-19 press release by DRDGold indicates underground areas closed and underground mine areas placed on maintenance and care in 2008. Location for East Rand ERPM mine is general area; see https://www.mindat.org/loc-10864.html for mindat.org location, -26.24722, 28.22722 is south of location of surface area activity shown on map in this study)

Kennedy Mine: California, USA

95) Wilkerson, G. and David Lawler. 2007. Jackson To Grass Valley, Geologic Field Guide; **In:** *Roadside Geology And Mining History Of The Mother Lode - Part 2: Jackson To Grass Valley, Geologic Field Guide (Amador, Sacramento, El Dorado, Placer, and Nevada counties), Excursions along the Highway 49 corridor, March 15-17, 2007*; Bureau Land Management; http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/pdfs/bakersfield_pdfs/field_trips/mother_lode_central.Par.81782.File.dat/2007_jackson_to_grass_valley.pdf-; and http://www.blm.gov/ca/st/en/fo/bakersfield/Programs/geology/fieldguide_motherlode_central.html; accessed February 11, 2016 (NOTE: Kennedy mine, Map 23C and page 37; first claim in 1856; operations ceased in 1942; shaft inclined; vertical depth of 5,912 feet /1,802 m; workings are in Mariposa slate and Logtown Ridge / Bower Creek Volcanics / metavolcanics, late Middle to early Late Jurassic; intruded by quartz porphyry. USGS data http://pubs.usgs.gov/of/2002/of02-195/OF02-195K.pdf)

Soudan Underground Mine, Breitung Township, St. Louis County, Minnesota

96) Peterson, D. March 2007. *Imagining Scientific Realities Deep Underground: Utilizing Knowledge and 3-d Geologic Modeling, Fundamental Tenets of the University of Minnesota Proposed Institute for Underground Science and Soudan DUSE*L Report of Investigations NRRI/RI-2007/02; Natural Resource Research Institute , Univ. Minnesota, Duluth, MN, USA; https://drive.google.com/file/d/0B23uzT8P1ra-TXhLVGJrMnQxZWc/view?pli=1 ; and http://www.nrri.umn.edu/egg/REPORTS/RI200702/RI200702.html ; accessed February 11, 2016 (NOTE: work cooperatively with Fermi; several site locations over time in complex; e.g., 713m overburden / 2090mwe original proposed depth; test area in Soudan Underground Laboratory 2007 down to a depth of 1500m, i.e., 4125 meters of water equivalent (MWE); near Tower MN; Late Archean granite)

*97) **Brumfiel, G. 2007. Deep science*** strikes gold after latest *site* is named; ***Nature*** 2007: ***448***(7151):***232-233***. DOI: 10.1038/448232a.*;* http://www.readcube.com/articles/10.1038/448232a ; accessed February 11, 2016 (NOTE: Map of underground physics research facilities; discussion of world physics labs, space needs and proposed work; includes - Homestake mine ~2250m; Soudan ~710m; Sudbury ~2070m; Boulby ~1070m; Frejus ~1700m; Mont Blanc ~`800m; Gran Sasso ~1400m; Baksan ~1700m; Kamioka ~1000m)

98) University of Minnesota, Soudan Underground Laboratory (website; accessed February 11, 2016). http://www.sudan.umn.edu/ (NOTE: 2,341'bgl; greenstone terrain, 2.7 Ga; see also Super Cryogenic Dark Matter Search webpage, LBNL; http://cdms.berkeley.edu/experiment.html ; physics testing in SNOLAB and Soudan mine)

Enterprise / Mount Isa Mines: Queensland, Australia (Australia's Deepest Mines)

99) Mount Isa Mines (a Glencore Company), Website accessed February 11, 2016. http://www.mountisamines.com.au/EN/Pages/default.aspx

100) McLellan, J.G., R. O'Sullivan, B. Miller and D. Taylor. 2014. Geomechanical Modelling of the Mount Isa Copper Deposit – Predicting Mineralisation; Ninth International Mining Geology Conference / Adelaide, SA, 18–20 August 2014; p. 197-205; http://www.researchgate.net/profile/John_Mclellan2/publication/273062699_Geomechanical_Modelling_of_the_Mount_Isa_Copper_Deposit__Predicting_Mineralisation/links/54f6459f0cf27d8ed71d730f.pdf ; accessed February 11, 2016 (NOTE: Paroo Fault, which has juxtaposed older basement Eastern Creek Volcanics against the younger Mount Isa Group sediments of 1655 ± 4 Ma; Mount Isa copper deposit extensive, hosted almost entirely within the Urquhart Shale, a unit of the Mount Isa Group sediments and part of the Isa Superbasin; X41 mine (Pb, Zn; 1100 and 1900 orebodies) and the Enterprise mine (copper; 3000 and 3500 orebodies); Palaeoproterozoic to Mesoproterozoic Superbasins; adjacent to the city of Mount Isa, Queensland, -20.720656, 139.468072)

101) Mining Technology (website; accessed February 11, 2016). Mount Isa Copper Mine, Australia; http://www.mining-technology.com/projects/mount_isa_copper/ (NOTES: copper mining began in 1953; Enterprise with internal shaft to depth of 1900m bgl from ~1000m bgl; deepest hard rock mines in Australia are the copper and silver / zinc / lead mines in Mount Isa, Queensland at >1,800 m (5,900 ft.). Mount Isa Mines, Ltd.; Glencore / Xstrata Group, now Glencore; discovered 1923; technology innovations in processing ore; Lower Proterozoic Urquhart Shale; "P49" service and hoisting shaft (8 m in diameter) sinking started in 1971, and completed to a depth of 1040 m in 1975 for Pb / Zn resource exploitation (reference is out of date; ownership validated by https://en.wikipedia.org/wiki/Mount_Isa_Mines; accessed February 11, 2016; Glencore/Xstrata merge, 2013, become Glencore plc); Enterprise mine is the most recently developed copper ore source at Mount Isa and is Australia's deepest mine, with an internal shaft which reaches a depth of 1,900m (Mount Isa Copper Mine, Australia; accessed February 16, 2016; Mount Isa Lead, Zinc, and Silver mine, Australia, http://www.mining-technology.com/projects/mount_isla_lead/ ; accessed February 16, 2016; Isa mine area disc. 1923; Lower Proterozoic Urquhart Shale sequence; location = 20°42′58″S 139°28′34″E = -20.716111, 139.476111

Crownpoint, New Mexico (Wyoming Mineral-Conoco Crownpoint Project)

102) Hunter, H. E. 1983. Drilled Shaft Construction at Crownpoint, New Mexico; 22 pp., Chapter 34; *In*: Sutcliffe, H., and J.W. Wilson (eds.), 1983. *Proceedings of the Rapid Excavation and Tunneling Conference, Volume 1, Rapid Excavation and Tunneling Conference*, Chicago, Illinois, June 12-16, 1983; American Institute of Mining, Metallurgical, and Petroleum Engineers, American Society of Civil Engineers; http://pbadupws.nrc.gov/docs/ML0404/ML040480468.pdf ; accessed February 16, 2016 (NOTE: Wyoming Mineral-Conoco Crownpoint Project represents the first time that big bole drilling has been exclusively used to develop totally a privately financed mine below a depth of 1000 feet; Uranium mine; Three shafts, one ten feet in diameter and two six feet in diameter, and completed in 1982 to depths of 2243'(120" diameter), 2188' and 2188' (both 72" diameter) respectively; reverse circulation; Grants Mineral Belt approximately 60 miles northwest of Grants, New Mexico, in Section 24, T17N, R13W NMPM, McKinley County, about 1/2 mile west of town site of Crownpoint, New Mexico); Reverse

circulation air lift; San Juan Basin; Uranium found in Westwater Canyon Member of the Jurassic Morrison Formation at ~ 2000'bgl. Project never completed due to price collapse; more recently considered for ISR U recovery; Approximate area location = 35.687594, -108.164151

103) Uranium Resources, Inc. (website; accessed February 16, 2016). Crownpoint project; http://www.uraniumresources.com/projects/new-mexico/crownpoint; (NOTE: Uranium mineralization in Westwater Member of the Morrison Formation at a depth of from 2,100 to 2,300 feet; URI planning ISR project once approvals obtained.)

Seismic Research and Events: South Africa

104) Ogasawara, H., et al. 2015. Stress and strength at seismic event hypocenters in deep South African gold mines and the M5.5 Orkney Earthquake; (presentation with abstract of proposal - Ogasawara, H., et al. 2015. Drilling into seismogenic zones of M2.0 – M5.5 earthquakes in deep South African gold mines (DSeis)), *ICDP Workshop Proposal submitted to ICDP on 15 January 2015*; http://www.seismo.ethz.ch/research/groups/schatzalp/Download/S1P04_Ogasawara.pdf ; accessed February 16, 2016 (Note: near Orkney Klerksdorp goldfields of the Witwatersrand basin; 8/5/2014, an M5.3/ 5.5; One of the SATREPS observational sites; break was below mining levels; normal fault with strike slip component; quake >5km depth; monitoring with strong motion, strainmeter, and seismic recorders; triggered events in mine levels with normal fault motion.)

105) Vervaeck, A. August 5, 2014. Deadly earthquake in South Africa in Orkney and Klerksdorp - 1 fatality and 38 injured; Earthquake Report.com, August 11, 2014; http://earthquake-report.com/2014/08/05/strong-earthquake-south-africa-on-august-5-2014/ ; accessed February 16, 2016 (Note: map, selected details, casualties; damages)

SATREPS / Moab – Khotsong: South Africa

106) Kilian, A. 2015 (May 8). What Role does deep mining play in seismic activity in South Africa? *Creamer Media's Mining Weekly* (Earthquakes and Mining); http://www.miningweekly.com/article/mining-rekated-2015-05-08; accessed February 16, 2016 (NOTE: Japanese research programme the Science and Technology Research Partnership for Sustainable Development (SATREPS); Council for Scientific and Industrial Research (CSIR))

107) Montiea, B. 2015 (April 3). Mining-induced earthquake research in final stages. *Creamer Media's Mining Weekly* (Earthquakes and Mining); http://www.miningweekly.com/article/mining-induced-earthquakes-research-in-final-stages-2015-04-03 ; accessed February 16, 2016 (NOTES: **SATREPS**, Japan's Science and Technology Research Partnership for Sustainable Development; funds South African Council for Scientific and Industrial Research and Japan researchers from Ritsumeikan University. Instrumented AngloGold Ashanti's Moab Khotsong gold mine and mines of West Rand)

JAGUARS, Mponeng: South Africa (Japanese-German Acoustic Emission Research in South Africa)

108) Kwiatek, G., and Y. Ben-Zion. 2013. Assessment of *P* and *S* wave energy radiated from very small shear-tensile seismic events in a deep South African mine. *Jour. of Geophysical Research: Solid Earth* 118(7), p. 3630-3641; http://onlinelibrary.wiley.com/doi/10.1002/jgrb.50274/abstract; http://onlinelibrary.wiley.com/doi/10.1002/jgrb.50274/pdf ; accessed February 16, 2016. (NOTES: JAGUARS seismic network in the Mponeng deep gold mine, South Africa; The JAGUARS project continuously monitors microseismic activity at 3.5km depth in Mponeng gold mine, Republic of South Africa)

109) GFZ / Helmholtz Center, Potsdam German Research Center for the Geosciences, Das Deutsche GeoForschungsZentrum) website; accessed February 16, 2016 *Microseismicity and acoustic emission in deep gold mine in South Africa Jaguars*; http://www.gfz-potsdam.de/en/section/geomechanics-and-rheology/projects/microseismicity-and-acoustic-emission-in-deep-gold-mine-in-south-africa-jaguars/; (Note: JAGUARS (JApanese-German Underground Acoustic Emission Research in South Africa); JAGUARS project continuously monitors microseismic activity at 3.5km depth in Mponeng gold mine, Republic of South Africa; planned expanded study in TauTona with NELSAM group; many laboratory results indicate intriguing relations between very small events (acoustic emission, AE) and macroscopic failure; monitors at 3.5km bgl; ~2007-present)

110) Kozłowska, M., et al. 2014. Nanoseismicity and picoseismicity rate changes from static stress triggering caused by a Mw 2.2 earthquake in Mponeng gold mine, South Africa; *Journal of Geophysical Research (Solid Earth)* 120(1):290-307, doi:10.1002/2014JB011410. http://onlinelibrary.wiley.com/doi/10.1002/2014JB011410/abstract ; abstract online, accessed February 23, 2016

111) Yabe, Y., et al. 2009. Observation of numerous aftershocks of an Mw 1.9 earthquake with an AE network installed in a deep gold mine in South Africa; *Earth Planets Space* 61, p. e49–e5; The Society of Geomagnetism and Earth, Planetary and Space Sciences (SGEPSS); http://www.researchgate.net/publication/228625077_Observation_of_numerous_aftershocks_of_an_Mw_1.9_earthquake_with_an_AE_network_installed_in_a_deep_gold_mine_in_South_Africa (Mponeng Gold Mine, ~3300m bgl); accessed February 23, 2016

NELSAM, Tau Tona and Mponeng, South Africa

112) Boettcher, M.S., et *al*. 2015. Moment Tensors and Other Source Parameters of Mining-Induced Earthquakes in TauTona Mine, South Africa; **Bull. Seis. Soc. Am**., Vol. 105, No. 3, pp. 1576–1593; http://www.unh.edu/esci/people/pdf/Boettcher_2015_BSSA.pdf ; https://ceps.unh.edu/sites/ceps.unh.edu/files/departments/earth_sciences/boettcher_2015_bssa.pdf ; accessed February 23, 2016 (NOTE: NELSAM-project at TauTona-Mine. Natural Earthquake Laboratory in South African Mines (NELSAM is successor project to DEFSAM; Tau Tona mine test at ~3600mbg; includes temporary stations from PASSCAL / Program for the Array Seismic Studies of the Continental Lithosphere deployment in TauTona and Mponeng Mines; included former Integrated Seismic Systems International (ISSI) stations; Vredefort meteorite impact (2.023 Ga))

Seismicity / Rock Bursts - General

113) Young, R.P. (ed.) 1993. *Rock Bursts and Seismicity in Mines 93: Proceedings of the Third International Symposium, Kingston, Ontario, 1993*. Balkema Publishers, Rotterdam, Netherlands. 462pp.

http://civil.engineering.webservices.utoronto.ca/staff/professors/rpyoung/publications/papers/rpy88.htm); accessed February 23, 2016 (NOTE: sampling of abstracts address Creighton, Lac du Bonnet Granite)

Rock Properties and Seismic - General

114) Gercek, H. 2007. Poisson's ratio values for rocks. *International Journal of Rock Mechanics and Mining Sciences*, vol. 44, no. 1. pp. 1–13; http://ac.els-cdn.com/S136516090600075X/1-s2.0-S136516090600075X-main.pdf?_tid=66e890b8-fe87-11e4-b053-00000aacb35d&acdnat=1432082002_d2196596bac4a2afc691f9d4c96baa3e ; accessed February 23, 2016 (Note: generalized rock properties data)

Tau Tona, Driefontein, Mponeng Mines, Seismic Programs: South Africa

115) Milev, A.M., and S.M.Spottiswood. 2005. Strong ground motion and site response in deep South African mines; *The Journal of The South African Institute of Mining and Metallurgy*, V. 105, AUGUST 2005; pp. 515-524; http://www.saimm.co.za/Journal/v105n07p515.pdf ; accessed February 23, 2016 (NOTE: Tau Tona, Driefontein, Mponeng, Kloof monitored along with other mines)

116) Ortlepp, W. 2006. Comment on the paper "Strong ground motion and site response in deep South African mines" in the *Journal South African Institute of Mining and Metallurgy* V. 105, pp. 515-524; *The Journal of The South African Institute of Mining and Metallurgy* Volume 106, August 2006, pp. 593-598; http://www.saimm.co.za/Journal/v106n08p593.pdf ; accessed February 23, 2016 (NOTES: see reply to comment, Milev and Spottiswood, p. 598-599)

117) AngloGold Ashanti (website; accessed July 15, 2014); http://www.anglogoldashanti.com/en/Pages/default.aspx ; accessed February 23, 2016 (NOTE: Seismic studies in several mines, integrated investigations available through webpages for AngloGold Ashanti)

GROUNDWATER RESIDENCE TIME, DEEP TIME: South Africa deep mines, Groundwater residence time – Precambrian shield areas – unique chemistries.

South Africa: Witwatersrand Basin, Mponeng, Tau Tona, Kloof and Driefontein mines

118) Lippmann, J., M. Stute, T. Torgersen, D.P. Moser, J.A. Hall, L. Lin, M. Borcsik, R.E.S. Bellamy, T.C. Onstott . 2003. Dating ultra-deep mine waters with noble gases and ^{36}Cl, Witwatersrand Basin, South Africa. *Geochimica et Cosmochimica Acta*, 67(23):4597-4619. Article online through http://www.sciencedirect.com/science/article/pii/S0016703703004149 ; accessed February 23, 2016 (NOTE: results suggest residence times of the fluids in fissures in this region (up to 3.3 km depth) are of the order of 1–100 Ma; modeling of the data suggests residence times are in excess of a million years; model variations extend age to tens of millions of years; Witwatersrand Basin is within Archaean Kaapvaal Craton (2.7-3.1Ga) of South Africa; Vredefort Dome (2.02Ga) is located near the center of the basin and formed as the results of a meteorite impact.)

South Africa: Kloof, Driefontein Mines, South Africa

119) Lippmann-Pipke, J., B.Sherwood Lollar, et al. 2011. Neon identifies two billion year old fluid component in Kaapvaal Craton. *Chem. Geol*. 283, 287–296; http://www.princeton.edu/geosciences/people/onstott/pdf/Lippmann-Pipkeetal-2011-ChemGeol.pdf ; accessed February 23, 2016 (NOTE: the Witwatersrand Basin, south Africa; neon isotopes in addition to prior collected isotope data; Rand Group, a subgroup of the Witwatersrand Supergroup, and in the Ventersdorp Contact Reef (VCR) which is located at the unconformity between the Witwatersrand and the overlying Ventersdorp Supergroup. The rock formations of the Witwatersrand Supergroup are mostly quartzites and conglomerates and were deposited sometime after 2914 Ma and before 2714 Ma" … Mponeng mine (26°.25.5′S, 27.25′E), Tau Tona mine (26.24′S, 27°25′E), Kloof mine (26°24′S, 27°36′ E) and Driefontein mine (26°24′S, 27°30′E); fluid inclusions is a ≥2 Ga; other water in millions of years residence time)

International: Examples of Regional Aquifers, GW Residence Times, Issues

120) IAEA (International Atomic Energy Agency). 2011. Using Isotopes Effectively To Support Comprehensive Groundwater Management; *Nuclear Technology Review*, Attachment 3. IAEA General Conference (55) INF/5, July 13, 2011; International Atomic Energy Agency. http://www.iaea.org/About/Policy/GC/GC55/GC55InfDocuments/English/gc55inf-5-att3_en.pdf ; accessed February 23, 2016 (NOTE: international examples, long residence times)

Japan: Kobe deep ground water He isotopes

121) Morikawa, N., et al. 2005. Estimation of groundwater residence time in a geologically active region by coupling 4He concentration with helium isotopic ratios; *Geophysical Research Letters*, Vol. 32(2), L02406, 2005; first published online 29 Jan., 2005; Wiley online. http://onlinelibrary.wiley.com/doi/10.1029/2004GL021501/pdf ; accessed February 23, 2016 (Note: GW residence time – contains examples, wide age range, methods summarized; examines brines and flux, flow velocity, tens to hundreds thousands yrs. residence time permitted with He analysis; corrected calibration w Ne20 data; 25k-230k yrs. residence time estimates from He concentration and isotopic ratio determination).

International: Examples, issues

122) Sherwood-Lollar, B. et *al.* 2013. Ancient Waters of the Precambrian Shields: Implications for subsurface life and astrobiology; COGB Seminar Abstract. http://eaps-www.mit.edu/paoc/events/cogb-seminar-barb-sherwood-lollar-toronto ; abstract only, accessed February 23, 2016

South Africa: Mponeng gold mine

123) Lin, L. H., et al. 2006. Long-term sustainability of a high-energy, low-diversity crustal biome. *Science* 314(5798), 479–482; http://www.researchgate.net/publication/6742978_Long-term_sustainability_of_a_high-energy_low-diweniff_crystal-biome ; accessed February 23, 2016 (NOTE: isolated groundwaters with residence times in tens of millions of years for fracture waters, and billions of years isolation for fluid inclusions; 3-to 4-km-deep fracture in the 2.7-billion-year-oldArchean Ventersdorp Supergroup meta-basalt, in which fracture water ages of tens of millions of years… fracture zone 2.825 km below the land surface (km bls) in the Mponeng gold mine, South Africa; VCR ore zone)

United States: GW Residence Time R&D Examples and Issue with He

124) Lowenstern, J. B., Evans, W. C., Bergfeld, D. & Hunt, A. G. 2014. Prodigious degassing of a billion years of accumulated radiogenic helium at Yellowstone. *Nature* 506, 355–358 (2014); http://www.nature.com/nature/journal/v506/n7488/full/nature12992.html ; accessed abstract March 1, 2016 (NOTE: abstract and figures online; results demonstrate the extremes in variability of crustal helium efflux on geologic timescales and imply crustal-scale open-system behavior of helium in tectonically and magmatically active regions; demonstrates issues with He isotopic residence time estimates)

124a) IAEA. 2015. *Isotope Hydrology: Revisiting Foundations and Exploring Frontiers*, International Symposium, Vienna, Austria, May 11-15, 2015, Book of Extended Synopses (Oral Presentations); IAEA Water Resources Programme, IAEA-CN-225. http://www-naweb.iaea.org/napc/ih/documents/other/Oral%20presentations.pdf ; accessed March 9, 2016

International: GW Residence Time R&D Examples

125) DOE, Office of Science (webpage; accessed March 1, 2016). October 2012. Sleuthing the Fate of Water in Ancient Aquifers and Ice Cores: http://science.energy.gov/np/highlights/2012/np-2012-10-b/ ; (NOTE: Contact Zheng-Tian Lu, ANL. Precision analytical techniques developed for fundamental experiments in nuclear physics now enable routine measurements of ultra-low concentrations of Krypton radioisotopes in samples of water, ice, and gas. state-of-the-art Atom Trap Trace Analysis (ATTA) instrument has been developed by a team of physicists working at Argonne National Laboratory working in collaboration with Earth scientists and other supporting agencies in the U.S. and worldwide. The ages of groundwater, ranging from 200,000 to 1,000,000 years old, in the Nubian Aquifer underneath the Eastern Sahara Desert, the Great Artesian Basin of Australia, and the Guarani Aquifer of South America; see IAEA, 2011)

International: GW Residence Time R&D Examples

126) Lu, Zheng-Tian. 2012. Tracer Applications of Noble Gas Radionuclides in the Geosciences (October 09, 2012); White Paper, 30 pp; Argonne National Laboratory; http://www.phy.anl.gov/events/tangr2012/TANGR2012%20Whitepaper%2010-09-2012.pdf ; accessed March 1, 2016

International: GW Residence Time R&D Examples

127) Sturchio, N. C., et al. 2004. One million year old groundwater in the Sahara revealed by krypton-81 and chlorine-36; *Geophys. Res. Lett.* 31(5) L05503; http://agupubs.onlinelibrary.wiley.com/agu/issue/10.1002/grl.v31.5/ ; access abstract March 1, 2016

International GW Residence Time R&D Examples

128) Gray, Richard. 2014. Earth's oldest body of water found beneath Canada contains more than all of the world's rivers, swamps and lakes put together; *DailyMail.com* (website), December 18, 2014; http://www.dailymail.co.uk/sciencetech/article-2878885/Huge-quantities-Earth-s-oldest-water-discovered-deep-underground-supporting-unknown-lifeforms.html#ixzz3gToCO3Rv ; http://www.dailymail.co.uk/sciencetech/article-2878885/Huge-quantities-Earth-s-oldest-water-discovered-deep-underground-supporting-unknown-lifeforms.html ; accessed March 1, 2016 (NOTE: Sherwood-Lollar and others, global map with site testing locations; billion year residence time to recent groundwater age discussion)

OTHER SELECTED DEEP MINES OF INTEREST

Pyhäsalmi Mine (Zn / Cu): Oulu Province, Pyhäjärvi, Finland (Center for Underground Physics, CUPP)

129) Mindat.org (website; accessed March 3, 2016) Pyhäsalmi Mine, Pyhäjärvi, Finland; http://www.mindat.org/loc-13126.html ; location http://www.mindat.org/maps.php?id=13126

130) Peltoniemi, Juha. 2005. Underground physics in the Pyhasalmi Mine; presentation at *Second Annual Meeting CUPP Project; University of Oulu, Finland*; http://ilias.in2p3.fr/ilias_site/meetings/second_annual_meeting/presentations/Peltoniemi_CUPP-PRA-Prague.PDF ; accessed March 3, 2016 (NOTES: One of the deepest active metal mines in Europe; Pyhäsalmi Mine (Zn / Cu / pyrite) in Pyhäjärvi, Finland at 1,444 meters (~4737'). Oulu Province; Olli shaft depth 3440' in 1996; internal Timo shaft from 3445'-4724' in 1996; 63°39′31″N 26°02′28″E, 63.658611, 26.041111 ; mine operator, formerly INMET, Canada; currently, 2013, First Quantum Minerals Ltd; Centre for Underground. Physics in Pyhäsalmi (CUPP), underground physics research laboratory)

131) Geological Survey of Finland (website, accessed March 3, 2016). Pyhäsalmi Mine; http://tupa.gtk.fi/karttasovellus/mdae/raportti/534_Pyh%C3%A4salmi.pdf

132) Gleeson, Daniel. 2010. Innovation at Depth (InfoMine website); Operation Focus – Finland, *International Mining. April, 2010*; p. 10-18; http://www.infomine.com/library/publications/docs/InternationalMining/Gleeson2010b.pdf ; accessed March 3, 2016 (NOTES: Timo shaft sunk in 2001 to 1440m; Zn/Cu deposit; formerly run by Outokumpu; Canada's Inmet Mining purchased the operation; established Finnish subsidiary Pyhäsalmi Mine Oy)

133) Centre for Underground. Physics in Pyhäsalmi (CUPP) website accessed March 3, 2016. http://www.cupp.fi/ ; (NOTES: deepest hard rock mine in Europe; ~4000mwe, 1450m bgl; mine description at http://www.cupp.fi/images/cupp_brochure.pdf and http://www.cupp.fi/index.php?option=com_content&view=article&id=3&Itemid=41&lang=en)

134) Puustjärvi, Heikki (ed.). 2006. *Pyhäsalmi Modeling Project, 13.5.1997-12.5.1999*; Technical Report, Outokumpu Mining Oy / Geological Survey of Finland; http://tupa.gtk.fi/raportti/arkisto/m19_3321_99_1_10.pdf ; accessed March 3, 2016 (Notes: volcanogenic massive sulphide (VMS) deposits; Geology discussed in Section B; Svecofennian domain between the Archaean Basement Complex in the east and the Central Finland Granitoid Complex in the southwest. Lithologically this area belongs to the NW-trending Savo Schist Belt (SSB); Svecofennian domain closely related to the 2.0-1.8 Ga old Paleoproterozoic island arcs; SSB consists of meta volcanic units and metamorphosed migmatitic mica

gneisses, which are originally turbiditic metasedimentary rocks; associated Paleoproterozoic intrusive rocks; volcanism is closely related to early, syntectonic magmatism of the Central Finland Granitoid Complex, c. 1890-1875 Ma; volcanic and intrusive complex; deposit is a typical massive sulphide deposit surrounded by volcanites and an alteration halo;)

Boulby Mine and Underground Laboratory: United Kingdom

135) Mining Technology (websites; accessed March 3, 2016). Boulby, United Kingdom (Industry Projects), http://www.mining-technology.com/projects/boulby/ and http://www.mining-technology.com/projects/boulby/boulby3.html ; (NOTES: potash and salt mine; production K began in 1973; Cleveland Potash, Ltd., operator; Boulby Mine depth at ~1,400 meters / 4593'; shaft depth 1,100 meters, 3608'; at 1100m deep, it is the deepest mine in Great Britain. ICL Fertilizers Europe parent company; 5.5m-diameter, 1,150m-deep shafts through the sandstone was achieved by ground freezing and grouting of the rock shaft; two shafts, ~1150m depth bgl; Permian evaporates, >225 mybp. Location 54.5534, -0.8245

136) DigPlanet website; accessed March 3, 2016. Boulby mine. http://www.digplanet.com/wiki/Boulby_Mine (NOTES: 1000km / 620 miles subsurface road tunnel; links)

137) STFC Boulby Underground Laboratory (Science and Technology Facilities Council) website; accessed March 3, 2016. *Welcome to the Boulby Underground Laboratory*; http://www.boulby.stfc.ac.uk/Boulby/ ; http://www.boulby.stfc.ac.uk/boulby/default.aspx ; (NOTE: 1100m below surface; STFC = Science and Technology Facilities Council; evaporites are Late Permian age, Zechstein salt basin age equivalent; also see

138) STFC (Science and Technology Facilities Council; UK, Royal Charter) website; accessed March 3, 2016. *Boulby Underground Laboratory*: Overview; http://www.stfc.ac.uk/Boulby/Overview/39340.aspx (NOTE: Zechstein Salt, ~ 200 mya; over 1000km tunnels)

139) Talbot, C.J. and C.P. Tully, P.J.E. Woods. 1982. The structural geology of Boulby (potash) mine, Cleveland, United Kingdom. *Tectonophysics*, Volume 85, Issues 3–4, 20 May 1982, Pages 167–204; http://www.sciencedirect.com/science/article/pii/0040195182901020 ; accessed abstract March 3, 2016 (NOTE: Upper Permian potash and salt of the third Zechstein Cycle)

140) *Subterranea Britanica*, Site Records website (accessed March 3, 2016). *Boulby Potash Mine – a site visit*; http://www.subbrit.org.uk/sb-sites/sites/b/boulby_mine/index.shtml (Note: General overview; salts, potash, evaporite minerals; facility photos)

Uranium Mine No. 16 (Shaft No. 16): Háje, Příbram, Central Bohemia, Czech Republic

141) *Mindat.org* (Website**;** accessed March 3, 2016). Uranium Mine No. 16 (Shaft No. 16): Háje, Příbram, Central Bohemia, Czech Republic; http://www.mindat.org/maps.php?id=25641 and http://www.mindat.org/loc-25641.html (NOTE: Regarded as the deepest mine in Europe, 16th shaft of the uranium mines in Haje, Príbram, Czech Republic at 1,838 meters / 6030'; uranium and base metal ore district; 49.6783333333 , 14.0605555556

Bergwerk Saar Coal Mine: Ensdorf, Saarland, Germany

142) Silicon Investor. 2014. (Website, accessed March 3, 2016); Peak Oil reality or Myth, of an out of Control System – Message Board #29868673; http://www.siliconinvestor.com/readmsg.aspx?msgid=29868673; (Notes: discussion with reference to Wikipedia documentation; last updated in 2008; second deepest EU mine regarded as Bergwerk Saar coal mine, the last working (closed in 2012) coalmine (in Ensdorf), Saarland, Germany at 1,750 meters / 5741'. Surface and subsurface mine depth and size records; limited discussion)

143) *Coal Age* (website, accessed March 3, 2016). 2012. Last Saar Coal Mine in Germany Closes; *Coal Age, World News* http://www.coalage.com/news/world-news/2253-last-saar-coal-mine-in-germany-closes.html#.Va7UVHnJAy4 , (NOTE: operated by RAG AG / Deutsche Steinkohle AG (DSK); closed mine in 2012 after period following 2008 collapse of mine sections near town of Ensdorf);

144) Neutkens, Harjo. 2009. Millerite; *in Mindat.org* (Website; accessed March 3, 2016) http://www.mindat.org/mesg-79-130896.html ; (NOTES: Carboniferous coals; Westphalian / Stephanian of Saar Basin deposits; Bergwerk Saar coal mine)

145) *Mining Technology* (Website; accessed March 3, 2016). Hard coal mining in Germany; http://www.mining-technology.com/projects/hard-coal-mining/ ; (NOTES: Bergwerk Saar coal mine location, 49°19'10"N 6°46'46"E = 49.319444, 6.779444

Eagle Mine Project: Michigamme Township, Marquette County, Michigan, USA

146) *Lundin Mining* (Website; accessed March 3, 2016); Operations and development, Eagle Mine; http://www.lundinmining.com/s/EagleMine.asp and http://eaglemine.com/ companion website; (Notes: Located in Michigamme Township, Marquette County, Michigan (Upper Peninsula); formerly Rio Tinto property; Ni, Cu mine; magmatic massive sulphide deposit; production start, 2014; disc. 2002; decline ramp access; 46°44'47.0"N 87°52'50.0"W; 46.746389, -87.880556 ; inclined ramp access to ~1000' depth, 13% grade ramp, 18' diameter; only producing nickel mine in the Lower 48 states.

147) *Lundin Mining* (website pdf, accessed March 3, 2016). March 2015. Eagle Mine, USA; http://www.lundinmining.com/i/pdf/Summary_Report_Eagle-Mine.pdf (Ni, Cu, associated cobalt, platinum, palladium, silver and gold)

148) *Mining Artifacts* and History (website accessed March 3, 2016); Michigan copper mines (webpage), Mining Artifacts and History; http://www.miningartifacts.org/Michigan-Copper-Mines.html and see homepage at http://www.miningartifacts.org/ (Notes: presents historical and pictorial look at Michigan Copper Mines, area of Eagle Mine Project)

149) Spence, Robert. 2015. Lundin Mining-Eagle Mine: Creating a Legacy at Eagle Mine. *Mining Global*, March 2015, pp. 46-65. http://issuu.com/miningglobal/docs/miningglobal-march2015?e=12042171/11678958 ; accessed March 3, 2016 (NOTE: production start in 2014; purchased from Rio Tinto in 2013; Controversial project; won public acceptance; model practices.)

150) Kennecott Exploration (D. Rossell, S. Coombes). 2005. *Eagle Project Mining Permit Application*. Appendix C-1, Geology of the Eagle Nickel-Copper Deposit, Michigan, USA (In: Kennecott Eagle Minerals Co., Eagle Project, Final Mine Permit Application, Volume 1, Appendix C: Geologic and Geotechnical Reports for the Eagle Project, http://www.lic.wisc.edu/glifwc/Kennecott/permitap2/Mining/Vol1/Vol1A/Eagle%20Deposit.pdf ; accessed March 3, 2016 {NOTE: see 2006 Application, http://www.lic.wisc.edu/glifwc/kennecott/permitap2/mining/vol1/mine%20permit%20app%20text.pdf ; magmatic massive to semi-massive sulfide / disseminated sulfide deposit; meta-volcanics and meta-sedimentary sequence; located proximal to Mesoproterozoic Midcontinent rift within the Baraga Basin; Paleoproterozoic pelitic sediments intruded by the Eagle (two intrusions, Yellow Dog intrusions) peridotite intrusions that hosts the Eagle deposit and are part of the Mesoproterozoic Baraga-Marquette dike swarm); 2013, Lundin mining bought Eagle from Rio Tinto 2013.}

Hecla Star Mine (Shaft): Burke, Shoshone County, Idaho, USA

151) Hecla Mining (website). Hecla's The Star mine: Idaho (Coeur d'Alene Mining District) http://www.hecla-mining.com/operations/operations_predevelopment_starnoonday.php ; access in July 20, 2015; no longer accessible March, 2016 (NOTES: once the deepest in North America at 8,100 feet – is shut down in 1982; Heckla and Star mines located in (adjacent, abandoned; closed 1981) Burke, Shoshone County, Idaho; 47°31'13.0"N, 115°49'13.0"W; 47.520278, -115.820278 Silver, lead, zinc mine; located North of Mullan, ID; also located 2 miles N of Lucky Friday Mine; in predevelopment work; may integrate operations with Lucky Friday Mine (Hecla Mining); access to 2000 level; Precambrian meta-sedimentary rocks of the Belt Super-group; hydrothermal vein fill deposits in fractured rock, often within and adjacent to faulted zones; see also, Hecla Mining Exploration report, Silver Valley area; Silver valley; discussed at http://www.hecla-mining.com/silver-valley/; Hecla evaluating prospective areas).

Sunshine Silver Mine Project: Silver Valley area, Idaho, USA

152) Tetra Tech, Inc. 2012. *Mineral Resources and Preliminary Economic Assessment of the Sunshine Silver Mine Project, Big Creek, Idaho*; NI 43-101 Technical Report; Tetra Tech, Inc.; 159 pp. (prepared for Sunshine Silver Mines) http://www.sunshinesilvermining.com/images/PDF/SSMC_Sunshine_Mine_NI43101_PEA_December_2012.pdf ; accessed March 3, 2016 (NOTE: <<8000'; Belt Supergroup, Pre-Cambrian; located in northern Idaho on Big Creek, four and one-half miles southeast of the town of Kellogg,, Silver Valley, Idaho; Coeur d'Alene Mining District; operator, Sunshine Silver Mining and Refining; 1825m bgl; Precambrian Belt Supergroup, Middle Proterozoic age sedimentary rocks ~ 1.47 to 1.6 billion years ago; discovery, 1884; Jewell Shaft sunk to ~2080', 1936 and reaches 4000' bgl today; ; No 10 shaft internal, sunk 3100 Level and eventually sunk to an elevation equivalent to the 6000 Level; workings to 6000' bgl; mesothermal stratabound vein Deposits; stratiform Proterozoic deposits (1,500-900 ma); late Cretaceous hydrothermal origin … possibly related to the formation of the Idaho Batholith. See also http://www.sunshinesilvermining.com/sunshine-mine webpage; location 47º30'6" N, 116º4'10" W; 47.501667, -116.069444)

Quincy copper mine: Hancock, Houghton County, Michigan, USA

153) *Mining Artifacts* (website; accessed July 20, 2015). Michigan Copper Mines; http://www.miningartifacts.org/Michigan-Copper-Mines.html and http://www.miningartifacts.org/Mining-Photo-Index.html Historic Mining Photos; webpage from site http://www.miningartifacts.org/, *Mining Artifacts and History*; accessed March 3, 2016 (NOTES: Quincy operated continuously from 1848-1931; closed; developed shafts that reached an inclined depth of over nine thousand feet (over six thousand feet in vertical depth, or approximately five thousand feet below sea level), making it the deepest mine in the United States, and one of the deepest mines in the world for its time.... for Quincy mine area in copper...A total of 9 shafts were driven; 2 of these shafts, No.2 and No.6, reached 9,280 ft. deep on the incline (approx. 6,800 ft vertical). 47.137037, -88.573233

154) *Mindat.org* (website accessed March 3, 2016) http://www.mindat.org/loc-3842.html = Quincy Mine, Hancock, Houghton Co., Michigan, USA

155) Michigan Technological University (website accessed March 3, 2016). Mining Engineering History: Mine Shafts of Michigan Part 5; http://www.mg.mtu.edu/MINE_SHAFTS/shaft5zd.htm

156) Butler, B., and W. Burbak. 1929. The copper deposits of Michigan. *U.S. Geol. Surv. Professional Paper 144*; U.S. Geological Survey, 238pp. http://pubs.er.usgs.gov/publication/pp144 and http://www.minsocam.org/msa/collectors_corner/usgs/pp144toc.htm ; accessed March 3, 2016

157) World Heritage Encyclopedia / Project Guttenberg (accessed March 3, 2016), Quincy Mine; http://self.gutenberg.org/articles/quincy_mine (Note: production until 1945)

158) Bornhorst, T. and R. Baron. 2011. Copper deposits of the western Upper Peninsula of Michigan; In: Miller, J.D., Hudak, G.J., Wittkop, C., and McLaughlin, P.I. (eds.) The Geological Society of America Field Guide 24 2011, p. 83 - 99; http://www.geo.mtu.edu/~raman/papers2/BornhorstBarronFT.pdf ; accessed March 3, 2016

Crownpoint, New Mexico

159) Beahm, D. 2012. Crownpoint and Hosta Butte Uranium Project, McKinley County, New Mexico, USA; Mineral Resource Technical Report National Instrument 43-101 (Prepared for Tigris Uranium); http://encoreenergycorp.com/wp-content/uploads/2014/08/TU-Crownpoint-Hosta-Butte-Technical-Rpt.PDF ; accessed March 7, 2016 (Notes: recent activity in area; ISR project envisioned in 2015)

Table 2 References (# 160 – 469f) with Notes Supporting Map Layer 2 (URLs, Repositories, Sites)

Primary General Source References (160-189) for Map Layer 2 and Table 2

160) Manepally, C., R. Fedors, H. Basagaoglu, G. Ofoegbu, R. Pabalan. 2011. *Coupled Processes Workshop Report: Prepared for the U. S. Nuclear Regulatory Commission*. Center for Nuclear Waste Regulatory Analyses, San Antonio, TX; 76 pages (Section 4). http://pbadupws.nrc.gov/docs/ML1127/ML112730032.pdf accessed April 26, 2016 (NOTE: Document summarizes R&D international research coupled processes for US NRC)

161) NWTRB (Nuclear Waste Technical Review Board). 2009. *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*. http://www.nwtrb.gov/reports/nwtrb%20sept%2009.pdf ; accessed April 26, 2016

162) IAEA. Sept 2001. *The Use Of Scientific And Technical Results From Underground Research Laboratory Investigations For The Geological Disposal Of Radioactive Waste IAEA*-Tecdoc-1243. Vienna, Austria. (Table 1 is basis for URL summaries, modified by others and herein for enhancements / verifications) http://www-pub.iaea.org/MTCD/publications/PDF/te_1243_prn.pdf ; accessed March 21, 2016

163) NEA / OECD (Nuclear Energy Agency/ Organisation for Economic Co-Operation and Development). 2001. *The Role of Underground Laboratories in Nuclear Waste Disposal Programmes*; OECD Publications, Paris, France (2001) https://www.oecd-nea.org/rwm/reports/2001/nea3142.pdf ; accessed April 26, 2016 (Note: See Table 3)

164) NEA / OECD (Nuclear Energy Agency, Organisation for Economic Co-Operation and Development). 2013. *Underground Research Laboratories (URL); Radioactive Waste Management*, NEA No. 78122, NEA/RWM/R(2013)2; 52 pages. Nuclear Energy Agency / Organisation for Economic Co-Operation and Development**;** http://www.oecd-nea.org/rwm/reports/2013/78122-rwm-url-brochure.pdf ; accessed April 26, 2016 (NOTE: lists URLs, operators, websites; informational summary Table 2.3; appendices A and B, URLs, Management organizations)

165) Richard, R., et al. 2011. *Basis for Identification of Disposal Options for Research and Development for Spent Nuclear Fuel and High-Level Waste*; FCRD-USED-2011-000071, SAND2011-3781P; http://www.energy.gov/sites/prod/files/2013/06/f1/FY11%20-%20Basis%20for%20Identification%20of%20Disposal%20Options%20for%20R%26D%20for%20Spent%20Nuclear%20Fuel%20and%20High-Level%20Waste_2.pdf ; accessed April 26, 2016 (NOTE: See table 7-1; key basis for table development)

166) World Nuclear Association (website accessed April 26, 2016) Country Profiles http://www.world-nuclear.org/info/Country-Profiles/

167) Birkholzer, J.T. 2012. *Status of UFD Campaign International Activities in Disposal Research***;** FCRD-UFD-2012-000295 (Tables 2-1, 3-1). http://energy.gov/sites/prod/files/2013/06/f1/FY12%20Status%20of%20UFD%20Campaign%20International%20Activities%20in%20Disposal%20Research.pdf ; accessed April 26, 2016 (NOTES: for Czech Republic studies, p. 18/19; p.6, DECOVALEX2015, Task C2, Bedrichov Tunnel Experiment: Interpretation of inflow patterns and tracer transport behavior in fractured granite, organized by NAWRA; p. 18-20; p. 64,67, 75/76; e.g., Bedrichov water supply tunnel, Bohemia; 2600m tunnel, ~120m overburden; Task C2, page 18/19; 75; tables on pages 2 and 61; used as ref for Czech Republic: Bedrichov Tunnel)

167a) Faybishenko, B, and J. Birkholzer, D. Sassani, and P. Swift (editors). 2016. *International Approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation; Fifth Worldwide Review*, LBNL-1006984; Lawrence Berkeley National Laboratory, Sandia National Laboratories; https://www.osti.gov/scitech/servlets/purl/1353043 and at https://eesa.lbl.gov/wwr5/ (Note: key document summarizing international program status for disposal, R&D, and siting; source for Ukraine, Slovakia, Slovenia, Canada, other. See reference 167b, herein, for additional international work on repositories and repository safety case; see Reference 168a)

167b) Apted, Michael and Joonhong Ahn (Eds.). 2017. *Geological Repository Systems for Safe Disposal of Spent Nuclear Fuels and Radioactive Waste* (2nd Edition); Woodhead Publishing Series in Energy, Woodhead Publishing; Elsevier Ltd., 802 pages; https://www.elsevier.com/books/geological-repository-systems-for-safe-disposal-of-spent-nuclear-fuels-and-radioactive-waste/apted/978-0-08-100642-9 (Note: The subject reference became available as this study was being completed; available materials in the report were examined for compatibility with information contained herein. Major inconsistencies were not identified. The reader is referred to the publication for most up-to-date published information on repository safety investigations and references. The document was not used as a primary source reference because it was not readily accessible as online source)

168) Birkholzer, J., 2014. *International Collaboration Activities in Different Geologic Disposal Environments***;** FCRD-UFD-2014-000065; LBNL-6782E; http://www.energy.gov/sites/prod/files/2014/10/f19/FCRDUFD2014000065InternationalCollabActivities2014.pdf ; accessed April 26, 2016 (NOTE: Table 2.1; See Section 4.1 and Figure 4-4 for KURT and borehole locations; Table 2-1 for site selection status; survey summary international repositories; e.g., use as reference for Republic of Korea: KURT URL)

168a) Faybishenko, B., Jens Birkholzer, P. Persoff, D. Sassani, P. Swift. 2016. *International Approaches for Nuclear Waste Disposal in Geological Formations: Report on Fifth Worldwide Review*; FCRD-UFD-2016-000630, LBNL-1006121; http://www.ourenergypolicy.org/wp-content/uploads/2016/09/Nuclear-Waste.pdf (Note: see published {Reference 167a} for final report - Faybishenko, B, and J. Birkholzer, D. Sassani, and P. Swift (editors). 2016. *International approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation; Fifth Worldwide Review*, LBNL-1006984; Lawrence Berkeley National Laboratory, Sandia National Laboratories. Information in this document was used to populate Table 2 for Bulgaria, Slovakia, Ukraine, others. For added information on Bulgaria, see http://www.wmsym.org/archives/2014/papers/14291.pdf)

168b) Witherspoon, P.A., and Bodvarsson, G. S., eds., (2006). *Geological Challenges in Radioactive Waste Isolation: Fourth Worldwide Review*. Report LBNL-59808; https://drive.google.com/file/d/0By-1oCLrzv_JTkN5Q3ZXSkJUTkU/view (NOTE: Chapter 1, Table 1.1)

168c) Earth and Environmental Sciences, Berkeley Lab (website). *Worldwide Review: Geologic Challenges in Radioactive Waste Isolation*; http://eesa.lbl.gov/worldwide-review/ (Note: Fifth Worldwide Review Workshop on the Challenging Issues in Deep Geologic Disposal of Nuclear Wastes, which was held in Berkeley on May 25-26; https://goo.gl/FGy3J6 . See also hyperlink WW5 Presentations, https://drive.google.com/folderview?id=0B3KTfL4IfhRFQ0cxNUY4OTdYSWM&usp=sharing)

169) IGDTP / Implementing Geological Disposal of Radioactive Waste Technology Platform (website accessed April 26, 2016); *European Underground Research Laboratories*; http://www.igdtp.eu/index.php/links/85-european-underground-research-laboratories (Note: also see links for IGDTP Waste management organizations webpage http://www.igdtp.eu/index.php/links); accessed April 26, 2016

170) Hovorka, S. D. 1998. *Characterization of bedded salt for storage caverns—a case study from the Midland Basin, Texas: Final Report*; (Prepared for National Petroleum Technology Center U. S. Department of Energy Bartlesville, Oklahoma); Bureau of Economic Geology, Austin, Texas; https://www.researchgate.net/publication/236399880_Characterization_of_bedded_salt_for_storage_caverns_--_A_case_study_from_the_Midland_Basin_Texas ; accessed April 26, 2016 (Notes: Also published as The University of Texas at Austin Geological Circular 00-1, 105 pp. (Note: Reference for WIPP, TX salt sites, Permian Basin area; Midland Basin, Texas, salt storage study includes Texas and New Mexico; Permian bedded salt; regional geology of Midland and Delaware Basins, Texas and New Mexico; focus on Palo Duro Basin, northern Texas with area references)

171) Kuhlman, K.L. 2013. Historic Testing Relevant to Disposal of Heat-Generating Waste in Salt: A summary of in situ tests conducted in geologic salt, focusing on heated salt creep, heated brine migration, and crushed salt reconsolidation. *Radwaste Solutions* September-October 2013, pp. 22-28; http://kris.kuhlmans.net/papers/kuhlman-2013-historic-testing-in-salt-radwaste-solutions.pdf ; accessed July 29, 2015 {NOTES: 1960s, Salt Vault was carried out by ORNL for the AEC in abandoned Carey Salt Company bedded salt mines in Lyons and Hutchinson, Kansas. In the 1970s and 1980s, after termination of the Lyons, Kansas studies, DOE Repository workers identified the following salt disposal sites for evaluation: Palo Duro Basin (bedded salt) in northern Texas (including the Deaf Smith and Swisher sites); Paradox Basin (salt anticline) in eastern Utah and western Colorado (including the Davis Canyon and Lavender Canyon sites); Richton and Cypress Creek domes in Mississippi; Vacherie Dome in northern Louisiana; Oakwood Dome in east Texas; in 1986, the list of potential repository sites was reduced to three sites, including the Deaf Smith, Texas, site and the two non-salt sites at Hanford, near Richland, Wash., and Yucca Mountain, in Nye County, Nev. Reference for Lyons, Kansas – Salt sites USA, France and Germany}

172) Kuhlman, K. L. 2014. *Technical Basis for Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste in Salt*; Presentation to U.S. Nuclear Waste Technical Review Board Meeting, Albuquerque, NM, March 19, 2014 at Sandia National Laboratories; 27 slides; http://www.nwtrb.gov/meetings/2014/march/kuhlman.pdf ; accessed July 29, 2015 (NOTES: covers testing at: Hutchison Kansas; Lyons, Kansas; Avery Island, LA; WIPP, NM; ANDRA Amelie Test '87-'94; Asse II, Germany. Excellent summary of salt testing programs, URL/URF studies in salt including: WIPP, NM, 1980s-90s, 2000s; Asse, Germany, 1968-'98; Hutchinson, KS, 1959-'61; Salt Vault at Lyons KS, 1962-'67; ANDRA Amelie '87-'94; Mississippi Chemical Company MCC Potash, 1980-'81, before WIPP; Avery Island, LA, 1978-'83; laboratory testing programs and field observations, e.g., Grand Saline Mine, Dallas TX area. Use as reference for Lyons, Kansas – Salt sites USA, France and Germany; WIPP)

173) Kuhlman, K. L. and S. David Sevougian. 2013. *Establishing the Technical Basis for Disposal of Heat-Generating Waste in Salt* (FCRD-UFD-2013-000233, SAND2013-6212; http://www.energy.gov/sites/prod/files/2013/12/f5/EstablishTechnicaBasisHeatGenWasteInSalt.pdf ; accessed July 29, 2015 (NOTES: covers historic testing at: Kansas sites, Pre-Salt Vault and Salt Vault; Gulf Coast salt dome sites at Avery Island; WIPP; Amelie, France Potash Mine; Asse, Germany. Use as reference for Lyons, Kansas – Salt sites USA, France and Germany)

174) Winterle, J., et al. 2012. *Geologic Disposal Of High-Level Radioactive Waste In Salt Formations*; 45 pages; Center for Nuclear Waste Regulatory Analyses, San Antonio, TX; http://pbadupws.nrc.gov/docs/ML1206/ML12068A057.pdf accessed July 28, 2015{NOTES: History and overview of disposal in salt formations; examples - 1) Avery Island, Heated borehole test with supporting laboratory analyses; valuated migration of brine inclusions; collected moisture released during test; concluded water released during cooling stage; 2) WIPP; 3) Asse Mine, heated drifts, borehole seals; 4) other = In the 1980s, DOE considered seven sites for the permanent disposal of HLW in salt formations (Jain, 1986): Richton Dome Site (Perry County, Mississippi); Vacherie Dome Site (Webster and Bienville Parishes, Louisiana); Cypress Creek Dome Site (Perry County, Mississippi); Lavender Canyon Site, Paradox Basin (San Juan County, Utah); Davis Canyon Site, Paradox Basin (San Juan County, Utah); Deaf Smith County Site, Palo Duro Basin (Permian, Texas); Swisher County Site, Palo Duro Basin (Permian, Texas). These sites can be categorized into two groups depending on how the salt was formed or subsequently deformed: salt domes (the first three sites) and bedded salts (the last four sites). On average, bedded salts are believed to contain a volume of brine inclusions that is 10 times greater than dome salts. Use as reference for salt disposal, general}

175) NSF (National Science Foundation). 2007. DUSEL - Facilities, Findings and recommendations; In *Deep Science: a Deep Underground Science and Engineering Initiative* (p. 35, Figure 1, underground laboratories worldwide); National Science Foundation; http://science.energy.gov/~/media/hep/pdf/files/pdfs/Dusel_101206.pdf ; accessed April 26, 2016 (NOTE: Deep Underground Science and Engineering Laboratories initiative for investigation in geoscience and particle / astroparticle physics; listing and figure for laboratories, depth, and mwe estimates; ~2007 vintage for material presented)

176) IAEA (International Atomic Energy Agency). 2000 (April). Status and Trends (based on an assessment of WMDB data); In: *Radioactive Waste Management Profiles: a Compilation of Data from the Waste Management Database No. 3;* 11 pp.; *In*: IAEA, International Atomic Energy Agency, WMDB Profiles Report; http://www-pub.iaea.org/MTCD/publications/PDF/rwmp-3/S&T.pdf ; accessed April 26, 2016 (Note: cover page and introductory text, http://www-pub.iaea.org/MTCD/publications/PDF/rwmp-3/RWMP-V3.pdf ; key reference is "Table- Main Underground Research Facilities" showing "information compiled by consultants at an IAEA sponsored meeting 1999"; table updates IAEA 1999 URL information)

177) IAEA. 2001. Section 7, Radioactive Waste Disposal; IAEA-WMDB-ST-1; pp. 66-76 (see Table 7-IV), In *Radioactive Waste Management Status and Trends*; IAEA; http://www-pub.iaea.org/MTCD/publications/PDF/wmdb-st-1/IAEA-WMDB-ST-1-4.PDF ; and http://www-pub.iaea.org/MTCD/publications/PDF/wmdb-st-1/IAEA-WMDB-ST-1-1.PDF ; accessed April 26, 2016 (NOTE: also see IAEA, 2005,

Radioactive Waste Management, Status and Trends, Issue # 4, IAEA-WMDB-ST-4 http://www-pub.iaea.org/MTCD/publications/PDF/WMDB-ST-4.pdf covers Richard Repository, Czech Republic, pp.117-120, but not included in this study; limestone cavern disposal example)

178) EDRAM / International Association for Environmentally Safe Disposal of Radioactive Material (website, accessed April 18, 2016). *The Role of Underground Laboratories in Nuclear Waste Disposal Programmes*; http://www.edram.info/en/edram-home/joint-activities/the-role-of-underground-laboratories-in-nuclear-waste-disposal-programmes/ (Note: Reference Tables 1-3; important source; Contains listing of URLs, sites, acronyms and definitions for nuclear waste facilities)

179) OECD/NEA. 2000. *Geologic Disposal of Radioactive Waste in Perspective*; OECD/NEA; https://www.oecd-nea.org/cen/publications/2458-geologic-disposal-rwm.pdf ; accessed May 12, 2016 (NOTE: see table on p. 27, URLs)

180) Kanney, J. 2008. *Underground Research Laboratories Outside North America - General Training on Methodologies for Geological Disposal in North America* (IAEA Network of Centers of Excellence. SAND2008-7187P); presentation slides; http://www.slidefinder.net/u/underground_research_laboratories_outside_north/kanney_sand2008-7187p/17620431 ; accessed April 24, 2016

181) Delay, J. et al. 2014. Three decades of underground research laboratories: what have we learned? In: Norris et al. (eds.) *Clays in Natural and Engineered Barriers for Radioactive Waste Confinement*; Geological Society, London, Special Publications, 400:7-32 http://sp.lyellcollection.org/content/400/1/7.abstract ; abstract accessed April 24, 2016 (NOTE: covers activities and contributions from 5 URLs; disposal in clay environment study at Mol (Belgium, HADES URL), Centre de Meuse–Haute-Marne (France), and Mont Terri Rock URL (Switzerland); granite studies at Aspö HRL (Sweden) and Grimsel Test Site (Switzerland))

International: Repository and URL studies, waste management; cooperation / training

182) European Nuclear Society (ENS). 2006. TOPSEAL 2006, Transactions, International Topical Meeting, Olkiluoto Information Centre, Finland, 17 – 20 September 2006; European Nuclear Society, Brussels, Belgium; https://www.euronuclear.org/events/topseal/transactions/TopSeal-Transactions.pdf ; accessed April 25, 2016 (Note: Miscellaneous information for range of environments, countries)

183) Davies, C. (Editor). 2008. *Euradwaste '08, Seventh European Commission Conference on the Management and Disposal of Radioactive Waste, Community Policy and Research & Training Activities*; http://ec.europa.eu/research/energy/pdf/euradwaste_08.pdf ; accessed April 26, 2016 [Note: Not highly informative on this work, but several example sites discussed in 1) Marie-Claude Dupuis. 2008. Radioactive waste management: Where do we stand?; 2) SESSION III: Co-operation in geological disposal; 3) SESSION IV: Communication of risk and uncertainties; 4) SESSION VI: Near-field processes; 5) SESSION VIII: Performance assessment studies – coordination of RD&D for waste disposal]

184) Chapman, N. (Editor). 2004. Geological Disposal of Radioactive Wastes Produced by Nuclear Power … from concept to implementation; European Commission, EU, Luxembourg: Office for Official Publications of the European Communities, 42pp. http://ec.europa.eu/research/energy/pdf/waste_disposal_en.pdf; accessed April 26, 2016 (Note: Not highly informative on this work, but several example sites and experimental studies are discussed)

185) Martell, M., and G. Ferraro. 2014. *Radioactive Waste Management Stakeholders Map in the European Union; European Commission Joint Research Centre, Institute for Energy and Transport (Report EUR 26692*); Luxembourg: Publications Office of the European Union; http://publications.jrc.ec.europa.eu/repository/bitstream/JRC90331/90331_final.pdf; https://ec.europa.eu/jrc/sites/default/files/90331_final.pdf; accessed May 4, 2016 (NOTES: Country profiles; planned HLW disposal facilities at Olkiluoto (FI), Bure (FR), Forsmark (SE); pages 13-14, waste management organizations table; LLW also included; stakeholder information on regulatory body also included; Finland Olkiluoto site selected for the construction of the final repository for spent fuel; the facility referred to as Onkalo (the underground cave) is located close to the Olkiluoto site; France awaiting completion of Ciego project in Meuse/Haute-Marne near Underground Research Laboratory in Bure; Germany Gorleben HLW disposal under consideration for decade; Germany Konrad iron ore mine preparing for disposal LLW; Asse II salt and Morsleben both closed LLW disposal sites; Sweden plans final repository for spent fuel in Östhammar municipality, close to the Forsmark nuclear power plant; repository operational by 2015; UK Cumbria / Sellafield areas “search to see if there is anywhere in the Allerdale and/or Copeland areas suitable for a repository for higher activity radioactive waste”, but slow to decision anticipated)

185a) Štefula, Vladan. 2006. SAPIERR - Support Action: Pilot Initiative for European Regional Repositories, Final Report; European Commission, Nuclear Science and Technology; Directorate-General for Research, Euratom (EUR 22400); https://cordis.europa.eu/pub/fp6-euratom/docs/sapierr-projrep_en.pdf (Note: see report for general background information on regional repository discussion; example participation, Slovakia)

186) IAEA (website accessed May 12, 2016). *Underground Research Facilities Network (URF)*. IAEA Nuclear Fuel Cycle and Waste Technology, Waste Technology Section, Underground Research Facilities Network; https://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/URF/overview.html ; (NOTE: describes IAEA URL network for training in and demonstration of waste disposal technologies and the sharing of knowledge)

186a) Streeper, C., and J. Whitworth, J.A. Tompkins. 2009. Lack of international consensus on the disposition and storage of disused sealed sources; *Progress in Nuclear Energy* 51 (2009) 258-267; Elsevier; http://osrp.lanl.gov/Documents/LAURS_Documents%20Page/LAUR-08-0548.pdf (Note: Tables 1, 2; Figure 1 in article provide summary of disposal facility types and locations and national approach to disposal for global view of countries)

186b) EPRI / Electric Power Research Institute (Intera for EPRI). 2010. *EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste Volume III—Review of National Repository Programs* (1021614); EPRI, Palo Alto, California; https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwis45KaoPXTAhVW0GMKHaDRC

k0QFgglMAA&url=https%3A%2F%2Fpublicdownload.epri.com%2FPublicDownload.svc%2Fproduct%3D000000000001021384%2Ftype%3DProduct&usg=AFQjCNHV-2KXsv3_qlu_MDQCzLAqMU_iPQ&sig2=3nuQ6JeAOry0ohxp5a0nYg and http://cybercemetery.unt.edu/archive/brc/20120620234107/http://brc.gov/sites/default/files/documents/1021614.pdf (Note: Same as Reference 466 in content; Intera prepared report for EPRI)

187) EUROSAFE Forum 2013 (website accessed August 17, 2015). http://www.eurosafe-forum.org/eurosafe2013 ; {NOTE: EUROSAFE Forum 2013, Safe disposal of nuclear waste; France host group formerly as IPSN, now as Nuclear Radioprotection and Safety Institute, IRSN; example discussion of the Tounemire URL, France, by Barnichon, http://www.eurosafe-forum.org/sites/default/files/Eurosafe2013/Seminar%202/2.01_TSO_Research_Programme_IRSN_Paper.pdf)

Natural analog study, crystalline URL and repository analog

188) Laverov, N.P., V. A. Petrov, V. V. Poluektov, R. M. Nasimov,J. Hammer, A. A. Burmistrov, and S.I. Shchukin. 2008. The Antei Uranium Deposit: A Natural Analogue of an SNF Repository and an Underground Geodynamic Laboratory in Granite; *Geology of Ore Deposits*, 2008, Vol. 50, No. 5, pp. 339–361; Pleiades Publishing, Ltd.; http://download.springer.com/static/pdf/321/art%253A10.1134%252FS1075701508050012.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1134%2FS1075701508050012&token2=exp=1440196436~acl=%2Fstatic%2Fpdf%2F321%2Fart%25253A10.1134%25252FS1075701508050012.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1134%252FS1075701508050012*~hmac=378b93ad6de9b783bb1b6564f30036d5ffba840a520e1d6e9887ac3240193a59 ; and http://download.springer.com/static/pdf/321/art%253A10.1134%252FS1075701508050012.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1134%2FS1075701508050012&token2=exp=1440633207~acl=%2Fstatic%2Fpdf%2F321%2Fart%25253A10.1134%25252FS1075701508050012.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1134%252FS1075701508050012*~hmac=3642fea4e321dc4762cf9e5c4887d84edcccf6c3072599a60e9785d5bced561c and http://link.springer.com/article/10.1134%2FS1075701508050012#page-1; accessed May 4, 2016 (NOTE: Antei vein-stockwork uranium deposit in the southeastern Transbaikal region, localized in Paleozoic granite at a depth of 400–1000 m opened by mine workings; character and limitations in use of uranium deposits as natural analogues of repositories of SNF consisting of 95% UO2. Underground Research Laboratories in granite discussed include Sweden (Äspö), Canada (Whiteshell), Switzerland (Grimsel), Japan (Mizunami), and Finland (ONKALO), as well as the El Berrocal (Spain), Palmottu (Finland), Sanerliu (China), and Kamaishi (Japan). Excellent summary for each URL / URF; analog data, safety case contribution. Antei U deposit granite analog for UO2 in SNF for disposal sites; example, Japan's Kamaishi granite, mine. Palmottu U deposit, gneiss and granitic bedrock, Nummi-Pusula, Finland, http://en.gtk.fi/research/program/energy/waste/palmottu.html 1987-1996, 1996-2000 and post 2003 research project as analog; summary report at http://tupa.gtk.fi/julkaisu/ydinjate/yst_121.pdf ; Proterozoic Svecofennian orogenic belt, 1.8Ga; location Palmottu, 60.478052, 23.76211; groundwater characteristics. Analog at Palmottu (Finland), Sanerliu (China); Finland Palmottu U deposit, gneiss and granitic bedrock. Aspo HRL is localized in the Smaland granite–granodiorite pluton, 1750 Ma in age; TBM 5m diameter used for excavation. Palmottu deposit is situated in southwestern Finland at the coast of the Palmottu Lake. Dikes of microcline granite that cut through Precambrian mica granite gneiss The Sanerliu deposit is situated in Hunan province in southern China (Min et al., 1998) and localized in the Mesozoic Lujing pluton of porphyritic granite (the Rb/Sr age is 215.2 ± 6.3 Ma), which underwent albitization and microclinization 132 Ma ago. Uranium ore formed ~50-100Mya. The Kamaishi iron skarn deposit of northeastern Japan is localized in the Mesozoic Kurihashi granodiorite pluton, 120–110 Ma in age. Extensive source information may be found for international studies of analogs at *Natural Analogue Working Group* website for more information on their studies of analogue sites for geologic repositories of high-level radioactive waste, http://www.natural-analogues.com/ , Reference 188a)

188a) *Natural Analogue Working Group* (website, accessed May 2017); http://www.natural-analogues.com/ (Note: for more information on their studies of analogue sites for geologic repositories of high-level radioactive waste)

189) MacKinnon, R.J. 2015. *The Use of Underground Research Laboratories to Support Repository Development Programs: A Roadmap for the Underground Research Facilities Network*, Sandia Report SAND2015-9427; Sandia National Laboratories, Albuquerque, NM, 50 pp., http://prod.sandia.gov/techlib/access-control.cgi/2015/159427.pdf ; accessed May 17, 2016 (Note: see Figure 2.1 for chart illustrating URLs and history; basis for figure from earlier studies identified above)

Other General and Site Specific References (190-469f) and Sources for Map Layer 2 and Table 2

Belgium: HADES URF, SCK•CEN site in Mol; EIG EURIDICE (Economic Interest Grouping, European Underground Research Infrastructure for Disposal of nuclear waste in Clay Environment

190) SCK-CEN (website accessed April 25, 2016). *HADES underground Laboratory*; http://science.sckcen.be/en/Facilities/HADES ; (NOTE: located beneath SCK-CEN facility; first site specific built URF in Europe; initiated in 1980; 225 m bgl; Boom Clay; managed since 1995 by EIG EURIDICE; Economic Interest Grouping between SCK•CEN and ONDRAF/NIRAS, the Belgian agency for radioactive waste)

191) EURIDICE GIE / European Underground Research Infrastructure for Disposal of nuclear waste in Clay Environment (website accessed April 24, 2016). *Welcome to EURDICE*; http://www.euridice.be/en ; {NOTES: Belgium R&D program with international participants; EIG EURIDICE is an Economic Interest Grouping (EIG), an economic partnership between the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) and the Belgian Nuclear Research Centre (SCK•CEN; http://www.sckcen.be/en); operates HADES underground research laboratory (High Activity Disposal Experimental Site); depth of 225 metres in the Boom Clay formation, two shafts; first shaft in 1980; PRACLAY gallery constructed in 2007; located beneath the SCK-CEN facility; see also "From Manual to Industrial", http://www.euridice.be/en/content/manual-industrial; excavation techniques; websites accessed April 25, 2016)

192) EURIDICE ESV (website accessed April 25, 2016). *HADES underground research Laboratory*; http://www.euridice.be/en/content/hades-underground-research-laboratory

193) EURIDICE / European Underground Research Infrastructure for Disposal of nuclear waste in Clay Environment (website accessed April 25, 2016). *HADES Laboratory Location Underground*; http://www.euridice.be/en/content/location-underground-0 (NOTE: 225 metres below the SCK•CEN site in Mol; also "Role of EIG", http://www.euridice.be/en/content/role-eig-euridice-geological-disposal-research ; Belgian RD&D programme on geological disposal is coordinated by ONDRAF/NIRAS. Clay disposal, communications with stakeholders)

194) EURIDICE GIE / European Underground Research Infrastructure for Disposal of nuclear waste in Clay Environment Economic Interest Grouping (website accessed April 25, 2016). *Excavation and construction technology (HADES)*; http://www.euridice.be/en/content/excavation-and-construction-technology

195) SCK-CEN / Belgian Nuclear Research Center (website accessed April 25, 2016). http://www.sckcen.be/ (Note SCK-CEN: (Note: 1952: founding of "Centre d'Etude pour l'Application de l'Energie Nucléaire" [en abrégé, le STK-CEAEN, Studiecentrum voor de Toepassingen van Kernenergie; in 1957, renamed Studiecentrum voor Kernenergie - Centre d'Etude de l'Energie Nucléaire / SCK_CEN])

196) SCK-CEN / Belgian Nuclear Research Center (website accessed April 25, 2016). *The well-thought out disposal of radioactive waste* http://www.sckcen.be/en/Technology_future/Radioactive_waste (NOTE: Hades, Mol, BelgiumYpesian Claystones, Belgium; Paleogene, Eocene, Ypesian; managed by ESV Euidice. See references 197-199 for detail)

197) SCK-CEN (website accessed April 25, 2016). *The well-thought out disposal of radioactive waste - Safe disposal of high-level waste in deep clay layers* http://www.sckcen.be/en/Technology_future/Radioactive_waste/Geological_disposal

198) SCK CEN Science Platform Belgian Nuclear Research Center (website accessed April, 2016). *Engineering of an underground laboratory in clay*. http://science.sckcen.be/en/Disposal_radioactive_waste/Engineering_underground_laboratory_clay (NOTES: Hades is 3.5m diameter gallery; boom clay; 225m bgl; mct note = HADES is operated by EURIDICE and located at the premises of the Belgian Nuclear Research Centre SCKCEN, www.sckcen.be)

199) Sneyers, A. et al. 2002. International co-operation and partnerships at the HADES underground research facility (Mol, Belgium); *WM'02 Conference*, February 24-28, 2002, Tucson, AZ; 15 pages; Waste Management Symposia; http://www.wmsym.org/archives/2002/Proceedings/59/449.pdf ; accessed April 25, 2016

Belgium: possible host unit, Doel Nuclear Zone

200) Van Marcke, P., B. Laenen, and L. Wouters. 2005. *The Ypresian Clays as Possible Host Rock for Radioactive Waste Disposal: An Evaluation*; NIRONO TR.2005-01; VITO, FANINBEL and ONORAF/NIRAS, Belgium; accessed April 25, 2016 (NOTE: See also Safety Assessment and Feasibility Interim Reports: SAFIR 1; SAFIR2, 2001. Doel Nuclear Zone located along Schelde River, north of Antwerp; ONDRA/NIRAS, The Belgian Agency for Radioactive Waste and Enriched Fissile Materials)

Canada: URL and Repository Siting

201) NWMO / Canadian Nuclear Waste Management Organization (website "homepage", accessed April 25, 2016); http://www.nwmo.ca/home?language=en_CA

201a) NWMO News Release, 6/6/2017, NWMO to Focus Field Studies on Fewer Communities; June, 2017 | Toronto (Note: Central Huron and White River no longer under consideration; of the 11 areas selected for Phase 2 studies, six now remain: Blind River and Elliot Lake; Ignace; Hornepayne; Huron-Kinloss; Manitouwadge; and South Bruce. https://www.nwmo.ca/; https://www.nwmo.ca/en/More-information/News-and-Activities/2017/06/01/10/19/News-Release-NWMO-to-Focus-Field-Studies-on-Fewer-Communities ; also see http://www.world-nuclear-news.org/ ; activities in 2018 not reflected; verify with additional references; siting location downselection continues)

Canada: Pinawa - Lac du Bonnet URL for HLW, Pinawa, Manitoba

202) Everitt, R., and J .McMurray, A Brown, C Davison. 1996. *Geology of Lac du Bonnet Batholith, Inside and Out: AECL Underground Research Laboratory, Southern Manitoba – Field Trip Guidebook B5*, Geological Association of Canada Annual Meeting, Winnipeg, Manitoba, May 27-29, 1996. http://www.manitoba.ca/iem/info/libmin/gacmac/guidebook_b5.pdf accessed April 25, 2016

203) Chandler, N. A. 2003. Twenty years of underground research at Canada's URL; Waste Management Symposia *WM'03 Conference*, February 23 – 27, 2003, Tucson AZ; 15pp. http://www.wmsym.org/archives/2003/pdfs/118.pdf ; accessed April 25, 2016 (NOTE: Atomic Energy of Canada Limited's / AECL's; construction started in 1982; Lac du Bonnet, Manitoba, Canada; main shaft access originally to 255m bgl later extended to 443m bgl; located within the Canadian Shield in the Lac du Bonnet granite batholith; granite at the URL is ~ 2.6 Ga years old; main test levels at depths of 240 m and 420 m below surface;)

204) Kuzyk1, G.W., and Sangki Kwon. 2006. Application of Controlled Blasting During the Construction of the Canadian Underground Research Laboratory; 8pp. *Tunneling and Underground Space Technology*, May 2006; International Tunneling Association, Elsevier; http://www.ctta.org/FileUpload/ita/2006/data/pita06-0164.pdf ; accessed April 25, 2016; (NOTE: Korean Atomic Energy Research Institute (KAERI) at that time planning URL; used AECL work as example; Canadian Underground Research Laboratory (URL) constructed by Atomic Energy of Canada Limited (AECL); 443-m-deep shaft; tunnels with drill and blast; evaluated method; shows construction blast technology used.)

205) Davison, C. 1984. Monitoring hydrogeological conditions in fractured rock at the site of Canada's Underground Research Laboratory, pp. 95-102. National Ground Water Association, *Ground Water Monitoring Review*; V4 N4; P95-102, Fall, 1984; NGWA; http://info.ngwa.org/GWOL/pdf/842432744.PDF ; accessed April 26, 2016 (NOTE: for testing hydrology for site; early fracture and flow study; vertical access shaft;)

206) Atomic Energy of Canada Limited / AECL (website / homepage accessed April 26, 2016); www.aecl.ca/site3.aspx ; http://www.aecl.ca/en/home/default.aspx (NOTE: closure of URL resulted in new mission for AECL in R&D management; former URL at Lac

Du Bonnet, Manitoba, Canada; manages Canada's radioactive waste under contractual arrangement with Canadian National Energy Alliance / CNEA for the management and operation of Canadian Nuclear Laboratories / CNL)

207) Owen, Bruce. 2010. Whiteshell labs closes underground facility forever; *Brandon Sun* - Online Edition, December 8, 2010 http://www.brandonsun.com/breaking-news/whiteshell-labs-closes-underground-facility-forever-111511344.html?viewAllComments=y ; accessed April 26, 2016 (NOTE: seal techniques to be examined; shaft access to 420m bgl; construction, 1983-1985; open 1985; Lac du Bonnet area; facility sealed and will be monitored long-term for seal effectiveness.)

Canada: Bruce site, Deep Geologic Repository (LLNW/ILNW), Kincardine, Ontario

208) Ontario Power Generation (website accessed April 26, 2016). What is the Deep Geologic Repository (DGR)? http://opgdgr.com/ (NOTES: Ontario Power, DGR - Bruce nuclear site, 680m bgl; proximal to Bruce NPS; also reference OPG site: http://www.opg.com/generating-power/nuclear/nuclear-waste-management/Deep-Geologic-Repository/Pages/Deep-Geologic-Repository.aspx)

209) Ontario Power Generation / OPG (website accessed July 30, 2015. OPG's Deep Geologic Repository Project for Low & Intermediate Level Waste brochure; http://opgdgr.com/assets/pdf/DGR_Overview_Brochure_Updated_Aug_2013.pdf ; accessed April 26, 2016 (Note: 680m bgl; at the Bruce nuclear site, in Kincardine, Ontario, shore of Lake Huron)

210) Canadian Environmental Assessment Agency (website; accessed April 26, 2016). *Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste Bruce Nuclear Site, Ontario*; http://www.ceaa-acee.gc.ca/050/details-eng.cfm?evaluation=17520 ; (NOTES: background information on actions related to Ontario Power environmental impact reports and assessment for the DGR at Bruce Site)

211) NWMO / Canadian Nuclear Waste Management Organization (website accessed April 26, 2016). https://www.nwmo.ca/ ; link to DGR (Deep Geologic Repository) https://www.nwmo.ca/en/A-safe-approach/Facilities/Deep-Geological-Repository (NOTE: NWMO provides technical input, developed design for OPG; links to reports on DGR provided)

212) Hatch, Ltd. (website accessed April 26, 2016). *Nuclear Power Projects - Deep Geologic Repository for Low and Intermediate Level Waste* https://www.hatch.ca/Power/Nuclear/projects/deep_geologic_rep.htm (Note: Reference not accessible; seeking: Hatch, Ltd. 2010. Ontario Power Generation's Deep Geologic Repository for Low and Intermediate Level Waste 2010. Preliminary Design Report. Hatch, Ltd., H333000-WP700-05-124-0001, Rev.2, 357pp. http://www.nwmo.ca/uploads_managed/MediaFiles/1606_h333000-wp700-05-124-0001.pdf ; was accessed July 30, 2015; contains geologic and design information)

213) Heystee, R. 2008. Proposed Deep Geologic Repository for Low and Intermediate Level Radioactive Waste at the Bruce Site, Tiverton, Ontario; International Technical Conference - Underground Disposal Unit Design & Emplacement Processes for a Deep Geological Repository - Practical Aspects of Deep Radioactive Waste Disposal Session 5 Session 5 - Paper N Paper N° 26 (presentation), *ESDRED International Conference*, 16-18 June 2008, Czech Technical University – Prague, Czech Republic; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/41/025/41025042.pdf and http://www.esdred.info/conference/reports/26-Richard-J-Heystee.pdf ; accessed April 26, 2016 (Note: Proposed Deep Geologic Repository within late Ordovician Limestone/Dolostone, Carbonate rocks, ~680m bgl; 4.5m ventilation shaft and 6.5 m diameter main access shaft planned)

France: IRSN / Institut de Radioprotection et de Surete Nucleaire / Institute for Radiological Protection and Nuclear Safety

214) IRSN / Institut de Radioprotection et de Surete Nucleaire / Institute for Radiological Protection and Nuclear Safety (website "home", accessed May 2, 2016). www.irsn.fr/EN/Pages/home.aspx (NOTES: IRSN has public authority with industrial and commercial activities; nation's public service expert in nuclear and radiation risks, and its activities cover all the related scientific and technical issues)

France: Andra - Repository Disposal and Test Related Sites / Areas; ANDRA, French National Radioactive Waste Management Agency (Agence nationale pour la gestion des déchets radioactifs)

215) Andra / National Radioactive Waste Management Agency / Agence Nationale Pour la Gestion Des Déchets Radioactifs (website "home", accessed May 2, 2016). French National Radioactive Waste Management Agency http://www.andra.fr/international/; (NOTES: links for Cigeo preliminary definition project review)

216) ANDRA / National Radioactive Waste Management Agency /Agence Nationale Pour la Gestion Des Déchets Radioactifs (websites and links accessed May 2, 2016), International; http://www.andra.fr; http://www.andra.fr/international/ (Note: responsible for waste management; operates Meuse/Haute-Marne Centre CMHM with the Underground Research Laboratory LSMHM located in Bure (Meuse district at the border of the Haute-Marne district; LSMHM Underground Research Laboratory sited at Bure in the Meuse district and aiming at studying the feasibility of the reversible geological disposal of high-level and long-lived intermediate-level radioactive waste in the Callovo-Oxfordian clay formation. This facility was licensed on August 3 1999 and its construction as such (access shafts, basic drift network with underground ventilation) has been achieved in 2006. Operating The Cigéo project, 2015; see www.cigeo.com , siting and evaluation for a disposal facility in progress)

France: Cigeo Project, Meuse / Haute-Marne

217) CIGEO.com / CIGEO Project / ANDRA (website accessed May 2, 2016). *Cigeo in brief*; www.cigeo.com and http://www.cigeo.com/en/ (NOTES: If approved, a deep geological disposal facility for radioactive wastes is to be built in France along the boundaries of the Meuse and Haute-Marne departments; emplacement level, 500m bgl in clay / argillite; Callovo-Oxfordian clay; operations to begin in 2025)

218) ANDRA. 2014. *Andra #13: Activity Report and Sustainable Development* (Annual Report; Agence nationale pour la gestion des déchets radioactifs); http://www.andra.fr/international/download/andra-international-en/document/editions/544va.pdf ; accessed April 26, 2016 (Note: Cigeo report information)

219) ANDRA. 2013. *Cigeo Project: Deep geological disposal facility for radioactive waste in Meuse/Haute-Marne* (Summary of Project Owner File). http://www.andra.fr/download/andra-international-en/document/editions/529va.pdf ; accessed May 2, 2016

220) ANDRA. 2013. *The Cigeo Project: Meuse/Haute-Marne: reversible geological disposal facility for radioactive waste* (Project Owner File; see Public debate of 15 May to 15 October 2013); 103pp. http://www.andra.fr/download/andra-international-en/document/editions/504va.pdf ; accessed May 2, 2016 (NOTES: Meuse / Haute-Marne site and Callovo-Oxfordian clay, Paris Basin; zone proposed by Andra, located a few kilometres from the URL, was approved by the Government; page 34 and 35 show maps of site area and facilities location proposals; recent summary of Ciego project given by V. Schwarz at March 2015 Waste Management Conference, Phoenix, AZ; http://www.andra.fr/international/download/andra-international-en/document/news/201503_wm2015-phoenix-discoursvsschwarz.pdf)

221) Dupuis, Marie-Claude. 2010. Status, responsibilities and missions of ANDRA (France); *Technical meeting on RWMO – Paris, 7&8 June 2010*; Agence Nationale Pour La Gestion Des Déchets Radioactifs / National Radioactive Waste Management Agency (ANDRA). http://www-ns.iaea.org/downloads/rw/conventions/fourth-review-cycle/tm-paris/Session%201/andra-france.pdf ; accessed May 2, 2016 (NOTE: Includes Underground Laboratory in Meuse/Haute-Marne near Bure; siting process at the time)

222) Areva SA / "Société Anonyme" (website accessed May 2, 2016); http://www.areva.com (NOTE: Areva is a private company, whose main shareholder is CEA / France's Atomic Energy Commission)

223) EdF / Électricité de France (website accessed May 2, 2016); https://www.edf.fr/en/home (Note: electricity utility that owns and operates all nuclear power plants in France)

224) OECD-NEA (Organization Economic Cooperation Development / Nuclear Energy Agency). *Radioactive Waste Management Programmes In OECD/NEA Member Countries: France*; 13 pages. https://www.oecd-nea.org/rwm/profiles/France.pdf ; accessed May 2, 2016

France: General Information, waste management, geologic disposal, underground studies

225) ANDRA / National Radioactive Waste Management Agency / Agence Nationale Pour la Gestion Des Déchets Radioactifs (website May 2, 2016). *Institutions*; http://www.andra.fr/international/pages/en/menu21/national-framework/overview-of-relevant-institutions/andra-1599.html (NOTE: links to outlines of relevant institutions; e.g., IRSN, the French Institute for Radioprotection and Nuclear Safety link http://www.andra.fr/international/pages/en/menu21/national-framework/overview-of-relevant-institutions/irsn-1602.html)

226) ANDRA / National Radioactive Waste Management Agency (website accessed May 2, 2016). *Dossier 2005* (reports and links): http://www.andra.fr/international/pages/en/menu21/waste-management/waste-management-issues-at-national-level/high-level-waste-and-intermediate-level-long-lived-waste/dossier-2005-1636.html (NOTE: reports and links for *Dossier 2005* summarizing 15 years of investigations of argillite / Callovo-Oxfordian Formation host unit, granite studies and reference materials for disposal investigations, safety analyses, and management strategy)

227) ANDRA / National Radioactive Waste Management Agency. 2005. *Dossier 2005, Andra research on the geological disposal of high-level long-lived radioactive waste - Results and perspectives*; Report Series; Agence Nationale Pour la Gestion Des Déchets Radioactifs (ANDRA); http://www.andra.fr/international/download/andra-international-en/document/editions/265va.pdf (NOTE: Contents provide summary of research on a repository in a clay formation, Meuse/Haute-Marne site, and Research on a repository in a granite formation); accessed May 2, 2016

France: Repository investigations - granite

228) ANDRA / National Radioactive Waste Management Agency. 2005. *Dossier 2005 Granite: Synthesis- Assets of granite formations for deep geological disposal* http://www.andra.fr/international/download/andra-international-en/document/editions/267va.pdf ; accessed May 2, 2016

France: repository investigations – argillite (Bure area, Meuse/Haute-Marne)

229) ANDRA / National Radioactive Waste Management Agency. 2005. *Dossier 2005 Argille Synthesis: Evaluation of the feasibility of a geological repository in an argillaceous formation - Meuse/Haute-Marne site*; ANDRA http://www.andra.fr/international/download/andra-international-en/document/editions/266va.pdf; accessed May 2, 2016 (see Ciego Project)

230) ANDRA / National Radioactive Waste Management Agency (website, accessed May 2, 2016). *Research infrastructure* http://www.andra.fr/international/pages/en/menu21/waste-management/research-and-development/research-infrastructures-1621.html (NOTE: Andra's major research facility is the LSMHM Underground Research Laboratory at Bure, Meuse district; reversible geological disposal of high-level and long-lived intermediate-level radioactive waste in the Callovo-Oxfordian clay formation; licensed on August 3 1999; construction achieved in 2006.)

France: Fanay Augères/Tenelles

231) AREVA NC. 2010. Visiting AREVA NC, Bessines (slide presentation); *EMRAS Working Group Presentation* http://www-ns.iaea.org/downloads/rw/projects/emras/emras-two/first-technical-meeting/fourth-working-group-meeting/working-group-presentations/workgroup2-presentations/presentation-4th-wg2-areva-1.pdf ; accessed May 2, 2016 (NOTES: Uranium mines and mining in France; see relation of North Limousin, France ~20 km N of Limoges, in Ambazac mountains; Vieilles Sagnes, Limousin; Fanay references; cores, mining samples, data storage facility)

France: Tournemire URL (argillite)

232) IRSN / Institute de Radioprotection et de Surete Nucleaire (website, accessed May 2, 2016). *Une station expérimentale à Tournemire: Un laboratoire grandeur nature*; http://www.irsn.fr/dechets/recherche/outils/tournemire/Pages/laboratoire-grandeur-nature.aspx and *Contexte géologique*, http://www.irsn.fr/dechets/recherche/outils/tournemire/Pages/contexte-geologique.aspx ; (Note: history, geology and characteristics of Tournemire URL; access to IRSN home page = http://www.irsn.fr/EN/Pages/home.aspx and http://www.irsn.fr/FR/Pages/Home.aspx;

http://www.irsn.fr/EN/Pages/home.aspx ; Jurassic; Toarcien sous une couverture de 200 à 250 mètres d'épaisseur de roches calcaires; Toarcien supérieur)

233) Rejeb, A. 2005. Perturbations induites par le creusement en 2003 d'une galerie dans le site de Tournemire; Chapter 3.1, p. 4-15, in*: IRSN - Rapport scientifique et technique 2005: Sûreté du stockage géologique de déchets radioactifs*; http://www.irsn.fr/FR/Larecherche/Organisation/Programmes/Documents/F3RST05-3.pdf ; accessed May 2, 2016 (NOTE Jurassic Toarcien Argillites, Marnes, l'Aveyron)

234) Cabrera, J. 2002. Characterization of discontinuities in a clay medium (Tournemire experimental station): Key issues relating to the safety assessment of radioactive waste disposal; *IRSN Scientific and Technical Report STR2002*, Chapter 7, *Safety of Radioactive Waste*, p. 227-232; IRSN, Institute de Radioprotection et de Surete Nucleaire http://www.irsn.fr/EN/Research/publications-documentation/Aktis/Scientific-Technical-Reports/STR-2002/Documents/Chap07art3GB.pdf ; accessed May 2, 2016 (NOTE: Location/ geologic map = ; Report content found at http://www.irsn.fr/EN/Research/publications-documentation/Aktis/Scientific-Technical-Reports/STR-2002/Pages/Scientific-and-technical-report-2002-1610.aspx ; geology, rock character, geologic map)

235) IRSN / Institute de Radioprotection et du Surete Nucleaire (website accessed May 2, 2016). *Tournemire experimental station*; http://www.irsn.fr/en/research/scientific-tools/experimental-facilities-means/tournemire/Pages/TOURNEMIRE-experimental-station.aspx ; (NOTES: Institute de Radioprotection et du Surete Nucleaire / IRSN in 1992, the Tournemire experimental station, together with the Mol (Belgium), Mont-Terri (Switzerland) and Bure (Meuse, France) laboratories, is now one of the four underground laboratories in Europe carrying out research on disposal in clay formations._French National Radioactive Waste Management Agency (Andra) is responsable for designing, constructing and operating a geological radioactive waste disposal facility. Pending approval, this facility will be opened in eastern France in 2025. With this in mind, Andra has been operating an underground laboratory in Bure (Meuse) since 1999, where it carries out studies and research. To ensure an independent assessment of Andra's project, IRSN has been carrying out its own research at the Tournemire experimental station in southern Aveyron for the last 21 years. Located in a former railway tunnel built over 120 years ago).

France: Andra and geologic repository plans (and international work), Meuse/Haute-Marne

236) Dupuis, Marie-Claude. 2006. Current Status of the French Radioactive Waste Disposal Programme. *TOPSEAL 2006, Transactions, International Topical Meeting, Olkiluoto Information Centre, Finland*, 17 – 20 September 2006; European Nuclear Society, Brussels, Belgium; https://www.euronuclear.org/events/topseal/transactions/TopSeal-Transactions.pdf ; https://www.euronuclear.org/events/topseal/transactions/Paper-Session-I-Dupuis.pdf ; accessed May 2, 2016 (NOTE: ANDRA: Agence nationale pour la gestion des déchets radioactifs, French National Radioactive Waste Management Agency; government decision for continuation of operations in the Meuse/Haute-Marne with the creation of a URL {2001} in Bure (argillite); the Gard and Vienne (granite) Sites were abandoned; Meuse/Haute-Marne URL shaft sinking completed in 1999; initial research conducted at ~445m bgl; currently testing to 490m bgl; 2015 set as the deadline to submit the statutory application in order to commission a deep geological repository for high-level and long-lived radioactive waste by 2025. Transaction volume contains 2006 status of repository and URL testing programs for international view, see ENS 2006 https://www.euronuclear.org/events/topseal/transactions/TopSeal-Transactions.pdf .)

France: Tournemire URL (argillite) and Bure

237) Barnichon, J.-D. 2013. A TSO research programme on the safety of geological disposal and its necessary evolution along the development of a national industrial project; *Eurosafe 2013, Seminar 2* (http://www.eurosafe-forum.org/eurosafe2013#Seminar_2 and http://www.eurosafe-forum.org/sites/default/files/Eurosafe2013/Seminar%202/2.01_TSO_Research_Programme_IRSN_Paper.pdf ; accessed May 2, 2016 ; (NOTES: French National Radioactive Waste Management Agency (Andra) and deep disposal activities; planned deep geologic disposal facility operations start in 2025; Bure (Meuse) URL since 1999; Andra as operator; planned repository license application in 2015; Tournemire (France), Mol (Belgium), Mont-Terri (Switzerland) and Bure (Meuse, France) URLs are the four European laboratories conducting research on disposal in clay formations. Tounemire in tunnel; testing in galleries within Toarcian argillite; western part of the Causses Permo-Mesozoic sedimentary basin; testing history and program summary)

France: Bure / Meuse URL (argillite) and Deep Geologic Repository Siting

238) Andra. 2010. *The Presence Of Andra In The Meuse And Haute-Marne Districts; Andra fact sheet*; http://www.andra.fr/download/andra-international-en/document/355VA-B.pdf ; accessed May 2, 2016; (NOTE: Meuse and Haute-Marne URL and geologic study; host unit identified as Callovo-Oxfordian Jurassic argillites ~500 m bgl as target; introduction to activities including siting deep geologic repository in area, i.e., Cigeo, a deep reversible disposal facility for high-level and intermediate-level long-lived waste; siting, testing, monitoring, public interaction summaries; 2025 start-up for repository anticipated; site area location maps)

239) Rebours, H. and J. Delay, A. Vinsot. 2006. Scientific investigation in deep boreholes at the Meuse/Haute Marne Underground Research Laboratory, Northeastern France; *International Topical Meeting TOPSEAL 2006. Transactions*; 5pp. https://www.euronuclear.org/events/topseal/transactions/Paper-Poster-Rebours.pdf and http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/38/099/38099808.pdf ; accessed May 2, 2016 (NOTES: location information for test holes, maps, geologic profiles; largely detailed background information characterizing area of interest for repository siting)

France: Amelie mine

240) Gale, H.S. 1920. The Potash Deposits of Alsace. *Contributions To Economic Geology*, 1920, PART I., pp. 17-55.; http://pubs.usgs.gov/bul/0715b/report.pdf ; accessed May 2, 2016; (NOTE: early description of Alsace potash mines, France; early shaft access for Amelie Shaft 1, depth, ~2165'; Shaft 2 depth, ~1788' constructed in 1912)

241) Ghoreychi, M.M., M. Raynal, J. Roman. 1992. Implementing and monitoring thermomechanical tests in a salt formation of a French potash mine; *American Rock Mechanics Association, 33rd U.S. Symposium on Rock Mechanics (USRMS)*, 3-5 June, 1992, Santa Fe, New

Mexico; https://www.onepetro.org/conference-paper/ARMA-92-0181 ; (NOTE: thermo-mechanical studies in Amélie Mine at a depth of 520 meters); abstract and part introduction only accessed May 2, 2016

China National Nuclear Corporation / CNNC

242) China National Nuclear Corporation / CNNC (webpage accessed May 5, 2016). http://en.cnnc.com.cn/ (Note: according the World Nuclear Association, CNNC is responsible for the implementation of the waste disposal project; see http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx)

China: Beishan area, Gansu Province, repository and URL Sites

243) Wang, Ju. 2014. **On area-specific underground research laboratory for geological disposal of high-level radioactive waste in China;** *Journal of Rock Mechanics and Geotechnical Engineering*, Volume 6, Issue 2, April 2014, Pages 99–104; abstract, https://doaj.org/article/cbb637a4f653494b8d3c90c91017a57a ; http://www.sciencedirect.com/science/article/pii/S1674775514000110 ; http://dx.doi.org/10.1016/j.jrmge.2014.01.002; accessed May 4, 2016 (NOTE: proposed site area specific URL by **2020** in Beishan area. "Area screening (1990–present): Since 1990, most efforts have been made on the Beishan area. Studies include regional crust stability, tectonic evolution, lithological studies, hydrogeological studies and preliminary geophysical survey. However, site selection for a HLW repository started in Xinjiang Uygur Autonomous Region in 2012."…" In July 2011, the China Atomic Energy Authority, together with the Ministry of Environment Protection, approved that the Beishan area is "the first priority area" for China's HLW repository. The approval has laid a solid basis on building an "area-specific URL" in Beishan area. " "During 1999–2013, surface geological, hydrogeological and geophysical surveys and borehole drilling were conducted in Jiujing, Yemaquan and Xinchang–Xiangyangshan granitic subareas. 11 deep boreholes and 8 shallow boreholes (BS01-BS19) have been drilled and a series of borehole tests, such as pumping tests, injection tests, borehole televiewer and borehole radar survey, water-sampling and geo-stress measurement were conducted. Results show that the granite massif has enough volume in terms of good integrity and favourable engineering conditions." The Beishan area is "the first priority area" for China's HLW repository; 8 granite intrusions have been chosen as candidate subareas for HLW repository. Among them, 3 subareas (Jiujing, Xinchang–Xiangyangshan and Yemaquan) have been selected as the most potential subareas; dominant rocks are porphyritic monzonitic granite and tonalite; URLs around world include granite (the Äspö URL, the ONKALO facility, the Mizunami URL, etc.), claystone (the Meuse/Haute-Marne URL), stiff clay (the HADES facility), rock salt (the Gorleben facility, the WIPP facility), tuff (the Yucca Mountain's ESF); discussion of "generic URLs" and "site-specific URLs"; goal to build a URL by 2020)

244) World Nuclear Association (website accessed May 4, 2016). *China's Nuclear Fuel Cycle. Country Profiles, WNA*; http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx ; (NOTES: China National Nuclear Corporation / CNNC; three candidate repository locations, Beishan area, Gansu province; studied since 1986 and expected completion by 2020; all are in granite; underground research laboratory to be built 2015-20; construct the final HLW repository from 2040-2050.

245) Ju, Wang et al. 2004. Geology of Jiujing section, Beishan area, Gansu province-the preselected area for China's high level radioactive waste repository (on the scale of 1/50,000); In: Wang et al., 2004, *The progress report of geological disposal of high level radioactive waste in China in the past ten years*"; abstract located at (in Chinese) http://inis.iaea.org/search/search.aspx?orig_q=RN:43088373 accessed August 17, 2015; (NOTE: Bantan unit is preliminarily considered as one of the best candidates of repository site in Jiujing section)

246) Zhou, W., and M.J. Apted, W.M. Cheng, J. Wang. 2013. Performance assessment of the candidate site for HLW repository in Beishan China; In: *14th International High-Level Radioactive Waste Management Conference (IHLRWMC 2013), Integrating Storage, Transportation, and Disposal*, pp. 338–346, Albuquerque, New Mexico, USA, 28 April – 2 May 2013 – (6883); American Nuclear Society, Curran Associates, Inc., http://toc.proceedings.com/18659webtoc.pdf ; not available online May 2, 2016 (Notes: Performance assessment, FEPs and scenarios for Beishan area site as a generic disposal environment in granite, saturated zone)

247) Zhou, W., and M. Stenhouse, M. J. Apted (Intera, Inc.), W. M. Chen, J. Wang. 2013. Site-Specific FEP Analysis for the Beishan Area, China, (BRIUG); In: *14th International High-Level Radioactive Waste Management Conference (IHLRWMC 2013), Integrating Storage, Transportation, and Disposal*, pp. 331–337, , Albuquerque, New Mexico, USA, 28 April – 2 May 2013 - (6882); American Nuclear Society, Curran Associates, Inc., http://toc.proceedings.com/18659webtoc.pdf ; not available online May 2, 2016 (NOTE: analysis for the Xinchang section, Xinchang-Xiangyangshan subarea located in Beishan, Gansu Province)

248) Wang, Ju, and Zihua Zong, Rui Su, Weimin Chen (BRIUG). 2013. Geological Disposal Program for High Level Radioactive Waste in China: Update 2012; In: *14th International High-Level Radioactive Waste Management Conference (IHLRWMC 2013), Integrating Storage, Transportation, and Disposal*,, pp. 346–351; Albuquerque, New Mexico, USA, 28 April – 2 May 2013 - (6980); American Nuclear Society, Curran Associates, Inc., http://toc.proceedings.com/18659webtoc.pdf ; proceedings not accessed online (NOTES: Preliminary repository concept is a shaft-tunnel, in saturated zones in granite waste form is vitrified HLW; geological disposal program has 3 stages: (1) Laboratory Studies and Site Selection for HLW Repository (2006-2020); (2) Underground in situ tests (2021-2040); (3) repository construction (2041-2050); major milestones, complete the construction of an underground research facility by 2020; Beishan site Gansu Province has been considered as the first priority site for China's HLW repository; also drilling in granite intrusions in Xinjiang for comparison; responsible party is China Atomic Energy Authority; site selection for China's HLW repository started in 1985; 3 sub-areas (Jiujing, Xinchang-Xiangyangshan and the Yemaquan) have been chosen as the three most potential sub-areas. In 2012, 2 new sub-areas Shazhaoyuan and Suanjingzi were proposed for further investigation.); document not available online

249) Dong, YanHui, and GuoMin Li, and Ming Li. 2009. Numerical modeling of the regional ground water flow in Beishan area, Gansu Province; *Chinese Science Bulletin*, September 2009, Volume 54, Issue 17, pp 3112-3115; http://link.springer.com/article/10.1007%2Fs11434-009-0344-7#page-3 and http://link.springer.com/article/10.1007%2Fs11434-009-0344-7# and http://link.springer.com/article/10.1007/s11434-009-0344-7 for abstract / link http://download.springer.com/static/pdf/518/art%253A10.1007%252Fs11434-009-0344-7.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1007%2Fs11434-009-0344-7&token2=exp=1462216965~acl=%2Fstatic%2Fpdf%2F518%2Fart%25253A10.1007%25252Fs11434-009-0344-7.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1007%252Fs11434-009-0344-

7*~hmac=aaa55948a0927dacb0a48559d351fc25e7fc1817911730d53b96c271acd5d7a5 accessed May 2, 2016 (NOTE: good map for orientation; download document);

250) Zhang, H.-Y, et al. 2012. Swelling behaviors of GMZ bentonite–sand mixtures inundated in NaCl–Na2SO4 solutions*; Nuclear Engineering and Design 242* (2012) 115– 123. Elsevier; http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=4&ved=0CDwQFjAD&url=http%3A%2F%2Fwww.paper.edu.cn%2Fselfs%2Fdownpaper%2Fcuisuli109146-self-201403-3&ei=VFEXVPfGB4moogSD2IH4Bg&usg=AFQjCNFGZTBrYP9zOE24aQ0VgO3FSsto0Q&sig2=qXqfnjNHtkMV8CnXC3taDQ ; accessed May 2, 2016; (NOTE: contains geologic map of Baishan area);

China: Deep Borehole Disposal

251) Zhou, Yun. 2012. An Initial Exploration of the Potential for Deep Borehole Disposal of Nuclear Wastes in China; *Nautilus Institute; NAPSNet Special Reports*, October 23, 2012; http://nautilus.org/napsnet/napsnet-special-reports/an-initial-exploration-of-the-potential-for-deep-borehole-disposal-of-nuclear-wastes-in-china/ ; accessed May 2, 2016; NAPSNET / Nautilus Peace and Security, Nautilus Institute for Security and Sustainability

Czech Republic: URLs, repository, siting process

252) NEA (Nuclear Energy Agency / Organisation for Economic Co-operation and Development). 2014. "*Deliberating Together on Geological Repository Siting: Expectations and Challenges in the Czech Republic*", NEA/RWM/R(2014)1, www.oecd-nea.org/rwm/docs/2014/rwm-r2014-1.pdf ; accessed May 2, 2016 (NOTES: p. 7: the selection of the final and reserve sites was set for the year 2015, while construction is to be completed only in the year 2050 and operation reached in 2065. Due to the moratorium on geological works observed in 2004 -2009 the final site selection target date was moved to 2018.)

253) Surao (Radioactive Waste Repository Authority / RWRA / Surao = Sprava uložišť radioaktivnich odpadů). Surao Annual Report 2012 http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=2&cad=rja&uact=8&ved=0CCUQFjAB&url=http%3A%2F%2Fwww.surao.cz%2Feng%2Fcontent%2Fdownload%2F5840%2F32019%2Ffile%2FZprava_o_cinnosti_2012_ENG_web.pdf&ei=mkDSVP6CAsq-ggTs94HwDA&usg=AFQjCNEPOpB6iOvQzjp-zOVdj72ahDadAw&bvm=bv.85076809,d.eXY accessed May 2, 2016 (Note: As in 2013 annual report, with possible sites discussed)

254) World Nuclear News (dated October 28, 2014). Accessed August 13, 2015. *Site studies to begin for Czech repository*; WNN, World Nuclear Association, London; http://www.world-nuclear-news.org/WR-Site-studies-to-begin-for-Czech-repository-2810144.html ; (NOTE: Environmental ministry issued license to the Radioactive Waste Repository Authority (SURAO / Surao = Sprava uložišť radioaktivnich odpadů) to conduct initial stage of geological investigation work at candidate sites that include: Horka (Budišov) and Hrádek (Rohozná), both in the Vysočina region; Čihadlo (Lodhéřov) and Magdaléna (Božejovice) in the South Bohemia region; Březový potok (Pačejov) in Plzeň region; and Čertovka (Lubenec) in the Plzeň and Ústí-nad-Labem regions. A former military area at Boletice in South Bohemia region is also under consideration. Czech repository depth ~ 500 metres - construction to begin ~ 2050, and operational in 2065.)

255) Pospíšková, Ilona. 2014. Preparation of a deep geological repository in the Czech Republic; *TUNEL [Underground Construction, Development, Research, Design, Realization] Magazine*, Volume 23, No. 2/2014, p. 11-17. Underground Construction (Development, Research, Design, Realization) Magazine of the Czech Tunneling and Slovak Tunneling Associations; http://www.ita-aites.cz/files/tunel/2014/tunel_2_14-140630.pdf ; accessed May3, 2016

256) Slovak, Jiri. 2008. Deep Geological Repository Development Process in the Czech Republic (Presentation; Surao, CZ); IAEA Training Course, Las Vegas, NV, Nov 3-14, 2008; http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=7&cad=rja&uact=8&ved=0CEUQFjAG&url=http%3A%2F%2Fwww.sandia.gov%2FIAEA%2FPresentations%2FIAEA%2520Participant%2520Present%2FIAEA_TC_LasVegas_Slovak.pptx&ei=3ZS9U_-PIM6nyATI54DYDA&usg=AFQjCNGjrYXVgkltoPf381UlbM6uvXsRZw&sig2=nlT4O5Nm0PubuBH0aZMHqA&bvm=bv.70138588,d.aWw ; also at http://docslide.us/documents/radioactive-waste-repository-authority-1-deep-geological-repository-development-process-in-the-czech-republic-jiri-slovak-radioactive-waste-repository.html ; accessed May 5, 2016 [NOTE: website is not easy to use; time sink; 6 proposed HLW sites; non-HLW waste sites (ILW/LLW) currently at Richard, Dukovany, Bratrstvi]

257) SURAO (Radioactive Waste Repository Authority / RWRA / Surao = Sprava uložišť radioaktivnich odpadů). 2008 RAWRA Annual Report. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0CCgQFjABahUKEwi7rPLIy7PHAhWFPT4KHQpTCWI&url=http%3A%2F%2Fwww.surao.cz%2Feng%2Fcontent%2Fdownload%2F303%2F4621%2Ffile%2FAR%2520RAWRA%252008.pdf&ei=kaXTVfufE4X7-AGKpqWQBg&usg=AFQjCNGsOxyeGb43zQGla35vkACNaZK3aw&sig2=DNHQtgHayxHBZqAa6xLKmA&bvm=bv.99804247,d.cWw ; accessed May 5, 2016 (NOTES: Five former military areas in the Czech Republic were examined for DGR siting: Hradiště, Brdy, Boletice, Březina and Libavá; in 2009, the Boletice area, South Bohemia, was chosen as the potentially favorable location by RAWRA; Hradiště in North-West Bohemia is also a potentially favorable site. RAWRA identified 6 potentially viable sites: 1] Lubenec- Blatno (Ústecký; Čistá-Jesenice massif); 2] Pačejov - railway station (Plzeňský; Central Bohemia pluton); 3] Božejovice - Vlksice (Jihočeský; Central Bohemia pluton); 4] Pluhův Žďár – Lodhéřov (Jihočeský; Central Bohemia pluton); 5] Rohozná (Vysočina; Moldanubicum massif); 6] Budišov (Vysočina; Třebíč-Meziříčí massif. Evaluation of sites through 2014/2015; 2016 note, siting delay ~3 years due to moratorium on geostudies. Spellings of towns and area names may vary by report; caution).

257a) SURAO (website accessed November 14, 2016). *SURAO information* (sheet and links); http://www.surao.cz/cze/Informacni-koutek/Dokumenty-ke-stazeni/Prezentace-geologicko-pruzkumnych-praci/Pruzkumna-uzemi-pro-zvlastni-zasah-do-zemske-kury (Note: In 2015, SURAO / Czech Radioactive Waste Repository Authority presented communities with overview of the planned geological surveys to be performed at the Čertovka Čihadlo, Magdaléna, Horka and Kraví hora sites and in 2016 similar presentations were provided for communities in the Hrádek and Březový potok site areas)

257b) SURAO (website accessed November 14, 2016). *Čertovka Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8185/44416/file/%C4%8Certovka.pdf (Notes: Čertovka.pdf 5.29 MB; Usti Nad Labem Region, SE of Lubenec and west of Blatno, ~50.120423, 13.3181; granite)

257c) SURAO (website accessed November 14, 2016). *Čihadlo Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8186/44420/file/%C4%8Cihadlo.pdf (Notes: Čihadlo.pdf 4.97 MB; granite; near Lodherov and Hajdek area, ~49.2260, 14.9608; Jindřichův Hradec District in the South Bohemian Region)

257d) SURAO (website accessed November 14, 2016). *Horka Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8187/44424/file/Horka.pdf (Notes: Horka.pdf 5.43 MB; granite; area near Hodov and north of Budisov, ~49.291023, 15.9850)

257e) SURAO (website accessed November 14, 2016). *Magdalena Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8188/44428/file/Magdalena.pdf (Notes: Magdalena.pdf 5.93 MB; syenitic granitic crystalline rock; SW of Jistebnice and near area of Bozejovice and Svoriz; ~49.471508, 14.497503)

257f) SURAO (website accessed November 14, 2016). *Kraví hora Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8189/44432/file/Krav%C3%AD%20hora.pdf (Note: Kraví hora.pdf 6.08 MB; metamorphic granulitic unit; near area surrounding Stritez ~49.440859, 16.26053, and SE of Bukov; near Žďár nad Sázavou District in the Vysočina Region)

257g) SURAO (website accessed November 14, 2016). *Hrádek Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8715/47232/file/hradek.pdf (Note: hradek.pdf 795,87 kB; light grey, fine grained granitic rock; location is East of Novy Rhychnov and in and N of Rohozna ~49.365052, 15.394765, west of Hojkov, Vysočina Region)

257h) SURAO (website accessed November 14, 2016). *Březový potok Locality / Area* (Information sheet); http://www.surao.cz/cze/content/download/8716/47236/file/brezovy_potok.pdf (Note: brezovy_potok.pdf 5,57 MB; granodiorite; located NW of Velky Bor in area surrounding Manovice and Jetenovice and Kbelik peak ~49.386536, 13.675857; Plzeň Region)

Czech Republic: Bedrichov Water Supply Tunnel, Josefuv Dul,

258) DECOVALEX (website accessed May 2, 2016). *Bedrichov Tunnel Test Case, DECOVALEX 2015, Task C2*; http://www.decovalex.org/task-c2.html; http://www.decovalex.org/ (Note: see references by Birkholzer et al., annual reports on international studies, used fuel R&D for DOE)

259) Klomínský J., Woller F. (eds.) 2010. *Geological studies in the Bedrichov water supply tunnel; RAWRA Technical Report 02/2010*; 103 p., Czech Geol. Survey, Prague. ISBN 978-80-7075-760-4; http://www.geology.cz/extranet/vav/environmentalni-technologie/radioaktivni-odpady/bedrichov-tunnel.pdf ; accessed May 2, 2016 (NOTES: 6km long tunnel; Krkonoše-Jizera Composite Massif; porphyritic biotite granite = Jizera granite; examines EDZ effected by tomography of the Jizera granite across the boundary of the TBM and the drill and blast tunnel driving technology; financed by the Radioactive Waste Repositories Authority (RAWRA) and implemented by the Czech Geological Survey (CGS); Krkonoše-Jizera Composite Massif; Fig. 2, tunnel location illustration, geology; in Jizerska – Hory Mts.; A tunnel is 3.6 m diameter; B tunnel is 2.6 m diameter; first third of tunnel A drilled by TBM; remainder of Tunnel A was drill and blast; Tunnel B excavated by TBM; tunnels operated by North Bohemian Water Supply and Water Management Company; excellent geotechnical summary; States it is 6km tunnel A/B; locality map, geologic map; "B" section of the tunnel connects Bedřichov water treatment plant with the Orion water reservoir near the city of Liberec; see RAWRA / Radioactive Waste Repository Authority; biotite granite (Jizera and Liberec granite) in the Bedřichov tunnel; construction, drill and blast with TBM use; Jizerské Hory Mountains, Krkonoše-Jizera Composite Massif; Radioactive Waste Repositories Authority (RAWRA); see maps, Figures 1-3)

260) Stemberk, Josef, and B. Košťák. 2008. Recent tectonic microdisplacements registered in Bedřichov Tunnel "A" in the Jizerské Hory Mts. (N Bohemia); *Acta Geodyn. Geomater*. V 5, No. 4(152), 377–388, 2008; http://www.irsm.cas.cz/materialy/acta_content/2008_04/4_Stemberk.pdf; accessed May 2, 2016; (NOTES: Fig. 1 Position of the Bedřichov Tunnel "A" and monitoring points inside the tunnel; "Bedřichov A tunnel was driven into Jizera granite formation in the left slope of Desná River Valley in 1981 to a total length of 2593 m and diameter 3.1 m.")

261) Wang, Y., et al. 2014. *International Collaborations on Fluid Flows in Fractured Crystalline Rocks: FY14 Progress Report*; FCRD-UFD-2014-000499; SAND-16913R; http://prod.sandia.gov/techlib/access-control.cgi/2014/1416913r.pdf ; accessed May 2, 2016 (NOTES: Location: Bedrichov located in Jizera Mountains, Bohemian Massif, Krkonoše-Jizera Composite Massif. Tunnel ~ 1 km in length; max depth of 200 m within fractured granite; constructed 1980-1981; the first 890m from the southwest with a tunnel boring machine and the remaining part by a drill-and-blast method. Contributions from participant Federal Institute for Geosciences and Natural Resources / BGR, Germany)

Czech Republic: Rozna Mine

262) *Ministry of Industry and Trade, Czech Republic*, Press Release dated 7/8/2014. *Minister Mládek went down to the uranium mine Rožná I.* http://www.mpo.cz/dokument152012.html ; accessed May 2, 2016 (NOTES: Minister's visit to Rozna Mine; last Uranium mine located in the Dolní Rožínka municipality; examined depth of 1150 meters in the mine Rožná I; Rožná is the second largest uranium deposit in the country following Příbram; locality map http://www.diamo.cz/en/rozna , estimated Bukov URF ~ 49.494646, 16.215142)

Czech Republic: Bukov URF

263) Surao (Radioactive Waste Repository Authority / RWRA / Surao = Sprava uložišť radioaktivnich odpadů). *Surao Annual Report 2013*

http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&cad=rja&uact=8&ved=0CCAQFjAA&url=http%3A%2F%2Fwww.surao.cz%2Feng%2Fcontent%2Fdownload%2F7461%2F40717%2Ffile%2FAnnual_Report_2013_ENG_web.pdf&ei=mkDSVP6CAsq-ggTs94HwDA&usg=AFQjCNGnJQoy6Z1wzqWfZD8k68McHdn3SQ&bvm=bv.85076809,d.eXY , accessed May 2, 2016 (NOTES: Covers the Bukov URF; DOPAS project at Josef for sealing; repository siting and studies; PVP Bukov underground facility within the Rožná uranium mine complex was launched in 2013)

264) *TUNEL Magazine*. 2014, volume 23, No. 2 (website accessed May 2, 2016). *Tunnel Magazine* (Underground Construction Development, Research, Design, Realization); Czech Tunneling and Slovak Tunneling Associations. http://www.ita-aites.cz/files/tunel/2014/tunel_2_14-140630.pdf (NOTES: Volume dedicated to radioactive waste management studies of SURAO. Surao = Sprava uložišť radioaktivnich odpadů; Bukov Underground Research Laboratory (PVP Bukov) situated near the Bukov section of the Rožná I uranium mine; studies planned for 500m depth bgl; multiple articles in English and Czech; underground studies, deep geologic repository concept, other. The site is located in the southern wing of the Rožná uranium deposit some 300m from the Bukov mine at level 12 around 520m beneath the earth's surface.)

265) Dvořáková, Markéta, and Marek Vencl, Petr Kříž. 2014. Development of the Bukov underground research facility; *TUNEL [Underground Construction (Development, Research, Design, Realization) Magazine*; Czech Tunneling and Slovak Tunneling Associations] Magazine, Volume 23, No. 2/2014pp. 18-22; http://www.ita-aites.cz/files/tunel/2014/tunel_2_14-140630.pdf ; accessed April 25, 2016 (NOTES: facility is located in the southern wing of the Rožná uranium complex in the Vysočina (Highlands) region, Czech Republic; close to the Bukov (B1) Shaft in the village of Bukov near Žďár nad Sázavou in the Vysočina region; in southern wing of the Rožná uranium deposit some 300m from the Bukov mine at level 12 around 520m bgl; Bukov URF is located in the Strážec Moldanubic formation, a migmatitised paragneiss, migmatites, orthogneiss and granulites with numerous intrusives, amphibolites, marbles and quartzites; groundwater residence time sample = infiltrated water beneath an average annual temperature lower than at present – probably from the last glacial period… 22 thousand years; water pH = 9.8; admixed with recent water. Bukov URF is to be completed at a depth of more than five hundred meters in the Rožná uranium mine. The laboratory is used by the Radioactive Waste Repository Authority (SÚRAO) in research preceding the site selection for the construction of a deep geological repository for spent nuclear fuel. The Rozna (Dolni Rozinka) mine, ~55km NW of Brno; was Europe's only operating uranium mine, but operations are to be discontinued (1957-2012?). Geology: Moldanubian rocks - highest grade metamorphic rocks of Variscan age in Europe; gneisses, migmatites, amphibolites; granitic intrusives; Devonian / Carboniferous; groundwater age is pre-Holocene, but only 10s of thousands year age; residence time and flow indicators show tens of years for GW movement.)

266) Vondrovic, L., and M. Vencl, M. Dvořaková, J. Slovák, I. Pospišková. 2015. Underground Research Facility in Highly Anisotropic Rocks, Bukov URF, Czech Republic (Radioactive Waste Repository Authority); *IHLRWM 2015, Charleston, SC, April 12-16, 2015*; p.390-393; Site areas shown; focus Bukov URF; Bukov underground generic laboratory is located in the eastern part of the Czech Republic near the Kraví hora candidate repository site and adjacent to the Rožná uranium mine at a depth of 600m below the earth's surface. From the geological point of view the facility is located in the northeastern part of the Moldanubian Zone of Variscan orogen and composes migmatitized paragneisses with amphibolite layers. The felsic granulites display the same deformational history as that of the nearby Kraví hora candidate locality…. 1990s, RAWRA (The Czech Radioactive Waste Authority) defined 7 areas (Fig. 1) to be subjected to further multidisciplinary investigation. The localities were chosen based on the Swedish concept due to similarities between the geological conditions of that country and the Czech Republic. Six of the localities are located in granitic rock (with a crystallization age of between 515-320Ma) and one is made up of high-grade metamorphic rock (migmatites, granulites. Currently under construction). Proceedings CD ROM only)

Czech Republic: Josef Stola Mine / Stola Josef; Josef Underground Facility; general information URLs

267) Šťástka, Jiří. 2014. Mock-up Josef demonstration experiment; TUNEL [Underground Construction, Development, Research, Design, Realization] Magazine, Volume 23, No. 2/2014pp.65-73; http://www.ita-aites.cz/files/tunel/2014/tunel_2_14-140630.pdf ; accessed May 2, 2016 (NOTES: Seal test, generic repository study with physical modelling of the THMCH behavior of a bentonite layer; in crystalline rock, Stola mine; Josef gallery was driven for surveying a gold deposit in the Psí Hory locality, located in the westernmost open part of the gold deposit, Mokrsko West (one of deposits in the Psí Hory locality, the region of Příbram; volcanic rock types forming the Slapy spur of the Central Bohemian magmatic complex, amphibolite-biotite granodiorites of the Sázava-River type. The granodiorites are of the Variscan (Hercynian) age. Heater emplaced in vertical hole with bentonite packing)

268) Shaw, Richard. 2013. European research programmes for geological disposal of radioactive waste and the role of Underground Rock Laboratories; (presentation), British Geol. Survey, Natural Environment Research Council; http://www.eurogeologists.de/images/content/stockholm/7.%20Richard%20Shaw,%20Radioactive%20Waste%20Team%20Leader,%20British%20Geological%20Survey%20European%20research%20programmes%20for%20geological%20disposal%20of%20radioactive%20waste%20and%20the%20role%20of%20Underground%20Rock%20Laboratories.pdf ; last accessed August 17, 2015; cannot access (NOTES: Josef Stola = granite uranium mine; 110m overburden. Purpose built URLs: Bure, Hades, Aspo; Existing infrastructure used: Mont Terri, Grimsel; Abandoned features used: Josef, Tounemire; see Boulby laboratory (1100m bgl, salt); list of URLs and lithology; excellent photos of URLs; Radioactive Waste Repository Authority / RAWRA)

269) CTU / Czech Technical University, and CEG / Centre of Experimental Geotechnics. 2013. *Josef URC Annual Report*, 2013; Regional Underground Research Centre, Josef URC, CTU in Prague; Faculty of Civil Engineering (FCE); http://ceg.fsv.cvut.cz/CEG_site/en/VR_2013_EN_final_web.pdf ; accessed May 2, 2016 (NOTE:_Czech Technical University, Prague (CTU), faculty of Civil Engineering; Centre of Experimental Geotechnics / Centrum Experimentalni Geotechniky (CEG); Josef URL and the DOPAS seal project; GPS: N 49°43'50.145", E 14°20'54.591" / 49.730592, 14.348495 ; the largest experimental mine in Europe which is part of the Prague Technical University – test facility 80m bgl; Known as the Josef Underground Research Centre (Josef URC) and the Josef Underground Laboratory in granitic / crystalline massif; projects detailed; references; see Czech version, http://ceg.fsv.cvut.cz/o-nas/stola-josef)

270) Svoboda, J; Smutek J. 2013. *Progress Report (WP 4.2.3) - Baseline Hydraulic Measurements: crystalline rocks. FORGE Report D4.14*. 73pp. European Commission, Fate of Repository Gases (FORGE); Euratom 7th Framework Programme Project: FORGE http://www.bgs.ac.uk/forge/docs/reports/D4.14.pdf; accessed May 5, 2016 (NOTES: also access ; http://www.forgeproject.org/ and http://www.bgs.ac.uk/forge/ ; gas behavior; example focus crystalline rock, Josef Underground Facility, Czech Rep.; Josef Underground Facility, operated by the Faculty of Civil Engineering (Czech Technical University in Prague, Centre for Experimental Geotechnics (CEG)), located near

Slapy Dam, villages of Celina and Mokrsko in the Pribram district of Central Bohemia, Czech Republic; main drift is 1836m, with a cross-section of 14–16m2. The overlying rock thickness is 90–150m. Psi hory (hills) gold-bearing district, which is located mainly in the Proterozoic Jilovske belt, in rock of more than 600 million years old; penetrated by Variscan Central Bohemian Pluton granitoid; underground complex consists of two main sections (Celina and Mokrsko). Celina and the eastern part of Mokrsko are situated in tuffs and vulcanites of the Jilovské belt. Most of the western section of Mokrsko lies in granodiorite of the Central Bohemian Pluton); Czech Radioactive Waste Repository Authority (SÚRAO) / Czech Radioactive Waste Repository Authority / RAWRA)

Czech Republic: Pribram mining District, Kutna Hora District

271) Cathro, R.J. 2006. Economic Geology: The Central European Silver Deposits (Part 9); *Canadian Institute of Mining, Metallurgy and Petroleum (CIM), CIM Magazine*, March/April, 2006; http://www.cim.org/en/Publications-and-Technical-Resources/Publications/CIM-Magazine/March-April-2006/history/economic-geology.aspx ; accessed May 2, 2016; (NOTES: Two major Czech districts, Pribram, the largest, is located 55 kilometres southwest of Prague whereas the other district, Kutna Hora, is located about 55 kilometres to the east-southeast; mineralization associated with a swarm of diabase dykes that cut a Cambrian sandstone and arkose units; veins commonly follow the contacts of the dykes. The ore zones occur near and below a regional reverse fault that separates the Cambrian sequence from the overlying Proterozoic slate unit; shafts eventually became the deepest in Europe. The silver-lead-zinc ore was mined to a depth of over 1,500 metres from five shafts, until production ceased in 1978. The deepest shaft, Prokop, reached 1,579 metres, with mining conducted on 41 levels; metasediments)

Czech Republic: Pribram uranium mining area

272) Broz, M., and M. Vencovsky, V. Stejskal. 2004. Interpretation of levelling measurements in the area of the Príbram uranium deposit after termination of mining; *Acta Geodyn. Geomater*.Vol.1, No.4 (136), 29-47, 2004; http://www.irsm.cas.cz/materialy/acta_content/2004_04/4_Broz.pdf ; accessed May 4, 2016 (Note: useful summary of Pribram mines and mining district geology; Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic)

Czech Republic: U mine # 16 / Pribram Shaft 16; Haje, Pribram, Central Bohemia

273) Mindat (website accessed May 2, 2016). Uranium Mine No. 16 (Shaft No. 16), Háje, Příbram, Central Bohemia Region, Bohemia (Böhmen; Boehmen), Czech Republic; http://www.mindat.org/loc-25641.html

274) Žák, Karel, J. Rohovec, & T. Navrátil. 2009. Fluxes of Heavy Metals from a Highly Polluted Watershed During Flood Events: A Case Study of the Litavka River, Czech Republic; *Water Air Soil Pollut* (2009) 203:343–358; http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=3&cad=rja&uact=8&ved=0CCcQFjAC&url=http%3A%2F%2Fwww.researchgate.net%2Fprofile%2FTomas_Navratil4%2Fpublication%2F225775116_Fluxes_of_Heavy_Metals_from_a_Highly_Polluted_Watershed_During_Flood_Events_A_Case_Study_of_the_Litavka_River_Czech_Republic%2Flinks%2F00b4951bed4b6d9da3000000.pdf&ei=BdYAVfDlEovEggTRpYTYAg&usg=AFQjCNGiAQnPm-e2WqPg6LK0yMBTe0cxqA&bvm=bv.87920726,d.cWc and http://www.researchgate.net/profile/Tomas_Navratil4/publication/225775116_Fluxes_of_Heavy_Metals_from_a_Highly_Polluted_Watershed_During_Flood_Events_A_Case_Study_of_the_Litavka_River_Czech_Republic/links/00b4951bed4b6d9da3000000.pdf ; accessed May 2, 2016 (NOTE: Fig. 1 location map for ore district, streams; Litavka River drains the historical mining, ore processing, and smelting region of Příbram, a Ag–Pb–Zn±Sb ore district. Heavy metal transport character; POR, Pribram Ore Region; Ag–Pb–Zn±Sb vein type ores mined to 1600m bgl at Březové Hory and Bohutín deposits; Pribram uranium deposits located to SE of main mineral belt and deepest shaft #16 had direct vertical depth of 1,838 m below the surface)

275) Mindat.org (websites**;** accessed May 3, 2016). *Uranium Mine No. 16 (Shaft No. 16): Háje, Příbram, Central Bohemia, Czech Republic*; http://www.mindat.org/maps.php?id=25641 and http://www.mindat.org/loc-25641.html (NOTE: Regarded as the deepest mine in Europe, 16th shaft of the uranium mines in Haje, Príbram, Czech Republic at 1,838 meters / 6030' bgl; uranium and base metal ore district; 49.6783333333 , 14.0605555556

Czech Republic: Pribram, Brezove Hory

276) Škácha, P. and Viktor Goliáš, Jiří Sejkora, Jakub Plášil, Ladislav Strnad, Radek Škoda, Josef Ježek. 2009. Hydrothermal uranium-base metal mineralization of the Jánská vein, Březové Hory, Příbram, Czech Republic: lead isotopes and chemical dating of uraninite**;** *Journal of Geosciences*, 54 (2009), 1–13; http://petrol.natur.cuni.cz/~jgeosci/content/jgeosci.030_2009_1_skacha.pdf ; accessed May 2, 2016 (NOTE: Fig. 1 is excellent locality regional map with some mines identified, mining areas, geologic map)

Czech Republic: Josef Gallery Tour; status international programs, crystalline

277) Mariner, P., E. Hardin, and J. Mikšová. 2013. Proceedings of the Scientific Visit on Crystalline Rock Repository Development; SAND2013-0339, February 28, 2013, Sandia National Laboratories, Albuquerque, NM; http://energy.sandia.gov/wp/wp-content/gallery/uploads/crrd-sand-2013-0339.pdf ; last accessed August 19, 2015 (NOTE: Appendix C with presentation slides; full report with Participant information from Czech Republic, Germany, Korea, Lithuania, Mexico, Pakistan, Poland, Romania, Slovak Republic, Spain, Switzerland, United Kingdom, USA; excellent summary)

Japan: JAEA / Japan Atomic Energy Agency

278) JAEA / Japan Atomic Energy Agency (website accessed May 3, 2016); http://www.jaea.go.jp/english/index.html

Japan: Kamaishi Fe/Cu mine; Kitakami Mountains, Kamaishi City, Iwate Prefecture, Tohoku Region, Honshu Island

279) Mindat.org (website accessed May 2, 2016). *Kamaishi mine, Kamaishi City, Iwate Prefecture, Tohoku Region, Honshu Island, Japan*; http://www.mindat.org/loc-12391.html; Mineralogical Research Company (Note: iron copper mines; 500m bgl; contact metasomatic skarn ores in Permian limestone adjacent to Cretaceous age granitic dioritic intrusive body; iron ore; copper gold silver facies); abandoned iron-copper; contact metasomatic (skarn) ores in Permian limestone; iron (magnetite orebodies) and copper-gold-silver)

280) Uchida, Etsuo. 1986. Relation between Zonal Arrangements of Skarns and Temperatures of Formation at the Kamaishi Mine, Northeastern Japan. *Mining Geology*, 36(3):195-208. https://www.jstage.jst.go.jp/article/shigenchishitsu1951/36/197/36_197_195/_pdf and https://www.jstage.jst.go.jp/article/shigenchishitsu1951/36/197/36_197_195/_article; accessed May 2, 2016 (Note: Early Cretaceous Ganidake granodioritic intrusion; several deposit types, some hydrothermal alterations skarn; article location data followed; Northeastern Japan; ~ 39º15'N, 141º 41'E; approximate ~ 39.250007, 141.687755; recheck location as 39º15', 141º41'; 39.248684, 141.687267)

281) Thio, Kian Hie, and Susumu Nishimura. 1980. Fission-Track Ages of the Metallogenetic Epoch in Kamaishi Mine, Japan; *Memoirs of the Faculty of Science, Kyoto University, Series of Geol. and Minera*l., Vol. XLVII, No. 1, pp. 43-47. http://repository.kulib.kyoto-u.ac.jp/dspace/bitstream/2433/186636/1/mfskugm%20047001_043.pdf ; (NOTES: 111.7 Mya for the Ganidake granodiorite and 95+-9 Mya for the Kurihashi granodiorite and age of mineralization for Kamaishi ore; North Kitakami, Honshu area; ore occurs at contact between Paleozoic limestone and Ganidake igneous complex; iron copper ore); accessed May 3, 2016

282) Sakamoto, Takabumi, and Ryohei Otsuka, Naoya Imai. 1975. Stevensite from the Kamaishi Mine, Iwate Prefecture, Japan; *J. Japan. Assoc. Min.Petr, Econ. Geol.* 70, 1-11; https://www.jstage.jst.go.jp/article/ganko1941/70/1/70_1_1/_pdf ; accessed May 2, 2016. (NOTES: "The Kamaishi mine is situated in the eastern part of the Kitakami Massif ~ lat. 39°12'N, 141°50'E; 39.199479, 141.833568; not best location data for mine. Occurrences in limestone and skarn; the iron and copper ore deposits of the mine belongs to contact-metasomatic type; the largest producer of iron and copper ores in Japan.")

283) Asahara, M.T., and Tsuyoshi Tanaka. 2007. An attempt to determine the age of geological fractures by applying Rb–Sr mineral isochron dating to fracture-filling minerals; *Geochem. Journal*, Vol. 41, pp. 165 to 172; http://www.terrapub.co.jp/journals/GJ/pdf/4103/41030165.pdf; accessed May 3, 2016 (NOTES: fracture fill mineralogy, samples from fractures in the Kurihashi granodiorite and a skarn in the Kamaishi mine; fracture fill age ~ 74 to 58 Mya; skarn results from intrusion of the Ganidake complex into the Carboniferous limestone; Tohoku region experienced violent igneous activity from the Late Cretaceous to the Tertiary; fracture-filling minerals from the skarn indicate a crystallization age in the range 120 to 380 Ma, fracture fill at 64Ma; age and history of fracture mineralization addressed)

284) Deleted.

285) Deleted.

286) Deleted.

Japan: Horonobe Underground Research Center / Laboratory, Horonobe-cho, Hokkaido

287) JAEA / Japan Atomic Energy Agency (website accessed May 3, 2016). *Horonobe Underground Research Center*; www.jaea.go.jp/english/04/horonobe/index.html and http://www.jaea.go.jp/english/04/horonobe [Note: Horonobe Underground Research Laboratory (Horonobe URL) project, Japan Atomic Energy Agency (JAEA) planned at Horonobe-cho in northern Hokkaido; reports found at http://www.jaea.go.jp/english/04/horonobe/report.html; sedimentary rock disposal research; JAEA was formerly JNC / Japan Nuclear Cycle Development Institute with Nuclear Waste Management Organization of Japan (NUMO)]

288) JNC / Japan Nuclear Cycle Development Institute (now JAEA). 2004. *International Workshop on Horonobe Underground Research Laboratory Project* (Abstracts), JNC TN5400 2004-004. http://www.jaea.go.jp/english/04/horonobe/img/Abstruct_Horonobe_WS.pdf ; accessed May 3, 2016 (Notes: Neogene sedimentary sequences (ascending orders; Souya coalbearing Formation, Masuhoro Formation, Wakkanai Formation, Koetoi Formation and Yuchi Formation), which are underlain by igneous and Palaeogene to Cretaceous sedimentary basement; argillaceous sedimentary formations are selected for host geology for the URL; URL in diatomaceous mudstone of Neogene Koetoi and Wakkanai Formations; planned 3 shafts to 500m bgl; access shaft planned; two 6.5m (access) and one 4.5m (ventilation) diameter shafts expected; testing at 250m and 500m levels)

289) Hama, Katsuhiro, and M Seya, T Yamaguchi. 2005. *Horonobe Underground Research Laboratory Project Investigation Program for the 2005 Fiscal Year*. JNC TN5510 2005-002; JNC; http://www.jaea.go.jp/english/04/horonobe/img/pdf/0506plan.pdf ; accessed May 2, 2016 (NOTE: slide presentation; photos for location of facilities; progress and plans)

290) Goto, Junichi, and Katsuhiro Hama. 2003. *Horonobe Underground Research Laboratory Project Plan of Investigation Program for Fiscal Year (2003/2004)*, JNC TN5510 2003-001; JNC; http://www.jaea.go.jp/english/04/horonobe/img/pdf/0304plan.pdf ; accessed May 2, 2016 (NOTE: Plan for 2003; includes maps, location data)

Japan: JAEA - Mizunami URL (Tono center), Horonobe Underground Research Center

291) JAEA / Japan Atomic Energy Agency (website "home", accessed May 2, 2016). http://www.jaea.go.jp/english/index.html (Note: for research facilities see http://www.jaea.go.jp/04/tisou/english/research_facilities/research_facilities.html ; for Geologic isolation research and development links, see http://www.jaea.go.jp/04/tisou/english/index/e-index.html)

Japan: MIU / Mizunami Underground Research Laboratory (URL), Mizunami City, Gifu Prefecture (Tono)

292) Mizunami Underground Research Laboratory (website accessed November 16, 2015; *About MIU Project*; www.jaea.go.jp/04/tono/miu_e/project/project.html (NOTES: Mizunami Site located on city-owned land at Akeyo-cho, Mizunami City; Shobasama Site, a sister site 1.5km to the west, is where an extensive network of deep boreholes were used for initial investigations of the deep geological environment; status 11/16/2015, ventilation and main shafts both at ~500m bgl)

293) JAEA / Japan Atomic Energy Agency (website accessed May 2, 2016). *Mizunami Underground Research Laboratory (MIU), Tono*; Japan Atomic Energy Agency; http://www.jaea.go.jp/jnc/ztounou/miu_e/toppage.html (NOTE: coordinated by Tono Geoscience Center (TGC), Japan

Nuclear Cycle Development Institute (JNC); Mizunami Underground Research Laboratory (MIU) Project in the Tono area, central Japan; two 1,000m deep shafts and several drifts will be excavated; crystalline rock studies in URL in Mizunami City, Gifu Prefecture)

294) JAEA (website accessed May 2, 2016). *Mizunami Underground Research Laboratory*; http://www.jaea.go.jp/04/tono/miu_e/index.html (NOTES: updated depth of shafts = Main shaft, 500.4/1,000m; Ventilation shaft, 500.2/1,000m; not much progress in past few years or worked stalled; crystalline rock test facility, Tono area; Mizunami City, Gifu Prefecture)

295) Hama, Katsuhiro, et al. 2014. Mizunami Underground Research Laboratory Project Annual Report for Fiscal Year 2013, JAEA-Review 2014-038; JAEA; http://jolissrch-inter.tokai-sc.jaea.go.jp/pdfdata/JAEA-Review-2014-038.pdf = in Japanese; see maps and figures; accessed July, 2015; revisit May 2, 2016

296) TGC / Tono Geoscience Center, and JNC / Japan Nuclear Cycle Development Institute. 1999. *Master Plan of Mizunami Underground Research Laboratory;* Tono Geoscience Center (TGC), Japan Nuclear Cycle (JNC) Development Institute. JNCTN7410 99-008; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/31/043/31043225.pdf ; accessed May 2, 2016 (NOTES: "laboratory will be constructed at the Shobasama-bora site in Akeyo-cho, Mizunami City, Gifu Prefecture"…)

297) Osawa, H., and K. Koide, E. Sasao, T. Iwatsuki, H. Saegusa, K. Hama, T. Sato. 2015. Current Status of R&D Activities and Future Plan of Mizunami Underground Research Laboratory. *2015 International High-Level Radioactive Waste Management American Nuclear Society (ANS) Conference*, April 12-16, 2015, Charleston, SC; p.371-378. Not available online; abstract only, http://jolissrch-inter.tokai-sc.jaea.go.jp/search/servlet/search?5049085&language=1 (NOTES: MIU has been completed to the -500 m level. Phase III research activities underground since 2010; Phases I and II report available via a web-based report "CoolRep H26"…. ; By 2012, at 500m; excavated through an overlying sequence of Miocene sedimentary rock (Mizunami Group) and into the late Cretaceous Toki Granite… MIU with two shafts, the Main Shaft (6.5m diam.) and the Ventilation Shaft (4.5m diam.); two experimental levels, at the 300 m level and the 500 m level; sub-stages, at the 100m, 200m and 400m levels)

298) JAEA (Japan Atomic Energy Agency) webpage accessed May 5, 2016. *Mizunami Underground Research Laboratory*; http://www.jaea.go.jp/04/tono/miu_e/ ; (NOTES: see latest news, depth of shafts, August 21, 2015: each shaft ~500m present construction depth below ground level; for site subsurface facility illustration see

299) Suzuki, Yohey; Konno, Uta, et al. 2014. Biogeochemical Signals from Deep Microbial Life in Terrestrial Crust. *PLoS ONE* 9(12): e113063. doi:10.1371/journal.pone.0113063; http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0113063; accessed May 5, 2016 (NOTE: See Figure 1: The location and schematic underground layout of the Mizunami Underground Research Laboratory (MIU) with investigated boreholes and a geological cross section14. Figure_1.tif. PLOS ONE. 10.1371/journal.pone.0113063.g001. http://figshare.com/articles/_The_location_and_schematic_underground_layout_of_the_Mizunami_Underground_Research_Laboratory_MIU_with_investigated_boreholes_and_a_geological_cross_section_14_/1273270)

Japan: Tono Mine, Gifu prefecture

300) Kanai, Yutaka, et al. 1998. Geochemical micro-behavior of natural U-series nuclides in granitic conglomerate from the Tono mine, central Japan; *Geochemical Journal*, Vol. 32, pp. 351 - 366, 1998; https://www.jstage.jst.go.jp/article/geochemj1966/32/6/32_6_351/_pdf; accessed May 3, 2016 (NOTES: Geology of the Tono uranium mine deposits: basement Cretaceous biotite granite ("Toki granite") dated 70 Ma; overlying sediments are Miocene Mizunami Group and the Plio-Pleistocene Seto Group; orebodies are mostly formed in the Toki Lignite bearing Formation in lowest Mizunami Group; age of U mineralization is ~10 Ma.)

301) Koide, Hitoshi. 1991. Geologic problems of radioactive waste disposal in Japan; *Episodes*, Vol. 14, no. 3, pp. 299-302; http://co2.eco.coocan.jp/ref/91Episode.pdf and http://www.episodes.org/index.php/epi/article/viewFile/63275/49386; accessed May 3, 2016 (Notes: uraniferous sediments Miocene age over granitic basement and Kamaishi mine of Iwate Prefecture granitic tests envisioned; largest uranium deposit in Japan at Tono area; Japan Atomic Energy Research Institute (JAERI); Tono mine of southeastern Honshu; origin of ore, uranium precipitated from groundwater into coarse sediments of Miocene age channel over granitic basement; Tono mine schematic; shaft ~150m bgl; EDZ tests; predictions and model validation techniques for disruptive events)

302) Katayama, N.; Kubo, K.; Hirono, S. 1974. Genesis of uranium deposits of the Tono Mine, Japan, In: *International Atomic Energy Agency, Vienna (Austria); Proceedings series*; p. 437-452; ISBN 9200402747; Worldcat; 1974; IAEA; Vienna; Symposium on the formation of uranium ore deposits; Athens, Greece; 6 May 1974; IAEA-SM--183/11; http://inis.iaea.org/search/search.aspx?orig_q=RN:6215004; abstract accessed May 2, 2016

Japan: Tono Geoscience Center, Mine, and Mizunami URL (MIU); Gifu Prefecture

303) JAEA / Japan Atomic Energy Agency / Tono Geoscience Center / TGC (website accessed May 5, 2016) *Tono Geoscience Center*; http://www.jaea.go.jp/04/tono/tgc_e/index_e.html (NOTE: map and photos of facilities; also see Horonobe Underground Research Project in Horonobe-cho, Hokkaido, and Mizunami Underground Research Laboratory (MIU) Project)

304) TGC (Tono Geoscience Center) and JNC (Japan Nuclear Cycle Development Institute). 2002. *Master Plan of the Mizunami Underground Research Laboratory Project*, JNC TN7410 2003-001; 153 pp.; Tono Geoscience Center (TGC) / Japan Nuclear Cycle Development Institute (JNC); http://www.jaea.go.jp/04/tono/miu_e/publ/tn74102003-001.pdf ; accessed May 3, 2016 (Note: JNC selected crystalline rock investigation at Mizunami City, Gifu Prefecture; investigation of sedimentary rock is at Horonobe, Hokkaido; Mizunami Underground Research Laboratory / MIU, and located in Akeyo-cho, Mizunami City; MIU galleries will be excavated and the Shobasama Site; two 1,000 m shafts planned; galleries of the MIU will be excavated in the Cretaceous Toki Granite; Neogene age sediment studies at Tono (1986ff) and Kamaishi Mines (1988-1998) used for preparatory information; Shaft 2 excavation initiated, 1991; testing from Tono shaft 2 ~150m bgl, 6m diameter. Kamaishi mine galleries at 300 and 700m bgl in a crystalline rock (Kurihashi Granodiorite)

305) Mizunami Underground Research Laboratory (website accessed May 12, 2016); http://www.jaea.go.jp/04/tono/miu_e/index.html ; (NOTES: 2 shafts in construction at Mizunami; both ~500m bgl in November, 2015. Tono Geoscience Center (TGC), Japan Atomic Energy Agency (JAEA) have been carrying out geoscientific research at two locations: the location for investigation of crystalline rock is in Mizunami City, Gifu Prefecture; the location for investigation of sedimentary rock is at Horonobe, Hokkaido.)

306) Sugihara, Kozo. 1995. Safety Management in PNC's Shaft Excavation Effects Project, pp. 121-138, In: U.S. National Committee on Tunneling Technology, National Research Council, 1995, *Safety in the Underground Construction and Operation of the Exploratory Studies Facility at Yucca Mountain*; National Academies of Science, Washington, DC; accessed May 4, 20176 (NOTES: see section "Overview of the Shaft Excavation Effects Project, Tono Mine"; mining operations began in 1972; Tono uranium mine shaft testing of EDZ; new shaft to ~150m; lining inner diameter, 6m; http://www.nap.edu/openbook.php?record_id=4897&page=123

307) JAEA / Japan Atomic Energy Agency (website, accessed May 3, 2016). *The Tono Geoscience Center (TGC);* http://www.jaea.go.jp/04/tono/tgc_e/faciliti_e.html ; (NOTES: TGC, Shobasama site, MIU site, Tono Mine location map; facilities, research, information; 2005, integration of JNC and JAERI (Japan Atomic Energy Research Institute) to form the JAEA (Japan Atomic Energy Agency); best estimated locations: Tono Mine, 35.387816, 137.215887 ; Shobasama site, Akiyocho Tsukiyoshi, Mizunami, Gifu Prefecture, 35.382459, 137.224089; MIU Construction site, Akiyochō Yamanouchi, Mizunami-shi, Gifu-ken, 35.377761, 137.237233)

Japan: Tono and Kamaishi mines, testing; Horonobe and Mizunami URLs

308) Sugihara, K. 2009. Geologic disposal of high-level radioactive waste and the role of rock engineering; *International Journal of the JRCM* (Japanese Committee for Rock Mechanics), Vol. 5, No.1, pp.19-24; http://www.rocknet-japan.org/IJJCRM/v5n1/v5n1-04.pdf ; accessed May 4, 2016; {NOTES: Japan Atomic Energy Agency (JAEA); in situ experiments have been performed at the Tono Mine in soft sedimentary rocks (testing 1986-2003) and at the Kamaishi Mine in hard crystalline rocks (testing 1988-1998; Mizunami Underground Research Laboratory (MIU; start 1996) project for crystalline rocks and the Horonobe Underground Research Laboratory (Horonobe URL; start 2001) project for sedimentary rocks; Nuclear Waste Management Organization of Japan (NUMO), responsible for waste disposal HLW; Japan Atomic Energy Agency (JAEA); see Figures; Tono mine, Tertiary and Quaternary sedimentary sequences unconformably overlying a Cretaceous granitic basement; 1) Tono mine: geology, Mizunami group, mainly tuffaceous mudstone and sandstone; 3 shafts; No.2 shaft, 6m diameter, ~150m deep; 2) Kamaishi Mine: geology, Paleozoic and Cretaceous sedimentary rocks and two igneous complexes, the Kurihashi Granodiorite and the Ganidake Granodiorite; early testing ~260m bgl. EDZ from drill and blast construction has impact on rock properties out to 1plus meters; 3) Mizunami URL, geology is Tertiary and Quaternary sedimentary rocks overlying a late Cretaceous granitic basement; excavated in the late Cretaceous Toki Granite; Tertiary/Recent deformation; 1000m depth; main shaft 6.5m diameter; ventilation shaft 4.5m diameter; were still under construction in 2009}

Republic of Korea: KAERI, Korea Atomic Energy Research Institute

309) KAERI / Korea Atomic Energy Research Institute (website accessed May 12, 2016); www.kaeri.re.kr:8080/english/ (NOTES: links for KURT, the KAERI Underground Research Tunnel, see http://www.kaeri.re.kr:8080/english/sub/sub03_02_01_05.jsp)

Republic of Korea: KURT/ KAERI underground research tunnel (URL), Yusung Gu, Daejeon

310) Cho, Won Jin; Kwon, Sang Ki; Park, Jeong Hwa; Choi, Jong Won. 2007. KAERI underground research tunnel; *Journal of the Korean Radioactive Waste Society*; v. 5(3); ISSN 1738-1894; Sep 2007; p. 239-255; (Korea Atomic Energy Research Institute, Daejeon); see https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=39041135; International Nuclear Information System (INIS), IAEA source documents; abstract access May 3, 2016

311) KAERI / Korea Atomic Energy Research Institute (website accessed May 3, 2016). *Fuel Cycle* (https://www.kaeri.re.kr/english/sub/sub04_03.jsp ; home, https://www.kaeri.re.kr/english/sub/sub04_01.jsp ;

312) KAERI / Korea Atomic Energy Research Institute (website accessed May 3, 2016*). KAERI Underground Research Tunnel;* http://www.kaeri.re.kr:8080/english/sub/sub03_02_01_05.jsp ; accessed May 3, 2016 (Note: 90m bgl maximum depth; host rock is granite; Yusung Gu, Deajeon; Korea Atomic Energy Research Institute, KAERI; 6m x 6m x 180m tunnel access; KURT is located at a mountainous area inside of KAERI territory in Yusung Gu, Deajeon, Korea. The Korea Atomic Energy Research Institute (KAERI); KAERI Underground Research Tunnel / KURT has total length of 255m with 180m long access tunnel and two research tunnels of total 75m long. The maximum depth of 90m bgl; tunnel is 6m x 6m profile; major infrastructure for validating the safety and feasibility of the suggested disposal system; access 6m x 6m x 180m tunnel; tunnel construction in 2005/2006; located inside of KAERI territory in Yusung Gu, Deajeon, Korea; ~90m bgl; granite; three faults and fracture zones cross the access tunnel; andesitic dykes were encountered)

313) Bang, Sang Hyuk, and Seokwon Jeon, and Sangki Kwon. 2011. Modeling the hydraulic characteristics of a fractured rock mass with correlated fracture length and aperture: application in the underground research tunnel at KAERI; *Nuclear Engineering and Technology*, Vol.44 No.6 August 2012; p.639-652; http://www.kns.org/jknsfile/v44/6-11-26.pdf ; accessed May 4, 2016 (NOTES: groundwater flow in fractured crystalline rock)

Germany: Bundesanstalt fur Geowissenschaften und Rohstoffe / BGR / Federal Institute for Geosciences and Natural Resources

314) Bundesanstalt fur Geowissenschaften und Rohstoffe / BGR / Federal Institute for Geosciences and Natural Resources (webpage accessed May 2, 2016) homepage; http://www.bgr.bund.de/EN/Home/homepage_node_en.html

Germany: BfS / Bundesamt fur Strahlenschutz, Federal Office for Radiation Protection

315) BfS / Bundesamt fur Strahlenschutz, Federal Office for Radiation Protection (website accessed May 3, 2016). Homepage; http://www.bfs.de/EN/home/home_node.html ; (NOTE: responsible for radioactive waste disposal, among other activities; headquarters in Salzgitter; see research page for details on R&D approach and activities;)

316) BfS / Bundesamt fur Strahlenschutz, Federal Office for Radiation Protection (website accessed May 4, 2016). *Repositories*; http://www.bfs.de/EN/topics/nwm/repositories/repositories_node.html (Note: Asse II mine, Morsleben and Konrad repository facilities; and Gorleben mine site exploration work terminated in 2013; http://www.bfs.de/EN/topics/nwm/repositories/site-selection/gorleben/gorleben.html . Asse II salt mine near Wolfenbüttel is an approximately 100-year-old potash and salt mine; waste being removed and mine decommissioned. http://www.bfs.de/EN/topics/nwm/repositories/asse/asse.html . Konrad mine near Salzgitter, iron ore mine converted to repository, http://www.bfs.de/EN/topics/nwm/repositories/konrad/konrad.html . Morsleben located in Saxony-Anhalt is an over 100-year-old potash and rock salt mine; BfS applied to decommission repository; Bartensleben mine in Morsleben served to mine potash and rock salt before it became a repository for radioactive waste in 1971; http://www.bfs.de/EN/topics/nwm/repositories/morsleben/morsleben.html)

Germany: BfS / Bundesamt für Strahlenschutz, Federal Office for Radiation Protection - Repositories

317) BfS / Bundesamt für Strahlenschutz, Federal Office for Radiation Protection (websites accessed May 3, 2016). *Nuclear waste management*; http://www.bfs.de/EN/topics/nwm/nwm_node.html

318) BfS / Bundesamt für Strahlenschutz, Federal Office for Radiation Protection (websites accessed May 3, 2016). *Repositories*, http://www.bfs.de/EN/topics/nwm/repositories/repositories_node.html ; (NOTE: BfS responsible for repositories; Gorleben, an exploratory mine under consideration for repository; radioactive waste stored in Morsleben and Asse; Konrad mine is currently being converted to a repository. Siting and site selection issues remain; "Working Group for the Selection of Repository Sites" [AkEnd]. From BGE website, https://www.bge.de/en/bge/organisation; it is noted that BfS and DBE employees are being moved under BGE during and after 2017; BGE / Die Bundesgesellschaft für Endlagerung, reflecting change in German organizational structure)

Germany: Asse Mine URL (salt)

319) BfS (website accessed November 16, 2015). *Asse Mine;* http://www.asse.bund.de/Asse/EN/home/home_node.html (NOTE: Asse II salt mine near Wolfenbüttel is an approximately 100-year-old potash and salt mine. Between 1965 and 1995, Helmholtz Zentrum München used the mine to test the handling and storage of radioactive waste in a repository. Between 1967 and 1978, 46,950 cubic metres of radioactive waste in 125,787 drums were emplaced. BfS, 2009, assumed operatorship for the Asse II mine from Helmholtz Zentrum München; BfS was to retrieve waste and decommission mine; Zechstein ~ 230 mya salt deposits; waste emplacement from 511 to 750m bgl; later comment, Asse II - 765 m shaft which was later extended to 950 m for research)

320) BfS / Bundesamt für Strahlenschutz, Federal Office for Radiation Protection (website accessed May 4, 2016). *Decommissioning of the Asse (II) mine*; http://www.bfs.de/EN/home/home_node.html and http://www.bfs.de/EN/topics/nwm/repositories/asse/asse.htm (NOTE: BfS, 2009, assumed operatorship for the Asse II mine from Helmholtz Zentrum München; BfS is responsible for: Konrad, Morsleben, Asse and Gorleben)

Germany: Gorleben salt dome and URL

321) Kothe, Angelika, et al. 2007. *Description of the Gorleben Site Part 2: Geology of the overburden and adjoining rock of the Gorleben salt dome*; Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR), Hanover; http://www.ptka.kit.edu/downloads/ptka-wte-e/Description_Gorleben_Part2_Geology-overburden-adjoining_rock_en.pdf ; accessed May 4, 2016 (NOTES: Zechstein salt, Permian);

322) Klinge, Hans, et al. 2007. *Description of the Gorleben Site Part 1: Hydrogeology of the overburden of the Gorleben salt dome*; Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR), Hanover; http://www.ptka.kit.edu/downloads/ptka-wte-e/Description_Gorleben_Part1_Hydrogeology_overburden_en.pdf ; accessed May 4, 2016 (NOTES: Zechstein salt, Permian; maps and detail geology)

323) BfS / Bundesamt für Strahlenschutz, Federal Office for Radiation Protection (website accessed May 4, 2016). *Gorleben*. http://www.bfs.de/EN/topics/nwm/repositories/site-selection/gorleben/gorleben.html (NOTE: Exploratory mine, decommissioning in process; will remain "open" until ruled out as repository)

324) Otto, Helmut, and E. Berger, P. Nowack. 2010. Gorleben exploration mine / Erkundungsbergwerk Gorleben: Schächte – untertägige Infrastruktur – Verschluss der Gefrierlochbohrungen; *Thyssen Mining Report 2010*, p. 50-53; Thyssen Schachtbau GmbH; http://thyssen-schachtbau.com/images/schachtbaubohren/projekte/pdf/sb_gorleben_erkundungsbergwerk_de.pdf ; accessed May 4, 2016 (Note: In German so translation is questioned; Site with Gorleben development work descriptions for shafts; brochure from 2010; freezer section in salt shaft 1 and work discussions; Shaft 1 ~930m bgl; shaft 10m or 11.5m DD, 7.5m ID liner)

Germany: Morsleben Repository (Decommissioning; Salt); Bartensleben mine in Morsleben (Saxony Anhalt)

325) Behlau, Joachim, and Gerhard Mingerzahn. 2001. Geological and tectonic investigations in the former Morsleben salt mine (Germany) as a basis for the safety assessment of a radioactive waste repository; *Engineering Geology* Volume 61, Issues 2–3, August 2001, Pages 83–97; El Sevier; http://www.sciencedirect.com/science/article/pii/S0013795201000382 ; accessed abstract May 4, 2016 (NOTE: Morsleben repository location in Saxony–Anhalt. Geology: Zechstein salt strata, Stassfurt to Aller beds (z2–z4) are exposed in the Morsleben mine; part of Werra Formation present , Allertal zone salt structure; salt body is primarily a tectonic structure and is not halokinetic. Morsleben repository has two shafts. The older shaft, Marie, was dug in 1897, the Bartensleben shaft in 1914. Potash and rock salt were mined until the 1960s; no wastes emplaced since 1998; studies supported by Bundesamt für Strahlenschutz / BfS / Federal Office for Radiation Protection, and the Bundesanstalt für Geowissenschaften und Rohstoffe / BGR / Federal Institute for Geosciences and Natural Resources. Also see related salt disposal report, https://www.energy.gov/sites/prod/files/2017/02/f34/1Proc6thUSGermanWorkshopSaltRepositoryR%26D.pdf)

326) BfS / Bundesamt fur Strahlenschutz, Federal Office for Radiation Protection (website accessed May 4, 2016); *Decommissioning of the Morsleben repository*; http://www.bfs.de/EN/topics/nwm/repositories/morsleben/morsleben_node.html ; (NOTES: Bartensleben mine in Morsleben (Saxony Anhalt) served to mine potash and rock salt before it became a repository for radioactive waste in 1971, ended 1998; decommissioning of repository overseen by Federal Office for Radiation Protection / BfS; also see http://www.endlager-morsleben.de/Morsleben/EN/home/home_node.html)

Germany: Konrad iron mine / repository and URL, Salzgitter

327) Konrad (website home accessed May 4, 2016). *Konrad*; http://www.endlager-konrad.de/Konrad/EN/themen/themen_node.html; http://www.endlager-konrad.de/Konrad/EN/themen/endlager/endlager_node.html and http://www.endlager-konrad.de/Konrad/EN/konrad/konrad_node.html (NOTE: disposal and testing ~800-1000m bgl; BfS information site; see valuable links at bottom of page / URL; plans for disposal LLW/ILW; numerous low information content links; iron ore mine; Bundesamt für Strahlenschutz 2015)

328) Brennecke, P. W. 2010. Waste Acceptance Requirements for the Konrad Repository; *IAEA -DISPONET Workshop "Waste Acceptance Criteria for Disposal of Very Low, Low, and Intermediate Level Waste" Peine/ Salzgitter, Germany*, September 28 -30, 2010. https://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/DISPONET/disponetfiles/WAC_Peine2010/1Waste_Acceptance_Req_Konrad_rep-BfS.pdf ; accessed May 4, 2016 (NOTES: presentation, 23 pages; author from BfS; Konrad Iron ore deposit geology, coral oolite; 800-1300m depth for emplacement Upper Jurassic, Malm; 2 shafts for access;)

329) Kunze, V. 2008. Konrad Repository Facing its construction- 8229; *WM2008, Waste Management Conference* February 24-28, 2008, Phoenix, AZ; http://www.wmsym.org/archives/2008/pdfs/8229.pdf ; no longer accessible online (NOTE: Konrad iron ore mine near Salzgitter, Fed. State Lower Saxony; Morsleben site, aka ERAM / Das Endlager für radioaktive Abfälle Morsleben, a site for LLW/ILW; Asse, LLW/ILW; Konrad iron ore mine with 2 shafts sunk in 1957 and 1962; mining ceased, 1976; planned disposal at 800 -1300m bgl. Upper Jurassic Malm age unit for iron formation)

330) Thyssen Schachtbau GmbH (website accessed May 5, 2016). Shaft Sinking and Drilling Division. *The Konrad transformation – from iron-ore mine to a final waste repository*; http://thyssen-schachtbau.com/en/schachtbau-bohren/aktuelles/148-the-konrad-transformation-from-iron-ore-mine-to-a-final-waste-repository ; (NOTE: Rehabilitated shaft 1 and directed to do same for shaft 2 at Konrad.)

331) Biurrun, E. and B. Hartje. 2003. License for the Konrad deep geological repository; *Waste Management Symposium, WM'03 Conference*, February 23-27, 2003, Tucson, AZ; 6pp. http://www.wmsym.org/archives/2003/pdfs/607.pdf ; accessed May 4, 2016 (NOTE: shaft 1 is 1232m; shaft 2, 999m deep; ore unit, Upper Jurassic; Konrad 1, 1232m bgl;)

332) Brewitz, W. et al. 1980. Conceptual Design Of Stable Galleries In Deep Ore Formation for the Safe Disposal of Low And Decommissioning Wastes From Nuclear Power Stations In The Federal Republic Of Germany; *ISRM International Society of Rock Mechanics - Rockstore 80*, 23-27 June, Stockholm, Sweden; https://www.onepetro.org/conference-paper/ISRM-Rockstore-1980-103 ; access May 4, 2016, partial document and abstract (NOTE: Konrad, early paper; near Salzgitter, Lower Saxony; 2 shafts, 7m diameter each. Sedimentary oolitic iron ore (Minette type), Jurassic age, Gifhorner Trough; see http://pubs.usgs.gov/bul/b2004/model34f.pdf)

333) DGRJRP / Deep Geologic Repository JRP / Joint Review Panel. 2012. *DGR (Deep Geologic Repository) Joint Review Panel, International Visit Report, Konrad Repository, Salzgitter, Germany*, October 22-23, 2012; (report Appendices 2-9, Konrad including geology, hydrology, mining); 291pp. DGRJRP, Ottawa, CA; http://www.ceaa.gc.ca/050/documents/p17520/88557E.pdf ; access May 4, 2016 (NOTE: slide presentations given to review panel included; Konrad host unit is coral oolite, 150My; Canadian review panel reviews ILW/LLW disposal at Konrad; Report includes: Appendix 3, Geology of the Konrad area, by Nicole Schubarth-Engelschall, slide presentation; studies conducted 1976-1990; shaft 1 sunk 1957/1960; shaft 2, 1960/1962; mining stopped 1976; ore concentrated in Upper Jurassic Malm, Oxfordian unit; top seal, Cretaceous argillites; western flank "basin" against salt dome; Malm/Oxfordian, Upper Jurassic iron oolite deposits mined)

Germany: Shaft construction, Gorleben, Konrad, other (large diameter drilling)

334) Deilmann-Haniel / Redpath Group (website accessed May 4, 2016). *Shaft Sinking and Ground Freezing*; brochure, 26pp. Deilmann-Haniel GmbH, Germany; http://www.deilmann-haniel.com/fileadmin/user_upload/german/pdfs/Prospekt_Schachtbau_und_Gefrieren_DE_EN.pdf ; (NOTES: Page 6, Gorleben project; inner diameter shaft liner 7.5 m; shafts 1, 2 to 933m/843m. Page 7, 12and 14, Konrad project, 6m inner diameter shaft to 240m in rehabilitation work. Page 8, an additional example large diameter drilling, shaft sinking at Primsmulde, Germany, shaft drilling project to 1,256m, 8.2m drilling diameter; follows pilot hole of 1,150m of 1.8m diameter)

Hungary: Public Limited Company for Radioactive Waste Management (formerly PURAM)

335) Public Limited Company for Radioactive Waste Management (formerly PURAM / Public Agency for Radioactive Waste Management), Hungary (website accessed May 4, 2016); www.rhk.hu/en/ (Note: Bataapati operating repository for LLW/ILW; Boda/Mecsek HLW investigation location)

Hungary: Boda Claystone and clay repository studies

336) Lázár, K. and Zoltán Máthé. 2012. Claystone as a Potential Host Rock for Nuclear Waste Storage; Chapter 4, *In*: Marta Valaškova and Gražyna Simha Martynkova (editors), "*Clay Minerals in Nature - Their Characterization, Modification and Application*"; 326pp. http://www.intechopen.com/books/clay-minerals-in-nature-their-characterization-modification-and-application/claystone-as-a-potential-host-rock-for-nuclear-waste-storage ; accessed May 4, 2016 (NOTES: Callovo-Oxfordian formation in Bure, France, the Opalinus Clay in Mont Terri, Switzerland, and the Boom Clay in Mol, Belgium; Boda Claystone Hungary; Upper Permian sedimentary sequence of the Boda Claystone Formation (BCF) is located in Western Mecsek Mountains, southern Transdanubia, SW Hungary; Pannonian Basin; Underground Research Laboratory in Boda claystone was established and had been maintained in a depth of 1050 m below ground level (1994 – 1998))

Hungary: Mecsek mining, repository and URL siting

337) Csıvári, Zs. Berta-M. 2008. History of the uranium production in Mecsek; IAEA, Mecsek Oko zRt, *Technical Meeting on Uranium Exploration and Mining Methods; Amman, Jordan*, November 17-20, 2008; accessed May 4, 2016;

http://www.iaea.org/OurWork/ST/NE/NEFW/documents/RawMaterials/TM%20JOR/32%20History%20of%20the%20uranium%20production%20in%20MECSEK%20final%201.pdf

Hungary: West Mecsek uranium mining district; Boda Claystone Formation repository siting studies

338) Konrád, Gy, G. Hámos, Z. Máthé, and L. Kovacs. 2013. Boda Claystone Formation (BCF)—the potential host rock of high-level radioactive waste repository in Hungary; *Eurogeologists Workshop on Radioactive Waste Disposal (RWD)* on 30 May 2013in connection with EFG Council Meeting in Stockholm 1-2 June 2013; Mecsekérc Zrt; http://eurogeologists.eu/images/content/stockholm/10.%20Gyula%20Konrad,%20Ass.%20Prof.,%20University%20of%20Pecs.pdf ; and http://www.eurogeologists.de/images/content/stockholm/10.%20Gyula%20Konrad,%20Ass.%20Prof.,%20University%20of%20Pecs.pdf ; last accessed August 17, 2015 (NOTE: presentation for workshop; U ore in sandstone overlying Boda Claystone Formation; for HLW and spent fuel; located outside Pecs; Boda, Middle Permian, lacustrine claystone; geology, mineralogy, rock properties; Boda claystone studies in Pecs area and location maps, cross sections; evaluation for repository HLW, SNF; uranium mining district; Permian, Guadeloupian age; Middle Permian, 250-260 Ma; lacustrine deposits; see also European Federation of Geologists Website)

Hungary: Pecs area, Mecsek Ore

339) Csovari, M., Z. Berta, J. Csicsak, G. Folding. 2005. Mecsek Ore, Pecs, Hungary case study (in: K.E. Roehl, T. Meggyes, F.G. Simon, D.I. Stewart (editors), *Long-Term Performance of Permeable Reactive Barriers*, Chapter 9); El Sevier; https://books.google.com/books?id=0MJap7ncvx8C&pg=PA261&lpg=PA261&dq=Long-Term+Performance+of+Permeable+Reactive+Barriers,+Chapter+9);+El+Sevier&source=bl&ots=hUyml4PgZ-&sig=npml1596VOZp7aHnx5XgyXsWXFE&hl=en&sa=X&ved=0CDAQ6AEwA2oVChMImYP8rLCfxwIVQW4-Ch1BCwyB#v=onepage&q=Long-Term%20Performance%20of%20Permeable%20Reactive%20Barriers%2C%20Chapter%209)%3B%20El%20Sevier&f=false ; accessed May 4, 2016

340) Csovári, Zs. Berta-M. 2008. History of the uranium production in Mecsek; In: *Technical Meeting on Uranium Exploration and Mining Methods*, MECSEC/IAEA, Amman, 17-20 November 2008 (Presentation). http://www.iaea.org/OurWork/ST/NE/NEFW/documents/RawMaterials/TM%20JOR/32%20History%20of%20the%20uranium%20production%20in%20MECSEK%20final%201.pdf ; accessed May 4, 2016 (NOTES: historical and location information; near village of Kovágószolos; 46.076476, 18.123010)

Hungary: Bátaapáti, Tolna County; IL/LLW geologic disposal; general

341) World Nuclear Association (website accessed May 4, 2016). *Nuclear Power in Hungary*. http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Hungary/ ; (NOTES: LLW repository with PURAM formerly as operator group. The residents of Bátaapáti (30km from Pecs; 46.224614, 18.601333) voted in 2005 to approve construction of a repository for low- and intermediate-level wastes; approved by Parliament; granite, 200-250m depth; disposal site considered for clay at Buda in Mecsek Mountains but opening planned for 2060; state-owned body responsible for waste management, waste disposal and decommissioning is the Public Limited Company for Radioactive Waste Management (Radioaktív Hulladékokat Kezelő Kft., RHK Kft), formerly the Public Agency for Radioactive Waste Management (PURAM); start of operation of a deep geological HLW/SF repository is planned by 2047; Boda claystone formation near Buda in the southwest Mecsek Mountains is being investigated, and a preliminary safety analysis has been made for a deep geological repository; operational by 2060)

342) Gaich, A., F. Deák, F., and M. Pötsch. 2012. High Resolution 3d Imaging during the Construction of National Radioactive Waste Repository from Bátaapáti, Hungary; *American Geophysical Union, Fall Meeting 2012*, abstract #H33J-1473, 12/2012 http://adsabs.harvard.edu/abs/2012AGUFM.H33J1473G - abstract only; accessed abstract May 4, 2016

343) IAEA / International Atomic Energy Agency. 2009 (updated). *Hungary: Country Profile*. International Atomic Energy Agency, Country Profiles, 2009. http://www-pub.iaea.org/MTCD/publications/PDF/cnpp2009/countryprofiles/Hungary/Hungary2008.htm ; accessed May 4, 2016 (NOTE: Public Limited Company for Radioactive Waste Management (Radioaktív Hulladékokat Kezelő Kft., RHK Kft), formerly the Public Agency for Radioactive Waste Management (PURAM); start of operation of a deep geological HLW/SF repository is planned by 2047; see sections on waste management and "Safety and waste management issues". For IAEA Country Nuclear Power Profiles, all countries, 2009 edition, online, see http://www-pub.iaea.org/mtcd/publications/pdf/cnpp2009/pages/countryprofiles.htm)

344) Baksay, Attila. 2015. Low and Intermediate Level Waste Disposal in Hungary; *International Workshop on the Safe Disposal of Low Level Radioactive Waste*, ASN Headquarters, Montrouge, France, 3-5 February, 2015; IAEA and Gov. France coordinated workshop. http://gnssn.iaea.org/RTWS/general/Shared%20Documents/Waste%20Management/Feb%202015%20WS%20on%20LLW%20disposal/Day%202)%20Hungary.pdf ; accessed May 4, 2016; (NOTES: slide presentation, 26 pp.; LLW/ILW disposal focus; for workshop information, see http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/Info_sredisce/Tecaji_konference_seminarji/tecaji_MAAE/Montrouge_2015_Attachment.pdf)

345) Republic of Hungary. 2011. *Republic Of Hungary National Report, Fourth Report* {prepared within the framework of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management}; http://www.oah.hu/web/v3/HAEAPortal.nsf/6F5866DC74FA9B9CC1257C5C00369E44/$FILE/4th_nat_rep_JC.pdf ; accessed May 4, 2016 (Notes: more recent information contained in OKO Zrt. et al. 2015)

345a) OKO Zrt. et al. 2015. *National Programme of Hungary on the Management of Spent Fuel and Radioactive Waste, Strategic Environmental Assessment*; Budapest; http://www.kormany.hu/download/6/93/a0000/Nat_Progr_rad_waste_SEA_EnvRep_EN.pdf ; accessed June 22, 2016 (Note: area location pictured)

Finland: Posiva Homepage (Olkiluoto, Final Repository for SNF; ONKALO URL)

346) *Posiva* (website homepage accessed May 4, 2016). http://www.posiva.fi/en (NOTE: on homepage, select on top bar, "Final Disposal", and navigate to links of interest, i.e., use links on left column to select "Final Disposal Facility" and "ONKALO"; deposition tunnels located at a depth of ~ 400-450 meters inside the Olkiluoto bedrock; access tunnel and four vertical shafts lead from the surface down to the repository; access tunnel to 455m, testing generally =< 450m bgl; slope of the tunnel is 1:10. It is 5.5 m wide and 6.3 m high; underground rock characterisation facility (ONKALO) that extends approximately to the depth of 450 meters)

346a) NucNet (website accessed June 23, 2016). Posiva to work with Fennovoima on Hanhikivi-1 final disposal; *NucNet News in brief*, June 22, 2016; http://www.nucnet.org/ and http://www.nucnet.org/all-the-news/2016/06/22/posiva-to-work-with-fennovoima-on-hanhikivi-1-final-disposal (Notes: Each nuclear power company in Finland is responsible for the final disposal of its own spent nuclear fuel; Posiva will provide Fennovoima with services for final disposal {site selection, 2040s; operational ~2090s} of spent nuclear fuel from planned Hanhikivi-1 nuclear plant. Initial geologic studies planned for potential sites, Pyhäjoki and Eurajoki areas. Olkiluoto in Eurajoki is the site of Posiva's Onkalo underground laboratory and final repository for used fuel from Olkiluoto and Loviisa nuclear stations.)

Finland: Olkiluoto repository and Onkalo URL

347) Posiva. 2007. Geological disposal of spent nuclear fuel in Finland: *RWD workshop, Stockholm University*; presentation, 37 slides; Posiva. http://www.eurogeologists.eu/images/content/stockholm/5.%20Ismo%20Aaltonen,%20Chief%20Geologist,%20Posiva%20Oy,%20Finland.pdf ; last accessed August 10, 2015 (NOTES: Olkiluoto selected; planned ~2012 construction of ONKALO (access tunnels and shaft) and site confirmation; planned disposal ~2020. Five preliminary sites evaluated: 1.Romuvaara in Kuhmo; 2.Veitsivaara in Hyrynsalmi; 3.Kivetty in Äänekoski; 4.Syyry in Sievi; 5.Olkiluoto in Eurajoki)

Finland: Olkiluoto Final Repository for SNF, and Onkalo research tunnel and URL

348) Fox, Aaron, K. Forchhammer, A. Pettersson, P. La Pointe, Doo-Hyun Lim. June 2012. *Geological Discrete Fracture Network Model for the Olkiluoto Site, Eurajoki, Finland*, Version 2.0, Posiva 2012-27; POSIVA OY, Olkiluoto, Eurajoki , Finland; http://www.posiva.fi/files/2822/POSIVA_2012-27web.pdf ; accessed May 4, 2016

349) Paananen, M., et al. March, 2006. *Geological Model of the ONKALO Area*, Version 0, Working Report 2006-13; Posiva Oy, Olkiluoto, Finland; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/43/074/43074732.pdf ; accessed May 4, 2016

350) Posiva (website accessed May 5, 2016). *The construction of ONKALO*; http://www.posiva.fi/en/final_disposal/onkalo/the_construction_of_onkalo ; {NOTES: ONKALO URL at Olkiluoto (2004, start construction) excavated by drilling and blasting; three shafts planned: 1) personnel shaft, with 4.5m diameter 2) supply air shaft, 3.5m diameter, and 3) exhaust air shaft, 3.5m diameter; underground bedrock research facility excavated as part of the location studies performed in Olkiluoto in Eurajoki; vehicle access tunnel depth ~455 m bgl. Tunnel gradient, 1:10; 5.5 m wide and 6.3 m high, 455m depth bgl. See also http://www.posiva.fi/en/final_disposal/onkalo , http://www.posiva.fi/en/final_disposal/final_disposal_facility , and http://www.posiva.fi/en/final_disposal/onkalo#.VdJZ4Hnlsy4 for Posiva webpages related to disposal and URF at Onkalo (hiding place) site area, underground rock characterisation facility; e.g., http://www.posiva.fi/files/1299/POSIVA_2003-03.pdf }

351) Posiva (website accessed May 4, 2016). *Final Disposal: Repository* http://www.posiva.fi/en/final_disposal and http://www.posiva.fi/en/final_disposal/final_disposal_facility/repository#.Vkte6Xnlsy4 (NOTE: use "repository link; deposition tunnels are located at a depth of about 400-450 meters inside the Olkiluoto bedrock; access tunnel and four vertical shafts lead from the surface down to the repository; Olkiluoto final repository for SNF)

352) Posiva (webpage accessed May 4, 2016). *ONKALO*; http://www.posiva.fi/en/final_disposal/onkalo (NOTE: access tunnel to 455m, testing generally =< 450m bgl; slope of the tunnel is 1:10. It is 5.5 m wide and 6.3 m high; underground rock characterisation facility (ONKALO) that extends approximately to the depth of 450 meters; Construction of ONKALO link states diameter of the passenger shaft is 4.5 m and the diameters of the supply air shaft and exhaust air shaft are 3.5 m. For Geological Survey Finland Onkalo investigation, GTK website, http://en.gtk.fi/research/program/energy/waste/onkalo.html for tunnel mapping and related links)

353) Posiva (webpage accessed May 4, 2016). Posiva is granted construction license for final disposal facility of spent nuclear fuel (press release 12/11/2015); http://www.posiva.fi/en/media/press_releases/posiva_is_granted_construction_licence_for_final_disposal_facility_of_spent_nuclear_fuel.3225.news#.Vkp4AHnlsy4 (NOTE: Posiva can now proceed to construction of the final disposal facility in Olkiluoto; spent fuel assemblies will be encapsulated and placed in the bedrock at a depth of about 400 metres for permanent disposal; ONKALO is research tunnel; also, http://www.posiva.fi/en/media/press_releases)

Russian Federation: Repository and URL siting

354) World Nuclear News (website accessed May 9, 2016). 2014. *Yeniseysky underground laboratory by 2024* (October 17, 2014); http://www.world-nuclear-news.org/WR-Teniseysky-underground-laboratory-by-2024-17101401.html

Russian Federation: Underground Research Facilities, Krasnoyarsk's Yeniseisky District

355) Gupalo, T.A., et al. 2005. Creation and plan of an underground geologic radioactive waste isolation facility at the Niznekansky Rock Massif in Russia. *Waste Management Conference, 2005*, February 27-March 3, 2005, Tucson, Arizona. http://www.wmsym.org/archives/pdfs/5415.pdf ; accessed May 5, 2016 (NOTES: studies of Verkhne-Itatski site and Yeniseiski site for URL; study at 1km deep borehole at Yeniseiski site; funded in part by OCRWM (?verify); previously identified Scientific Production Association Mayak in Cheyabinsk region and the Nizhnekansky granitoid masif in the Krasnoyarsk region, the latter being priority area. Report provides key location map for the Nizhnekansky massif area; Jardin LLNL, J. Williams DOE, co-author; describes Joint geologic repository program (2.5 yrs; ISTC Partner Project 2377) between International Science and Technology Center (ISTC) and Federal State Unitary Enterprise / All Russian Research and Design Institute of Production Engineering (NVIPIPT) ; covers site characterization activities near MCC K-26 site; See Figure 1

and 2 for site area locations; ***Chemical Combine*** Krasnoyarsk-26 (***MCC*** K-26) Minatom MCC K-26 location within Nizhnekansky granitoid massif area; key figures for location information)

356) World Nuclear Association (website accessed May 5, 2016). *Russia's nuclear fuel cycle; Waste disposal, geologic repositories.* http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Fuel-Cycle/ (NOTES: References 2012 article by Kireeva (Anna). Nizhnekansky Rock Massif at Zheleznogorsk in Krasnoyarsk Territory was put forward as a site for a national deep geological repository; National Operator for Radioactive Waste Management (NO RAO) envisages the establishment of an underground laboratory in the Yeniseysky area with nine years' research; completed the design documentation for the underground laboratory in March 2015; decision on repository construction is due by 2025, and the facility itself is to be completed by 2035; deep liquid waste injection sites also planned)

357) Kireeva, Anna. 2012. Closed Siberian nuclear city prepares to build radwaste repository. *Nuclear Monitor*, August 31, 2012 | No. 754; World Information Service on Energy (WISE) and Nuclear Information and Resource Service (NIRS); http://www.nirs.org/mononline/NM%20754.pdf ; accessed May 5, 2016 (NOTES: URL expected development near Siberia city of Krasnoyarsk,Yeniseisky District; other recent news indicates residents of the city of Zheleznogorsk, Krasnoyarsk, approved at a July 30, 2013 public environmental hearing on a project to construct an underground research laboratory to study the possibility of constructing a long term subterranean radioactive waste repository. The laboratory, near Krasnoyarsk's Yeniseisky District will conduct a minimum of nine years of study. Rosatom and Mining and Chemical Combine / MCC involved; Nizhne-Kansk Range; EIS available; Zheleznogorsk (Krasnoyarsk region) URL planned; Nizhnekansky granitoid rock massif; Yeniseisky District. Also presented in Bellona (website), August 2, 2012; Closed Siberian nuclear city prepares to build permanent nuclear waste repository; Bellona Foundation http://bellona.org/news/uncategorized/2012-08-closed-siberian-nuclear-city-prepares-to-build-permanent-nuclear-waste-repository; accessed May 5, 2016)

358) Digges, C. (Bellona website accessed May 5, 2016). November 13, 2014. *Russian environmentalists demand further discussion of deep nuclear waste burial*; Bellona Foundation; http://bellona.org/news/nuclear-issues/radioactive-waste-and-spent-nuclear-fuel/2014-11-russian-environmentalists-demand-discussion-deep-nuclear-waste-burial (NOTES: project is the responsibility of Russia's newly constituted National Operator for nuclear waste handling, or NO RAO; The Nizhnekansky Rock Mass has been approved in public hearings in 2012 as the spot for the repository; once a location for the URL is determined, plans for shafts to be constructed 500 to 600 meters into the Nizhnekansky Rock Mass)

Russian Federation: Repository siting status

359) NEA / Nuclear Energy Agency, OECD / Organisation for Economic Co-operation and Development. 2014. *The Safety Case for Deep Geological Disposal of Radioactive Waste: 2013 State of the Art Symposium Proceedings* 7-9 October 2013, Paris, France; Radioactive Waste Management, NEA/RWM/R (2013)9, March 2014; NEA/OECD; 450 pp. http://www.oecd-nea.org/rwm/docs/2013/rwm-r2013-9.pdf; (NOTES: international programs, safety case examples; Russia's program status, pp. 293-298; repository depth ~ 450-525 m bgl; also refer to: Nilsen, Thomas. 2013. Nuclear repository could end up in Arctic; *Barents Observer*. http://barentsobserver.com/en/nature/2013/11/nuclear-repository-could-end-arctic-27-11. Article indicates 8 locations considered in arctic / Barents / Arkhangelsk region) accessed May 5, 2016, June 2017

Russian Federation: Repository and URL near Krasnoyarsk's Yeniseisky District

360) Kudryavtsev, E.G., et al. 2009. Construction of a Deep Geological Disposal Facility for Final Isolation of High-Level Waste in the Nizhnekansky Rock Massif (Krasnoyarsk region); *CEG Programs for Deep Geological Repositories and Underground Labs; CEG Workshop on Disposal of Radioactive Waste and Spent Nuclear Fuel – Experience and Plans*; CEG, Sweden, 24-26 February 2009 (short paper = http://www.iaea.org/OurWork/ST/NE/NEFW/CEG/documents/ws022009/4-5.%20Programs%20for%20Deep%20Geological%20Repositories%20and%20Underground%20Labs/4.7%20Creation%20of%20DGR%20in%20Krasnoyarsk%20Region%20Engl.pdf ; accessed May 5, 2016 (NOTES: Figure 1, site locations, disposal sites; For the location of laboratory two sites were defined, namely: "Verkhneitatsky" (it includes two subsites – "Itatsky" and "Kamenny") and "Yeniseisky" (see Figure 1). "Yeniseysky" subsite 37 site for repository. Ages of rocks at the depths of underground facilities location are of more than 1800 million years; underground waters below 200 m are of 7 thousands of years and more. URL to ~500m bgl with 2 shafts planned for access. For meeting index and presentations, see https://www.iaea.org/OurWork/ST/NE/NEFW/CEG/ceg_ws022009%20.html; for presentation, see https://www.iaea.org/OurWork/ST/NE/NEFW/CEG/documents/ws022009/4-5.%20Programs%20for%20Deep%20Geological%20Repositories%20and%20Underground%20Labs/4.7%20Creation%20of%20DGR%20in%20Krasnoyarsk%20Region%20(presentation)%20Engl.pdf ; The Contact Expert Group for Nuclear Legacy Initiatives in the Russian Federation (CEG) worked under IAEA Waste Technologies Section auspices)

361) Jardine, L.J. 2005. *Development of a Comprehensive Plan for Scientific Research, Exploration, and Design: Creation of an Underground Radioactive Waste Isolation Facility at the Nizhnekansky Rock Massif*; UCRL-TR-213167; https://e-reports-ext.llnl.gov/pdf/321359.pdf ; accessed May 6, 2016 (NOTE: includes Final Report; See Figures 3.1-3.3, page 173, and Figure 3.9, Figure 4.4; English and Russian Versions of text; ISTC Partner Project #2377, "Development of a General Research and Survey Plan to Create an Underground RW Isolation Facility in Nizhnekansky Massif," funded a group of key Russian experts in geologic disposal, primarily at Federal State Unitary Enterprise All-Russian Design and Research Institute of Engineering Production (VNIPIPT) and Mining Chemical Combine Krasnoyarsk-26 (MCC K-26), and U.S. DOE-RW. International Science and Technology Center in The Russian Federation (ISTC) Partner Project was targeted to the creation of an underground research laboratory in Russian Federation; covers Verkhne-Itatsky and Yeniseisky sites)

Russian Federation: Repository and URL Investigations

362) Jardine, L., and T.A. Gupalon. 2001. *Geologic Repository Plan for Disposal of PU Containing and other Radioactive Materials in Russia* (UCRL-CR-146982 B512155); https://e-reports-ext.llnl.gov/pdf/241272.pdf ; accessed May 9, 2016 (NOTE: See Figure 8 for prospective sites 1-South; 2-Verchne-Itatsky; 3 –Nizne-Itatsky; 4-Telsky; 5 – Eniseysky; 6 – Kemenny; 7- Itatsky, all in Nizhnekansky rock massif; general area confluence of the Bolshoy and Maly Itat rivers; For Mayak area studies = VNIPIPT VNIPIpromtehno1ogii supported studies; several areas identified Figure 9; discusses underground borehole repository; key location illustrations, geology aspects)

363) Poluektov, P., L. Sukhanov, and T. Gupalo. 2005. The Status and Trends in the Area of Radioactive Waste Management in the Russian Federation; presentation to IAEA RW TEC group; https://www.iaea.org/OurWork/ST/NE/NEFW/documents/WATEC2005/Russia-SukhanovWATEC2005last.pdf ; (NOTE: Presentation material; chemical / radiological concerns / business / government radiochemical enterprise groups in Russian Federation; Siberian Chemical Combine (SCC) in Siberia; Mountain Chemical Combine (MCC) in Siberia; Production Association "Mayak" (PA 'Mayak"); RW disposal: suitable sites are investigated near the Kalinin, Leningrad and Kola NPPs); accessed May 9, 2016

364) Schweitzer, G. E., and A. Chelsea Sharber (Editors). 2005. *An International Spent Nuclear Fuel Storage Facility, Exploring a Russian Site as a Prototype; Proceedings of an International Workshop. Committee on the Scientific Aspects of an International Spent Nuclear Fuel Storage Facility in Russia;* Office for Central Europe and Eurasia Development, Security, and Cooperation Policy and Global Affairs; National Research Council Of The National Academies in cooperation with the Russian Academy of Sciences. The National Academies Press, Washington, D.C. http://www.nap.edu/openbook.php?record_id=11320&page=R1; http://www.nap.edu/openbook.php?record_id=11320&page=R5 ; (NOTE: see pp 143-151; Consideration of international high level waste repository to be located near the Priargunsk Mining-Chemical Production Association (City of Krasnokamensk, Chita Oblast); accessed May 9, 2016

364a) Rabung, T., D. García, V. Montoya, J. Molinero (eds.). 2013. Final Workshop Proceedings of the Collaborative Project ''*Crystallline ROCK Retention Processes" (7th EC FP CP CROCK), Karlsruhe, 14 – 16 May 2013*; Karlsruhe Institute of Technology Scientific Publishing; 310pp. www.cordis.europa.eu/pub/fp7/euratom-fission/docs/crock-final-workshop-proceedings_en.pdf {Note: See page 212, Figure 20; area locations approximate: 1) Yeniseisky 56.280516, 93.661598; 2) Itatsky 56.188, 93.9131; 3) Kemenny 56.15298, 93.9446}

Spain: ENRESA (Empresa Nacional de Residuos Radiactivos); testing, waste management

365) ENRESA (website accessed May 9, 2016). ENRESA (Empresa Nacional de Residuos Radiactivos); http://www.enresa.es/

366) OECD / Organisation for Economic Co-operation and Development, NEA / Nuclear Energy Agency. 2013 (website accessed May 9, 2016). *Radioactive Waste Management Programmes in Organization for Economic Co-operation and Development, Nuclear Energy Agency (OECD/NEA) Member Countries, Spain*, 2013; https://www.oecd-nea.org/rwm/profiles/Spain_profile_web.pdf (NOTE: Empresa Nacional de Residuos Radiactivos, S.A (ENRESA); work on the deep geological disposal option has been on-going since 1985)

367) World Nuclear Association (website accessed May 9, 2016). *National Policies, Radioactive Waste Management* - Appendix 3 (updated April 2013). http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Appendices/Radioactive-Waste-Management-Appendix-3--National-Policies/ ; (NOTE: Reference Spain and other countries)

Spain: El Berrocal natural analogue granitic system

368) Reyes, E., and L. Perez delVillar, A. Delgado, G. Cortecci, R. Nunez, M. Pelayo, J.S. Cozar. 1998. Carbonatation processes at the El Berrocal natural analogue granitic system Spain/: inferences from mineralogical and stable isotope studies. *Chemical Geology* 150 (1998); p. 293–315
http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=3&cad=rja&uact=8&ved=0CC8QFjAC&url=http%3A%2F%2Fwww.researchgate.net%2Fprofile%2FAntonio_Delgado_Huertas%2Fpublication%2F233883146_Carbonatation_processes_at_the_El_Berrocal_natural_analogue_granitic_system_%2528Spain%2529_inferences_from_mineralogical_and_stable_isotope_studies%2Flinks%2F02bfe50c86e2c340e5000000.pdf&ei=AjLuVMKSCoOkgwTW3ILgAw&usg=AFQjCNGPwDqOIH_CA5CYbg6SZSJyIa9-Vg ; accessed May 9, 2016 (NOTE: "…El Berrocal granitic pluton, which forms the hill upon which the site is located, at an altitude of 900 m a.s.l… The El Berrocal pluton is located at the central part of the Centro-Iberian Zone, in the Spanish Hercynian Massif (Julivert et al., 1972); near the contact between the Tajo River Tertiary basin and the Sierra de Gredos")

369) Gómez, P., et al. 2006. Hydrogeochemical characteristics of deep groundwaters of the Hesperian Massif (Spain); *Journal of Iberian Geology* 32 (1) 2006: 113-131. http://revistas.ucm.es/index.php/JIGE/article/viewFile/JIGE0606120113A/32799; accessed May 9, 2016 (Note: Reference P. Rivas et al. (Editors, and compiled by W. Miller) 1995. *El Berrocal project - Characterization and validation of natural radionuclide migration processes under real conditions on the fissured granitic environmen*t; Summary report on Phase 1; Report EUR 15908, European Commission, Nuclear Science and Technology, Luxembourg;
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0ahUKEwiuiLD517zNAhVk6oMKHUS9D0MQFgg1MAQ&url=http%3A%2F%2Fbookshop.europa.eu%2Fde%2Fel-berrocal-project-pbCDNA15908%2Fdownloads%2FCD-NA-15-908-EN-C%2FCDNA15908ENC_001.pdf%3Bpgid%3Dy8dIS7GUWMdSR0EAlMEUUsWb000062SJitml%3Bsid%3D1EIX_s-O-e8X9505rgiJWa2rdoFrrm1NqBI%3D%3FFileName%3DCDNA15908ENC_001.pdf%26SKU%3DCDNA15908ENC_PDF%26CatalogueNumber%3DCD-NA-15-908-EN-C&usg=AFQjCNG31L8_fB7zp6_OokUMDar4irOEkg ; accessed June 22, 2016

Sweden: SKB, Svensk Kärnbränslehantering AB; Swedish Nuclear Fuel and Waste Management Company

370) SKB / Svensk Kärnbränslehantering Svensk Kärnbränslehantering (website accessed May 9, 2016). http://www.skb.com/ (NOTES: Svensk Kärnbränslehantering AB, SKB, Swedish Nuclear Fuel and Waste Management Company; in 2011, SKB applied to the authorities for permission to build a repository for spent nuclear fuel in Forsmark; method selected means that the fuel is placed in copper canisters surrounded by bentonite clay about 500 metres underground in Swedish bedrock; selected site Short-lived Radioactive Waste, Spent Fuel Repository at Forsmark; plans for operating repository in 2030s)

Sweden: SKB – Spent Fuel Repository site selected; Forsmark, municipality of Östhammar

371) SKB (website, accessed May 9, 2016). "*How Forsmark was selected*"; http://www.skb.com/future-projects/the-spent-fuel-repository/how-forsmark-was-selected/ ; (NOTES: In 2009, SKB selected a site for the Spent Fuel Repository; location, Söderviken south-east of the Forsmark nuclear power plant, Forsmark in the municipality of Östhammar; planned initial construction work in 2020s)

Sweden: Äspö Hard Rock Laboratory (HRL)

372) SKB (website accessed May 9, 2016). *Äspö Hard Rock Laboratory*; http://www.skb.com/research-and-technology/laboratories/the-aspo-hard-rock-laboratory/, and http://www.skb.com/; SKB, The Swedish Nuclear Fuel and Waste Management Company (Note: Aspo underground hard rock laboratory at Äspö north of Oskarshamn; Aspo ~500m bgl; within Misterhult Archipelago close to the Oskarshamn NPP; survey work began in 1986; URL constructed 1990-1995; additions later; SKB's ; site chosen as Final Repository for Short-Lived Radioactive Waste is located at Forsmark in the municipality of Östhammar; see SFR, Forsmark Repository, SKB Final Repository for Short-Lived Radioactive Waste (SFR); http://www.skb.com/our-operations/sfr/ ; accessed May 9, 2016 SFR is located at Forsmark in the municipality of Östhammar; SFR is situated 50 metres below the bottom of the Baltic and comprises four 160-metre long rock vaults and a chamber in the bedrock with a 50-metre high concrete silo for the most radioactive waste. Two parallel kilometre-long access tunnels link the facility to the surface. Operations since 1988.)

373) Stanfors, R., I. Rhén, E. Tullborg, P. Wikberg. 1999. Overview of geological and hydrogeological conditions of the Äspö hard rock laboratory site; *Applied Geochemistry* Vol. 14, Issue 7, September 1999, p. 819–834; http://www.sciencedirect.com/science/article/pii/S0883292799000220 ; abstract accessed May 9, 2016 (NOTES: Äspö Hard Rock Laboratory, was excavated at a depth of 450 m below the island of Äspö; location maps, profiles; granitoids 1.4 Ga to 1.8 Ga; intrusions and dikes, 1 Ga; regional fracture zones; dates back to 1.85 Ga and is dominated by granitoids belonging to the Trans-Scandinavian Igneous Belt but also includes basic sheets and xenoliths and dikes of fine-grained granite. ~Seven tectonic episodes identified)

374) Zellman, Olle. 1995. Underground safety at the Äspö Hard Rock Laboratory, pp. 113-120, Chapter 11; In: *U.S. National Committee on Tunneling Technology, National Research Council, 1995, Safety in the Underground Construction and Operation of the Exploratory Studies Facility at Yucca Mountain*; National Academies of Science, Washington, DC; http://www.nap.edu/openbook.php?record_id=4897&page=113 ; accessed May 9, 2016 (NOTES: Äspö Hard Rock Laboratory (HRL), Sweden; safety oriented discussion; Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB, or SKB) duty to dispose of nuclear waste; Precambrian granites that are 1.7 billion to 1.8 billion years old; tunnel ~500m depth; 3 shafts; spiral tunnel access ramp; focus on plans. 57.432912, 16.661267 from Wikipedia)

375) Hardenby, C., Oskar Sigurdsson. 2010. *Äspö Hard Rock Laboratory: The TASS-tunnel, Geological mapping, R-10-35*; Svensk Kärnbränslehantering AB (SKB), Swedish Nuclear Fuel and Waste Management Co., Stockholm http://www.skb.se/upload/publications/pdf/R-10-35.pdf ; accessed last, July 29, 2015

376) SKB (Svensk Kärnbränslehantering). 2006. *The Aspo Hard Rock Laboratory* (accessed pdf online August 10, 2015); Swedish Nuclear Fuel and Waste Management Company, SKB AB, Svensk Karnbranslehantering , Stockholm; 12 pp; http://www.skb.se/upload/publications/pdf/Aspo_Laboratory.pdf ; (NOTE: 500m bgl; outside Oskarshamn; constructed between 1990 and 1995; used for location purposes)

377) Milnes, A.G. 2002. *Swedish deep repository siting programme: Guide to the documentation of 25 years of geoscientific research (1976–2000), Technical Report TR-02-18*; Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel, and Waste Management Co., Stockholm Sweden; 190pp. http://www.skb.se/upload/publications/pdf/tr-02-18.pdf ; accessed May 9, 2016 (Äspö HRL is constructed in granitoids of the Transscandinavian Igneous Belt (see Section 2.5) at a coastal site in southeastern Sweden. The main rock types encountered were medium grained quartz monzonites ("Äspö diorite") and adamellites ("Ävrö granite"), intersected by fine grained Småland granites; age granitic rock ~ 1.8Ga)

Sweden: Stripa mine Project

378) Andreson, B., and P.Halen. 1978. *Mining methods used in the underground tunnels and test rooms at STRIPA, Technical Project Report* No. 8; Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns in Crystalline Rock; LBL-7081, SAC-08, UC-70; Stallbergsbolagen, Ludvika, Sweden; http://www.escholarship.org/uc/item/28j3b3jp and http://escholarship.org/uc/item/28j3b3jp#page-1 ; accessed May 9, 2016 (NOTE: leptite, quartz banded hematite ore, 50% Fe; granitic body at depth)

379) Witherspoon, P., N. Cook, and J. Gale. 1980. *Geologic storage of radioactive waste: results of field investigations at STRIPA, Sweden*; LBL-11585; http://escholarship.org/uc/item/0gw815c9#page-1 (NOTES: studies conducted in crystalline rock ~340m bgl; mine depth to 410m bgl.; mine with banded hematite ore, high grade metamorphosed volcanic rock, Precambrian age; associated with intrusive body and dikes) accessed May 9, 2016

380) Sie, P.M.J., and S.K. Frape. 2002. Evaluation of the groundwaters from the Stripa mine using stable chlorine isotopes; *Chemical Geology* 182 Ž2002. 565–582; http://lrg.elte.hu/oktatas/Elemek%20korforgasa%20PhD/Kiraly%20Csilla%20Elemek%20korforgasa%20FClBrJ/Sie%20Frape%20Cl%20isotope%20study%20Stripa%20mine%20Sweden.pdf ; last accessed August 10, 2015 (NOTE: approximate location given: 59º43'N, 15º5'3"W; near Lindesbergs Museum 59.706771, 15.096450 exact location; evidence of mixing and stratification; old mine Stripa in Bergslagen - Sweden - Äntligen Vilse)

380a) Fairhurst, C., et al. 1993. *Stripa Project 1980-1992, Overview Volume I*, Executive Summary, Nagra Technical Report 93-41; https://www.nagra.ch/data/documents/database/dokumente/$default/Default%20Folder/Publikationen/NTBs%201991-1993/e_ntb93-41.pdf

Sweden: Forsmark facility siting

381) SKB (Svensk Kärnbränslehantering). 2012. *Site Investigation: Forsmark 2002–2007* (Edition 1, 2008; Edition 2, 2012); http://skb.se/upload/publications/pdf/Site_investigation_Forsmark_2002-2007.pdf ; accessed August 10, 2015 (NOTE: location information, geology summary; public involvement; access through SKB website online)

382) SKB / Svensk Kärnbränslehantering (website accessed May 9, 2016). *How Forsmark was selected*. http://www.skb.com/future-projects/the-spent-fuel-repository/how-forsmark-was-selected/ (Note: location determination; had choice between Forsmark in Östhammar

Municipality and Laxemar in Oskarshamn Municipality after 2 years site studies;; resolved with favor of Forsmark; SKB has chosen Forsmark, Östhammar Municipality as the site for the final repository for spent nuclear fuel; construction in 2020s)

383) Thegerström, Claes (SKB). 2010. Deep Geological Disposal of Nuclear Waste in the Swedish Crystalline Bedrock Nuclear Waste Management: from Public Perception to Industrial Reality; *American Association for the Advancement of Science Annual Meeting, San Diego, February 18-22, 2010*; https://ec.europa.eu/jrc/sites/default/files/jrc_aaas2010_waste_thegerstrom.pdf; accessed May 9, 2016 (NOTE: 12 slide presentation on Aspo, Forsmark, SFR; siting history; Forsmark repository in Östhammar Municipality location and graphics; site location approximated from slide as 60.399940, 18.183639

384) Swedish National Council for Nuclear Waste. 2011. *Nuclear Waste; State-of-the-Art Report 2011 — geology, barriers, alternatives*. Report from the Swedish National Council for Nuclear Waste, Stockholm 2011 (Translation of SOU 2011:14); Kärnavfallsrådet, The Swedish National Council for Nuclear Waste Report, Fritzes ett Wolters Kluwer-foretag, Stockholm 2011; http://www.karnavfallsradet.se/sites/default/files/SOU_2011_14.pdf.eng_.pdf ; accessed May 9, 2016

Switzerland: Nagra / National Cooperative for the Disposal of Radioactive Waste; Swisstopo; ENSI / Swiss Federal Nuclear Safety Inspectorate; waste management and facility siting

385) Nagra / National Cooperative for the Disposal of Radioactive Waste (website home, accessed May 9, 2016); http://www.nagra.ch/en (NOTES: National Technical Competence Centre in the field of deep geological disposal of radioactive waste; prepare and implement solutions for waste management and disposal; founded in 1972; In 2014, Swiss Federal Nuclear Safety Inspectorate (ENSI) okays continued investigations for repository siting; Nagra identifies two siting areas for a surface facility in siting regions Zürich Nordost and Nördlich Lägern; see http://www.nagra.ch/en/history.htm)

386) NAGRA / National Cooperative for the Disposal of Radioactive Waste (website accessed May 9, 2016). *Disposal where?* http://www.nagra.ch/en/locationareas.htm ; http://www.nagra.ch/en/disposalwhere.htm (Notes: sites and locations considered for surface and subsurface storage and disposal; geological siting regions for HLW, http://www.nagra.ch/en/hlwsitingregions.htm; National Cooperative for the Disposal of Radioactive Waste now considering two areas, Zürich Nordost (http://www.nagra.ch/en/hlwzuerichnordost.htm location ~ **47.639108, 8.647899) and** Jura Ost (http://www.nagra.ch/en/hlwjuraost.htm ; location ~ 47.490075, 8.146043) for stage 3 investigations; Swiss technical competence centre in the field of deep geological disposal of radioactive waste; best location map for the two areas considered. See References 167a and 168a and note for additional infrmation including: A) HLW repos, 400–900 m below the ground surface, Opalinus clay host; B) Test area URL planned; C) Stage 1 studies = 5 or 6 regions identified 2011 and approved. Site areas were: 1) North of Lägern (ZH, AG), 'Brauner Dogger', Opalinus Clay (HLW/L/ILW); 2) Jura Ost (AG), Opalinus Clay (HLW/L/ILW); 3) Jura-Südfuss (SO, AG), Effingen Beds, Opalinus Clay (L/ILW); 4) Zürich Nordost (ZH, TG), 'Brauner Dogger', Opalinus Clay (HLW/L/ILW); 5) Südranden (SH), Opalinus Clay (L/ILW), and 6) Wellenberg (NW, OW), Marl formations of the Helveticum (L/ILW). In Stage 2 siting work, reduced the number of siting regions to at least two for each repository type; eliminated Wellenberg; identified most suitable areas as Jura Ost and Zürich Nordost / selected; others remain possible sites for future evaluations.)

387) NAGRA / National Cooperative for the Disposal of Radioactive Waste (website accessed May 4, 2016). http://www.nagra.ch/en ; (NOTE: see also - Nagra since 2011; http://www.nagra.ch/en/history.htm ; siting evaluation continued for deep geologic repository; 2005, Nagra submission of a report outlining the options for siting a HLW repository; major events in siting and testing for Nagra to 2015)

388) Swisstopo / Federal Office of Topography (website home, accessed May 9, 2016); www.swisstopo.ch, www.swisstopo.admin.ch/internet/swisstopo/en/home.html

389) ENSI / Swiss Federal Nuclear Safety Inspectorate (website accessed May 4, 2016). *Waste management, radioactive waste*; http://www.ensi.ch/en/waste-disposal/ (NOTE: general information and links for ENSI activities)

390) ENSI / Swiss Federal Nuclear Safety Inspectorate (website accessed May 4, 2016). *Waste management, Deep geologic repositories*; http://www.ensi.ch/en/waste-disposal/deep-geological-repository/ (NOTE: siting process follows the "Sectoral Plan for Deep Geological Repositories", Reference 391, herein)

391) ENSI / Swiss Federal Nuclear Safety Inspectorate (website accessed May 4, 2016). *Sectoral Plan for Deep Geological Repositories (SGT), 2011*; website location Waste management, Deep geologic repositories, Sectoral Plan for Deep Geological Repositories, http://www.ensi.ch/en/waste-disposal/deep-geological-repository/sectoral-plan-for-deep-geological-repositories-sgt/#etappe1 (NOTES; references and links; areas under consideration include three siting areas in Opalinus clay for high-level radioactive waste (HLW): 1) North-east Zurich, Cantons of Zurich and Thurgau; 2) Nördlich Lägeren Region, Cantons of Zurich and Aargau; 3) Eastern Jura Canton of Aargau. For details see: Swisstopo. 2010. *Assessment of Collective Profiles and Derived Host Rocks, and Bases for the Derivation of Siting Areas in the Sectoral Plan for Deep Geological Repositories, ENSI Expert Report 33/067*, Swiss Federal Office Of Topography (Swisstopo), Wabern; http://www.ensi.ch/en/waste-disposal/deep-geological-repository/sectoral-plan-for-deep-geological-repositories-sgt/#etappe1, in German)

Switzerland: Mont Terri Rock Laboratory (argillite URL), Jura Canton, St-Ursanne

392) Bossart, P., 2009. *Swisstopo: URF Network, CS meeting, 20-21 April 2009* (IAEA-URF network, CS meeting, 20-21 April 2009). http://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/URF/documents/Status/2009/MS/Switzerland_swisstopo.pdf ; accessed May 9, 2016 (Note: Swisstopo discussion; organization; Mont Terri Project, Swisstopo slide presentation location Mont Terri Site location approximate 47.378493, 7.162601; location placed on map on ridge between tunnel opennings. off motorway tunnel with port north of St. Ursanne; gallery construction 1996-2008…; shale/argillite, sand and calcareous facies with fault encountered in drifts; Swisstopo sought association with IAEA URF group)

393) Mont Terri Project (homepage website, accessed May 9, 2016); http://www.mont-terri.ch/internet/mont-terri/en/homepage.html and http://www.mont-terri.ch; (NOTE: Opalinus clay; international studies; constructed off Mont Terri motorway tunnel, near St-Ursanne in the

Canton of Jura; URL is 300 m underground; Swisstopo funds the operation and maintenance; for page links, see geologic background http://www.mont-terri.ch/internet/mont-terri/en/home/geology.html; rock laboratory http://www.mont-terri.ch/internet/mont-terri/en/home/rock_lab.html ; situated in the Folded Jura; Opalinus Clay is around 180 million years old (Aalenian), Middle Jurassic rock series, Jura Mountain area; recognized by ammonite fossil species occurrence)

394) Jockwer, N., and Klaus Wieczorek. 2006. *Heater Test in the Opalinus Clay of the Mont Terri URL: Gas Release and Water Redistribution* (Contribution to Heater Experiment (HE); Rock and bentonite thermohydro-mechanical (THM) processes in the nearfield). Gesellschaft für Anlagenund Reaktorsicherheit (GRS) mbH. GRS 223. http://www.grs.de/en/content/grs-223-heater-test-opalinus-clay-mont-terri-url; http://www.grs.de/sites/default/files/pdf/GRS-223.pdf ; accessed May 9, 2016

395) Lisjak, A., B. Garitte, G. Grasselli, H.R. Müller, T. Vietor. 2015. The excavation of a circular tunnel in a bedded argillaceous rock (Opalinus Clay): Short-term rock mass response and FDEM numerical analysis. *Tunnelling and Underground Space Technology* 45 (2015) 227-248). http://dx.doi.org/10.1016/j.tust.2014.09.014 ; limited online access May 9, 2016 (NOTE: excellent graphics and descriptive text for test)

Switzerland: Grimsel Test Site, Underground Research and Development (crystalline URL, Aar Massif), Canton Bern

396) Grimsel Test Site / GTS (website accessed May 9, 2016). *Grimsel Test Site: underground research and development URL* (Information, Introduction) www.grimsel.com/ ; (NOTES: links; see also Nagra; in the granitic rock of the Aar Massif in Switzerland. It lies at a depth of around 450 metres bgl; reached by an access tunnel belonging to the Kraftwerke Oberhasli AG (KWO), the local hydro-power company; tunnel diameter ~3.5m; constructed 1983; also for location refer to http://www.grimsel.com/gts-information/about-the-gts/gts-location-a-visiting and for geology http://www.grimsel.com/gts-information/about-the-gts/geology-of-the-gimsel-test-site ; Aar Massif granites ~300Mya; deformed 40Ma; part of central Alp tectonic features; crystalline rock URL; location ~46.576602, 8.333629)

397) Nagra (website brochure accessed May 9, 2016). *The Grimsel Test Site: research on safe geologic disposal of radioactive waste*, brochure, http://www.grimsel.com/images/stories/pdfs/e_flg10.pdf (Note: Grimsel test facility is reached via the access tunnel of the Oberhasli AG hydropower plant (KWO); 450m bgl; established in 1984 for R&D; Nagra, National Cooperative for the Disposal of Radioactive Waste as operator; GTS located in granitic formations of the Aar Massif.)

398) *Grimsel Test Site: Brochures* (website and links accessed May 4, 2016). http://www.grimsel.com/media-and-downloads/grimsel-test-site-publications/grimsel-brochures (Note: Grimsel / other fact sheets / brochures; location map and summary material on tests and facility)

Taiwan: waste management, disposal

399) World Nuclear Association (website accessed May 9, 2016). *Nuclear power in Taiwan*; http://www.world-nuclear.org/info/Country-Profiles/Others/Nuclear-Power-in-Taiwan/ (NOTE: Players in program are Ministry of Economic Affairs, Atomic Energy Council, Taipower; Decisions on LLW and HLW disposal projects are pending; reprocessing agreements with France; geological repository in granite for high-level wastes is envisaged for 2055 operation; working with Sweden SKB)

400) Scheinman, L. et al. 2010. Nuclear Power and Spent Fuel in East Asia: Balancing Energy, Politics and Nonproliferation; *The Asia Pacific Journal: Japan Focus* (25-2-10, June 21, 2010); http://www.japanfocus.org/-ferenc-dalnoki_veress/3376 ; accessed May 9, 2016 (NOTES: recycling path; Taiwan power, waste, reprocessing, disposal options review / international repository, East Asia area)

401) Taiwan, Republic of China. 2004. *The Republic Of China National Report For The Convention On Nuclear Safety*; Atomic Energy Council, Executive Yuan, Taiwan, Republic Of China 2004; http://www.aec.gov.tw/english/nuclear/files/Taiwan_CNS_first.pdf ; accessed May 9, 2016 (NOTE: summary of nuclear management practice, Taiwan; siting power plant example, Article 17: discussions, storage, siting evaluation example; report for Convention on Nuclear Safety; Taiwan nuclear programs responsibility of Atomic Energy Council)

402) Liu, Wen-Chung. 2013. *Radioactive Waste Management in Taiwan*; Atomic Energy Council, Taiwan; Atomic Energy Agency, Taiwan. http://www.aec.gov.tw/webpage/policy/cooperation/files/index_02_1-05.pdf ; accessed May 9, 2016 (NOTE: slide presentation; HLW storage with goal of direct disposal)

403) Huang, Gillan Chi-Lun. 2012. *Environmental Justice And Public Participation: A Case Study Of Nuclear Waste Management And Policy In Taiwan*; University Of Newcastle Upon Tyne Faculty Of Humanities And Social Sciences School Of Geography, Politics And Sociology; 311pp., https://theses.ncl.ac.uk/dspace/bitstream/10443/1631/1/Huang%2012.pdf; accessed May 9, 2016 (NOTE: Environmental justice: site area EJ example; international waste management practices)

United Kingdom: Nuclear Waste management, siting, public participation

404) *Nuclear Decommissioning Authority / NDA* (website accessed May 9, 2016). http://www.nda.gov.uk/ (NOTE: homepage, publications; waste management responsibilities)

405) Radioactive Waste Management / RWM / UK. 2014. *National Geological Screening Report from Technical Event 30*. September 2014. RWM / UK; Radioactive Waste Management Limited (RWM)'s National Geological Screening Technical meeting, Geological Society, London, 30th September 2014. http://www.nda.gov.uk/publication/national-geological-screening-report-from-technical-event-30-september-2014/ ; last accessed August 11, 2015, now archived; (NOTES: Contained meeting presentation material; one of better summaries of siting and evaluation process, UK, international)

406) Defra (Department for Environment Food and Rural Affairs), BERR (Department for Business Enterprise and Regulatory Reform), the devolved administrations for Wales and Northern Ireland. 2008. *Managing Radioactive Waste Safely: A Framework for Implementing Geological Disposal* (a White Paper presented to Parliament);

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228903/7386.pdf ; http://www.official-documents.gov.uk/document/cm73/7386/7386.pdf ; accessed May 9, 2016 (NOTE: siting geologic repository facility and public participation example discussion)

407) Beale, H., and C. Mogg. 1993. Deep repository development - progress in the UK. *Proceedings of the Waste Management 1993 Conference Papers*, Vol. 1, p. 113-115; Waste Management Symposia http://www.wmsym.org/archives/1993/V1/24.pdf ; http://www.wmsym.org/archives/year.cfm?y=1993&v=1; accessed May 9, 2016 (NOTE: early plans for siting activities and evaluation)

408) Holton, D., et al. (AMEC). 2012. *Project Ankhiale: Disposability and full life cycle implications of high-heat generating UK wastes (*High-Heat Generating Wastes IPT Roadmap, Finalv2 NDA-RWMD-095 TN_18043), RWM Reports; 292pp. http://www.nda.gov.uk/publication/high-heat-generating-wastes-ipt-roadmap-finalv2-nda-rwmd-095-tn_18043/ ; and archived at http://webarchive.nationalarchives.gov.uk/20150817115932/http://www.nda.gov.uk/publication/high-heat-generating-wastes-ipt-roadmap-finalv2-nda-rwmd-095-tn_18043/ ; accessed November 21, 2016 (NOTE: Nuclear Decommissioning Authority (NDA) is responsible for planning and implementing geological disposal in the UK and has set up the Radioactive Waste Management Directorate (RWMD) for this purpose; generic investigation approach outlined; UK summary roadmap, 2012, for management and disposal of heat producing waste, glass waste HLW/SNF; generic disposal concepts; Project aims to enhance understanding of the factors affecting geological disposal of high-heat generating wastes)

United Kingdom: Sellafield Rock Characterization Facility, Cumbria (early plan of URL)

409) Allison, J.A. 1996. The RCF [Rock Characterisation Facility]: engineering issues. Proof of evidence; In: Haszeldine, R.S.; Smythe, D.K. (eds.); *Radioactive waste disposal at Sellafield, UK: site selection, geological and engineering problems*; Glasgow Univ., United Kingdom. Dept. of Geology and Applied Geology; 520 p; ISBN 0 852615 24 8; Worldcat; 1996; p. 371-402; University of Glasgow; Glasgow, United Kingdom. https://inis.iaea.org/search/search.aspx?orig_q=RN:28059940 ; abstract accessed May 9, 2016 (NOTE: uncertainties with the proposed construction by UK Nirex Ltd of an underground Rock Characterisation Facility (RCF) at a site in the Sellafield area)

410) Hooper, A.J., and J Mathieson. 1998. The role of underground research in the Nirex deep disposal programme; *Waste Management Symposium March 2-4, 1998, Tucson, AZ; Technical Session - International Radioactive Waste R&D Programs*; http://www.wmsym.org/archives/1998/html/sess45/45-05/45-05.htm (NOTE: NIREX summary brief; NDA formerly NIREX; Geological investigations conducted at two sites, Dounreay in Caithness, NE Scotland {see http://www.dounreay.com/ 58.578084, -3.747044 }, and Sellafield in Cumbria; underground research laboratory or Rock Characterisation Facility (RCF) was considered for construction at a site near Sellafield {near Longlands Farm, Gosforth area, plan of 1995; see http://www.jpb.co.uk/nirexinquiry/nirex.htm ; and http://www.westcumbriamrws.org.uk/documents/143-NDA_briefing_note_for_Geology_Information_Seminar.pdf , 2010 update}. Target host was basement rocks of the Borrowdale Volcanic Group. The Borrowdale Volcanic Group of rocks, Caradocian / late Ordovician (`450Mya), for the main galleries of the proposed RCF; average depth ~ 700m bgl; authority support lacking and project ceased)

United States: Department of Energy (DOE), Nuclear Energy (NE) links

411) US /DOE / United States *Department of Energy* (website, accessed May 17, 2016). www.energy.gov

412) US DOE *Office of Nuclear Energy* / NE (website accessed May 9, 2016). http://www.energy.gov/ne/office-nuclear-energy

413) US DOE *Fuel Cycle Technologies* / FCT (website accessed May 9, 2016). http://www.energy.gov/ne/nuclear-reactor-technologies/fuel-cycle-technologies

414) US DOE *Used Nuclear Fuels Disposition R&D* / UNFD (website accessed May 9, 2016). http://www.energy.gov/ne/fuel-cycle-technologies/used-fuel-disposition-research-development (Note: reference documents)

United States: Bedded and Domal Salt (pre-salt Vault, Salt Vault, Avery Island, WIPP, Deaf Smith), France (Amelie), Germany (Asse)

415) Kuhlman, K., and S.D. Sevougian. 2013. *Establishing the Technical Basis for Disposal of Heat-Generating Waste in Salt*; FCRD-UFD-2013-000233, SAND2013-6212; 86pp. http://energy.gov/sites/prod/files/2013/12/f5/EstablishTechnicaBasisHeatGenWasteInSalt.pdf ; accessed May 2, 2016 (NOTES: FEPS, testing summaries; Salt Vault, Experiments on the 300-m level of the Carey salt mine in Lyons, Kansas; ORNL testing in Hutchinson KS salt mine; U.S. Gulf Coastal Plain Jurassic-age salt upwelling through soft overlying sediments during Cretateous-Tertiary time resulting in domal salt formations; testing in Avery Island salt mine, near New Iberia, Louisiana; Mississippi Chemical Company (MCC) potash mine is located stratigraphically above the WIPP disposal horizon at approximately 350-m depth in the McNutt Potash zone of the Permian Salado Formation; Laboratory testing of core from Deaf Smith area, Palo Duro Basin, Texas; Amélie potash mine in France is located in the Upper Salt (Salt IV) unit of the Stampien Formation in the Upper Eocene-Lower Oligocene Mullhouse sedimentary basin; Asse facility near Wolfenbüttel in Lower Saxony (north-central) Germany; Asse is a former potash and salt mine, with a 100+ year history; testing at 490m – 800m bgl.)

416) Beckman, J.D. and Alex K. Williamson. 1990. Salt-Dome Locations In The Gulf Coastal Plain, South-Central United States; *U.S. Geological Survey, Water-Resources Investigations Report 90-4060*; accessed May 2, 2016; http://pubs.usgs.gov/wri/1990/4060/report.pdf (NOTES: Salt domes considered in 1970s-1980s by DOE; see Table 2: map code, salt-dome name, location, depth to salt and caprock, diameter and volume of salt domes, and sources of data)

417) ONWI / BMI (Battelle Memorial Institute). 1988. *Salt Repository Project Closeout Status Report*; BMI/ONWI/C--28; TI88 016839; Office of Nuclear Waste Isolation, Battelle Mem. Inst., Columbus, OH; http://curie.ornl.gov/system/files/documents/SEA/Salt_Repository_Project_Closeout.pdf and https://inis.iaea.org/search/search.aspx?orig_q=RN:20013108 ; accessed May 12, 2016 (NOTES: Avery Island (near New Iberia LA) testing at 168m / 550'depth bgl in domal salt, 1978-1984; Asse mine testing; Deaf Smith Co., TX ESF planned but project terminated before

implementation stage; repository site areas considered: YM, NV; Swisher Site, TX; Deaf Smith site, TX; Lavender and Davis Canyons, UT; Vacherie Dome, LA; Cypress Creek and Richton Domes, MS; Hanford Site.)

United States: Carey Salt mine, Lyons, Kansas; Project Salt Vault; early disposal studies

418) Robert Peltier, Robert. 2010 (July 9). *U.S. Spent Nuclear Fuel Policy: Road to Nowhere [Part II: Project Salt Vault];* Master Resource, a free market energy blog; https://www.masterresource.org/energy-policy/spent-nuke-fuel-policy-2/ and http://www.masterresource.org/2010/07/spent-nuke-fuel-policy-2/ accessed May 9, 2016 (NOTES: review of Project Salt Vault; Lyons Kansas, Carey Salt mine, radioactive source heat and impacts tested; mine operated 1890-1948; 1020' bgl; 1965 radioactive test materials emplaced; canisters delivered through shaft for handling and emplacement; 14 assemblies, 7 canisters; 19" diameter shaft for delivery; 1972 AEC withdrew from site)

419) Walters, R.F. 1978. Land Subsidence in Central Kansas Related to Salt Dissolution; Kansas Geological Survey, Bulletin 214; *Part I: Salt Deposits of Kansas: Regional Geology, Hutchinson Salt Member of the Wellington Formation;* http://www.kgs.ku.edu/Publications/Bulletins/214/03_salt.html ; websites accessed May 9, 2016 (Notes: multiple sites for document parts*;* for Localities = http://www.kgs.ku.edu/Publications/Bulletins/214/08_app.html; for Index and Executive Summary, http://www.kgs.ku.edu/Publications/Bulletins/214/index.html; mines used for HLW / SNF disposal testing fall within the Permian sequence, Hutchinson Salt Member of the Wellington Formation)

420) Bradshaw, R. L., J. J. Perona, and J. O. Blomeke, 1964. *Demonstration Disposal of High-Level Radioactive Solids in Lyons, Kansas Salt Mine: Background and Preliminary Design of Experimental Aspects*, ORNL/TM-734, Oak Ridge National Laboratory, Oak Ridge, Tennessee. http://web.ornl.gov/info/reports/1964/3445600507949.pdf ; accessed May 11, 2016 (Notes: Carey Salt Company Mine, Lyons, Kansas; thermal impacts tests; 14 fuel assemblies in 7 packages test planned; ~1000'bgl; planning document)

421) Bradshaw, R. L., and W. C. McClain, eds., April 1971. *Project Salt Vault: A Demonstration of the Disposal of High-Activity Solidified Waste in Underground Salt Mines*, ORNL-4555, Oak Ridge National Laboratory, Oak Ridge, Tennessee; 360pp. http://web.ornl.gov/info/reports/1971/3445600597245.pdf

422) Kansas Department of Health and Environment, Bureau of Environmental Remediation, Remedial Section. January 13, 2003. *Plugging the Old Lyons Salt Mine; Kansas Department of Health and Environment, Bureau of Environmental Remediation/Remedial Section State Water Plan Contamination Remediation Program*. http://www.kdheks.gov/ars/download/accomplishments/accomplyonsaltmine.pdf ; accessed August 11, 2015 (NOTE: Salt last produced in 1948; in 1890, 8 by 16-foot rectangular shaft to a depth of 1,024 feet; verify its relation to Carey Salt Mine, Lyons, KS; different Care)

423) Lomenick, T.F. 1996. *The Siting Record: An Account Of The Programs Of Federal Agencies And Events That Have Led To The Selection Of A Potential Site For A Geologic Repository For High-Level Radioactive Waste*, ORNL/TM-12940; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/27/063/27063469.pdf and -http://web.ornl.gov/~webworks/cpr/rpt/84706.pdf; accessed May 9, 2016 (Note: several areas rejected by KGS; 2 areas proposed for consideration in state, salt; U. Kansas, 1972; includes historical review of salt study locations, i.e., Kansas /New Mexico, and addresses 12 potential crystalline sites for second repository location; review of US disposal R&D; sites evaluated; WIPP, Lyons / Salt Vault, crystalline sites)

United States: Project Salt Vault, Mines and testing in Lyons (Rice Co.) and Hutchinson KS

424) Walters, R.F. 1978. *Land Subsidence in Central Kansas Related to Salt Dissolution; Kansas Geological Survey Bulletin 214*; Lawrence, KS; http://www.kgs.ku.edu/Publications/Bulletins/214/03_salt.html and www.kgs.ku.edu/Publications/Bulletins/214/index.html ; accessed May 11, 2016; (NOTE: KS bull. placed on web July 24, 2009; originally published February 1978; geology of Kansas, salt, mines, subsidence issues; Hutchinson Salt Member of the Permian Wellington Formation; AEC Test Hole No. 1--Sec. 26, T. 19 S., R. 8 W., Rice County, Kansas, Figs. 6,7; compare Carey Salt Company mine, Hutchinson, Kansas (38.045741, -97.870919) to Carey Salt mine, Lyons, Kansas Salt Shaft 1 borehole 38.3558583, -98.1934129; AEC contracted the coring of two holes at Lyons in 1970, designated as AEC Test Holes No. 1 and No. 2 (drilled 1970; TD ~1300', 1215.6', respectively); the shaft was mined to bed near the base of the salt, depth 1013 feet to 1024 feet in the Carey Salt Mine, was the cleanest and most minable bed (free of shale partings); Hutchinson salt member of Permian Wellington Formation; Carey Salt Company (Lyons) mine, inactive; standby status; Sec. 34, T. 19 S., R. 8 W; Rice County, Kansas; Carey Salt Mine Main Shaft hand dug 7' X 16' in 1889-1890; total depth 1083.5 feet; Section 34, few feet NW of Center of Section; salt deposits 806' to 1068'; Mine ceiling 9'; older areas 12'; floor of mine 1024'. AEC entry shaft, Carey Salt Mine, rotary drilled shaft, 1964; total depth 1060 feet; Section 34, C NE SW; AEC mine rooms; entry shaft for simulated radioactive waste containers, Project Salt Vault; mine floor at 1000'; ceiling 15'. ORNL report clarifies radioactive materials emplaced in 1965, terminated in 1967; location Section 34, T19S, R8W, Rice County, June 2016 best estimated location 38.354635, -98.193433 AEC drilled shaft. Additional references not available online from period include: i) University of Kansas, 1972. *Geology, Hydrology, Thickness, and Quality of Salt at Three Alternative Sites for Disposal of Radioactive Waste in Kansas*; Lawrence, Kansas. Not available online; proposed 2 added areas for future study; never explored; and ii) Bayne, C.K.; and Brinkley, Dwight, (eds.). 1972. *Geology, hydrology, thickness and quality of salt at three alternate sites for disposal of radioactive waste in Kansas*; Kansas Geological Survey; and Kansas University, Center for Research, Inc.; (for) U.S. Atomic Energy Commission; and Union Carbide Corp. Corporation, Nuclear Division, Oak Ridge National Laboratory, ORNL/SUB-3484/2; 63 pages (avail. as *Kans. Geol. Survey, Open-file Rept.*, no. 72-13; document not available online from KGS. Site A is located in south-central Lincoln County, Site D-2 located in south-central Wichita County, and Site A-1 located in north-western Lincoln County; areas west of Site A-1 and in south-central Harper County, in the reference authors' opinions, appear to be the best prospects for future study in Kansas. NTIS # ORNL/SUB/3484-2; however, sites fail to meet the criteria / guidelines concerning thickness and quality)

United States: Project Gnome, Salado Salt; Eddy County, NM

425) Rawson, D., C. Boardman, and N. Jaffe -Chazan. 1964. *Project Gnome: The Environment Created by a Nuclear Explosion in Salt*; PNE-107F; Lawrence Radiation Laboratory, Livermore, CA; http://www.osti.gov/scitech/servlets/purl/4612556 and http://www.osti.gov/scitech/biblio/4612556 ; accessed May 9, 2016 (NOTE: First nuclear test conducted for Plowshare Program, 1961, located south of Carlsbad, Eddy County, NM; 3.1 kiloton test, in bedded salt; 32°15′45″N 103°51′55.1″W; 32.262500, -103.865306 Google Maps and

Wikipedia.org location; 361m (1184’ bgl) in Permian Salado Fm. /salt; no data on shaft diameter; more literature search later is required; WIPP website states depth 1216’ bgl, http://www.wipp.energy.gov/science/ug_lab/gnome/gnome.htm ; Permian Salado Formation bedded salt)

426) Environmental Protection Agency. 1998. *Offsite Environmental Monitoring Report: Radiation Monitoring Around United States Nuclear Test Areas, Calendar Year 1996*, EPA-402-R-97-015; EPA, Las Vegas, Nevada; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/30/000/30000464.pdf ; accessed May 9, 2016 (Note: long term hydrogeological monitoring by DOE Legacy Management; Projects SHOAL and FAULTLESS sites in Nevada, Projects GASBUGGY and GNOME sites in New Mexico, Projects RULISON and RIO BLANCO sites in Colorado, and the Project DRIBBLE site in Mississippi; Gnome test in 1961)

United States: Climax Stock, Nye Co. NV; Nevada Test Site / Nevada National Security Site, NTS/NNSS (crystalline test, SNF / thermal / radiological / hydrological testing)

427) Allingham, J.W. and I. Zietz. 1961. *Geophysical Data on the Climax Stock, Nevada Test Site, Nye County, Nevada*; Report TEI-794. United States Geological Survey; http://pubs.usgs.gov/tei/794/report.pdf ; accessed May 9, 2016 (NOTE: Stock 1 mile in diameter at shallow level, increase with depth with estimated 6 miles diameter at 15,000’ depth; studied to prepare for weapons test in massive granitic body; granodiorite and quart monzonite {test utilized Piledriver shaft in 1970s; Cretaceous age later established}; 37.223937, -116.059557, Wikimapia)

428) Mariner, P., et al. 2011. *Granite Disposal of U.S. High-Level Radioactive Waste*, SAND2011-6203; Sandia National Laboratories, Albuquerque, NM; http://prod.sandia.gov/techlib/access-control.cgi/2011/116203.pdf ; accessed May 9, 2016; (NOTES: generic granite repository; summary of granite repository studies; URL at a depth of 420 m in the Climax monzonite stock; Table 1-3)

429) Patrick, W. C. 1986. *Spent-Fuel Test - Climax: An Evaluation of the Technical Feasibility of Geologic Storage of Spent Nuclear Fuel in Granite*. UCRL-53762 *Executive Summary of Final Results*. Lawrence Livermore National Laboratory, Livermore, California; 19pp.; http://www.osti.gov/scitech/servlets/purl/60116 ; accessed May 9, 2016 (NOTES: 1978-1983 testing; Spent-Fuel Test-Climax (SFT—C); demonstrate the feasibility of spent-fuel handling and to address technical concerns related to granitic rocks; located 420 m bgl; Climax stock quartz monzonite, Cretaceous; listing of reports produced for Climax tests; aka "Piledriver" site, since 1960s nuclear test hole into Climax stock was used in activity; 0.61m diameter emplacement boreholes drilled for fuel emplacement testing; Piledriver shaft provided access to 420m test level; 0.76m shaft also drilled for test)

430) Patrick, W. C. 1986. *Spent-Fuel Test - Climax: An Evaluation of the Technical Feasibility of Geologic Storage of Spent Nuclear Fuel in Granite*. UCRL-53702 final Report. Lawrence Livermore National Laboratory, Livermore, California http://www.osti.gov/scitech/biblio/60112-spent-fuel-test-climax-evaluation-technical-feasibility-geologic-storage-spent-nuclear-fuel-granite-final-report ; accessed May 12, 2016 (Note: Nevada Test Site (NTS) now Nevada National Security Site; OCRWM over sight of testing 1983-1986 with report products; 3 year fuel storage phase test; Climax Stock Cretaceous Quart Monzonite; Piledriver Shaft access; a summary report for companion report UCRL-53702, 1987)

431) Arnold, B.W., et al. 2013. *Deep Borehole Disposal Research: Demonstration Site Selection Guidelines, Borehole Seals Design, and RD&D Needs*; FCRD-USED-2013-000409, SAND2013-9490P; Sandia National Laboratories, Albuquerque (prepared for US DOE, UNFD), 221pp. http://www.mkg.se/uploads/DB/Deep_Borehole_Disposal_Research-Demonstration_Site_Selection_Guidelines_Borehole_Seals_Design_and_RD&D_Needs-Arnold_et_al-prepared_for_DOE_by_Sandia_National_Laboratories_FCRD_USED-2013-000409_SAND2013-9490P_Oct_25_2013.pdf ; accessed May 12, 2016; (NOTES: “Between 1978 and 1983, as part of the Spent Fuel Test – Climax project, a 420 m borehole was drilled into the granitic Climax stock at the Nevada Test Site to test the lowering, storage, and retrieval of canisters containing full-size commercial PWR used fuel assemblies (Patrick, 1986). A transport cask system was used to raise the canisters to the vertical position and lower them into the borehole where they resided for 3.5 years until retrieved. The study examined the effects of radiation, temperature, and drilling damage”… Spent Fuel Test – Climax project (Patrick 1986) as primary reference for section discussion)

432) Steinberg, R., and G. Fitzpatrick. 1971. *Selamic Holography for Underground Viewing*, Semiannual Technical Report, Bendix Research, Southfield Michigan; BRL Project 2411, Report 6050; http://www.dtic.mil/dtic/tr/fulltext/u2/734693.pdf ; accessed May 11, 2016 (NOTE: utilize Piledriver tunnel system and access hole in Area 15; Piledriver was 1400’ deep; Hardhat event and nuclear tests produced fracture systems; 1501 shaft in area; nuclear testing fractured bedrock 500-1000’ out from test locations; granite site evaluation discussions of many locations; reasons for selection of Climax for study; other crystalline sites summarized)

433) NNSA / National Nuclear Security Administration. 2005. *Nevada Test Site Guide*; DOE/NV-715, Rev.1; NNSA, National Nuclear Security Administration, Nevada Site Office, Las Vegas, NV (D. Scammel, editor); http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/doe%20nv%202001e.pdf ; accessed May 11, 2016; (Note: see pages 61-62, Hardhat and Piledriver tests; HardHat test, 1962, 5.7 kiloton test at 900’ depth; Piledriver test, 1962, 62 kiloton test, 1400’ depth; fuel emplaced, heated, monitored for up to 5 years)

434) NNSA / National Nuclear Security Administration. 2005. *Nevada Test Site Environmental Report 2005; Attachment A, Nevada Test Site Description*; DOE/NV/11718--1214, DOE/NV/25946—007; http://nnsa.energy.gov/sites/default/files/nv_sweis/appendixG/DOE%202006.pdf ; accessed May 11, 2016 (NOTE: see key Climax references; NTS renamed Nevada National Security Site)

434a) Case, J.B. and P.C. Kelsall. 1987. *Modification of Rock Mass Permeability in the Zone Surrounding a Shaft In Fractured, Welded Tuff*; SAND 86-7001; Sandia National Laboratories, Albuquerque, NM; http://www.nrc.gov/docs/ML0319/ML031990494.pdf ; accessed June, 2016 (Notes: see Nevada NNSS G-Tunnel, Edgar Mine CSM studies; also see http://www.mines.edu/EdgarMine)

United States: WIPP / Waste Isolation Pilot Plant; repository for TRU; URL function; Eddy County, New Mexico

435) DOE. 2007. *Waste Isolation Pilot Plant Geotechnical Analysis Report For July 2005 – June 2006*, March 2007; DOE/WIPP 07-3177, Volume 1; http://www.osti.gov/scitech/servlets/purl/925911-QaMGqa/ ; http://www.osti.gov/scitech/servlets/purl/925911 ; accessed May 11,

2016 {NOTES: Four shafts at WIPP: 1) Salt Shaft drilled 1981with nominal inside diameter to 880' of 10', and from 880'-2298' nominal diameter of 12'; 2) Waste Shaft, 6' diameter drilled '81/'82 and enlarged '83/'84 to diameter of 20-23' with 19' inner diameter liner to 837'bgl and from 900'-2286' ID of 23'; 3) Exhaust Shaft, drilled '83/'84, diameter from ~900'- 2150' / 655m is 15'; and 4) Air Intake Shaft, drilled '87/'88 to depth 903' with diameter of 16' and from 903'-2150' diameter of 20'.} WIPP is operated by Nuclear Waste Partnership LLC; http://www.nwp-wipp.com/ ; location 32.371667,-103.793611)

436) Likar, V.F., and W.R. Cooper. 1984. WIPP construction methods and progress. *Proceedings of Waste Management Conference, 1984*, V1, p. 257-260; Waste Management Symposia; http://www.wmsym.org/archives/year.cfm?y=1984&v=1 and http://www.wmsym.org/archives/1984/V1/43.pdf ; accessed May 11, 2016

437) Frobenius, P., et al. 1983. Exploratory Shafts and Underground Test Facility for the Waste Isolation Pilot Plant (WIPP), Chapter 23, p. 365-386; In: Sutcliffe, H., and J.W. Wilson (eds.), 1983. *Proceedings of the Rapid Excavation and Tunneling Conference, Volume 1, 1983 Rapid Excavation and Tunneling Conference*, Chicago, Illinois, June 12-16, 1983; American Institute of Mining, Metallurgical, and Petroleum Engineers, American Society of Civil Engineers); http://pbadupws.nrc.gov/docs/ML0404/ML040480468.pdf ; accessed May 11, 2016 (NOTE: see shaft description; 3 shafts, 1 exhaust shaft; early characteristics for facility shaft work; multiple articles presented here; see Crownpoint drilling also)

United States: WIPP, (Eddy Co.) NM; Project Salt Vault, Lyons, Kansas

438) Heaton, John. 2011. *Presentation to southern States Energy Board November 17, 2011, on behalf of Carlsbad, NM Department of Development*. http://www.sseb.org/downloads/Presentations/TRU/Heaton.pdf; accessed May 11, 2016; (NOTES: WIPP, ~650m, ~2150'; 1981-1989, main construction phase, WIPP; 1999 receive waste (TRU). Salt Vault experiments, 1965-1968; promoting Eddy Lea Energy Alliance / ELEA LLC; review of salt disposal, storage, favorable siting area; storage characteristics)

United States: Blue Ribbon Commission, repository, waste management, siting

439) Blue Ribbon Commission on America's Nuclear Future (L. Hamilton et al.). 2012. Appendix C, Status of Nuclear Waste Management Programs in Other Countries; In: *BRC Report to Secretary of Energy, Blue Ribbon Commission on America' s Nuclear Future and other parts – Report of the Blue Ribbon Commission on America's Nuclear Future* ; http://energy.gov/ne/downloads/blue-ribbon-commission-americas-nuclear-future-report-secretary-energy ; accessed May 12, 2016

United States: Texas waste management (Waste Control Specialists: licensed LLW disposal; licensing for HLW storage)

440) Radioactive Materials Division, Texas Commission on Environmental Quality. 2014. *Assessment of Texas's High Level Radioactive Waste Storage Options*; https://www.documentcloud.org/documents/1100389-tceq-assessment-of-texas-high-level-radioactive.html ; accessed May 12, 2016 (Note: Texas HLW management report 2014; general overview status HLW SNF storage and disposal, options. Also see WCS homepage, http://www.wcstexas.com/, for information on LLW disposal site and licensing for HLW disposal)

United States: Yucca Mountain, Nye County, Nevada; URL and Repository studies, waste management

441) DOE / Department of Energy. 2008. *Yucca Mountain License Application for Construction Authorization* (and 2009 Rev. 1 update). http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html ; accessed May 12, 2016 (NOTE: documents contain geologic information on various underground studies conducted for site characterization including repository area, and underground studies / URL/URF data for YM facility and reference materials to supporting technical basis document suite)

442) OCRWM/DOE (Office of Civilian Radioactive Waste Management / Department of Energy). 2000. *Natural Resource Assessment*, ANL-NBS-GS-00000 1 REV 00. MOL.20010406.0010. http://www.osti.gov/scitech/search/semantic:861092/filter-results:F and http://www.osti.gov/scitech/servlets/purl/861092**;** accessed May 12, 2016

United States: Repository testing and siting

443) Wynn, J.C. and E. H. Roseboom. 1987. Role of geophysics in identifying and characterizing sites for high-level nuclear waste repositories; *Journal of Geophysical Research*, Vol. 92, No. B8, PAGES 7787-7796, July 10, 1987; http://onlinelibrary.wiley.com/doi/10.1029/JB092iB08p07787/pdf ; accessed abstract May 12, 2016; (NOTE: originally nine candidate sites; of those, two candidate sites were identified in volcanic rocks on DOE reservations (one in basalts at the Hanford site, Washington, and one in ash flow tuffs at the Nevada Test Site), four were in bedded salt (two in the Paradox Basin, Utah, and two in the Palo Duro Basin, Texas), and three were in salt domes (two in Mississippi and one in Louisiana) [Smedes, 1982}. In December 1984, DOE announced that the Hanford Reservation in southeastern Washington State, Yucca Mountain at the Nevada Test Site in southern Nevada, and Deaf Smith County in the Permian Basin of Texas have been proposed for the detailed site characterization. Draft EAs published by DOE in 1983/84 and final EAs in 1986; Deaf Smith County in the Permian Basin of Texas)

United States: BWIP / Basalt Waste Isolation Project, testing and siting

444) Brandt, C. A., and W. H. Rickard, Jr., M.G. Hefty. 1990. *Interim Reclamation Report: Basalt Waste Isolation Project Exploratory Shaft Site*, PNL-7270**;** Pacific Northwest Laboratory, Battelle Memorial Institute**; Richland, WA;** http://www.osti.gov/scitech/servlets/purl/7027879 ; accessed May 12, 2016 (NOTES: Historical overview; shaft development plans outlined; Hanford Site lies within the Pasco Basin, the structural and topographic low part of the Columbia Plateau. ESF is situated within the Cold Creek Syncline, which is a low area between the Umtanum Ridge-Gable Mountain structure and the Yakima Ridge anticline; Near-surface facilities on Gable Mountain**;** ***Project*** **(*BWIP*),** Hanford Reservation, Washington; Basalt Waste Isolation Project (BWIP) work initiated in 1976; 1976-1982 testing and evaluation; The BWIP Site Characterization Report was published in November 1982; stop work; EA in May 1986 (some of summary notes are from EA, 1986); recommended as potential site; approved as candidate site 1986; work ceased with passage NWPA 1987. In 1982, ESF starter shaft drilled for first 30m of 1158m proposed; work stopped; 2.8m diameter shaft drilling planned)

445) DOE/OCRWM (U.S. Department of Energy / Office of Civilian Radioactive Waste Management). 1986. *Environmental Assessment, Reference Repository Location, Hanford Site, Washington*. DOERW-0070, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C; Vol. 1, 2, and 3.
http://curie.ornl.gov/content/nuclear-waste-policy-act-section-112-environmental-assessment-reference-repository-location Volume I;
https://curie.ornl.gov/system/files/Hanford_EA_Vol_1_HQZ.19870302.0324.pdf ;
http://curie.ornl.gov/content/nuclear-waste-policy-act-section-112-environmental-assessment-reference-repository-locatio-0 Volume II;
https://curie.ornl.gov/system/files/Hanford_EA_Vol_2_HQZ.19870302.0325.pdf ;
https://curie.ornl.gov/content/nuclear-waste-policy-act-section-112-environmental-assessment-reference-repository-locatio-1 Volume III
https://curie.ornl.gov/system/files/Hanford_EA_Vol_III__Part_3_MOL.19970207.0144_pgs_726-800.pdf ; accessed November, 2016

446) Gephart, R.E., and S. M. Price. 1983. Geohydrologic characterization and qualification of a high-level waste site in basalts. *Waste Management Symposium, Tucson, AZ (USA), 27 Feb - 3 Mar 1983*, Vol. 2, pp 151-158; American Nuclear Society; La Grange Park, IL (USA); http://www.wmsym.org/archives/1983/V2/26.pdf ; accessed May 12, 2016 (NOTE: BWIP aka Reference Repository Location; Hanford site underlain by basalt flows ~3000m thick; Grande Ronde Basalts with candidate host units of Cohassett, McCoy Canyon, and Umtanum basalt flows, ~900-1100m bgl; Columbia Plateau, Pasco Basin; Miocene Columbia River Basalt Group, ~17.5-6 mya; Yakima fold belt region; Cold Creek syncline depression)

447) Landon, R., and B. Bjornstad. 1986. *Preliminary Stratigraphic and Structural Model of the Reference Repository Location, Hanford Site*, SD(RHO)-BWI-TI-293, R0; Site Department, Rockwell Hanford Operations, Rockwell Hanford, Battelle Memorial Institute, Richland, WA; http://pdw.hanford.gov/arpir/pdf.cfm?accession=E0015559 ; accessed May 12, 2016 (Note: provides informative maps, profiles, geology, stratigraphy, regional structure illustrations; reference repository location illustration)

448) Westinghouse Hanford Company, Inc. 1988. *Basalt Waste Isolation Project, Near Surface Test Facility Reclamation Plan*. http://pdw.hanford.gov/arpir/pdf.cfm?accession=E0017772 ; accessed May 12, 2013 **(**NOTES: final EA which was issued on May 28, 1986, "Environmental Assessment, Reference Repository Location, Hanford Site, Washington" (DOE, 1986); Near Surface Test Facility (NSTF) constructed as part of the Basalt Waste Isolation Project (BWIP) underground laboratory for BWIP… The Near Surface Test Facility (NSTF) is located on the north face of Gable Mountain. Gable Mountain is located near the center of the Hanford Site. The area lies within the Pasco Basin, the structural and topographic low part of the Colombia Plateau, glacially related floods that inundated the Pasco Basin prior to approximately 13,000 years ago… Elevation at the Near Surface Test facility site is approximately 660 ft…. Gable Mountain is 11 mi. long and 1.5 mi. wide; three tunnels were excavated by standard practice; drill and blast underground mining method. Also refer to National Research Council. 1987. *Underground Engineering at the Basalt Waste Isolation Project*. National Academies Press, Washington, DC; Cohasset Formation host unit; shaft sinking initiated and discontinued with 1987 NWPA AA law implementation)

United States: testing and siting, crystalline program

449) Smedes, W. 1983. *A National Survey of Crystalline Rocks and Recommendations of Regions to Be Explored for High-Level Radioactive Waste Repository Sites, Technical Report, BMI OCRD-1*, Battelle; Columbus, OH. http://www.osti.gov/scitech/servlets/purl/6275533 ; accessed May 12, 2016 (Note: also see https://www.leg.state.mn.us/docs/pre2003/other/860910.pdf , State of Minnesota's review, 1986)

United States: Davis Canyon, San Juan County, Utah (with list and location of 1980s candidate sites)

450) DOE/OCRWM (U.S. Department of Energy / Office of Civilian Radioactive Waste Management). 1986. *Environmental Assessment of the Davis Canyon Site, Utah*, DOE/RW-0071 /0077, Volume (1 of 3); OCRWM, Washington, DC; https://babel.hathitrust.org/cgi/pt?id=uiug.30112048318676;view=1up;seq=3 (accessed May 12, 2016) and at curie.ornl.gov (NOTE: Davis Canyon and Lavender Canyon sites, Gibson Dome area, are ~2.4 km apart; ultimately, DOE concludes Davis Canyon is preferred site in Paradox Basin, favored over the Lavender site in same area; identified as one of five sites suitable for characterization; Mid-Pennsylvanian salt basinal units, Paradox Basin, , San Juan Co., UT; depth to salt 889m; DOE in 1983 identified 9 potentially acceptable sites to include
* = 1984 site selected for further study, site characterization
Deaf Smith Site, TX - Palo Duro / Permian Basin, Texas; bedded salt
Swisher Site, TX - Palo Duro / Permian Basin, Texas; bedded salt
Vacherie Dome, LA (1500m borehole); Gulf Coast; near Webster/Bienville parish line; ~545' dbgl to top salt.
Richton Dome, Mississippi (400m borehole); domal salt; Gulf Coast; salt top 722'bgl; Perry County
Cypress Creek Dome, Mississippi; domal salt; Gulf Coast; 1271bgl to salt
*Hanford Site, BWIP, Benton County, Washington – Volcanic / basalt (DOE property); Pasco Basin; Columbia Plateau; basement consists of Yakima Foldbelt structure (aka Reference Repository site); located ~46.60601,-119.538138
Davis Canyon, San Juan County, Utah – Pennsyl. Paradox Basin bedded salt; target depth, 2900', Paradox Formation; 38.11268,-109.654198
Lavender Canyon Utah – Pennsyl. Paradox Basin bedded salt; 38.068366,-109.626732
*Nevada Test Site (Yucca Mountain), Nevada – volcanic / welded tuff (DOE property); Nye County, NV; Great Basin
Later (1986) DOE had identified 5 sites suitable for characterization and 3 sites for characterization; then came the 1987 NWPA AA; also see Reference 423, Lomenick, 1996)

United States: Davis and Lavender Canyons, San Juan County, Utah

451) Duffy, Christopher J. and B. Hall. 1984. *Review and Evaluation of the Gibson Dome High Level Nuclear Waste Repository Environmental Assessment: Geohydrologic Issues (1984). Reports. Paper 507*; Utah Water Research Laboratory, Logan UT; http://digitalcommons.usu.edu/water_rep/507 ; and http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1506&context=water_rep ; accessed May 12, 2016 (NOTE: Paradox Basin hydrology focus)

United States: Vacherie Dome, Bienville/Webster Parish Line, LA

452) Kendorski, F. 1985. Geotechnical Review Of The Statutory Environmental Assessment (EA) For Vacherie Salt Dome Site, Webster and Bienville Parishes, Louisiana; Kendorski, Consulting Engineer, Downers Grove, IL; prepared for LA Dept. Environ. Qual.; 191 pp. http://pbadupws.nrc.gov/docs/ML0320/ML032050687.pdf ; accessed May 12, 2016 (NOTE: reasons dome not top candidate presented in review from outside perspective from available EA information; North Louisiana Salt Basin; Jurassic/Cretaceous and Tertiary diapirism)

United States: Gulf Coast salt domes

453) ONWI/BMI, Office of Nuclear Waste Isolation / Battelle Memorial Institute. 1981. *Evaluation of Area Studies of the U.S. Gulf Coast Salt Dome Basins - Technical Report*, March 31, 1981; ONWI-109 (Draft), Office of Nuclear Waste Isolation / Battelle Memorial Institute (ONWI/BMI), Columbus, OH; http://curie.ornl.gov/system/files/documents/SEA/Eval_Area_Studies_Gulf_Coast_Salt_Dome_Basins_part_1_NNA.19870407.0014-part_1.pdf ; last accessed August 24, 2015 (NOTES: Physiography and geologic information, for acceptable domes Vacherie, Cypress Creek, Lampton, Richton; domes proposed as excluded are Rayburn's, Keechi and Oakwood Domes (Rayburn's and others also included for discussion); Richton and Vacherie are favorable, and Richton as more favorable. Louann salt of Late Triassic / Early Jurassic age as salt source for domal formations.)

United States: Gulf Coast salt domes; geothermal gradient – LA TX MS Gulf Coast

454) ONWI/BMI, Office of Nuclear Waste Isolation / Battelle Memorial Institute. 1983. *Geothermal Studies of Seven Interior Salt Domes; Technical Report*, June 1983; ONWI-289, Office of Nuclear Waste Isolation / Battelle Memorial Institute (ONWI/BMI), Columbus, OH; http://igor.beg.utexas.edu/readingroom/fulltext.aspx?ID=56434; accessed May 12, 2016 (NOTES: BHT used for gradient / geothermal information, salt dome basinal areas; regional location information only; geologic profiles and geothermal gradient maps produced for each dome / area considered)

United States: Disposal in Salt (Avery Island, Asse II, Carey mines, WIPP)

455) Sevougian, S.D. et al. 2013. *RD&D Study Plan for Advancement of Science and Engineering Supporting Geologic Disposal in Bedded Salt: March 2013 Workshop Outcomes*; FCRD-UFD-2013-000161, R0, SAND2013-4386P; Appendix J, Salt R&D Workshop Presentations: see K. Kuhlman, Heated salt testing history, pp. 273-278; http://energy.gov/sites/prod/files/2013/08/f2/RDDStudyPlanDisposalBeddedSaltWkshpOutcome%20.pdf ; accessed May 12, 2016 (Notes: The history of testing in salt; DOE workshop held March 6-7, 2013; Kuhlman slide set covers: Kansas Carey salt mines; Avery Island, LA, testing '78 – '83, New Iberia, LA; Laboratory testing; Germany's Asse II, and WIPP, NM. In 1978 in situ heated salt tests began at the Avery Island salt mine for investigation of commercial HLW disposal in salt domes11. They performed long-duration (1858 days) heated borehole studies (up to 9.6 kW, see Figure 3), a set of three brine migration experiments (including deuterium-marked tracer studies), gas permeability studies of heated salt, and accelerated borehole closure (corejacking) tests.

United States: Bedded Salt (Avery Island, Iberia Parish, Louisiana; Asse II; Carey mines; WIPP)

456) Kuhlman, K. and Bwalya Malama. 2013. *Brine Flow in Heated Geologic Salt*; SAND2013-1944, March, 2013. Sandia National Laboratories, Albuquerque, New Mexico / Livermore, California; http://prod.sandia.gov/techlib/access-control.cgi/2013/131944.pdf and https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=23009028; accessed May 12, 2016 (Note: Thermal testing in Avery Island, ~550' bmsl; 1978; Kuhlman data, Ref. 455; location 29º 53' 43.53", -91º 54' 27"; 29.893891, -91.910105)

United States: Richton Dome, Perry County, Mississippi

457) DOE / OCRWM (U.S. Dept. Energy, Office of Civilian Radioactive Waste Management). 1986. *Environmental assessment overview; Richton Dome Site, Mississippi*; DOE/RW-0078; Dept. Energy, Office of Civilian Radioactive Waste Management, Washington, D.C.; http://curie.ornl.gov/content/environmental-assessment-overview-richton-dome-site-mississippi ; http://curie.ornl.gov/system/files/documents/SEA/Richton_Dome_Overview_HQZ.19870615.6671.pdf ; last accessed August 25, 2015 (NOTES: DOE found Richton Dome site is suitable for characterization. Figures show locations of Richton and Cypress Creek domes in south Mississippi; geologic profiles; Richton Dome site is 4km NW of the town of Richton in Perry County; For the 5 sites to be named, "DOE has decided to nominate the Richton Dome site as suitable for site characterization. The other potentially acceptable sites selected for nomination are Davis Canyon, Utah; Deaf Smith County, Texas; the reference repository location at the Hanford Site, Washington; and Yucca Mountain, Nevada."… "DOE has determined the three sites that are preferred for characterization. In alphabetical order, those sites are Deaf Smith County, Texas; the reference repository location at the Hanford site, Washington; and Yucca Mountain, Nevada." Represents status in 1986)

United States: Deaf Smith County site, Texas

458) DOE/OCRWM (U.S. Dept. Energy, Office of Civilian Radioactive Waste Management). 1986. *Environmental Assessment, Overview, Deaf Smith County Site, Texas*, DOE/RW-0075; DOE/OCRWM (U.S. Department of Energy, Office Civilian Radioactive Waste Management), Washington, D.C.; http://curie.ornl.gov/content/nuclear-waste-policy-act-section-112-environmental-assessment-overview-deaf-smith-county ; and http://curie.ornl.gov/system/files/documents/SEA/Deaf_Smith_County_EA__Overview.pdf ; last accessed August 27, 2015 (NOTE: Palo Duro Basin, Deaf Smith County, Texas; Permian San Andreas Formation (evaporites); preferred site over Swisher County site for Permian Basin / Palo Duro area; Deaf Smith site one of 5 nominated by DOE; Figure 2, excellent location information for site area; horizon of interest ~2400-2500' bgl; nominated as one of 5 sites suitable for characterization; additional reference not located online is: DOE *Site Characterization Plan, Deaf Smith County, Texas, Consultation Draft*, 10 Vol. DOE/RW-0162, U.S. Department of Energy, 1988)

459) DOE/OCRWM (U.S. Dept. Energy, Office of Civilian Radioactive Waste Management). 1986. *Environmental Assessment, Deaf Smith County Site, Texas*, Vol. I,2, DOE/RW-0069-Vol.1,2; DOE/OCRWM (U.S. Department of Energy, Office Civilian Radioactive Waste Management), Washington, D.C.; http://curie.ornl.gov/content/nuclear-waste-policy-act-section-112-environmental-assessment-deaf-smith-county-site-texas-0 ; and http://curie.ornl.gov/system/files/documents/SEA/Deaf_Smith_County_EA_Vol_1.pdf ; last accessed August 27, 2015 (NOTE: 2300-2500bgl for host unit location; see Volume 2, http://curie.ornl.gov/system/files/documents/SEA/Deaf_Smith_EA_Vol_2_HQP.19870601.1596.pdf ; and http://www.osti.gov/scitech/search/semantic:TI91017493/filter-results:F and http://www.osti.gov/scitech/servlets/purl/5578927 ; accessed May 12, 2016 2016; OSTI number TI91017493)

United States: Siting efforts, 1980's; candidate sites

460) DOE/OCRWM, U.S. Department of Energy, Office of Civilian Radioactive Waste Management. 1988. *Consultation Draft, Site characterization Plan Overview, Yucca Mountain Site, Nevada Research and Development Area, Nevada*. DOE/RW-0161, TI89 012574; U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C.; http://www.osti.gov/scitech/servlets/purl/60724 ; accessed May 12, 2016 (NOTES: "1. The Secretary of Energy has nominated five sites as suitable for characterization and has issued environmental assessments to accompany each nomination. 2. The Secretary has recommended three of the nominated sites for characterization as candidate sites for the first repository, and the President has approved the recommendation. The three sites are the Yucca Mountain site in tuff in the State of Nevada, the Deaf Smith County site in salt in the State of Texas, and the Hanford site in basalt in the State of Washington. **3.** The Secretary has made the preliminary determination that the recommended candidate sites are suitable for development as repositories.")

United States: Siting, 1970's / 80's; Salt domes (Locations)

461) Beckman, J.D., and Alex K. Williamson. 1990. *Salt-Dome Locations In The Gulf Coastal Plain, South-Central United States*; U.S. Geological Survey, Water-Resources Investigations Report 90-4060; Austin, TX.; http://pubs.usgs.gov/wri/1990/4060/report.pdf ; accessed August 27, 2015; (NOTES: Obtain latitude and longitude from Table 2 for Gulf Coast Domes to use in exercise. Approximate locations for Gulf Coast 8 domes examined by DOE after USGS, WRI90-4060, 1990, Table 2: Rayburn (32.24, -92.93); Vacherie (32.46, -93.18); Cypress Creek (31.14, -88.96); Lampton (31.22, -89.72); Richton (31.36, -88.95); Keechi (31.85, -95.70); Oakwood (31.56, -95.95); Palestine (31.74, -95.73; Lampton, Marion County, MS; Rayburn, Bienville Parish, LA; Vacherie, Webster/Bienville Parishes, LA; Cypress Creek, Perry Co. MS; Richton, Perry Co., MS; Keechi, Andreson Co., TX; Oakwood, Freestone-Leon Co. line, TX; Palestine, Anderson Co., TX)

462) Hart, Peter, and Johnson, R.L., et al. 1981. *Survey of Salt dome Investigations*; US Nuclear Regulatory Commission; 57pp. http://pbadupws.nrc.gov/docs/ML0405/ML040550357.pdf ; accessed May 17, 2016 (NOTE: survey, field guide information)

International: Underground program review, waste management, repository programs

463) ISAG (NEA Advisory Group on In-Situ Research and Investigations for Geological Disposal). 1987. *Geological Disposal of Radioactive Waste - In-Situ Research and Investigations in OECD Countries, A status report.* NEA/OECD. http://pbadupws.nrc.gov/docs/ML0320/ML032060325.pdf ; accessed May 12, 2016; (NOTE: historical review of repository concepts, underground testing activities, repository developments of member countries)

464) Martell, M., & Gianluca Ferraro. 2014. *Radioactive Waste Management Stakeholders Map in the European Union; JRC Science and Policy Reports, European Commission Report* May 2014; Report EUR 26692 EN; doi:10.2790/24752, ISBN 978-92-79-38648-0. Luxembourg: Publications Office of the European Union, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/radioactive-waste-management-stakeholders-map-european-union-report-may-2014?search and http://publications.jrc.ec.europa.eu/repository/bitstream/JRC90331/90331_final.pdf ; accessed May 12, 2016 (NOTES: maps of EU countries nuclear waste-related facilities)

465) Damveld, H. and Dirk Bannink. 2012. Management of spent fuel and radioactive waste: State of affairs a worldwide overview; In *Nuclear Monitor*, May 2, 2012, 746/7/8; WISE/NIRS; http://www.nirs.org/mononline/nm746_48.pdf ; accessed May 12, 2016 (NOTE: focus on policy, historical development work, disposal issues and plans)

466) Intera / EPRI. 2010. *EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste: Volume III—Review of National Repository Programs.* EPRI, Palo Alto, CA: 2010. 1021614; prepared by Intera for EPRI (Electric Power Research Institute); http://cybercemetery.unt.edu/archive/brc/20120620234107/http://brc.gov/sites/default/files/documents/1021614.pdf ; last accessed August 11, 2015 (Note: See Reference 186b)

Russian Federation: NORAO - operator and management

467) NORAO (website accessed May 12, 2016). *National Operator for Radioactive Waste Management* (The Federal State Unitary Enterprise) http://www.norao.ru/eng (NOTE: NO RAW has been specified as the National Operator for handling nuclear waste materials and single organization authorized to carry out final disposal of radioactive waste (RAW); ROSATOM is the RF business management, investments, R&D organization for nuclear industries and enterprise.)

Russian Federation: siting URL and HLW repository; Krasnoyarsk Krai

468) Anderson Ye. B., and Ye. F. Lyubtseva, V. G. Savonenkov, S. I. Shabalev, N. L. Alekseev. 2005. Creation of an Underground Storage Facility for Spent Nuclear Fuel near the City of Zheleznogorsk (Eastern Siberia). *In*: Glenn E. Schweitzer and A. Chelsea Sharber (Editors). 2005; pp. 156-176, Chapter 19. *An International Spent Nuclear Fuel Storage Facility, Exploring a Russian Site as a Prototype; Proceedings of an International Workshop*. Committee on the Scientific Aspects of an International Spent Nuclear Fuel Storage Facility in Russia; Office for Central Europe and Eurasia Development, Security, and Cooperation Policy and Global Affairs; National Research Council Of The National Academies In cooperation with the Russian Academy of Sciences. The National Academies Press, Washington, D.C. http://www.nap.edu/openbook.php?record_id=11320&page=R5 ; accessed May 17, 2016 {NOTE: map potential site areas Nizhnekansk massif; Nizhnekansky Massif, Russia, K-26 area; Figure 3 illustrates location of the most promising area sites, Itatsky, Kamenny, Yenisei site; Fig.4 site locations. Estimated locations, (Nizhnekanskiy Massif near Altay-Sayan Orogenic area, West-Siberian/Siberian Platform contact zone. 1) Yeniseiskiy site area, 56.338241, 93.659369, Zheleznogorsk, Krasnoyarsk Krai (priority site), Russia; 2) Itatskiy Site 56.193032, 93.992145, Beryozovsky District, Krasnoyarsk Krai, Russia; 3) Kamennyi Site 56.141345, 94.001318, Uyarsky District, Krasnoyarsk Krai, Russia}

Republic of Korea: Repository roadmap

469) Jee-yeon, Seo. 2016. Korea releases 1st roadmap to build facility for spent nuclear fuel; *The Korea Herald*, May 25, 2016 (website); http://www.koreaherald.com/view.php?ud=20160525000823 ; accessed May26, 2016 (Notes: Korea will select a site for an underground storage

facility to permanently dispose spent nuclear fuel, or high-level radioactive waste, by 2028 and complete the construction of the facility by 2053, according to the first roadmap for the project released by the Ministry of Trade, Industry and Energy on May 25th. Ministry of Trade, Industry and Energy / MOTIE, Office of Energy and Resources. *Korea Times* reported Korea will be looking at international disposal options, such as Australia proposal for host repository, http://www.koreatimes.co.kr/www/news/biz/2016/05/488_205511.html ; see reference 469a)

469a) Nuclear Fuel Cycle Royal Commission, Government of South Australia. 2016. *Nuclear Fuel Cycle Royal Commission's Report, May 2016*. Government of South Australia; http://yoursay.sa.gov.au/pages/nuclear-fuel-cycle-royal-commission-report-release/ and http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf (Note: South Australia examination of geologic disposal; summary information; safety case and examples)

469b) Nuclear Fuel Cycle Royal Commission (website accessed October, 2016). *South Australia*. http://nuclearrc.sa.gov.au/

469c) South Australia's Citizens' Jury. November, 2016. *South Australia's Citizens' Jury (Two) on Nuclear Waste Final Report*. http://assets.yoursay.sa.gov.au/production/2016/11/06/07/20/56/26b5d85c-5e33-48a9-8eea-4c860386024f/final%20jury%20report.pdf , and http://nuclear.yoursay.sa.gov.au/ , and http://assets.yoursay.sa.gov.au/production/2016/11/06/07/20/56/26b5d85c-5e33-48a9-8eea-4c860386024f/final%20jury%20report.pdf ; (Note: The report was a key input to the Governments response to the Royal Commission Report at the end of the year.)

469d) Case, J.B. and P.C. Kelsall. 1987. *Modification of Rock Mass Permeability in the Zone Surrounding a Shaft In Fractured, Welded Tuff*, SAND 86-7001; Sandia National Laboratories, Albuquerque, NM; http://www.nrc.gov/docs/ML0319/ML031990494.pdf ; accessed June, 2016 (Notes: see Nevada NNSS G-Tunnel, Edgar Mine CSM studies; also see http://www.mines.edu/EdgarMine . As with Edgar mine, ROK seeks understanding of engineered disturbed zone. CSM Edgar location in mountains above Idaho Springs and the nearby communities of Black Hawk, Central City and Georgetown. Mine location, 39.747284,-105.525328)

Bulgaria: Potential Repository Sites

469e) Karastanev, D. 2016. Site Selection Approach to Geological Disposal of High-Level Waste in Bulgaria (Chapter 3). In: B. Faybishenko, J. Birkholzer, D. Sassani, and P. Swift (editors), *International Approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation; Fifth Worldwide Review*, LBNL-1006984; Lawrence Berkeley National Laboratory, Sandia National Laboratories; https://www.osti.gov/scitech/servlets/purl/1353043 and https://eesa.lbl.gov/wwr5/ (Note: see References 167a, 168a)

469f) Eco Energoproekt Ltd., OOD. 2015. *Environment Impact Assessment (EIA) Report On Investment Proposal, Construction Of National Disposal Facility For Low And Intermediate Level Radioactive Waste – NDF, Part I, Anotation of the Investment Proposal For Construction, Activities And Technologies of NDF*; Eco Energoproekt Ltd. prepared for State Enterprise "Radioactive Waste"; Sofia, Republic of Bulgaria, January, 2015 (Note: Weblink for document was not found, but several for non-technical summary are accessible. Document includes Environmental Impact Assessment Report (EIAR) for the Radiana site / Kozloduy ILW/ LLW GDF and covers other sites of interest. The SE "RAW" is assigned construction responsibilities for DGR NDF for disposal of low and intermediate active waste; news release from SERAW indicates construction authorized 6/2017; see http://dprao.bg/en . Additional information also found at http://www.wmsym.org/archives/2014/papers/14291.pdf)

Table 3 References (# 470 – 609f) and Notes Supporting Map Layer 3 (Boreholes)

Deep Borehole Disposal: General

Primary General References (470-492) for Map Layer 3 and Table 3

470) Beswick, J. 2008. *Status of technology for deep borehole disposal*. Technical Report, EPS International Contract No. NP 01185, EPS International, 2008, Rev 7 (for Nuclear Decommissioning Authority / NDA). 91 pp. http://www.mkg.se/uploads/DB/NDA_Status_of_Technology_for_Deep_Borehole_Disposal_April_2008.pdf ; accessed March 22, 2016 (NOTE: See reference 491. Important points from deep borehole summary material. *Key well: KTB well TD 9101m, 6.5" drilled diameter; 8729m depth, drilled diameter 8.5"; 6018m, drilled diameter 14.75"; report includes drilled hole and shaft discussions, other lessons learned and examples:

> *SHAFTS: Shafts up to 5 m in diameter and greater drilled. Pioneering work in shaft drilling was driven by the underground nuclear explosive testing programmes which started in 1957. A 4.4 m diameter shaft was drilled to 0.75 km in the Agnew area in Western Australia which was completed in 1982 and more recently (date unknown) a 5.8 m diameter shaft was drilled to 0.52 km in Australia. *Blind shaft drilling. Betws Colliery in South Wales undertaken by Pigott Shaft Drilling in the early 1980s; the shaft was drilled and cased to 0.22 km at 3.75 m diameter in a single pass. *Radioactive waste study: Sellafield and Dounreay in the 1990s with boreholes up to 2 km deep, a final diameter of 159 mm (6.25 in). *The shaft drilling industry: has adopted a simple mud system using water or light mud with reverse circulation and air lift system. Typically a 340 mm diameter drill pipe is used with a concentric 178 mm pipe to provide the facility to both recover the drilling fluid in a reverse circulation arrangement and to create the air lift in the return line. Water or drilling mud is circulated between the outer pipes and the casing or borehole wall, across the bit cutters to remove the cuttings and is *'sucked'* to the surface through the drill pipe by an air lift. *Military (DOE/AEC): The US Government drilled 550 big holes totaling 320 km in length at diameters ranging from 1.22 m to 3.66 m with some opened to 6.4 m to depths of 0.15 km to 1.5 km primarily in Nevada. Drilling rates ~ 30 m per day in the soft rocks [Rowe 1993]. The deepest 3 m diameter drilled hole is thought to be the 1.68 km UC-4 hole drilled in Hot Creek Valley in south central Nevada for the US Atomic Energy Commission drilled in about 1967 for a nuclear test detonation. The deepest 2.28 m shaft is the 1874 m (possibly 1905 m depending on the reference) deep UA-1 hole on Amchitka Island in the Aleutians as part of the US AEC program, ~1969-1970. *Beswick Figure 4.1 and related text, technical capabilities: 1) The Basel well had a final diameter of 251 mm, was the first well other than the KTB well drilled to a bottom hole diameter size greater than 216 mm in the crystalline basement. 2) A 300 mm diameter option to 4 km or 5 km is probably achievable now. 3) In the Swedish case, the review for SKB [Harrison 2002] suggested that an 800 mm diameter hole to 4 km *may* be possible in the strong relatively homogeneous granite with few fractures. 4) Diameter of 800 mm could be drilled to 4 km in the context of the Swedish geology; it represents one of the most challenging projects ever... 5) At the Gravberg-1 deep gas well, Sweden, the top 4 km was drilled with water in 311 mm diameter before borehole instability precluded further drilling without weighted drilling fluid. 6) The 750 mm case starts to deviate significantly from current experience and equipment probably below 2 km. Need for significant tool and drilling process development. 7) The 1000 mm diameter case is well outside current experience or anticipated borehole development in the future except for a relatively shallow borehole. It is considered technically impracticable in the foreseeable future to drill such a large diameter borehole to 4 km….deep disposal boreholes to 5 km in large diameters of 750 mm and 1000 mm clear diameter are high risk and too far outside the practicable envelope. 8) Beswick Table 5.1: Classification of deep borehole feasibility and related text, technical capabilities: ***Examples –** Borehole in Pennsylvania drilled to ~1.2 km in ~ 2000 CE; 620 mm (24 in diameter hole) from 693 m to 1,188 m with 508 mm (20 in) casing; is the deepest large diameter borehole ever drilled with a down-the-hole hammer system. The borehole was drilled through shales, sandstones and limestone for gas storage using a Numa's Champion 240 hammers and special polycrystalline diamond (PCD) carbide bits. The PCD carbide bits are reported to be three to five times harder, 100% more wear resistant … than a standard carbide bit [NUMA 2001].)

471) NIREX. 2004. June 2004; *A Review of the Deep Borehole Disposal Concept for Radioactive Waste*; Nirex Report no. N/108; United Kingdom Nirex Limited; 78pp; http://webarchive.nationalarchives.gov.uk/20150817115932/http://www.nda.gov.uk/publication/a-review-of-the-deep-borehole-disposal-concept-for-radioactive-waste-nirex-report-n108-june-2004/ ; http://www.mkg.se/uploads/Nirex_Report_N_108_-_A_Review_of_the_Deep_Borehole_Disposal_Concept_for_Radioactive_Waste_June_2004.pdf ; accessed March 22, 2016 (Note: NIREX Table 3 identifies wells in crystalline basement of note; summary of early projects and recent work in or by: US, Nagra /Swiss, Denmark, SKB Pass Project. Examples from source: Gravberg-1; Russia's Kola and Tyrnauz boreholes, and Ukraine Krivoy Rog boreholes; NIREX Table 3 lists deep wells, year spud, depth; it references NEDRA (SKB) study that summarizes deep borehole work; Russia's Kola well 12261m in Proterozoic meta-volcanic-sedimentary rock; Krivoy Rog well 5000m, in Ukraine within Proterozoic / Archean metasediments and other; Tymauz borehole, 4001m TD in 2my granite; drilling design and economic options; PASS study borehole drilling options; Pu disposal and the USA; cost and issues with various options. Update = Management of geologic disposal programs in UK: NIREX, Nuclear Industry Radioactive Waste Executive became United Kingdom Nirex Limited, and integrated into the UK Nuclear Decommissioning Authority, or NDA, in 2007. For core information, see http://data.gov.uk/dataset/nirex-rock-cores-and-core-samples-from-deep-boreholes website)

472) von Hippel, D., and P. Hayes. 2010. *Deep Borehole Disposal of Nuclear Spent Fuel and High Level Waste as a Focus of Regional East Asia Nuclear Fuel Cycle Cooperation*. Nautilus Institute; 47pp. http://nautilus.org/wp-content/uploads/2012/01/Deep-Borehole-Disposal-von-Hippel---Hayes-Final-Dec11-2010.pdf ; accessed March 22, 2016 (NOTE: general information, geopolitical aspects also discussed)

473) Schlumberger Data and Consulting Services. 2004 (2005, Rev). *Benchmarking Deep Drilling*; Schlumberger Data and Consulting Services, Pittsburg, PA; 151pp. http://www.netl.doe.gov/kmd/cds/disk11/pdfs/benchmark.pdf ; accessed March 23, 2016 (NOTE: Prepared for DOE Office Fossil Energy. US wells 15000' plus; groupings by operators and types, USA / Canada; technology and cost. Deep Trek Project. Used DOE HIS database, wells in US. Report that Pinnacle Technologies studied well completions below 15000' to avoid duplication of effort; selected data set of deep wells with TVD drilled 1997-2001, Table 3; Table 2 lists 15000' wells by basin, geology; attempt to find database of wells used for study; Schlumberger revised report in 2005 for NETL DEEP TREK project)

474) Beswick, A.J., F. Gibb, and K. Travis. 2014. Deep borehole disposal of nuclear waste: engineering challenges; Paper 1300016; 20pp.; *Proceedings of the Institution of Civil Engineers*, *Energy*, Volume 167, Issue 2, April 2014, pages 47–66; ICE Publishing; http://www.mkg.se/uploads/DB/Deep_borehole_disposal_of_nuclear_waste-engineering_challenges_Beswick_Gibbs_Travis_Proceedings_of_the_Institution_of_Civil_Engineers_April_2014.pdf ; and http://www.icevirtuallibrary.com/content/article/10.1680/ener.13.00016 ; accessed March 22, 2016 (Note: 1983/1984, a 3810 m (Magoun 1) deep hole was drilled and a string of 0.508 m (20 in) casing installed in the 0.66 m (`26") diameter hole to a depth of 3800 m in Louisiana, with an internal drift diameter of 0.462 m (see Reference 527). KTB hole developed 12.25" diameter to 8328m depth; a deep geothermal well designed by Beswick was completed in Switzerland in 2007 to a depth of 5 km with a diameter at TD of 251 mm (9.875 in) with a penetration of 2.4 km into the crystalline basement in the Rhine Graben structure; Kola well drilled in the Murmansk peninsula in the former USSR (Russia) into the Baltic Shield eventually achieved a depth of 12.22 km with a 215 mm (8.50 in) final diameter; the KTB superdeep borehole in Bavaria drilled from 1990 to 1994 was drilled to 9.1 km with a final diameter of 165 mm (6.50 in). For nuclear test holes drilled for US AEC, the deepest 2.28 m shaft is the 1874 m (possibly 1905 m depending on the reference) deep UA-1 hole on Amchitka Island in the Aleutians as part of the US Atomic Energy Commission programme in 1969-1970 period. The US Government drilled 550 big holes totaling 320 km in length at diameters

ranging from 1.22 m to 3.66 m with some opened to 6.4 m to depths of 0.15 km to 1.5 km primarily in Nevada; The deepest 3 m diameter drilled hole is thought to be the 1.68 km UC-4 hole drilled in Hot Creek Valley in south central Nevada for the US Atomic Energy Commission drilled in about 1967 for a nuclear test detonation.)

474a) Beswick, J. 2017. Borehole construction and operation for disposal in crystalline rock; *Radwaste Solutions*, Vol. 24, No. 1, Spring 2017, pp. 28-32; American Nuclear Society

United States: Subsea drilling technologies / NPC and ERD

475) National Petroleum Council. 2011. *Subsea Drilling, Well Operations And Completions; Paper #2-11* (Working Document of the NPC North American Resource Development Study, Offshore Operations Subgroup of the Operations & Environment Task Group, Subsea Drilling, Well Operations and Completions); pp. 1-45; http://www.npc.org/prudent_development-topic_papers/2-11_subsea_drilling-well_ops-completions_paper.pdf ; accessed April 21, 2016 (NOTE: See Figures 6, and figure in B. Appendix 2; covers extended reach drilling characteristics; deep water technologies; deep well information captured in References 470, 474, Beswick)

Uruguay: Raya-1; drilling technologies

475a) Schuler, M. April 1, 2016. Maersk Drillship Spuds World's Deepest Well; gCaptain (a maritime and offshore website); http://gcaptain.com/maersk-venturer-begins-drilling-worlds-deepest-well/ (Note: Raya-1 prospect, is being drilled offshore Uruguay in a water depth of 3,400 meters (11,156 feet)... The well is being drilled by the Maersk Venturer drillship for a consortium involving Total SA and ExxonMobil. The previous record for world's deepest well by water depth was held by Transocean's ultra-deepwater drillship Dhirubhai Deepwater KG1. The well was drilled in 2013 off the east coast of India in water depths of 3,174 m (10,411 feet). Later reports state Block 14 Raya-1 well plugged and abandoned; non-commercial. Approximate rea location -36.1062, -52.8947; also see http://www.spectrumgeo.com/press-release/exxon-and-total-join-forces-to-drill-uruguays-1st-offshore-record-breaking-deep-water-well)

India: India's Oil and Natural Gas Corporation Limited (ONGC) ultra-deep water drilling Technologies

475b) Cheang, Chee Yew. 2013. Transocean Sets World Record for Deepwater Drilling Rigzone, News website, July 9, 013; http://www.rigzone.com/news/oil_gas/a/127610/transocean_sets_world_record_for_deepwater_drilling .
(Note: Transocean drillship Dhirubhai Deepwater KG1 set a new world record for the deepest water depth by an offshore drilling rig; drilled a well in 10,411 feet (3,174 meters) water depth while working for India's Oil and Natural Gas Corporation Limited (ONGC), India. ONGC well # 1-D-1 in Exploratory Block KG-DWN-2005/1 was spud June 18, 2013; # 1-D-1 is the third well to be drilled beyond the 10,000 feet water depth. In May 2016 - India's ONGC still held the current record at 3174m deepwater offshore. Krishna-Godavari Basin (Basin area location approximate: 16.6359, 83.1591)

Russian Federation: Sakhalin-1 Project; deep water and extended reach drilling technologies

475c) World Oil (News, 4/14/2015). Sakhalin-1 sets new extended reach drilling record, Rosneft says; http://www.worldoil.com/news/2015/4/14/sakhalin-1-sets-new-extended-reach-drilling-record-rosneft-says (Note: Exxon lead consortium Sakhalin-1 Project, Sea of Okhotsk, off the northeastern coast of Sakhalin Island, Russian Federation; ExxonNeftgas operator. Since 2011, several extended reach drilling records; Chayvo, Odoptu, and Arkutun Dagi offshore fields; e.g., in 2015, Rosneft drilled well O-14 from platform to Chayvo field, measured depth 13,500m and horizontal reach of 12,033m; in 2013, Z-42 well measured depth of 12,700 m, horizontal reach of 11,739 m; in April 2014, Z-40 well, a measured depth of 13,000 m and a horizontal reach of 12,130 m; in 2012, Z-44 well, MD 12376, became longest well, world extended reach record at time. Sakhalin-1 area location 52.9633, 143.4937. Also see http://www.sakhalin-1.com/en-ru/company/about-us/about-sakhalin-1-project. Sakhalin-II project develops Piltun-Astokhskoye oil field and the Lunskoye natural gas field offshore Sakhalin Island. Sakhalin-III's develops Veninsky, Kirinsky fields. Gazprom-operated Yuzhno-Kirinskoye (2010) and Mynginskoye fields located in the Sea of Okhotsk Kirinsky block; part of Gazprom Sakhalin-III; http://www.offshoreenergytoday.com/gazprom-finds-new-gas-field-in-sea-of-okhotsk/, and map https://arcticecon.wordpress.com/category/russia/sea-of-okhotsk/)

Deep Borehole General Information: NWTRB, DOE

476) NWTRB (U.S. Nuclear Waste Technical Review Board) Fact Sheet (website accessed March 22, 2016). *Deep Borehole Disposal of Spent Nuclear Fuel and High-Level Waste*; http://www.nwtrb.gov/facts/BoreholeFactSheet.pdf

477) NWTRB (U.S. Nuclear Waste Technical Review Board). 2016. *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program - A Report to the U.S. Congress and the Secretary of Energy*; http://www.nwtrb.gov/reports/DBD_final.pdf; accessed March 22, 2016.

478) Kuhlman, K. 2015. *Deep Borehole Field Test Site Characterization* (presentation); U.S. Nuclear Waste Technical Review Board Briefing, Albuquerque, NM, July 16, 2015; similar material at http://www.nwtrb.gov/meetings/past-meetings/board-workshop-2015 (but Oct. presentation is no longer available), http://www.nwtrb.gov/meetings/2015/oct/kuhlman-om.pdf and https://rampac.energy.gov/docs/default-source/storage/s3.pdf and https://rampac.energy.gov/docs/default-source/storage/ufd_wg_9_2015061058ab7ac58d7064d5adfcff00004b4072.pdf?sfvrsn=2; accessed March 31, 2016 {Notes:
Fenton Hill (3); New Mexico, operations 1975-1987; depths ~3km, ~4.2km, ~4.6km; diameter at TD ~ 8¾", 9⅞"; (R&D, HDR)
Urach-3; SW Germany, operations 1978-1992; depth ~4.4km; diameter at TD 5½; (R&D EGS)
Gravberg 1 / Siljan test; Central Sweden; operations 1986-1987; depth ~6.6km; diameter at TD 6½" (R&D, gas well)
Cajon Pass; California; operations 1987-1988; DOSSEC; depth ~ 3.5km; diameter at TD ~ 6¼" (?6.5; verify), near San Andreas Fault (R&D)
KTB (2); SE Germany; Operations 1987-1994; depth ~ 4 km, 9.1km; diameter at TD 6, 6½" (R&D)
Soultz-sous-Forêts GPK (3); NE France; operations 1995-2003; depth ~5.1km, 5.1km, 5.3km; diameter at TD 9⅝" (R&D EGS)
Kola SG-3; NW Russian Federation; operated 1970-1992; depth ~ 12.2km; diameter at TD ~ 8½" (R&D)

479) Kuhlman, K. et al. 2015a. *Deep Borehole Field Test: Characterization Borehole Science Objectives*; FCRD-UFD-2015-000131, SAND2015-4424R; http://prod.sandia.gov/techlib/access-control.cgi/2015/154424r.pdf and http://www.osti.gov/scitech/biblio/1184360; accessed March 31, 2015

Deep Borehole Disposal: overview, opportunity, issues

480) Halsey, W.G., L.J. Jardine, C.E. Walter, 1995. Disposition of Plutonium in Deep Boreholes, paper prepared for submittal to the *NATO International Scientific Exchange Program Advanced Research Workshop, Disposal of Weapons Plutonium-Approaches and Prospects*, St. Petersburg, Russia, May 14-17, 1995. Lawrence Livermore National Laboratory, UCRL-JC-120995 Rev 1. http://www.osti.gov/scitech/servlets/purl/86875 ; accessed March 31, 2016

480a) DOE / U.S. Department of Energy. 1996. *Technical summary report for surplus weapon-usable plutonium disposition*. Office of Fissile Materials Disposition. Report DOE/MD-0003 Rev 1. 1996. https://fas.org/nuke/control/fmd/docs/PUD71996.pdf ; accessed June 27, 2016 (Note: discussion of deep borehole disposal alternative, Section 5.4; not informative for drilling achievements)

480b) Harms, U., and T. Wohrl. *The Thrill to Drill - After a decade of International Scientific Drilling, A prospect for the future*; brochure, 24pp. ICDP / International Continental Scientific Drilling Program, GeoForschungsZentrum Potsdam, Potsdam, Germany http://www.iodp-icdp.es/sites/default/files/public/page/97/brochure-icdp.pdf ; accessed June 27, 2016 (Note: general information on ICDP; Listing and map illustrating deep drilling programs internationally)

Deep boreholes – General seismic testing and deep borehole drilling R&D

481) NEA / Nuclear Energy Agency (NEA/OECD) and CSNI (Committee on the Safety of Nuclear Installations]. 2013/2014. *Seismic observation in deep boreholes and its applications; Workshop) Proceedings, Niigata Institute of Technology, Kashiwazaki, Japan; 7-9 November 2012*, Volume 2 (Presentation materials); NEA/CSNI/r(2013)11/part2; NEA/CSNI/R(2013)11; October 2013; NEA/CSNI, http://www.oecd-nea.org/nsd/docs/2013/csni-r2013-11-part2.pdf ; and http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=NEA/CSNI/R(2013)11/PART1&docLanguage=En ; accessed March 31, 2016

482) DOSECC / Drilling, Observation and Sampling of the Earths Continental Crust (website homepage; accessed March 31, 2016); http://www.dosecc.org/ (NOTE: cooperative R&D group; also see DOSECC publications and brochures, http://www.dosecc.org/index.php/publications/reports-and-brochures)

Drilling: General - Best Practices in Scientific Drilling / technology

483) Cohen, A. and D. Nielson (Eds.). 2007. *Best Practices in Development of Scientific Drilling Projects*; DOSECC 2nd ed.; DOSECC. DOSECC / NSF (Drilling, Observation and Sampling of the Earths Continental Crust, National Science Foundation); Salt Lake City, UT; 32pp. http://www.ldeo.columbia.edu/~polsen/cpcp/Best_Practices_-_2nd_Ed_-_FINAL.pdf , and http://www.dosecc.org/images/stories/DOSECC_pdfs/Best_Practices_-_2nd_Ed_-_FINAL.pdf ; accessed March 31, 2016

484) SKB (Svensk Kärnbränslehantering). 1989. *Storage of Nuclear Waste in Very Deep Boreholes: Feasibility study and assessment of economic potential*. Technical Report 89−39. SKB, Stockholm, Sweden: Svensk Kärnbränslehantering AB. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&uact=8&ved=0CC8QFjADahUKEwjau5GZ_MTHAhWBFz4KHTqYB0U&url=http%3A%2F%2Fwww.skb.se%2Fupload%2Fpublications%2Fpdf%2FTR89-39webb.pdf&ei=QsLcVdqSA4Gv-AG6sJ6oBA&usg=AFQjCNEyJSQO7Txe9rOq2rcac7BlVddWeg&sig2=OGB9PsSj3nbqFJejOADCTQ and http://www.skb.se/upload/publications/pdf/TR89-39webb.pdf ; accessed August 25, 2015 (NOTE: Table 3.1, listing of deep boreholes in crystalline rock, 1500m or greater; summarizes many key deep boreholes)

United States: Deep Boreholes, general

485) Dyman, Thaddeus, T.A. Cook. 2001. Summary of Deep Oil and Gas Wells in the United States through 1998, Chapter B; *In*: T. Dyman and V. Kuuskraa (eds.), *Geologic Studies of Deep Natural Gas Resources*, U.S. Geological Survey Digital Data Series 67; 2001. USGS, Denver. http://pubs.usgs.gov/dds/dds-067/CHB.pdf and http://pubs.usgs.gov/dds/dds-067/ ; accessed March 31, 2016 (NOTE: Twenty thousand seven hundred fifteen wells have been drilled deeper than 15,000 feet (4,572 m) in the U.S. since the first deep well was drilled in 1920, according to data in PI-Dwights WHCS data files through December 1998. See their Table 1, deepest wells in the U.S.)

486) Finger, J. and Doug Blankenship. 2010. *Handbook of Best Practices for Geothermal Drilling*; SAND2010-6048**;** Sandia National Laboratories, Albuquerque, NM; http://www1.eere.energy.gov/geothermal/pdfs/drillinghandbook.pdf ; accessed April 20, 2016 (Note: Geothermal well drilling, planning, management, technology)

Deep drilling summary, geothermal analog: Europe –France, Finland, Sweden, Switzerland

487) Marsic, Niko, and Bertil Grundfelt. 2013. *Review of geoscientific data of relevance to disposal of spent nuclear fuel in deep boreholes in crystalline rock*; P-13-12. Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Co., Stockholm; 31 pp.; http://www.skb.se/upload/publications/pdf/P-13-12.pdf ; accessed March 22, 2016 (NOTE: SKB Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Co., Stockholm; four boreholes discussed in detail. **A] Outokumpu Deep Drilling Project, Finland**: Well R2500 was drilled largely in metasediments in upper section in 2004–2005 (testing to 2010) by the Outokumpu Deep Drilling Project of the Geological Survey of Finland (GTK),and International Continental Scientific Drilling Program (ICDP); Outokumpu region located in Fennoscandian Shield, eastern Finland; ore province, massive Cu-Co-Zn sulphide deposits within the Palaeoproterozoic Karelian metasedimentary schist belt; hole is located SE of the town Outokumpu in the metasedimentary allochthonous upper part of the Kalevian unit in the upper part of the Karelian schist; sub-vertical hole TD 2,516 m, with TVD at TD at 2,497 m; core ~<100mm; small hole, but "deeper" than usual for crystalline terrain . Area location guess 62.7, 29.08; B) Lund – DGE#1 and DGE#2, Sweden, Skane: Tornquist deformation zone; wells are located within the fault zone running along the Romele horst ridge in Stora Råby SE of Lund, southern Sweden; DGE#1 spud in 2002; drilled into 2003; DGE #1 TD ~3701.8m deep; Mesozoic sediments to ~2000m; enter crystalline granitic/gneissic basement ~2000m deep. DGE#2 spud in 2004; TD1927m mostly in sedimentary rock; #2 TD in basement; sediments tested of Mesozoic age; DGE wells drilled 2001-2003; located within tectonized basement of the Tornquist deformation zone; on Romele horst ridge in Stora Råby south-east of Lund in southern Sweden; Lund Institute of Technology (LTH), Lund's Energy AB; DGE#1 has a total depth of 3,701.8 m and ~1,950 m was drilled in

sedimentary rocks (mainly claystone, sandstone, mudstone and siltstone) and the last 1,756 m in basement rocks (mainly gneiss, dolerite, metabasite and granite). DGE#2, was drilled during the summer 2004 mainly in sedimentary rock to a total depth of 1,927 m. C) Soultz – GPK1 – GPK4 & EPS1: EGS/HDR France: geothermal production site with 4 wells; GPK2 TD 4955m; GPK4 TD 4982m; GPK3 TD 5091m Soultz-sous-Forêts, GPK 3; wells drilled 1999-2004; GPK1 TD 3600m, spud 1992; EPS-1 well drilled in 1997, TD 2227m; granite ~1,400 m and overlain by Cenozoic / Mesozoic sediments; located on the western side of the Rhine Graben in Soultz-sous-Forêts, Alsace, France; Soultz – GPK1 – GPK4 & EPS1 also described; EGS well tests; western side of the Rhine Graben in Soultz-sous-Forêts, Alsace, France; The two boreholes GPK2 (4,955 m) and GPK4 (4,982 m) are used as production wells and the third central borehole, GPK3 (5,091 m), is used as an injection well, i.e., Soultz-sous-Forêts, GPK 3; EPS1 well (2227m); part of European Enhanced Geothermal System (EGS, formerly Hot Dry Rock, HDR) programme. D) Basel – Basel-1, Switzerland: Geothermal well, near Basel in north-western Switzerland at the intersection of the southern end of the Upper Rhine Graben and the Jura mountains.; granite rock matrix; drilled to 5,009 m depth and cased to 4,629 m bgl; borehole with 2,400 m Tertiary, Mesozoic and Permian sediments. The top granite at 2,426 m; no metamorphic units encountered.)

487a) Haring, M. et al. 2008. Characterisation of the Basel 1 enhanced geothermal system; *Geothermics* 37(2008) 469-495; Elsevier; online at *Sciencedirect.com*; http://labex-geothermie.unistra.fr/sites/labex-geothermie.unistra.fr/IMG/pdf/1998_geothermics_haring_etal.pdf ; accessed August 10, 2016

Deep Drilling and Technology: General; Oil and Gas vs Geothermal Drilling / Cost

488) NETL / National Energy and Technology Laboratory (website accessed May 23, 2016). *NETL Deep Track* Folder / Fact sheet; U.S. Department of Energy, Office of Fossil Energy; http://www.netl.doe.gov/publications/factsheets/program/prog072.pdf (NOTES: examine gas potential that exists in formations below 20,000' bgl; deep drilling technology development)

489) Tester, J., et al. 2011. *Oil and Gas Well Drilling*; Lecture notes; http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/CHEME%206666%20Lecture%20Series-2011/CHEME%206666_07_Drilling%20Lecture.pdf ; accessed March 31, 2016 (NOTES: Geothermal vs oil and gas well cost 2006 Joint Association Survey on Drilling Costs. Cost completion geothermal. 5000m deep list and discussions; examples: 1) Cooper Basin, Habernero-2; 2) Soultz GPK-4; drilling technology overview for non-specialist; advanced cost analysis by depth, by well type; technology contribution to cost valuations in future; enhanced geothermal well cost for development vs O&G well)

United States: Deep Borehole RD&D

490) Arnold, W.B. et al. 2012. *Research Development and Demonstration Roadmap for Deep Borehole Disposal*; FCRD-USED-2012-000269, SAND2012-8527P; Sandia National Laboratories (prepared for U.S. DOE Used Fuel Disposition Campaign), Albuquerque, NM; http://energy.gov/sites/prod/files/2013/06/f1/FY12%20Research,%20Development,%20and%20Demonstration%20Roadmap%20for%20Deep%20Borehole%20Disposal.pdf ; accessed March 31, 2016 (NOTES: DBH 17" = 0.43m; existing deep hole descriptions for deep holes in crystalline rock; Russia Kola, 12,262m; German KTB 9101m, with 14.75 diameter hole to 6000m depth; Sweden Gravberg-1 6700m; page 36 of text, "Deep holes in crystalline rock would include Kola Superdeep Borehole, Russia (12,262 m); German Continental Deep Drilling Program (KTB) hole in Germany (9,101 m); and the Gravberg-1 borehole in Sweden (6,700 m). The KTB hole set 13-3/8" casing in a 14-3/4" hole to a depth of 6,000 m, and is perhaps the closest analog to the demonstration hole proposed here. Information is also available from the Hot Dry Rock project in New Mexico and the British Hot Dry Rock project at Rosemanous (for HDR in UK, pre-1990s, see http://iretherm.ie/documents/Publications_by_Others/Batchelor_1987.pdf). To our knowledge, the largest diameter and most productive geothermal borehole (~50 MWe) is Vonderahe-1 at the Salton Sea geothermal field in California. It has 24" casing set in a 32" hole to 620 m and is completed 14-3/4" open hole to 1,684 m ... Ikeuchi et al., (1996) document one of the world's "hottest boreholes" that was completed in granite at a temperature of ~500° C. Recently, extensive planning was done to drill an 8-1/2" borehole to a depth of 4,500 m in Iceland. The well "(IDDP-1) was drilling at 12-1/4" when it intersected rhyolite magma at a depth of 2104 m and temperature of 1050o C (Holmgeirsson et al., 2010).")

490a) Winterle, J., R. Pauline and G. Ofoegbu. 2011. Regulatory Perspectives on Deep Borehole Disposal Concepts; Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas; http://pbadupws.nrc.gov/docs/ML1114/ML111470719.pdf ; accessed June 29, 2016

United States: Extended Reach Drilling Technology Developments

491) Jellison M., Muradov, A., Hehn L., Foster, B., Elliot G. and Sanclemente L. 2009. Ultra-high-strength drill pipe expands the drilling envelope (A new lightweight steel alloy will allow wells to be drilled farther and deeper). *World Oil*, 230(7), July 2009. http://www.worldoil.com/magazine/2009/july-2009/special-focus/ultra-high-strength-drill-pipe-expands-the-drilling-envelope-jul-2009 ; and http://www.worldoil.com/uploadedimages/Issues/Articles/Jul-2009/09-07_Ultra_Jellison_fig4.gif ; accessed March 31, 2016 (NOTES: extended reach drilling, materials science developments; Extended Reach Drilling / ERD; ultra-high strength steel could reduce pipe weight by 30%; field trials / R&D; see same figures as used in Beswick, 2008, Reference 470, 474, herein)

Site and area-specific sources: References 492 – 609f

Deep Borehole Disposal: General, Asia

492) Chapman, Neil. 2013. *Deep Borehole Disposal of Spent Fuel and Other Radioactive Wastes, NAPSNet Special Reports*, July 25, 2013, http://nautilus.org/napsnet/napsnet-special-reports/deep-borehole-disposal-of-spent-fuel-and-other-radioactive-wastes/ ; accessed September 3, 2015 (NOTES: survey national programs and deep borehole evaluation; status east Asian nations deep borehole programs, China, Japan, Rep. Korea. Japan has several very deep holes, constructed by METI (the Ministry of Economy, Trade and Industry) in the 1990s, e.g.: Shin-Takenomachi (1993) to 6,310 m, with a cased diameter of ~17.8 cm OD and a bottom temperature of 197 C; Mishima (1992) to 6,300 m with a bottom temperature of 226 C; Higashi-kubiki (1989-1990) to 6,001 m, cased to 5000 m at about 24.4 cm OD and uncased below that. In China, deep borehole disposal was not considered as an option for HLW management and has not been studied closely; CCSD-1, 2005, China's national drilling R&D project completed a 5 km deep borehole; ROK considering several options, and DBH is one)

493) Chapman, Neil. 2014. *Deep Borehole Disposal of Spent Fuel: International Developments and Implications for NE Asia, NAPSNet Special Reports*, March 24, 2014; http://nautilus.org/napsnet/napsnet-special-reports/deep-borehole-disposal-of-spent-fuel-international-developments-and-implications-for-ne-asia/ and http://nautilus.org/napsnet/napsnet-special-reports/deep-borehole-disposal-of-spent-fuel-international-developments-and-implications-for-ne-asia/#axzz31pNVQXRK ; accessed March 28, 2016 (NOTE: overview of international deep borehole disposal programs for nuclear waste)

China: Planning deep borehole drilling (preparation for CCDP-1)

494) Wei, Zhang. 1997. The technical concept for the drilling of a 5000m deep scientific core-hole; pp 127-133; In: Dawei Hong (ed.) *Structure of the Lithosphere and Deep Processes*; Proceedings of the 30th International Geological Congress, Volume 4; VSP/BV, Netherlands. Only partial text and introduction available at: http://books.google.com/books?id=OZTHvQtPYAsC&pg=PA128&lpg=PA128&dq=deep+borehole+casing+configuration+diameter&source=bl&ots=9rr_KYS9Rb&sig=fD9fD6huxGuSpU-YDRNGAuf3F88&hl=en&sa=X&ei=cDd1U4apDYGPqAab2YD4DQ&ved=0CBsQ6AEwADgU#v=onepage&q=deep%20borehole%20casing%20configuration%20diameter&f=false; accessed March 30, 2016.

China: CCSD-1 / China Continental Scientific Drilling Project, Donghai County, Jiangsu Province (with ICDP / International Continental Scientific Drilling Program)

495) Wang, D. et al. 2015. *The China Continental Scientific Drilling Project: CCSD-1 Well Drilling Engineering and Construction*; Springer Geology, Science Press, Beijing / Springer-Verlag; preview portions of manuscript online at http://www.springer.com/br/book/9783662465561 , http://link.springer.com/book/10.1007%2F978-3-662-46557-8 and https://books.google.com/books?id=5C0TBwAAQBAJ&pg=PP6&lpg=PP6&dq=Chinese+continental+scientific+drilling+(CCSD)&source=bl&ots=uVy2RvymOT&sig=j6dgNQFWA43OM8I9xSg76nES4xs&hl=en&sa=X&ved=0ahUKEwiJsv_YltXLAhWEQCYKHb3FCY8Q6AEISjAG#v=onepage&q=Chinese%20continental%20scientific%20drilling%20(CCSD)&f=false ; accessed March 22, 2016 (Notes: CCSD-1 is located in Maobei Village of Donghai County, Lianyungang City, Jiangsu Province; south of Adabie-Sulu ultra-high pressure metamorphic belt; southern UHP metamorphic belt with ; the ultramafic rock and eclogite are hosted in coesite-bearing gneiss; and see; drilling and operation start 2001, complete in 2005; ~5000m / 5158m depth; continuous core; crystalline rock; 34º24'36"N, 118º40'12"E

496) ICSDP (ICDP) International Continental Scientific Drilling Program (website accessed March 22, 2016). Donghai; www.icdp-online.org; http://www.icdp-online.org/home/ ; http://www.icdp-online.org/projects/world/asia/donghai/ ; www.icdp-online.org/projects/world/asia/donghai/details , http://donghai.icdp-online.org ; also http://www.icdp-online.org/media/icdp-flyers-brochures/ (Note: age Archean, Proterozoic rock)

497) Zhang, Xiaoxi, and Hui Zhang. 2008. The core drilling technique of Chinese continental scientific drilling (CCSD). *33rd International Geological Congress, Oslo, August 6-14, 2008*. Programme Book, http://iugs.org/33igc/fileshare/PDF/IGC+programme+book.pdf; *Proceedings;* abstract last accessed abstract July 23, 2015; see also http://iugs.org/33igc/coco/FilePool-c10728-p5002-e1-l0-p5001.html , p. 142, 143 (NOTES: CCSD-1 located in the Dabie-Sulu region of eastern China. Donghai County, Jiangsu Province; Dabie-Sulu UHPM gneiss, eclogite and HPM; TD 5000m (later reported to be 5158m (see He et al., 2008); diameter at TD, 6.25" (157mm); drilling 2001-2005; used new drilling and coring systems)

498) He, L., S. Hu, S. Huang, W. Yang, J. Wang, Y. Yuan, and S. Yang. 2008. Heat flow study at the Chinese Continental Scientific Drilling site: Borehole temperature, thermal conductivity, and radiogenic heat production, *J. Geophys. Res.*, 113, B02404, 16pp. http://onlinelibrary.wiley.com/doi/10.1029/2007JB004958/pdf ; http://onlinelibrary.wiley.com/doi/10.1029/2007JB004958/abstract ; accessed preview August 27, 2015; accessed abstract March 23, 2016 {NOTE: main hole, 5158m TD; map location for wells, PP1, PP2, illustrated; excellent source of information on testing) CCSD MH is located at 34º24'36"N, 118º40'12"E, 17 km southwest of Donghai County of the Lianyungang city; drilled spud 2001, completed 2005, TD 5158 m deep main hole (CCSD MH); MH is located at 34º 24' 36"N, 118º 40' 12"E, 17 km southwest of Donghai County of the Lianyungang city; ultra-high pressure metamorphic belt test; a) CCSD MH: 34º24'36N, 118º40'12E; 5158m TD; b) Kola SG-3: 69º25'N, 30º44E; 12,262m TD; c) KTB HB: 49º48'58.8"N, 12º7'19.2"E; 9,101m TD. CCSD1 Spud in 2001 verify location}

499) Cui, Jun-wen, Lian-jie Wang, Pengwu Li, Zhe-min Tang, Dong-sheng Sun. 2009. Wellbore breakouts of the main borehole of Chinese Continental Scientific Drilling (CCSD) and determination of the present tectonic stress state. *Tectonophysics* 475 (2009) 220–225; http://ac.els-cdn.com/S0040195109001851/1-s2.0-S0040195109001851-main.pdf?_tid=c1410a7e-3d01-11e4-848e-00000aacb362&acdnat=1410804027_be7d2f836e68c0ead2a314a35d6073c3 ; accessed preview March 22, 2016 (NOTE: 5118vs 5158m? TD; Sulu–Dabie high-pressure (HP)–ultrahigh-pressure (UHP) metamorphic belt; adequate location map; inland of Sulu-South Yellow Sea, west of Lianyungang, east side of Tanlu Fault)

499a) Harms, U., C. Koeberl, and M. Zoback (Eds.). 2007. Continental Scientific Drilling: a Decade of Progress and Challenges for the Future; Springer; Berlin Heidelberg; 370pp. https://books.google.com/books?id=NVhLaTXKcdsC&pg=PA38&lpg=PA38&dq=Chinese+Continental+Scientific+Drilling+Project&source=bl&ots=ra3g4mwM50&sig=pjpsVY4Za5pO8cNZ3Z39hg3a_4g&hl=en&sa=X&ei=_RXIVPP5EMKHyATb4YKQAw&ved=0CFYQ6AEwCA#v=onepage&q=Chinese%20Continental%20Scientific%20Drilling%20Project&f=false ; accessed June 2016 (Note: Harms and Emmerman, p. 38, CCDP: drilled ultra-high pressure metamorphic belt, Dabie Sulu region, eastern China; convergent margin block collision 210-220Ma; ultramafics and eclogite in gneiss; drilled 2002-2005; TD 5158m, followed 2000m pilot hole drilled in 2002)

500) Zheng, Yong-Fei, et al. 2009. Chemical geodynamics of continental subduction-zone metamorphism: Insights from studies of the Chinese Continental Scientific Drilling (CCSD) core samples; *Tectonophysics* 475 (2009) 327–358; https://www.researchgate.net/profile/Yong-Fei_Zheng/publication/222894392_Chemical_geodynamics_of_continental_subduction-zone_metamorphism_Insight_from_studies_of_the_Chinese_Continental_Scientific_Drilling_CCSD_core_samples/links/0c96052cbaec4d3552000000.pdf ; accessed March 22, 2016 (Notes: Summary geologic character and history; geologic map; location map)

500a) Xu, Z., et al. 2006. Petrofabrics and seismic properties of garnet peridotite from the UHP Sulu terrane (China): Implications for olivine deformation mechanism in a cold and dry subducting continental slab; *Tectonophysics* 421: 111 – 127; El Sevier; http://www.academia.edu/13846537/Petrofabrics_and_seismic_properties_of_garnet_peridotite_from_the_UHP_Sulu_terrane_China_Implications_for_olivine_deformation_mechanism_in_a_cold_and_dry_subducting_continental_slab (also available through Science Direct); accessed August 2, 2016

501) Zhou, Yun. 2012. *An Initial Exploration of the Potential for Deep Borehole Disposal of Nuclear Wastes in China*; NAPSNet Special Reports, October 23, 2012; The Nautilus Peace and Security Network (NAPSNet), Nautilus Institute; http://nautilus.org/napsnet/napsnet-special-reports/an-initial-exploration-of-the-potential-for-deep-borehole-disposal-of-nuclear-wastes-in-china/ ; accessed March 23, 2016. (NOTE: Section 5.2; Sections 4 and 5 examine conceptual models for disposal in granite, and in deep borehole; CCSD-1, final depth reached 5158 m for a borehole of 157 mm in diameter)

Germany: KTB borehole, Continental Deep Drilling Program

502) Bram, Kurt, et al. 1995. The KTB Borehole - Germany's superdeep telescope into the earth's crust; *Oilfield Review, Scientific drilling*; Schlumberger; pp. 4-22; http://www.slb.com/~/media/Files/resources/oilfield_review/ors95/jan95/01950422.pdf ; accessed March 22, 2016 (NOTE: KTB holes; Schlumberger describes logging and core suite, guide-hole test, and main test hole… Hole and string design; review of deep drilling programs and technology; hole with 8.5" casing to ~8600m, 6.5" to ~8700m; TD 9101m / 29,859'; drilled 1990-1994; HB hole)

503) Emmermann, R. and Jorn Lauterjun. 1997. The German Continental Deep Drilling Program KTB: Overview and major results. *Journal of Geophysical Research*, Vol. 102, No. B8, pp. 18,179-18,201, August 10, 1997 http://onlinelibrary.wiley.com/doi/10.1029/96JB03945/pdf ; April 20, 2016 {NOTE: German Continental Deep Drilling Program KTB (Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland); drilling testing program ran 1987-1994. The HB hole was planned to 12km depth, but reached its final depth of 9101 m at a temperature of ~265ºC; TD, 1994; spud = 1990. Pilot program 1987; sinking a pilot hole to 4000m, Vorbohrung, KTB-VB). HB Superdeep hole, TD 9101m, Hauptbohrung, KTB-HB casing program, see illustration KTB-HB. HB encountered paragneisses, metabasites and "variegated series of gneisses and amphibolites; final depth, 9101m; deep hole drilled 1990-1994; initial work in 1982-1990; Geological Survey of Lower Saxony, Hannover, was operations lead / technical group; science activities coordinated by Deutsche Forschungsgemeinschaft (DFG); Bohemian Massif consisting of tectono-metamorphic units of the Variscan Orogin fold belt: the Saxothuringian, the Moldanubian, and the Tepla Barrandia; located in a small, isolated tectono-metamorphic unit called the ZEV (Zone of ErbendorfVohenstrauß), composed of paragneisses, metabasites and a "variegated" series of gneisses and amphibolites. Excellent maps and illustrations subsurface, data. In 1996, operations assumed by GeoForschungsZentrum Potsdam (GFZ). Location ~ 49.815278, 12.120556 from Wikipedia google map}

504) Rohr, C., et al. 1990. German Continental Deep Drilling Program (KTB) - Geological Survey of the Pilot Hole "KTB Oberpfalz VB" (transcription of content in) KTB-Report, 90-8, B1 - B55, 65 Abb.; Hannover; in (R. Emmermann et al., editors) *KTB Pilot Hole, Results of Geoscientific Investigation in the KTB Field Laboratory, 0 - 4000.1 m*; http://www.oberrheingraben.de/KTB/PilotGeol01.htm ; accessed November, 2016.

505) Haak, V. & A.G. Jones. 1997. Introduction to special section: The KTB deep drill hole. *Journal of Geophysical Research*, 102 (B8): 18175−18177; http://onlinelibrary.wiley.com/10.1002/(ISSN)2156-2202b/specialsection/KTBHOLE1 ; and http://onlinelibrary.wiley.com/doi/10.1029/96JB03944/pdf ; accessed April 25, 2016 (NOTES: KTB summary for KTB volume; free access to all articles; superdeep borehole which reached a final depth of 9101 m; KTB, Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland; 13 5/8ths casing

505a) International Continental Scientific Drilling Program / ICDP (websites accessed June 27, 2016). KTB at Windischeschenbach; http://www.icdp-online.org/home/ ; http://www.icdp-online.org/projects/world/europe/windischeschenbach/ (Note: for KTB hole website and other countries use link for listing of projects; KTB project, 2 holes same area, 4000m and 9101m TD; recommended to use http://ktb.icdp-online.org)

506) Harrison, T. 2000. *Very Deep Borehole: Deutag's Opinion on Boring, Canister Emplacement and Retrievability*; SKB Rapport R-00-35; Well Engineering Partners BV. SKB / Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Co. Stockholm, Sweden. http://www.mkg.se/uploads/DB/SKB_R-00-35_Very_deep_borehole_Deutags_opinion.pdf , accessed March 30, 2016, and http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/32/001/32001775.pdf ; accessed March 30, 2016 (NOTES: "Deutag Europe have been involved in only one deep, large bore drilling project, the "Kontinentale Tiefbohrprogramm der Bundesrepublik Deutschland (KTB)" super-deep borehole project, between October 1990 and October 1994, where a well was drilled through the top 9000 m of the continental crust in the Rhine Valley. See Figure 2-1."; KTB-HB with 12.25" diameter hole to 7784m depth; TD 9031m. "The main technological achievement for the Deutag was the building and management of the world's largest land drilling rig, UTB-1 GH 3000 EG" (shown in Figure 2-2). The rig, with a "total weight of 2500 tonnes, a depth rating of 12000 m and a maximum installed capacity of 12900 HP, was purpose-built for the project."; plan for hole and retrieval outlined, rigs, casing etc.)

Germany: Gross Schoenebeck well, geothermal laboratory facility

507) Wulf Brandt & Geothermics Group. 2007. Drilling a geothermal well into a deep sedimentary geothermal reservoir –conclusions from case study Gross Schoenebeck. Presentation of Wulf Brandt & Geothermics Group, GFZ GeoForschungs Zentrum, *Drilling cost effectiveness and feasibility of high temperature drilling: Conference, Reykjavik, Iceland, Workshop 4*; Potsdam, 2007; 17pp. presentation; http://engine.brgm.fr/web-offlines/conference-Drilling_cost_effectiveness_and_feasibility_of_high-temperature_drilling_-_Reykjavik,_Iceland,_Workshop4/other_contributions/14-slides-0-3_Drilling_Gross_Schoenebeck.pdf ; accessed March 28, 2016. (NOTES: Gross Schoenebeck well, geothermal, 8.5" hole ~3165 to 3880m; TD ~4400m; deviated hole with fracturing test; 8.5" hole 3840-4375m drill depth; TD 4500m drilled depth, sedimentary rock formations. Excellent lessons learned for drilling)

508) Huenges, E. et al. 2002. The in-situ geothermal laboratory Groß Schönebeck: learning to use low permeability aquifers for geothermal power; In: *Proceedings, Twenty-Seventh Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 28-30, 2002*, SGP-TR-171; 4 pp.; https://earthsciences.stanford.edu/ERE/pdf/IGAstandard/SGW/2002/Huenges.pdf ; accessed March 28, 2016 (NOTE: Early Permian, Rotliegend formation (pre-Zechstein; sedimentary and volcanic in older section of North German Basin; ~50km N of Berlin; GFZ; in 2000, deepened well to 4294m)

509) GFZ / GeoForschungs Zentrum (website accessed March 28, 2016). *Geothermal research platform* Groß Schönebeck. German Research Center for Geosciences; Helmholtz Center, Potsdam; http://www.gfz-potsdam.de/en/scientific-infrastructure/laboratories/gross-schoenebeck/ (NOTES: location, 52.903820, 13.601646)

Germany: Urach geothermal borehole; Swabian Alb, Bad Urach

510) Haenel, R. 1982. The Urach geothermal project (Swabian Alb, Germany); Schweizerbart science publishers, Stuttgart, Germany; 419pp (Note: Forward and Table of Contents, http://www.schweizerbart.de/publications/detail/isbn/9783510651078/The_Urach_geothermal_project_Swabian_Alb_Germany?l=DE)

511) Schanz, H. et al. 2009. Hot dry rock project – a general overview; Zukunfts Investitions Program (ZIP), 9 pages; http://www.geothermal-energy.org/pdf/IGAstandard/EGC/szeged/O-7-09.pdf ; accessed April 18, 2016 (Notes: Borehole Urach 3 location only approximate from maps, 48.506822, 9.373690)

512) Tenzer, H., et al. 2003. Main Results and further research work at HDR-Test site of Urach Spa Development of a HDR Demonstration Pilot-Plant.; Chapter 3.2, in *International Seminar on Hot Dry Rock Technology*; http://www.geothermal-energy.org/pdf/IGAstandard/ISS/2003Germany/III/3_1.ten.pdf ; accessed April 18, 2016 (Note: Urach 3 borehole drilled for hot/dry rock geothermal project 1977-1992; #3 drilled to 3334m bgl and extension to 3488m bgl in metagneiss unit, and further deepened to 4444m with gneiss at total depth; borehole deviated 335m from surface location; near Urach Spa geothermal anomaly; comparable to Tenzer et al., 1999 reference 513)

513) Tenzer, H. et al. 1999. HDR research programme and results of drill hole Urach 3 to depth of 4440 m - The key for realisation of a HDR programme in southern Germany and northern Switzerland; European Geothermal Conference (Proceedings, Volume 2) September 28-30, I999 - Basel, Switzerland, p. 147-156; https://pangea.stanford.edu/ERE/pdf/IGAstandard/EGC/1999/Tenzer2.pdf

514) Tenzer, H., et al. 2006. Geomechanical facies concept in exploration techniques of EGS sites, Soultz-sous-Forets and Spa Urach. *GRC Transactions*, V.30, pp. 353-360; in *Geothermal Resources – Securing our Energy Future*; Geothermal Resources Council http://pubs.geothermal-library.org/lib/grc/1025058.pdf and http://www.geothermal.org/publications.html ; accessed April 18, 2016

515) Meier, Udo and P.L. Ernst. 1981. Drilling and completion of the Urach 3 HDR test well (Conference: *International Geothermal Drilling and Completions Technology Conference, Albuquerque, NM, USA, 21 Jan 1981*), SAND-81-0036C; OSTI #886094; http://www.osti.gov/geothermal/servlets/purl/886094 ; accessed March 31, 2016 {Note: well 3 drilled and completed (to temporary TD) in 1979; total depth 3334m;; drilled in formerly active volcanic area located ~40 km south of Stuttgart; drilled ~1700m into granitic basement rock; 8.5" hole to TD; bottom hole drifted over 100m from surface location; original hole}

516) Stober, I. 2011. Depth- and pressure-dependent permeability in the upper continental crust: data from the Urach 3 geothermal borehole, southwest Germany; *Hydrogeology Journal* (2011) 19: 685–699; http://download.springer.com/static/pdf/380/art%253A10.1007%252Fs10040-011-0704-7.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1007%2Fs10040-011-0704-7&token2=exp=1459552828~acl=%2Fstatic%2Fpdf%2F380%2Fart%25253A10.1007%25252Fs10040-011-0704-7.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1007%252Fs10040-011-0704-7*~hmac=5e3aeeeeaaae7b4785a2a4caece2e687ac80482743f3baa6373e4a073a494a18 and http://download.springer.com/static/pdf/380/art%253A10.1007%252Fs10040-011-0704-7.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Farticle%2F10.1007%2Fs10040-011-0704-7&token2=exp=1459552877~acl=%2Fstatic%2Fpdf%2F380%2Fart%25253A10.1007%25252Fs10040-011-0704-7.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Farticle%252F10.1007%252Fs10040-011-0704-7*~hmac=418a00e87f71410123098aca60fc3bcf6bf0c61fde76e6cc7c6bd2bb13aad9dc ; accessed April 18, 2016 (Note: states well is ~4.5km deep; gneissic basement in the 4.5-km deep Urach 3 borehole contains an interconnected fluid-filled fracture system. Depth of borehole in 1992 was 4444m. Crystalline basement encountered at 1604m bgl. ; basement at the Urach drill site belongs to the Moldanubian domain of the central European continental crust; Triassic/Jurassic and Permian sequence to 1604m; crystalline to basement; perm tests and pressure tests)

517) Stober, I. & K. Bucher. 2000. "Hydraulic properties of the upper continental crust: data from the Urach 3 geothermal well" in Stober, I. & K. Bucher [Eds.] *Hydrogeology of Crystalline Rocks*, p. 53-78, Kluwer. Abstract available online at http://link.springer.com/chapter/10.1007%2F978-94-017-1816-5_3#page-1 ; accessed abstract April 25, 2016 (NOTES: 4500m deep, Germany; crystalline basement test; 4500m deep research Urach 3 borehole at Urach (SW Germany); used for hydraulic testing of the crystalline basement. Review of other deep holes: Kola, KTB, France /Soultzsous-Forêts, NAGRA holes, other; granitic and gneissic basement contains an interconnected fluid-filled fracture system and behaves hydraulically like a confined fractured aquifer. Thus standard hydraulic well-tests can be used in the basement)

518) Stober, I. & K. Bucher. 2004. Fluid Sinks within the Earth's Crust. *Geofluids*, 4:143-151. Abstract online, http://onlinelibrary.wiley.com/doi/10.1111/j.1468-8115.2004.00078.x/abstract ; accessed abstract April 25, 2016 {Note: In Urach 3, gneisses of the Variscian crystalline basement reached at 1600 m bgl (in Black Forest basement); additional 2800 m drilled through the fractured crystalline rocks; TD ~4400m; hydraulic potential decreases with depth}

France: Soultz-sous-Forêts (Alsace) borehole, Enhanced Geothermal System

519) BRGM / Bureau de Recherches Géologiques et Minière (France Geological Survey website accessed April 18, 2016). *Deep geothermal energy: the Soultz-sous-Forêts site has reached the sustainable production phase;* http://www.brgm.eu/project/deep-geothermal-energy-soultz-sous-forets-site-has-reached-sustainable-production-phase (Notes: In production mode since 2010; EGS pilot project geothermal complex 20 years in development; also http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/projekt_0409_engl_Internetx.pdf for summary data)

520) Genter, Albert, et al. 2010. Current Status of the EGS Soultz Geothermal Project (France); *Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010*; 6 pages; http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/3124.pdf ; accessed April 19, 2016 {Note: 3 boreholes to ~5 km depth; crystalline basement testing; GPK2,3,4; Rhine Graben, a Tertiary graben; basement complex - Paleozoic granitic basement contains hydrothermally altered and fractured zones (HAFZ) bearing natural brines having a salinity of 100g/L}

521) BGR / Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover; the Federal Institute for Geosciences and Natural Resources (website accessed April 18, 2016) *Hot-Dry-Rock-Project Soultz*; http://www.geozentrum-hannover.de/EN/Themen/Energie/Projekte/Geothermie/Soultz_en.html ; (Note: activities in Soultz are coordinated by the GEIE EMC, Groupement Européen d'Intérêt Economique "Exploitation Minière de la Chaleur" a consortium of German and French companies; project run from 1987- present; Upper Rhine Valley; 48.931174, 7.866407

522) Sanjuan, B., M. Brach, A. Genter, R. Sanjuan, J. Scheiber, S. Touzelet. 2015. "Tracer testing of the EGS site at Soultz-sous-Forêts (Alsace, France) between 2005 and 2013" in *Proceedings World Geothermal Congress, April 19-25, 2015*, Melbourne Australia. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/31033.pdf ; accessed April 25, 2016 (NOTE: examines wells geothermal wells GPK-4, GPK-3 and GPK-2 of the EGS site at Soultz-sous-Forêts, in Alsace (France). Wells ~5000m depth; 48.931064, 7.866523)

Republic of Korea: Deep Borehole Disposal, other

523) Kang, Jungmin. 2010. *An Initial Exploration of the Potential for Deep Borehole Disposal of Nuclear Wastes in South Korea*; NAPSNet Special Report (Nautilus Peace and Security), Nautilus Institute, 22pp.; http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/JMK_DBD_in_ROK_Final_with_Exec_Summ_12-14-102.pdf ; accessed March 22, 2016 (NOTE: also see 2014 Nautilus report, Reference 524 herein, Kang (2014), Update: Potential for Deep Borehole Disposal of Nuclear Wastes in ROK)

524) Kang, Jungmin. 2014. *Update: Potential for Deep Borehole Disposal of Nuclear Wastes in ROK, NAPSNet Special Reports*, July 01, 2014, http://nautilus.org/napsnet/napsnet-special-reports/update-potential-for-deep-borehole-disposal-of-nuclear-wastes-in-rok/ ; accessed March 22, 2016 (Note: Korea Atomic Research Institute / KAERI currently examining options for disposal; crystalline favored host)

524a) Richards, M., et al. 2015. Gwangju, South Korea Temperature Data for 3.5 km Well; *Proceedings World Geothermal Congress 2015* Melbourne, Australia, 19-25 April 2015; https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/11111.pdf (Note: latitude 35° 9' 21", Longitude: 126° 50' 4"; 35.155833, 126.834444; Okchon fold belt; drilling plutonic (batholith) granites of Upper Proterozoic and the more recent Bulguksa granites of Cretaceous age; 2015, current depth ~3.5km, planned TD ~7km; also see http://altarockenergy.com/wp-content/uploads/2014/12/AltaRock-ON-Energy-Partnership.pdf for news release on partnership formed for future technology application)

524b) Lee, Tae Jong, Y. Song, et al. 2015. Three Dimensional Geological Model of Pohang EGS Pilot Site, Korea; *Proceedings World Geothermal Congress 2015*, Melbourne, Australia, 19-25 April 2015; https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/31025.pdf

Japan: Deep borehole disposal consideration

524c) Tokunaga, Tomochika. 2013. *A consideration on the Possible Deep Borehole Disposal in Japan, Update of the Presentation at Seoul*; DBD Working Group Meeting, Beijing, China, May 29, 2013 (presentation); http://nautilus.org/wp-content/uploads/2013/08/Japan_tokunaga_presentation_May_29_2013_rev.pdf ; accessed August 3, 2016 (Note: provides summary of solicitation of community interest to host disposal facility; no takers ; one positive response withdrawn after election of local official; 4 year process ending in 2007; process evolving, but little progress in siting through 2013)

524d) Niu, Ben, and T. Yoshimura, A. Hirai. 2000. Smectite diagenesis in Neogene marine sandstone and mudstone of the Niigata Basin, Japan; *Clays and Clay Minerals*, Vol. 48, No. 1, 26-42, 2000; http://www.clays.org/journal/archive/volume%2048/48-1-26.pdf

Chile: 2010 Chilean mining accident; rescue capsule, and rapid drilling example in hard rock

525) Wikipedia (website accessed March 22, 2016). *2010 Copiapó mining accident*; Wikipedia.org; https://en.wikipedia.org/wiki/2010_Copiap%C3%B3_mining_accident ; accessed March 22, 2016 {NOTES: Capsule retrieval; location in Copiapó; "Chilean mining accident," 5 August 2010, 121-year-old San José copper–gold mine, Atacama Desert 45 kilometers (28 mi) north of Copiapó, northern Chile; 700 meters (2,300 ft) underground: Rescue Plan A = Strata 950 model raise borer type drilling rig often used to create circular shafts between two levels; Plan B = Schramm Inc. T130XD air core drill – first to reach group; Plan C = Operated a powerful Canadian made RIG-421 oil drilling rig. Capsule used to rescue the 33 men was the *Fénix 2*, a device 54 centimeters (21 in) in diameter. 2300 feet with multiple retrievals (33 individuals). -27.158609° -70.497655°}

525a) MinDat.org (website accessed August 3, 2016). *San José Mine, Copiapó Province, Atacama Region, Chile*; http://www.mindat.org/loc-221153.html

United States: Deep Borehole, Large diameter example: Magoun No. 1, Concordia Parish, LA

526) Fontenot, E. 1986. Drilling a 26-in. Diameter Hole to 12,550 ft: A Case History; *SPE Annual Technical Conference and Exhibition*, 5-8 October, New Orleans, Louisiana; SPE-15365-MS; https://www.onepetro.org/conference-paper/SPE-15365-MS and https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0CCMQFjABahUKEwjMwJbpldnHAhUKjQ0KHYQAClc&url=https%3A%2F%2Fwww.onepetro.org%2Fconference-paper%2FSPE-15365-MS&usg=AFQjCNHtRhyFx1gxAzAzPzERETwd106jug&sig2=5Z-orgigAVdVYk9I98_Q-g&bvm=bv.101800829,d.cWw ; accessed March 22,

2016 (Note: L.W. Magoun #1 on November 30, 1983 in Section 23, Township 7N, Range 7E in Concordia Parish, Louisiana. "(T)he goal of reaching TD in an 8-1/2" hole, was the need to set two large diameter protective strings of casing deeper than ever attempted. The casing strings programmed in the subject well were 20" at 12,600' and 14" at 17,500'. The standard hole sizes for these casing diameters are 26" and 17-1/2". This paper only discusses the 26" portion of the well, however, it should be noted that lessons learned in drilling the 26" hole were applied to the 17-1/2" hole."; approximate location 31.560098, -91.72104)

527) Pejac, R.D. and E.P. Fontenot. 1988. Design, testing and planning considerations for a 20 in record casing string. *SPE Drilling Engineering* 3(2):187-194; (Paper SPE 13433 first presented at the 1985 SPE/IADC Drilling Conference held in New Orleans, March 6-8). http://www.osti.gov/scitech/biblio/7005064 , https://www.onepetro.org/journal-paper/SPE-13433-PA , and https://www.onepetro.org/download/journal-paper/SPE-13433-PA?id=journal-paper%2FSPE-13433-PA ; accessed March 22, 2016 (NOTE: Standard Oil Production Company, 1984, a total of 12,455 ft (-3800 m) of 20-in., C-95 casing was successfully run and cemented to the surface in L.W. Magoun No. 1, Concordia Parish, LA; Sohio Petroleum) Location information from Standard Oil, L.W. Magoun No. 1, Concordia Parish, LA; planned TD 25000' well; to TD 25,015' with a bottom hole size of 8-1/2". Record 26" diameter hole to 12550'; Section 23, Township 7N, Range 7E in Concordia Parish, Louisiana, estimated location 31.5N, - 91.7W; also see Reference 526)

528) Minge, J.C., R.D. Pejac & W.T. Asbill. 1986. "Threaded Connection Qualification Procedures Utilized for an Ultra-Deep High Pressure Gas Well" in *SPE Annual Technical Conference and Exhibition*, 5-8 October New Orleans, Louisiana, 1-14; https://www.onepetro.org/conference-paper/SPE-15516-MS ; accessed April 25, 2016 (NOTE: 8-1/2 in. hole to 25,000 ft was planned; 1984-1986, Standard Oil Production Company (SOPC) drilled and completed an ultra-deep, high pressure, sour gas wildcat in Concordia Parish, Louisiana. Feasibility studies for the 25,000 ft L.W. Magoun #1; 20 in. surface casing was run to 12,455 ft. and 14 in. protection casing was set at 16,796 ft. Only abstract / introduction available online to all users)

529) deleted

United States: Arizona State A-1; aka Anshutz-Texoma A-1 (Phillips Arizona State A-1), Pinal County, AZ

530) Keith, S.B. 1980. The great Southwestern Arizona overthrust oil and gas play: Drilling commences. *Earth Sciences and Mineral Resources in Arizona*, Vol. 10, No.1 , March 1980, Field Notes from The State of Arizona Bureau of Geology and Mineral Technology; http://www.azgs.az.gov/arizona_geology/archived_issues/Spring_1980.pdf ; accessed March 22, 2016 (NOTES: location map for prospective well; 1980, Anschutz Corporation, Texoma 'Production Co. {Peoples Gas Company of Chicago}; Section 2 T. 7 S, R. 10 E. of Pinal County, between Tucson and Florence; prepared to drill to 20,000 feet)

531) Oil and Gas Permit Files, AZ State. ~1981. Philips Petroleum A1 State, 7S, 10E, sec 2; Pinal County, AZ; formerly Anschutz Texoma 1-10-2; http://repository.azgs.az.gov/resources/og/OGPermitFiles/0702.pdf ; accessed March 22, 2016 (NOTES: total depth 18,013' in Precambrian Gneiss; API # 02-021-20003 ; spud 1980. 32.83827, -111.28320; estimated location

532) Ryder, R. 1983. Petroleum Potential of Wilderness Lands in Arizona (Chapter C), *In*: Miller, Betty M. (ed.). 1983. *Petroleum Potential in Wilderness Lands of Western United States.* USGS Circular 902 A-P; U.S. Geological Survey, Washington, DC http://pubs.usgs.gov/circ/1983/0902a-p/report.pdf ; accessed March 22, 2016 (Note: see also- Ryder, R. 1983 Petroleum Potential of Wilderness Lands in Arizona, Misc. Invest. Series Map I-1537, http://pubs.usgs.gov/imap/1537/report.pdf ; accessed March 22, 2016; general geology provided for Arizona, Pinal Co. area; geologic profiles; main document suite contains general geologic information for individual states considered; each chapter has site for state document and map. The following potentially useful reference could not be located for online reference = Reif, D.M., and Robinson, J.P., 1981, Geophysical, geochemical, and petrographic data and regional correlation from the Arizona State A-1 well, Pinal County, Arizona: *Arizona Geological Society Digest*, V. XIII, p. 99-109.)

United States: Deep Drilling / Large diameter boreholes: historical; Anadarko Basin, 1-27 Bertha Rogers, Washita County, Oklahoma

533) American Oil and Gas Historical Society (website accessed March 28, 2016). *Anadarko Basin in Depth*. http://aoghs.org/editors-picks/anadarko-basin-depth/ (NOTES: Robert Hefner III, of the GHK [Glover-Hefner-Kennedy Company] 1967-1969, first ultra-deep well drilled by Hefner 24,473'; Hefner's second well, was Baden No. 1, drilled in 1972 near Elk City, Oklahoma; TD 30,050'.
Third deep well drilled spud in 1972, Bertha Rogers well, Washita County, Oklahoma. Berth Rogers well was deepest hole in the world until USSR deep drilling project [spud, 1970], Kola Superdeep Borehole at 40230' TD in 1979 [orig. hole] 1989 [SG-3 kickoff hole 40230']; Bertha Rogers remained deepest hole in US until 2004. Also discusses Parker Drill Rig 114 built for the AEC for atomic weapons testing; Qatar well reached 40318' [TVD 35770'] in 2008, and in 2011, a 40502' well drilled offshore Russia island of Sakhalin to 40502'. Side note = Bertha Rogers well Sec27, T10N, R19W reportedly part of, proximal to Dill City area archived Superfund Site / Brownfields hazardous waste disposal area, 35.29007, -99.168485.)

534) Oklahoma Corporation Commission. 1974. *Well Completion Report, Bertha Rogers 1-27*, GHK/Lone Star. Oklahoma Corporation Commission, Oil and Gas Conservation Division, Oklahoma City, Oklahoma; http://imaging.occeweb.com/OG/Well%20Records/00000005/OCC_OG_0G5BFM7_1L8M2C4.pdf ; accessed April 20, 2016 (Notes: Well sheet states TD drilled 7 and 7/8ths" diameter hole; Sec27, T10N, R19W, finished drilling in 1974 at TD of 31441'; 14" casing cemented in to 14,198'; mud logs and location for Bertha Rogers well from USGS, https://www.sciencebase.gov/catalog/item/imap/50dde12fe4b0e31bb02858d0)

535) Wells, Bruce. Bertha Rogers No. 1 Well sets World Depth Record; *OilPro* (website accessed April 20, 2016): This Week in Petroleum History (April 13, 1974); http://oilpro.com/gallery/157/2356/bertha-rogers-no-1-well-sets-world-depth-record (Notes: At TD, liquid molten sulfur encountered; bottom temperature 475F and 24850psi. GHK Co., 1-27 (GHK/Lone Star Producing Co. 1–27) Bertha Rogers, Washita Co., OK, 1974)

535a) Oklahoma Geological Survey / OGS (website and database, accessed March, 2016). Homepage http://www.ogs.ou.edu/homepage.php and database of wells https://economy.okstate.edu/caer/files/economics_of_deep_drilling.pdf ; for 2005 update on deep wells in Oklahoma, see Snead, 2005, https://economy.okstate.edu/caer/files/economics_of_deep_drilling.pdf)

United States: Wyoming, Deep wells, Wind River Basin, Madden Field area

536) Nelson, P.H., P.K. Trainor, and T.M. Finn. 2009. *Gas, Oil, and Water Production in the Wind River Basin, Wyoming*; U.S. Geol. Surv., Scientific Investigations Report 2008–5225; 24pp.; U.S. Geological Survey; Reston, Virginia; http://pubs.usgs.gov/sir/2008/5225/downloads/SIR08-5225.pdf ; accessed March 28, 2016 (NOTE: area geography, map, geology, physical properties; mud weight, water, temp data analysis – Madden field anticline area; evaporites and seals; overpressures, compartmentalization pressure, production; more than a dozen Madden area ultra-deep boreholes drilled)

United States: Bighorn 1-5, Wind River Basin, Fremont County, Wyoming

536a) Collins, J., and J Graves, 1989. The Bighorn No. 1-5, a 25000'Precambrian test in central Wyoming; Soc. Petrol. Drilling Engineers, V4, Issue 01, pp. 13-16. SPE-14987-PA; https://www.onepetro.org/journal-paper/SPE-14987-PA?event-fire=false ; https://www.onepetro.org/journal-paper/SPE-14987-PA ; https://www.onepetro.org/download/journal-paper/SPE-14987-PA?id=journal-paper%2FSPE-14987-PA ; accessed June 28, 2016 (Note: 1983-1985 drilling; Monsanto Oil Co. drilled to 24,877', 7583m TD in Precambrian unit with top at ~24,816' on Madden anticline, Wind River Basin, Wyoming. Produced from Mississippian Madison limestone (top at 23,800') depth. Details: 1) 1,490' - 7,024' / 454 - 2141 m: A 17 1/2 -in. [44.4-cm] pilot hole with a packed BHA was initially drilled to 5,550' / 1692 m; logged to obtain shallow-reservoir information, then opened to 26 in. [66 cm] by use of a packed BHA to 7024'. The remainder of this section was drilled with a 26-in. [66-cm] bit without a preceding pilot hole; 20-in. [50.8-cm] drill string was cemented with the inner string method. 2) 7,024 to 13,970 ft [2141 to 4258 m]: The upper drift diameter of the 20-in. [50.8-cm] casing requited the use of nonstandard size 18 1/4in. 46.4-cm] bits. Three surface strings (30, 20, and 16 in. [76.2, 50.8, and 40.6 cm]) were required to reach 14,000 ft [4270 m]. 3) 13,970'-17,009' / 4258 - 5184 m: drilled with 14-in. [35.6-cm] bits and a packed BHA. 4) 17,009' - 19,850' [5184 to 6050 m]: used l0 5/8ths-in. [27-cm] bits; 4) 19,850' - 22,273' / 6050 - 6789 m: a variety of 8 1/2 in bits used. 5) 22,273' - 24,877' / 6789 - 7583 m: Drilling with 6 1/2-in. [16.5-cm] diamond bit to TD. Location, T38N, R90W, sec. 5; deepest recorded bottom hole drift at 3.5 degrees.)

536b) Finn, T. 2007. Subsurface Stratigraphic Cross Sections of Cretaceous and Lower Tertiary Rocks in the Wind River Basin, Central Wyoming, Chapter 9 in *Petroleum Systems and Geologic Assessment of Oil and Gas in the Wind River Basin Province, Wyoming*; U.S. Geological Survey Digital Data Series DDS–69–J; U.S. Geological Survey, Washington, D.C. http://pubs.usgs.gov/dds/dds-069/dds-069-j/REPORTS/69_J_CH_9.pdf

United States: Madden Deep Unit #2-3 Bighorn; Wind River Basin, Madden Anticline, Fremont County Wyoming

536c) Brown, R.G., and Shannon, L.T. 1989. The #2-3 Bighorn: an ultra-deep confirmation well on the Madden Anticline; *In*: J. Eisert (ed.) *Gas Resources of Wyoming; 40th Annual Field Conference Guidebook, 1989*; p.181-187; Casper, Wyoming. (Note: describes deep Madden boreholes; see Nelson et al., 2009, Reference 536 for summary information; not accessible online)

United States: Shell Government 1, Fremont County, Wyoming

537) Berg, R.R. 1962. Mountain flank thrusting in Rocky Mountain foreland, Wyoming and Colorado. *Bull. Amer. Assoc. Petrol. Geol*. Vol. 46, No. 11, pp. 2019-2032; http://www.muststayawake.com/SDAG/library/Berg1962.pdf ; accessed March 28, 2016 (NOTE: Shell Government 1, Wyoming, TD 10689'; 7000' of Precambrian schist drilled for sub-thrust play; Paleozoic, Mesozoic overturned section on Cretaceous. Laramide deformation, Cretaceous to Eocene. Location Sec 9, T42N, R105W; penetrates EA thrust). For location, used Wyoming State Fremont County mapping software access through http://fremontcountywy.org/county-assessor/mapserve/ at http://maps.greenwoodmap.com/fremontwy/map, public land survey base. Section 9 center location is 43.620, -109.460

Australia: deep drilling, geothermal wells overview

538) AGEA / Australian Geothermal Energy Association Inc. (website accessed March 22, 2016). *Australian Projects Overview*; http://www.agea.org.au/geothermal-energy/australian-projects-overview/ ; {NOTES: Australia Geothermal projects with links. Summaries for 1) Panax / Raya drills in 2010 1st deep well, Salamander 1, Penola Project, Limestone Coast area of South Australia to test a Hot Sedimentary Aquifer (HSA) resource; for details, examine corporate websites: 1) Raya and Panax Geothermal, www.panaxgeothermal.com.au , http://www.panaxgeothermal.com.au/projects-australia.htm, and http://www.rayagroup.com.au/projects-domestic-otway-penola.htm , no longer accessible; 2) Penola Project, Otway Basin, Raya's Salamander-1 well, 4000m depth; 2) Paralana Geothermal Energy Joint Venture Project, Mt Painter region in South Australia's northern Flinders Ranges; http://www.petratherm.com.au/projects/paralana . 3) Geodynamics Limited, Australia's first Enhanced Geothermal Systems (EGS) generated power at the Habanero 1 MWe Pilot Plant.}

539) Petratherm Limited (website accessed November 29, 2016), www.petratherm.com.au and http://www.petratherm.com.au/projects/paralana (Notes: Paralana Geothermal Energy Joint Venture Project, located adjacent to the Mt Painter region in South Australia's northern Flinders Ranges; Paralana 2, drilled in 2009 to 4000m TD. Mesoproterozoic basement rocks of the Mt Painter Complex; Paralana Area location -30.213124, 139.725319)

540) Panax Geothermal (website not accessible April 20, 2016); www.panaxgeothermal.com.au (Notes: Panax link goes to Raya Group website. Penola Project, Limestone Coast area of South Australia, Salimander 1, Otway Basin; TD in 2010.

541) Raya Group (website accessed April 20, 2016); http://www.rayagroup.com.au/projects-domestic-otway-penola.htm ; no longer accessible online (Notes: Penola Project, Limestone Coast area of South Australia, Salimander 1, Otway Basin, TD in 2010; Raya's Limestone Coast Project covers most of the South Australian part of the Otway basin, hot sedimentary aquifers in the Otway basin. The Penola Project is part of the Limestone Coast Project. Penola EGS area location ~ -37.45, 140.8)

542) Geodynamics Limited (website accessed November 29, 2016). http://geodynamics.com.au/ (Notes: drilled Habanero 4 near Innamincka in South Australia and commissioned and produced Australia's first Enhanced Geothermal Systems (EGS) generated power at the Habanero 1 MWe Pilot Plant. (Notes: The Cooper Basin project represented Australia's most successful geothermal project. Following the successful completion of the 1 MWe Habanero Plant Trial; plant located near Innamincka, SA, Australia; area location, -27.745515, 140.736674; also see http://geodynamics.com.au/investor-centre/asx-announcements/ ; Habanero 1, TD 4347m; Habanero 2, TD 4296m; Habanero 3 TD 4140m; Habanero 4 TD 4122; depth to crystalline granitic basement is ~3600m in each hole; wells cut fault near TD; Nappamerri Trough, Innamincka Granite; also area for Jolokia 1 borehole; SA project ending; site remediation underway, http://geodynamics.com.au/wp-content/uploads/2016/11/2016-GDY-AGM-Presentation-for-ASX.pdf and http://geodynamics.com.au/wp-content/uploads/2016/11/20161125-Chairmans-Address-2016-AGM.pdf)

542a) Bendall, B., C. Huddlestone-Holmes, & B. Goldstein. 2013. The current status of geothermal projects in Australia - a national review; *Proceedings, Thirty-Eighth Workshop on Geothermal Reservoir Engineering, Stanford University*, Stanford, California, February 11-13, 2013; SGP-TR-198; https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2013/Bendall.pdf ; accessed November 29, 2016 (Note: Geodynamics Cooper Basin area target is Big Lake Suite granite; issues with overpressures and fractures; Likely Habanero 1, 2, 3, 4 are interconnected by fracture zones; characterization EGS was TBD in 2013; information is outdated in this site; see reference 542)

542b) Government of South Australia, Department of State Development (website accessed November 29, 2016). *Geothermal Energy / AGEG / Status of Geothermal License Activity*; http://geothermal.pir.sa.gov.au/ageg/status_of_geothermal_licence_activity

542c) Nuclear Fuel Cycle Royal Commission, Government of South Australia. 2016. *Nuclear Fuel Cycle Royal Commission Report*. http://yoursay.sa.gov.au/system/NFCRC_Final_Report_Web.pdf ; accessed November 29, 2016 (Note: Deep borehole not considered in SA evaluation)

543) Budd, A.R., and E.J. Gerner. 2015. Externalities are the Dominant Cause of Faltering in Australian Geothermal Energy Development. In: *Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19-25 April 2015*; 13pp. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/04015.pdf ; accessed March 23, 2016 (NOTES: Figure 1, location map for geothermal projects; Salamander-1 drilled in Otway Basin, Penola Trough, 8.5" diameter for bottom 1000m of hole in sandstone section at TD. Between 2003 and 2012, 9 deep geothermal wells drilled in Australia; Habanero-2 at 4459m, drilled in 2004. Geodynamics drilled **Jolokia-1** in same granitic sequence drilled by Habanero wells, spudded May 2008 and drilled to 4911 m, becoming Australia's deepest onshore well; Geodynamics Ltd Origin Energy Pty Ltd Joint Venture Habanero project in the Cooper Basin; mixed results; investors view as risk; Town of Penola, South Australia, location = -37.378955, 140.837289; Innamincka area, Innamincka Deeps area location approximately -27.744642, 140.737356. Australia: Table selected geothermal deep wells:

Date Drilled Name Project Operator Depth Max. Temperature Target
2003 Habanero-1 Innamincka Deeps Geodynamics 4421 m 243 °C EGS - granite
2004 Habanero-2 Innamincka Deeps Geodynamics 4459 m 244 ºC EGS - granite
2008 Habanero-3 Innamincka Deeps Geodynamics 4200 m 242 ºC EGS - granite
2008 Jolokia-1 Innamincka Deeps Geodynamics 4911 m 278 ºC EGS - granite
2009 Savina-1 Innamincka Deeps Geodynamics 3700 m Well suspended EGS - granite
2009 Paralana-2 Paralana Petratherm 3725 m 176 °C EGS – meta-sediment
2010 Salamander-1 Penola Panax 4025 m 171 °C HSA – sandstone; Otway Basin
2011 Celsius-1 Innamincka Shallows Origin 2417 m 160 °C HSA - sandstone
2012 Habanero-4 Innamincka Deeps Geodynamics 4204 m 242 ºC EGS – granite)

544) Rivenbark, M. et al. 2011. Deep geothermal well completions: a review of downhole problems and specialized technology needs; *Proceedings, Thirty-Sixth Workshop on Geothermal Reservoir Engineering, Stanford University*, Stanford, California, January 31 - February 2, 2011 (SGP-TR-191); https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2011/rivenbark.pdf ; accessed March 31, 2016 (NOTE: Cooper Basin, geothermal, Queensland/South Australia border; granodiorite of the Early to Mid-Carboniferous Big Lake Suite, lie beneath the Cooper and Eromanga basin sequences; granitic units 13,000 ft bgl; Geothermal well depths exceed 14,000 ft and temperatures exceed 600°F. Used 9 5/8ths casing, then 7"; Granite will require hydraulic fracturing to increase surface area for efficient heating of injected water." Proterozoic basement, Carboniferous granites and granodiorites. Vertical well was drilled to a measured total depth of 16,075 ft (~4900m); 9-5/8" casing was set to 12,345 ft and then activity was suspended for two years… During that time, a scale composed of hausmannite, an oxide of manganese, formed inside of the 9-5/8" casing covering nearly the entire 12,345 ft."… Neither well location nor name were provided in the article.)

RECORD TECHNOLOGY APPLICATIONS –DEEP WATER

United States: Shell Cardamom Field, Garden Banks Block 427, Gulf of Mexico

545) Shell Oil Company (websites accessed March 23, 2016). *Cardamon Deep-Water Project*; http://www.shell.us/energy-and-innovation/energy-from-deepwater/shell-deep-water-portfolio-in-the-gulf-of-mexico/cardamom.html (NOTES: Auger Platform set in 1994; Shell drilled the record-setting Cardamom discovery well from Auger Platform in 2010 – snaking the drill pipe down under a salt dome overhang to nearly 6.4 kilometers below the sea bed and 5 kilometres (3 miles) away from the platform's drilling rig. Oil piped through the existing Auger platform, Shell's first deep-water tension-leg platform installed 20 years ago in 1994.

546) Shell Oil Company (websites accessed March 23, 2016). *Shell announces second major 2014 start up in deep-water Gulf of Mexico with Cardamom development first oil*, http://www.shell.com/global/aboutshell/media/news-and-media-releases/2014/shell-announces-cardamom-development-first-oil.html (NOTES: The Cardamom field is located in Garden Banks Block 427, approximately 225 miles (362 kilometres) southwest of New Orleans, Louisiana, in water more than 2,720 feet (800 metres) depth; drilled from Auger Platform; ; conflict in data = this stated 6.4 km below sea floor; water depth 2720' / 800m; multimedia http://multimediacapsule.thomsonone.com/royaldutchshellplc/shell-announces-cardamom-development-start-up-in-deep-water-gulf-of-mexico and third website link, Cardamon deep water project http://www.shell.us/energy-and-innovation/energy-from-deepwater/shell-deep-water-portfolio-in-the-gulf-of-mexico/cardamom.html#vanity-aHR0cDovL3d3dy5zaGVsbC51cy9hYm91dHNoZWxsL3Byb2plY3RzLWxvY2F0aW9ucy9ndWxmLW9mLW1leGljby1kZWVwd2F0ZXIvcG9ydGZvbGlvL2NhcmRhbW9tLmh0bWw for summary, photos)

United States: Shell Stones Project, Walker Ridge block 508, Gulf of Mexico

547) SUBSEAIQ Offshore Field Development Projects: *Stones* (website accessed March 22, 2016). http://www.subseaiq.com/data/Project.aspx?project_id=350&AspxAutoDetectCookieSupport=1 (NOTES: Stones-2 to a true vertical depth of 28,560 feet (8,705 meters) in a water depth of 9,576 feet (2,919 meters); Stones-3, reached a depth of 29,400 feet (8,961 meters); Walker Ridge Block 508)

548) Shell Oil Company (United States) *Stones Deepwater Project* (website accessed March 22, 2016); http://www.shell.us/energy-and-innovation/energy-from-deepwater/shell-deep-water-portfolio-in-the-gulf-of-mexico/stones.html (NOTES: ; Block 508 in the Walker Ridge ; disc. 2005; the reservoir depth is around 8,077 meters (26,500 feet) below sea level and 5,181 meters (17,000 feet) below the mud line. Lower Tertiary, 320 kilometers (200 miles) southwest of New Orleans, Louisiana; accumulation in Lower Tertiary section; ~2,900 meters (9,500 feet) water depth. See also 2013 Press Release http://www.shell.com/global/aboutshell/media/news-and-media-releases/2013/new-gulf-mexico-stones-08052013.html; and http://www.shell.us/energy-and-innovation/energy-from-deepwater/shell-deep-water-portfolio-in-the-gulf-of-mexico/stones.html (Water depth ~9,500 feet; reservoir depth ~26,500 feet below sea level, ~17,000' below mud line)

United States: Shell Perdido Project, Alaminos Canyon Block 857, Gulf of Mexico

549) Shell Global (website accessed March 22, 2016). *Major Project / Perdido*; http://www.shell.com/about-us/major-projects/perdido.html ; (NOTES: Shell Perdido Field, production, Perdido in 2010 was world's deepest offshore drilling and production facility; 2,450 meters (8,000 feet) of water… will produce from the Great White, Silvertip, and Tobago offshore fields… Located 320 kilometers (200 miles) from the Texas coast in Alaminos Canyon Block 857; … 26°7′44″N 94°53′53″W, 26.128889,-94.898056 ; location from https://en.wikipedia.org/wiki/Perdido_%28oil_platform%29 ; see also http://www.shell.com/energy-and-innovation/deep-water/unlocking-energy-from-deep-water.html#iframe-L3dlYmFwcHMvZGVlcF93YXRlci92Mi9pbmRleC5odG1s for major deep water offshore projects

549a) Nixon, Lesley, and Eric Kazanis, Shawn Alonso. 2016. *Deepwater Gulf of Mexico, December 31, 2014*; OCS Report, BOEM 2016-057; U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, Office of Resource Evaluation, August 2016; https://www.boem.gov/Deepwater-Report-2014/ ; https://www.boem.gov/Deepwater-Gulf-of-Mexico-Report-2014/ ; (Note: The Perdido Hub spar was installed in 2009 in AC block 857 in 7,817' of water, claiming the world water-depth record for a spar. The hub hosts production from three fields: Great White (AC857) and Tobago/Silvertip (AC859) Fields; first production 2010. A spar is a type of floating oil platform typically used in very deep waters, and is named for logs used as buoys in shipping that are moored in place vertically. Blowout and explosion aboard the Deepwater Horizon drilling rig caused oil to flow into the Gulf of Mexico for 87 days before the well was sealed. In 2016, the Stones (WR508) facility will feature the use of the northern GOM's second FPSO [floating production, storage, and offloading]. The FPSO will be installed in approximately 9,500' of water, setting the world water-depth record for a production facility.)

United States: Chevron and partners; Jack/St. Malo Fields, Deepwater, Gulf of Mexico

549b) Chevron. 2017. Jack/St. Malo: Expanding Chevron's Reach in the deepwater U.S. Gulf of Mexico; (a supplement to) *Offshore - Oil and Gas Journal / Oil and Gas Financial Journal*; PennWell Custom Publishing; 57 pages; https://www.ogj.com/content/dam/ogj/Executive%20Briefs/CHEVRON%20JACK%20ST%20MALO%20PUBLICATION.pdf (Note: Excellent summary of complex deep water project and subsea operational activities and facilities; also see https://www.chevron.com/projects/jack-stmalo; St. Malo discovered in 2003; Jack discovered in 2004. Field reservoirs separated by ~25 miles. Production from semi-submersible platform, the Walker Ridge Regional host. Water depth ~7000'; reservoir is Lower Tertiary / Paleogene age Wilcox Trend; well depths in 28000' range. Production start in 2014; 1000-1400' pay interval; high temperature and pressure environment. Excellent summary of project, participants and their technological and engineering contributions. From Offshore Technology, https://www.offshore-technology.com/projects/jackstmalodeepwaterp/ , the Jack field lies in Walker Ridge blocks 758 and 759; St Malo field lies in Walker Ridge Block 678 at a water depth of 2,100ft. See reports of The Bureau of Ocean Energy Management [BOEM])

United States: BP Tiber Oil Field, Keathley Canyon Block 102, Gulf of Mexico

550) British Petroleum (website accessed May 20, 2016). *Deepwater Gulf of Mexico*; http://www.bp.com/en_us/bp-us/what-we-do/exploration-and-production/deepwater-gulf-of-mexico.html (NOTE: oil discovery in the deep water Gulf in 2009, is believed to be one of the largest finds in the region. Drilled to a total depth of 35,055 feet, including 4,132 feet of water; Keathley Canyon, Block 102, Tiber Oil Field. Operations suspended since Deep Water Horizon Macondo event in 2010; location of Tiber from Wikipedia, https://en.wikipedia.org/wiki/Tiber_Oil_Field, 26.878333° -93.268333° in Keathley Canyon block 102)

551) Harrison, Edward. May 30, 2010. How BP's Deepwater Horizon oil find was originally reported in September 2009; *Credit Writedowns* (website accessed March 22, 2016), https://www.creditwritedowns.com/2010/05/how-bps-deepwater-horizon-oil-find-was-originally-reported-in-september-2009.html (NOTE: Deepwater Horizon drilled the Tiber well in 2009 to 35,050' vertical depth and 35,055' (10685m) feet measured depth (MD), or more than six miles, while operating in 4,130' (1260m) of water. Next major BP Deep Water Horizon well was the Macondo Prospect in Mississippi Canyon, with April 2010 disaster after which work ceased in Gulf. Tiber unverified data = other articles state deeper section of hole to be 5.5" diameter. Add TD depth drilled to water depth, and some recorded depth then as 11945m / 39190' TD; estimated 4 billion barrels in place. 26.878333° -93.268333°, Tiber location and data; Lower Tertiary deep water sands; location taken from Wikipedia.org, https://en.wikipedia.org/wiki/Tiber_Oil_Field)

United States: BP / Deepwater Horizon, Macondo Borehole: Mississippi Canyon Block 252, Gulf of Mexico / GOM

552) Deepwater Horizon Study Group. 2011. *Final Report on the Investigation of the Macondo Well Blowout*; 124p.; Center for Catastrophic Risk Management (CCRM) and U.C. Berkeley http://ccrm.berkeley.edu/pdfs_papers/bea_pdfs/dhsgfinalreport-march2011-tag.pdf ; accessed March 31, 2016 (NOTE: ?reported 9 7/8ths" casing to 18126', yet 8.5" hole to TD@18360'; Investigation of the Macondo Well Blowout

Disaster, March 1, 2011. Location of BP Macondo prospect, 28.736667°, -88.386944° Mississippi Canyon Block 252; spud, 10/2009; location from Wikipedia.org, https://en.wikipedia.org/wiki/Macondo_Prospect , Macondo Prospect)

United States: Large diameter boreholes, DOE; Climax, NNSS

553) NNSA/NSO (National Nuclear Security Administration, Nevada Site Office). 2005. *Nevada Test Site Guide*; DOE/NV-715 Rev. 1; DOE / NNSA / /Nevada Site Office, Las Vegas, NV. http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/doe%20nv%202001e.pdf ; accessed March 28, 2016 (NOTES: emplacement holes or shafts at NTS for subsurface tests = typical depths 600-2200', hole diameter 74-120"; Drill bits used = size range of 144"-36"; see pages 61, 62 for Pile Driver and Climax test; poor connection to server; NTS now designated Nevada National Security Site)

553a) Heuze, F.E. 1981. *Climax Granite, Nevada Test Site, as a host for a rock mechanics test facility related to the geologic disposal of high level nuclear wastes*; Lawrence Livermore National Laboratory, Livermore, California; Technical report UCID—18946; 44 pp. http://www.osti.gov/scitech/servlets/purl/59217 ; accessed July 25, 2016

United States: Large diameter boreholes, DOE / NNSS Nevada National Security Site

554) DOE/NNSA/NSO. 2010. *Big Hole Drilling, Nevada National Security Site History*: DOE/NV-773; DOE/NV, Las Vegas, NV; https://www.nnss.gov/docs/fact_sheets/DOENV_773.pdf (NOTE: large diameter holes drilled with e.g., 96" bit; develop dual string airlift reverse circulation for drilling test holes with ~13 3/8" pipe; 36" diameter holes common)

United States: Large diameter boreholes, DOE Testing and Plowshare Program (Plowshare Program; examples = Gasbuggy, Rio Blanco, Rulison tests

555) American Oil and Gas Historical Society (website accessed March 28, 2016). *"Gasbuggy" Tests Nuclear Fracking*; http://aoghs.org/technology/project-gasbuggy/ ; (NOTES: 1967, Gasbuggy test, drilled in 1967 to 4240' part of Plowshare program to test fracking technology Using Atomic Explosion. Parker Drilling Rig No. 114: In 1969, Parker Drilling Company signed a contract with the U.S. Atomic Energy Commission to drill a series of holes up to 120 inches in diameter and 6,500 feet in depth in Alaska and Nevada for additional nuclear bomb tests. Parker Drilling's Rig No. 114 was one of three special rigs built to drill the wells; test in New Mexico; Gasbuggy 18" warhead lowered into hole, ~60 miles from Farmington, New Mexico; 4,042' deep; device was 13' long and 18" wide to 4240' [discrepancy]; EM sign states 4227' detonation; northwest of Sante Fe ~90 miles, Carson Nat. For., Rio Arriba County, New Mexico, T29N, R4W. In 1969, Project Rulison – at a site near Rulison, Colorado – detonated a 43-kiloton nuclear device almost 8,500 feet underground to produce commercially viable amounts of natural gas. A few years later, project Rio Blanco, northwest of Rifle, Colorado, was designed to increase natural gas production from low-permeability sandstone. The May 1973 Rio Blanco test consisted of the nearly simultaneous detonation of three 33-kiloton devices in a single well, according to the Office of Environmental Management. The explosions occurred at depths of 5,838, 6,230, and 6,689 feet below ground level. It would prove to be the last experiment of the Plowshare program. The Plowshare program was canceled in 1975. Atomic Energy Commission downhole nuclear detonations to release natural gas trapped in shale.)

United States: Large Diameter holes, technology development and capabilities, A.E.C. (DOE)

556) Allen, J.H. ~1978. *Drilling large diameter holes; Parts 1,2, 3*; Smith Tool Company, Compton, CA; reprints from *Society Of Mining Engineers of A.I.M.E.*, preprint no. 76-AU-67; and by *World Mining Magazine*, from the January, 1976 issue, and others; http://pbadupws.nrc.gov/docs/ML0404/ML040480471.pdf ; accessed March 28, 2016 (NOTES: A collection of several reports by the same author; reviews large hole drilled for AEC; number of 72" diameter holes drilled [2790', 4000' and 5000' depths] rotary drilling reverse circulation)

United States: Faultless Project; Nye County, Nevada National Security Site

557) Mackedon, Michon. *Project Faultless: Central Nevada's Near Miss as an Atomic Proving Ground, Eureka Co., NV*; Eureka County, NV, Nuclear Waste Office (website accessed March 28, 2016). http://www.yuccamountain.org/faultless.html (NOTES: Faultless tested January 19, 1968, Central Nevada Test Area; AEC seeking alternative test site to NTS / NNSS; Three deep emplacement holes were drilled on the Central Nevada test area [CNTA] site, one for Faultless and the other two in anticipation of tests which would immediately follow a successful calibration of the site. A second test was even assigned the code name, Adagio. The size of the Adagio drillhole suggests that it was planned to be a test in the multi-megaton range, three or perhaps 4 megatons; largest underground test ever conducted by the U.S. was 5 megaton Cannikin, in 1971, at Amchitka, Alaska.)

557a) DOE Office of Legacy Management (website accessed August 2016). *CNTA Site (Faultless)*; http://www.lm.doe.gov/CNTA/Sites.aspx (GEMS map site for LM managed properties, see https://gems.lm.doe.gov/)

557b) Fenix and Scissons. 1973. *Abandonment of drilled holes, Central Nevada Test Area*; Fenix and Scissons, Las Vegas, NV; http://www.lm.doe.gov/CNTA/CNT1973.pdf

558) Nevada Division of Environmental Protection, Bureau of Federal Facilities (website accessed March 28, 2016). *Remediation Central Nevada Test Site*; http://ndep.nv.gov/cnta/cnta.html ; [NOTES: Faultless test, well UC-1, TD in zeolitized tuff, 1968, the Atomic Energy Commission (AEC), Department of Energy (DOE), detonated a nuclear device with a yield of 200 to 1,000 kilotons at a depth of 3,200 feet below ground surface. located in the Hot Creek Valley in central Nevada; Nye County. Seeking locations for various sites, used Wikipedia and Google map to identify following or verify general locations identified on maps in publications; also see http://www.lm.doe.gov/CNTA/Sites.aspx; Faultless borehole diagram found at http://www.lm.doe.gov/CNTA/CNT1973.pdf; Location verification: Faultless (Wikipedia, wikimaps.org, Google Maps, Wikimapia.org); Central Nevada Test Site, Hot Creek Valley, Nye County, Nevada 38.63421°N 116.21622°W; 38.634232, -116.216181. Also Plowshare Project tests (Wikipedia: https://en.wikipedia.org/wiki/List_of_nuclear_test_sites and https://en.wikipedia.org/wiki/Operation_Crosstie) tests: 1) Gnome (Wikipedia) 8.4 miles SW from WIPP, Eddy County, NM; 32.26298°N 103.86592°W; 2) Gasbuggy (Wikipedia), east of Farmington, Rio Arriba County, NM; 36.6778°N 107.2089°W; 3) Rio Blanco Nuclear Test RB-

E-01: Project Rio Blanco (Google), Rifle, Rio Blanco County, CO; 39.799572, -108.375993; 4) Rulison test (Wikipedia), near Rifle, CO; ?39.79322°N 108.3672°W?); present day Gnome data, see http://www.lm.doe.gov/gnome/Sites.aspx]

558a) DOE Office of Legacy Management (websites accessed August 2016). *LM Sites*; http://energy.gov/lm/sites/lm-sites; GEMS map site for LM managed properties, see https://gems.lm.doe.gov/

United States: Plowshares Program, Gnome Site, Eddy County, New Mexico

558b) DOE Office of Legacy Management (websites accessed August 2016). Gnome-Coach site; http://www.lm.doe.gov/gnome/Sites.aspx (Note: For GEMS map site for LM managed properties, see https://gems.lm.doe.gov/)

United States: NNSS (formerly NTS) and Other "Big Holes", Nevada National Security Site

559) Lackey, M.D. 1983. Big Hole Drilling - The State of the Art; Chapter 33, pp. 533-543; In: Sutcliffe, H., and J.W. Wilson (eds.), 1983. *Proceedings of the Rapid Excavation and Tunneling Conference, Volume 1*, 1983 Rapid Excavation and Tunneling Conference, Chicago, Illinois, June 12-16, 1983; American Institute of Mining, Metallurgical, and Petroleum Engineers, American Society of Civil Engineers; http://pbadupws.nrc.gov/docs/ML0404/ML040480468.pdf ; http://www.osti.gov/scitech/servlets/purl/6301544 ; accessed March 28, 2016 (NOTE: Nevada Test Site, Nevada National Security Site; large diameter holes, approximately 450 big holes drilled, at least 48" in diameter, to depths of >500'; Twenty "Big Holes" were drilled in 1981, 64 inches to 96 inches in diameter to an average depth of 1,590 feet; Reynolds Electrical & Engineering Company submittal of draft for symposium; selected larger diameter deep boreholes drilled off NNSS detailed)

United States: Gasbuggy, Plowshares Program; Rio Arriba County, New Mexico

559a) Holmes and Narver. 1983. Project Gasbuggy *Site Restoration Final Report*; Holmes and Narver, U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada; www.lm.doe.gov/Gasbuggy/GSB000018.pdf ; accessed July 21, 2016

559b) DOE Office of Legacy Management (website accessed July 22, 2016). *Gasbuggy (New Mexico) Site*; http://www.lm.doe.gov/gasbuggy/Sites.aspx; http://www.lm.doe.gov/Gasbuggy/Documents.aspx (Note: For GEMS map site for LM managed properties, see https://gems.lm.doe.gov/)

559c) Cutler, W., and H. Kendrick. 1968. Drilling and testing operations for project Gasbuggy; *Proceedings 43rd Annual Fall Meeting of the Society of Petroleum Engineers of AIME*, Houston, Texas, September 29-October 2, 1968; http://www.osti.gov/scitech/servlets/purl/4835959/ ; http://www.osti.gov/scitech/biblio/4835959/ ; accessed July 21, 2016

United States: Rulison Project, Plowshares Program; Garfield County, Colorado

559d) Reynolds, M., B. Bray, R. Mann. Project Rulison: A Preliminary Report; p. 597-628, in: *Proceedings of the Symposium on Engineering with Nuclear Explosives, January 14- 16, 1970, Las Vegas, Nevada*, CONF-700101, CFSTI, Vol. 1, http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/36/010/36010810.pdf for present day, http://www.lm.doe.gov/rulison/Sites.aspx ; accessed July 21, 2016

559h) DOE Office of Legacy Management (website accessed August 2016). Rulison Site; http://www.lm.doe.gov/rulison/Sites.aspx (Note: For GEMS map site for LM managed properties, see https://gems.lm.doe.gov/)

United States: Rio Blanco Project, Plowshares Program; Rio Blanco County, Colorado

559e) CER Geonuclear Corporation and Continental Oil Company. 1975. *Project Rio Blanco Final Report: Detonation Related Activities*; 95pp; http://dspace.library.colostate.edu/webclient/DeliveryManager/digitool_items/cmu01_storage/2014/09/08/file_1/333569 ; accessed July 21, 2016

559f) Holzer, F., and D. Emerson, 1971. *Possible Effects of the Rio Blanco Project on the Overlying Oil Shale and Mineral Deposits*, UCRL-51163; Lawrence Livermore National Laboratories, Livermore, California; TID-4500, UC-35; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/03/026/3026946.pdf ; accessed July 21, 2016

559i) DOE Office of Legacy Management (Websites accessed August 2016). Rio Blanco Site; http://www.lm.doe.gov/rio_blanco/Sites.aspx (Note: For GEMS map site for LM managed properties, see https://gems.lm.doe.gov/)

United States: Climax Spent Fuel Test; Nevada National Security Site, Nye County, Nevada

559g) Patrick, W.C. 1986. *Spent-Fuel Test—Climax: An Evaluation of the Technical Feasibility of Geologic Storage of Spent Nuclear Fuel in Granite; Executive Summary of Final Results*; UCRL-53762; Lawrence Livermore National Laboratory / University of California, Livermore, California; http://www.osti.gov/scitech/servlets/purl/60116 ; accessed July 21, 2016

Sweden: DGE#1and #2 geothermal and hydrologic test boreholes, Lund, Scania, Sweden

560) Bjelm, Leif. 2006. Under balanced drilling and possible well bore damage in low temperature geothermal environments; In*: Proceedings, Thirty-First Workshop on Geothermal Reservoir Engineering, Stanford University*, Stanford, California, January 30-February 1, 2006; SGP-TR-179; https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2006/bjelm.pdf ; accessed April 20, 2016 (Notes: In 2002/2003, DGE#1 drilled to 3701.8m TD in gneissic basement rock; DEG, Department of Engineering Geology; deep drilling capability in hard formations as a function of drilling methods. Tornquist Zone structural feature; basement at ~2000m; quartz rich gneiss/gneiss granite)

Sweden: Spent Fuel Repository, Forsmark; Forsmark Repository area characterization borehole

561) SKB / Swedish Nuclear Fuel and Waste Management Company / Svensk Kärnbränslehantering AB (website accessed March 30, 2016). http://www.skb.com/ {NOTE: 2011, SKB applied to the authorities for permission to build a repository for spent nuclear fuel in Forsmark}

562) Harrison, Tim. 2000. Very Deep Borehole: Deutag's opinion on boring, canister emplacement and retrievability; R-00-35, SKB / Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Co; 67 pages; http://www.mkg.se/uploads/DB/SKB_R-00-35_Very_deep_borehole_Deutags_opinion.pdf; accessed March 28, 2016 (Notes: Deutag involved in "Kontinentale Tiefbohrprogramm der Bundesrepublik Deutschland (KTB)" drilling in Rhine Valley, 1990-1994; 8665m to TD 9031m, 6.5" hole; 8.5" hole ~8665m to 7784m; example deep well in New York State, MHP borehole may be useful to investigate further)

563) Claesson, Lars-Åke, and Göran Nilsson. 2006. *Forsmark site investigation: Drilling of the telescopic borehole KFM06C at drill site DS6*; Report P-05-27; Svensk Kärnbränslehantering AB, Stockholm, Sweden; http://www.skb.se/upload/publications/pdf/P-05-277.pdf ; last accessed September 8, 2015 (NOTE: map with exploration characterization boreholes illustrated; difficult to download / access; change browser)

Sweden: Deep borehole investigation

564) Ahall, K-I. 2006. *Final deposition of High-level Nuclear Waste in very deep boreholes: an evaluation based on recent research of bedrock conditions at great depths*. Swedish NGO Office of Nuclear Waste Review. MKG Report No. 2; MKG (Miljöorganisationernas kärnavfallsgranskning, i.e., Swedish NGO Office of Nuclear Waste Review); http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/38/088/38088522.pdf ; accessed March 31, 2015 (NOTE: design options; performance issues)

565) Julin, C., et al. 1998. *The Very Deep Hole Concept - Geoscientific appraisal of conditions at great depth; SKB Technical Report 98-05*; SKB, Svensk Karnbranslehantering AB, Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden; 124pp. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/30/007/30007156.pdf ; accessed March 31, 2016 (Note: Considered disposal option for 2-4km depth; evaluation of available data; figure 3-3 helpful for reader; examines available information on deep boreholes in Europe; also mentions mines, but only data used was from Canadian mines. Gravberg-1 well in Sweden Siljan ring followed by drilling of similar hole in ring, borehole Sternberg-1; KTB, Das Kontinentale Tiefbohrprogramm der Bundesrepublik Deutschland, drilled Gravberg hole to 9101 m in October 1994; KTB deep borehole, in the first 4000 m, with a few exceptions, the inclination of the wellbore was maintained within 1°. General geologic history, tectonics in Europe presented)

Sweden: Siljan Ring, Impact structure and Gravberg-1 well (fractured granitic / crystalline rock)

566) PASSC Earth Impact Database (website, accessed March 28, 2016). *Silja*n; Planetary and Space Science Centre (PASSC), University of New Brunswick, Fredericton, New Brunswick, Canada http://www.passc.net/EarthImpactDatabase/siljan.html (NOTES: Siljan, Sweden, N 61° 2', E 14° 52', 52km diameter, age 376.8 ± 1.7 Mya. See Reference 566a, Swedish Scientific Drilling Program {SSDP} conducted work in Siljan area)

566a) Swedish Scientific Drilling Program / SDDP (website accessed November, 2016). *Concentric Impact Structures in the Paleozoic*; http://www.ssdp.se/projects/cisp.html ; (Note: CISP / Concentric Impact Structures in the Paleozoic)

567) Boden, A. and Eriksson, K.G., eds. 1988. Deep Drilling in Crystalline Bedrock; *Proceedings of the International Symposium held in Mora and Orsa*, September 7 -10, 1987, Springer-Verlag, New York; Volume 2; https://books.google.com/books?id=I6bwCAAAQBAJ&pg=PP4&lpg=PP4&dq=Deep+Drilling+in+Crystalline+Bedrock,+v.+1,+Springer-Verlag,+1988&source=bl&ots=DdQJkvEVec&sig=UCyvRVe1sE_34syvsibsuKPXgoY&hl=en&sa=X&ved=0CCcQ6AEwAmoVChMI_MLroebdxwIVBDM-Ch2obgli#v=onepage&q=Deep%20Drilling%20in%20Crystalline%20Bedrock%2C%20v.%201%2C%20Springer-Verlag%2C%201988&f=false ; accessed March 28, 2016 (NOTES: in Volume 2, pp. 19-21, listing of deep holes to that time, diameter, depth, location information; Gravberg-1 well, TVD`6.7km; spud 1986. Excellent summary of deep well granitic / crystalline drilling projects. For selected crystalline drilling projects, see Figure 4, page 18, 19; several of the projects are presented in table, herein. See also Boden, A. and Eriksson, K.G. (eds.). 1988. *Deep Drilling in Crystalline Bedrock*, v. 1, Springer-Verlag, New York, for further details)

569) Komor, S. and J. Valley. 1990. Deep drilling at the Siljan Ring Impact Structure: oxygen-isotope geochemistry of granite. *Contributions to Mineralogy and Petrology*, 105(5)/516-532; Springer; abstract accessed March 28, 2016; http://link.springer.com/article/10.1007%2FBF00302492#page-2 and http://pubs.er.usgs.gov/publication/70016084; (NOTES: 362Mya impact; bedrock age 1.7Ga; drilled by energy company Vattenfall)

570) Castano, J., et al. 1988. Geochemical studies of gases in crystalline rocks, Siljan Ring well, Sweden; *5th Annual Meeting, Abstracts and Program, The Society for Organic Petrology (TSOP)*; http://archives.datapages.com/data/tsop/TSOPv5_1988/castano.htm ; abstract accessed March 28, 2016 (NOTE: TVD in sidetrack 2 depth 6394m; sidetrack 3 was in progress in 1988, planned depth 7500m)

Sweden: COSC # 1 borehole (Collisional Orogeny in the Scandinavian Caledonides), Are, Jämtland County, Sweden

571) Lorenz, H., J.-E. Rosberg, et al. 2015. COSC-1 – drilling of a subduction-related allochthon in the Palaeozoic Caledonide orogen of Scandinavia; *Scientific Drilling*., 19, 1–11, 2015; doi:10.5194/sd-19-1-2015; www.sci-dril.net/19/1/2015/ , and http://www.sci-dril.net/19/1/2015/sd-19-1-2015.html ; accessed March 28, 2016 (NOTES: Location information, Table 1, 63.401629 N 013.202926 E; elevation 522.8m asl; 2495m depth; drilled in 2014)

572) Hedin, P. 2015. *Geophysical studies of the upper crust of the central Swedish Caledonides in relation to the COSC scientific drilling project*. Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 1281. 87 pp. Uppsala: Acta Universitatis Upsaliensis. ISBN 978-91-554-9320-2. https://uu.diva-portal.org/smash/get/diva2:849748/FULLTEXT01.pdf ; accessed March 30, 2016 (NOTES: Dissertation presented at Uppsala University and evaluated Hambergsalen, Geocentrum, Villavägen 16, Uppsala, Friday, 16 October 2015; 55km seismic profile used for selection of the optimum location for the two 2.5 km deep COSC boreholes; COSC-1 was drilled in 2014 and reached the targeted depth; excellent core recovery. Target, Lower Seve Nappe formed during *Collisional Orogeny in the Scandinavian Caledonides (COSC)* – (project name); Part of Paleozoic Caledonides; 400mya collision of the two continents Baltica and Laurentia with partial subduction of the former beneath the latter. Closing of Iapetus ocean began in Cambrian and continued through

Ordovician; nappes formed with 400km displacement onto Baltic – shortening; Scandes, dominate the geology and topography of Norway and western Sweden; Western Jämtland, Sweden was chosen for scientific deep drilling with DBH targets located in the province of Jämtland, west central Sweden, Scandinavian Caledonides. Baltoscandian Platform forms the basement underneath the Caledonian cover. The first borehole, COSC-1, was drilled near the town of Åre in 2014 to investigate the formation of allochthon, the Seve Nappe Complex. The second borehole, COSC-2, was in the planning stages and will study the nature of deformation in the underlying allochthons along the basal detachment (the décollement) and in the underlying basement. Lower, Middle, Upper and Uppermost Allochthons, all overlying the Precambrian autochthonous basement; the Lower Allochthon is derived from the Baltica platform (continental shelf) and foreland basin, the Middle Allochthon is dominated by units that originated from the Baltoscandian rifted margin and continent / ocean transition zone; the Upper Allochthon is composed of igneous suites and sedimentary formations of the Iapetus oceanic domain; the Uppermost Allochthon comprises fragments of the Laurentian continental margin. Cambrian sedimentary rocks including black alum shales rest unconformably on top of the Precambrian crystalline basement; … the frontal décollement continues westwards and probably reaches the Swedish-Norwegian border at a depth of about 6 km. The kerogen-rich alum shales are thought to have acted as a lubricant along this basal detachment. The first borehole, COSC-1 [ICDP drill site 5054-1-A, IGSN: ICDP5054EEW1001], initial drilling in 2013; completed in 2014; TD 2495.8; hole/core diameter to TD, hole/core diameters of 123/85 mm, 96/63 mm and 76/48 mm. Geology = Lower Seve Nappe, comprising alternating layers of felsic calcsilicate/ gneisses and amphibolites; mylonitic 1700-2300m, and mafic rocks were encountered at about 2314 m and a transition from gneissic to lower-grade metasedimentary rocks occurs around 2350 m. COSC-1 coring ~ 2.5 km vertical section through the Lower Seve Nappe revealed a thick mylonite zone. It is present in nearly 800 m of the lowermost part of the core and was not fully penetrated at the drilled Total Depth. Recent discoveries of microdiamond inclusions in garnets within paragneisses at both Åreskutan (Klonowska et al., 2015) and Snasahögarna (Majka et al., 2014a) witness to the ultrahigh pressure metamorphism and subduction of the Middle Seve Nappe to depths exceeding 100 km.; abandoned copper mine at Fröå.")

572a) Swedish Scientific Drilling Program, SSDP (website accessed August 2, 2016), Collisional Orogeny in the Scandinavian Caledonides; http://www.ssdp.se/projects/cosc/ and http://www.ssdp.se/projects/cosc/cosc-1.html

Russian Federation: SG-4 Borehole

573) Ayarza, P., C. Juhlin, et al. 2000. Integrated geological and geophysical studies in the SG4 borehole area, Tagil Volcanic Arc, Middle Urals: Location of seismic reflectors and source of the reflectivity; *Journal of Geophysical Research, Vol.* 105, No. B9, pp. 21,333-21,352, September 10, 2000; http://onlinelibrary.wiley.com/doi/10.1029/2000JB900137/pdf ; accessed abstract and preview March 30, 2016 (NOTES: SG-4 is 5400m deep borehole, Russia, Middle Urals. Excellent summary of geology; approx. location 58.38N, 58.73E; drilled within Silurian pyroclastics, volcaniclastics, and basalt (arc system, Tagil); spud, 1985; 1999, reached 5401m depth; planned for 15000m deep well in future; pilot hole and main hole appear deviated; TVD=?; hole diameter not recorded here; http://wikimapia.org/15722589/Ural-Superdeep-Borehole-SG-4 location also available for location information; 58°22'38"N, 59°43'46"E from ru.wikipedia.org (Russian), 58.377222, 59.729080)

Russian Federation: Kola superdeep borehole, SG-3, Murmansk Oblast, Russia

574) USSR Ministry of Geology. 1984. *The Kola Super-deep Borehole (Guide)*; http://ariealt.home.xs4all.nl/2014/dark_ecology/kola_super-deep_booklet.html ; preview September 2, 2015 (NOTES: 12,262m TD; 69º23'46.4"N, 30º36'31.2"E; 21.5 cm diameter at TD, 2.7Ga age)

575) Wikipedia (website accessed March 28, 2016). *Kola Superdeep Borehole*; https://en.wikipedia.org/wiki/Kola_Superdeep_Borehole ; (NOTES: in Murmansk Oblast, Russia; 12,262 metres TD for SG-3; Pechengsky District, on the Kola Peninsula, 69°23'46"N 30°36'32"E; ; 69.396219,30.608667 ; Archean. Link to Official Russian website, Kola superdeep borehole, http://superdeep.pechenga.ru/ , in Russian; location on Google maps also available)

576) Gorbatsevich, F., et al. 2010. Structure and permeability of deep-seated rocks in the Kola Superdeep Borehole Section (SG-3); *Acta Geodyn. Geomater.* Vol. 7, No. 2 (158), 145–152, 2010; https://www.irsm.cas.cz/materialy/acta_content/2010_02/1_Gorbatsevich.pdf ; accessed March 30, 2016 (Note: located in the Pechenga graben-syncline. Down to a depth of 6842 m the SG-3 section is represented by sedimentary-volcanic rocks of the Lower Proterozoic Pechenga complex; below the gneisses and amphibolites of the Archaean basement occur.)

576a) NEDRA / Scientific Industrial Company on Superdeep Drilling and Comprehensive Investigation of the Earth's Interior. 1992. *Characterization of crystalline rocks in deep boreholes. The Kola, Krivoy Rog and Tyrnauz boreholes*; SKB Technical Report, 92-39; Svensk Kärnbränslehantering AB, Stockhlm, Sweden; http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/25/037/25037437.pdf ; and http://dspace.library.dc-uoit.ca/uoit/bitstream/dcuoit/988/1/1990.PDF accessed June, 2016 {Note: KOLA, SG-3, 12261 m deep, Kola Peninsula, Baltic Shield, ~ 69°25'N, 30°44'W, spud 1970; Pechenga Trough, a part of the Pechenga-Imandra-Vargus zone; igneous and metamorphic units; Proterozoic sedimentary and volcanic rocks overlying Archaean granite and gneiss; diameter 245mm at 8770m. KRIVOY ROG SG-8, 5000m deep, Ukraine; spud, 1984; planned 12000m TD; in 1991, ~5000m; Ukrainian Shield, Late Archaean to Early Proterozoic (3600-1300 Ma). Krivoy Rog-Kremenchug structure depression formed 1.8-2.0Ga / Proterozoic; Krivoy Rog series, i.e. different types of schist, iron-deposits, conglomerate, arkose, amphibolite, other; thrust fault @5000m. TYRNAUZ borehole, 4001 m deep and located between the Black Sea and the Caspian Sea; drilled during 1987-1989. The Tyrnauz borehole was drilled within the Eldjurtinsky granite, which is the youngest intrusion in the area. The intrusion is 1.8-1.9 Ma old which corresponds to the Pleistocene age; within Pshekish-Tyrnauz zone, Caucasian folded belt (Cenozoic)}

577) ICDP / International Continental Scientific Drilling Program (website accessed March 31, 2016). *Kola Superdeep Borehole (KSDB) - IGCP 408: Rocks and Minerals at Great Depths and on the Surface*, International Continental Scientific Drilling Program; http://www-icdp.icdp-online.org/front_content.php?idcat=695 ; (NOTES: Russia, northeastern Scandinavian Shield, Kola Peninsula, Murmansk reg, Zapolyarniy; 69° 23' N, 30° 36' E ; drilling 1970-1994;

578) Gravity Wiki (webpage accessed August 25, 2015). *Kola Superdeep Borehole*; http://gravity.wikia.com/wiki/Kola_Superdeep_Borehole ; and accessed March 31, 2016 (NOTES: Spud, 1970; deepest sidetrack, SG-3, reached 12,261 metres (40,230') in 1989; work-over stopped in 1992; world depth record once held by the Bertha Rogers hole in Washita County, Oklahoma at 9,583 m (31,440') with TD in molten sulfur)

Russian Federation: Vorotilovo Deep Borehole, Puchezh-Katunk impact

579) Esipko O.A., Kolbasova A.V., Rosaev A.E. ?2002. *On problem of interpretation and forecasting space-temporary variations of geophysical fields on results of deep scientific drilling*. http://acat02.sinp.msu.ru/presentations/kolbasova/acat.pdf ; accessed March 28, 2016 (NOTE: 75 kilometers to the north of Nizhniy Novgorod, on the left bank of the Volga River, in the central part of the Puchezh-Katunki ring structure"; borehole bottom sequence composed mainly of Archaean and Lower Proterozoic gneisses, amphibolites, crystalline schists; TD 5374m; 212mm diameter hole at TD; Impact feature drilled by Vorotilovo borehole)

580) Popov, Y.A.; Pimenov, V.P.; Pevzner, L.A.; Romushkevich, R.A.; Popov, E.Y. 1998. Geothermal characteristics of the Vorotilovo deep borehole drilled into the Puchezh-Katunk impact structure. *Tectonophysics*, Volume 291, Number 1, 15 June 1998, pp. 205-223 *(Special Issue, Heat Flow and the Structure of the Lithosphere - IV)*; Elsevier; http://www.sciencedirect.com/science/article/pii/S0040195198000419 and http://ac.els-cdn.com/S0040195198000419/1-s2.0-S0040195198000419-main.pdf?_tid=b0fea162-5353-11e5-8219-00000aacb35f&acdnat=1441405642_b2383ce553870766cd08e47c40ba0687 ; accessed March 28, 2016 (NOTE: Vorotilovo borehole, 5374 m TD, *aka, SG-7?,* Vorotilovo borehole, East European Platform, (57.1°N, 43.6°E) ; *Nizhny Novogorod Oblast*; spuds August 8, 1989; TD May 25, 1992; central part of the large Puchezh-Katunk impact structure, which is located in the East European Platform; crater formed ~175 Mya; also see PASSC Impact database; see http://www.passc.net/EarthImpactDatabase/puchezhkatunki.html)

581) Naumov, M. V. 2002. Impact-Generated Hydrothermal Systems: Data from Popigai, Kara, and Puchezh-Katunki Impact Structures (p. 117-171); in J. Plado, and L.J. Pesonen (Eds.), *Impacts in Precambrian Shields; Impact Studies*, 2002, pp 117-171; Springer. TOC at http://link.springer.com/book/10.1007%2F978-3-662-05010-1; TOC accessed September 3, 2015 (Note: P-K is good example to study for post-impact hydrothermal alteration systems)

Russian Federation / Ukraine: Vorotilovo and other Deep Boreholes in Russia and Europe, other

582) Popov, Y., R. Romushkevich, D. Gorobtsov, and D. Korobkov. 2012. Vertical variations in heat flow inferred from experiments in deep boreholes; *Geophysical Research Abstracts*, Vol. 14, EGU2012-9216, 2012, EGU General Assembly 2012*;* http://meetingorganizer.copernicus.org/EGU2012/EGU2012-9216.pdf ; abstract accessed March 28, 2016 (Note: Weak on wells / data)

582a) Popov, E. et al. 2014*. New thermal data and challenges of heat flow variations evaluations for basin petroleum exploration. IPTC-18095-MS; International Petroleum Technology Conference,* Kuala Lampur, Malaysia, December 10-12, 2014; 12 pages; https://www.onepetro.org/download/conference-paper/IPTC-18095-MS?id=conference-paper%2FIPTC-18095-MS ; accessed June 27, 2016 {Notes: Heat flow and structure, deep boreholes, international; well depths up to 12,262m for Boreholes from Russian and ICDP / International Continental Drilling Program. Listing: 1) Kola SG-3, crystalline; Kola Peninsula, NW Russia; 2) Ural SG-4, fold belt, Russia; 3) Timano-Pechora, sedimentary basin, Russia; 4) Kolva, sedimentary basin, Russia; 5) Tyumen, SG-6, sedimentary basin, Russia; 6) Tyrnyaus, crystalline rock, Russia; 7) Vorotilovo, (?aka SG-7), impact structure, Russia; 8) Yen-Yakha sedimentary basin, Russia; 9) Saatly SG-1, sedimentary basin, Azerbaidzhan; 10) Noerdlingen-72, impact structure, Ries, Germany; 11) Yaxcopoil-1 (Mexico) deep holes impact structure; 12) Eyreville, impact structure, USA; 13) KTB, crystalline, Germany; 14) Krivoy Rog, aka SG-8, crystalline, Ukraine; 15) Muruntau, crystalline, Uzbekistan; 16) Severo-Molokovo, East European Platform, Russia; 17) Vysokovo, East European Platform, Russia; 18) Yarudeyskaya, West Siberia, Russia. Figure 1: listing and global view map SG-6 (Tyumen) and SG-7 (En-Yakhin) superdeep boreholes in the Yamal-Nenets autonomous district (YaNAD)); Other superdeep holes identified as SG-6 and SG-7 superdeep boreholes (Yamal-Nenets Autonomous Okrug), and Vorotilovo, Tyumen, Yen-Yakha (all - Russia), Saatly (Azerbaidzhan), and deep scientific and parametric boreholes Kolva, Timano-Pechora, Tyrnyaus, (all - Russia), Krivoy Rog (Ukraine), Muruntau (Uzbekistan), Nordlingen-72 (Germany), Yaxcopoil-1 (Mexico)and … Severo-Molokovo, Vysokovo, Yarudeyskaya (Russia), Eyreville (USA) and from the revision of previous experimental geothermic data for the Moscow syncline (the East European platform) and Ural region from Popov, Y. et al., 2014 and 2012.}

582b) Zhamaletdinov A.A., M. Petrishchev, A. Shevtsov, V. Kolobov, et al. 2014 (2013). Electromagnetic Sounding of the Earth's Crust in the vicinities of the SG-6 and SG-7 Superdeep Boreholes in the Fields of Natural and Powerful Controlled Sources, p. 88-91; reprinted from / *Doklady Akademii Nauk,* 2012, Vol. 445, No. 2, pp. 205–209; http://www.spsl.nsc.ru/FullText/konfe/snch_2014-1.pdf ; accessed July 24, 2016

582c) Aquatic Company (Moscow) and Maurer Engineering (Houston). 1999. Implement Russian aluminum drill pipe and retractable drilling bits into the USA; *Development of Aluminum Drill Pipe in Russia; Final Report, TR99-23*, Vol. 1 (Report prepared for Federal Energy Technology Center, U.S. Dept. Energy); http://www.osti.gov/scitech/servlets/purl/766364 ; accessed July 24, 2016

582d) Faybishenko, B. 2015. The Concept of Deep Borehole Geological Disposal in Ukraine; UFD Annual Meeting, June 10, 2015; Lawrence Berkeley National Laboratory, Berkeley, California; presentation. https://rampac.energy.gov/docs/default-source/storage/ufd_wg_1_20150610.pdf?sfvrsn=2 ; accessed July 24, 2016.

582e) Nezhdanov, A.A., V.V. Ogibenin, M.V. Melnikova, A.S. Smirnov. December 5, 2012. Structure and Stratification of Triassic-Jurassic Formations in the Northern Part of Western Siberia; *ROGTEC* (Russian Oil and Gas Technologies) *Magazine*, December 5, 2012; https://rogtecmagazine.com/structure-and-stratification-of-triassic-jurassic-formations-in-the-northern-part-of-western-siberia/ accessed December 1, 2016 (history and tectonics, Urengoi–Koltogory rift system and the Yenisei–Khatanga basin areas; TBD literature search, SG-6)

Finland: Outokumpu borehole, ICDP

583) ICDP online (International Continental Scientific Drilling Program website accessed March 28, 2016). *Outokumpu Deep Drilling Project and Geolaboratory*; International Continental Scientific Drilling Program, http://www.icdp-online.org/projects/world/europe/outokumpu/ (NOTES: ~2500m depth; Precambrian ophiolites, Finland; drilled 2004/2005; For data see http://www-icdp.icdp-online.org/front_content.php, and http://www-icdp.icdp-online.org/front_content.php?idcat=707 ; location 62° 43' 4" N, 29° 3' 43" E; 62.717777, 29.061918 deep laboratory facility)

584) Kukkonen, I. (ed.). 2011. *Outokumpu Deep Drilling Project 2003-2010*; *Geological Survey of Finland, Special Paper 51*; 252p.; Vammalan Kirjapaino Oy, Finland; http://tupa.gtk.fi/julkaisu/specialpaper/sp_051.pdf ; accessed March 30, 2016 (Note: Gneiss, pegmatitic

granites; Paleoproterozoic metasedimentary and ophiolitic sequence, within Karelian Schist Belt; drilled in 2004/2005; TD 2516m; planned and constructed / drilled 22cm diameter borehole to TD; copper Zn mining district; also see projects http://www.icdp-online.org/home/)

Finland: GTK / Geological Survey of Finland

584a) Geological Survey of Finland / GTK / Geologian tutkimuskeskus (website accessed June 27, 2016). http://en.gtk.fi/ (Note: for added information and searches, see http://hakku.gtk.fi/en?action=index&controller=home&locale=fi ; http://hakku.gtk.fi/en/reports)

Finland: Ore zones and geology

584b) Saltikoff, Boris, et al. 2006. *Metallogenic zones and metallic mineral deposits in Finland*, Geological Survey of Finland, Special Paper 35; http://tupa.gtk.fi/julkaisu/specialpaper/sp_035.pdf ; accessed June 27, 2016 (Note: provides explanation for metallogenic map; includes Outokumpu Cu, Palmottu, Pyhäjärvi V-Fe-Ti; geologic and geophysical summary information, maps; regional domains; ore zone geology; extensive references)

International Deep boreholes: Russia, Germany, Finland,

585) Gorbatsevich, F., et al. 2007. *Some Properties of Deep Crystalline Rocks From Deep and Superdeep Boreholes (SG3, KTB, SG4 AND ODB)*; Kola Science Center, Geologic Institute, Apatity, Russia; https://www.researchgate.net/publication/242704802_SOME_PROPERTIES_OF_DEEP_CRYSTALLINE_ROCKS_FROM_DEEP_AND_SUPERDEEP_BOREHOLES_SG3_KTB_SG4_AND_ODB ; accessed March 30, 2016 [NOTE: Finnish (ODB), Ural (SG4), Kola (SG3), German (KTB) wells; "Among the programmes aimed at the study of the properties and state of the earth crystalline crust the most interesting results were obtained when drilling the Kola (12261 m), Ural (~6010 m) Saatly (8267 m), Krivoi Rog (3600 m) etc"…"Gravberg-1 (Sweden) and KTB (Germany)"; German KTB located at the town of Windischeschenbach, Bavaria, depth 9.1 km. Finnish ODB Outokumpu (near a polymetallic deposit) TD 2516m.; author provides complimentary study on SG-3 borehole, http://www.irsm.cas.cz/materialy/acta_content/2010_02/1_Gorbatsevich.pdf]

585a) Gorbatsevich, F., *et al*. 2005. Geodynamics and structure of the upper Earth's crust: data obtained from the Russian superdeep borehole drilling programme; *Geophysical Research Abstracts*, Vol. 7, 00154, 2005, European Geosciences Union, 2005; http://meetings.copernicus.org/www.cosis.net/abstracts/EGU05/00154/EGU05-J-00154-1.pdf ; accessed June 27, 2016 [Note: Russian superdeep boreholes drilling program / RSBDP; holes drilled at Ural, Tyrnyauz, Vorotilov and Kola holes that penetrated crystalline massifs; Ural superdeep borehole (SG-4) has been drilled in the western part of the Tagil megasynclinorium; SG-4 cuts Palaeozoic rocks (~340-440 Ma), to a depth of about 5.4 km. Tyrnyauz deep hole (TGS) is located near the ore field of the large-scale Tyrnyauz deposit of wolfram and molybdenum, in the north-western part of the Caucasus; penetrated the central part of the 1.2–2.5 Ma Eljutin granite intrusion to 4km depth. Vorotilov deep borehole / VGS is situated in the Puchezh-Katunki impact structure (central part of the Russian plate, to the North of Nizhny Novgorod, TD 5374m; Archean basement rocks encountered at 2-3 km composed of gneisses and amphibolites. The Kola Superdeep Borehole (SG-3) has been drilled in the northern limb of the Pechenga rift structure, composed of rhythmically alternating volcanic and volcano-sedimentary sequences with TD of 12261m; Proterozoic (0–6842 m) and Archaean (6842–12,261 m); boundary between the Proterozoic and Archaean complexes (6842 m)]

585b) Gorbatsevich. F.F. 2008. Some properties and structure of the crystalline crust from Superdeep drilling data (SG-3, SG-4, KTB); *Acta Geodyn. Geomaterials*, Vol. 5, No. 4(152), 351–360; http://www.irsm.cas.cz/materialy/acta_content/2008_04/2_Gorbatsevitch.pdf ; accessed June 27, 2016 [Note: discovery of strongly anisotropic rock velocity in the SG-3, SG-4 and KTB boreholes; Kola (12261 m), Ural (6010 m) Saatly (8267 m), Krivoi Rog (3600 m) etc.; Gravberg-1 was 6.6 km ; German superdeep borehole KTB located at the town of Windischeschenbach, Bavaria, reached a depth of 9.1 km. The Kola borehole intersected the lower Proterozoic complex of the Pechenga Formation and an Archaean granite and metamorphic complex; Proterozoic complex (9-6842 m) is composed of metavolcanic and metasedimentary rocks; Kola's Archaean complex (6842-12261 m) is composed of gneisses, amphibolites and meta-ultrabasite, pegmatites and granites; age of the crystalline rocks in the SG-3 is in the range of 1765-2835 Ma. SG-3 Archaean complex (6842-10144 m) are gneisses, amphibolites, granite. KTB borehole in crystalline basement of the Bohemian massif in the south of Germany; in tectonometamorphic massif of Zone ErbendorfVohenstrauss (ZEV) formed 330-400 million years ago; KTB pilot hole reached a depth of 4000 m; in 1994 main hole was terminated at a depth of 9101 m. Ural superdeep borehole (SG-4) was drilled in the western limb of the Tagil megasynclinorium with the aim of comprehensive study of the Palaeozoic section of the Ural typical eugeosynclinal zone; penetrated rocks of the Silurian Immenov Fm dated at 400-440 Ma. In the interval down to a depth of 5.5 km a uniform sequence of volcanoclastic basic and intermediate rocks encountered; composed of coarse tephroid and tuff of pyroxene-plagiophyre basalt and andesite-basalt, whose pyroclastic material mainly belongs to plagiophyre andesite. From 3.5- 5.1 km, a flyschoid unit is located. Gravbeg-1 (Sweden) and Vorotilov (Russia) boreholes were drilled within astroblemes; rocks from the Saatly, Muruntau and Krivoi Rog borehole sections have been studied in less detail]

585c) Eppelbaum, L., and B. Khesin. 2011. Development of 3-D Gravity-Magnetic Models of the Earth's Crust of Azerbaijan and Adjacent Areas: an Overview; *Positioning*, 2011, 2, 84-102; http://file.scirp.org/pdf/POS20110200004_50404370.pdf

585d) Leonid A. Buryakovsky, L., and G. Chilingar, F. Aminzadeh (editors). 2001. *Petroleum Geology of the South Caspian Basin*; Chapter 1, Geology of Azerbaijan and the South Caspian Basin; Gulf Professional Publishing / Butterworth–Heinemann / Reed Elsevier group; Woburn, Massachusetts; http://www.nigc.ir/Portal/Images/Images_Traning/files/files/chemist%20book/chemical%20listed/Petroleum_Geology_of_the_South_Caspian_Basin.pdf ; accessed July 25, 2016

Germany, Russia and Sweden deep boreholes / data

586) Smellie, John. 2004. *Recent geoscientific information relating to deep crustal studies. SKB Rapport* R-04-09, SKB / Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Co. Stockholm; 32pp. http://www.skb.se/upload/publications/pdf/R-04-09.pdf ; accessed March 28, 2016 (NOTE: Examines KTB and German Continental Deep Drilling Programme, well located at the western margin of the crystalline Bohemian Massif, culminating in two deep boreholes; one pilot hole to 4000 m and the main hole to 9101 m) and Russia (e.g. the Superdeep Well SG-3 to 12 262 m at Kola, Zapolyarny. Describes Sweden Deep Geothermal Energy Project "presently" (2004) in progress

in the vicinity of Lund. This is financed by Lund's Energi AB and run by the Department of Engineering Geology at the Lund Institute of Technology; one borehole has been drilled to a depth of 3701.80 m with a diameter of 17.5 inches and in crystalline basement rock (reports due in 2004, so older program). Russian SG-4 borehole (at 5401 m) drilled in the Tagil Volcanic Arc, Middle Urals; thermal character of SG holes and SKB provided in report)

International: Intergovernmental Panel on Climate Change; Underground Storage CO2

587) Benson, S., P. Cook, et al. 2005. Underground Geologic Storage, Chapter 5, pp. 195-276. *In*: B. Metz et al. (editors), 2005 *IPCC Special Report on Carbon Dioxide Capture and Storage*; Intergovernmental Panel on Climate Change; Cambridge University Press, Cambridge, UK; 431pp. https://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf , accessed March 30, 2016; and https://www.ipcc.ch/pdf/special-reports/srccs/srccs_chapter5.pdf ; accessed March 30, 2016 (NOTE: IPCC, Intergovernmental Panel on Climate Change; Capture and Storage CO2; regional geology and examples; see figures, tables and test outlines; regional geology maps); related links at https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#2)

United States: Deep Boreholes, New Mexico, Arizona, Texas, Northern Mexico, basement penetrations; Arizona State A-1

588) Brennan, D., and S. Thompson. 1989. Oil and Gas Exploration Wells Drilled to Precambrian Basement in southeastern Arizona and Southwestern New Mexico. Paper T121:64 (pp. 64-70), ***In*:** H. Drewes and R. Dyer (eds.), *Tectonics of the Eastern Part of the Cordilleran Orogenic Belt, Chihuahua, New Mexico and Arizona: El Paso, Texas to Tucson, Arizona June 29–July 4, 1989 Field Trip Guidebook T121*; Amer. Geophys. Union, Washington, D.C.; http://onlinelibrary.wiley.com/book/10.1029/FT121 ; http://onlinelibrary.wiley.com/doi/10.1029/FT121p0064/pdf ; accessed March 31, 2016 ; http://onlinelibrary.wiley.com/doi/10.1002/9781118668818.fmatter/pdf ; http://onlinelibrary.wiley.com/doi/10.1029/FT121p0064/summary ; {NOTES: Basement penetrations data compiled; Phillips No. 1 Sunland Park well in Dona Ana County, New Mexico; Phillips No. A1 Tombstone State well in Cochise County, Arizona is the only one that appears to have penetrated a basement-involved thrust; in that well, Precambrian granite overlies Cretaceous sedimentary rocks. Excellent maps for region wells. Chihuahua State, Mexico: Pemex No.1 Chinos penetrated Permian to Cambrian sedimentary rocks down to 4,381 meters (14,373'), and Precambrian granite gneiss to 4,411 meters (14,473'). The Pemex No.1 Moyotes penetrated Cenozoic rocks down to 685 meters (2,247') (unconformity), Lower Cretaceous sedimentary rocks to 2,365 meters (7,759'), Upper Jurassic sedimentary rocks to 3,395 meters (11,138') (major unconformity), Permian sedimentary rocks to 4,810 meters (15,781'), and Precambrian granite gneiss to 4,943 meters (16,217'). Precambrian rocks in the two wells were dated by the rubidium-strontium method as 1,327 Ma and 890 Ma, respectively"}

United States: (aka Phillips / Anschutz Texoma) Arizona State A-l well, Pinal County, Arizona

589) Thompson, Sam III, Tovar R., J. C., and Conley, J. N. 1978. Oil and gas exploration wells in the Pedregosa basin. In: *New Mexico Geological Society Guidebook, 29th Field Conference, Land of Cochise,* p. 331-342; https://nmgs.nmt.edu/publications/guidebooks/downloads/29/29_p0331_p0342.pdf ; accessed March 31, 2016 (NOTES: map with well locations; well location table, township/range/sec provided; numerous deep wells in Chihuahua; Pemex 1 Camello well, TD 5595m; several 5000m deep wells drilled in area 1960/70s; Pedregosa Basin, AZ, NM, Chihuahua, Mexico)

590) Ryder, Robert. 1983. *Petroleum Potential of Wilderness Lands, Arizona*; In: Petroleum Potential Of Wilderness Lands in the Western United States, United States Geological Survey Circular 902-C, and Misc. Investigations Series, Map I-1537; pamphlet, 22pp. U.S. Geol. Survey., Washington, D.C. http://pubs.usgs.gov/imap/1537/report.pdf ; accessed March 31, 2016 (NOTE: regional geology, maps, hydrocarbon distribution)

591) Arizona Oil and Gas Conservation Commission (website accessed March 31, 2016). Well data (interactive map); http://welldata.azogcc.az.gov/ and folder http://repository.azgs.az.gov/resources/og/OGPermitFiles/0702.pdf (NOTE: Bit size 17.5", 10900'; stated TD 18013'; T7S R10E, Sec 2; 32.841, -111.283; P&A 2/1981; 13 5/8ths casing at 10,835'

592) Sell, James, et al. 1995. *Field Guide to the Superior Region, Pinal County, Arizona; Guidebook for the Arizona Geological Society Fall Field Trip, October 28, 1995*; Arizona Geological Society, Tucson, AZ. http://docs.azgs.az.gov/SpecColl/2008-01/2008-01-0567.pdf ; accessed March 31, 2016 {Note: See Reference 593}

593) Reif, D. M., and Robinson, J. P., 1981, Geophysical, geochemical, and petrographic data and regional correlation from the Arizona State A-l well, Pinal County, Arizona: *Arizona Geological Society Digest*, v. XIII, p. 99-109. (NOTE: Phillips Arizona State A-1 hole TD at 18,013'; State A-1 penetrated 700 feet of alluvium, then granite wash (valley fill) to 3,879 feet; , granite to granodiorite (Unit 1) of 1.39 billion year age to 10,761 feet; Unit 2, a muscovite granite with a 47 million year age, encountered to 12,755'. Unit 3, a biotite hornblende gneiss ~ 1.5 billion year age to 18,013 feet T.D.; drilled into crystalline rocks of a metamorphic core complex and remained in them to a total depth of 18,013 feet. Northwest of Tucson. Pinal County, AZ, from Keith, 1979, and Hansen, 1980; field guides show well located off "Deep Well Road"; well record indicates 13 5/8ths" casing to 10935' in 17.5" hole; this is data source for the Sell et al. (1995) field guide book information on borehole, Reference 592 herein)

594) Keith, S. B. 1979. The great southwestern Arizona overthrust oil and gas play, the drilling commences: *Field notes from the State of Arizona, Arizona Bureau of Geology and Mineral Technology*, v. 9, no. 1, p. 10-14. http://www.azgs.az.gov/arizona_geology/archived_issues/Spring_1980.pdf accessed March 31, 2016 (NOTE: Anschutz – Texoma State 1-10-2; Spud, 1980 early over-thrust play in Arizona; see seismic lines on pages 6-8.)

United States, New Mexico: Grimm et al. 1 Mobil-32, Dona Ana County, NM

595) Muckelroy, D.A. 1982. Hydrocarbon source-rock evaluation study, Grimm et al no. 1 Mobil-32 Well, Dona Ana County, New Mexico; *New Mexico Bureau of Mines and Mineral Resources Open File Report* No. OF 199; https://geoinfo.nmt.edu/publications/openfile/downloads/100-199/199/ofr_199.pdf ; accessed March 31, 2016 (Notes: TD 21,756' in Ordovician

Dolomite; Dona Ana County, T25S R1E Sec 32; 32.090453, -106.864052 approximate location for area. Notable as one of the deeper holes in the area of Basin for many years)

United States: Amchitka Tests, Alaska – big hole project, AEC (1971 Cannikin Test)

596) LLNL / Lawrence Livermore National Laboratory (website accessed March 31, 2016). Accomplishments in the 1970s (1971, Cannikin); LLNL; http://web.archive.org/web/20050217061020/http://www.llnl.gov/50th_anniv/decades/1970s.htm ; [NOTE: Cannikin event at Amchitka Island, Alaska; test on November 6, 1971; Project Cannikin / Operation Grommet - the world's largest underground nuclear test (~5-megaton blast; induced equivalent of magnitude 7 quake); Amchitka Island, Aleutian Islands, Alaska. Drilled borehole characteristic: 6,150 feet (1,870 m) deep with 90 inch (2.3 m) diameter.]

597) *Wikipedia* (website accessed March 31, 2016). W71; http://en.wikipedia.org/wiki/W71 (Note: Cannikin test description; W71 was lowered into a man-made cavern 52 feet (16 m) in diameter; the ~5-megaton blast generated the ground motion of a 7.0 Richter-scale-magnitude earthquake; test resulted in a vertical ground motion of more than 15 feet (4.6 m) at a distance of 2,000 feet (610 m) from the borehole, equivalent to an earthquake of magnitude 7.0 on the Richter scale. A mile (1.6 km) wide and 40 feet (12 m) deep crater formed two days later. Cannikin test.)

598) *Wikipedia (*website accessed March 31, 2016). Amchitka; https://en.wikipedia.org/wiki/Amchitka#Milrow_and_Cannikin_tests (NOTE: location not correct / not adequate as reference for test)

599) Burger, J., et al. 2004. Science, policy, and stakeholders: Developing a consensus science plan for Amchitka Island, Aleutians, *Alaska.Environmental Management*, Vol. 34, No. 5, pp.1-12; Springer Science +Business Media, Inc. (Published online). http://www.cresp.org/Amchitka/Amchitka_Final_Report/finalreport/01Append_intro/1E_APPEND_1E.pdf ; accessed March 31, 2016 (NOTE: Summary of science plan development for Amchitka site by team from CRESP (Consortium for Risk Evaluation with Stakeholder Participation); cleanup and remediation of contaminated sites to extent possible; Amchitka used for three nuclear tests with Cannikin being biggest shot in 1971; it was largest US test; see http://www.cresp.org/Amchitka/Amchitka_Final_Report/ and http://www.cresp.org/Amchitka/Amchitka_Final_Report/finalreport/chapters/00_Front_F8_01_05.pdf).

600) Powers, C.W., Burger, J., Kosson, D., Gochfeld, M., and D. Barnes, eds., et al. 2005. *Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment.* Consortium for Risk Evaluation with Stakeholder Participation; Institute for Responsible Management, Piscataway, New Jersey. http://www.cresp.org/Amchitka/Amchitka_Final_Report/finalreport/chapters/00_Front_F8_01_05.pdf ; accessed March 31, 2016 (Note: remediation and effects of testing, Amchitka Island

601) Unsworth, Martyn, et al. 2005. Geophysical Investigations II - Magnetotelluric measurements for determining the subsurface salinity and porosity structure of Amchitka Island, Alaska, Chapter 6, 28pp. In: *Final Report of the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) - Amchitka Independent Science Assessment* http://www.cresp.org/Amchitka/Amchitka_Final_Report/finalreport/chapters/06_Chapter6_F7_26_05.pdf ; accessed March 31, 2016.

602) Powers, C.W., Burger, J., et al. (eds.). 2005. *Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment*. Consortium for Risk Evaluation with Stakeholder Participation, Institute for Responsible Management, Piscataway, New Jersey. http://www.cresp.org/Amchitka/Amchitka_Final_Report/finalreport/chapters/00_Front_F8_01_05.pdf ; accessed March 31, 2016 (NOTE: Final Report for Consortium for Risk Evaluation with Stakeholder Participation. Three underground nuclear tests: Long Shot (80 kilotons in 1965), Milrow (about 1000 kilotons in 1969), and Cannikin (about 5000 kilotons in 1971, the largest U.S. underground test); WikiMiniAtlas Cannikin Test location, 51°28′13.20″N 179°6′40.75″E; 51.471867,179.110794)

602a) DOE Office of Legacy Management (website accessed August, 2016). *Amchitka Site*; http://www.lm.doe.gov/Amchitka/Sites.aspx

DEEP BOREHOLES, General: Kuhlman et al., 2015; key reference – boreholes summary

603) Kuhlman, K., et al. 2015. *Conceptual Design and Requirements for Characterization and Field Test Boreholes: Deep Borehole Field Test;* FCRD-UFD-2015-000131 Rev. 1 SAND2016-5692 R; report not available online; {NOTES: see https://rampac.energy.gov/docs/default-source/storage/ufd_wg_9_2015061058ab7ac58d7064d5adfcff00004b4072.pdf?sfvrsn=2 for related information, and References 478/479, herein. Relevant information summary: The USA R&D DBFT included plans for drilling two boreholes nominally 200 m [660'] apart to approximately 5 km [16,400'] total depth. The CB is the smaller-diameter (i.e., 21.6 cm [8.5"] diameter at total depth) borehole. The FTB is the larger-diameter (i.e., 43.2 cm [17"] diameter. The Nevada Test Site (Patrick, 1986), Spent Fuel Test-Climax was conducted from 1978 to 1983 at what is now the Nevada Nuclear Security Site. The Kola project included drilling the SG-3 borehole (21.6 cm [8.5"] diameter) to a total depth of 12.2 km in the former Soviet Union. Scientific and technical findings from the project (1970 1992) are discussed in two sets of conference proceedings dedicated to the project (Kozlovsky 1987; Fuchs et al. 1990). The Fenton Hill project included drilling three boreholes (22.2 cm [8¾"] and 25.1 cm [9⅞"] in diameter) as part of an enhanced geothermal project to total depths of 3, 4.2, and 4.6 km near Los Alamos, New Mexico (Fehler 1989, Reference 604 herein; Brown 2009, Reference 605 herein). The Urach-3 borehole was a 14 cm [5.5"] diameter enhanced geothermal borehole to 4.4 km depth in southwestern Germany. The borehole was originally drilled in 1978, and deepened multiple times (Stober & Bucher 2000, 2004; References 517, 518 herein). The Gravberg borehole was a 16.5-cm [6.5"] diameter wildcat natural gas borehole drilled to 6.6 km depth in the Siljan Impact Structure in central Sweden. A summary of the data collected during drilling (1986 1987) is given by SKB (1989; Reference 484). The Cajon Pass borehole was a 15.9-cm [6.25"] diameter borehole to 3.5 km depth near the San Andreas Fault in Southern California; scientific findings from the project (1987 1988) are featured in a different special section of *Journal of Geophysical Research* (Reference 608, herein). The KTB project included coring a 15.2-cm [6"] diameter borehole to 4 km; next depth and drilling a 16.5-cm [6.5"] diameter borehole to 9.1 km in south eastern Germany. The KTB project (1987 1994) is summarized by Bram et al. (1995; Reference 502, herein). Eindings from the project are featured in a special section of *Journal of Geophysical Research* (Haak & Jones 1997; Reference 505 herein). The Soultz-sous-Forêts GPK geothermal project drilled three 24.4 cm [9⅝"] diameter boreholes to 5.1 and 5.3 km depth in northeastern France (Sanjuan et al. 2015; Reference 522, herein). Also see Cochran and Hardin (2015). Minge et al. (1986; Reference 528 herein)

summarized the 1984-1986 Standard Oil Production Company well drilling and completion of the ultra-deep gas well L.W. Magoun No. 1 in Concordia, Parish LA to a depth of 7.6 km [25,015'] in sedimentary rocks. During the completion process, the well was drilled to an intermediate depth of 3.8 km [12,455'] at a diameter of 66 cm [26"]. A world-record size string of 50.8 cm [20"] diameter C-95 casing was installed and cemented to this depth (Pejac and Fontenot, 1988; Reference 527, herein).

Site	Bores	Location	Years	Depth [km]	Diam* [in]	Purpose
Kola SG-3	1	NW USSR	1970-1992	12.2	8½	Geologic Exploration + Techno. Develop.
Fenton Hill	3	New Mexico	1975-1987	3, 4.2, 4.6	8¾, 9⅞	Enhanced Geothermal
Urach-3	1	SW Germany	1978-1992	4.4	5½	Enhanced Geothermal
Gravberg	1	Central Sweden	1986-1987	6.6	6½	Gas Wildcat in Siljan Impact Structure
Cajon Pass	1	California	1987-1988	3.5	6¼	Geomechanics near San Andreas Fault
KTB	2	SE Germany	1987-1994	4, 9.1	6, 6½	Geologic Exploration + Technology Development
Soultz-sous-Forêts GPK	3	NE France	1995-2003	5.1, 5.1, 5.3	9⅝	Enhanced Geothermal

Also see Reference 478, Kuhlman, 2015 (presentation), and Reference 479, Kuhlman *et al*. 2015}

France: Soultz-sous-Forets

603a) Dezayes, C., et al. 2005. Deep-Seated Geology and Fracture System of the EGS Soultz Reservoir (France) based on Recent 5km Depth Boreholes; *Proceedings World Geothermal Congress 2005*, Antalya, Turkey, 24-29 April 2005; https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/1612.pdf ; accessed July 28, 2016

Iceland: Iceland Deep Drilling Project (IDDP 2), Reykjanes Geothermal Field area

603b) Iceland Deep Drilling Project (website accessed February, 2017); http://iddp.is/ (Note: status of drilling, see http://iddp.is/2016/12/21/season-greetings/ ; http://iddp.is/wp-content/uploads/2016/09/Uppl%C3%BDsingaskilti_rev.pdf ; http://www.sci-dril.net/16/73/2013/sd-16-73-2013.pdf ; http://iddp.is/wp-content/uploads/2017/02/IDDP-2-Completion-websites-IDDP-DEEPEGS.pdf)

603c) Friðleifsson, G. O. 2015. Iceland Deep Drilling Project – IDDP: Lessons learned and future prospects (presentation; IDDP 1); *Innovation for Cool Earth Forum*, October 7-8, 2015, 2nd Annual Meeting, Tokyo, Japan; http://www.icef-forum.org/annual_2015/speakers/october7/cs1/gp/pdf/20034_gudmundur_omar_fridleifsson.pdf ; accessed February, 2017

United States: New Mexico, Fenton Hill Borehole geothermal project, Sandoval County, NM

604) Fehler, M.C. 1989. Stress control of seismicity patters observed during hydraulic fracturing experiments at the Fenton Hill hot dry rock geothermal energy site, New Mexico. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* 26(3-4):211-219; http://www.sciencedirect.com/science/article/pii/0148906289919712 ; abstract accessed March 31, 2016

604a) Grigsby, C., et al. 1984. Geochemical behavior of a hot dry rock geothermal reservoir; New Mexico Geological Society 35th Annual Fall Field Conference Guidebook: Rio Grande Rift: Northern New Mexico, 1984; pp. 265-270; New Mexico Geological Society; http://nmgs.nmt.edu/publications/guidebooks/35 , and https://nmgs.nmt.edu/publications/guidebooks/downloads/35/35_p0265_p0270.pdf ; accessed August 3, 2016

605) Brown, D.W. 2009. "Hot Dry Rock Geothermal Energy: Important Lessons from Fenton Hill"; in *Proceedings Thirty-Fourth Workshop on Geothermal Reservoir Engineering, Stanford University*, February 9-11, 2009. Abstract online, http://en.openei.org/wiki/Hot_Dry_Rock_Geothermal_Energy-_Important_Lessons_From_Fenton_Hill ; paper online at https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2009/brown.pdf ; accessed March 31, 2016 (NOTE: Fenton Hill hot dry rock test well / HDR Test site about 40 miles west of Los Alamos; Fenton Hill HDR Test Site in the Jemez Mountains of north-central NM, west of Valles Caldera; tested until 1995; depth ~3500m test hole depth)

606) Open EI (website accessed March 31, 2016). *Fenton Hill HDR Geothermal Area Project*; http://en.openei.org/wiki/Fenton_Hill_HDR_Geothermal_Area (Notes: HDR testing during 1995; period of drilling and testing preceded HDR work during the 1970s and 1980s. Wells in area ~<3500m; 35.879804, -106.674903; see https://en.openei.org/wiki/Fenton_Hill_HDR_Geothermal_Area#History_and_Infrastructure)

United States: DOSECC Cajon Pass – San Andreas Fault Deep Borehole Test, Cajon Pass, San Bernardino Co., CA

607) Zoback, M.D. et al. 1988. The Cajon Pass scientific drilling experiment: overview of Phase 1; *Geophysical Research Letters*, Vol. 15, No. 9, p. 933-936, August Supplement, 1988; http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1456&context=usgsstaffpub and , http://authors.library.caltech.edu/39281/1/grl4044.pdf; accessed April 20, 2016 (Note: Phase 1 depth only at 2115m bgl in 1987; later phase, borehole reached 3.5km depth; Cajon Pass Borehole; well, 3.5km depth; best guess from maps 34.322103, -117.478165. Official wellhead location is "DOSECC" Federal 2-26, 1144'S and 1982'E of NW comer of NW comer, sec. 26, T3N, R6W, 34º18'52"N, 117º28'38"W; the site is N 1.3 km (0.8 mile) up the Baldy Mesa road from Cajon Junction at the intersection of 1-15 and Route 138)

607a) Beyer, L.A., F. G. Clutsom and F. V. Grubb. 1989. *Basic Data and Preliminary Density Profile from a Borehole Gravity Survey Made in the Cajon Pass Scientific Drillhole, California*; United States (Department of the Interior) Geological Survey, Open-File Report 89-458; https://pubs.usgs.gov/of/1989/0458/report.pdf (Notes: DOSECC Cajon Pass Scientific Drill-hole (Federal 2-26). LOCATION: 26-3N-6W San Bernardino Co California; drilling phase II, well was deepened to 3,510 m (11,515 ft). The 7 5/8-inch casing string extends from 5,494 feet to 11,380 feet)

607b) Silver, L., and E. James. 1988. Geologic setting and lithologic column of the Cajon Pass deep drillhole; *Geophysical Research Letters*, Vol. 15, no. 9, pages 941-944, August Supplement 1988; http://authors.library.caltech.edu/39281/1/grl4044.pdf (Note: The official wellhead location is "DOSECC" Federal 2-26, 1144 feet S and 1982 feet E of the NW comer of the NW comer of sec. 26, T3N, R6W, latitude 34º18'52", longitude 117º28'38"W. The site is N 1.3 km (0.8 mile) up the Baldy Mesa road from Cajon Junction at the intersection of 1-15 and Route 138)

608) Zoback, M.D. & A.H. Lachenbruch. 1992. Introduction to special section on the Cajon Pass scientific drilling project. *Journal of Geophysical Research*, 97(B4):4991−4994. http://onlinelibrary.wiley.com/doi/10.1029/91JB03110/epdf ; accessed August 25, 2015 (NOTES: Cajon Pass well, 3.5km depth; article not instructive for location. Also see Cajon Pass, Reference 478, Kuhlman, 2015, presentation)

United States: San Andreas Fault Observatory at Depth (SAFOD), Earthscope, near Parkfield, Monterey County, CA

608a) Zoback, M., S. Hickman, W. Ellsworth, et al. 2011. Scientific drilling into the San Andreas Fault Zone —An overview of SAFOD's first five years; *Scientific Drilling*, No. 11, March 2011, p. 14-28; http://www.sci-dril.net/11/14/2011/sd-11-14-2011.pdf ; https://www.researchgate.net/publication/262303238

608b) Jeppson, T., K. Bradbury, and J. Evans. 2010. Geophysical properties within the San Andreas Fault Zone at the San Andreas Fault Observatory at Depth and their relationships to rock properties and fault zone structure; *Journal Of Geophysical Research*, V. 115, B12423, doi:10.1029/2010JB007563, 2010; http://onlinelibrary.wiley.com/doi/10.1029/2010JB007563/pdf ; accessed April 3, 2017

609) Earthscope (website accessed April 20, 2016). *SAFOD (San Andreas Fault Observatory at Depth)*; http://www.earthscope.org/science/observatories//safod [Notes: location 35.974028,-120.552425; Brochure at http://www.earthscope.org/assets/uploads/pages/safod_five_years_hi.pdf ; states Phase 1 in 2004 drilled 1.5km vertically, Phase 2 in 2005 directionally drilled with TVD bgl ~2.7 km depth; Phase 3 with sidetracks drilled and completed in 2007; pilot hole also drilled to 2.2 km as part of ICDP); also http://earthquake.usgs.gov/research/parkfield/safod_pbo.php, and http://safod.icdp-online.org/ (ICDP web)]

609a) Tembe, S., et al. 2006. Frictional strength of cuttings and core from SAFOD drillhole; *Geophysical Research Letters*, Vol. 33, L23307, doi:10.1029/2006GL027626, 2006; http://earthquake.usgs.gov/research/rockphysics/papers/Tembe2006.pdf ; accessed August 18, 2016

United States: Injection, liquid disposal well examples; induced seismic events

609b) U.S. Bureau of Reclamation (BoR). 2012. Review of Geologic Investigations and Injection Well Site Selection, Paradox Valley Unit, Colorado; *Bureau of Reclamation Technical Memorandum* No. 86-68330-2012-27; U.S. Department of the Interior Bureau of Reclamation, Technical Service Center. http://www.coloradoriversalinity.org/docs/CRB_TM_final_reduced.pdf ; accessed August 18, 2016

609c) U.S. Army, Rocky Mountain Arsenal, Remediation Venture Office (website accessed August 15, 2016); *Deep Injection Well Fact Sheet*; http://www.rma.army.mil/files/3513/7599/5929/DeepInjectionWell.pdf ; accessed August 18, 2016

609d) Nicholson, C., and R. Wesson. 1990. Earthquake Hazard Associated With Deep Well Injection - A Report to the U.S. Environmental Protection Agency; *U.S. Geological Survey Bulletin 1951*; 74pp. http://pubs.usgs.gov/bul/1951/report.pdf ; accessed August 18, 2016

609e) Evans, D.M. 1966. Man-made earthquakes in Denver; *Geotimes*, Vol. 10, No. 9, p. 11-17; http://www.coloradogeologicalsurvey.org/Docs/ERC/MAN-MADE%20EARTHQUAKES%20IN%20DENVER-EVANS%201966b.pdf ; accessed August 18, 2016

609f) Evans, D.M. 1966. THE DENIER area earthquakes and the Rocky Mountain Arsenal disposal well; *The Mountain Geologist* v.3, p. 23-36; https://scits.stanford.edu/sites/default/files/evans_0.pdf ; accessed November, 2016

Table 4 References (#610-743) and Notes Supporting Map Layer 4 (Underground Physics Facilities)

Primary References (610-622), Table 4 and Map Layer 4 (Underground Physics Facilities)
International Deep Underground Laboratories:

610) NSF (National Science Foundation). 2007. DUSEL - Facilities, Findings and recommendations; In *Deep Science: a Deep Underground Science and Engineering Initiative* (p. 35, Figure 1, underground laboratories worldwide); National Science Foundation; http://science.energy.gov/~/media/hep/pdf/files/pdfs/Dusel_101206.pdf ; accessed March 22, 2016; (NOTE: Deep Underground Science and Engineering Laboratories / DUSEL initiative for investigation in geoscience and particle / astroparticle physics; listing and figure for laboratories, depth, and mwe estimates; ~2007 vintage for material NELSAM project at 3800m bgl, in quartzite)

611) Spooner, Neil. 2010. Underground Facilities, Technological Challenges; pp. 184-192; Contribution to the Workshop - Blondel, A. and F. Dufour, F (eds.), Proceedings *European Strategy for Future Neutrino Physics Workshop*, CERN, Geneva, Switzerland, 1 - 3 Oct 2009; CERN European Organization for Nuclear Research, CERN 2010-003, November, 2010; CERN, Geneva, Switzerland; https://cds.cern.ch/record/1230422/files/p166.pdf ; http://cds.cern.ch/record/1976737/files/Future-neutrino-184-192.pdf ; see also http://cds.cern.ch/record/1240330; accessed March 22, 2016 (see Reference 655a, herein)

612) Spooner, Neil. 2009. Underground Facilities, Technological Challenges; In *World Underground Science Facilities for Neutrino Physics: Prospects for Large Caverns for LB Neutrinos (100 Kton - 1 Mton); Progress in Europe - LAGUNA*; 43 pages; i) http://laguna.ethz.ch:8080/Plone/Public/talks/2010/access.pdf ; and ii) http://indico.cern.ch/event/59378/session/4/contribution/19/attachments/996253/1416783/LAGUNA_SITE-CERNv20909.pdf ; accessed January 11, 2017 (NOTE: Spooner presentation and reports are key source reference for facilities examined in this synthesis of underground physics laboratories. Large Apparatus studying Grand Unification and Neutrino Astrophysics / LAGUNA group; underground physics labs, general test and tables / depth; status of international underground physics and astrophysics facilities; summarizes archived LAGUNA report in *Community Research and Development Information Service [CORDIS], Final Report Summary - LAGUNA [Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics];* http://cordis.europa.eu/result/rcn/59267_en.html; http://cordis.europa.eu/result/rcn/173788_en.html ; accessed March 22, 2016; not available 1/11/2017. Also see Reference 655a, herein)

613) Neutrino Facilities Assessment Committee, National Research Council. 2003. Science Potential of a Deep Underground Laboratory, pp. 32-58, Chapter 4. In: *Neutrinos and Beyond: New Windows on Nature;* 90 pp., National Academies Press, Washington D.C. http://www.nap.edu/catalog/10583/neutrinos-and-beyond-new-windows-on-nature ; accessed March 22, 2016 (NOTE: Among most physics URLs, document includes data from Mt Blanc and Canfranc, ~page 54.)

614) Goodman, Maury. July 2003. New Projects in Underground Physics; i*n*: *Tenth International Symposium on Neutrino Telescopes, Venice, Italy, Neutrino Telescope 2*, pp. 457-468 (July 2003). http://arxiv.org/pdf/hep-ex/0307017.pdf ; accessed March 22, 2016 (NOTE: Gran Sasso Laboratory in a mountain road tunnel in Italy; Kamioka mine is located in the Japanese Alps on the western side of Japan; Baksan facility is located in the Caucasus mountains in southern Russia; Sudbury Neutrino Observatory (SNO) in INCO's Creighton mine near Sudbury, Ontario; Soudan Underground Physics Laboratory, State of Minnesota Department of Natural Resources park with former mine in Iron Range. Frejus laboratory is in a tunnel between France and Italy; Waste Isolation Pilot Plant, or WIPP facility, in Carlsbad New Mexico; Homestake, South Dakota mine facility proposed; India with one of the earliest and deepest underground facilities, the KGF mine experiment ran from the 60's-90's, and two newly considered sites presented)

615) Sullivan, W. 1982. A basic particle of the universe may be decaying; *New York Times*, Science; http://www.nytimes.com/1982/09/14/science/a-basic-particle-of-the-universe-may-be-decaying.html ; accessed March 22, 2016 (NOTE: Mont Blanc; 7,550 feet underground in the Kolar Gold Field of India; Morton Salt Mine under Lake Erie each with testing in 1980s)

616) Duffaut, Pierre. 2007. Engineering of large & deep rock caverns for physics research*. Next Generation of Nucleon Decay and Neutrino Detectors (*NNN05). Aussois, Savoie, France April 7-9, 2005 (presentation); http://www.slac.stanford.edu/econf/C0504071/pdf/duffaut.pdf and http://www.slac.stanford.edu/econf/C0504071/ ; accessed March 22, 2016 (NOTE: Presentation of Underground cavern / power plants, salt solution caverns, tunnels, mines, examples, global; CFMR, French Committee on Rock Mechanics. Additional features described by Duffaut with contribution to Geotec, Hanoi, 2011 Conference; at http://ecolo.org/documents/documents_in_english/G4-Largecaverns-Duffaut-2011.pdf; accessed March 22, 2016)

617) Gerbier, G. 2005. Laboratoire Souterrain de Modane: past, present, future. *Next Generation of Nucleon Decay and Neutrino Detectors (NNN05*). Aussois, Savoie, France April 7-9, 2005 (Presentation); http://www.slac.stanford.edu/econf/C0504071/pdf/gerbier.pdf and http://www.slac.stanford.edu/econf/C0504071/presentations.htm ; accessed March 22, 2016 ; (NOTES: LSM facility is off railroad tunnel; testing 1984; 1750m bgl; 4800mwe; Institute of Underground Science, Boulby mine, UK (IUS); Pyhasalmi lab, Finland, Loboratoire Souterrain de Modane, France (LSM); Laboratorio Subterrauneo de Canfranc, Spain (LSC); Laboratori Nazionali del Gran Sasso, Italy (LNGS)

618) Bettini, A. 2007. *The World Underground Scientific Facilities: A Compendium*; 33pp. http://www.lsc-canfranc.es/Docs/Presentations/uglabs.pdf ; and http://arxiv.org/ftp/arxiv/papers/0712/0712.1051.pdf ; accessed March 22, 2016 {NOTE: summarizes: **1)** Russian Federation, Baksan Neutrino Observatory, 1966, beneath Mountain Andyrchi (http://www.inr.ac.ru/INR/Baksan.html accessed March 22, 2016, Reference 638 ; Institute for Nuclear Research (INR) of the Russian Academy of Sciences, Baksan Neutrino Laboratory. **2)** Boulby, UK, 1000m potash mine shaft access with inner tunnel access to~1440m; Reference 722; http://www.imperial.ac.uk/high-energy-physics/research/experiments/zeplin/ accessed March 22, 2016; Imperial College Research, Boulby, high energy physics Zeplin Research Program (also see References 718-721). **3)** LNGS. Laboratori Nazionali del Gran Sasso. L'Aquila, Italy (http://www.lngs.infn.it/ ; http://www.lngs.infn.it/en/lngs-overview accessed March 22, 2016), since 1987; tunnel access; up to 1400m bgl;

neutrino and astroparticle physics R&D; located between L'Aquila and Teramo; Reference 646. **4)** LSC. Laboratorio Subterráneo de Canfranc, Spain; since 1980s; Reference 637, http://www.lsc-canfranc.es/en/ accessed March 22, 2016; road tunnel; new tunnels, 2005; max. 850m bgl. **5)** LSM. Laboratoire Subterrain de Modane, France; Reference 644; accessed March 22, 2016; facility access via Frejus roadway tunnel; ~1700m overburden; Reference 644. **6)** SUL/Solotvina Underground Laboratory, Ukraine; access via salt mine shaft to ~ 430m; since 1984; salt mine; currently may not be operating; Institute for Nuclear Research, Kiev, Ukraine; Transcarpathian region, western Ukraine; The Solotvina Underground Laboratory (SUL) was constructed in 1984 by the Lepton Physics Department (LPD) of the Institute for Nuclear Research. **7)** Kamioka Observatory, Japan; since 1983; http://www-sk.icrr.u-tokyo.ac.jp/aboutus/index-e.html ; accessed May 24, 2016; mine tunnel/road access; ~1000m bgl max; Reference 657. **8)** OTO-Cosmo Observatory, Japan; http://wwwkm.phys.sci.osaka-u.ac.jp/info/syoukai/oto-e.html accessed March 22, 2016; former rail tunnel (Tentsuji) access; maximum ~467m bgl; center of the Oto-Tentsuji tunnel; Reference 651. **9)** Y2L, Korea; dmrc.snu.ac.kr; access by road tunnel; Yangyang Pumped Storage Power Plant; up to 700m bgl; aka as Yangyang underground research laboratory; Kangwondo Prefecture; beneath Mt. JeomBong; http://q2c.snu.ac.kr/KIMS/KIMS_index.htm , accessed March 22, 2016; KIMS (Korea Invisible Mass Search); Reference 652. **10)** INO/ The India based Neutrino Observatory, India; http://www.imsc.res.in/~ino/ accessed March 22, 2016; purpose built 2km tunnel access; ~1400m bgl; Reference 640. **11)** SNO-Lab / Sudbury, Ontario, Canada; http://www.snolab.ca/ and http://www.sno.phy.queensu.ca/ accessed March 22, 2016; vertical shaft access, ~2000m bgl; SNO, Sudbury Neutrino Observatory, Reference 667. **12)** SUL/Soudan Underground Laboratory, Minnesota USA; http://www.soudan.umn.edu/ accessed March 22, 2016; access via old mine shaft, slight incline to~700m; in state park; Reference 723. **13)** Sanford / DUSEL / Homestake Mine, South Dakota, USA; testing at 1450, 200m bgl; 2 main shafts for access; http://sanfordlab.org/ (Ref 624 and 50. Also documented updates of Bettini work in: Reference 618a} accessed March 22, 2016

618a) National Research Council (Ad Hoc Committee to Assess the Science Proposed for a Deep Underground Science and Engineering Laboratory / DUSEL; Board on Physics and Astronomy; Division on Engineering and Physical Sciences). 2012. *An Assessment of the Science Proposed for the Deep Underground Science and Engineering Laboratory (DUSEL)*; Chapter 11: Appendix D: Survey of the Principal Underground Laboratories. National Academies Press; 142pp. https://www.nap.edu/read/13204/chapter/11 and https://www.nap.edu/catalog/13204/an-assessment-of-the-science-proposed-for-the-deep-underground-science-and-engineering-laboratory-dusel

International: Underground Scientific Facilities (physics / astrophysics)

619) Bettini. A. 2014. New underground laboratories: Europe, Asia and the Americas; *Physics of the Dark Universe*, Volume 4, September 2014, Pages 36–40 (Dark TAUP2013 special volume); http://www.sciencedirect.com/science/article/pii/S2212686414000181; accessed March 22, 2016 [NOTE: Deep Underground physics labs recent summary, 2014, describes several proposed labs under consideration in India, China, elsewhere, some that are not included in tables.) **1)** BNO, Baksan Neutrino Observatory, 1966; built under the mount Andyrchi in the Caucasus. First purpose-built neutrino laboratory; operated by INR-RAS; 300-3500m bgl; Reference 639, http://www.inr.ru/eng/ebno.html ; accessed March 22, 2016. North Caucasus in the area of the Baksan river, elevation 1700 m; 43°16′32″N 42°41′25″E; 43.275556,42.690278. **2)** LNGS, Gran Sasso, Italy, conceived in 1979, completed in 1987; Reference 646, http://www.lngs.infn.it/http://www.lngs.infn.it/en ; accessed March 22, 2016; 42.419831, 13.517228. **3)** Kamioka Underground Observatory: initially1983; tests now identified by name, KamiokaNDE and SuperKamiokaNDE Underground Observatory; KamiokaNDE website http://www-sk.icrr.u-tokyo.ac.jp/aboutus/index-e.html , and Reference 657; accessed March 22, 2016. Kamioka Underground Observatory, the predecessor of the present Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo, established in 1983; KAMIOKA Nucleon Decay Experiment, KamiokaNDE for test; 4,500 ton water Cherenkov detector was placed at 1,000 m underground of Mozumi Mine of the Kamioka Mining and Smelting Co. located in Kamioka-cho, Gifu, Japan 36°25.6′N 137°18.7′E ; 36.4267°N 137.3117°E (Mt. Ikeno); see superK location for site. **4)** Super Kamiokande Official Website, Reference 657, http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html and http://www-sk.icrr.u-tokyo.ac.jp/sk/sk/index-e.html ; accessed March 22, 2016; SK detector is located at ~1,000 meter underground in the Kamioka-mine, Hida-city, Gifu, Japan. The underground facilities are located 1000m below the top of the 1369m high Mt.Ikeno-yama; 50,000 ton water Cherenkov detector constructed and readied 1991/96; 36°25′32.6″N 137°18′37.1″E ; 36.425722°N 137.310306°E ; checked and found 36.427549, 137.299978 more likely; Le Laboratoire Souterrain de Modane, testing reported ~1200-1700 m bgl, located along Tunnel Route Fréjus / Savoie, reference 644 accessed March 22, 2016; also known as the Fréjus Underground Laboratory; in the Frejus tunnel; 45.189951, 6.684824; Laboratorio Subterráneo de Canfranc , http://www.lsc-canfranc.es/en/index.htmlaccessed March 22, 2016 under the Pyrenees mountain El Tobazo; Spanish side of the Aragon Pyrenees; tunnel access; University of Zaragoza is operator; Reference 637 ; accessed March 22, 2016; abandoned railway's Tunnel of Somport (7874 m) is now used as an emergency lane for the motorway's Tunnel of Somport (8602 m) and is also used for the Laboratorio subterráneo de Canfranc, Reference 637 (Canfranc underground laboratory); town location 42°42.93′N 0°31.53′W; rail station location 42°45′02″N 0°30′53″W; 42.75065°N - 0.51460°W. **7)** http://www.sanfordlab.org Creighton nickel mine, Canada; CUPP = Centre for Underground Physics in Pyhäsalmi (Finland). Reference 713, http://www.cupp.fi CJPL = China JinPing underground laboratory; planned 2400m bgl; in progress; under JinPing Mountain; tunnel access; 3 options. **11)** ANDES (Agua Negra Deep Experiments Site); road tunnel to be constructed. Maximum overburden 1750m; **12)** Oto Cosmo in Japan; **15)** SOUDAN; **16)** WIPP.]

619a) Ianni, Aldo. 2017. Status of underground Labs (abstract); *15th International Conference on Topics in Astroparticle and Underground Physics, TAUP2017*; https://indico.cern.ch/event/606690/contributions/2661223/ and presentation, "Considerations on underground laboratories", https://indico.cern.ch/event/606690/contributions/2661223/attachments/1500286/2337525/TAUP2017-Ianni.pdf (Note: excellent summary of some features for some of the existing deep underground laboratories; generally matches information contained in this Global Survey table)

620) Nuijten, G. A. 2011. Laguna design study: underground infrastructures and engineering. 1st International Workshop towards the Giant Liquid Argon Charge Imaging Experiment; *Journal of Physics: Conference Series 308* (2011) 012029, IOP Publishing; http://iopscience.iop.org/article/10.1088/1742-6596/308/1/012029/pdf;jsessionid=DCA23FCF74585B96AD25BCC2116CEAAC.ip-10-40-2-81; accessed March 22, 2016 (and http://iopscience.iop.org/1742-6596/308/1/012029/pdf/1742-6596_308_1_012029.pdf); accessed March 22, 2016 (NOTES: LAGUNA = Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics; considering: i) Pyhäsalmi Mine Oy site: owner, Inmet Mining Corporation; underground Cu / Zn mine, central Finland, municipality of Pyhäjärvi. At present, it is the deepest mine in Europe, depth of 1440 m bgl. In 1962, mine began as an open pit operation; by 1967, operations commenced underground. Mining is carried out via the new 1440 meter deep Timo Shaft. The Mine has one decline, one main transport hoist shaft and one ventilation shaft. ii) Fréjus site is near Italian-French border adjacent to the Fréjus Highway tunnel connecting villages of Modane, France and Bardonecchia, Italy. LSM, Laboratoire Souterrain de Modane, created in 1982. iii) Boulby mine, North East

England, in Yorkshire; iv) Canfranc near Spanish-French border adjacent to Somport Highway tunnel; Canfranc Underground Laboratory (LSC) is new facility; Consortium of the Spanish Ministry of Science and Innovation

621) Astroparticle Physics European Consortium / APPEC (website accessed March 22, 2016). *Underground Laboratories*; http://www.appec.org/infrastructures/underground-labs.html (Note: Astroparticle physics facilities included – Boulby/UK, 1100m bgl, 2805mwe new test level; Cleveland Potash Limited, owners, http://www.stfc.ac.uk/boulby/default.aspx , see references 718-721, and http://www.boulby.stfc.ac.uk/boulby/default.aspx , accessed May 22, 2016; Gran Sasso, Italy, aka LNGS, ~3800mwe, Reference 646, http://www.lngs.infn.it/en accessed March 22, 2016; the Low Noise Underground Laboratory / Laboratoire Souterrain Bas Bruit / LSBB, France, http://www.lsbb.eu/, Reference 642, , and http://www.lsbb.eu/index.php/en/ accessed March 22, 2016; Laboratorio Subterráneo de Canfranc, Spain, Reference 637; accessed March 22, 2016; Laboratoire Subterrain de Modane, France, min. 4000mwe, average 4800mwe, reference 644 , accessed March 22, 2016; Modane is deepest of facilities with rock overburden ~ 4,000 m.w.e., with average overburden, 4,800 m. w.e.).

621a) Paling, Sean. 2015. Developments in the World's Deep Underground Laboratories - Status and future plans for some of the world's deep underground laboratories; (Presentation) STFC Boulby Underground Science Facility; http://www.lowbg.org/ugnd/workshop/sympo_all/201605_Tokyo/slides/12pm/12pm_05.pdf and https://indico.cern.ch/event/439062/contributions/1085696/attachments/1145114/1641485/UGLabs_Review_SNOLAB2015_short.pdf ; accessed January 12, 2016 (Note: Includes Boulby, Gran Sasso, Modane, Canfranc, Kamioka, Jinping, Yangyang, INO, SNOLab, SURF, Soudan, WIPP, ANDES, Stawell)

621b) Coccia, E. 2009. Underground Laboratories (Presentation, 87 slides); Eleventh International Conference on Topics in Astroparticle and Underground Physics / TAUP2009, Rome, July 1-5, 2009; http://taup2009.lngs.infn.it/slides/jul5/coccia.pdf ; accessed January 2017 (Note: overview of underground facilities and testing; compilation of numerous contributors.)

Underground Physics Research Labs

622) Sobel, Hank. 2005. Underground Labs in Japan and North America (50 slide presentation); *TAUP'05, Ninth International Conference on Topics in Astroparticle and Underground Physics*, University of Zaragoza, Spain, September 2005; http://www.ps.uci.edu/~sobel/Temp2/Sobel_TAUP'05_Underground_Labs.pdf ; accessed March 22, 2016; see Proceedings Volume (eds., A. Bottino, et al.), *Journal of Physics: Conference Series 39* (2006), http://iopscience.iop.org/1742-6596/39/1;jsessionid=853341C74FC28B7E1C1924EAB33F7C1A.c1.iopscience.cld.iop.org and *J. Phys. Conf. Series 39 438*; accessed March 22, 2016 (NOTES: Japan and North America underground research labs. 2005 discussion)

Site-specific references (623-741a) supporting Table 4, Map Layer 4 (Physics Facilities)

United States: Sanford Underground Research Facility (SURF), Homestake mine, Lead, South Dakota

623 & 49) Caddey, S.W. et al. 1991. The Homestake Goldmine: an early Proterozoic iron-formation-hosted gold deposit, Lawrence County, South Dakota (Chapter J, p. J1-J67); Chapter J, *In*: *Geology and Resources of Gold in the United States* (eds. D. Shawe et al.),U.S. Geol. Surv. Bull. 1857; http://homestake.sdsmt.edu/Protected/USGS%20Bulletin%201857-J.pdf ; accessed February 9, 2016 (NOTES: Early Proterozoic; 2Ga; intruded and Metamorphosed through ~1.8 Ga to 1.7 Ga; Greenstone belt deposits iron formations as of world for that age and distribution.)

624 & 50) Sanford Underground Research Facility / SURF (website; accessed May 24, 2016). http://sanfordlab.org/ (NOTE: Yates and Ross Shafts important to current projects; Homestake Mine; testing at 1450m and 200m bgl; 2 main shafts for access)

625 & 51) *Homestake -- Background material for DUSEL (Deep Underground Science and Engineering Laboratory)*: Resources (website; accessed February 10, 2016); http://homestake.sdsmt.edu/Resources.htm (Note: links to geology, Sanford URL)

626 & 52) Campbell, T. J. (website). *Homestake Reference Book: Geology*; http://homestake.sdsmt.edu/HRB/Refer.htm; accessed February 10, 2016

627 & 53) Campbell, T.J. (website). *Synopsis of Homestake Mine Geology*; http://homestake.sdsmt.edu/Geology/geology.htm ; accessed February 10, 2016 (NOTE: Poorman, Homestake, and Ellison formations; metavolcanics, metasediments, iron formations; gold mine now closed, Lead area, Black Hills, SD)

628) Marshak, Marvin. July 1, 2003. Decision to flood hits US underground science plans; *Cern Courier*, July 1, 2003. http://cerncourier.com/cws/article/cern/28893 ; accessed May 24, 2016 (Note: history and events related to selection and nature of Homestake mine as deep laboratory; lower section of mine began to flood in this period; pumps shut down; summary of proposed approach to future controls)

628a) Heise, J. 2015. The Sanford Underground Research Facility at Homestake; Journal of Physics: Conference Series 606 (2015) 012015 (2nd Workshop on Germanium Detectors and Technologies); IOP Publishing; http://iopscience.iop.org/article/10.1088/1742-6596/606/1/012015/meta; http://iopscience.iop.org/article/10.1088/1742-6596/606/1/012015/pdf ; accessed March 3, 2017 (Note: general location, ~44° 20' 46.65" N 103° 45' 30.31" W)

628b) Cho, Adrian. July 21, 2017. Excavation starts for U.S. particle physicists' next giant experiment; *Science Magazine* - News (online), AAAS; http://www.sciencemag.org/news/2017/07/excavation-starts-us-particle-physicists-next-giant-experiment (Note: At Sanford Underground Research Facility (SURF); Experiment location ~1480 meters bgl ; Long-Baseline Neutrino Facility (LBNF). The detector itself is known independently as the Deep Underground Neutrino Experiment (DUNE)—will comprise four massive tanks of ultrapure liquid argon.... Excavation initiation for four chambers measuring roughly 70 meters long, 20 meters wide, and 29 meters high. DOE now anticipates covering $1.5 billion of the total cost.)

United States: Underground Physics Facilities, Waste Isolation Pilot Plant (WIPP), New Mexico

629) WIPP (Waste Isolation Pilot Plant), NM website; http://www.wipp.energy.gov/science/index.htm ; accessed March 22, 2016 (Note: location - check in Google map, 32.371667, -103.793611)

629a) U.S. Department of Energy, Waste Isolation Pilot Plant (website accessed January 2017); Underground Laboratory; http://www.wipp.energy.gov/science/ug_lab/ug_labnew.html

629b) Mewhinney, J. A. and R. Nelson. 2000. More than a waste repository, WIPP is a national resource; *Waste Management Conference*, February 27-March2, 2000, Tucson, Arizona. 13 pages; http://www.wmsym.org/archives/2000/pdf/61/61-3.pdf ; accessed January 2017

United States: Henderson mine, Clear Creek County, Colorado; DUSEL former candidate site

630) Henderson Underground Science and Engineering Project (website homepage accessed November 15, 2016); http://nngroup.physics.sunysb.edu/husep/ and http://nngroup.physics.sunysb.edu/husep/Henderson_DUSEL_Capstone/ ; accessed May 24, 2016 (Note: Henderson Mine, Colorado; Wikipedia has better summary information; https://en.wikipedia.org/wiki/Henderson_molybdenum_mine)

631) Wikipedia (website accessed May 24, 2016). Henderson molybdenum mine; https://en.wikipedia.org/wiki/Henderson_molybdenum_mine ; (Note: underground molybdenum mine discovered in 1964, located west of the town of Empire in Clear Creek County, Colorado; porphyry-type deposit consisting of a stockwork of small veins of molybdenite in rhyolite porphyries of Tertiary age that intrude into Precambrian Silver Plume granite. Location 39.771068, -105.845960)

United States: Mt. San Jacinto, Riverside County, California; DUSEL former candidate site

632) Deep Underground Science and Engineering Lab at Mt. San Jacinto, CA (website accessed May 24, 2016) http://www.ps.uci.edu/~SJNUSL/ (Note: plan for 7-8km nearly horizontal tunnel and depth planned at 2km bgl; new construction advantage; location 33.814712, -116.679438; former DUSEL candidate site)

633) Mt. San Jacinto Natural History Association (website accessed May 24, 2016). *Geology of the San Jacinto Mountains*; http://www.msjnha.org/nature/geology.html (Notes: homepage http://msjnha.org/ ; Peninsular Ranges Province; granitic plutonic Mesozoic batholith)

United States: Icicle Creek Laboratory site, Chelan County, Washington; DUSEL former candidate site

634) CNA Consulting Engineers (website accessed May 24, 2016). *Underground Science Laboratories - Icicle Creek Laboratory, Washington*; http://www.cnaengineers.com/underground-science-laboratories.htm (Note: in granite / crystalline rock; eliminated in down-selection by NSF in 2003; Homestake selected; CAN engineering used for several DUSEL-like projects, i.e., candidate sites and the identification of national underground science laboratory, NUSL; Cashmere Mountain location from www.google.com/maps)

635) Stricherz, V. 2006. NSF supports underground lab effort; *UW Today*, June 22, 2006. http://www.washington.edu/news/2006/06/22/nsf-supports-underground-lab-effort-2/ (Note: under Cashmere Mountain; cost considerations, site option dropped; UW decided to focus on Burlington Northern Santa Fe Railway Pioneer Tunnel option, 2006; Pioneer Tunnel's portal lies just west of Stevens Pass near the community of Scenic. The 5.3-mile tunnel is ~3,400 feet deep; approximate area location Pioneer Tunnel entrance 47.715176, -121.145716)

Spain: Underground Research Laboratory, Canfranc (LSC)

636) Morales, J. et al. 2005. The Canfranc Underground Laboratory - Present and Future; pages 447-452, In: N. Spooner and V. Kudryavtsev (eds.), *Proceedings of the Fifth International Workshop on the Identification of Dark Matter, (IDM 2004) : Edinburgh, UK, September 6-10, 2004;* World Scientific, Hackensack, USA, 662pp. http://www-lsm.in2p3.fr/ilias/n2/Docs/Paper_idm04_LSC1.pdf ; accessed March 22, 2016 (Note: also see reference 644)

637) Laboratorio Subterráneo de Canfranc (website accessed March 22, 2016), http://www.lsc-canfranc.es/en/ and http://www.lsc-canfranc.es/en/index.html (Note: other laboratories described; under the Pyrenees mountain El Tobazo; Spanish side of the Aragon Pyrenees; tunnel access; University of Zaragoza is operator; abandoned railway's Tunnel of Somport (7874 m) is now used as an emergency lane for the motorway's Tunnel of Somport (8602 m) and is also used for the Laboratorio subterráneo de Canfranc / Canfranc underground laboratory; overview documented in Wikipedia, https://en.wikipedia.org/wiki/Canfranc_Underground_Laboratory for station location ~ 42.75065°, -0.51460°; 1] Spain, Canfranc Station 42.747446, -0.515338; 2] France, tunnel 42.818194, -0.560990)

637a) Laboratorio Subterráneo de Canfranc. 2010. Feasibility study for large underground caverns and auxiliary infrastructure facilities of the Laguna Project at the LSC (Canfranc, Huesca, Spain), Revision 8, February 2010; 198p. http://www.hep.shef.ac.uk/tmp/LAGUNA-TechUpdates/LSC%20Revision%2020100208-2.pdf ; accessed August 29, 2016

Russian Federation: Baksan Neutrino Observatory BNO; Prielbrusye, Kabardino-Balkarian Autonomous Republic, Caucasus

638) Baksan Neutrino Observatory BNO (website accessed May 24, 2016). http://www.inr.ac.ru/INR/Baksan.html (Note: INR / Institute for Nuclear Research, Baksan Neutrino Observatory is situated in Prielbrusye, the Caucasus; initiated investigations in 1966; beneath Mountain Andyrchi; neutrino telescopes was set up in Prielbrusye, the Kabardino-Balkarian Autonomous Republic in the Caucasus, http://www.inr.ac.ru/INR/Welcome.html#more)

639) Baksan Neutrino Observatory (website accessed May 24, 2016); http://www.inr.ru/eng/ebno.html ; (Notes: Is situated in the North Caucasus in the area of the Baksan river at a height of 1700 m above the sea level; underground setups are located under the mount Andyrchy (3922 m) at different distances from the entrance of the adit which is 4000 m in length; 1966; built under the mount Andyrchi in the Caucasus.

First purpose-built neutrino laboratory; operated by INR-RAS; 300-3500m bgl; North Caucasus in the area of the Baksan river, elevation 1700 m; location verified with google maps; 43°16′32″N 42°41′25″E; 43.275556,42.690278

India: India-based Neutrino Observatory (INO): Pottipuram village in Theni district of Tamil Nadu state; and Kolar Gold Fields Experiments, Kolar district, Karnataka State

640) *India-based Neutrino Observatory / INO* (website accessed May 24, 2016). General information on INO; http://www.imsc.res.in/~ino/ (Note: underground laboratory and associated surface facilities at Pottipuram in Bodi West hills of Theni District of Tamil Nadu; ; to be accessed by a 2100 m long and 7.5 m wide tunnel; Pottipuram site under the Bodi West Hills range was the most suitable in this region since it afforded the shortest tunnel length (1910 metres), the tunnel portal could be located in Poromboke land completely within Tamil Nadu; see homepage http://www.ino.tifr.res.in/ , below)

640a) *India-based Neutrino Observatory / INO*. 2012. Frequently Asked Questions about the India-based Neutrino Observatory at Bodi West Hills, Pottipuram, Theni District, Tamil Nadu; INO/IMSc/2012/, September, 2012 (Revised); http://www.imsc.res.in/~ino/Faq/inofaq_2012.pdf ; website accessed May, 2016

640b) India-based Neutrino Observatory / INO, Outreach materials (website accessed May 2016); http://www.ino.tifr.res.in/outreach/english/about.html (Note: map location from website map illustration)

641) *India-based Neutrino Observatory / INO* (website accessed May 24, 2016) http://www.ino.tifr.res.in/ {Note: Rock cover of approx.1200 m; District of Tamil Nadu; decided on a site in Bodi West Hills(BWH) region near Pottipuram village in Theni district of Tamilnadu state; 110KM from the temple town of Madurai; presentation, http://www.ino.tifr.res.in/ino//Talks/2016/Science_Congress_Talk_Art_2016.pdf ; historical presentation list, http://www.ino.tifr.res.in/ino//talks.php#year2016 and http://www.ino.tifr.res.in/outreach/english/about.html ; other links, Wikipedia indicate INO ~1,300 meters bgl (4,300 ft) deep cave under Ino Peak; government approval for project in 2015 and construction to begin. Other links at INO website provided additional facility, status, and location information http://www.ino.tifr.res.in/ino/faq.php ; about same as Google maps shows location 9.956046, 77.283598; photo and map www.ino.tifr.res.in/outreach/english/about.html. See http://www.ino.tifr.res.in/ino/faq.php#projectlocation , Figure 2; also http://www.imsc.res.in/~ino/Faq/inofaq_2012.pdf , Ref. 640a}

641a) Wikipedia.org (webpage access August, 2016). *Kolar Gold Fields*; https://en.wikipedia.org/wiki/Kolar_Gold_Fields (Note: location information)

641b) Wikipedia.org (webpage access August, 2016). *Particle experiments at Kolar Gold Fields*; https://en.wikipedia.org/wiki/Particle_experiments_at_Kolar_Gold_Fields

641c) Show mines of India (website accessed August 23, 2016). *Kolar Gold Fields*; http://www.showcaves.com/english/in/mines/Kolar.html ; (Notes: Muon and other physics investigations ~196. First cosmic ray / neutrino data available in 1965 under Tata Institute of Fundamental Research (TIFR), Mumbai, Osaka City University, Japan and Durham University, UK. Kolar district is located in Karnataka State; all mines closed since 2003; former operator was Bharat Gold Mines Limited; first mine shaft in 1875; the 3.2 km (10500') deep Champion Reef Mine long considered one of worlds deepest mines. Geology: Located on the Deccan Plateau within the Kolar Shist Belt, 2.7Ga old associated with a 2.5Ga suture zone, Dharwar Craton, southern India; schists / amphibolites cut by quartz-carbonate vein gold mineralization; ore veins are characterized by thin zone of alteration in adjacent host rock. Champion Reef mine used for experiments; location 12.940458, 78.259388)

641d) Pal, Sanchari. 2018. Neutrino Observatory Project Gets Centre's Approval: Why Its Huge For India; *The Better India* (website), March 15, 2018; https://www.thebetterindia.com/134447/neutrino-project-ino-bodi-hills-theni-tamil-nadu-india/ (Note: Ministry of Environment and Forests (MoEF) grants environmental clearance for lab in Bodi West hills, Tamil Nadu's Theni district, pending approval from Wildlife Board and Tamil Nadu Pollution Control Board. Pottipuram is the village near the proposed site. Kolar Gold Field (KGF) experiment in Karnataka, first atmospheric neutrino detection, 1965; 1951-1992 operations in KGF, sponsor was Tata Institute of Fundamental Research. . China announcing the construction of a similar neutrino observatory in its Jiangmen province. Like the INO, the Jiangmen Underground Neutrino Observatory is also expected to be completed by 2020-2022. For the INO, see http://www.ino.tifr.res.in/ino/ , Reference 641)

France: LSBB / Bas Bruit Underground Research Laboratory, Department Vaucluse

642) Laboratoire Souterrain Bas Bruit / LSBB / The Low Noise Underground Laboratory (website accessed May 22, 2016) http://www.lsbb.eu/ ; and http://www.lsbb.eu/index.php/en/ and http://www.lsbb.eu/index.php/en/ct-menu-item-18 (Note: Situé dans le département du Vaucluse; in karst platform carbonate deposits; ~3.9km galleries and tunnel access to vaults)

643) Gaffet, S., et al. 2009. A 3D Broadband Seismic Array at LSBB, *IRIS Data Services Newsletter*, 11(3); https://ds.iris.edu/ds/newsletter/vol11/no3/a-3d-broadband-seismic-array-at-lsbb/ (Note: access via 3.7 km Tunnel system; The Laboratoire Souterrain à Bas Bruit (LSBB or Underground Low-noise Laboratory) in Rustrel, southern France; deepest vault is 518 m below the surface, i.e., ~1500-meter water equivalent, m.w.e.; located within the regional natural park of the Luberon; associated with Fontaine-de-Vaucluse aquifer; approximate location, 43.935169, 5.485182; probable entrance estimated 43.92865°, 5.48705°).

France: Laboratoire Subterrain de Modane / LSM; Frejus roadway tunnel

644) Laboratoire Subterrain de Modane / LSM (website accessed March 22, 2016). http://www-lsm.in2p3.fr/ (Note: France, min. 4000mwe, average 4800mwe; Le Laboratoire Souterrain de Modane, sous 1700 mètres de roche, est situé le long du Tunnel Routier du Fréjus en Savoie. Operational since 1982; Frejus roadway tunnel; 45.189951, 6.684824; also see http://www-lsm.in2p3.fr/plaquette/index.html)

644a) Semeraro, Martino et al. 2016. Assessing the interaction between the excavation of a large cavern and existing tunnels in the alps; Systra; https://www.systra.com/IMG/pdf/systra-wtc2016-assessing_the_interaction-ld.pdf ; accessed January 17, 2017 (Note: Laboratoire Souterrain de Modane (LSM); in 2007, Frejus tunnel owners decision to construct safety tunnel, to be located at ~ 50m from the existing tunnel and the laboratory owner CNRS / Centre National de Recherche Scientifique, decided to expand laboratory. Construction in Piemonte zone which are characterized by calc-schist and represent most of the geology of the highway tunnel; calc-schist consists of 2 facies: the schistose phyllitic facies, and the carbonate facies; strain analysis used for design)

Italy: Gran Sasso National Laboratory (LNGS)

645) Coltorti M. et al. 2011. U and Th content in the Central Apennines continental crust: a contribution to the determination of the geo-neutrinos flux at LNGS; *Geochimica et Cosmochimica Acta* 75 (2011) 2271-2294; El Sevier; http://arxiv.org/ftp/arxiv/papers/1102/1102.1335.pdf ; and http://ac.els-cdn.com/S001670371100041X/1-s2.0-S001670371100041X-main.pdf?_tid=abd7d3cc-5d92-11e5-961c-00000aacb362&acdnat=1442532203_81e20015800d814b417c8f4e6c2ec9c8 ; accessed March 22, 2016 (NOTE: 3-d model to moho developed; useful location maps and developed geologic model crustal profiles)

646) Laboratori Nazionali del Gran Sasso / LNGS / Gran Sasso National Laboratory (website accessed March 22, 2016); http://www.lngs.infn.it/en. , and http://www.lngs.infn.it/en/lngs-overview (Note: conceived in 1979, completed in 1987; ~3800mwe; 42.419831, 13.517228)

China: Jinping Underground Laboratory (CJPL), Sichuan Province

647) Li, Jainmin, Xiangdong Ji, Wick Haxton, Joseph S.Y. Wang. 2014. The second-phase development of the China JinPing underground Laboratory. *13th International Conference on Topics in Astroparticle and Underground Physics, TAUP 2013*. http://arxiv.org/abs/1404.2651; accessed March 22, 2016 (NOTES: adjoins JinPing auto tunnel complex; proposed tunnel test locale will be ~2400m bgl.)

647a) Li, Jianmin. 2015. The recent status and prospect of China Jinping Underground Laboratory; *XIV International Conference on Topics in Astroparticle and Underground Physics / TAUP2015*, Torino, Italy, September 7-11, 2015; Presentation, 29 slides; http://www.taup-conference.to.infn.it/2015/day3/parallel/dma/3_li.pdf ; accessed January 2017

648) PandaX Dark Matter Experiment (website accessed May 24, 2016); http://pandax.physics.sjtu.edu.cn/ (NOTE: work initiated in 2009; for map, see http://pandax.physics.sjtu.edu.cn/wp-content/uploads/2012/01/cjpl.png ; Location estimated Jinping tunnels on Ya Long River 28.139440, 101.786038)

649) Ji, Xiangdong. 2014. Status of PandaX; (Presentation, 37 slides) Dark Matte Conference, UCLA, Feb. 28, 2014; http://www.pa.ucla.edu/sites/default/files/webform/pandaX.pdf ; accessed March 22, 2016 (NOTE: PANDax at 2500mbgl; equipment installed and testing during 2013; first large-scale liquid noble gas experiment in China; contains map of facility location)

650) Yue, Qian. 2010. Status and Prospects of China JinPing Deep Underground Laboratory (CJPL) and China Dark Matter Experiment (CDEX); http://irfu.cea.fr/Meetings/TeVPA/slides/19_07_pm_Yue.pdf ; accessed March 22, 2016 (NOTES: also provides mwe for each active physics laboratory international; Ertan Hydropower Development Company; two tunnels for transportation; 17km long; planned 2400m bgl; in progress; under JinPing Mountain. Y2L, Korea; 2100mwe; tunnel; Canfranc, Spain; 2450 mwe; mine; Kamioka, Japan; 2700mwe; mine; Boulby, UK; 2800 mwe; mine; INO, India; 3500 mwe; mine; LNGS, Italy; 3500 mwe; tunnel; Baksan, Russian Fed.; 4400 mwe; tunnel; Modane, France; 4800 mwe; tunnel; DUSEL, USA; 4500 mwe; 7000 mwe; mine; SNO, Canada; 6000 mwe; mine; CJPL, China; 7500 mwe; tunnel)

China: Jiangmen Underground Neutrino Observatory, Kaiping, Jiangmen prefecture, Guangdong Province

650a) He, Miao. 2014. Jiangmen Underground Neutrino Observatory / JUNO (presentation); *Neutrino Oscillation Workshop*, Conca Specchiulla (Otranto, Lecce, Italy), September 7-14, 2014; see location map, slide 9; http://www.ba.infn.it/~now/now2014/web-content/TALKS/bTue/Par1/hem_juno.pdf (Note: Slide 9, illustrated facility location proximal to 22.125, 112.5095; Kaiping, Jiangmen prefecture (Pearl River Delta region), Guangdong Province, China; construction start 2015, completion expected 2020. Information on geology and other items not established by brief literature review; thus, site not included in table of this report. Additional information may be found at http://juno.ihep.cas.cn/ , http://english.ihep.cas.cn/ib/dbajb/)

Japan: Oto Cosmo Observatory, Oto-Tentsuji tunnel, Nara Prefecture

651) Oto Cosmo Observatory, Osaka University, Physics *(website* accessed March 22, 2016*);* http://wwwkm.phys.sci.osaka-u.ac.jp/info/syoukai/oto-e.html (NOTES: rail tunnel ~ 100km south of Osaka, Japan; ~467m bgl; ~1400 mwe; former rail tunnel (Tentsuji) access; center of the Oto-Tentsuji tunnel of the Goshin Line; 5 km stretch of tunnel)

652) Takahisa, K., et al. 2000(?). Oto Cosmo Observatory (RCPN, Osaka University Research Center for Nuclear Physics); http://www.rcnp.osaka-u.ac.jp/~annurep/2000/genkou/sec3/takahisa2.pdf ; accessed March 22, 2016 (NOTE: tunnel between Oto Village and Nishiyoshino Village, Nara Prefecture)

653) Ejiri, H., K. Fushimi and I. Ogawa. 2003. Oto Cosmo Observatory- Underground Laboratory for Nuclear Particle Physics; In: H. Ejiri and I Ogawa (Eds.), Proceedings of the NDM03, Session XI, Underground Laboratories, The 1st Yamada Symposium on Neutrinos and Dark Matter in Nuclear Physics, June 9-14, 2003, Nara, Japan (YS1-NDM03); http://ndm03.phys.sci.osaka-u.ac.jp/proc/PDF/Session_XI.pdf ; accessed March 22, 2016 (Note: see references 610 and 622, herein)

654) Wikipedia (website accessed May 24, 2016) Yoshino District, Nara Prefecture https://en.wikipedia.org/wiki/Yoshino_District,_Nara (Note: Oto and Nishiyoshino merged with Gojo in 2005; location of area uncertain; placed on Google maps arbitrarily E of Gojo 34.344097, 135.746014)

655) Nakahata, M. 2004. Japan and eastern facilities; LRT2004 (December 12, 2004; slide presentation); *Low Radioactivity Techniques, Topical Workshop*, Laurentian University campus, Sudbury, ***Canada*** December12 - 14th , 2004; http://lrt2004.snolab.ca/talks/session1/nakahata.pdf; accessed March 22, 2016 (NOTES: Japan and Korean facilities described; Yang Yang

Underground Laboratory [Y2L], ROK, Republic of South Korea; tunnel, ~700m bgl; Kamioka Underground Laboratory, Japan;~800-1000m bgl; tunnel access)

655a) Korner, G-E (Editor). 2008. *Nuclear Physics News*, Vol. 18, No.4, 44 pages; Nuclear Physics European Collaboration Committee (NuPECC); http://www.nupecc.org/npn/npn184.pdf ; accessed January, 2017 (Note: news and information on underground physics facilities and activities; Feature article (by Spooner, pp. 15, 16, Tables 1 and 2) captures similar information as presented in Spooner, References 611, 612, herein)

Japan: Kamioka Observatory / Underground Facility and mine; KAMIOKANDE; Hida City, Gifu Prefecture, Chubu Region, Honshu Island

656) Nakahata, M. 2004. See reference 655, herein, http://lrt2004.snolab.ca/talks/session1/nakahata.pdf , accessed March 22, 2016 (Note: See http://lrt2004.snolab.ca/talks/session1/)

657) Kamioka Observatory (website accessed May 24, 2016), *About*; http://www-sk.icrr.u-tokyo.ac.jp/aboutus/index-e.html (Note: Kamioka Underground Observatory, 1000m bgl max.; the predecessor of the present Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo, was established in 1983. Kamioka administered by Institute for Cosmic Ray Research (ICRR), University of Tokyo; Kamiokande, Super-Kamiokande studies; mine tunnel road access; tests now identified by name, KamiokaNDE and SuperKamiokaNDE Underground Observatory; the predecessor of the present Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo, established in 1983; KAMIOKA Nucleon Decay Experiment, KamiokaNDE for test; 4,500 ton water Cherenkov detector was placed at 1,000 m underground of Mozumi Mine of the Kamioka Mining and Smelting Co. located in Kamioka-cho, Gifu, Japan 36°25.6′N 137°18.7′E ; 36.4267°N 137.3117°E (Mt. Ikenoyama); see location for site also http://www-sk.icrr.u-tokyo.ac.jp/sk/physics/atmnu-e.html)

657a) Super-Kamiokande (website accessed January, 2017). The world's largest underground neutrino detector; Institute for Cosmic Ray Research, Univ. Tokyo; http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html (Note: links provided to additional information, news, and reports for Kamioka area test complex)

658) Mindat.org. (website accessed May 24, 2016). *Kamioka mine, Hida City, Gifu Prefecture, Chubu Region, Honshu Island, Japan*; http://www.mindat.org/loc-2199.html ; (Note: Mitsui mining exploited several orebodies, including the Tochibora, Urushiyama, and Maruyama ore bodies, in skarns. Was at one time the largest zinc mine in East Asia and the most efficient zinc mine in the world. Closed in 2001 or 2002, since which time the mine has been used by Tokyo University for an underground neutrino observatory; portions of the Kamioka mine are across the prefectural border in Toyama. Location checked with Google maps and Wikimapia as 36.352994, 137.319909; compare USGS BofR data Mozumi mine / Kamioka mine location ~ 36.33192, 137.33205; https://mrdata.usgs.gov/mrds/show-mrds.php?dep_id=10231812 ; Skarn replacing limestone; primary product is Zn; vein deposits, amphibole, gneiss; Mozumi mined for Ag, Cu, Pb; Kamioka / Mozumi mine Zn)

659) Mindat.org. (website accessed May 24, 2016). *Mozumi deposit, Kamioka mine, Hida City, Gifu Prefecture, Chubu Region, Honshu Island, Japan*; http://www.mindat.org/loc-108075.html

660) Nakagawa, Tetsuo. 2005. Study on the Excavation of the Hyper-KAMIOKANDE Cavern at Kamioka Mine in Japan (Presentation); (J. Dumarchez, ed.) *Next Generation of Nucleon Decay and Neutrino Detectors (NNN05); Aussois, Savoie, France April 7-9, 2005*; http://www.slac.stanford.edu/econf/C0504071/pdf/nakagawa.pdf, accessed March 22, 2016 (NOTES: Kamioka Ag, Pb, Zn Mine operations ceased in 2001; Kamiokande under construction 1991-94; Hype-K proposed location at Mozumi mine; excellent paper collection, testing details, facility overview; see www.slac.stanford.edu/econf/C0504071/presentations.htm)

Republic of Korea: Y2L, Yangyang Underground Laboratory, Gangwon / Kangwon Province

661) Nakahata, M. 2004. See above; http://lrt2004.snolab.ca/talks/session1/nakahata.pdf; accessed March 22, 2016

662) *Yangyang Laboratory* (website accessed May 25, 2016). http://q2c.snu.ac.kr/KIMS/KIMS_index.htm ; Quest for Connecting Quarks to the Cosmos; Korea Invisible Mass Search / KIMS; KIMS Center for High Energy Physics, Seoul National University (Note: Yangyang underground research laboratory; beneath Mt. JeomBong access by road tunnel at Pumped Storage Power Plant; is under construction now in Kangwondo-prefecture; located at 700m deep under Mt.JeomBong elevation ~1400m; 38.041394, 128.594164)

Chile / Argentina: ANDES, Agua Negra Deep Experiment Site

663) CLES / Consorcio Latinoamericano de Experimentos Subterráneos. 2011. *ANDES - Agua Negra Deep Experiment Site An Underground Laboratory In The Agua Negra Tunnel*; pamphlet, 14 pages / slides; The ANDES Underground Laboratory And The Latin American Consorsium For Underground Experiments / Consorcio Latinoamericano de Experimentos Subterráneos (CLES); http://andeslab.org/pdf/ANDES-en.pdf ; accessed May 24, 2016 (NOTES: 14 km of the tunnel, close to the Argentina-Chile borderline; overburder maximum ~1700-1750m bgl; Agua Negra road tunnel planned for construction with research facility concept in mind; also visit http://andeslab.org/, Reference 664, accessed March 22, 2016. Location from Google maps, -30.197943, -69.850534; verified with Wikimaps.org location)

664) ANDES (website accessed March 22, 2016), http://andeslab.org/ (NOTE: ANDES, Agua Negra Deep Experiment Site - An Underground Site and Underground Laboratory; Latin American Consorsium for Underground Experiments / Consorcio Latinoamericano de Experimentos Subterráneos (CLES))

665) Kenyon, Peter. 2011. Andes link a priority for Chile-Argentina-Brazil; *Tunnel Talk*, December 2011, http://www.tunneltalk.com/Chile-Argentina-Dec11-Agua-Negra-makes-infrastructure-priority-list.php ; accessed March 22, 2016 (NOTES: road tunnel entrance portals, at 3,950m on the Argentine side and 3,750m on the Chilean side; geology, outcrops of Choiyoi Group rock with intrusions of rhyolite, basalt and aplite dykes, sills and veins; located within the Rio Colorado fault zone that is located in the Rio Colorado, a superficial high-angle reverse fault; online magazine, Tunnel Talk, www.tunneltalk.com accessed March 22, 2016)

666) Geoconsult. 2012. *Tunél Paso De Agua Negra, Agentina / Chile*; Geoconsult ZT GmbH, Geoconsult SA, Buenos Aires / Dela Torre & Associados, San Juan; http://www.geoconsult.eu/tl_files/geoconsult/theme/media/img/projects/en/01%20-%20planning/Agua%20Negra_engl.pdf; accessed March 22, 2016 (NOTES: Summary geotechnical report/ brochure; geology = sub vertical Permian-Triassic andesitic and basaltic as well as rhyolitic and dacitic volcanic, volcaniclastic and pyroclastic rocks of the Choiyoi Formation overlain discordantly by Tertiary rocks of the Doña Ana Formation consisting of tuffs, volcaniclastic, pyroclastic and clastic sediments.)

666a) Heredia, N., et al. 2012. The basement of the Andean Frontal Cordillera in the Cordon del Plata (Mendoza, Argentina): geodynamic evolution; *Andean Geology* 39(2): 242-257 (May 2012); http://www.mendoza-conicet.gob.ar/portal/ianigla/upload/andean-geology-39-2012-heredia-et-al.pdf ; accessed August 24, 2016

Canada: SNOLab (Sudbury Neutrino Observatory), Creighton mine, Sudbury, Ontario, Canada

667) SNOLab / Creighton Mine, Ontario, Canada (website accessed March 22, 2016); http://www.snolab.ca {NOTES: Located 2 km below the surface in the Vale Creighton Mine located near Sudbury Ontario Canada, SNOLAB is an expansion of the existing facilities constructed for the Sudbury Neutrino Observatory (SNO) solar neutrino experiment; Inco's Creighton mine; Sudbury – SNOLAB = 2073m, ~6800'bgl (6000mwe); mineralization between norite / granite-gabbro; 2073m continuous shaft at Creighton Mine, ; other site states Sudbury SNOLAB, depth 2073m, 6010mwe; location from Wikipedia, 46.471639, -81.186619}

668) Sudbury Neutrino Observatory (website accessed May 25, 2016). http://www.sno.phy.queensu.ca/ accessed March 22, 2016; Queens University (Note: vertical shaft access, ~2000m bgl; SNO, Sudbury Neutrino Observatory at INCO's Creighton mine near Sudbury, Ontario, Canada; established in 1984; construction start in 1990; geologic profile of mine and laboratory, http://www.sno.phy.queensu.ca/images/mine.GIF; composition of footwall, granitic / gabbroic; composition of hanging wall noritic rock; mineralized fault zone; vertical shaft to 6800', ~2073m)

669 & 44) Phaneuf, C., and J-C. Mareschal. 2014. Estimating concentrations of heat producing elements in the crust near the Sudbury Neutrino Observatory, Ontario, Canada; *Tectonophysics* 622, p. 135-144; Elsevier, B.

670 & 45) Faggart, B.E., A. Basu, and M Tatsumoto. 1985. Origin of the Sudbury Complex by Meteoritic Impact: Neodymium Isotopic Evidence; Reports; *Science* 230, p. 436-439 (October 25, 1985); http://www.uta.edu/ees/faculty/basu/assets/publications/Sudbury.pdf ; accessed March 22, 2016 (Note: basement is 2.5Ga, impact 1.84Ga; formerly was 2073m, ~6800'bgl /6000mwe; mineralization between norite / granite-gabbro; 2073m continuous shaft at Creighton Mine. Crust age of 2.56 ± 0.13 billion years, similar in age to the early Proterozoic metavolcanic and metasedimentary rocks of the Huronian supergroup and of the Archean Superior Province-style basement that underlies the Sudbury structure... melted by an impact event some 1840 million years ago to produce the Sudbury Complex.)

671 & 46) ESG Solutions (website accessed February 9, 2016). Rockburst re-entry protocol at a deep underground Nickel mine in Sudbury, Ontario, a Case Study; *ESG Solutions*; 20 Hyperion Court, Kingston, Ontario, Canada; V.; http://www.sciencedirect.com/science/journal/00401951/622 and http://ac.els-cdn.com/S0040195114001280/1-s2.0-S0040195114001280-main.pdf?_tid=18edace8-cf7b-11e5-8d27-00000aacb35f&acdnat=1455056511_c1d8d126ab5cbbfb3234b4177373889f and http://ac.els-cdn.com/S0040195114001280/1-s2.0-S0040195114001280-main.pdf?_tid=18edace8-cf7b-11e5-8d27-00000aacb35f&acdnat=1455056511_c1d8d126ab5cbbfb3234b4177373889f ; accessed March 22, 2016 {NOTE: aka SNOLab, Sudbury Neutrino Observatory; thermal gradient; located at 46.475°N and 81.201°W; on the south range of the Sudbury impact structure; Wikipedia coordinates confirmation 46.471639, -81.186619; SNOLab is located at a depth of ~2000 m in the Creighton Mine; geoneutrino studies will provide robust constraints on the distribution of U and Th in the mantle; SNOLAB was installed 2040m; bgl in the Creighton Nickel Mine owned and operated by Vale INCO; 46.475°N and 81.201°W; impact occurred at ca 1850 Ma; Sudbury Structure straddles the boundary between the Archean Superior Province to the North, and the Paleoproterozoic Southern Province to the east and south; The initially circular structure was subsequently deformed during the Penokean (ca 1800 Ma) and Grenville (ca 1100 Ma) orogenies, which gave the Sudbury basin its present elliptical shape; Sudbury Structure is comprised of a central basin, the Whitewater group which filled the central depression and is underlain by the Sudbury Igneous Complex, and the breccia rocks of the footwall surrounding the SIC. The Whitewater Group is composed of three sedimentary formations; the Sudbury Igneous Complex generally consists of granophyre on top and norite-gabbro on the bottom, with a total thickness of ≈3 km. The footwall is made up of Archean and Proterozoic rocks that have been fractured, brecciated and partially melted following the meteoritic impact. The structure is in contact with the Archean (Levack) gneiss of the Superior Province to the north and with the low grade metamorphosed sediments of the Southern Province to the South. See primary source data - https://www.esgsolutions.com/sites/esgsolutions.com/files/rockburst_re-entry_v1.pdf and https://www.esgsolutions.com/technical-resources/case-studies/rockburst-re-entry-protocol-at-a-deep-underground-nickel-mine-in-sudbury-ontario ; Vale Inco Limited, Creighton nickel mine in Sudbury, Ontario; Canada's deepest mine; operations since 1901; Sudbury Igneous complex; microseismic monitoring system; safety; geologic section }

672) Caterpillar. 2008. Vale Inco's Creighton mine: Digging deeper by the day. *Viewpoint, Perspectives on Modern Mining*, 2008, Issue 4; Caterpillar Global Mining; https://mining.cat.com/cda/files/2785508/7/Creighton_Eng.pdf ; accessed March 22, 2016 {NOTES: Vale Inco mine; excellent review of mine and methods; Creighton's copper-nickel sulphide ore body was discovered in 1856; underground mining start in 1906; Sudbury Igneous Complex (SIC). The rocks of the SIC, which are dated at 1,850 million years, are exposed within an elliptical ring with a long-axis of 72 kilometers (45 miles) and a short-axis of 27 kilometers (17 miles); sulphides associated with the sub-layer norite or quartz diorite; high-grade sulphide pods located in the footwall; and sulphides associated with shearing; 2008, mining at 2,377 meters (7,800 feet); working on mining methods with group including Centre of Excellence in Mining Innovation (CEMI); All personnel and materials access the mine via the 9-shaft cage; All ore is hoisted up 9-shaft, using a 5,200-kilowatt (7,000-horsepower) double-drum hoist and two 13.5-tonne (15-ton) aluminium skips; 2133m, 7000' depth workings shaft access in 2008}

673) Atkinson, Gail M., et al. 2008. A Very Close Look at a Moderate Earthquake near Sudbury, Ontario; *Seismological Research Letters* V. 79, No. 1 p. 119-131, Jan./Feb. 2008; http://srl.geoscienceworld.org/content/79/1/119.short , http://srl.geoscienceworld.org/content/79/1/119.full and http://srl.geoscienceworld.org/content/79/1.toc ; accessed March 22, 2016 (NOTES: nickel-copper ore, open since 1901; located along the southern periphery of the Sudbury Structure, interpreted by most researchers as a relict giant impact; situated near the base of the impact melt

sheet, near its contact with the footwall. The SNO laboratory, where the closest seismic instruments are located, is situated within a massive igneous unit (norite) within the Sudbury Igneous Complex; mining induced seismicity, analysis)

United States: Morton Salt Mine, Fairport Harbor, Lake County, Ohio (neutrino detector)

674) GSSI / Geophysical Survey Systems, Inc. (website accessed March 22, 2016). Case Study, Mining, A Salty Situation (the Morton Salt Mine); http://www.geophysical.com/Documentation/Case%20Studies/GSSICaseStudy_MortonSalt.pdf ; (NOTES: Use GPR; Morton mounted the SIR-20 and 400 MHz antenna on their continuous miner machine, which allows them to detect the thickness of salt on the mine's floor and ceiling; operating 2000' underground and 2 ½ miles out under Lake Erie to mine a 450 million year old bed of halite, Silurian Salina salt.)

675) Taylor, Larry. 1989. Two thousand feet below Lake Erie. *Skin Diver*, September, 1989, p. 80-81.116-119; http://www-personal.umich.edu/~lpt/erie.htm ; accessed March 22, 2016 (NOTES: United States neutrino detector is 2000 feet underground in a salt mine near Fairport, Ohio (slightly east of Cleveland). The detector is the collaborative effort of the Proton Decay Group of the University of Michigan, the University of California (Irvine) and the Brookhaven National Laboratory. In 1989, was Morton-Thiokol salt mine, aka Fairport Mine; detector pool is housed in a cavern about 150' x 130' x 110')

676) Rustbelt Reclamation. 2015. *Morton Salt Mine*; Rustbelt Reclamation (website), Cleveland, Ohio. http://www.rustbeltreclamation.com/salvages-1/2015/7/7/570-headlands-road ; accessed March 22, 2016 (NOTES: Irvine-Michigan-Brookhaven (IBM) neutrino detector from 1981 to 1991; Fairport Harbor, east of Cleveland; mined first in 1959; good background information, pictures; detector pool tank is 80'x70'x70'; ~2000' bgl; location map; ~ 41.755394, -81.284720)

677) Bionta, R.M. et al. 1983. Search for Proton decay into e+... *Physical Review Letters*, July 4, 1983, Vol. 51, No. 1, pp.27-30 (material presented on webpage http://www-personal.umich.edu/~jcv/imb/imbp3.html and https://journals.aps.org/prl/issues/51/1 ; accessed March 22, 2016 (NOTES: see also http://www-personal.umich.edu/~jcv/imb/imb.html and http://www-personal.umich.edu/~jcv/imb/imbp2.html for photos; accessed March 22, 2016)

United States: Cargill Salt Mine, Whiskey Island, Cuyahoga County, Ohio

678) Krouse, Peter. 2013. Cargill stops mining salt under Lake Erie out of safety concerns. *Cleveland.com*, August 21, 2013; http://www.cleveland.com/business/index.ssf/2013/08/cargill_salt.html ; accessed March 22, 2016 (NOTES: illustrations by Gus Chan, *Plain Dealer*; Cargill Salt mine below Lake Erie, ~1700' depth below lake bottom; under Lake Erie adjacent to Cleveland; at mouth of the Cuyahoga River; map of properties mined beneath lake; Silurian Salina salt deposit; illustrative of safety concerns along lake; location 41.528751, -81.706226)

South Africa: Underground physics facilities (inception stage, Huguenot Tunnel as physics URL)

679) Wyngaardt, Shaun, and Richard Newman. 2014. Report on First workshop titled "*Towards a South African Underground Laboratory*", March 6-7, 2014, Stellenbosch University / iThemba LABS NRF, South Africa; http://www.physics.sun.ac.za/gamma5/wp-content/uploads/report-on-sa-underground-physics-workshop-6-7mar14-released-11apr141.pdf ; accessed March 22, 2016 {NOTES: South African Underground Laboratory / SAUL: potential to establish underground research facilities inside the Huguenot Tunnel (Paarl, Western Cape; granite and sandstone present / Table Mountain SS, quartzitic; also examine option down a deep mine-shaft in South Africa's Gauteng province; presentation materials at http://www.physics.sun.ac.za/gamma5/category/research/projects and https://drive.google.com/file/d/0B380b7765J5lRF9IR1ZWOEdlM1E/edit accessed March 22, 2016; article on dark matter search; southern hemisphere data needed for physics / astrophysics studies; area location -33.732484, 19.111133. Additional summary presentation, Wyngaardt et al., TAUP 2013 talk, https://conferences.lbl.gov/event/36/session/35/contribution/162/material/slides/0.pdf }

680) *South African Underground Physics project* (website accessed March 22, 2016); Nuclear, Radiation and Health Physics SU; Nuclear Physics, Stellenbosch University; http://www.physics.sun.ac.za/gamma5/south-african-underground-physics-project (Note: no news identified since 2015 to determine status of proposal to construct Huguenot facility)

681) Nuclear, Radiation and Health Physics, Nuclear Physics at Stellenbosch University (websites accessed May 25, 2016). *South African Underground Physics project;* http://www.physics.sun.ac.za/gamma5/south-african-underground-physics-project with workshop link, https://drive.google.com/file/d/0B380b7765J5lRF9IR1ZWOEdlM1E/edit?pref=2&pli=1 (Note: Exploring potential for underground physics laboratory in the Huguenot Tunnel; Du Toitskloof Mountains; examines Gran Sasso Laboratory; sequence primarily composed of Table Mountain Sandstone / quartzitic SS; link includes workshop presentations, ~2008, summaries of physics investigations, underground laboratories)

South Africa: SATREPS / Science and Technology Research Partnership for Sustainable Development; Orkney Klerksdorp and AngloGold Vaal River Operations area gold fields, Witwatersrand basin

682 & 104) Ogasawara, H., et al. 2015. Stress and strength at seismic event hypocenters in deep South African gold mines and the M5.5 Orkney Earthquake; (presentation with abstract of proposal); Drilling into seismogenic zones of M2.0 – M5.5 earthquakes in deep South African gold mines (DSeis*), ICDP Workshop Proposal submitted to ICDP on 15 January 2015*; http://www.seismo.ethz.ch/research/groups/schatzalp/Download/S1P04_Ogasawara.pdf ; accessed February 16, 2016 (Note: SATREPS; near Orkney Klerksdorp goldfields of the Witwatersrand basin; 8/5/2014, an M5.3/ 5.5; One of the SATREPS observational sites; break was below mining levels; normal fault with strike slip component; quake >5km depth; monitoring with strong motion, strain meter, and seismic recorders; triggered events in mine levels with normal fault motion.)

683 & 105) Vervaeck, A. August 5, 2014. Deadly earthquake in South Africa in Orkney and Klerksdorp - 1 fatality and 38 injured; *Earthquake Report.com*, August 11, 2014; http://earthquake-report.com/2014/08/05/strong-earthquake-south-africa-on-august-5-2014/ ; accessed February 16, 2016 (Note: map, selected details, casualties; damages)

684 & 106) Kilian, A. 2015 (May 8). What Role does deep mining play in seismic activity in South Africa? *Creamer Media's Mining Weekly* (Earthquakes and Mining); http://www.miningweekly.com/article/mining-rekated-2015-05-08; accessed February 16, 2016 (NOTE: Japanese research programme the Science and Technology Research Partnership for Sustainable Development (SATREPS); Council for Scientific and Industrial Research (CSIR) with studies involving Moab/Khotsong, Gauteng, SA; according to annual report, Moab / Khotsong 1st production in 2006, AngloGold Ashanti)

685 & 107) Montiea, B. 2015 (April 3). Mining-induced earthquake research in final stages. *Creamer Media's Mining Weekly* (Earthquakes and Mining); http://www.miningweekly.com/article/mining-induced-earthquakes-research-in-final-stages-2015-04-03 ; accessed February 16, 2016 (NOTES: **SATREPS**, Japan's Science and Technology Research Partnership for Sustainable Development; funds South African Council for Scientific and Industrial Research and Japan researchers from Ritsumeikan University. Instrumented AngloGold Ashanti's Moab Khotsong gold mine and mines of West Rand)

686) Japan Science and Technology Agency (website accessed March 22, 2016, http://www.jst.go.jp/EN/). SATREPS website; *Observational Studies in South African Mines to Mitigate Seismic Risks*: *Observe Earthquakes at Proximity at 1-3 km Depths from Earth's Surface*; http://www.jst.go.jp/global/english/kadai/h2114_southafrica.html ; accessed March 22, 2016 (Note: Joint study JST/SA, SA mines; site shows conference link for 2016, SATREPS / Science and Technology Research Partnership for Sustainable Development / SATREPS, a Japanese government program)

687) Durrheim, R.J., et al. 2012. Establishment of SATREPS experimental sites in South African gold mines to monitor phenomena associated with earthquake nucleation and rupture; p. 173-188. In: Y. Potvin (eds.); *Deep Mining 2012; Australian Centre for Geomechanics*, Perth, ISBN 978-0-9806154-8-7; http://researchspace.csir.co.za/dspace/bitstream/10204/5831/1/Durrheim_2012.pdf ; accessed March 22, 2016 (NOTES: investigations and drilling, Moab–Khotsong Mine (AngloGold Ashanti's Vaal River operations), Driefontein Gold Mine (Goldfields), other; outlines progress made in science drilling and testing in mines; program JST implemented by Japan International Cooperation Agency (JICA) and associated with CSIR /Council for Scientific and Industrial Research, South Africa, and CGS / Council for GeoScience, South Africa)

South Africa: JAGUARS (Japanese-German Acoustic Emission Research in South Africa), NELSAM (Natural Earthquake Laboratory in South African Mines), and DAFSAM (Drilling Active Faults Laboratory in South African Mines)

688 & 117) AngloGold Ashanti (website accessed February 23, 2016); http://www.anglogoldashanti.com/en/Pages/default.aspx ; (NOTE: Seismic studies in several mines, integrated investigations available through webpages for AngloGold Ashanti. See Reference 610, NSF / National Science Foundation, 2007. DUSEL - Facilities, Findings and recommendations)

689) AngloGold Ashanti (website presentation accessed May 25, 2016). 2014. South African Surface Operations Site visit; South African Region Technology Innovation Presentation, January, 2014; AngloGold Ashanti. http://www.anglogoldashanti.com/en/Media/Presentations/20140131_AGA_SA_site_visit.pdf (Note: AngloGold Ashanti mine locations verified with Google Maps and Wikimapia.org

West Wits Operations, near Carletonville: JAGUARS, NELSAM
Mponeng mine -26.437057, 27.431744
Tau Tona -26.415249, 27.427438
Savuka -26.420982, 27.404544

Vaal River Operations, near Klerksdorp: SATREPS, NELSAM
Kopanang -26.982481, 26.741987
Great Noligwa -26.959778, 26.785512
Moab/Khotsong -26.984938, 26.801244

690 & 108) Kwiatek, G., and Y. Ben-Zion. 2013. Assessment of *P* and *S* wave energy radiated from very small shear-tensile seismic events in a deep South African mine; *Jour. of Geophysical Research: Solid Earth* 118(7), p. 3630-3641; http://onlinelibrary.wiley.com/doi/10.1002/jgrb.50274/abstract; http://onlinelibrary.wiley.com/doi/10.1002/jgrb.50274/pdf ; accessed February 16, 2016. (NOTES: JAGUARS seismic network in the Mponeng deep gold mine, South Africa; The JAGUARS project continuously monitors microseismic activity at 3.5km depth in Mponeng gold mine, Republic of South Africa)

691 & 109) GFZ / Helmholtz Center, Potsdam / German Research Centre for Geosciences / Das Deutsche GeoForschungsZentrum (website accessed May 25, 2016). *Microseismicity and Acoustic Emission in Deep Gold Mine in South Africa JAGUARS*. http://www.gfz-potsdam.de/en/section/geomechanics-and-rheology/projects/microseismicity-and-acoustic-emission-in-deep-gold-mine-in-south-africa-jaguars/ (Note: JAGUARS / JApanese-German Underground Acoustic Emission Research in South Africa; JAGUARS project continuously monitors microseismic activity at 3.5km depth in Mponeng gold mine, Republic of South Africa; planned expanded study in Tau Tona with NELSAM group. many laboratory results indicate intriguing relations between very small events (acoustic emission, AE) and macroscopic failure; monitors at 3.5km bgl; ~2007-present. Location verification with Google Map and Wikipedia and Wikimapia org; JAGUARS = Mponeng gold mine, ~ 1 mile south of Tau Tona, near Carletonville, -26.436111,27.430556; NELSAM = Tau Tona gold mine, Western Deep Levels, Carletonville, -26.416111,27.4275; DAFSAM = fault drilled in Tau Tona mine)

692 & 110) Kozłowska, M., et al. 2014. Nanoseismicity and picoseismicity rate changes from static stress triggering caused by a Mw 2.2 earthquake in Mponeng gold mine, South Africa; *Journal of Geophysical Research (Solid Earth)* 120(1):290-307, doi:10.1002/2014JB011410. http://onlinelibrary.wiley.com/doi/10.1002/2014JB011410/abstract ; abstract online, accessed February 23, 2016

693 & 111) Yabe, Y., et al. 2009. Observation of numerous aftershocks of an Mw 1.9 earthquake with an AE network installed in a deep gold mine in South Africa; *Earth Planets Space* 61, p. e49–e5; The Society of Geomagnetism and Earth, Planetary and Space Sciences (SGEPSS);

http://www.researchgate.net/publication/228625077_Observation_of_numerous_aftershocks_of_an_Mw_1.9_earthquake_with_an_AE_network_installed_in_a_deep_gold_mine_in_South_Africa ; accessed February 23, 2016 (Note: Mponeng Gold Mine, ~3300m bgl)

694 & 112) Boettcher, M.S**.**, et *al*. 2015. Moment Tensors and Other Source Parameters of Mining-Induced Earthquakes in TauTona Mine, South Africa; *Bull. Seis. Soc. Am.*, Vol. 105, No. 3, pp. 1576–1593; http://www.unh.edu/esci/people/pdf/Boettcher_2015_BSSA.pdf ; https://ceps.unh.edu/sites/ceps.unh.edu/files/departments/earth_sciences/boettcher_2015_bssa.pdf ; accessed February 23, 2016 (NOTE: NELSAM-project at Tau Tona-Mine. Natural Earthquake Laboratory in South African Mines (NELSAM is successor project to DEFSAM; Tau Tona mine test at ~3600mbg; includes temporary stations from PASSCAL / Program for the Array Seismic Studies of the Continental Lithosphere deployment in Tau Tona and Mponeng Mines; included former Integrated Seismic Systems International (ISSI) stations; Vredefort meteorite impact ~2.023 Ga)

695) Wikipedia.org (website accessed May 25, 2016). *Tau Tona mine*; https://en.wikipedia.org/wiki/TauTona_Mine (Note: At 3.9 kilometers (2.4 mi) deep (Western Deep #3 shaft) near Carletonville; clusters with Mponeng and Savuka mines; all AngloGold Ashanti owned; Tau Tona with 800km tunnels; operations 1962, with first shaft to 2 km deep in 1957; location verified Tau Tona gold mine, Western Deep Levels, Carletonville, -26.416111,27.4275)

696 & 115) Milev, A.M., and S.M. Spottiswood. 2005. Strong ground motion and site response in deep South African mines; *The Journal of The South African Institute of Mining and Metallurgy*, V. 105, AUGUST 2005; pp. 515-524; http://www.saimm.co.za/Journal/v105n07p515.pdf ; accessed February 23, 2016 (NOTE: Tau Tona, Driefontein, Mponeng, Kloof monitored along with other mines)

697 & 116) Ortlepp, W. 2006. Comment on the paper "Strong ground motion and site response in deep South African mines" in the *Journal South African Institute of Mining and Metallurgy* V. 105, pp. 515-524; *The Journal of The South African Institute of Mining and Metallurgy* Volume 106, August 2006, pp. 593-598; http://www.saimm.co.za/Journal/v106n08p593.pdf ; accessed February 23, 2016 (NOTES: see reply to comment, Milev and Spottiswood, p. 598-599)

698) Lucier, A.M., M. D. Zoback et al. 2009. Constraining the far-field in situ stress state near a deep South African goldmine. *International Journal of Rock Mechanics & Mining Sciences*, 46, p. 555-567 https://pangea.stanford.edu/departments/geophysics/dropbox/STRESS/publications/MDZ%20PDF's/2008/Lucier,%20Zoback%20et%20al%20IRMS2008%20in%20press.pdf ; accessed March 22, 2016 (NOTES: NELSAM study at 3650 m bgl; prepublication version available online; TauTona and Mponeng mines)

699) GeoStructure Group, U of Oklahoma (website accessed March 22, 2016). *NELSAM, Natural Earthquake Laboratory in South African Mines;* http://earthquakes.ou.edu/nelsam/index.html (NOTES: NELSAM aka "son of DAFSAM"; investigating seismogenic processes at focal depths of earthquakes in deep gold mines of South Africa; planned activity in Tau Tona mine, Western Deep, South Africa; NELSAM site, TauTona mine, located in the 118 and 120 levels, ~ 3,600 m below the surface; site centered on the Pretorius fault-zone; seismic investigation with reports to 2006 on this website; few links on site are active)

700) Boettcher, M.S. 2015. (website, faculty and staff profile) *Earthquake Source Processes in Deep South African Gold Mines- The NELSAM Project*; The University of New Hampshire, Department of Earth Sciences; http://www.unh.edu/esci/people/boettcher-m_microseismicity.html ; accessed March 22, 2016 (NOTES: reviews participants and activities, early conclusions; see profile and recent publications some Mponeng studies, seismicity; http://www.unh.edu/esci/people/boettcher-m.html ; accessed March 22, 2016; recent publications associated with work on JAGUARS / Japanese-German Underground Acoustic Emission Research in South Africa project; see links to Kozlowska et al., 2015, https://ceps.unh.edu/sites/ceps.unh.edu/files/departments/earth_sciences/boettcher_jgrb50971.pdf, event character and distribution; sensors installed in the Mponeng deep gold mine in South Africa; recorded seismic activity; with Mponeng as key mine for study, Western Deep Levels, 3km+ depth)

701) Reches, Ze'ev, et al. 2006. Building a Natural Earthquake Laboratory at Focal Depth (DAFSAM-NELSAM Project, South Africa): Progress Reports (doi:10.2204/iodp.sd.3.06.2006), *Scientific Drilling*, No. 3, September 2006, pp. 30-33; https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CBwQFjAAahUKEwia5dqJtZXJAhWI1x4KHeHBC7c&url=https%3A%2F%2Fwww.iodp.org%2Fdoc_download%2F3730-sd35p3033&usg=AFQjCNGSml7lWO1URfZI8d8u9Ihu-Xub6w&sig2=LYLke-OXvMl_2zQKZ-d2Ng&bvm=bv.107467506,d.dmo ; accessed March 22, 2016 (NOTES: linked DAFSAM / Drilling Active Faults Laboratory in South African Mines; NELSAM / Natural Earthquake Laboratory in South African Mines; projects focus on building an earthquake laboratory in deep gold mines in South Africa. Instrumented Mponeng and Tau Tona mines)

South Africa: General - Seismic investigations in deep mines; rock properties, rock bursts

702) Linzer, L., et al. 2007. *A Summary of Recent Research in Seismology in South Africa: Report*; International Union of Geodesy and Geophysics; 29 pages. http://www.iugg.org/members/nationalreports/southafrica07-iaspei.pdf ; accessed March 22, 2016 {NOTES: R&D including Investigation into the risks posed by large seismic events in gold mining areas and SA R&D in mines. German. Japan, SA, USA; South African National Seismograph Network (SANSN)… "The Africa Array initiative is a long-term (20 years) programme co-directed by the University of the Witwatersrand and the University of Pennsylvania; Inkaba Ye Africa is a multidisciplinary initiative between South African and German earth scientists; and the DAFSAM (Drilling Active Faults Laboratory in South African Mines) - NELSAM (Natural Earthquake Laboratory in South African Mines) project involves South African, German, Japanese and American scientists."… research groups also identified are CSIR (Council for Scientific and Industrial Research), Integrated Seismic Systems International (ISSI)… earthquake laboratory at a depth of 3540 m in the vicinity of the Pretorius fault at Tau Tona Gold Mine; seismic investigations since 1992; SA has not made a report to IUGG since then?}

703) Durrheim, R. 2010. Mitigating the risk of rock bursts in the deep hard rock mines of South Africa: 100 years of research; In: J. Brune (editor), *Extracting the Science: a century of mining research*, Society for Mining, Metallurgy, and Exploration, Inc., pp. 156-171 (prepared for SME Annual meeting and exhibit, 21-24 February 2010, Phoenix, Arizona; 100th Anniversary of founding U.S. Bur. Mines)

http://www.africaarray.psu.edu/publications/pdfs/SME100_Durrheim_Rockburst%20research.pdf ; accessed March 22, 2016

704 & 113) Young, R.P. (ed.) 1993. *Rock Bursts and Seismicity in Mines 93: Proceedings of the Third International Symposium, Kingston, Ontario, 1993.* Balkema Publishers, Rotterdam, Netherlands. 462pp. http://civil.engineering.webservices.utoronto.ca/staff/professors/rpyoung/publications/papers/rpy88.htm); accessed February 23, 2016 (NOTE: sampling of abstracts address Creighton, Lac du Bonnet Granite)

705 & 114) Gercek, H. 2007. Poisson's ratio values for rocks. *International Journal of Rock Mechanics and Mining Sciences*, vol. 44, no. 1. pp. 1–13. http://ac.els-cdn.com/S136516090600075X/1-s2.0-S136516090600075X-main.pdf?_tid=66e890b8-fe87-11e4-b053-00000aacb35d&acdnat=1432082002_d2196596bac4a2afc691f9d4c96baa3e ; accessed February 23, 2016 (Note: generalized rock properties data)

South Africa: Deep mines, hydrology, seismic

706) Hubert, G. (Golder S.A.), 2006. Report on investigation into the risks to miners, mines and the public associated with large seismic events in gold mining districts - hydrogeological considerations (Appendix 4.4, Golder and Associates, SA). In: Durrheim, R.J., et al. *Investigation into the risks to miners, mines, and the public associated with large seismic events in gold mining districts (DME/CSIR), Republic of South Africa* http://www.csir.co.za/websource/ptl0002/pdf_files/news/2006_dme/Seismic/DMEInvest_largeseismiceventsvol2_%20app4.4.pdf ; and http://www.csir.co.za/websource/ptl0002/pdf_files/news/2006_dme/Seismic/DMEInvestigationlargeseismiceventsvol1.pdf ; accessed March 22, 2016 (NOTES: flooding SA mines; summary report and recommendations; excellent summary of mines, events in mines; hydrology, flooding; faults and fracture role; operational safety measures; locations; impact seismic; Council for Scientific and Industrial Research (CSIR) in South Africa; DME: Department of Minerals and Energy, Rep. S. Africa)

Finland: Pyhäsalmi Mine (Zn / Cu*)*, Center for Underground Physics at Pyhäsalmi (CUPP), Oulu Province, Pyhäjärvi

707) Enqvist, T., et al. 2004. *CUPP – Centre for Underground Physics in Pyhasalmi*; http://physicsatmwatt.web.cern.ch/physicsatmwatt/Contributions/CERN_paper-Enqvist.pdf ; accessed May 24, 2016 {NOTES: Pyhasalmi mine in Pyhajarvi, Finland, is the deepest operational base-metal mine in Europe. Operator Pyhasalmi Mine Ltd (owned by the Inmet Mining Corporation, Canada) produces zinc, copper and pyrite; operations in new section began in 2001; first envisioned in 1993 for CUPP operations; centre of the town to the mine is~5 kilometers; access via spiral decline by car to ~1440m; mining to 1080m level ceased in 2001. Pyhasalmi mine is located in municipality of Pyhajarvi; The old part of the mine extends down to the depth of 1080 m (3000 mwe); accessed by car or by truck via the spiral-shaped decline (1:7) going all the way down into 1440 metres; maximum depth of the new mine (start 2001) reaches 1440 metres, corresponding to 4000 m.w.e.}

708) Geological Survey of Finland (websites accessed May 24, 2016). *Zinc in Finland*; http://en.gtk.fi/informationservices/commodities/zinc.html ; *Mineral Deposits and Exploration*, http://gtkdata.gtk.fi/mdae/index.html, and *Mineral Deposits Report, Pyhäsalmi* ; http://tupa.gtk.fi/karttasovellus/mdae/raportti/534_Pyh%C3%A4salmi.pdfhttp://tupa.gtk.fi/karttasovellus/mdae/raportti/534_Pyh%C3%A4salmi.pdf ; (NOTES: Mine in shallower levels through 2001; deeper ore delineated; active mining resumed; Zn province within Paleoproterozoic island arc setting of Savo Belt in central Finland; mined since 1962; see also http://tupa.gtk.fi/karttasovellus/mdae/raportti/534_Pyhäsalmi.pdf accessed May 22, 2016; formed as submarine synvolcanic hydrothermal system with massive sulphides by replacement of volcanics; interactive map of Finland's mines; location verified with Google Map and Wikimapia.org; 63.661077, 26.040931)

709 & 129) Mindat.org (website; accessed March 3, 2016) *Pyhäsalmi Mine, Pyhäjärvi, Finland*; http://www.mindat.org/loc-13126.html ; location http://www.mindat.org/maps.php?id=13126

710 & 130) Peltoniemi, Juha. 2005. Underground physics in the Pyhasalmi Mine; presentation at *Second Annual Meeting CUPP Project; University of Oulu, Finland*; http://ilias.in2p3.fr/ilias_site/meetings/second_annual_meeting/presentations/Peltoniemi_CUPP-PRA-Prague.PDF ; accessed March 3, 2016 (NOTES: One of the deepest active metal mines in Europe; Pyhäsalmi Mine (Zn / Cu / pyrite) in Pyhäjärvi, Finland at 1,444 meters (~4737'). Oulu Province; Olli shaft depth 3440' in 1996; internal Timo shaft from 3445'-4724' in 1996; 63°39′31″N 26°02′28″E, 63.658611, 26.041111 ; mine operator, formerly INMET, Canada; currently, 2013, First Quantum Minerals Ltd; Centre for Underground. Physics in Pyhäsalmi (CUPP), underground physics research laboratory)

711 & 131) Geological Survey of Finland (website, accessed March 3, 2016). Pyhäsalmi Mine, mineral deposits report; http://tupa.gtk.fi/karttasovellus/mdae/raportti/534_Pyh%C3%A4salmi.pdf

712 & 132) Gleeson, Daniel. 2010. Innovation at Depth (InfoMine website); Operation Focus – Finland, *International Mining. April, 2010*; p. 10-18; http://www.infomine.com/library/publications/docs/InternationalMining/Gleeson2010b.pdf ; accessed March 3, 2016 (NOTES: Timo shaft sunk in 2001 to 1440m; Zn/Cu deposit; formerly run by Outokumpu; Canada's Inmet Mining purchased the operation; established Finnish subsidiary Pyhäsalmi Mine Oy)

713 & 133) CUPP / Centre for Underground Physics in Pyhäsalmi (websites accessed March 3, 2016). http://www.cupp.fi/ ; (NOTES: deepest hard rock mine in Europe; ~4000mwe, 1450m bgl. Mine description at *Deeper Understanding*, CUPP Brochure, http://www.cupp.fi/images/cupp_brochure.pdf , *Pyhäsalmi Mine*. http://www.cupp.fi/index.php?option=com_content&view=article&id=3&Itemid=41&lang=en (Note: These contain geologic and mine summary information; see other links at site)

714 & 134) Puustjärvi, Heikki (ed.). 2006. *Pyhäsalmi Modeling Project, 13.5.1997-12.5.1999*; Technical Report, Outokumpu Mining Oy / Geological Survey of Finland; http://tupa.gtk.fi/raportti/arkisto/m19_3321_99_1_10.pdf ; accessed March 3, 2016 (Notes: volcanogenic massive

sulphide (VMS) deposits; Geology discussed in Section B; Svecofennian domain between the Archaean Basement Complex in the east and the Central Finland Granitoid Complex in the southwest. Lithologically this area belongs to the NW-trending Savo Schist Belt (SSB); Svecofennian domain closely related to the 2.0-1.8 Ga old Paleoproterozoic island arcs; SSB consists of meta volcanic units and metamorphosed migmatitic mica gneisses, which are originally turbiditic metasedimentary rocks; associated Paleoproterozoic intrusive rocks; volcanism is closely related to early, syntectonic magmatism of the Central Finland Granitoid Complex, c. 1890-1875 Ma; volcanic and intrusive complex; deposit is a typical massive sulphide deposit surrounded by volcanites and an alteration halo)

United Kingdom: Boulby Mine and Underground Laboratory, North Yorkshire County

715 & 135) Mining Technology (websites; accessed March 3, 2016). *Boulby, United Kingdom* (Industry Projects), http://www.mining-technology.com/projects/boulby/ and http://www.mining-technology.com/projects/boulby/boulby3.html ; (NOTES: potash and salt mine; production K began in 1973; Cleveland Potash, Ltd., operator; Boulby Mine depth at ~1,400 meters / 4593'; shaft depth 1,100 meters, 3608'; at 1100m deep, it is the deepest mine in Great Britain. Cleveland Potash Limited, which is now a subsidiary of Israel Chemicals Ltd.; ICL Fertilizers Europe parent company; 5.5m-diameter, 1,150m-deep shafts through the sandstone was achieved by ground freezing and grouting of the rock shaft; two shafts, ~1150m depth bgl; Permian evaporates, >225 mybp. Location 54.5534, -0.8245)

716 & 136) DigPlanet (website accessed March 3, 2016). *Boulby mine*. http://www.digplanet.com/wiki/Boulby_Mine (NOTES: 1000km / 620 miles subsurface road tunnel; links)

717 & 137) STFC Boulby Underground Laboratory / Science and Technology Facilities Council (website accessed March 3, 2016). *Welcome to the Boulby Underground Laboratory*; http://www.boulby.stfc.ac.uk/Boulby/ ; http://www.boulby.stfc.ac.uk/boulby/default.aspx ; (NOTE: 1100m below surface; STFC = Science and Technology Facilities Council; evaporites are Late Permian age, Zechstein salt basin age equivalent)

718 & 138) STFC (Science and Technology Facilities Council; UK, Royal Charter) website; accessed March 3, 2016. *Boulby Underground Laboratory: Overview*; http://www.stfc.ac.uk/Boulby/Overview/39340.aspx (NOTE: Zechstein Salt, ~ 200 mya; over 1000km tunnels)

719 & 139) Talbot, C.J. and C.P. Tully, P.J.E. Woods. 1982. The structural geology of Boulby (potash) mine, Cleveland, United Kingdom. *Tectonophysics*, Volume 85, Issues 3–4, 20 May 1982, Pages 167–204; http://www.sciencedirect.com/science/article/pii/0040195182901020 ; accessed abstract March 3, 2016 (NOTE: Upper Permian potash and salt of the third Zechstein Cycle)

720 & 140) *Subterranea Britanica*, Site Records website (accessed March 3, 2016). *Boulby Potash Mine – a site visit*; http://www.subbrit.org.uk/sb-sites/sites/b/boulby_mine/index.shtml (Note: General overview; salts, potash, evaporite minerals; facility photos)

721) STFC Boulby Underground Laboratory (website accessed May 22, 2016). *Welcome to the Boulby Underground Laboratory*; http://www.stfc.ac.uk/boulby/default.aspx , and http://www.boulby.stfc.ac.uk/boulby/default.aspx (Note: UK STFC / Science and Technology Facilities Council science operations management; Boulby UK, 1100m bgl, 2805mwe new test level; Cleveland Potash Limited, owners; shaft access; >1000km tunnels)

722) Araujo, H, *et al*. (website accessed May 24, 2016). Lux/Zeplin: Searching for the mysterious dark matter with liquid xenon detectors; High Energy Physics, Imperial College, London; http://www.imperial.ac.uk/high-energy-physics/research/experiments/zeplin/ ; accessed March 22, 2016

United States: Soudan mine / Underground Research Laboratory: Breitung Township, St. Louis County, Minnesota

723) Soudan Mine, MN (website accessed March 22, 2016); http://www.soudan.umn.edu/ (Note: access via slightly inclined old mine shaft to ~700m; developed to 2341' bgl; located in state park; Soudan first test, 1981; second test, 1986; testing to present; for history, see link https://www.physics.umn.edu/outreach/soudan/tour/ ; location verified with Google Maps and Wikimapia.org; 47.818824, -92.240489)

724 & 96) Peterson, D. March 2007. *Imagining Scientific Realities Deep Underground: Utilizing Knowledge and 3-d Geologic Modeling, Fundamental Tenets of the University of Minnesota Proposed Institute for Underground Science and Soudan DUSE*L Report of Investigations NRRI/RI-2007/02; Natural Resource Research Institute , Univ. Minnesota, Duluth, MN, USA; https://drive.google.com/file/d/0B23uzT8P1ra-TXhLVGJrMnQxZWc/view?pli=1 ; and http://www.nrri.umn.edu/egg/REPORTS/RI200702/RI200702.html ; accessed February 11, 2016 (NOTE: work cooperatively with Fermi; several site locations over time in complex; e.g., 713m overburden / 2090mwe original proposed depth; test area in Soudan Underground Laboratory 2007 down to a depth of 1500m, i.e., 4125 meters of water equivalent (MWE); near Tower MN; Late Archean granite; Hematite ores of the Soudan mine; geologic complexities; see Reference 723 http://www.soudan.umn.edu/; reference to proposals for expanded DUSEL)

725 & 97) Brumfiel, G. 2007. Deep science strikes gold after latest site is named; **Nature** 2007: 448(7151):232-233. DOI: 10.1038/448232a.; http://www.readcube.com/articles/10.1038/448232a ; accessed February 11, 2016 (NOTE: Map of underground physics research facilities; discussion of world physics labs, space needs and proposed work; includes - Homestake mine ~2250m; Soudan ~710m; Sudbury ~2070m; Boulby ~1070m; Frejus ~1700m; Mont Blanc ~`800m; Gran Sasso ~1400m; Baksan ~1700m; Kamioka ~1000m)

726 & 98) University of Minnesota, (website accessed February 11, 2016) *Soudan Underground Laboratory*. http://www.sudan.umn.edu/ (NOTE: 2,341'bgl; greenstone terrain, 2.7 Ga; see also Super Cryogenic Dark Matter Search webpage, LBNL; http://cdms.berkeley.edu/experiment.html ; physics testing in SNOLAB and Soudan mine)

United States: Kimballton Underground Research Facility (KURF) and mine, Giles County, Virginia

727) *Lhoist Group / Lhoist North America* (website accessed March 22, 2016); http://www.lhoist.com/ ; (NOTE: Lhoist is operator at mine; produces pebble lime and hydrated lime. Virginia Kimballton works located at 37.381810, -80.664314; however, 37.382149,-80.659583 is KURF Kimballton Mine Portal, see below

728) Center for Neutrino Physics, Virginia Tech (website accessed March 22, 2016). *Kimballton Underground Research Lab is Open for Business*; Archived Features http://cnp.phys.vt.edu/cnp-bin/features.pl?story=001 (NOTE: "Bruce Vogelaar, Director of KURF says, 'The Kimballton Underground Research Facility, or KURF for short, is located about half an hour from the Virginia Tech campus, and provides a low background environment for detector development with drive-in access.' The lab currently consists of a 35,000 square foot building, which sits under an overburden of 1700', or 1450 mwe {?}. Liquid nitrogen, fiber-optic internet, and ample power are all available. The host mine is in limestone so the radon level and rock background are lower than many comparable labs.")

729) Kimballton Underground Research Facility, VT Physics (website; accessed March 22, 2016). *US Deep Underground Laboratories*; http://www.phys.vt.edu/~kimballton/kurf/pub/w.shtml?home/locations.jpg and http://www.kimballton.org/ (NOTE: map, links; VT / Virginia Tech)

730) Adams, M. and J. Stroup. 2014. Mining for neutrinos (How Tech Ticks); *Virginia Tech Magazine*, Vol. 36, No. 3, Spring, 2014; http://www.vtmag.vt.edu/spring14/mining-for-neutrinos.html ; accessed March 22, 2016 (NOTES: working mine operated by Lhoist North America; KURF operated by VT, Dept. Physics; Giles County; neutrino investigations, some funded by DOE; see illustrations, mine)

731) Virginia Tech Department of Physics. 2013. *Kimballton Underground Research Facility* (Presentation / KURF update, 2013). http://www.phys.vt.edu/~kimballton/kurf/pub/w.shtml?home/kurf-update.pdf ; accessed March 22, 2016); Virginia Polytechnic Institute and State University Blacksburg, VA (NOTE: mine operator = Lhoist North America, KURF operator Virginia Tech Department of Physics; Access by truck; maximum depth 2300', i.e., ~1900mwe assuming limestone; KURF is Paleozoic limestone host; Gran Sasso is dolomite host; KURF within Butt Mountain Synclinorium /thrust package; uses and proposed activities; location verification Google maps and Wikimapia.org)

732) Eilertsen, N. 1964. Ming methods and cost, Kimballton Limestone Mine, Standard Lime and Cement Co., Giles County, Virginia; U.*S. Bur Mines Information Circular* 8214; 50 pages. http://catalog.hathitrust.org/Record/006866170 and http://babel.hathitrust.org/cgi/pt?id=mdp.39015077577271;view=1up;seq=1 ; accessed March 22, 2016 (NOTE: formerly APG Lime Corporation / Standard Lime and Cement Company, Chemical Lime Co.); Mine high calcium limestone for lime production; OneMine.org)

733) Bernstein, A., et al. 2014. *Remote Reactor Monitoring*; LLNL-TR-663012; Lawrence Livermore National Laboratory; https://e-reports-ext.llnl.gov/pdf/784480.pdf ; accessed March 22, 2016; (Notes: WATCHMAN / WATer CHerenkov Monitor for ANtineutrinos Project - The overall goal of the WATCHMAN collaboration is to experimentally demonstrate the potential of water Cerenkov anti-neutrino detectors as a tool for remote monitoring of nuclear reactors. Current projects identified a suitable deployment location for the kiloton scale detector at the Morton Salt mine near Cleveland, OH, provided an initial detector design, and began measurements of backgrounds relevant to the large underground detectors at the Kimballton Underground Research Facility (KURF). Program in development; preferred site is the Morton Salt Mine in Ohio, the Alternative site is near the Advanced Test Reactor at Idaho National Laboratory in Idaho; TBD)

734) Bernstein, A., and collaborators. 2013. *WATCHMAN (WATer CHerenkov Monitoring of Anti-Neutrinos): A Field Demonstration of Remote Reactor Monitoring* (Presentation, 39 slides); http://www.phys.vt.edu/~kimballton/kurf/pub/home/presentations/Bernstein_WATCHMAN_Slides_for_KURF_June_2013.pdf ; accessed March 22, 2016 (NOTES: 100-1400' overburden potential test locations; presentation contains maps of active mines and power reactors; Collaborators, LLNL = A. Bernstein, N. Bowden, S. Dazeley, D. Dobie ; SNL = P. Marleau, M. Gerling, K. Hulin, J. Steele, D. Reyna; seeking expansion of project to include detector at Boulby Mine, 1000m depth)

735) Roundtree, S. D. 2014. Kimballton Underground Research Facility, Abstract J12.00006; *American Physical Society* / APS April 5–8, 2014, Savannah, Georgia), *Bulletin of the American Physical Society*, Volume 59, Number 5http://meetings.aps.org/Meeting/APR14/Session/J12.6 ; accessed March 22, 2016 (NOTES: laboratory was built in 2007; drive in access; over 50 miles of drifts, all 40' x 20'+; 1700 bgl, 1450 mwe)

736) Virginia Tech. 2005. *Kimballton / Dusel: a deep underground research facility website*. Appendix B: Kimballton Geology; 25 pages; http://www.phys.vt.edu/~kimballton/dusel/s2p/b1.pdf and http://www.phys.vt.edu/~kimballton/dusel/ ; accessed March 22, 2016 (NOTES: potential for Access to ~7500' depth; imbricate thrust sheets; current depth >2000'; "Allegheny Mountains of southwestern Virginia, near the western edge of the Appalachian Valley and Ridge Physiographic Province", Appalachian foreland fold-thrust belt; Butt Mountain; Middle Ordovician Limestone; within Thrust sheets associated with the Narrows thrust zone and St Claire, Butt Mountain Synclinorioum area. Location, 37.382149,-80.659583 is KURF Kimballton Mine Portal, Giles County, VA, N of Ripplemead VA; numerous links at http://www.phys.vt.edu/~kimballton/dusel/) accessed March 22, 2016

Poland: Sieroszowice mine, Polkowice / Sieroszowice, Polkowice County

737) KGHM Polska Miedź (website accessed November, 2016). *Polkowice-Sieroszowice mine*; http://kghm.com/en/our-business/mining-and-enrichment/polkowice-sieroszowice (Note: KGHM formerly Kombinat Gorniczo-Hutniczy Miedzi)

737a) Zalewska, A. et al. 2010. SUNLAB - Sieroszowice Underground LABoratory - introduction; *Epiphany 2010 Conference* January 7, 2010 (Presentation); http://doczz.net/doc/4295184/sunlab-%E2%80%93-sieroszowice-underground-laboratory and http://epiphany.ifj.edu.pl/epiphany.2010/pres/zalewska2.pdf ; accessed January 2017 (Note: Photo in presentation of mine used to locate on google maps; in 2010-2012, remained proposed site. The presentation contains picture of a mine located at 51.501939, 16.106658. Also see https://www.hindawi.com/journals/ahep/2013/461764/ for evaluation of proposal; current status not determined for this study. In addition, full document published: Zalewska, A., et al. 2010. LAGUNA in Polkowice - Sierowice mine in Poland; *ACTA Physica Polonica B*, Vol. 41[7]: 1803-1820; http://www.actaphys.uj.edu.pl/fulltext?series=Reg&vol=41&page=1803)

738) Bartlett, S. C., et al. 2013. *Technical Report on the Copper-Silver Production Operations of KGHM Polska Miedź S.A. in the Legnica-Glogów Copper Belt Area of Southwestern Poland*; Micon Internatioal Limited; 159 pp. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwixjZf7sLDQAhVI74MKHZhCBZ4QFggfMAE&url=http%3A%2F%2Fkghm.com%2Fsites%2Fkghm2014%2Ffiles%2Fdocument-attachments%2Fkghm_technical_report_micon.pdf&usg=AFQjCNHkyMCS9IqhlABCO35ylXBq4PX22A&bvm=bv.139250283,d.amc ; accessed November, 2016

Romania: Slanic Prahova mine

739) Mitrica, B., and R. Margineanu. 2012. Geological investigation of rock at the underground laboratory at Slanic Prahova, Romania (presentation); *Underground Synergies with Astro-particle Physics: Multi-Disciplinary Studies in the World's Deep Underground Science Facilities*, 17-19 December 2012, Durham, UK*; ASPERA / AStroparticle Physics European Research Area network;* http://indico.cern.ch/event/199223/contributions/378095/attachments/295992/413605/Mitrica_Durham_2012.pdf ; accessed November, 2016 (Note: Slanic Prahova mines, physics underground laboratory in salt; studies, facility, design, geology; data; Unirea salt mine)

740) Har, Nicolae, et al. 2006. New data on the mineralogy of the salt deposit from Slănic Prahova (Romania); *Studia Universitatis Babeş-Bolyai, Geologia*, 2006, 51 (1-2), 29 -33; http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1244&context=geologia ; accessed November, 2016

Australia: SUPL / Stawell (mine) Underground Physics Laboratory, Victoria

741) Jamasmie, Cecilia. 2016. Canada's Kirkland Lake halts gold mine in Australia, leaves up to 150 jobless; *Mining.com*, http://www.klgold.com/Home/default.aspx ; http://www.mining.com/canadas-kirkland-lake-halts-gold-mine-in-australia-leaves-up-to-150-jobless/ accessed January, 2017 (Note: News source for background on SUPL, see http://www.smh.com.au/technology/sci-tech/scientists-hope-to-strike-gold-in-global-hunt-for-dark-matter--at-the-bottom-of-a-stawell-mine-20160609-gpf14p.html)

741a) Dean Lawson. 2017. Projects on track despite Stawell Gold Mine ceasing operations; call for support; *The Weekly Advisor*; http://www.theweeklyadvertiser.com.au/2016/12/14/stawell-gold-mine-closure-prompts-call-for-government-support/ ; accessed January23, 2017 (Note: Kirkland Lake Gold assures continuity of support for test facility)

India: Jaduguda Underground Research Laboratory, Jadugora, Purbi Singhbhum district, Jharkhand state

742) Bagla, Pallava. Aug. 31, 2017. India joins hunt for dark matter; *Science Magazine*-news, Asia/Pacific Physics, AAAS; http://www.sciencemag.org/news/2017/08/india-joins-hunt-dark-matter (Note: See INO, Item 4.11, herein)

743) Sarangi, A.K. 2003. Grade control in Jaduguda uranium mine, Jharkhand. *Trans. Mining, Geological and Metallurgical Institute of India (MGMI)*: 99(1-2), 2002-2003 (12 pp.); http://www.ucil.gov.in/pdf/myth/Grade%20control%20in%20Jaduguda,%20Jharkhand.pdf

Table 5 References (#750-851) and Notes (Pits): Global Survey of Large Deep Open Pit Mine

General References – Open Pits

750) Mining Global (staff writer). September, 2015. *Top 10 Largest Open Pit Mines in the World*; http://www.miningglobal.com/top-10/photos-top-10-largest-open-pit-mines-world (Note: general reference for Escondida, Udachny, Chuquicamata, Grasberg, Hull-Rust-Mahoning, Diavik, Kimberly, Kalgoorlie Super Pit, Mir, and Bingham Canyon; appropriate as source material for partial list and overview of sites)

751) Mining-technology.com, September 2013. *Top 10 deep open-pit mines*; http://www.mining-technology.com/features/feature-top-ten-deepest-open-pit-mines-world/ [Note: Bingham Canyon (1.2km), Chuquicamata (>850m), Escondida (645m), Udachny (630+m), Muruntau (600m), Fimiston Open Pit (Super Pit) {600m}, Grasberg (550m), Betze-post (>500m), Nanfen (~500m), Aitik (430m)]

752) United States Geological Survey (website, data). Mineral Resources Online Spatial Data, (website and links); https://mrdata.usgs.gov/

753) United States Geological Survey (website, data). Mineral Resources Online Spatial Data, *Mineral Resource Data System* (website). https://mrdata.usgs.gov/ and https://mrdata.usgs.gov/mrds/

754) United States Geological Survey (website, data). Mineral Resources Online Spatial Data, *Global assessment of undiscovered copper resources* (website, updates). https://mrdata.usgs.gov/mrds/updates/updates-20110216-1610.html

755) United States Geological Survey (website, data). Mineral Resources Online Spatial Data; *Major Mineral Deposits of the World;* https://mrdata.usgs.gov/major-deposits/ and https://mrdata.usgs.gov/major-deposits/map-us.html (Note: see related global interactive map, https://mrdata.usgs.gov/general/global.html)

755a) 10mosttoday (website, blog). August, 2013. *10 Most Incredible Open-Pit Mines*; 10mosttoday.com; https://10mosttoday.com/10-most-incredible-open-pit-mines/ (NOTES: dimensions and depths for Mir, Bingham, Kalgoorlie, The Big Hole / Kimberley, Diavik, Ekati, Grasberg, Chuquicamata, Udachnaya, Escondida open pit mines, with photographs of sites; photo reference sources provided, but data should be verified; – TBV; dimensions of pits also measured using google earth / maps, and reported in table as "measured" but only as rough estimates since several pits are complex group of pits; well done article; appropriate as source material for partial list and overview of sites)

Site-Specific References – Open Pits

Aitik: near Gällivare, Norrbotten County, Sweden

756) Boliden AB (website). *Mines: Boliden Aitik*; http://www.boliden.com/operations/mines/boliden-aitik/ and http://www.boliden.com/sv/verksamhet/gruvor/boliden-aitik/ (Note: mine depth, 450m; see https://www.boliden.com/sv/ ; https://www.boliden.com/ ; copper mine; depth 450m; established 1968; Cu, Ag, Au produced)

757) Mining-technology (website). *Aitik Copper Mine, Sweden*; http://www.mining-technology.com/projects/aitik/

758) Porter GeoConsultancy (website). *Aitik, Sweden*; http://www.portergeo.com.au/database/mineinfo.asp?mineid=mn190 (Note: Ore is hosted by Paleo- to Mesoproterozoic metamorphosed Svecofennian sediments and intrusives surrounded by granitic intrusions, within a supracrustal metamorphosed shear zone of Precambrian age)

759) Wanhainan, C., et al. 2012. Modification of a Palaeoproterozoic porphyry-like system: Integration of structural, geochemical, petrographic, and fluid inclusion data from the Aitik Cu–Au–Ag deposit, northern Sweden; *Ore Geology Reviews* 48 (October 2012): 306-331, Elsevier; http://www.sciencedirect.com/science/article/pii/S0169136812001497 (Note: sulphide Cu-Au-Ag ore deposit; Palaeoproterozoic, strongly metamorphosed porphyry copper deposit that was affected ca. 100 Ma later by a regional hydrothermal event; ore hosted by 1.9 Ga quartz monzodiorite and altered volcaniclastics; quartz vein stockwork formation and porphyry copper mineralisation with event ~1.8Ga)

760) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Aitik;* https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=1833 (Note: Cu mine; Plutonic terrane, Early Proterozoic; hydrothermal deposit, Sweden; best map location 67.066395, 20.950047, Google map)

Betze-Post: Eureka County, Nevada, United States

761) Barrick Gold Corporation (websites). *Barrick, Nevada*; http://www.barrick.com/operations/barrick-nevada/default.aspx (Note: Mine tour and data to 2014, see http://barrick.q4cdn.com/808035602/files/presentation/2014/Nevada-Mine-Tour-Goldstrike.pdf)

762) Cole, Andy. 2014. *Barrick Gold Corporation* (website / presentation): *Nevada Mine Tour / Goldstrike*; http://barrick.q4cdn.com/808035602/files/presentation/2014/Nevada-Mine-Tour-Goldstrike.pdf

763) Armstrong, A.K., et al. Preliminary facies analysis of Silurian and Devonian autochthonous rocks that host gold along the Carlin Trend, Nevada; in "Carlin-type gold deposits (Chapter 6)", *Contributions to the Gold Metallogeny Of Northern Nevada*, United States Geological Survey Open File Report 98-338, pages 38-68; United States Geological Survey; https://pubs.usgs.gov/of/1998/of98-338/chapters/chp06.pdf

764) MiningTechnology (website). *Betze-Post Gold Mine, Nevada, United States of America*; http://www.mining-technology.com/projects/-betze-post-gold-mine-nevada/ (Note: 2.2km long and 1.5km wide, with a depth of more than 500m)

765) United States Geological Survey. Mineral Resources On-Line Spatial Data, Sediment-hosted Gold Deposits: *Betz-Post*; https://mrdata.usgs.gov/sedau/show-sedau.php?rec_id=44 (Note: Late Devonian syn-sedimentary, Eocene reset; age of intrusive events, 159.3–154.6, Jurassic; 38.3–37.8 Ma, Eocene; ore in Devonian Popovich Fm.; Carlin Trend; location 40.981667, -116.378333; Barrick Gold; discovery 19??; production 1974-2011 and ?; 40.981667, -116.378889 location, Google Map)

766) Wikipedia.org (website). *Goldstrike mine*; https://en.wikipedia.org/wiki/Goldstrike_mine (Note: gold disc., 1962; production 1975; gold was epithermally deposited in carbonate or silicate sedimentary rocks; 3 mines, Betze-Post open-pit mine, and the Meikle and Rodeo underground mines; Barrick owner operator since 1986)

766a) Plume, R.W. 2005. *Changes in Ground-Water Levels in the Carlin Trend Area, North-Central Nevada, 1989–2003; United States Geological Survey Scientific Investigations Report 2005–5075* (prepared in cooperation with Nevada Department of Conservation and Natural Resources, Division of Water Resources); U.S. Geological Survey, Carson City, Nevada; https://pubs.usgs.gov/sir/2005/5075/sir2005-5075.pdf)

766b) Zhan, J. 2012. Mine Dewatering and Water Management at Barrick Goldstrike Mine in the Carlin Trend, Nevada (Presented at *U.S. EPA Hardrock Mining Conference 2012, Denver, CO, USA, April 3-5, 2012*; Barrick Goldstrike Mines, Inc); https://clu-in.org/download/issues/mining/Hard_Rock/Wednesday_April_4/02_Monitoring_and_Treatment/02_Zhan.pdf (Note: 3700m x 2000m x 400m bgl; 520m drawdown in water level in 2012 in mine area. For discussion of underground mines, see Carter, R.A. 2012. Rodeo's Roadheader Experiment pays off; *Engineering and Mining Journal*, June 20, 2012; http://www.e-mj.com/features/2114-rodeos-roadheader-experiment-pays-off.html#.WgI53f-nGos)

766c) U. S. Bureau of Reclamation. 2008. Draft Supplemental environmental Impact Statement (SEIS), Betz Pit Expansion Project; BLM /NV / EK /PL-GI-08/22+1793; Bureau of Land Management, Elko, Nevada; https://books.google.com/books?id=CvUxAQAAMAAJ&pg=RA1-PA2&lpg=RA1-PA2&dq=Goldstrike+mine+groundwater&source=bl&ots=ed9yq00oXw&sig=RzvngFGWhftsG6pujddSfBAcK80&hl=en&sa=X&ved=0ahUKEwiZ-6_bt63XAhVfF2MKHWBjAyoQ6AEIOzAD#v=onepage&q=Goldstrike%20mine%20groundwater&f=false (Note: *Federal Register*, Notice of Availability of Final Supplemental Environmental Impact Statement for the Betze Pit Expansion Project, Eureka and Elko Counties, NV, pp. 13462-13463; 2009; ROD to follow. Also https://www.federalregister.gov/documents/2009/03/27/E9-6768/notice-of-availability-of-final-supplemental-environmental-impact-statement-for-the-betze-pit)

Bingham Canyon: Salt Lake County, Utah, United States

767) Rio Tinto / Kennecott (website home page); http://www.kennecott.com/ (Note: Links for Bingham Canyon)

768) Rio Tinto (website). *Bingham Canyon Mine slide fact sheet*; http://www.kennecott.com/sites/kennecott.com/files/newsroom/pdf/slide_fact_sheet_fnl4_15_13_315pm.pdf and http://www.kennecott.com/operation (Note: estimated depth reported as ¾ mile, ~1200m, 3950'; location, Google map, 40.529166667, -112.153888889).

769) Mining-technology (website). *Bingham Canyon, United States of America*; http://www.mining-technology.com/projects/bingham/

770) United States Geological Survey: Mineral Resources Online Spatial Data (website), Major Mineral Deposits of the World. *Bingham Canyon*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=611 ; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=501 ; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=522 (Note: {USGS id 522} Hydrothermal mineral deposit / copper skarn; Au, Ag, Cu; Paleozoic section, host. {USGS id 501} Hydrothermal mineral deposit / Porphyry copper deposit; Cu, Mo, Ag, Au. {USGS id 611} Polymetallic replacement hydrothermal deposit; Ag, Pb, Zn, Au, Cu)

Boddington – Western Australia, Australia

771) Newmont Mining Corporation (websites). *Operations and Projects*; http://www.newmont.com/operations-and-projects/australia/default.aspx and

772) Newmont Mining Corporation (website). *Operations and Projects, Australia – Boddington*; http://www.newmont.com/operations-and-projects/australia/boddington-australia/overview/default.aspx

773) Amin, Kareem. 2015. Boddington Gold Mine; *MininGeology* (website / blogspot), http://miningeology.blogspot.com/2015/04/boddington-gold-mine.html)

774) McCuaig, T.C., et al. 2001. The Boddington gold mine: a new style of Archean Au-Cu deposit. AGSO-Geoscience Australia; in Cassidy, K.F., Dunphy, J.M. and Van Kranendonk, M.J., *2001 4th International Archaean Symposium, Extended Abstracts AGSO/Geoscience Australia Record 2001/37*; pp. 453-455; https://d28rz98at9flks.cloudfront.net/37671/Boddington_gold_mine_A_new_style_of_Archaean_Au_Cu_deposit_pgs_453_455.pdf

775) Mining-technology.com (website). Boddington Gold Mine (BGM), Western Australia (WA), Australia; http://www.mining-technology.com/projects/boddington (Note: The BGM is located within the Saddleback greenstone belt [SGB], a fault-bounded sliver of Archaean volcanic and shallow level intrusive rocks, surrounded by granitic and gneissic rocks)

776) United States Geological Survey: Mineral Resources Online Spatial Data, Global assessment of undiscovered copper resources (website). *Boddington*; https://mrdata.usgs.gov/sir20105090z/show-sir20105090z.php?id=36

777) United States Geological Survey: Mineral Resources Online Spatial Data (website). *Data for 10107452 (Boddington)*; https://mrdata.usgs.gov/mrds/show.php?labno=10107452 (Note: Boddington gold deposit; location, -32.73767, 116.3471. Host rock type is meta-clay, mud, volcanic rock (aphanitic); Western Gneiss Terrain - Saddleback Greenstone Belt.)

Chuquicamata: Antofagasta Region, Chile

778) Gustafson, L., D. Lindsay, & M. Zentilli. 2001. Geology of the Chuquicamata Mine: a progress report. *Economic Geology*. 96. 249-270. 10.2113/96.2.249; https://www.researchgate.net/publication/246315124_Geology_of_the_Chuquicamata_Mine_A_Progress_Report (Note: Porphyry copper deposit; initial intrusions probably at 36–33 Ma; mineralization with last major hydrothermal event at 31 Ma; to post-mineral brecciation and offset; paper [Mote et al.] in same volume gives range of 35My to 11My for mineralization, with one date at 17Ma. In addition, other authors are listed for cited article at https://pubs.geoscienceworld.org/economicgeology/article-abstract/96/2/249/22052/geology-of-the-chuquicamata-mine-a-progress-report?redirectedFrom=fulltext)

779) Mining-Technology (website). *Chuquicamata Copper Mine, Chile*; Mining Technology; www.mining-technology.com/projects/chuquicamata-copper (Note: see USGS references, below; open pit Cu Mo mine)

780) Mote, T. I., T. A. Becker, P. Renne, & G. H. Brimhall. 2001. Chronology of exotic mineralization at El Salvador, Chile, by 40Ar/39Ar dating of copper wad and supergene alunite; *Economic Geology* (2001) 96 (2): 351-366. https://pubs.geoscienceworld.org/economicgeology/article-abstract/96/2/351/22064/chronology-of-exotic-mineralization-at-el-salvador?redirectedFrom=fulltext (Note: range of 35My to 11My for mineralization, with one date at 17Ma.)

781) United States Geological Survey: Mineral Resources Online Spatial Data (website), Major Mineral Deposits of the World. *Chuquicamata*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=1102 (Note: Hydrothermal mineral deposit; Cu, Mo; mixed sedimentary and volcanic, Mesozoic age region; https://mrdata.usgs.gov/major-deposits/map-us.html)

782) United States Geological Survey: Mineral Resources Online Spatial Data - Global assessment of undiscovered copper resources (website). *Chuquicamata*; https://mrdata.usgs.gov/sir20105090z/show-sir20105090z.php?id=286 (Note: Cu-Mo deposit, Antofagasta, Chile; location -22.275, -68.9; Paleogene associated sequence clastic, volcanic-clastic)

783) SISGEO, Fact Sheet (online). *Chuquicamata Copper Mine - Chile*; https://www.sisgeo.com/uploads/schede/chuquicamata.pdf (Note: Atacama Desert, Chile; L=4,500m, W=3,540m, D=800m.; Related site, https://www.sisgeo.com/projects/geographical-areas/america-projects/item/chuquicamata-mine-codelco-chile.html?category_id=330)

Diavik: Northwest Territories, Canada

784) Rio Tinto (website). *Diavik*; http://www.riotinto.com/canada/diavik-2232.aspx (Note: Google map location 64.489933, -110.256762; additional Rio Tinto data provided for Diavik at https://www.sec.gov/Archives/edgar/data/863064/000100329715000165/e2x_99-1rt.htm)

785) Diavik Diamond Mines, Inc. (C. Yip, and K. Pollock) 2017. *Diavik Diamond Mine, Northwest Territories, Canada*; NI 43-101 Technical Report (Prepared for Dominion Diamond Corporation); http://www.ddcorp.ca/docs/default-source/43-101/2017-diavik-diamond-mine-technical-report.pdf?sfvrsn=6 (Note: kimberlites themselves are Eocene (54–58 Ma) volcanic deposits which intruded the older Archean (2.5–2.8 Ga) granitoid and metasedimentary rocks of the Slave Craton)

786) Jakubec, J., et al. 2017. Underground Diamond Mining at Ekati and Diavik Diamond Mines; *11th International Kimberlite Conference, Botswana, 2017* (poster); http://www.srk.com/sites/default/files/file/JJakubec_UndergroundMiningatEkatiandDiavik_2017.pdf

787) Shigley, J.E., et al. 2016. Mining diamonds in the Canadian Arctic: The Diavik Mine; *Gems & Gemology, Summer*, 2016, Vol. 52, No. 2; https://www.gia.edu/gems-gemology/summer-2016-diamonds-canadian-arctic-diavik-mine (Note: Diavik and Ekati mines data - Dominion company press release provides more information through 2017; examples are cited in http://www.businesswire.com/news/home/20170518006527/en/Dominion-Diamond-Exploration-Update-Announces-Maiden-Resource and http://www.mining.com/web/dominion-diamond-provides-exploration-update-announces-maiden-resource-leslie-pipe-ekati/)

788) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Diavik*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=998 (Note: 64.4583, -110.2333; igneous mineral deposit; diamond; in Archean terrane)

Ekati: Northwest Territories, Canada

789) Dominion Diamond Corporation (website). *Ekati Diamond Mine*; http://www.ddcorp.ca/operations/ekati-mine (Note: location from Google map, 64.715933, -110.619537. Sale by Dominion to Washington Companies, interest in Diavik and Ekati and exploration areas, July 2017; http://www.cbc.ca/news/canada/north/dominion-diamond-sold-washington-companies-1.4208284)

790) Carlson, J.A., et al. 2015. *Ekati Diamond Mine, Northwest Territories, Canada* (NI 43-101 Technical Report; prepared for Dominion Diamond Corporation; https://www.sec.gov/Archives/edgar/data/841071/000106299315001318/exhibit99-2.htm (Note: Contains detailed geologic, geographic, reserves / potential evaluation information)

791) Jakubec, J., et al. 2017. Underground Diamond Mining at Ekati and Diavik Diamond Mines; *11th international Kimberlite Conference, Botswana, 2017* (poster); http://www.srk.com/sites/default/files/file/JJakubec_UndergroundMiningatEkatiandDiavik_2017.pdf (Ekati pits are Koala, Koala North, Panda, and Beartooth)

792) Mining-Technology (website). *Ekati diamond mine – a timeline, Canada*; http://www.mining-technology.com/projects/ekati-diamond-mine-a-timeline/

793) United States Geological Survey: Mineral Resources Online Spatial Data, "*Mineral Operations Outside the United States*" (website). *Ekati* (https://mrdata.usgs.gov/minfac/show.php?labno=4452; and in "*Major Mineral Deposits*" at https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=1005 (Note: Ekati Mine, Lac de Gras region, Northwest Territories, 300km northeast Yellowknife; BHP Billiton Diamonds Inc.: 80% [BHP Billiton Group], Charles Fipke: 10%, Stewart Blussom: 10%; location, 64.733, -110.6)

Escondida: Antofagasta Region (Atacama Desert), Chile

794) BHP (website), *BHP Billiton Escondida Mine*; http://www.bhp.com/our-businesses/minerals-americas (Note: location -24.271242, -69.071388, Google map)

795) Garza, R.A. Padilla, et al. 2001. Geology of the Escondida porphyry copper deposit, Antofagasta Region, Chile; *Economic Geology*, Vol. 96, 2001, pp. 307-324; http://www.geo.arizona.edu/~bcarrapa/Andes%20papers/Padilla-GarzaEtal01.pdf

796) Mining-technology (website). *Escondida Copper, Gold and Silver Mine, Atacama Desert, Chile*; http://www.mining-technology.com/projects/escondida/

797) Ortiz, F.A., et al. 1986. Escondida porphyry copper deposit, II Region, Chile: history of the discovery; in W. J. Atkinson et al., *Mining Latin America*, Springer, Dordrecht; https://link.springer.com/chapter/10.1007%2F978-94-017-2286-5_28

798) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Escondida*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=1119 (Note: Hydrothermal mineral deposit; Cu, Ag. Map area with mixed sedimentary-volcanic terrane, Mesozoic)

Fimiston (Kalgoorlie) Super Pit: Western Australia, Australia

799) Newmont Mining Corporation (website). *Kalgoorlie, Australia*; http://www.newmont.com/operations-and-projects/australia/kalgoorlie-australia/overview/default.aspx (Note: site lacks updates since 2014)

800) Newmont Mining Corporation (website). *Operations and Projects*; http://www.newmont.com/operations-and-projects/default.aspx (Note: Location, google map, -30.774722, 121.509444)

801) KCGM / Kalgoorlie Consolidated Gold Mines (website). *The Super Pit*; http://superpit.com.au/; http://superpit.com.au/about/about-us/ ; http://superpit.com.au/about/history/ and http://superpit.com.au/wp-content/uploads/2015/04/Timeline-KCGM-A-Celebration-of-25-Years.pdf

802) Mining-technology.com (website). *Fimiston Open Pit "Super Pit" Gold Mine, Australia*; http://www.mining-technology.com/projects/superpitgoldmineaust/ (Note: Fimiston open pit mine, also known as Super Pit and Golden Mile, is the largest open pit gold mine in Australia, measuring 3.5km in length, 1.5km in width and 360m in depth (older data). Operated by Kalgoorlie Consolidated Gold Mines, a joint venture between Barrick Gold Corporation and Newmont Mining Corporation. Norseman-Wiluna greenstone belt of Western Australia; Golden Mile Dolerite hosts more than 2,000 ore lodes that extend over an area that is 5km in strike, 2km in width and 1km in depth; quartz felsic dykes dated at 2675Ma.

803) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Fimiston Kalgoorlie* (https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=34 (Note: Mixed sedimentary-volcanic terrane; Archean; Au-bearing hydrothermal deposit)

804) Vielreicher, N.M., et al. 2016. The giant Kalgoorlie Gold Field revisited; *Geoscience Frontiers*, Volume 7, Issue 3, May 2016, pp. 359-374 (research article); http://www.sciencedirect.com/science/article/pii/S1674987115000857 and http://www.sciencedirect.com/science/article/pii/S1674987115000857?_rdoc=1&_fmt=high&_origin=gateway&_docanchor=&md5=b8429449ccfc9c30159a5f9aeaa92ffb&dgcid=raven_sd_recommender_email ; Science Direct Open Access (Note: The Kalgoorlie Gold Field lies approximately in the centre of the well-endowed, Neoarchaean, Kalgoorlie granite-greenstone Terrane in the eastern Goldfields Province of the Yilgarn Craton in Western Australia . Fimiston open pit; a superpit measuring over 3.5 km long, >1.5 km wide and >500 m deep. Gold has been continuously produced since June 1893. Ores formed at ~ 2.645 Ga; Neoarchaean Kalgoorlie Gold Field contains the giant Golden Mile and world-class Mt Charlotte deposits; Fimiston lodes characterized by pyrite veinlets and disseminations, quartz veinlets and breccias, and banded quartz-carbonate veins with alteration predominantly hosted in the Golden Mile Dolerite sill; deposit area is intruded by swarms of porphyry dykes; gold mineralization was post-peak regional metamorphism of host rocks. Gold was deposited during accretion due to wall rock reaction and phase separation. The Kalgoorlie Gold Field is hosted within the Kambalda Domain, in an outlier of komatiites and basalts of the Kambalda Sequence, overlain by a >3000 m-thick succession of mostly dacitic rock, with lesser andesitic and rhyolitic volcaniclastic, sedimentary and volcanic rocks of the Black Flag Group.)

Grasberg: Papua Province, Western New Guinea (Irian Jaya), Indonesia

805) Asmarini, W. and H. Setiaji. 2017. Freeport, Indonesia to end years of wrangling over mining rights; *Reuters Commodities*, August 28, 2017; https://www.reuters.com/article/us-indonesia-freeport/freeport-indonesia-to-end-years-of-wrangling-over-mining-rights-idUSKCN1B90BZ (Note: Business news; contracts; mining rights, revenue sharing and labor issues, tax rates; Freeport-McMoRan Inc. to keep operating its giant Grasberg copper mine; world's second-biggest copper mine)

806) Mining Global (website; staff writer). 2015. *Grasberg: The World's Largest Gold Mine*; http://www.miningglobal.com/mining-sites/grasberg-worlds-largest-gold-mine

807) Mining-technology.com (website). *Grasberg Open Pit, Indonesia*; http://www.mining-technology.com/projects/grasbergopenpit/ (Note: 60 miles north of Timika, at Tembagapura in Irian Jaya; copper mine operated by PT Freeport Indonesia; stands at the collision of the Indo-Australian and the Pacific tectonic plates; nested coaxial porphyry ore bodies and sulphide rich skarn at the margins, while sedimentary strata includes Eocene clastic carbonate. Open pit; expected to be exhausted in 2015; planned transition to fully underground production.)

808) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Grasberg*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=285 (Note: Hydrothermal mineral deposit; Cu, Ag, Au; Mesozoic sedimentary terrane; location -3.8167, 137.2333 is incorrect; cites http://pubs.usgs.gov/of/2002/of02-268/; location, Google map, -4.059069, 137.113238 for PT Freeport Indonesia open pit)

Hull-Rust-Mahoning: St. Louis County, Minnesota

809) Mindat.org (webpage). *Mahoning-Hull-Rust Mine (Hull-Rust-Mahoning Mine; Hull-Rust Mine), Hibbing, Mesabi Range, St. Louis Co., Minnesota, USA*; https://www.mindat.org/locdetailed-11911.html

810) Minnesota Department of Natural Resources (website). *Taconite **(The Hull Rust Mahoning Mine in Hibbing, Minnesota)***; http://www.dnr.state.mn.us/education/geology/digging/taconite.html (Notes: area consists of ~30 older mines. 3.5 miles x 1.5 miles, max. depth 535')

811) United States Geological Survey: Mineral Resources Online Spatial Data, Mineral Resource Data System (website). *Hull-Rust Mine*; https://mrdata.usgs.gov/mrds/show-mrds.php?dep_id=10122446 (Note: St. Louis County, Minnesota; location, Google Map ~47.45219, -92.96052; iron ore, taconite)

812) United States Geological Survey: Mineral Resources Online Spatial Data, Mineral Resource Data System (website). *Mahoning Mine* (Hull Rust area); https://mrdata.usgs.gov/mrds/show-mrds.php?dep_id=10170567 (Note: Hibbing area, current location examined in Google map)

813) Wikipedia.org (website). *Hull–Rust–Mahoning Open Pit Iron Mine*; https://en.wikipedia.org/wiki/Hull%E2%80%93Rust%E2%80%93Mahoning_Open_Pit_Iron_Mine

Kimberley Big Hole: Northern Cape Province, South Africa

814) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *(Kimberley) DeBeers*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=2717 (Note: Igneous mineral deposit; -28.73333, 24.78333 is not proper location; see current study, "The Big Hole", Kimberley / DeBeers; Google Map location -28.739096, 24.758527)

815) African News Agency (ENEWS CHANNEL AFRICA / eNCA.com), December 2, 2015 (website link). *De Beers ends diamond history by selling Kimberley mine*s; eNCA.com; https://www.enca.com/south-africa/de-beers-ends-diamond-history-selling-kimberley-mines (Note: DeBeers established in 1888)

816) Field, M., et al. 2008. Kimberlite-hosted diamond deposits of southern Africa: A review; *Ore Geology Reviews* 34 (2008) 33–75(El Sevier); doi:10.1016/j.oregeorev.2007.11.002; ftp://ftp.gmg.rub.de/pub/Chak/1.%20Einf%C3%BChrung%20Lgst%20Erze_Prozesse/Ore%20Geology%20Reviews_34_2008_Diamond%20deposits-A%20reveiw.pdf (Note: see Robey, Jock. Geology of Kimberley Area [Presentation to Arid Zone Conference] https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=14&cad=rja&uact=8&ved=0ahUKEwj20rynkO7WAhVM7yYKHfXGC9sQFghoMA0&url=http%3A%2F%2Fazef.co.za.www10.jnb1.host-h.net%2F.cm4all%2Fiproc.php%2F2013%2FPresentations%2F4.1_Arid%2520Zone%2520Conference%2520talk%2520-%2520J%2520Robey.pdf%3Fcdp%3Da&usg=AOvVaw2IbbZfbFJm_Y9qIDoToDHM ; Kimberlite (~90My) intrudes Ventersdorp Allanridge Fm, andesite lavas (~2.6Ga) and older crystalline basement (~3.2Ga); Karoo Dwyka Glacial Shales(~300My); and Karoo dolerite sill (~180My) in Dwyka shale. Full reference needed for conference)

817) Wikipedia.org (website). *Kimberley, Northern* Cape (Province); https://en.wikipedia.org/wiki/Kimberley,_Northern_Cape#The_Big_Hole_and_other_mines (Note: In the Kimberley article, see section on "The Big Hole and other mines"; Big Hole page, see Reference 818)

818) Wikipedia.org (website). *"Big Hole"*; https://en.wikipedia.org/wiki/Big_Hole (Note: Location -28.738611, 24.758611)

Mir (Mirny kimberlite, diamond mine): Sakha Republic (Yakutia), Russian Federation

819) Alrosa (website). *Mirny Division*; http://eng.alrosa.ru/corporate-structure/mirny-mining-processing-division/ (Note: somewhat informative about scope of Alrosa activities)

820) Alrosa (website, news). *Underground Mine of Mir Commissioned*; http://eng.alrosa.ru/underground-mine-of-mir-commissioned/ (Note: Underground mine officially commissioned August, 2009; Construction of underground mine of Udachny site began in 2004; Mir open pit mined 1957-2001)

821) Bulanova, G.P., et al. 2014. An eclogitic diamond from Mir pipe (Yakutia), recording two growth events from different isotopic sources; *Chemical Geology* 381 (14 August 2014): 40-54; Elsevier; http://www.sciencedirect.com/science/article/pii/S0009254114002502 (Note: diamond records two growth events ; older diamond core grew from subducted organic carbon 2.1 Ga; 0.9 Ga rim grew from mantle metasomatic fluid; diamond was exhumed from ~180 to ~120 km depths between the two growth stages; pipe formed ~360mya)

822) Mindat (website). *Mirny Mine (Mir Mine; Mir Pipe; Myr Pipe), Mirny, Sakha Republic (Saha Republic; Yakutia), Eastern-Siberian Region, Russia*; https://www.mindat.org/loc-17899.html (Note: USGS location not used; Wikipedia.org and Google Map location 62.529422, 113.993539, and 1.25km diameter)

823) Mining-Technology (website). *Minry Diamond Mine, Russia*; http://www.mining-technology.com/projects/minry-diamond/ (Note: spelling error)

824) Olson, D.W. 2011. Gemstones, in *United States Geological Survey Minerals Yearbook – 2009*; United States Geological Survey; https://minerals.usgs.gov/minerals/pubs/commodity/gemstones/myb1-2009-gemst.pdf (Note: Underground mining initiated 2009 at Mirny by Alrosa)

825) Radio Free Europe (website; news), August 5, 2017. *Russian Rescuers Search For Eight Missing At Flooded Diamond Mine*; https://www.rferl.org/a/russian-rescuers-search-nine-missing-flooded-diamond-mine-mir-alrosa-/28660055.html (Note: Mir Mine, flooded shaft, workers missing; open pit mining since 1955 and ceased in 2001; subsurface mine since 2009)

826) Wikipedia (website). *Mir Mine*; https://en.wikipedia.org/wiki/Mir_mine (Note: Wikipedia, location, 62°31′45.92″N 113°59′36.74″E; 62.529422, 113.993539; also on Google Map, measured diameter ~1.25km)

Muruntau: Muruntau gold mine, ore field; Zarafshan, Central Kyzyl-Kum Region, Kyzyl-Kum Desert, Navoiy Province, Uzbekistan

827) Drew, L.J., B.R. Berger, and N.K. Kurbanov. 1996. Geology and structural evolution of the Muruntau gold deposit, Kyzylkum desert, Uzbekistan; *Ore Geology Reviews* 11(4):175-196; https://pubs.er.usgs.gov/publication/70018137 and http://www.sciencedirect.com/science/article/pii/016913689500033X?via%3Dihub (Note: Gold deposit hosted by the Cambrian to Ordovician Besopan Suite, a 5,000-m-thick sequence of turbiditic siltstones, shales and sandstones; units sheared, folded, intruded by plutons; hydrothermal fluids impact; 'Hercynian shearing in Permo-Carboniferous and Permian obduction of plates with Nappe formation)

828) Kempe, U., et al. 2016. The Muruntau gold deposit (Uzbekistan) – A unique ancient hydrothermal system in the southern Tien Shan; *Geoscience Frontiers*, Volume 7, Issue 3, May 2016, Pages 495-528; http://www.sciencedirect.com/science/article/pii/S1674987115001139#sec1 and http://www.sciencedirect.com/science/article/pii/S1674987115001139 (Note: large vein and stockwork systems hosted by older, competent metasediments [Besapan] and proximal to intrusive bodies or along the sheared zones; Mid-Late Paleozoic age mineralization; Kyzylkum gold district within the Tien Shan belt; gold mine)

829) Mindat.org (website). *Muruntau Mine, Muruntau ore field, Zarafshan, Central Kyzylkum Region, Navoiy Viloyati (Navoi), Uzbekistan*; https://www.mindat.org/loc-47384.html

830) Mining-technology (website). *Muruntau Gold Mine, Uzbekistan*; http://www.mining-technology.com/projects/-muruntau-gold-mine-uzbekistan/ (Note: Discovered 1968; Navoi Mining & Metallurgy Combinat (NGMK) owns the mine [was a Newmont venture until 2006]; mined since 1967; depth was at 600m and planned for 1000m depth)

831) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Muruntau*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=1892 (Note: Sedimentary terrane, Paleozoic age units. Location is ~ 41.516667, 64.583333; USGS same as on Google Map, measured 3.56km x 2.7km)

Nanfen: Benxi Area, Northeastern China (Nanfen District, Benxi Prefecture, Liaoning Province, China; iron mine)

832) Karam, K.S., et al. 2015. Slope stability risk management in open pit mines; *7th GiT4NDM and 5th EOGL International Conference, UAE University, Al-Ain* 19p, At Al-Ain; https://www.researchgate.net/publication/283716636_Slope_stability_risk_management_in_open_pit_mines (Note: Figure 7 of report and verified Nanfen location from https://www.researchgate.net/figure/283716636_fig4_Figure-7-Aerial-View-of-Nanfen-Open-Pit-Iron-Mine ; Benxi Steel, Nanfen Open Pit Iron Mine Project. Location from Google Map and Wikipedia.org ~3 km x 2 km, ~750m cut slope on one flank; 41.094892, 123.811032 as identified in Figure 7 of the report)

833) MinDat.com (website). *Nanfen Mine, Nanfen District, Benxi Prefecture, Liaoning Province, China*; https://www.mindat.org/loc-143443.html (Note: Iron deposit, hosted in the Dayugou formation of the Archean Anshan Group; iron deposits stratiform and are concordant to their host amphibolite, quartz-chlorite schist and mica-quartz schist; location verified for 41.094892, 123.811032 at https://www.mindat.org/nearestlocs.php?lat=41.09734&long=123.80712)

834) Su, Yuping, et al. 2015. Deep-seated crustal xenoliths record multiple Paleoproterozoic tectonothermal events in the northern North China Craton; *Precambrian Research*, Vol. 270 (November 2015): 318-333; El Sevier; http://www.sciencedirect.com/science/article/pii/S0301926815003162? (Note: See Figure 1, Tectonic subdivision of the North China craton; regional setting)

835) United States Geological Survey: Mineral Resources Online Spatial Data, Major Mineral Deposits of the World (website). *Nanfen*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=180 (Note: Sedimentary mineral deposits in China containing Fe)

836) Wang, E., C. Hann, J. Xia, and S. Yun. 2015. Geochemistry and Tectonic Significance of Chlorite Amphibolite in Nanfen BIF, Benxi Area, Northeastern China; *Journal of Geoscience and Environment Protection*, Vol.03 No.05(2015), Article ID:58079,8 pages [Scientific Research, Open Access]; http://file.scirp.org/Html/58079_58079.htm (Notes: BIF hosted within Neoarchean middle Anshan Group; Archean BIF-hosted iron deposits; setting, subduction-related back-arc basin; Anshan Group strata are hosted between two phases of Archean granite, which have ages of about 3.0 Ga and about 2.45 Ga; Ashan Group 2.50 - 2.55 Ga; middle Anshan Group is made up mainly of amphibolites, amphibole-bearing gneiss and biotite leptynite, also interbedded with muscovite quartz schist, and chlorite quartz schist with BIF. Open pit mine was 346m depth, in 2015.

Udachny: Sakha Republic (Saha Republic; Yakutia), Eastern-Siberian Region, Russia

837) Alrosa (website): *Udachny Division*; http://eng.alrosa.ru/corporate-structure/udachny-mining-and-processing-division/ (Note: For history, http://eng.alrosa.ru/about-us/history/; Alrosa as owner / operator. In 2015, open pit mining ends; http://eng.alrosa.ru/alrosa-completes-open-pit-mining-at-the-udachnaya-pipe/)

838) Alrosa (website). *Underground Mine of Mir Commissioned*; http://eng.alrosa.ru/underground-mine-of-mir-commissioned/ (Note: Construction of underground mine of Udachny mine site began in 2004)

839) Mindat.org (website). *Udachnaya-Vostochnaya pipe (Udachnaya pipe), Daldyn, Daldyn-Alakit kimberlite field, Sakha Republic (Saha Republic; Yakutia), Eastern-Siberian Region, Russia*; https://www.mindat.org/loc-5801.html (Note: Location indicated as 66.4333333333, 112.316666667, and in Google Maps; discovered 1955; Alrosa planned to halt open-pit mining in favor of underground mining in 2010; two intersecting kimberlite pipes, intruded into Lower Ordovician limestone)

840) Mining-Technology (website). *Udachny Diamond Mine, Russia*; http://www.mining-technology.com/projects/-udachny-diamond-mine-russia/

841) Ragozina, A.L. et al. 2014. U–Pb age of rutile from the eclogite xenolith of the Udachnaya Kimberlite Pipe; *Doklady Earth Sciences*, 2014, Vol. 457, Part 1, pp. 861–864. Pleiades Publishing, Ltd.; https://link.springer.com/article/10.1134/S1028334X14070162

842) Strekeisen, Alex (website). *Kimberlite, Udachnaya-East, Sakha-Yakutia* (Russia); http://www.alexstrekeisen.it/english/vulc/udachnaya.php (Note: Website focus, optical petrography; designed for students of geology, petrography and geology; summary of Udachny pipes, geology, photographs; excellent instructive materials)

843) U.S. Geological Survey, Mineral Resources On-Line Spatial Data, Major Mineral Deposits of the World (website); *Udachnaya*; https://mrdata.usgs.gov/major-deposits/show-ofr20051294.php?rec_id=2031 (Note: Mainly sedimentary terrane, Paleozoic; location 66.433333, 112.216667 is off to east of mine)

Berkeley Pit: Copper mine - Butte, Silver Bow County, Montana

844) Daley, J. 2016. Thousands of Snow Geese Die at Abandoned Pit Mine; *Smart News, Smithsonian.com* (website access), December 8, 2016; https://www.smithsonianmag.com/smart-news/toxic-montana-lakes-kills-hundreds-and-maybe-thousands-snow-geese-180961356/ (Note: references about pit - this is example of when “things” happen; not desired scenario for venture outcome)

845) History: *Berkeley Pit Lake* (website). Colorado State University, Department of Biology.; https://web.archive.org/web/20090428152420/http://rydberg.biology.colostate.edu/Phytoremediation/2003/Boczon/Berkeley_Pit_History.html

846) Guarino, Ben. 2016. Thousands of Montana snow geese die after landing in toxic, acidic mine pit; *Washington Post*, December 7, 2016; Speaking of science; https://www.washingtonpost.com/news/morning-mix/wp/2016/12/07/montana-snow-geese-searching-for-pond-land-in-toxic-mine-pit-thousands-die/?utm_term=.864c0d5b2136

847) Gammons, C.H., et al. 2006. An Overview of the Mining History and Geology of Butte, Montana; *Mine Water and the Environment (2006, Technical Communication)* 25: 70–75, IMWA Springer-Verlag 2006; https://link.springer.com/content/pdf/10.1007%2Fs10230-006-0113-7.pdf

Other:

848) Bourke, S.J. 2007. The Late Neolithic/Early Chalcolithic Transition at Teleilat Ghassul: Context, Chronology and Culture; *Paléorient*, Vol. 33, Numéro 1, pp. 15-32; http://www.persee.fr/doc/paleo_0153-9345_2007_num_33_1_5205

849) Cortizas, A.M., et al. 2015. Early atmospheric metal pollution provides evidence for Chalcolithic/Bronze Age mining and metallurgy in Southwestern Europe. *Science of The Total Environment*, Vol. 545–546 (1 March 2016), p. 398-406; Elsevier; http://www.sciencedirect.com/science/article/pii/S0048969715312341

850) Drusin, Teresa. 2012. *Ancient mines* (Ancienttrenches.com website); http://www.ancienttrenches.com/ancient-mines (Note: general summary information and photos with references on ancient mines; introductory summary material covering old and new world mining; recommended http://www.bradshawfoundation.com/ for human origins detail)

851) Scott, D.A. 2010. *Ancient Metals: Microstructure and Metallurgy*, Volume 1; Lulu.com, Conservation Science Press, Los Angeles, CA (Chapter 1, Metallography and metallurgy); https://books.google.com/books?id=mnw3AgAAQBAJ&pg=PA2&lpg=PA2&dq=copper+culture,+new+world&source=bl&ots=hw7NWpybb2&sig=mM3trAU2baFJ26QC4TAMao7dsXM&hl=en&sa=X&ved=0ahUKEwjRiuLm-5jXAhUW6mMKHQ-CAfQQ6AEIZTAO#v=onepage&q=copper%20culture%2C%20new%20world&f=false

TABLE EXPLANATIONS AND KEYS

Global Site Survey of Selected Deep Underground Facilities

Table 1 – Mines and Shafts
Table 2 – URLs, Repositories, Sites
Table 3 - Boreholes
Table 4 – Physics Facilities
Table 5 – Deep Open Pits

Table 1- Explanation and Key (Mines): Notable Deep Mines and Shafts, Deep Large Diameter Shafts, Subsurface Mining Engineering Capabilities and Achievements

The deepest mines and shafts in the world are presented with other examples of deep mines accessed by large diameter shafts or tunnels that represent recent and historical mining engineering capabilities and achievements from around the globe. Mines described in primary References 1-5 were supplemented with data obtained from accessible websites (links provided; access date in red) for sources to include geologic unit, age, basin, location information, shaft depth, shaft diameter, operations depth, discovery or production dates. Site specific reference material and weblinks are provided. In general, the approximate locations of mines were obtained from the referenced websites and verified using multiple sources and tools (e.g., Google Maps, InfoMines, Mining Technology, Wikimapia [www.wikimapia.org], Wikipedia, government and academic websites, operator / corporate websites, publications, and R&D webpages where possible; also see http://tools.wmflabs.org/geohack/ , http://mapper.acme.com, and https://maps.google.com/maps?output=classic&dg=brw). General interest mining and shaft operations examples are found in References 1-15. Topic specific (groundwater residence time [tens of millions / billion years], induced seismicity, hydrologic impacts,) and site specific references are # 16-159 (Mines and Shafts). References were selected from internet accessible materials in order to enable the user to explore sources from their desktop. Notes are included for many references to indicate to the user the type of information contained within referenced item and the source of information contained in the table; notes also include additional related website links for those interested in further background information. Site evaluations are important to confidence building for safety case assessments.

Mining engineering and safety culture advances now commonly permit excavation and operation to depths of 2-4km. The mining industry (R&D) is examining the feasibility of operations to depths of 5km. Mine examples included in the table consist of the world's 10 deepest mines and shafts, and historically significant deep mines. These mines generally have deep (<3km) large diameter shafts for access, extraction, and ventilation. Of those that were considered the deepest mines in the world as of 2014/2015, most are in South Africa and Canada. Other deep mines are included as recent or historical examples of capabilities for exploitation in "deep" crystalline rock; some are deeper ventures currently being considered by industry for development. Several mine sites are also included in other tables and map layers (e.g., nuclear waste management R&D, underground physics R&D; Creighton, Homestake, South African mines). References and links may be used to launch further study by the interested party using the related references, notes, and tables. Selected examples of significant mine accidents or incidents were included in table, references and notes. The potential exists for the conduct of R&D in cooperative ventures with industry partners and international R&D groups in mines (Table 1; e.g., South African mine seismic investigations; also see Table 4), Waste Management and Physics URLs (Tables 2 and 4), and deep boreholes (Table 3; e.g., continental drilling projects) located around the globe.

Table 1 - Mines
KEY:

mwe, m.w.e.	meters water equivalent
bgl	below ground level / below surface
Ga	billion years ago
Ma / mya	million years ago
m	meters
km	kilometers
ft / '	feet
GW	Groundwater

Table 2 - Explanation and Key (URLs, Repositories, Sites): Past, Planned, and Operating Underground Research Laboratories (URLs); Past, Present, Identified or Candidate URL and Repository Sites or Areas

Survey of selected global 1) underground science and engineering research laboratories / URLs and test facilities for investigating the disposal of spent fuel and nuclear waste materials, and 2) Underground deep geologic repositories (former and currently proposed or former candidate sites, existing deep mined geologic repository-related sites). Table is color coded for lithology of anticipated or known host unit [salt, yellow; argillite, tan; granitic crystalline, pink; no color for other sedimentary or basaltic]. The companion repository, URL, and site map layer allows users to observe site locations and ease of access to summary data for the site area, history, activity, status, geology, and other aspects.

Primary sources (e.g., IAEA, 2001 and key; see Richard et al., 2011, Table 7-1; herein, References 162, 165) and other important references for Table 2 and Map layer 2 are references # 160, 165, 167, 168, 178, 189. General references include References 160-189 for describing the facilities location, geology, science and engineering features (siting, operating) for repositories and underground research facilities and sites. Included are national and international nuclear waste program data, current and historical sites, candidate sites, former candidate sites, and repository program status information. References and notes will facilitate use by interested parties (students, and decision makers, etc.) and to provide web access links for each location or facility for additional background information. The reference material (URLs, Repositories, sites, underground testing; References 160-469f) is not intended to be comprehensive, but may be used as a starting point for interested parties to launch an exploration of sites using links, summary data, and the approximate location information provided for each site (historical, current). Future updates to table database would include corrections, clarifications and added data to assist the user (e.g., students, public) to better understand the site location, cultural features, geography, geology, and introductory information on the status of selected global waste management programs and associated underground R&D. The column titled "Operator / Responsible Organization" was intended to identify the current responsible nuclear waste management organization (Reference 161 as source), but in numerous cases, former management organization or facility operator has been identified.

Table 2 – URLs, Repositories, Sites

KEY:

Facility Type, Access, Depth (shaft or overburden) for URL	
	S = purpose built URL / SS = site specific
	G = generic URL
Host Rock and Geologic Information column is color coded for lithology of host unit	
	Argillite (brown)
	Salt (yellow)
	Granitic / crystalline (pink)
	Limestone (blue)
	Sandstone (none)
	Volcanic (none)
	Repository host type not selected (none).
bgl	Depth in feet or meters "below ground level"
m.w.e. / mwe	Depth in "meters water equivalent"
Ma / my	million years
Ga	billion years
TBD	To Be Determined
Argillite	used broadly here to include plastic clay layers, true argillites, and fissile shale rocks
Crystalline	includes intrusive igneous, primarily granitic in nature, and metamorphic (e.g., metasediments, metavolcanics, etc.) rock units
Nature of Experiments:	
	T – Thermal,
	C – Chemical
	H – Hydrogeological
	M – Mechanical
	R – Radiation
	D = Demonstration tests

Table 3 – Explanation and Key (Boreholes): Drilling Engineering Achievements Examples: Deep and / or Large Diameter Boreholes, Crystalline / Granite Tests, Deep Continental Crust Drilling, Characterization, Exploration and Exploitation Boreholes

Information for selected domestic and international deep and or large diameter borehole drilling examples are presented in companion Table 3, Map Layer 3 (Boreholes), and References 470-609d. Existing DOE and international nuclear waste disposal program literature address the deep borehole disposal option in greater detail. As economic and scientific challenges arose, drilling technologies have advanced, drilling engineering capabilities were proven for completion of deep large diameter boreholes for study, exploitation, and production. The intent of these materials is to highlight recent and historical technical engineering capabilities for drilling of deep or large diameter boreholes with some emphasis on those penetrating crystalline basement in onshore environments to demonstrate current or historical drilling engineering capabilities, achievements and limitations (e.g., Reference 471, Nirex Report, 2004, Table 3; Reference 470, Beswick, 2008; see Reference 603 borehole disposal study). Example exploration and production wells drilled for geothermal investigations, hydrocarbon exploitation, carbon sequestration projects, studies of the continental crust, and deep wells that encountered anomalous subsurface conditions are presented as examples of drilling engineering capabilities to help build confidence in the technical feasibility of the deep large diameter borehole drilling and testing. Selected U.S. offshore oil and gas wells of note are included to reflect engineering technical capabilities for the drilling of fairly large diameter boreholes (and directional drilling, extended reach) in deep waters to considerable depth, in the range of 15,000’ to >30,000 drilled depth. Liquid waste injection wells may be deep (~10000’ to >15000’), with “large” borehole diameter (>8-9”), and often penetrate crystalline basement. Several examples of liquid waste injection activity tied to induced seismic events are included because of the historical importance of the wells to the study of the cause and effect of induced seismic events (e.g., references 609b, 609c, and 609d). Deep borehole disposal of solid nuclear waste material is neither expected to induce seismicity nor to have significant area-wide adverse impacts on the subsurface geologic environment. Minor impacts may be expected and are largely limited to thermal / mechanical effects proximal to the borehole; impacts to the borehole host rock environment are expected to be minimal, controllable, and of relatively short temporal duration.

The references with notes (References 470-609f) and information in Table 3 (Boreholes) supporting Map Layer 3 should assist users (e.g., interested parties, students, decision makers) in identification of the source information, in the study of drilling engineering capabilities and limitations, and in examination of recent and historic domestic and international deep and/ or large diameter borehole drilling activities. The table and reference material form the basis for an interactive map that provides the user with approximate borehole location, geologic setting, and to identify and augment summary drilling and geologic information (depth, diameter, history, rock type and age). Engineering features, geologic background, and visualizing geographic locations may assist users in the understanding of drilling capabilities, limitations, challenges, and general geography and subsurface geology. Selected deep drilling studies of the continental crust, oil and gas boreholes of note, example liquid waste injection wells, and several geothermal exploration and development holes are included, herein, as are examples of the U.S. AEC/DOE cold war era large diameter “deep” holes drilled for weapons testing program and Project Plowshares. The weapons test and Plowshares suite of larger diameter boreholes are included to show the DOE / National Laboratories’ role in development of “big hole” drilling technologies during the past half century.

Future revisions of this material may incorporate additional geothermal and CO2 sequestration projects, salt solution projects, and gas or liquid storage (or disposal) in salt and other rock environments. General references for deep borehole drilling, large diameter boreholes and borehole disposal investigations are contained in references 470-487, and 488-490, 490a, 491. For related prior work, see U.S. *DeepTrek* program (Reference 473) and its database of deep boreholes. The references cited are generally accessible online and may serve as a launching point for further study beyond data presented in these references, tables, and interactive map. Many of the locations provided are approximate; these may be updated in the future with more accurate information.

Table 3 - Boreholes

KEY

aka	also known as
asl	above sea level
cfGpD = cfG/D	cubic feet gas per day
bgl	below ground level
bml	below mud line (offshore drilling)
bsl	below sea level
ft = ‘	feet
in. = “	inch
km	kilometers
m	meters
mm	millimeter
P&A	Plugged and Abandoned
Ga	billion years ago
Ma = My = Mya = M = Mybp	million years ago / million years before present; related to age
MM	million, related to oil or gas production volume
TBV	To be verified
TBD	To be determined
TD (DTD)	total depth drilled
TVD	True Vertical Depth

Table 4 – Explanation and Key (Physics Facilities): Selected Physics Underground Research Laboratories (URLs) and Facilities; Existing, Proposed, Candidate, Former R&D Facilities and Former Candidate Sites

Underground physics R&D facilities are commonly included in discussions of nuclear waste management as examples of other types and locations of underground research facilities. Physics underground laboratory R&D teams have conducted extensive subsurface geotechnical investigations that may be applicable to the study of salt, argillite, crystalline and deep borehole disposal. Geophysical data are available and example investigations are included in table with references (e.g., induced seismicity, micro-seismic data use in defining fault geometry at depth such as in deep, ~3km, South African mines). The map and table provide interested parties with a global and historical perspective on locations of selected underground physics facilities constructed in a variety of subsurface environments.

General references and notes for physics, geophysics, particle physics and astrophysics underground facilities are contained in references 610-622; in general, Table 4 physics underground facilities list was modified from References 611, 612, 618, 619, 620, 622. Future revisions may update facilities information omitted in compilation of these data (Sieroszowice, Poland) and enhance descriptive geotechnical and engineering information. These data demonstrate the global nature of existing and potential sites and provide further demonstration of engineering and technical capabilities. Facilities are identified and approximate locations are provided for physics R&D underground laboratories that may present opportunities for the conduct of subsurface R&D activities in a variety of geological environments. The approximate locations allow the user to visualize and explore site areas on associated interactive map, and the companion references and notes permit the user to readily initiate further study.

Table 4 – Physics Facilities

Key:

bgl	below ground level
bs	below surface (also described as feet or meters of “overburden”)
m.w.e. / mwe	meters water equivalent

Table 5- Explanation and Key (Pits): Deep Open Pit Mines.

Global survey of several of the world's deepest or largest open pit mines. Mine name, location, historical development information, operator / owner, geology. Depth in meters. Depth indicators include depth below ground level (bgl) or below surface level (bsl). Age is indicated by mya or My (million years ago, million years), Ga (billion years, billion years ago); CE, Common Era; BCE, Before Common Era; ybp, years before present. Map layer number (5) and each location are assigned an item number (i.e., 5.1, 5.2, 5.x …); these identifiers are provided in Table 5, column 1, and are as indicated in data table and pop-up features for each item presented on interactive map layer 5 (pits).

bgl – below ground level

TABLES

Global Survey of Selected Deep Underground Facilities

Table 1 – (Mines) Notable Deep Mines and Shafts, Deep / Large Diameter Shafts, Subsurface Mining Engineering Capabilities and Achievements

Table #. Item #	Mine	Operator /Owner	Location, Country	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.1	Mponeng: gold mine; formerly Western Deep Levels South Shaft 1	AngloGold Ashanti	SW of Johannesburg, West Wits region, Gauteng Province , South Africa	Shafts, 1981; South Shaft deepening in 1996	~4100m; 13451' (2.4km - >3.9km / 7874'- 12795'; operations to 4.1 km [13451'] depth; planned >4.0km-4.5km)	AngloGold Ashanti West Wits Operations: On Rim of Witwatersrand Basin. Ventersdorp Contact Reef (VCR); sequential grid mining method ; deepest operating stope is at a depth of 3.37km ops; twin-shaft system housing two vertical shafts and two service shafts; reports 3461m shaft depth in 2008; world's deepest; Mponeng shaft 1, deepened to 120 level, which is some 3.4km below datum; 7.2 m diam. Shaft: now beyond 3777m. Plan CL project to 4500m. Geology: Archean (2.7-2.9Ga) ~<3Ga; Witwatersrand Basin gold reefs strata subjected to several periods of metamorphic fluid impacts, 2.0-2.7Ga. GW RESIDENCE TIME: GW residence time > 1Ma, Lippmann et al., 2003, 2011; age of fluid inclusions from that time (billion years+); deep fracture waters indicated to be relatively isolated, and with 10-25 million years residence time (Noble gas age estimates by Sherwood-Lollar et al., 2013, 2014); uncertainty with estimation of residence time evident. Witwatersrand Basin is within Archaean Kaapvaal Craton (2.7-3.1Ga) of South Africa; Vredefort Dome (2.02Ga) in basin center result of meteor impact. SOMP, Reference 9; SEISMIC STUDIES: South Africa mine seismic studies, NELSAM, SATREPS, JAGUARS; microseismic monitoring at 3.5 km. See Table / Map Layer 4, Physics Facilities)	-26.434994, 27.431231	1-5; 8-15; 18-22; 6,7; Seismic: JAGUARS, 104-111; 115-117; general, 112 - 114; Groundwater: 6, 7, 118-119, 122, 123, 124a; GW: compare with 120 - 128 ; Also see Table 4, References 610, 682-706	-26.434994	27.431231
1.2	TauTona: gold mine	AngloGold Ashanti	West Wits region, South Africa	1957 shaft; 1961 ops.	~3900m; 12795' (1.85km to 3.45km most production ; Deepened to 3.9km)	AngloGold Ashanti West Wits Operations: VCR and CLR mined; (aka Western Deep No. 3) 800km of tunnels; 3 shafts, offset / staged; mining method longwall / scattered-grid; 2km shaft in 1957; rock face temperature currently reaches 60°C. Two shafts, 1850/3450m; operations to 3.6 km, 2006; deepen to 3.9km 2008; Seismic risk. Geology: Archean -3Ga; fluid inclusions, 2 Ga residence time.	-26.415304, 27.430540	1-5; 16-18; GW: 119; Seismic, JAGUARS, 108-111, 112; 115-117; 682-706	-26.415304	27.430540
1.3	Savuka: gold mine	AngloGold Ashanti	Gauteng, West Wits region of South Africa	1957 shaft; 1962 prod.	>3777m; 12392'	AngloGold Ashanti West Wits Operations: VCR and Carbon Leader Reef (CLR) mined, Witwatersrand Basin; aka Western Deep Level 2 shaft; Damaged by seismic event in 2008; restored by 2011; repair two shaft systems from 2850m underground; 3 shafts with longwall to sequential grid mining; near TauTona; seismic risk. Archean -3Ga	-26.422688, 27.403547	1-5; 16-18; 682-706	-26.422688	27.403547

Table #. Item #	Mine	Operator /Owner	Location	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.4	Driefontein: gold mine	Gold Fields, GFIMSA	Near Carletonville, Gauteng Province, South Africa	1952	~3400m; 11155'	Far West Rand Goldfields Witwatersrand Basin. Ventersdorp Contact Reef (VCR), Carbon Leader Reef (CLR) and the Middelvlei Reef; West Wits Line Goldfield of the Witwatersrand Basin; 8+ shaft systems; plans for shaft deepening to 4,121 m; longwall and scattered mining. Geology: Archean -3Ga. Fluid inclusions, 2.0 Ga, ref. 119. Cecil Rhodes, 1887, founder GoldFields Co. Near South Deep; located east of West Wits and on map, wikimap shaft 1; aka KDC (Kloof-Driefontein Complex; KDC East = Kloof; KDC West = Driefontein); maximum depth bgl ~3347m.	-26.391255, 27.487106	1-5; 23-26; seismic, 115-117; Groundwater: 6, 118-120	-26.391255	27.487106
1.5	Kusasalethu: gold mine	Harmony	W of Johannesburg, West Wits Line near Carletonville, Gauteng Province, South Africa	1978	~3600m; 11811' (~3.276km then deepened to ~3.6km)	AKA Elandskraal (Elandsrand and Deelkraal mines); Ventersdorp Contact Reef (VCR); Far West Rand; twin vertical and twin sub-vertical shaft systems; shafts~0-2225+m, 2225-3566m; sequential grid layout; scattered mining method with an integrated backfill support system; future production planned to 3.6km depth; Archean -3Ga ; Approximate Location: see South Deep area; schematic = http://www.mining-technology.com/projects/elsrand/elsrand3.html	-26.452748, 27.357949	1-5; 12, 31-33	-26.452748	27.357949
1.6	Moab Khotsong: gold mine	AngloGold Ashanti; sale pending to Harmony in 2017, References 30a-30c	Vaal River, W of Johannesburg, near Orkney & Klerksdorp, Vaal River region, Free State province, South Africa	2003 prod.	~3500m; 11483' (early production, 2.6km and >3.054km; reported in 2013, shaft deepened to 3.5km; world's deepest continuous shaft)	AngloGold Vaal River Operations: Vaal Reef (VR); in 2012, using 19 underground drilling machines; in 2011, main shaft was 3,500 m. Minor impact Aug 2014 quake (2006: single bratticed shaft, diameter 10.75m, single drop surface to 3,132 m, making Moab Khotsong the longest single drop shaft in the world); large URANIUM reserves; located near Great Noligwa and Kopanang; Seismic investigations, SATREPS. Age is Archean -3Ga.	-26.985112, 26.799774	1-5; 26-30, 30a, 30b, 30c; seismic / SATREPS, 104-107; 682-706; 30a-30c	-26.985112	26.799774

Table #. Item #	Mine	Operator /Owner	Location	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.7	South Deep: gold mine	Gold Fields GFIMSA, (Barrick)	SW of Johannesburg, Gauteng Province, South Africa	1961	~2995m; 9826'	Far West Rand Goldfields Witwatersrand Basin. Two shaft systems known as the South Shaft complex and the Twin Shaft complex; vertical main shaft is 2,991 m deep Twin shaft complex; 9.6m diameter shafts planned (as-built = ?) ventilation shaft is 2759m deep; switched from conventional mining to fully mechanized mining in 2008; part is drift and fill and long-hole stoping; uranium resource also. South Deep mine phase 1 will extend to 3,075m below the surface, while phase two will extend to 3,500m depth. Geology: Central Rand Group, conglomerates, VCR and Upper Elsburgs of the Mondeor Formation Archean -3Ga. Note: 110 level (2,888m bgl)	-26.404843, 27.684667	1-5, 8; 34-36	-26.404843	27.684667
1.8	Kidd Creek: copper / zinc mine	Glencore / Xstrata	~27km N of Timmins, Ontario, Canada	Disc. 1963; Open pit, 1966; Underground prod., 1972	~3010-3014m; 9889'+ (other sources, ~2.927km. Mine D in 2004; 9500' depth; 2006 completed to ~9889'bgl cited for approximate depth)	3 shafts not continuous to TD (shafts 1,2 ~0m-1400m; shaft 3, 1400m-2100m and offset; ~6800' depth); reportedly world's deepest copper/ zinc mine; blasthole stoping with cemented backfill; Mine D will extend Kidd Creek below No 3, from a depth of 2,100m to 3,100m. Shaft 4, at 1380m with 8.5m diameter (7.6m internal diameter of concrete lined wintze to 1651m; shaft bottoms at 3014m, according to Cementation Co. website). D-shaft, reported ~9889'bgl, ~2.927km. Geology: Archaean Abitibi greenstone belt; volcanogenic sulphide deposit in felsic Kidd Volcanic Complex. Average residence time fracture water system is 1.5Ga. Sherwood-Lollar, Holland et al., 2013, 4 noble gases, correlated mean age 1.1-1.6Ga for waters in deep mine; isolation typical for shield rock at depth? Report unconfirmed - shaft bottom to 3014m? Verify	48.686944, -81.371111	1-5; 37-43; GW residence time: 6,7	48.686944	-81.371111
1.9	Great Noligwa: gold mine	AngloGold Ashanti; sale pending, 2017, References 30a-30c	~15km SE of Orkney, Vaal River region, Free State province, South Africa	Nearly depleted	~2400-2600m; 7874'- 8530' (estimated range operations from various references)	AngloGold Vaal River Operations: Vaal Reef (VR) and Crystalkop Reef (CR). Twin shaft system with pillar mining; impacted by Aug 2014 quake; minor. Near Kopanang and Moab Khotsong mines; Archean -3Ga;	-26.960909, 26.785279	1-5; 27-30; seismic / SATREPS, 104-107; 682-706; 30a-30c	-26.960909	26.785279

Table #. Item #	Mine	Operator /Owner	Location	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.10	Creighton : nickel / copper mine	Vale (INCO)	City of Greater Sudbury, Ontario, Canada	Area 1st prod., 1901; deep disc. 1991	~2500m; 8202'	Deep mine: Physics / Astrophysical testing = <2400m (~7800') bgl; 5990mwe for SNOLAB (See Table 4 for physics URL discussion). Shrinkage mining and mechanized undercut-and-fill mining, and large-diameter blasthole method combined with vertical retreat mining. Sulfide ore. Creighton mine at 6800' bgl is the home of the world's deepest (2070 m) underground physics laboratory, formerly the Sudbury Nutrino Observatory, SNOLAB, now SNO+…. In 2008, mined to 2377m level. Was once world's deepest shaft at 7138', No. 9 shaft, and 2135m in 2008? Geology: Sudbury Igneous Complex, 1.85Ga; melt from impact of meteor into 2.5Ga rocks (Archean) of Canadian Shield. Mineralization along Noritic / dioritic unit fault contact with granite/gabbro footwall. Mining operations at 2470m (~2500m) in 2014	46.47301,-81.187291	1-5; 44-46; groundwater, 7	46.47301	-81.187291
1.11	Kopanang : gold and uranium mine	AngloGold Ashanti; sale pending to HSC, September 2017	SE of Orkney, Vaal River region, Free State province, South Africa	Production 1984; gold / uranium	~2600m, 8530' (2240m, 7349' mine operations)	AngloGold Vaal River Operations: gold with uranium as byproduct; conglomerates of the Central Rand Group of the Witwatersrand; Vaal Reef (VR), the Ventersdorp Contact Reef (VCR) and the secondary Crystalkop Reef (C Reef) Val Reef major prod.; twin shaft system to a depth of 2,324 meters; single shaft mined to 2600m; See Great Noligwa and Moab Khotsong are proximal mines. Archean – (2.7-2.9Ga) ~3Ga. AngloGold Ashanti Technology & Innovation Consortium (ATIC), 2010; R&D goal to improve safety, economics, and technology needs for existing and up to 5km depth operations. Large uranium reserves	-26.982052, 26.743126	27; seismic / SATREPS, 104-107; 682-706; 30a-30c	-26.982052	26.743126
1.12	Spring Hill: coal mine	Closed	Nova Scotia, Cumberland County, Springhill, Canada	~1872; closed 1958	~1325m; 4347' (Inclined access ramp 12000'/ 3658m ramp shaft; ramp ends @ ~4000' bgl, 1219m bgl; works to 1325m bgl	Inclined shaft with 16 degree slope to ~4000' bgl; world's deepest coal mine; mines in area flooded after 1958 mine disaster and saw closure; recent use for heat pumps, geothermal energy; explored for coalbed methane. Geology: Cumberland Basin; Pennsylvanian age coalbeds; continental fanglomerates, lacustrine, and swamp marsh facies of the Upper Carboniferous Cumberland Group	45.666666, -64.066666	47, 48	45.666666	-64.066666
1.13	Lucky Friday: Ag, Pb, Zn mine	Hecla Mining Co.; (Lucky Mining Co.)	Mullan, Shoshone Co., Idaho, United States	Disc. 1880; prod., 1942	~1889m; 6198' (~1859m, 6100', Silver Shaft; with 6200', 1889m bgl operations)	Deepest vertical shaft in the lower 48 states; silver, lead, zinc; Coeur d'Alene Mining District; rock bursts; (aka Gold Gulch); Silver Shaft 6100' vertical shaft; 18ft diameter. Offset area Shaft #4 expected to drive to 8800' from ~4900' level from tunnel off Silver shaft. Geology: Revett and Wallace Formations, mineralization in the Precambrian Belt Series rock; meta-sedimentary units; ore concentrated in vein/ fractures; Mid/MesoProterozoic, ~1.4Ga	47.471154,-115.778668	54-58	47.471154	-115.778668

Table #. Item #	Mine	Operator /Owner	Location	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.14	Homestake: gold mine (aka SURF / Sanford Underground Research Facility, DUSEL)	Barrick Gold, abandoned mine, former operator; testing operator South Dakota Science and Technology Authority, test management, Lawrence Berkeley National Laboratory	Lead, Lawrence Co., South Dakota, United States (Black Hills, SD)	1877 - Operations; underground physics testing, 1960s, 2007-present	~2438m; 8000'	Held record for deepest mine in the western hemisphere until recently; stepped offset shaft development; Mine descends to a depth of ~1.52 miles (2.44 kilometers);Two surface shafts (Ross, Yates), 3 winzes; Ross shaft ~5000'; test level ~4850' bgl); raised bore shafts constructed, e.g., 5', 7', 13' diameters for access, ventilation. Other shafts: Yates (17.5' diam. @ ~4900'/4850'), Ellison, Oro Hondo, No.5 to 6200' – air shaft… deepest shaft to ~ 8000'. Now site of the Sanford Underground Research Facility (aka DUSEL, SURF: deep underground science and engineering laboratory). Geology: Iron Formation hosted gold deposits. 4160mwe main test, but reported up to7000mwe (?). Age: 2Ga meta-sediments and meta-igneous host rocks; Intrusions and metamorphism ~1.7Ga; Paleo- Proterozoic. Main test sequence, Yates Member, Poorman Formation; Yates amphibolite	44.351839, -103.750973	49-53; 628a, 628b; also see Map 4, Table 4 SURF discussion	44.351839	-103.750973
1.15	Palabora: copper mine	Rio Tinto/Anglo-American with other partners since 2013	Palabora, Limpopo Province, South Africa	Open-pit prod., 1964; shaft completed in 2004	~1290m, 4232' bgl	2000m wide surface pit; 9.9m diameter service shaft 1272m deep; Prod. Shaft to 1290m, 7.4m internal diameter 300mm concrete lined shaft. Geology: Carbonitite ring complex. Unique Cu sulfide mineralization in carbonitite. Cu, Ni, Fe; Palabora alkali-igneous complex is a Precambrian (2.06Ga) intrusive carbonititic complex intruded into Archean granite; aka Phalaborwa	-23.992406, 31.139211	13; 59-61	-23.992406	31.139211

Table #. Item #	Mine	Operator /Owner	Location	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.16	Oyu Tolgoi: Cu/Au mine	Turquoise Hill Resources (and Rio Tinto, Mongolian Gov.)	Khanbogd district, Omnogovi Province, Mongolia	South deposit disc. 2001; Hugo deposit disc., 2002. Operations began 2012; Cu exploited in area since 13th century and back to bronze age	~1385m / 4543' bgl	Shaft 1, 1385 m depth, Hugo area 1385 m Shaft 1, 6.7m diameter, was completed in 2008; in 2010 initiate 10m diameter shaft 2 work (1319m bgl). Planned shafts 3 and 4 @ 11m diameter, 1180 and 1220 m bgl; shaft 5 planned to 1195m bgl. Geology: Early to Middle Paleozoic 'island arc-type' Cu-Au porphyry deposits of Gurvansayhan Terrane; arc volcanics of Devonian to Permian age plutons associated; multiple copper gold porphyry (e.g., porphyritic augite basalt) centers. See Reference 64; site best viewed on Google maps or Google Earth	43.00833, 106.843055	13; 62-66a	43.00833	106.843055
1.17	Resolution Copper Project	Rio Tinto / BHP	Superior, Pinal County, (Magma Mine, Pioneer Mining District), Arizona, USA	Magma prod., 1912; deep discoveries, 1995; Rio Tinto deep evaluation initiated ~2012	~2116m; 6943' bgl (Shaft 10)	Includes old Magma (Superior) Mine properties; multiple shafts exist and new ones to be developed. Porphyry copper ore body between 1500 and 2130m deep (5000-7000'). Shaft 10, nearly (~6740', July, 2014) to its final depth of 6,943 feet; deepest shaft sunk in the US; reported 28' diameter shaft. Project on hold – legal, land issues, 2014; political issues / land swap; near Apache Leap, AZ. Geology: Laramide porphyry copper province; Cretaceous/Tertiary (Paleogene) intrusive events ~63Mybp and before deposition of Apache Leap Tuff (<20Ma). Magmatic-hydrothermal systems; porphyry copper deposit. Rio Tinto developing "Mine of the Future" R&D program.	33.301336,-111.103363	13; 67-80	33.301336	-111.103363
1.18	Xinhu mine: (Example only, China coal mine activity)	Huaibei Coal Mining Co.	Anhui Province, China	Coal (details sought)	~1037m, 3402' bgl	8.1m diameter shaft; Permo-Carboniferous; Approximate center of Province is shown for mine location. This is only an example of China's extensive coal mining operations developing shaft access for resource exploitation. In China since 2000, ~ 40 shafts sunk, >1000m deep with shaft diameters up to 13m in China's Coal district. See also China's Shaft Construction Research Institute and National Engineering Lab, Beijing; (ref: Long, Zhiyang and Gui, Liangyu 2012); included to indicate nearly "routine" excavation of 1000m bgl shafts in projects. Location is general within province, only; specific mine not located.	32.23139,117.268066	5; 81,82;	32.23139	117.268066

Table #. Item #	Mine	Operator /Owner	Location	First Year Operations / Underground Operations	Depth	Comments	Latitude Longitude	References / Sources	Approx. Latitude	Approx. Longitude
1.19	Pumpkin Hollow: copper mine	Nevada Copper Co.	Yerington, Lyon County, Nevada, USA (Yerington Mining District)	Disc. 1960; geophysical anomaly	~610m; 2000' (Planned 652m / 2140ft bgl; completed 1900' bgl shaft, 24' diameter)	Shaft: planned 24 ft diameter shaft, to 2200'; shaft depth 12/15/2013, <600ft; 7/16/2014, ~1000'; 11/4/2014, shaft depth 1475'; mining copper, gold, iron; chalcopyrite- magnetite skarn; reported 1 million feet drilling /copious core taken; holes generally 1500-2500'max depth;. Geology: flanks of Jurassic age Yerington batholith; mineralized Triassic limestone / marble in skarn peripheral to Yerington Batholith (a granodiorite and diorite body); copper found as fracture fillings in skarn breccias, Triassic Mason Valley Fm; limestone altered to marble / skarn breccia. Note: significant post mineralization phase Oligocene-aged ignimbrites. In January, 2015, federal NV lands bill opens area of 4-5,000 acres for mine development in addition to existing 1200 acre area. Open pit also planned.	38.955671,-119.112396	83-89	38.955671	-119.112396
1.20	McArthur River: Key Lake Operation; uranium mine	Cameco Corporation and AREVA	Northern Saskatchewan, Canada	McArthur Disc. 1988; production, 1999; (Key Lake Disc. 1975)	~685+m / 2247' bgl	3 shafts; deepest 685m; world's largest uranium mine. Geology: south-eastern portion of the Athabasca Basin, Churchill structural province; Wollaston Domain; metasedimentary basement rocks are unconformably overlain by flat lying, unmetamorphosed sandstones, and conglomerates of the Helikian Athabasca Group (middle Proterozoic, ~0.9-1.5Ga). Mineralization zone occurs in both the Athabasca sandstone and adjacent basement rocks, near the main zone of thrust faulting; production of U ore; NI 43-101 Technical Report and Cameco.com	57.76250, -105.05194	90, 91, 91a	57.7625	-105.05194
1.21	LaRonde: gold mine	Agnico-Eagle	Cadillac, NW Quebec, Canada	Prod., 1988; Discovery, 1976	3008m; 9869' (Shaft #4. Penna shaft #3 is ~2246m+ / 7217'bgl; also, Shaft # 4 to 9800' / 2987+m bgl; exploitation planned to 3100m bgl. In June 2016, mine depth at 3008m, deepest mine in Americas)	Aka = Dumagami; Penna shaft reported to be deepest single lift mine shaft in western hemisphere; (completed 2003; #3 shaft, 7217' bgl; ~ 2.246km deep); new deeper shaft #4, mine extension reported depth goal was 3300m, 5.5m inner diameter concrete lined shaft to 2865m bgl from ~2000m bgl; interior shaft. Geology: Volcanic Massive Sulfide / VMS deposit; Ag, Cu, Zn, Au produced; Archean-age Abitibi volcanic belt, Bousquet Formation, Blake River Group; ~2.7Ga. Also see beagnicoeagle.com, Canadian Mining Journal News; plans to extend operations to 3.7km bgl. Penna shaft 48.252284,-78.429393	48.256284,-78.434143	92, 92a	48.256284	-78.434143

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1.22	East Rand: mine	ERPM, DRDGold, South Africa	Witwatersrand field area, Boksburg, Gauteng/, Mpumalanga Province, South Africa	Since 1893 /1896; discovered 1888	3585m / 11,761' bgl	Witwatersrand Basin. Was deepest mine operation in 2006 until AngloGold Ashanti West Wits operations mines deepened. East Rand Properties Mines, Ltd. Far East Vertical (FEV) Shaft Lower Area mined 2600-3200m depth; composite Reef; South East Vertical (SEV) Shaft; Hercules Shaft Upper Area, ~2000m mine; produces from Main Reef, Main Reef Leader and South Reef. DRD Gold selling ERPM, 7/2014. Geology: Archean, 3Ga yrs. Acid water entry control problems, labour, safety, economic issues. DRDGOLD Limited in 2008 placed underground mine on care and maintenance (seepage issue); underground areas closed	-26.213205, 28.249712	93, 94	-26.213205	28.249712
1.23	Kennedy mine: East Shaft	closed	Jackson, Amador County, California, USA	Shaft constructed ~ 1898	~3900'; 1189 bgl TVD (1802m; 5912' as inclined; approximate constructed length depth; estimated TVD = 3900')	Operations with inclined shaft 1898 – 1942 CE; early operations 1860; example of older deep mine in California. Geology: Mother Load, fissure fracture fill deposits in Jurassic Mariposa (slate) Formation and Logton Ridge / Bower Creek meta-volcanics, and adjacent to Jurassic greenstone to west and metamorphic schists of Permo-Carboniferous Calaveras Formation to east. Geochemistry: http://pubs.usgs.gov/of/2002/of02-195/OF02-195K.pdf ; tailings chemistry most available in literature.	38.367222, -120.779166	95	38.367222	-120.779166
1.24	Mount Isa / Enterprise mines	Glencore / Xstrata (Glencore)	Queensland, Australia	Silver discovered. 1928	~1900m; 6234' (internal shaft 1000m - 1,900m bgl)	Australia's deepest mine, with an internal shaft which reaches a depth of 1,900m; distinct copper zone, Pb / Zn zone; Enterprise shaft for copper exploitation; Enterprise mine is the most recently developed copper ore source at Mount Isa and is Australia's deepest mine, with an internal shaft which reaches a depth of 1,900m from 1000m bgl; copper mine. Associated area Zn mining "P49" shaft completed to 1040m with 8m diameter in 1975. Geology: Paroo Fault, which has juxtaposed older basement Eastern Creek Volcanics against the younger Mount Isa Group sediments of 1655 ± 4 Ma; Mount Isa copper deposit extensive, hosted almost entirely within the Lower Proterozoic Urquhart Shale (US), a unit of the Mount Isa Group sediments and part of the Isa Superbasin.	-20.716111, 139.476111	99-101	-20.716111	139.476111
1.25	Soudan: Underground Mine and Physics Laboratory	State of Minnesota; Currently a State Park, Minnesota, USA	Breitung Township, St. Louis County, Minnesota (Vermilion Range), USA	Iron mine; initial work, 1880s; underground mining by 1900; mine closed in 1962; tests terminated 2016 and MINOS test facility closed	~714m; 2,341' bgl	Underground physics laboratory testing continues; testing ~710m / 2341' bgl. Geology: mine within Late Archean granite associated with mineralization in ironstone formations (hematitic ore) and adjacent greenstone terrain, 2.7 Ga; Minnesota's Iron Range area, a Vermilion Range mine. Ancient water chemistry and biological activity. Soudan Underground (Research) Laboratory: in Soudan mine (closed mining) now located in state park; access by old mine shaft; slightly inclined, depth to ~700m and operations extended to ~2341' bgl; ~50 miles of subsurface excavations. Cooperative studies with Fermi Laboratory; test at ~713m bgl / 2090 mwe; deeper testing, Level 27, ~2300' bgl. Lake Vermilion-Soudan Underground Mine State Park still has tours of old mine, but not physics facility	47.819921, -92.241859	96-98; 614, 617, 619, 621a; 723-726 (repeated)	47.819921	-92.241859

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1.26	Crownpoint Project	Wyoming Mineral-Conoco	Crownpoint, McKinley County, New Mexico, USA	Uranium mining project; 1972	~684m; <2300' (Three drilled shafts to depths of 2243' and 2188'; 120" and 72" diameter shaft holes drilled)	Represents the first time that big hole drilling had been exclusively used to develop totally a privately financed mine below a depth of 1000 feet; Uranium mine; Three shafts (~1980), one ten feet in diameter and two six feet in diameter, and completed in 1982 to depths of 2243'(120" diameter), 2188' and 2188' (both 72" diameter) respectively; reverse circulation; Grants Mineral Belt approximately 60 miles northwest of Grants, New Mexico, in Section 24, T17N, R13W NMPM, McKinley County, about 1/2 mile west of townsite of Crownpoint, New Mexico; Reverse circ air lift. Geology: San Juan Basin; Uranium found in Westwater Canyon Member of the Jurassic Morrison Formation at ~ 2000'bgl. Project never completed due to U price collapse; more recently considered for ISR U recovery projects; Laramide Resources effort; mineralization, Morrison Formation.	35.687594, -108.164151	102, 103, 159	35.687594	-108.164151
1.27	Bergwerk Saar: coal mine	RAG AG (Ruhrkohle Aktiengesellschaft)	Ensdorf, Saarland, Germany	Coal mined since ~1730 in area.	1,750 meters / 5741' bgl	For many years, this was the second deepest mine in Europe; last of the Saar area coal mines to close, 2012. Geology: Carboniferous "hard" coals; Westphalian / Stephanian of Saar Basin deposits. Induced seismic event in area mine and associated closure decision	49.319444, 6.779444	142-145	49.319444	6.779444
1.28	Uranium Mine No. 16 (Shaft No. 16)		Háje, Příbram, Central Bohemia, Czech Republic	Uranium mine	1,838 meters / 6030' bgl	Regarded as the deepest mine in Europe, 16th shaft of the uranium mines in Haje, Príbram, Czech Republic at 1,838 meters / 6030'; uranium and base metal ore district	49.6783333333 , 14.0605555556	141	49.67833333	14.06055556
1.29	Boulby: mine and underground laboratory	Cleveland Potash, Ltd; ICL Fertilizers Europe; STFC	Redcar - Cleveland area, England, United Kingdom; east coastal area along North Sea	Potash and salt; subsurface salt mined since 1973	~1,400m / 4593' (operations depth. Shaft depth ~1,100 meters, 3608')	Mine depth at ~1,400 meters / 4593'; shaft depth ~1,100 meters, 3608'; at ~1100m deep, it is the deepest mine in Great Britain; Potash ore occurs between 1200-1500m bgl; 5.5m-diameter, 1,150m-deep shafts through the sandstone was achieved by ground freezing and grouting of the rock shaft; two shafts, ~1150m depth bgl; 1000 km of road tunnels. Geology: Permian evaporates, >225 mybp; Late Permian Zechstein salt basin age; see also STFC / Science and Technology Facilities Council, Boulby Underground Laboratory	54.5534, -0.8245	135-140	54.5534	-0.8245

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1.30	Pyhäsalmi : Zn / Cu mine	First Quantum Minerals (Canada)	Oulu Province, Pyhäjärvi, Finland	Discovered in 1958, for base metal deposit	~<1500m; ~4724' bgl (?4738', 1444m bgl) verify data	Near Pyhäjärvi, Finland; 1st or 2nd deepest operating metal mine in Europe; Pyhäsalmi Mine mined Zn / Cu; operations to depth ~1,444 meters (~4737'); Olli shaft depth 3440' in 1986; internal Timo shaft from 3445'to 4724' in 1996; shaft diameter reported 5m; mine houses the Centre for Underground Physics in Pyhäsalmi (CUPP). Savo Schist Belt, meta-volcanic, migmatitic mica gneiss (turbidite meta-sedimentary); Paleoproterozoic island arc terrain, 1.8-2.0Ga; proximal volcanic and intrusive complex, massive sulphide deposit, volcanics and alteration halo. Also see site / Item 4.16	63.658611, 26.041111	129-134	63.658611	26.041111
1.31	Eagle (Ni Cu) Mine Project	Lundin Mining	Michigamme Township, Marquette County, Michigan, USA	Discovered 2002; production start 2014	300-400m?; ~1000'+ (1000' bgl ramp access verified; current depth ?)	Formerly a Rio Tinto property; Ni, Cu mine; magmatic massive sulphide deposit; decline ramp access to ~1000' bgl depth, 13% grade ramp, 18' diameter. Geology: magmatic massive to semi-massive sulfide / disseminated sulfide deposit; meta-volcanics and meta-sedimentary sequence; located proximal to Mesoproterozoic Midcontinent rift within the Baraga Basin; Paleoproterozoic pelitic sediments intruded by the Eagle (two intrusions, Yellow Dog intrusions) peridotite intrusions that hosts the Eagle deposit and are part of the Mesoproterozoic Baraga-Marquette dike swarm. It is only producing nickel mine in the Lower 48 states. Social Issues = controversial project; won public acceptance; model practices; not a "deep" mine, but notable for project development and public involvement in process	46.746389, -87.880556	13; 146-150	46.746389	-87.880556
1.32	Hecla Star: mine/shaft	Hecla Mining Co.; (Lucky Mining Co.)	Burke, Shoshone County, Idaho, USA	Discovered late 1890s	~2469m; 8100' (mined to 8100' bgl; verify status)	Hecla's The Star mine, Coeur d'Alene Mining District, was once the deepest operating mine in North America at 8,100 feet bgl; is shut down in 1982; adjoins Heckla mine; Heckla and Star mines located in (abandoned; closed 1981/82) silver, lead, zinc mine; located 2 miles N of Lucky Friday Mine; in predevelopment work; may integrate operations with Lucky Friday Mine (Hecla Mining); current access to 2000 level. Geology: Precambrian meta-sedimentary rocks of the Belt Super-group; hydrothermal vein fill deposits in fractured rock, often within and adjacent to faulted zones; Hecla evaluation for reaccess and extended production area	47.520278, -115.820278	151	47.520278	-115.820278

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1.33	Sunshine Silver Mine Project	Sunshine Silver Mining and Refining	Silver Valley area, Idaho, USA	Discovered 1884; evaluating for renewed exploitation	~1829m; 6000' bgl (reported workings to 6000' bgl; verify status)	Belt Supergroup, Pre-Cambrian; located in northern Idaho on Big Creek, four and one-half miles southeast of the town of Kellogg,, Silver Valley, Idaho; Coeur d'Alene Mining District; 1825m bgl; Jewell Shaft sunk to ~2080’, 1936 and reaches 4000’ bgl today. No 10 shaft internal, sunk 3100 Level and eventually sunk to an elevation equivalent to the 6000 Level; workings to 6000’ bgl. Geology: Precambrian Belt Supergroup, Middle Proterozoic age sedimentary rocks ~ 1.47 to 1.6 billion years ago; mesothermal stratbound vein deposits; stratiform Proterozoic deposits (1,500-900 Ma); concentration mineralization thought to be of late Cretaceous hydrothermal origin … possibly related to the formation of the Idaho Batholith	47.501667, -116.069444	152	47.501667	-116.069444
1.34	Quincy: Cu mine	Quincy Mining	Hancock, Houghton Co., Michigan, USA	Discovered 1845; operated through 1945; see museum present day	~2073m; 6800' (reported workings to ~6,800'bgl; possibly TVD? Verify final status if reported depth is constructed depth or TVD)	Mine is now part of Keweenaw National Historical Park on Keweenaw Peninsula. Lower levels flooded after closure; 2 shafts, No.2 and No.6, reached 9,280 ft. deep on the incline, ~6,800 ft vertical depth bgl; Copper and silver produced (native copper); considered some of the deepest shafts in the world during late 1800s-early 1900s. Geology: Early Quincy mining was fissure mining of native copper, then exploited by amygdaloid mining (i.e., extracting lower-grade strataform orebodies in the "amygdaloid zones," the upper portions of basalt lava flows); When the mine ceased production in 1945, the Quincy Number 2 shaft was the world's deepest shaft (inclined), at 9,260 feet (2.82 km); copper occurs within Keweenawan lava flows, Most of the copper is hosted by rocks of the Mesoproterozoic Mid-Continent Rift system	47.137037, -88.573233	153-158	47.137037	-88.573233

Table 2 – (URLs, Repositories, Sites) Past, Planned, and Operating Underground Research Laboratories (URLs); Past, Present, Selected, and Candidate URL and Repository Sites or Areas

Table #. Item #	Facility / Site Name / Candidate Site Name	Location, Country	Operator /Responsible Org.	Facility Type (Generic/ G; Purpose built / S; Site Specific / SS), Access, Depth (shaft or overburden);	Host Rock / Geologic Information	Nature Of Experiments (References 160-167)	Period of Testing, Operations, Expected Repository Start (References 160-167)	Latitude / Longitude	Alternative Location information	References	Approx. Latitude	Approx. Longitude	Depth (meters bgl); simplified
2.1	HADES: URF/URL	Mol Site, Mol-Dessel; East of Antwerp, Belgium	EURIDICE EIG (European Underground Research Infrastructure for Disposal of nuclear waste In Clay Environment); EIG (Euridice - Economic Interest Group), and Belgian National Radioactive Waste Management Agency, Belgian National Agency for Radioactive Waste and Enriched Fissile Materials NIRAS / ONDRAF; SCK.CEN, Studiecentrum voor Kernenergie / Centre d'Étude de l'énergie Nucléaire ; a consortium	G (Generic, purpose-built, S); ~ 223 m or 225m bgl, with two vertical shafts; Diameter Shaft 2 is 3m, widens to 5m. Shaft 1, ~5m; HADES= High-Activity Disposal Experimental Site, Underground Research Facility located on SCK.CEN property.	Soft clay; soft plastic clay / argillite; Boom Clay (host unit is Rupelian, Lower Oligocene; Paleogene; will examine Ypesian claystones).	TCHMRD; (e.g., PRACLAY project and tunnel; connected to main HADES excavation)	Activities since 1980; shaft construction 1980-1984; 1985 phased testing; Initiated in URL; 1997-2007, gallery and drift construction including PRACLAY and gallery construction; first site specific built URF in Europe	51.218611, 5.093333	Approximate Location 51.224303,5.092163; SCK.CEN,, 51°13′07″N, 5°05′36″E	160-189; 190-199; 463-466	51.218611	5.093333	223m bgl

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2.2	Belgium Repository: HLW /SNF	TBD, Belgium	National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF / NIRAS), technical input from Belgian Nuclear Research Center (SCK•CEN)	TBD; HLW repository; two site areas being considered, with Mol / Dessel area focus	Argillite	Area data collection and testing; evaluation and selection pending	Site selection TBD; Possible repository ~2040. Examination of Mol/Dessel area (Rupelian Boom Clay), and the Doel Nuclear Zone and border areas (Ypresian clay; Eocene, Paleogene; Kortrijk Formation) R&D only.		Region of Mol / Dessel near Mol Power Station and nuclear zone, 51.223846,5.098257 and Doel Nuclear Zone 51.328895,4.256344 area	160-189; 190-200			NA / TBD
2.3	Doel Nuclear Zone: Considered Site Area	Doel Nuclear Zone , Belgium	National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF / NIRAS), technical input from Belgian Nuclear Research Center (SCK•CEN)	TBD; HLW repository site area considered	Argillite; Ypresian clay; Eocene, Paleogene; Kortrijk Formation	Area data collection and testing; evaluation and selection pending		51.328895, 4.256344	Approximate area location only	200	51.328895	4.256344	NA
2.4	Mol Nuclear Zone: Considered Site Area	Mol Nuclear Zone, Mol / Dessel, Belgium	National Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF / NIRAS), technical input from Belgian Nuclear Research Center (SCK•CEN)	TBD; HLW repository site area considered	Argillite; Rupelian, Boom Clay	Area data collection and testing; evaluation and selection pending		51.223846, 5.098257	Approximate area location only	160-189	51.223846	5.098257	NA

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2.5	Lac du Bonnet: Pinawa, URL (closed)	Pinawa, Manitoba, Canada	NWMO, Nuclear Waste Management Organization (formerly operated by AECL / Atomic Energy Canada Ltd.)	G/S (Generic URL purpose- built); 443m vertical shaft; upper rectangular shaft 2.8x4.9m; lower circular, 4.6m diameter ; Test levels at 240m, 420m; coreholes tested to 950m.	Granite; crystalline; Lac du Bonnet Batholith, Archean / Late Kenoran age granite intrusion (2.68 ±.081 Ga), western Superior Province, followed by hydrothermal alteration 2.2-2.5Ga.	TCHM	1984 - 2006; decommissioned, 2006/2010; subsurface closed in 2010; planned surface facility demolition and site remediation through 2014 with sealing test through 2016	50.252206, -95.866893		160-189; 201-207	50.252206	-95.866893	~443m
2.6	CA Repos.: HLW, SNF Repository: TBD	TBD; Ontario, Canada	NWMO, Nuclear Waste Management Organization	Repository siting technical study exercise underway since 2010; planned ~500m bgl (depth range 400-700m bgl); crystalline (6 sites) and sedimentary (3 sites) still considered in Ontario	Likely in granitic Canadian Shield locations	TBD (sting studies; early ground based testing)	HLNW/SNF - TBD; siting studies, selection, phased voluntary siting program; more than two dozen volunteer sites passed initial screening; several areas still under consideration with 2017 drilling expected in Ignace Township of Ontario. In 2015, NWMO was still considering sites in Ontario near White River, Manitouwadge, Hornepayne, Ignace, Blind River, Elliot Lake, Central Huron, Huron-Kinloss and South Bruce.	49.4165, -91.6589	NWMO is exploring mutliple sites in 4 areas within ~50 km of the town of Ignace, Ontario. First borehole drilling expected in 2017. Approximate location for Ignace provided in map. Central Huron and White River no longer under consideration. TBD	160-189; 201, 201a	49.4165	-91.6589	NA / TBD

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2.7	Bruce: Kincardine site	Kincardine, Bruce County, Ontario, Canada (near Lake Huron Shore; adjacent to OPG's Western Waste Management Facility, Bruce Site)	Ontario Power Generation, OPG / NWMO (NWMO, Nuclear Waste Management Organization)	S facility; ~2230', 680-686 m bgl planned / pending deep geologic repository license for disposal of LLW / ILW; planning shaft access, 4.5 and 6.5m diameter.	Limestone; argillaceous limestone; saline formation water; thick top seal; for disposal of LLW / ILW within lower member of Cobourg Formation, Ordovician. Deep Geologic Repository; planned two shafts, 4.5m and 6.5m diameter. Decision pending; some domestic and US opposition.	Licensing process initiated in 2011	Planned; in siting approval process; considerable opposition to project, domestic and USA	44.326381,-81.583464	44°19'35.0"N 81°35'00.5"W	160-189; 208-213	44.326381	-81.583464	NA; ~680m (planned)

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2.8	Beishan: Xinchang site URL	Beishan area , Northwest Gansu Province , Jiuquan prefecture (~50 miles north of Jiuquan, Gobi desert), China	CNNC (Chinese National Nuclear Corporation)	Nine candidate sites including several sites in Beishan area examined; plans to build URL 2015-2020; plan to operate 2020-2040+; expected depth ~500m+; "area-specific URL" (Wang, 2014); selected Xinchang site, Beishan for URL. BRUIG/CNNC constructed Beishan Exploration Tunnel, 2015; generic, purpose built tunnel in granite for preliminary testing.	Granite; crystalline; ~322Ma Carboniferous / Permian age intrusives	URL Siting evaluation concluded; Beishan area candidate locations for URL; Xinchang site selected for URL, Beishan area	Primarily surface testing in Gobi Desert, Beishan, since 1986; URL expected construction start in 2015/2016; URL by 2020. Nine candidate sites for URL. In 2016, selected URL site at Xinchang, Beishan area. Also constructed in 2015 Beishan Exploration Tunnel for URL activities.	40.849096, 97.585635	Approximate Location only: Beishan; 41N, 98E; 41.000176,98; area of interest 40◦00'– 42◦00'N, 96◦40'– 98◦40'E; 41N, 98E; estimated location of Xinchang is 40.849096, 97.585635	160-189; 242-251	40.849096	97.585635	NA; ~500m (planned)
2.9	Beishan: site area repository	Beishan, Gansu Province , China	CNNC (Chinese National Nuclear Corporation)	TBD; Repository area of investigation in Beishan; repository siting TBD; Plan 500m deep repository for ~2050; by 2012, 5 Beishan subareas (Jiujing, Xinchang – Xiangyangshan, Yemaquan, Shazhaoyuan and Suanjingzi) with most potential; final site will reflect results of URL site testing outcome; also examining deep borehole disposal concept; HLW / SNF	Granite / crystalline; porphyritic monzonitic granite and tonalite. ~322Ma, Carboniferous / Permian age intrusives. Repository in granite first; may then examine clay repository option	TBD; siting evaluation studies	Ongoing evaluation, siting studies; expected repository construction ~2040/2050; Beishan area drilling of 27 holes completed and 6 in progress; construction of generic test tunnel for URL construction methods evaluation	41.006589, 97.899513	Approximate area location only: Beishan, 41N, 97.9E. Example Beishan site areas considered are Jiujing, Xinchang, Yemaquan, Shazaoyuan and Suanjingzi; also area in Inner Mongolian Auton. Region	160-189; 242-251	41.006589	97.899513	NA; ~500m planned

2.10	Shaft 16	Haje, Príbram, Central Bohemia Region, Czech Republic	RAWRA / Radioactive Waste Repository Authority, or Správa úložišť radioaktivních odpadů, SÚRAO; note that CEZ is Czech Power (electric utility) Company	G facility; (galleries in U mine); indicated as once deepest mine in Europe; Pribram mine #16 = Shaft #16; mined from 1948-1991; included uranium base metals deposit; vein mineralization; U mined ~1450-1850m bgl; shaft vertical to 1838m bgl. At 961mbgl, gallery / tunnel built off shaft into granite for gas storage (Haje) project; shallow granitic units in fault contact (reverse) with subjacent sedimentary sequence. See Site 1.28, Deep Mines is same site	Crystalline / with sediments; (Reverse fault zone intruded with basic dikes; Brezove Hory District mineralization Pb/Zn/Ag-rich hydrothermal veins, U qtz veins in Cambrian sandstone; reported U occurs in bitumen rich sediments; Uranium District area hanging wall made of Proterozoic slates, meta sediments flanking pluton); plutons and mineralization was multiphased within Bohemian Massif area related to intrusive Variscan granitoids, 338-354Ma, Central Bohemian Plutonic Complex with Uranium District Uranites mineralization ~265Ma - 278Ma in Paleoproterozoic metasediments and metavolcanics flanking pluton.	Generic characterization studies; not being considered as repository or "URL" for country; potential for opportunistic test and evaluation in crystalline and sedimentary units at depth	Late 90's – present testing; U mined 1949-1992 when mining U was terminated (mining start /finish dates need verification; different sources with differing dates by ~ 1 year)	49.677070, 14.060439	approximate area 49.67346,14.054689 located flanking active mine and waste / spoil tailings	160-189; 252-257; 271, 272; 273-276	49.67707	14.060439	<1850m

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2.11	Josef: URL/URC; Josef Stola: URL/URC; Josef Gallery / Josef Underground Laboratory / Josef URC	Josef Gallery; near the Slapy dam; Central Bohemian Region, Czech Republic	Faculty of Civil Engineering CTU Prague, Center of Experimental Geotechnics / owner - Ministry of the Environment	G - facility; Josef Gallery (~50, 80-150mbgl); see reference 269. Former exploratory gallery is used for educational and research purposes; location from University Regional Underground Research Centre Josef URC / URL; testing <50m, argillaceous units	Crystalline / granite; Bohemian pluton, granodiorite; Upper Proterozoic metavolvanics and metavolcano-sedimentary units; current testing < 50m, argilla-ceous units	Generic characterization work	Josef Gallery excavated 1981-1991; 1991-2005, closed; 2007-present, used for educational / research purposes, CTU	49.730596, 14.348497	N 49°43'50.145" E, 14°20'54.591"	160-189; 263, 267-270; 277	49.730596	14.348497	<150m
2.12	Bedrichov	Bedrichov, Liberec Region, Czech Republic; {Tunnel connects Bedrichov(e) water treatment plant with Josefův Důl Dam}; ENE of Liberec	RAWRA/ Tech. Univ. Liberec (Radioactive Waste Repository Authority, or Správa úložišť radioaktivních odpadů, SÚRAO) Note that CEZ is Czech Power (electric utility) Company	G - facility; underground study associated with water supply Tunnel; 120-150m overburden; 2600m tunnel constructed ~1981; 2.6 - 3.6m diameter; A (3.6/3.1m diameter) and B tunnels (2.6m diameter) together ~6km long (Klominsky and Woller, 2010)	Crystalline / granite; Bedrichov Jizerské Hory Mountains, Krkonoše-Jizera Composite pluton; Jizera and Liberec granites (porphyritic /biotite granites), Jizera mountains, Carboniferous / Variscan age.	Generic characterization, modeling studies	Ongoing studies; conducted 2003-present; not intended for use as URL or repository	50.784401, 15.160557	Approximate location Dam N50.7946, E15.1955; A Tunnel oriented ENE/WSW, location ~ 50.792156,15.187397 (50.784401,15.160557 for tunnel entrance at treatment plant; for tunnels A/B, start point of the firs line is at 50.793954, 15.190684; 3/18/2015, pers. commun., J. Faltejsek)	160-189; 259-261	50.784401	15.160557	<150m

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2.13	Bukov: URF	Rozna mine, near village of Bukov (near Žďar nad Sazavou) in the Vysočina / (Highlands) Region (~1.5 km north of Dolní Rozínka), Czech Republic	SURAO; RAWRA, Diamo: Radioactive Waste Repository Authority, or Správa úložišť radioaktivních odpadů, SÚRAO; Diamo is state uranium company and mine operator	S - facility; Developed within the Rozna I Uranium mine, Bukov section; proximal to the Kraví hora candidate locality area, ~ 55 km northwest of Brno; examine depths 500-2000m; main site study at ~550m depth bgl; shaft access; mining to over 1200m bgl; in 2015, Rozna was only operating U mine in Europe	Crystalline; Bohemian Massif, Strážek Moldanubian unit; Moldanubian Zone of the Variscan orogen; migmatised paragneiss and amphibolites; groundwater age is fairly young (1800 - 21,000 ybp); relatively fast GW movement	Characterization, modeling studies, EBS test and demonstration	Initiated site construction in 2013; expect characterization 2015-2017; operations 2017	49.494646, 16.215142	Approximate location for town of Bukov 49.454345,16.22406; town of Razna 49.479641,16.236248 ; Rozna mine lat/long; changed from 49.492549,16.223288 to mine to west at alt. loc. 49.494646, 16.215142	160-189; 262-266; 271, 272	49.494646	16.215142	~550m

2.14	Repository Candidate study sites	Candidate site areas, Czech Republic: 1a) Horka (Budišov) and 1b) Hrádek (Rohozná), in the Vysočina region; 2a) Čihadlo (Lodhéřov) and 2b) Magdaléna (Božejovice) South Bohemia region; 3) Březový potok (Pačejov) in Plzeň region; 4) Čertovka (Lubenec) Plzeň and Ústí-nad-Labem regions; 5) former military area at Boletice in S. Bohemia, and Kraví hora added in 2009 as potential candidate site study areas	RAWRA Radioactive Waste Repository Authority , or Správa úložišť radioaktivních odpadů, SÚRAO; CEZ is Czech Power (electric utility) Company, responsible for storage and will coordinate with SURAO for disposal	Repository - Planned ~500m depth bgl; preference for crystalline; details TBD; plans to reduce number of candidate sites to two by ~2018-2020. Surface area of the candidate sites to be subjected to geological investigation in the next stage of the site selection process are listed here; local opposition	Crystalline; details provided for each site considered; 6 localities are in granitic rock with a crystallization age of between 515-320Ma, one in metamorphic unit	Site evaluation and selection work; evaluation of potential multiple locations; Czech environment ministry approval for initial geological surveys to begin at seven candidate sites; social issues; slow progress; envisioned underground storage for SNF; (Note: Czech Republic is operating underground LLW and ILW disposal at the Dukovany repository with SURAO as owner and CEZ as operator)	Repository Site selection studies and planning since ~2003; disposal operations planned for 2050; construction not expected until ~2040. down select to 2 sites by 2018; final site ~ 2025		TBD; detailed below by candidate site area; candidate site area older and newer site names are dual names given; citations differ on name provided, thus, both indicated here but Czech SURAO reference 257 used below for each candidate site area, not reference 254. Dukovany LLW/ILW repository is Dukovany NPP site 49.087, 16.1514	252-257; 257a-257h; 266	NA	NA	NA; ~500m (planned)

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2.15	Horka / Budišov: candidate site study area	Budišov, Vysočina Region, Czech Republic; (extends across the municipalities of Hodov, Rohy, Oslavička, Budišov, Náramečč, Vlčatín, Osové, Rudíkov and Oslavice)	RAWRA Radioactive Waste Repository Authority (SURAO, or Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	Crystalline; Třebíč Mezirici massif; dark, potassium-rich granite rocks	HLW Repository Site evaluation and selection work	Planning and initial testing since ~2003	49.291023, 15.9850	Area near Hodov and north of Budisov; not 49.888663, 15.9167, village of Horka, but not site area. Northern area = ~49.317907, 15.974679	254, 257, 257a, 257d	49.291023	15.985	NA;~500m (planned)
2.16	Hradek / Rohozná: candidate site study area	Rohozná, in the Vysočina Region, Czech Republic; extends across the municipalities of Rohozná, Dolní Cerekev, Cejle, Hojkov, Milíčov and Nový Rychnov	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	Crystalline; Bohemian massif, Moldanubicum pluton; granite age is ~303- 327 million years	HLW Repository Site evaluation and selection work	Planning and initial testing since ~2003	49.365052, 15.394765	East of Novy Rhychnov and in and N of Rohozna (49.365052, 15.394765), west of Hojkov, Vysočina Region	254, 257; 257a, 257g	49.365052	15.394765	NA; ~500m (planned)

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2.17	Čihadlo / Lodherov: candidate site study area	Lodhéřov, South Bohemia Region; Czech Republic; extends across the municipalities of Deštná, Světce, Lodhéřov and Pluhův Žďár	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	Crystalline; Klenová massif is a large granite area within the Bohemian massif, Czech-Moravian Highlands. The age of the granite ~298-398 million years	HLW Repository Site evaluation and selection work	Planning and initial testing since ~2003	49.215214, 14.959688	49°13'3"N 14°57'46"E	254, 257, 257a, 257c	49.215214	14.959688	NA; ~500m (planned)
2.18	Magdalena / Božejovice: candidate site study area	Božejovice; South Bohemia Region; Czech Republic; extends across the municipalities of Jistebnice, Nadějkov and Božetice; Vlksice	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	Crystalline; Central Bohemia granite zone (Central Bohemia pluton)	HLW Repository Site evaluation and selection work	Planning and initial testing since ~2003	49.471508, 14.497503	SW of Jistebnice and near area of Bozejovice and Svoriz; ~49.471508, 14.497503	254, 257, 257a, 257e	49.471508	14.497503	NA; ~500m (planned)

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2.19	Březový potok / Pačejov: candidate site study area	Pačejov; in Plzeň Region; Czech Republic; extends across the municipalities of Pačejov, Kvášňovice, Olšany, Maňovice, Chanovice and Velký Bor	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	Crystalline; 331-346 million year old; Central Bohemia granite zone (Central Bohemia pluton) upon Blatno granite rock	HLW Repository Site evaluation and selection work	Planning and initial testing since 2003; rail station	49.386536, 13.675857	NW of Velky Bor in area surrounding Manovice and Jetenovice and Kbelik peak ~49.386536, 13.675857	254, 257, 257a, 257h	49.386536	13.675857	NA; ~500m (planned)
2.20	Čertovka / Lubenec: candidate site study area	Lubenec; Plzeň and Ústí-nad-Labem Regions; Czech Republic; extends over Blatno and Lubenec in the Ústí Region and Tis u Blatna and Žihle in the Plzeń region	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	Crystalline; 450-505 million-year-old Tis granite massif which forms part of the Čistá-Jesenice granite massif	HLW Repository Site evaluation and selection work	Planning and initial testing since ~ 2003	50.120423, 13.3181	49.409326,13.320537; Usti Nad Labem Region, SE of Lubenec and west of Blatno; 50.120423, 13.3181	254, 257, 257a, 257b	50.120423	13.3181	NA; ~500m (planned)

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2.21	Boletice: candidate site study area	Former military area at Boletice in South Bohemian Region; Czech Republic	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl)	? Crystalline	HLW Repository Site evaluation and selection work TBD; suggested for consideration in 2009, but little evidence it was carried forward to date.	Planning and initial testing are TBD; identified in 2009 as potentially suitable site for deep repository; one of 5 military lands considered	48.830374, 14.216309		254, 257	48.830374	14.216309	NA; ~500m (planned)
2.22	Kravi Hora: candidate site area	South-Moravia and Vysočina Regions, Czech Republic (extends across the municipalities of Bukov, Věžná, Střítež, Milasín, Moravecké Pavlovice, Drahonín, Olší and Sejřku)	RAWRA Radioactive Waste Repository Authority (SURAO, Správa úložišť radioaktivních odpadů)	Candidate site study area (planned ~500m depth bgl); Bukov URF is in area	Crystalline; metamorphic rocks; granulites; within the included area is located proximal to the Bukov URF	HLW Repository Site evaluation and selection work	Planning and initial testing; added to site candidate list in 2009	49.440859, 16.26053	Near area surrounding Stritez ~49.440859, 16.26053, and SE of Bukov; note photo showed 49.461207,16.264315	160-189; 254, 257; 257a, 257f; 262-266; 271, 272	49.440859	16.26053	NA; ~500m (planned)

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2.23	ONKALO: URL	Olkiluoto; Länsi-Suomi region, Eurajoki, Finland	POSIVA OY	S/SS facility (in VLJ repository); main test level = 420-520mbgl; 520m shaft; other test 60-100m bgl; research tunnel; URL spiral access tunnel, 5.5m x 6.3m to ~455mbgl; with shafts, raised bore: diameter passenger shaft , 4.5 m; supply air shaft and exhaust air shaft are 3.5 m; Onkalo = Hiding Place; study SNF disposal; Onkalo URL aka URCF / Underground Rock Characterization Facility. Also see Item 2.24, Eurajoki VLJ	Granite (Mica gneiss, Tonalite; pegmatitic granite; gneiss); crystalline; Proterozoic age	HM+D	Studies since 1993; site characterization facility; 2004 VLJ URL construction; open in 2010; adjoins volunteered potential repository site; license application for repository submitted in 2010; authorized to construct repository in 2015; Onkalo is to be part of repository	61.235868, 21.483035		160-189; 346-353; see 167a, 168a	61.235868	21.483035	60-520m

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2.24	Eurajoki VLJ: Volunteered Repository	Olkiluoto Island, Eurajoki, Finland	POSIVA OY	S facility; High-level nuclear waste disposal site; VLJ repository, Olkiluoto; depth ~420m planned; disposal SNF. Associated site specific URL testing. Also see Item 2.23, Onkalo site URL	Granite / crystalline; (Mica gneiss Tonalite; pegmatitic granite); Proterozoic age	Site evaluation and Characterization; estimated 2020 to open repository; Olkiluoto / Eurajoki selected by process; volunteered site; one of 5 site areas investigated (Romuvaara in Kuhmo; Veitsivaara in Hyrynsalmi; Kivetty in Äänekoski; Syyry in Sievi; Olkiluoto in Eurajoki)	Tunnel / shaft construction, 2004-2011; application to construct, 2013; license to construct granted 2015; disposal operations expected ~2020. Posiva is initiating plans for second repository facility (estimated to be operational in 2090s; Ref 346a) for disposal of of spent nuclear fuel from planned Hanhikivi-1 nuclear plant. Olkiluoto, Eurajoki is the site of Posiva's Onkalo URL and repository for used fuel from Olkiluoto and Loviisa nuclear stations.	61.236734, 21.478434	Location ~ 10km NW of town of Eurajoki; located away from plant / Olkiluoto site; adjoins Onkalo URL, Olkiluoto, Eurajoki; on Olkiluoto Island	160-189; 346-353; 346a; see 167a, 168a notes	61.236734	21.478434	~420m
2.25	Fanay: URF	Fanay Augères / Tenelles, North Limousin, France (~20km N of Limoges, in Ambazac mountains; Vieilles Sagnes , Limousin; (Fanay Mine, Razès, Haute-Vienne, Limousin)	IRSN; Institut de Radioprotection et de Sûreté Nucléaire	G facility (galleries in U mine); Test depth ~100m bgl	Granite / crystalline; fractured; Crouzille District; western Massif Central, France Saint-Sylvestre (leucogranite) granitic plutonic complex; 350-360mya; younger overprint reported and ages of 324my; also with younger intrusions and deformation	TCHM	1980–1990 Testing	46.003397, 1.343482	Approximate location of Tenelles 46.011807,1.36827; Approximate Location of Fanay 46.00671N,1.351318E; Augeres 46.094186,1.72966; Reported location near town of Tenelles	160-189; 228, 231	46.003397	1.343482	~100m

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2.26	Amélie: URF	Amelie, Alsace Potash mines, France	ANDRA, = French National Radioactive Waste Management Agency, Agence nationale pour la gestion des déchets radioactifs	G facility (galleries in K mine) testing, some at 520m	Bedded salt: 1st K prod. 1910; 2 shafts, 2100-2200' deep; Tertiary / Paleogene; mined Upper Salt (Salt IV) unit; Stampien Fm; U. Eocene-L. Oligocene Mullhouse sedimentary basin	TMD	1986–1994	47.793640, 7.247264	47°47'36"N 7°14'49"E	160-189; 240, 241, 415	47.79364	7.247264	~520m
2.27	Tournemire : URL	Tournemire; Aveyron county, Ardeche Department, France (between Le Cernon and Le Soulzon rivers)	IRSN / ANDRA; (ANDRA = French National Radioactive Waste Management Agency, Agence nationale pour la gestion des déchets radioactifs ; IRSN, Institut de radioprotection et de sûreté nucléaire)	G (1885m long military built railway tunnel access with test galleries); 200m overburden; test areas to 350m bgl planned; Research Tunnel experimental station.	Shale; argillite; Early Jurassic; Toarcian, ~180mybp; Causses Permo-Mesozoic sedimentary basin	CHM	Since 1990, testing; added tunnels in 1996,2003; URL	43.978240, 3.010726	Tunnel ~2km N of town location 43° 58′ 12″ N 3° 01′ 13″ E	160-189; 226, 232-235; 237	43.97824	3.010726	~350m

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2.28	Bure: URL; Meuse-Haute Marne URL	Bure, Meuse/Haute Marne Districts, France	ANDRA, NARWM; (ANDRA = French National Radioactive Waste Management Agency, Agence nationale pour la gestion des déchets radioactifs	S/SS facility (purpose built); 400-500mbgl; 2 shafts sunk to 490m are 5m and 4m diameter; see Ciego Project; Bure URL a.k.a. LSMHM / Lab. Subter. Meuse/Haute Marne	Shale; argillite; Callovian / Oxfordian, Jurassic age (~155mybp), Paris Basin;	TCHM: testing only; by law, was not to be used as repository. Goal is reversible disposal. ANDRA studies crystalline disposal in URLs of Switzerland (Grimsel), Belgium, Canada, Japan, Finland, and Sweden (Aspo); Andra supports testing in argillites at Switzerland's Mont Terri	2000 – 2006 construction; shaft access; URL testing 2004 - present; see Cigeo Project documents	48.48444, 5.356389	48°29′04″N 5°21′23″E	160-189; 217-224 (Ciego); 229-230; 236, 237-239; see 167a, 168a note	48.48444	5.356389	~500m
2.29	Repository Siting: Bure area	Repository near Bure Area, Meuse / Haute Marne Districts, France	ANDRA, NARWM; (ANDRA = French National Radioactive Waste Management Agency, Agence nationale pour la gestion des déchets radioactifs	TBD; Meuse/Haute Marne Districts near Bure was approved for repository siting investigations in 2006; for HLW; see Ciego Project; Cigeo (Industrial Centre for Geological Disposal) in the town of Bure operating as part of Meuse/Haute Marne Underground Research Laboratory run by the National Agency for Radioactive Waste Management (Andra). Siting approved in 2016.	Shale; argillite; Callovian / Oxfordian, Jurassic age; Paris Basin	Estimate 2025 open; emplace waste, 2030	Selected site near Bure; planned ops to start construction in 2021, repository operations by 2025; emplace waste, 2030. See Cigeo Project documents, disposal ILW/HLW objective; plan and prepare, mitigate impacts to host community area	48.501365, 5.36253	Area location approximate for repository site area that may be slightly to north of location provided	214-216; 225-227; 228-230; 217-224 (Ciego); 236; 237-239; see 167a, 168a notes	48.501365	5.36253	NA; ~500m (planned)

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2.30	Asse II: URF / LLW repository	Asse / Schacht Asse II, Forschungsberg-werk – Asse Salt Mine; Lower Saxony, Wolfenbuettel/Braunschweig region, Germany	BfS with GSF (now Helmholtz Zentrum München)	G facility (test galleries in K/salt mine); >800m -950m bgl; mine leaks; Shaft 765m bgl, and deepened; testing program generally 490-800m bgl. Used for storage LLW/ILW; water seepage issues resulted in termination of storage development; in process for facility closure. Potash mine started ~1909	Domed salt; Zechstein; Permian units	TCHMRD	Testing, 1967-78, and disposal IL/LLW; 1977–1997. Water leakage experienced; now in sealing phase; decommissioned, R&R / recovery and remediation completion pending	52.129444, 10.670922		160-189; 314-318; 319, 320; 329, 415, 417, 418, 420; 455, 456	52.129444	10.670922	490-800m
2.31	Gorleben: URF	Gorleben, Lower Saxony, Germany	BfS/DBE/BGR (Office for Radiation Protection, BfS, Bundesamt für Strahlenschutz; Company for the Construction and Operation of Waste Repositories, DBE; Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe)	SS (purpose built, site specific); >800 mbgl (840m/933m); ID shaft 7.5m; Shaft 1, ~930m bgl,10m or 11.5m DD, 7.5m ID; Shaft 2, 843mbgl; expected disposal of a range of waste types	Domed salt; Zechstein domal salt, Permian age deposit; Mesozoic and Cenozoic age growth of salt dome. Variscan "basement" terrain	Characterization; work on hold	Shafts 1985; Operations since 1997; considering as disposal site for HLW; development interrupted since 2012; pending implementation of site selection legislation and process; activities remain suspended	53.028,11.34922		160-189; 243, 314-318; 321-324; 334	53.028	11.34922	~800-930m

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2.32	Konrad: Repository / URL	Konrad, Salzgitter Bleckenstedt, Lower Saxony, Germany	BfS/DBE (Office for Radiation Protection, BfS; Company for the Construction and Operation of Waste Repositories, DBE, Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe)	S facility, site specific (test galleries in Fe mine); >800mbgl. Former iron mine; two shafts, 1232m and 999m; diam. both shafts 1,2 = 7m; widen to 12m; emplacement depth 800-1300 m; Shaft Konrad 1, drilled 1957-1960; depth 1232m. Shaft Konrad 2, 1962 to depth 999m; waste disposal consideration ~1975; LLW/ILW disposal; Groundwater age = 10^7 to 1.5 x 10^8 yrs. Iron ore mining ceased in 1976.	Shale; lmst overlain by shale; ore discovered in 1933; coral oolitic lmst; Late Jurassic Malm Oxfordian age for iron formation; sedimentary oolitic iron ore (Minette type), Gifhorner Trough, NW German Basin	CHM	Since 1980; Development; Licensed for LL/IL waste disposal; operations expected by 2019	52.184984, 10.402744		160-189; 314-318; 327-334	52.184984	10.402744	~800-1300m
2.33	Morsleben: ERAM	Morsleben: Borde District, State of Saxony-Anhalt, Germany	DBE/BfS (Office for Radiation Protection, BfS; Company for the Construction and Operation of Waste Repositories, DBE, Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe; Das Endlager für radioaktive Abfälle Morsleben / ERAM)	S/SS facility (test galleries in K/salt mine and repository for L/ILW 1981-1998); 320 and 630m bgl; 2 shafts, dug 1897 and 1914; Bartensleben salt mine, mined through 1960s. ERAM = Das Endlager für radioaktive Abfälle Morsleben; water seepage issues; decommissioned and planned closure	Domed salt; Zechstein, Allertal zone; Bartensleben salt mine; Permian age salt.	D / Decommissioned	Since 1971; 1971-1998 testing and emplacement; no waste emplacement since 1998; Decommissioned	52.223212, 11.101277		160-189 (185); 314-318; 320, 325, 326, 329	52.223212	11.101277	~320-630m

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2.34	Repository HLW site area TBD	Germany	Office for Radiation Protection (BfS); Company for the Construction and Operation of Waste Repositories (DBE); AkEnd expert group, site selection. DBE / BfS employees transitioning to BGE (Die Bundesgesellschaft für Endlagerung), 2017ff.	TBD	TBD; likely in salt, but other rock environments are considered		Site selection paused; had planned for site selection process redefinition in 2015; had planned site selection and underground studies to 2031		TBD	314-318;	TBD	TBD	NA
2.35	Pécs: URF, U mine, closed	Pécs, Hungary (mines are E/NE of Boda; 4-10km to W/NW of Pecs; area of the Mecsek U mine region)	PLC/RWM (RHK Kft) / PURAM (PURAM = Public Agency for Radioactive Waste Management) Public Limited Company for Radioactive Waste Management (Radioaktív Hulladékokat Kezelő Kft., RHK Kft), formerly PURAM	G/S/SS facility (galleries in U mine; Mecsek underground mine; sedimentary hosted U deposit, sandstone); Shaft #5, ~1000m bgl; subsurface mines exploit Permian sandstone U deposits. Mine closed in 1998; planning exploration and restart of U mining in Mecsek area; URL activities in Boda claystone through 1998, ~1050m bgl. Plan potential emplacement zone 500-1000m bgl in Boda clay with URL studies ~2030-2055; repository after 2055	Shale / Argillite; Boda claystone Formation, middle Permian, Mecsek Mts, Pannonian Basin; lacustrine / playa deposits; unit age ~265 my	Characterization work; area mine closure and remediation programs; possible exploration work for U in future; URL / Repository siting TBD in Boda Clay, Mecsec district near Buda; possibly to locate HLW repository in granitic rock, same region, planned opening 2060; URL planned for same area for ~2020+	1995–1999; government ceased support for URL in mine and operations terminated in 1999. Boda / Mecsec area identified for siting HLW repository in Boda claystone near Buda; start 2047, operations by 2060; URL 2020 or 2030; TBD (Note: Bataapati LLW repository located to east at ~46.218632, 18.610852); BCF URL by 2030	46.110374, 18.122978	Approximate area location only; mining area location is 46.110374,18.122978 ; Pecs City area is 46°04′16″N 18°13′59″E; historical mine document, possible location near village of Kovágószolos, 46.076476, 18.123010	160-189; 335-340; see 167a, 168a, 469e and notes	46.110374	18.122978	~1000m

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2.36	Bátaapáti: National Radioactive Waste Repository (ILW)	Bátaapáti, Tolna County, Hungary	PLC/RWM (RHK Kft) / PURAM (PURAM = Public Agency for Radioactive Waste Management) Public Limited Company for Radioactive Waste Management (Radioaktív Hulladékokat Kezelő Kft., RHK Kft), formerly PURAM	Repository, S-facility; L/ILW repository; Mecsek mines region; emplacement in "caverns" 200-250m bgl; NRWR / National Radioactive Waste Repository	Granite / crystalline; Moragy Granite Formation, Paleozoic age	2008, operations initiated; waste received for subsurface emplacement, 2012; inclined access ramp	2008 initiation of activities subsurface operations / construction; open alcoves in subsurface, 2012 receiving waste. Residents voted to approve in 2005	46.219099, 18.610097	Paks Power Plant location 46.574439, 18.849192; ~60 miles north. Pecs ~30+ km to SW of repository	160-189; 335-338; 341-345, 345a	46.219099	18.610097	~200-250m
2.37	Tono: mine	Tono (Tohno) mine, (Mizunami City), Gifu Prefecture, Chubu Region, Honshu Island, Japan	JAEA/JNC; Japan Atomic Energy Agency, Japan Nuclear Cycle Development Institute	G (galleries in FeCu Uranium mine; Tsukiyoshi uranium **ore** deposits); shaft was 150m bgl overburden, in 1991); three shafts access; Test shaft #2, 150m depth, 6m diameter shaft); close to Mizunami URL; largest U deposits in Japan, Miocene sediment host	Sandstone; Toki group / Mizunami Group; Tertiary / Neogene – Miocene; Neogene sediments rest on Cretaceous Toki granitic plutonic complex; reference 307; testing 1986-2003 in Tertiary sedimentary rock	CHM	Since 1986	35.38793,137.215505	Approximate Location city 35°22′N 137°15′E; see Mizunami URL; 35.366666, 137.25; JAEA map suggests Mizunami URL (MIU) at 35.378129,137.237906; JAEA map suggests this is Tono Mine 35.38793,137.215505	160-189; 278; 300-302; 306, 308	35.38793	137.215505	~150m

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2.38	Kamaishi: mine	Kamaishi, Iwate Prefecture, Tohoku Region, northern Honshu, Japan	JAEA/JNC (Japan Atomic Energy Agency, Japan Nuclear Cycle Development Institute)	G (galleries in closed Fe–Cu mine); 1000mbgl; main operations, testing are ~300 (260mbgl) and 700m bgl; old mine is ~500m deep; http://www.mindat.org/loc-12391.html, reference 279; (see also NUMO, Nuclear Waste Management Organization of Japan); HLW disposal investigations	Granite; crystalline; Kitakami Massif ; contact-metasomatic type deposit associated with Cretaceous granitic intrusion; Deposits formed along west flank of the Ganidake igneous complex; mineralized along skarn in Permian Limestone; mineralization Kurihashi granodiorite 95-111My; with Fracture fill 74-58Mya; problematic ages, complex alteration history. Mined Fe ore and Cu/Ag/Au	Characterization work; testing crystalline rock, 1988-1998;	1988–1998; Mine was closed in 1998	39.250000, 141.68333	Approximate area only: 1) Mine area approximate location 39.200000, 141.833333 for Kamaishi mine reported location paper ~39°12'N, 141°50’E ; 2) Other paper states 39°15', 141°41'E; 39.250000, 141.68333). Mindat.org location 39.3, 141.6833; https://www.mindat.org/loc-12391.html ; Former Kamaishi mine office at 39.286099, 141.714906 (google map). Location mine TBVerified	160-189; 278; 279-283; 308	39.25000	141.68333	~300-700m

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2.39	Mizunami: MIU/URL	Mizunami, (near Tono area, Gifu Prefecture, Honshu), Japan	JAEA / JNC and NUMO (Nuclear Waste Management Organization of Japan; Japan Nuclear Cycle Development Institute, Nuclear Waste Management Organization)	G/S (purpose built); Planned two 6.5m diam. shafts to1000m bgl; actual as built is 6.5m diameter main and 4.5m diameter ventilation shafts, 2/13/2015, ~500m deep each of 1000m planned. (2005, JNC and JAERI joined to form JAEA; JNC / Japanese Nuclear Cycle Development Institute ; Japanese Atomic Energy Research Institute / JAERI)	Granite; crystalline rock; Toki Granite of the Ryoke Granite Complex, ~97mya, Cretaceous age; granite pluton onlapped by Neogene Miocene (Toki Formation, Mizunami group) uraniferous sediments of Tono mine deposits; formation waters are "fresh"	Under development; JAEA; see Tono Mine; Reference 307; R&D galleries at 500m.	Planned URL under development, in 2012, at 500m level; since 2010, experiments conducted at 300m and 500m levels; testing in area since 1996; Shobasama site is located close to close to Mizunami site (`1.5km distance) and constitutes site location for basement drilling program. Four holes drilled to depths up to 1.5 km to examine hydrology of Tsukioshi Fault in granite basement	35.378129, 137.237906	JAEA map suggests Mizunami URL (MIU) construction site is as given on this map; Shobasama site, 35.384985, 137.223452, not shown on this map	160-189; 278; 291-299; 303-308	35.378129	137.237906	~500-1000m
2.40	Horonobe: URL	Horonobe, Hokkaido, Japan	JAEA/ JNC; Japan Atomic Energy Agency (JAEA) and NUMO (Nuclear Waste Management Organization of Japan)	G/S (purpose built); three (up to) 500m deep shafts planned; initial shaft 350-meter (1,150-foot); tunnels at depth 250, 350, 500m test zones planned; 1000m borehole drilled in 2004 (HDB-11)	Sedimentary rocks; argillite; Neogene Koetoi and Wakkanai Fm., diatomaceous and siliceous mudstone; formation waters are "saline"	2001; Under development; R&D galleries operating at 350m, in ~2014.	URL testing start in 2014; construction start 2003; Surface testing start 1999	45.044578, 141.860361	Near center of Horonobe town = 45°1′N, 141°51′E; Approximate location of proposed URL in JAEA 2005 report	160-189; 278; 287-290; 308	45.044578	141.860361	~350-500m

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2.41	Repository siting TBD	Japan	JAEA, Japan Atomic Energy Agency and NUMO (Nuclear Waste Management Organization of Japan)	TBD; site selection ~2030	Seem to favor granite / crystalline host for repository; Argillite also possible; TBD	TBD	Repository siting TBD; seek volunteer communities; no interest expressed; JAEA seeking alternative approach to siting		TBD	278; 167a, 168a	TBD	TBD	NA
2.42	KURT: URL	Daejeon, Yuseong Gu area of city, Korea (ROK); within KAERI property, Yusung Gu area, Deajeon, Republic of Korea	KAERI / KRMC; KAERI Underground Research Tunnel (KURT); Korea Atomic Energy Research Institute (KAERI)	Generic, S; 80-90m overburden; tunnel, approx. 6mx6m tunnel; tunnels of 255m and 180m with test alcoves; expansion planned; also with associated 1km deep borehole for testing; see Birkholzer, 2014, Reference 168 herein	Crystalline; granite; Mesozoic age, (two mica granite; Permian, ~232~228 Ma)	TCHM	2005 / 2006 tunnel constructed; Testing URL; has 1km deep borehole for testing	36.424339, 127.363515		160-189; 167, 168; 309-313	36.424339	127.363515	~80-90m
2.43	Repository siting process	Republic of Korea	KAERI / KRMC	TBD	URL; investigating granite / crystalline and sedimentary / argillite; considered partnering for storage and disposal with South Australia, TBD	TBD	Repository siting TBD		TBD	309-313; 469, 469a, 469b, 469c, 469d	TBD	TBD	NA

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2.44	Yeniseisky: site area URL Planned (~Yesensky plot)	Zheleznogorsk / Shelezno gorsk (Krasnoyarsk Krai region), Yeniseisky District, Russian Federation	National Operator for Radioactive Waste Management (NO RAO) NO RAO government agency reported it had chosen the Nizhnekansky Rock Mass in the Krasnoyarsk Region of Central Siberia as the site for the lab and eventual long term underground storage / repository; URL would open in 2024; Yenisei ridge Kan river basin	SS: Planned ~500m depth (sources also indicate 450-535m and 550m planned (2013); Phased development to serve as basis for repository site selection later; NO RAO government agency reported it had chosen the Nizhnekansky Rock Mass in the Krasnoyarsk Region of Central Siberia as the site for the lab and eventual long term underground storage / repository; URL would open in 2024; Yenisei ridge Kan river basin; See other sites identified in Niz Granite Massif area: Yuzhny, Verkhne-Itatsky, Nizhne-Itatsky Telsky and Yeniseisky; Also: Kamenny site; Chelyabinsk region, Mayak; see below; References 361, 362. Located 7 km from MCC (Mining and Chemical Combine) MCC K-26 site. Has public approval / support; near Altay-Sayan Orogenic area, West-Siberian / Siberian Platform contact zone	Granite / crystalline; Nizhnekansky granitoid rock massif; Biotite granites, granodiorites; Yeniseisky site = Proterozoic/ Archeozoic basement complex / gneiss/schist and granitoid bodies >1.8Ga; intruded later by granitoids 470-850mya. Gneiss most common at site	Early construction phase anticipated	Construction phase URL and operational by 2020; testing; borehole in 2004; planned URL ~500m bgl; TBD	56.338241, 93.659369	Located east of City of Krasnoyarsk 56°01′N 93°04′E ; Area is located to SE of the Town of Zheleznogorsk 56°15′00″N, 93°32′00″E; 56.252697,93.565407. Approximate area only; not exact site area 56°15′00″N 93°32′00″E; or N56.331766, E93.543091; clustered in area. Located 7 km from MCC (Mining and Chemical Combine) MCC K-26 site.	160-189; 354-364, 364a; 467, 468	56.338241	93.659369	NA; ~500m (planned)

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2.45	Yuzhny: Once considered URL / repository site area	Krasnoyarsk Region, Central Siberia, Russian Federation	National Operator for Radioactive Waste Management (NO RAO) since 2012	Nizhnekansky Granite Massif area (~500m planned)	Granite / crystalline	Characterization pre-2000; ceased activities; never considered by NORAO as potential site		56.252697, 93.565407	Located to east of indicated site; clustered in area; verify location	See Yeniseisky site area	56.252697	93.565407	NA; ~500m (planned)
2.46	Verkhne-Itatsky: Once considered URL / repository site area	Krasnoyarsk Region, Central Siberia, Russian Federation	National Operator for Radioactive Waste Management (NO RAO) since 2012	Nizhnekansky Granite Massif area (~500m planned)	Granite / crystalline	Characterization pre-2000; ceased activities; never considered by NORAO as potential site		56.252697, 93.565407	Located to east of indicated site; clustered in area; need to verify location	See Yeniseisky site area	56.252697	93.565407	NA; ~500m (planned)
2.47	Nizhne-Itatsky, Telsky: Once considered URL / repository site areas	Krasnoyarsk Region, Central Siberia, Russian Federation	National Operator for Radioactive Waste Management (NO RAO) since 2012	Nizhnekansky Granite Massif area (~500m planned)	Granite / crystalline	Characterization pre-2000; ceased activities; never considered by NORAO as potential site		56.193032, 93.992145	Itatskiy Site , Beryozovsky District, Krasnoyarsk Krai, Russia; verify location	See Yeniseisky site area	56.193032	93.992145	NA; ~500m (planned)
2.48	Kamenny: Once considered URL / candidate repository site area	Uyarsky District, Krasnoyarsk Krai Region, Central Siberia, Russian Federation	National Operator for Radioactive Waste Management (NO RAO) since 2012	Nizhnekansky Granite Massif area; near Altay-Sayan Orogenic area, West-Siberian/Siberian Platform contact zone (~500m planned)	Granite / crystalline	Characterization pre-2000; ceased activities; never considered by NORAO as potential site		56.141345, 94.001318	Verify location	See Yeniseisky site area	56.141345	94.001318	NA; ~500m (planned)

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2.49	PA Mayak: Once considered disposal site areas	Chelyabinsk region, Mayak PA, Russian Federation	National Operator for Radioactive Waste Management (NO RAO since 2012); VNIPIpromtehnologii (VNIPIPT)	TBD; Production Association “Mayak” (PA ‘Mayak”), a chemical group, Urals. Large nuclear facility. Planned depth and other details not provided	Granite / crystalline; and upper sequence of volcanic sedimentary; complexes of metamorphic and igneous rocks and several intrusive rock massifs proximal to PA Mayak site areas. Associated mixed lithologies, Paleozoic / Mesozoic sedimentary basin deposits	Characterization pre-2000; ceased activities; drilled deep boreholes, encountered GW contamination in area; never considered by NORAO as potential site		55.7125,60.848056	No precise locations for sites; northwest of Chelyabinsk toward southern Urals; Location of Chelyabinsk 55.154722,61.375833; Mayak production Association site 55.7125,60.848056 (Wikipedia and Google map), fissile material storage facility area	355, 362, 363	55.7125	60.848056	NA
2.50	Yeniseisky: site /~Yesensky plot; Expected Repository area	Zheleznogorsk (Krasnoyarsk Krai region), Yeniseisky District, Russian Federation	National Operator for Radioactive Waste Management (NO RAO)	450-535m bgl planned for URL and or repository; NO RAO government agency reported it had chosen the Nizhnekansky Rock Mass in the Krasnoyarsk Region of Central Siberia as the site for the lab and eventual long term underground storage / repository; priority site; near Altay-Sayan Orogenic area, West-Siberian/Siberian Platform contact zone	Granite / crystalline; Nizhnekansky Rock Massif; Biotite granites, granodiorites; Yeniseisky site = Proterozoic /Archeozoic basement complex / gneiss/schist and granitoid bodies; intruded later by granitoids 470-850mya.	Characterization; focus of study for repository and URL	Since 2004; repository TBD; expected repository operations by 2035 if URL testing warrants	56.338241, 93.659369	Area proximal; 56°15′00″N 93°32′00″E ; N56.331766, E93.543091; 7-10 km from MCC; alternate estimate is Yeniseisky 56.280516, 93.661598	160-189; 354-364, 364a; 467,468	56.338241	93.659369	NA; ~500m (planned)

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2.51	El Berrocal: U mine test site	North of Town of Nombela, Toledo Province, Castile-LaMancha, Spain	ENRESA (Empresa Nacional de Residuos Radiactivos S.A.)	In 1960s, Spain conducted underground studies El Berrocal uranium mine; 1991-1995, natural analog studies in access gallery, ENRESA and others; ~70m bgl along access gallery; for additional analog studies, see reference 188a	Granite / crystalline; El Berrocal uranium mine is within uranium-bearing quartz vein deposit, Paleozoic granite, 297mya); Sistema Central, Spanish Hercynian Massif; El Berrocal granite intrudes Hercynian age granodiorites.	HC	Area studied in 1960s and later by ENRESA and EU international group in late 1980s-mid-1990s; opposition from local population in 1990s; detailed studies reduced. Fractured conductive granitic rock	40.189198, -4.522797	Approximate area location is North of Town of Nombela (40.157623,-4.503021); verify location	160-189; 366-369; 188a	40.189198	-4.522797	~70m
2.52	TBD URL and repository siting	Spain	Empresa Nacional de Residuos Radiactivos, S.A (ENRESA)	No URL facility; no repository site studies; planned 500m depth bgl for repository. Spain participates in international program URL studies. Inventory of Regional areas for HLW disposal studies and repository; several potential sites identified for investigation; URL and Repository siting TBD	Granite / crystalline, clay / argillite, salt; rock under consideration; investigations through international studies, existing URLs. No repository or URL specific site, TBD	TBD	TBD; plan operational repository by ~2050; Note: VLLW and LILW disposed at the El Cabril disposal center since 1992, northwest province of Córdoba, municipal district of Hornachuelos; in 2011, Villar de Canas in Cuenca had been selected as SNF storage facility site		TBD	366-369	TBD	TBD	NA

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2.53	Stripa: mine, analog disposal study	Stripa; Orebro County; (in Bergslagen mining district) near the Guldsmedshyltan region, Sweden	SKB (Swedish Nuclear Fuel Supply Company; Svensk Kärnbränslehanteringwith OECD/NEA)	G (galleries in Fe mine; Stripa Mine Project); 310-460m bgl; many tests @~360m bgl	Granite / crystalline; Stripa Granite; Banded hematite ore, leptite, high grade meta-volcanic rock and metasediments intruded by granitic plutons, qtz monzonite masses, 1.7Ga; Precambrian; Central Swedish Ore Province	TCHM	1976–1992	59.708324, 15.098277	59°42'30.0"N 15°05'53.8"E; approximate area location given	378-380, 380a	59.708324	15.098277	~300-460m
2.54	Äspö: URL / HRL (Hard Rock Laboratory)	Äspö HRL/URL is near Simpevarp, Oskarshamn, Kalmar County, Sweden	SKB (Svensk Kärnbränslehantering = Swedish Nuclear Fuel and Waste Management Company)	G/S (purpose built); 450m – 500m bgl; URL: 3.6km tunnel; 5m diameter TBM used to excavate tunnel. Note: on small island	Granite; Äspö diorite / Ävrö granodiorite, other; Precambrian, 1.85-1.9Ga; HRL also reported to be within Smaland granite – granodiorite pluton, 1.750 Ga (Laverov et al., 2008, ref. 188). Äspö HRL is constructed in granitoids of the Transscandinavian Igneous Belt	TCHMD	Since 1990; HRL, 1995; Ground water residence times vary; no meteoric water below 200m; residence times likely 10s to 100s thousands years	57.43291, 16.66128	Oskarshamn, Location is 57°15′54″N 16°27′00″E ; in Misterhult Archipelago near Oskarshamn nuclear power plant	160-189; 372-377	57.43291	16.66128	~450-500m

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2.55	Forsmark: Repository site area	Osthammar / Södervik en, near Forsmark, Uppsala County, northern Uppsala, Sweden	SKB (Svensk Kärnbränslehantering = Swedish Nuclear Fuel and Waste Management Company)	Repository: SNF; plan Spiral tunnel of 5km, 5m diameter, 500m depth. (The HLW disposal site was selected to be near Forsmark in Östhammar municipality located to east / southeast of power plant). Note: The (SFR) Final Repository for Short-Lived Radioactive Waste is located at Forsmark in the municipality of Östhammar @~50m bsl.	Granite / crystalline; dominated by metagranite to 1000m; granitic and metamorphic rock suite Age = 1.9Ga; Fennoscandian shield		Repository: Osthammer site selected by SKB in 2009; estimate 2023- 2029 to open; site investigations 2002-2007, trial drilling in Östhammar and Oskarshamn; preference for Forsmark's Östhammar; construction operations expected ~2020; operational repository 2030s; includes location public / affirmative voluntary host responses	60.394438, 18.211212	Near Forsmark; Forsmark = 60.374842N, 18.155251E; Approximate Location: Osthammer 60°16′N, 18°22′E, 60.266667 N, 18.366667 E; Forsmark Power Plant location 60° 24′ 12″ N, 18° 10′ 0″ E; 60.403333, 18.166667; SFR located ~60.409562, 18.208933	160-189; 370-372; 381-384	60.394438	18.211212	~500m
2.56	Grimsel: GTS / Grimsel Test Site URL	Grimsel, Canton Bern, Aar Massif, Grimsel region, Switzerland	NAGRA (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle / National Cooperative for the Disposal of Radioactive Waste)	G (dam tunnel access); 450m to 500m overburden; dam works associated; tunnel diam 3.5-2.3m; access tunnel of the Oberhasli AG hydropower plant; Grimsel Test Site	Granite; crystalline; Grimsel Granodiorite; Aar Massif granites (Variscan), ~300Ma, with 40 and 16Ma deformation	TCHM	Since 1983/84 URL	46.584028, 8.321556	Approximate location, Grimsel URL, 46°35'02.5"N 8°19'17.6"E; also estimated at 46.576602, 8.333629	160-189; 385-391; 396-398	46.584028	8.321556	450-500m

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2.57	Mont Terri URL	Mont Terri, Jura Canton, St-Ursanne, Switzerland	Swiss topo/ NAGRA (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle)	G (highway tunnel access and test galleries), purpose built; >300m-400m overburden; early testing ~250m -320m average bgl; Adjacent to Transjuranne motorway tunnel	Shale / argillite; Opalinus Clay; Folded Jura Mountains; Alpine overthrust fold formed 3-12 Mya; Host rock Age: (Aalenian), Jurassic ~180 Mya; Opalinus clay name derived from ammonite fossil contained in rock, *Leioceras opalinum*	TCHM	Since 1995/96	47.377604, 7.16609	St-Ursanne; 47.365746,7.157764; note difference in map locations of tunnel from source illustrated location (Bossart, 2009, References 392-395); alternate expression 47°22'39.4"N 7°09'57.9"E	160-189; 268; 336; 385-395	47.377604	7.16609	250-400m
2.58	Jura Ost area: Potential HLW Repository site areas	Switzerland	Swisstopo and NAGRA / Nationale Genossenschaft für die Lagerung radioaktiver Abfälle	TBD; 3 regions identified candidate areas are (Benken, Zürcher Weinland; Bözberg; North Lägeren areas); site selection in process projected 2 sites in downselect by 2014 (Zurich nordost, north of Lagern, and Jura Ost areas); host unit to be similar to opalinous clay or HLW disposal in Opalinus clay-like units expected	Shale / argillite; Opalinus Clay; Jurassic; Mt. Terri analog geology	Site investigations; Repository siting analysis 2006-2015; 4-5 potential site areas examined; 2 site areas selected in 2015; TBD	Repository Site Selection for two types repositories; TBD; operational HLW repository facility planned for after ~2060; LLW repository possible in 2050. At minimum, Jura Ost and Zürich Nordost selected for further consideration of 6 areas examined. Examining for HLW/I/LLW in both areas	47.490075, 8.146043	Potential areas of interest NE/SW trend N of Zurich; Zürich Nordost, ~ 47.639108, 8.647899, and Jura Ost ~ 47.490075, 8.146043; approximate example location only, Jura Ost. Alternate Jura Nordost area location ~47.629323, 8.645045	385-391; 167a, 168a	47.490075	8.146043	NA

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2.59	Repository Siting TBD	Taiwan	AEC (Atomic Energy Council, Radwaste Administration) / Taipower (TPC)	TBD	Granite / crystalline likely for selection; Mesozoic	Regional work 2005-2017; plan preliminary and detailed site studies, licensing, 2017-2044; current investigations ongoing at Kinmen Island (24.451838,118.375969)	Planned operational HLW repository by ~2055 for direct disposal in geologic facility; also used fuel disposal and or reprocessing abroad is considered; currently two dry storage facilities house spent fuel		TBD	399-403	TBD	TBD	NA
2.60	RCF: URF	Sellafield area, United Kingdom	NDA (Nuclear Decommissioning Authority) / NWMO, Radioactive Waste Management Division (NWMO/RWMD, formerly NIREX); NWMO, Nuclear Waste Management Authority	S; RCF = "Rock Characterisation Facility"; 100 m South from Longlands Farm (BNF property); LLW/ILW/~TrU; planned 650-900m depth for activities. Information / data available from wells drilled in Sellafield (in Cumbria, NW England) and Dounreay (in Caithness, NE Scotland) areas by Nirex; Preferred site was Cumbria site, Longlands Farm (BNF property, Gosforth Cumbria), near Sellafield for RCF. RCF underground facility never developed beyond planning and surface study.	Tuff / volcanics; Cumbrian "basement" is Borrowdale Volcanic Group; Ordovician (~450Mya)	Characterization conducted; project ceased; currently, National geological screening exercise is ongoing; 2008, reference 406 ; no active URF in UK	Project stopped in 1997. Never went to a construction phase. Study of area continued post-1998 with repository site identification efforts, but ceased again in 2013 with Cumbria Council withdrawal of support for repository in Cumbria area	54.425661, -3.467133	Cumbria, Sellafield works area, approximate Location: 54.425671, -3.506098; 54.4205°N 3.4975°W. Possible repository or RCF zone located a few km to east of Sellafield works and west of Gosforth (1997). Dounreay in Caithness, NE Scotland, 58.578084, -3.747044	160-189; 404-408; 409-410	54.425661	-3.467133	NA; planned ~650-900m

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2.61	Repository siting exercise UK	United Kingdom	NDA / Nuclear Decommissioning Authority; subsidiary Radioactive Waste Management LtdRWM /	TBD	TBD	Currently, National geological site screening exercise; follows final Cumbria withdrawal as potential geologic disposal location in 2013; process definition, site selection TBD; Reference 406	Repository siting TBD; stalled; 2008 white paper, Reference 406; generic studies, multiple rock environments; Sellafield area zone siting work ceased again in 2013 with Cumbria Council withdrawal of support for area repository		TBD	404-408	TBD	TBD	NA
2.62	Climax: Climax Spent Fuel Test / CSFT (SFT)	NNSS / NTS: Nevada National Security Site (Nevada Test Site); Climax Spent Fuel Test, Nye County, NV, USA	DOE	G (galleries in mined feature created for weapons tests in 1960s); 420 mbgl, shaft access; Piledriver and 2 other underground nuclear tests (1960s) in granitic rock; shaft and borehole drilled for testing and emplacement of fuel (.61 and .76m diameter) for spent fuel test = SFT. Made use of Piledriver tunnels for SNF test, access. Closed facility.	Granite; granodiorite / quart monzonite; Cretaceous Climax intrusion into Paleozoic and older rock	(TCHM)RD; emplacement and thermal test with spent fuel	1978–1983 (Climax Spent Fuel Test / Project) and to 1987; facility operations terminated / closed; original 1960s nuclear weapons test complex, examined thermal / mechanical effects on granite from event; SNF test demonstration and later thermal testing; supporting granitic repository study by DOE (discussed and detailed under deep borehole and weapons testing, Plowshares program. A drilling engineering example	37.22352, -116.05895	Ref. 423 presents discussion of 12 crystalline sites considered viable candidates (in 1996) for investigation in the future, possibly for second repository	160-189; 423, 427-434, 449; 469d; 553, 553a, 559g, 603	37.22352	-116.05895	420m

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2.63	G-Tunnel	NNSS / NTS: Nevada National Security Site (Nevada Test Site), Nye County, Nevada, USA	DOE / OCRWM: U.S. Department of Energy, Office of Civilian Radioactive Waste Management	G (tunnel); ~300m bgl	Tuff; Miocene; Rainier Mesa area	THM	1979–1990; Discontinued work; analog studies supporting Yucca Mountain investigation, disposal in bedded tuff; note that early hydro-mechanical studies were conducted concurrently at Edgar Mine, Idaho Springs, CO, involving SNL and CSM studies for OCRWM, EDZ study for shafts, 1980, because YM site design plans required input; G-tunnel and CSM facility served as surrogate sites generating information on mechanical damage from construction; e.g., drill and blast; impact on rock properties; other)	37.173859,-116.199903	Approximate Location: N37º 10’,W116º11’ 30”. Approximate location of Edgar Mine, ~ 39.747284,-105.525328	160-189; 434a, 469d	37.173859	-116.199903	~300m

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2.64	Lyons: KS, Carey Salt Mine URL; Project Salt Vault	Lyons, Rice County, Kansas, USA	AEC/DOE	G (galleries in mine); Test ~300m, and up to ~1000'bgl; 1964 AEC Shaft depth 1024'/1060'. The Lyons Carey salt mine shaft hand dug 1889-1890 at 7' X 16'; total depth 1083.5'. Testing was also conducted in Carey salt mine, Hutchinson, Kansas; that along with Lyons mine were pre-salt vault underground testing locations. The Hutchinson Carey Mine (aka - Strataca) is in Reno County, KS at ~ 650'bgl; currently mine is museum, business storage for non-nuclear materials. Lyons Carey mine closed and area restored.	Bedded salt; Hutchinson Salt Member of the Wellington Formation, Sumner Group, Permian System; formed along northern shelf of the Anadarko basin	TM	1965–1968; 1970s Test facility with 19" diameter shaft for waste / assemblies; project terminated. URL and once potential repository site, 1960s; URL and SNF demonstration. Pre-Project Salt Vault and Project Salt Vault studies; shaft filled / remediated; Lyons site (salt Vault 1965-67) and Hutchinson Carey mine (pre-1965) both utilized in Project Salt Vault studies; Spent Fuel Test at Lyons salt mine location, 1965-1967. In 1971, directed by Congress to terminate project	38.355876,-98.193312	Approximate Town Location: Lyons 38°20′42″N , 98°12′9″W; Lyons Carey Salt mine location from K Kuhlman 38°21'20.32"N , 98°11'35.91"W; Hutchinson Carey salt mine location ~38°02′37″N 97°52′03″W, 38.0439,-97.867541; verify Salt Vault shaft location	160-189; 171-173; 415-417; 418-426, 438; 455, 456	38.355876	-98.193312	~300m

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2.65	WIPP: TRU Repository	Carlsbad, Eddy County, New Mexico, USA	DOE; Nuclear Waste Partnership LLC	SS (TRU repository and URL; Waste Isolation Pilot Plant); 655m bgl; (671m) deep shaft; ~2150'bgl; Waste Isolation Pilot Plant, TRU waste disposal; 1580 mwe. Also see Project Gnome, nuclear weapon test in Solado salt units, depth 361m bgl; references 425, 426	Bedded salt; Permian Salado Fm, Delaware Basin	TCHMRD	Since 1982; 1982-1989, main construction phase. Exhaust shaft is 14' diameter in lined portion, ~15' in unlined portion after enlargement of 6'diam raise bore shaft. Explor shaft was blind sunk 12'diameter. Four shafts at WIPP: 1) Salt Shaft drilled 1981 with nominal ID to 880' of 10'; 880'-2298' nominal diameter of 12'; 2) Waste Shaft, 6' diameter drilled '81/'82 and enlarged '83/'84 to diameter of 20-23' with 19' ID liner to 837'bgl; 900'-2286' ID of 23'; 3) Exhaust Shaft, drilled '83/'84, diameter from ~900'- 2150' / 655m is 15'; and 4) Air Intake Shaft, drilled '87/'88 to depth 903' with diameter of 16'; 903'-2150' diameter of 20'.}; operating TRU facility, 1999; August, 2014, operations on hold until ~ late 2016; planned thermal test effects on salt; accepting waste again in 2017	32.371667, -103.793611	Approximate WIPP Location: 32°22′18″N 103°47′37″W; Project Gnome location ~ 32.262500, -103.865306. For WIPP, also see Item 4.22, Table 4, herein	160-189; 170; 172; 174; 415-417; 423; 425, 426; 435-440; compare with 460-466	32.371667	-103.793611	~655m

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2.66	Busted Butte: URL	Yucca Mountain, Nye County, Nevada, USA	DOE / OCRWM: U.S. Department of Energy, Office of Civilian Radioactive Waste Management	S (purpose built); ~50 - 70m overburden	Tuffs; Calico Hills, non-welded tuff; Miocene	CHM	Open 1997; walk-in tunnel access; operations to 2000; Suspended all operations at YM in 2010	36.777874,-116.418772			36.777874	-116.418772	~50-70m
2.67	Yucca Mountain: YM Repos. site, ESF and ECRB URL	Yucca Mountain, Nye County, Nevada, USA	DOE / OCRWM: U.S. Department of Energy, Office of Civilian Radioactive Waste Management	S/SS; once designated repository and operational URL ~1995-2010; depth ~1000', 300m below ground level; access ramps (25' diameter inclined access ramps and N/S drift); ECRB cross drift, 15' diameter. Ventilation shafts planned. Includes ESF Exploration Studies Facility with ~12km of ramps, tunnels / drifts, alcoves, niches, (~0-300m+ overburden; ~1000' bgl)	Welded Tuffs, Topopah Springs as host sequence; Miocene age; South flank Timber Mountain Caldera complex. ESF / Tunnel also encounters non-welded units	THMCD; Licensing, performance confirmation suspended in 2010	1993-2010 underground operations; suspended since 2010; project terminated. (United States Site selection TBD); One of three USA candidate sites selected for characterization for first repository in 1986, and only site identified for characterization post 1987 in accordance with NWPA AA, 1987; termination of project studies in 2010; "not a workable option"; in 2017, reconsideration of decision pending	36.852778, -116.426667	Approximate location: 36°51′10″N 116°25′36″W	160-189; 171; 243; 306; 374; 441-443; 450; 457; 460;	36.852778	-116.426667	~300m

2.68	Avery Island: salt test area	Avery Island, Iberia Parish, New Iberia, Louisiana, USA	Cargill Salt Mine; testing by DOE; boreholes	G (Shaft access), ~550', 168m below mean sea level	Salt dome; analog for 8 Gulf Coast area salt domes DOE examined in the 1970s/1980s; 3 in TX (Oakwood, Freestone /Leon County; Palestine and Keechi, Anderson County); 2 in Louisiana (Vacherie, Webster/Bienville Parish line; Rayburn's, Bienville Parish); and 3 domes in Mississippi (Lampton, Marion County; Cypress Creek and Richton, Perry County); 1 salt dome in LA and two domes in Mississippi (Vacherie Dome, LA; Cypress Creek and Richton Domes, MS) identified for further work; 1986, DOE down-selected to characterize 3 candidate sites, Yucca Mountain (Tuff), Hanford (basalt), and Deaf Smith County (bedded salt) site.	THM in boreholes and TH testing at 500' level in mine ; Neogene sediments of Gulf Coast flanking salt dome diapiric structure; salt reportedly is Triassic/Jurassic age LouAnn Salt; in situ heater tests. Performed (starting 1978) long-duration (1858 days) heated borehole studies (up to 9.6 kW), brine migration experiments (including deuterium-marked tracer studies), gas permeability studies of heated salt, and accelerated borehole closure (corejacking) tests.	1978-1983	29.893891, -91.910105	Approximate locations for Gulf Coast 8 domes examined by DOE: USGS, WRI90-4060, 1990, Table 2: Rayburn (32.24, -92.93); Vacherie (32.46, -93.18); Cypress Creek (31.14, -88.96); Lampton (31.22, -89.72); Richton (31.36, -88.95); Keechi (31.85, -95.70); Oakwood (31.56, -95.95); Palestine (31.74, -95.73); Reference 461	160-189; 172-174; 415-417; 455, 456. Siting in salt, pre-1987, reference 457-466; US crystalline program, 1980s, ref. 449-450; US salt sites, ref. 451-457; general status, repositories and siting, ref. 460-466	29.893891	-91.910105	~168m

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2.69	Davis Canyon: formerly considered salt repository Site	Davis Canyon Site, San Juan County, Utah, USA	DOE / OCRWM: U.S. Department of Energy, Office of Civilian Radioactive Waste Management	~890m+ (planned)	"Bedded" Salt: Pennsylvanian / Permian age; Paradox Basin; Davis site is near Lavender Canyon site; both located on salt anticlinal structure in basin; Gibson Dome area; target depth to salt ~890m bgl planned		Considered by DOE as possible salt repository location, but not one of final 3 sites selected by DOE in 1986 before 1987 NWPA AA.	38.095440, -109.656747	Approximate locations only; Lavender Canyon 38.060848, -109.638595; approximate location Davis Canyon 38.095440, -109.656747; >40 miles south of Moab, Utah; alternate reference indicates 38.11268,-109.654198 for Davis site	160-189; 171, 174, 417, 443, 450, 451, 457; 461	38.095440	-109.656747	NA; ~890m+ (planned)

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2.70	BWIP: aka, RRL / BWIP: Reference Repository Location / Basalt Waste Isolation Project; former candidate site area	Benton County, Washington (State), USA	DOE (National Waste Terminal Storage Program)	DOE Hanford Site property; known earlier as BWIP, 1976-1982, then as the RRL / Reference Repository Location on the Hanford site (1982-1986); 1982, planned large diameter exploratory shaft to be drilled to 1158m with diameter of 2.8m for the RRL; starter shaft depth only to 30'; operation ceased; 2 test boreholes planned to be drilled, but all activities terminated in accordance with NWPA AA 1987.	Basalt; volcanic units; Pasco Basin, Cold Creek Syncline, Columbia Plateau; underlain by deformed "basement" of the Yakima fold belt; Gable Mountain, surface test facility; ESF subsurface test areas to southwest; Columbia River Basalt group (6-17mya) subsurface Miocene Cohasset Formation as primary host unit and others of the Grande Ronde Basalt		1982-1986, Reference Repository Location; BWIP early studies, 1976-1982; identified and approved for detailed characterization in 1986, but stopped with passage of 1987 NWPA AA that directed DOE to terminate all BWIP activities within 90 days after December 22, 1987. One of three USA candidate sites selected for characterization for first repository	46.546305, -119.665858	Gable Mountain near surface test facility; 46.60601,-119.538138. Reference Repository location and Exploratory Shaft ~ 46.546305, -119.665858; field investigations conducted near 46.60601,-119.538138	160-189; 171, 417, 443; 444-448; 450; 457, 460	46.546305	-119.665858	NA; 1158m (planned)

Table #. Item #	Facility / Site Name / Candidate Site Name	Location, Country	Operator /Responsible Org.	Facility Type (Generic/ G; Purpose built / S; Site Specific / SS), Access, Depth (shaft or overburden);	Host Rock / Geologic Information	Nature Of Experiments (References 160-167)	Period of Testing, Operations, Expected Repository Start (References 160-167)	Latitude / Longitude	Alternative Location information	References	Approx. Latitude	Approx. Longitude	Depth (meters bgl); simplified
2.71	Deaf Smith: former candidate salt site area	Deaf Smith County, Texas, USA	DOE / OCRWM: U.S. Department of Energy, Office of Civilian Radioactive Waste Management	Studies did not progress beyond laboratory testing of core; planned ESF (depth ~2500' , 760m bgl), but activities terminated with 1987 NWPA AA (as Amended, Nuclear Waste Policy Act, 1987); identified and approved for detailed characterization in 1986, but stopped with passage of 1987 NWPA AA. Deaf Smith site and others were dropped from further consideration; Yucca Mountain was identified for characterization as the only candidate site for a high level waste repository (one of three USA candidate sites selected for characterization for first repository)	Bedded Salt; Palo Duro Basin / Permian Basin, Permian salt of the San Andreas Formation		1983, DOE identified 9 sites in 6 states (Yucca Mountain, NV; Hanford site, WA; Deaf Smith and Swisher sites, TX; Davis and Lavender Canyons, UT; Vacherie Dome, LA; Cypress Creek and Richton Domes, MS) that were judged potentially acceptable for a first repository. DOE nominated 5 sites as suitable for detailed characterization in 1984 (draft EAs for Yucca Mt., NV; Hanford, WA; Richton Salt Dome, MS; Deaf Smith, TX; Davis Canyon, UT) with publication of recommendation for site nominations in 1986 EAs; DOE Secretary nominated and President approved 3 candidate sites for further detailed characterization (Yucca, Hanford, Deaf Smith) but Deaf Smith and Hanford were dropped from further consideration with passage of Amended Nuclear Waste Policy Act (1987) that identified only Yucca Mountain as the only candidate site for a high level waste repository.	35.095171, -102.480092	Swisher County site approximate location is 34° 38' N latitude and 101° 42' W longitude (34.633333, -101.700000); Swisher County site also considered earlier in evaluations, but Deaf Smith Co. site was only TX candidate area identified for detailed evaluation and characterization in 1986.	160-189; 171, 174, 415, 417, 444-448, 450; 457-462	35.095171	-102.480092	NA; ~760m (planned)

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2.72	Bulgaria: HLW / ILW Repository siting	Bulgaria; five informally considered sites (2016)	State Enterprise Radioactive Waste (SE RAW)	Planning HLW/ILW repository, geologic disposal; 5 potential site areas considered in preliminary informal studies; see below; possible approximate maximum depth estimate recorded in right column for each site. Sites from reference 167a	Argillite: Clays and / or marls expected host unit	TBD; no ongoing official studies for HLW disposal; conducting simple feasibility assessments; current focus LILRW site area, Radiana site, the same area as Kozloduy	TBD		See potential site areas below	167a, 168a; 469e; 469f; general references are 160-189			
2.73	Varbitza	Near municipality of Varbitza, east of Vratsa, Vraca Province, Bulgaria	State Enterprise Radioactive Waste (SE RAW)	Informally considered repository site area location. ~350-500m bgl;	Argillite: Lower Cretaceous, Aptian, clayey marl of Sumer Formation	TBD	TBD	43.268656 23.874436	Approximate area location of site area; Varbitza Vratza Bulgaria 43.274879, 23.845438. Actual site near Vratza; better verify location	167a, 168a; 469e; 469f; general references are 160-189	43.000478	26.663448	~350-500m bgl;
2.74	Kozloduy	Near municipality of Kozloduy, Vratsa Province, Bulgaria	State Enterprise Radioactive Waste (SE RAW)	Potential repository site area location. ~300-500m depth; related to Radiana site study (LILRW); Radiana site approximate location 43.736714, 23.773496	Argillite: Miocene clay of the Smirnenski and Krivodol Formations	TBD; current focus is LILRW site area, Radiana site, the same area as Kozloduy	TBD	43.736714, 23.773496	Approximate area location; Associated with Radiana site area identified for disposal LILRW; see http://www.wmsym.org/archives/2014/papers/14291.pdf	167a, 168a; 469e; 469f; general references are 160-189	43.7367	23.7735	~300-500m depth

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2.75	Dekov	Near Dekov municipality of Dekov, Pleven Province, Bulgaria	State Enterprise Radioactive Waste (SE RAW)	Potential repository site area location. 300-500m bgl	Argillite: Aptian, Lower Cretaceous marl of Trumbesh Formation	TBD	TBD	43.602601, 25.108362	Approximate area location of municipality	167a, 168a; 469e	43.602601	25.108362	~300-500m bgl
2.76	Komarevo	Near municipality of Komarevo, Pleven Province, Bulgaria	State Enterprise Radioactive Waste (SE RAW)	Potential repository site area location. ~350-620m bgl; marls 300-1000m depth, host ~350m-620m depth	Argillite: Aptian, Lower Cretaceous marl of Trumbesh Formation;	TBD	TBD	43.584347, 24.622536	Approximate area location of municipality	167a, 168a; 469e	43.584347	24.622536	~350-620m bgl
2.77	Zlatar	Near municipality of Zlatar, Shumen Province, Bulgaria	State Enterprise Radioactive Waste (SE RAW)	Potential repository site area location. ~300-600m bgl; 2 zones between 300 and 600m depth	Argillite: Lower Cretaceous marl of the Gorna Oryahovitsa Formation;	TBD	TBD	43.110142, 26.949393	Approximate area location of municipality	167a, 168a; 469e; general refs. are 160-189	43.110142	26.949393	~300-600m bgl
2.78	Slovakia	Slovakia	Nuclear and Decommissioning Company (JAVYS) since 2012; earlier studies oversight by Dir. Gen, Slovenske elektrarne, Inc., with State Geological Institute of Dionyz Štur and DECOM prior to 2012	Potential repository site area locations; 3 areas, with 2 divided into 2 sub-areas each location (see below).	Crystalline or Argillite: Three localities in crystalline granitoid units, Hercynian (Variscan) Early to Upper Carboniferous age; 2 localities in Neogene argillites	Surface, shallow borehole studies; focus on repository siting; field studies in early investigation stage	Generic studies, 1996-present; URL and repository concept planning; siting the repository ~2030, and commissioning ~2065. Slovakia also participating in international repository development activities (decision on continuation by 2020), Slovakia and SAPIERR project I,II (Reference 185a)			See 167a, 168a and note; general references are 160-189			TBD

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2.79	Tribec Mts.	Tribec Mountains area, Nitra Region, Slovakia	Nuclear and Decommissioning Company (JAVYS)	Potential repository site area location.	Crystalline: in Tribec – Zobor Block, Zobor Massif, Western Carpathians, granitoid composition, Hercynian / Variscan / Late Carboniferous age		Conducted surface and shallow borehole studies in area	48.4543, 18.23	Approximate area location	See 167a, 168a and note; general references are 160-189	48.4543	18.23	TBD
2.80	Veporske /Stolicke vrchy	Veporske vrchy and Stollicke vrchy Mountains areas, South of Central Slovakia	Nuclear and Decommissioning Company (JAVYS)	Two potential repository site sub-areas	Crystalline: granitoid composition, Hercynian / Variscan / Late Carboniferous age; two sub-areas			48.70263, 19.5482	Approximate area location for two sub-areas	See 167a, 168a and note; general references are 160-189	48.70263	19.5482	TBD

Table #. Item #	Facility / Site Name / Candidate Site Name	Location, Country	Operator /Responsible Org.	Facility Type (Generic/ G; Purpose built / S; Site Specific / SS), Access, Depth (shaft or overburden)	Host Rock / Geologic Information	Nature Of Experiments (References 160-167)	Period of Testing, Operations, Expected Repository Start (References 160-167)	Latitude / Longitude	Alternative Location information	References	Approx. Latitude	Approx. Longitude	Depth (meters bgl); simplified
2.81	Rimavska / Cerova	Rimavska kotlina Basin, Cerova vrchovina Upland areas; South of Central Slovakia Region, Slovakia	Nuclear and Decommissioning Company (JAVYS)	Two potential repository site sub-areas	Argillite: ; two site areas in Neogene argillites; Cenozoic basin deposits; Szecseny Schlier (member of Lucenec Formation, Oligocene-Miocene age) and Lenartovce Beds (member of Ciz Formation); Ciz rests on crystalline basement		Surface and shallow borehole studies in area	48.3075, 20.0452	Approximate area location for two sub-areas	See 167a, 168a and note; general references are 160-189	48.3075	20.0452	TBD

Table #. Item #	Facility / Site Name / Candidate Site Name	Location, Country	Operator /Responsible Org.	Facility Type (Generic/ G; Purpose built / S; Site Specific / SS), Access, Depth (shaft or overburden);	Host Rock / Geologic Information	Nature Of Experiments (References 160-167)	Period of Testing, Operations, Expected Repository Start (References 160-167a)	Latitude / Longitude	Alternative Location information	References	Approx. Latitude	Approx. Longitude	Depth (meters bgl); simplified
2.82	Ukraine	Chernobyl Exclusion Zone / ChEZ, Ukraine	State Specialized Companies / SSCs; R&D by Ukraine Nation. Acad. of Sci. and Geological Survey, Scientific Research Centers of MECI and SAMEZ	3 potential repository site area locations in ChEZ; Zhovtneva, Veresnia, and Novosilky	Crystalline: granitoid; Archaean and Proterozoic crystalline rocks		Considering mined geologic and deep borehole disposal concept; early stages of site selection and pre-conceptual design; mined repository in 30-40 years (2048); deep borehole disposal in 10-15 years			See 167a, 168a note; general references are 160-189			~500m
2.83	Zhovtneva	Chernobyl Exclusion Zone / ChEZ, Ukraine	State Specialized Companies / SSCs; R&D by Ukraine Nation. Acad. of Sci. and Geological Survey, Scientific Research Centers of MECI and SAMEZ	One of 3 potential repository site area locations in ChEZ	Crystalline: Granitoids of Korosten complex; Archaean and Proterozoic crystalline rocks		More suitable for mined geologic facility construction; may be favored site due to location within ChEZ	51.2167, 29.3271	Approximate area location?	See 167a, 168a note; general references are 160-189	51.2167	29.3271	~500m
2.84	Veresnia	Just outside Chernobyl Exclusion Zone / ChEZ, Ukraine	State Specialized Companies / SSCs; R&D by Ukraine Nation. Acad. of Sci. and Geological Survey, Scientific Research Centers of MECI and SAMEZ	One of 3 potential repository site area locations in ChEZ	Crystalline: Granitoids of Korosten complex (?); Archaean and Proterozoic crystalline rocks		More suitable for mined geologic facility construction; secondary choice	51.0723, 29.5904	Approximate area location?	See 167a, 168a note; general references are 160-189	51.0723	29.5904	~500m
2.85	Novosilky	Chernobyl Exclusion Zone / ChEZ, Ukraine	State Specialized Companies / SSCs; R&D by Ukraine Nation. Acad. of Sci. and Geological Survey, Scientific Research Centers of MECI and SAMEZ	One of 3 potential repository site area locations in ChEZ	Crystalline: Granitoids of Zhytomyr complex and gneisses of Ros-Tykych series; Archaean and Proterozoic crystalline rocks		May be more suitable for deep borehole disposal	51.2771, 29.9515	Approximate area location?	See 167a, 168a note; general references are 160-189	51.2771	29.9515	~500m

Table 3 – (Boreholes) Drilling Engineering Achievements and Examples: Deep and / or Large Diameter Boreholes, Crystalline / Granite Tests, Deep Continental Crust Drilling, Characterization, Exploration and Exploitation Boreholes

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.1	Bighorn No. 1-5	Monsanto (MDU 1-5)	Wind River Basin, Madden Anticline, Fremont County, Wyoming, USA	1983-1985	~7583m, 24,877’	Oil and Gas Industry: Well TD in Precambrian basement; deep basin hole(s); reported cost of $25 million; several earlier area wells 14,000’-22,000’ TD; deepest off-crest production at ~19,000’. Reported gas tested from Mississippian Madison, 20MMCfG/D; 7,024’ - 13,970’ (2141- 4258 m). Over-pressured sections present; 12% H_2S tested. Casing and liner reported: 30”, 20”, and 16”strings down to 14,000’; 26” hole 1490’-7,024’; 18.25” bits 7024’-13970’. Interval 13,970’-17,009’ (4258 - 5184 m) was drilled with 14-in. [35.6-cm] bits; 19,850’ - 22,273’ (6050 - 6789 m) drilled with 8 1/2 in bits; 22,273’ - 24,877’ saw 6.5” bit used for drilling to TD	43.292701,-107.663956	Sec 5, T38N, R90W; Central area of County; Approximate alternate location estimate, 43.03°N 108.63°W; verify location	536, 536a, 536b	43.292701	-107.663956
3.2	Madden 2-3: Madden Deep Unit #2-3 Bighorn	BHP	Wind River Basin, Madden Anticline, Fremont County Wyoming, USA	1986-1988	~7391m; 24,250’	Oil and Gas Industry: Deep basin hole. Note only 5” casing to TD. Gas flow on test 38 MM cfGpD. Madison; 67% methane, 20% CO_2, 12% H_2S; Madden area with Upper Cretaceous, and Lower Tertiary (Teapot, Cody, Lance) and some Madison (Carboniferous / Miss.) limestone production. Madden production of dry gas only from Mississippian Limestone; Madison reservoirs range from 23,600 to 24,400’ bgl in the Bighorn 2–3, Bighorn 1–5, and Bighorn 4–36 wells; normal pressure below overpressure zones; dry and sour gas. Recent data shows more than a dozen superdeep wells drilled in the area; further research required to determine well geometry and drill bit size	43.295199,-107.626362	Approximate location in central Fremont County, 43.03°N, 108.63°W	536, 536a, 536b, 536c	43.295199	-107.626362

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.3	Shell 1 Government	Shell	Wind River Basin, Dubois, Fremont Co., Wyoming, USA	~1960	~3258m; 10689'	Oil and Gas Industry: Deep sub-thrust objective; 7400' of Precambrian basement schist drilled through in thrust sheet; location proximal to EA Thrust, northwestern Wind River Basin; Washakie Mountain Uplift; Laramide deformation, Cretaceous.-Eocene age; below the Precambrian basement rock of thrust sheet, drilled inverted Paleozoic/Triassic section, and with TD in normal oriented sub-thrust section of Cretaceous age. Note: In 1899, first oil well in Wyoming was drilled in Fremont Co.	43.614702,-109.461551	Approximate. Location of Dubois =43°32′9″N, 109°38′9″W ; Sec. 9, T42N, R105W	537; 536a, 536b, 536c	43.614702	-109.461551
3.4	AZ St. A1: Arizona State No. A-l	AKA: Phillips Petroleum State A1; Anschutz Texoma State No. 1-10-2	Northwest of Tucson, Pinal County, AZ, USA	Spud 3/1980; P&A 2/1981	~5490 m; 18,013'	Oil and Gas Industry: Phillips Arizona State No. A-l drilled into crystalline rocks (~4000' bgl) of a metamorphic core complex and remained in them for nearly 14,000' to a total depth of 18,013'; overthrust play test; 26" hole diameter to 4107'; 20" casing set to 4107'; 17.5" hole to 10,935'; 13 5/8ths" casing set to 10935'. Well ID = API 02-021-20003; hole was offered for research; 0-700', alluvium; valley fill, granite wash sediments to 3879'; TD in granitic Precambrian gneissic and granitic basement. Obstruction in hole at ~12,000'. Granite encountered at 3,879' to TD; age granitic rock 1.39Ga, 3879'-10761'; 10761- 12755', age granitic rock 47My; 12755-18013', 1.5Ga rock of metamorphic rock complex; well plugged and abandoned in 1981. For other older deep holes in Arizona / Mexico, see references 588, 590, 594, 595	32.83827, -111.28320	Sec 2 T7S R10E; alternate accurate AASG/SMU well database location, 32.84051298, -111.2827919	530-532; 588-594, 595	32.83827	-111.28320

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.5	Bertha Rogers 1-27	GHK/Lone Star Prod.	Washita County, Oklahoma, USA	1972-1974	~9583m; 31,441’	Oil and Gas Industry: Anadarko Basin; Paleozoic age sedimentary basin; liquid sulfur at TD in Cambrian-Ordovician (generally carbonate rocks) of Arbuckle sequence; API# = 3514920020. Drilled proximal to basin axis. Deepest well in world until Kola Borehole reached TD in 1979; remained deepest well in US until 2004. Gas zone completed, ~11,000-13,000’, in mixed clastic lithologies, arkosic sandstones and conglomerates of Pennsylvanian and Permian Granite Wash units; 14” casing cemented in to 14198’	35.309543, -99.192503	Approximate location in Sec.27, T10N, R19W, Indian B&M; Approximate location, 35.309, -99.193; near Dill City area disposal site; alt. loc. 35.29007, -99.168485; verify latitude and longitude	533-535, 535a, 578	35.309543	-99.192503
3.6	Magoun 1: L.W. Magoun 1	Standard Oil / SOPC, Sohio	Concordia Parish, Louisiana, USA	1984-1986	~7600m; 25,015’	Oil and Gas Industry: 20 in. surface casing was run to 12,455’. and 14 in. protection casing was set at 16,796’; record weight for casing; 1984, a total of 12,455’ [3800 m] of 20”., 169-lbf/ft [51-cm, 2.47-N/m) C-95 casing was successfully run and cemented to the surface; planned 25,000’ well; TD was 25,015’ with 8.5” diameter at TD. At the time, the well held record with 26” diameter hole drilled to 12550’. Drilled in Mesozoic / Cenozoic sequence of the onshore Gulf Coast	31.560098, -91.72104	Section 23, T7N, R7E; l/l estimated location for hole only	471-474; 526- 529, 603	31.560098	-91.72104
3.7	Paradox 1: Paradox Valley Unit (PVU): Salinity Control Well No. 1	Bureau of Reclamation	Montrose County, Colorado, USA	1987	~4800m TD; 15,900’	Brine Disposal well: Paradox Valley Unit (PVU) Salinity Control Well No. 1 (originally, Paradox Valley Injection Test Well #1) was completed in 1987 to TD 15,900-ft (4.8-km) in Precambrian basement (top at 15446’, in moderately metamorphosed diorite-gabbro schist) as a deep and fairly large diameter (reported 9 5/8ths” casing to 13,835’) injection well for long-term disposal of shallow brine. Stratigraphic sequence consists of (~15000' thick)Paleozoic age sedimentary rock on Precambrian basement	38.298024, -108.894687	Approximate location, 38°17'52.9"N 108°53'40.9"W	609b, 609c, 609d	38.298024	-108.894687

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.8	RMA: Rocky Mountain Arsenal	U. S. Army	Adams County, Colorado, USA	1961	~3671m; 12,045’	Liquid waste injection disposal well: Rocky Mountain Arsenal deep injection well was constructed in 1961, drilled to a depth of 12,045’ (3671m) feet and cased to a depth of 11,975’. Injection was associated with induced seismicity; injection ceased by 1966 and in 1985 the Army permanently sealed the disposal well. Reference 609e shows ~11" hole ~2000' to 11000' depth; Reference 609f shows 8.75" hole at total depth. Well drilled near axis of Denver-Julesburg Basin; Precambrian penetrated at TD; basement is granite-gneiss of Mount Morrison Formation; granite is medium to fine grained. Basin contains >10000' thick Cretaceous Mesozoic /Pennsylvanian-Permian age clastic sequence and only a thin lower Paleozoic unit is encountered; Precambrian penetrated at ~11935-11950', to TD at 12045'; basement consists of migmatitic gneiss, fractured basement rock; Pressurized injection of waste water resulted in disturbance of area fractures and stress field resulting in induced seismic events	39.855574, -104.85169	Approximate well location NW1/4, NE1/4, sec. 26, T2S, R67W, Adams County, Colorado, 39.855574, -104.85169; Arsenal area location ~ 39.828258°, -104.858740°	609b, 609c, 609d, 609e, 609f	39.855574	-104.85169

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.9	Innamincka / Habanero: Innamincka Project; Habanero wells	Geodynamics; enhanced geothermal systems project (EGS)	Cooper Basin, Queensland and Innamincka area, South Australia, Australia	2003-present; recent activity	>4000m; >13,000'	Geothermal / EGS, granitic: One of several geothermal energy drilling campaigns in Australia; multiple boreholes planned for Cooper basin; deep (4-6km target zones), hot boreholes approach 600ºF at ~14000'. Geodynamics is drilling basement holes penetrating Proterozoic basement intruded by Carboniferous age granites and granodiorites; target units of Big Lake Suite in Cooper Basin. Wells are {Habanero 1 (2003), 4,421m; Habanero 2 (2004), 4,459m; Habanero 3 (2008), 4,200m; Jolokia 1 (2008; was deepest well in Australia), 4,911m; Savina 1 (2009; well suspended), 3,700m; Habanero 4 (2012), 4,204 m}; significant pressure and temperature encountered; project was looking promising. Unidentified borehole drilled to 16,075' with 9 5/8ths casing run to 12345' (Rivenbark et al., 2011; see references 543, 544). Production casing with 9 and 5/8ths" diameter followed by ~7" diameter in lower part of hole. Geothermal system test and "production" from crystalline rock; further research needed to verify hole geometry. In 2016, Geodynamics renamed ReNu Energy; company chairman annual statement indicates Cooper Basin ventures are noneconomic for company; well site remediation near completion	-27.736719, 140.739326	Geodynamics example area; Cooper Basin location: 27S, 141E; Innamincka area, northeastern South Australia. The drilling area extends in an east/west belt about 8-10 km south of location on map south of town of Innamincka (Habanero wells: near -27.817083, 140.753950).	489, 538, 542, 542a, 542b, 542c, 543,544; hole diameter data also in references 523, 524	-27.736719	140.739326

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.10	Penola / Salamander : Penola Project, Salamander	Panax, Raya Group JV	Otway Basin, Penola Trough, Geothermal Wells; South Australia / Victoria, Australia	2010-? Recent activity	~4025m, 13205'	Geothermal EGS/HDR, Hot Sedimentary Aquifer: Australian deep geothermal boreholes for enhanced geothermal and hot dry rocks also include Otway Basin, Penola Trough, Panax's Salamander-1 (first well, drilled 2010), TD 4025m reportedly in Pretty Hill Sandstone. Exploration, R&D support from Australian government entities; geothermal system test in sedimentary rock,; Salamander #1, 8.5" hole for bottom 1000m of wellbore; well geometry requires further research. Panax Geothermal is now Raya Group. Raya group activities in SA appear stalled in 2015. Salamander 1 with 17.5" diameter hole to > 1700m bgl; must verify 1700m-3000m depth hole diameter.	-37.45, 140.8	Approximate area for Penola project is presented. Note the Town of Penola, South Australia, location = -37.378955, 140.837289;	538, 540, 541, 542b, 543, 544	-37.45	140.8
3.11	Paralana 2: Paralana Project, EGS	Petratherm Ltd, Paralana Geothermal Energy Joint Venture Project	Adjacent to the Mount Painter Region, Flinders Range, South Australia, Australia	Recent activity; ~2008-?	~4000m, 13123'	Geothermal well: Mount Painter complex, Mesoproterozoic basement rocks; meta-sediments, crystalline in broadly defined sense; EGS. Paralana No. 2 drilled in 2009 to 4003m; ~1250m Cambrian and thin Cretaceous sequence above Late Proterozoic Adelaidean sedimentary units (~1250m – 3700m), and penetrating into deep Mesoproterozoic basement rocks of the Mt Painter Complex including dolerite and metasediments; wellbore geometry requires further research; project reportedly stalled, 2016.	-30.213124, 139.725319	Approximate area only	538, 539, 543	-30.213124	139.725319

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3.12	KOLA SG-3	Murmansk Oblast, Russian Federation (R&D)	Pechengsky (Pechenga; also a nickel mining district), Murmansk area, Kola Peninsula, Russian Federation	1970-1989, 1992 (endphased work, 1994)	~12,261m ; 40,230’	R&D, Crustal Study: Record as deepest well in world, for depth below ground level, aka Kola Superdeep hole. Scientific drilling and testing project between 1970 and 2005; SG3 was world’s deepest hole; spud 1970, SG3 sidetrack hole reached total depth in 1989. SG3 within Archean (~>2.8Ga) units at TD; Precambrian Shield; intersected lower Proterozoic complex of the Pechenga Formation (9m-6842 m) composed of metavolcanic and metasedimentary rocks, amphibolite, granite; the Archaean granite and metamorphic complex (6842-12261 m) is composed of gneisses, amphibolites and meta-ultrabasite, pegmatites and granites. The age of the crystalline rocks in range of ~1.765-2.835 Ga; Scandinavian shield. Fractured units; zones tested are hydrogen gas rich. Reported as ~21.5cm and 8.5” diameter at ~12.2km.	69.39622,30.60867	69°23′46.39″N 30°36′31.20″E; Kola, Zapolyarny area; google map shows ~ 69.396058, 30.609631	471, 474, 478, 479, 490, 490a, 498, 517, 533, 574-576, 576a, 577, 578, 582, 582a, 582c, 582d, 585, 585a, 585b, 586, 603	69.39622	30.60867
3.13	Ural SG-4	Russian Federation (R&D)	Urals, near Nizhny Tagil, Sverdlovskaya oblast, Russian Federation	1985-2005	6015m , 19734'	R&D, Crustal Study: aka Ural superdeep hole SG-4; Tagil Volcanic Arc (mega-synclinorium, Paleozoic age), Urals, Variscan age orogenic event associated structure; arc volcanics, andesitic, dacitic, and lower basalt of Silurian age. Orogenic event in Permo-Carboniferous deformed area basinal units. From depth 3.5- 5.1 km, a flyschoid unit is encountered. NOTE: core log depth, TD depth reported in literature varies; clarify TD, TVD and logged depth differences, and year of source publication; lacking specifics for TD and sequence below 5.1km depth. Planned TD of 15000’. (Other TD depths reported as 5354m in 1995. Depth recorded as 5401m in 1999; phased drilling program). Located east of Perm, in Russia. Late Paleozoic units were named Permian (~1841) by R. Murchison after Perm area in Russia.	58.377222,59.729444	58°22'38"N 59°43'46"E from ru.wikipedia.org (Russian) 58°22'38"N 59°43'46"E; 58.377222, 59.729080; From http://wikimapia.org/15722589/Ural-Superdeep-Borehole-SG-4, location 58°22'38"N 59°43'46"E	573, 575, 582, 582a, 585, 585a, 585b, 586	58.377222	59.729444

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3.14	Vorotilovo	Russian Federation (R&D)	Russian Federation; ~75 kilometers north of Nizhniy Novgorod, Nizhniy Novgorod Oblast, left bank Volga River	1989-1992	5374m, 17631'	R&D, Crustal Study, Impact Feature: Vorotilovo Deep Well (VDW) drilled astroblem feature / ring structure, the Puchezh-Katunk Impact Structure, ~167 mybp to ~175Mya age of formation; drilled Archean and Early Proterozoic basement rocks; drilled central uplift of the ring structure. Hole remained uncased from 689m to TD for long period of time; borehole at TD reportedly 212mm (8.34") diameter; lower hole 1752m to TD with schists, biotite–amphibole gneisses and amphibolites. A two well complex designed for cross hole test purposes to function as geo-laboratory. (Identified as SG-7 in some references (reference 582a). Reference 582b: Uncertain this is same SG-7 discussed under SG-6 below; locations are different; must clarify SG-7 identities; reference 582b states SG-7 spud date in 2000 Bolshoi Urengoi field, at Pestsovyi Swell, 160 km northwest of the SG6 borehole)	56.954945,43.720264	Approximate area only N 56° 58', E 43° 43'; Vorotilovo Village, Nizhegorodskaya oblast', Russia, 56.955808, 43.721614; wellsite location requires verification	579-582, 582a, 585a, 585b	56.954945	43.720264
3.15	Tyrnyauz: Tyrnaus, Tyrnauz deep hole (TGS)	Russian Federation (R&D)	Tyrnauz, Kabardino-Balkaria, NW Caucasus, Russian Federation	1987-1989	4001m, 13126'	R&D, Crustal Study: Drilled into Eljutin / Eldjurtinsky granite intrusion; crystalline unit intruded 1.8-1.9 Ma (alternate age range ~1.2-2.5Ma) which corresponds to the Pleistocene age; within Pshekish-Tyrnauz zone, NW Caucasus folded belt (Cenozoic), a young mobile belt; drilled near the ore field of the large-scale Tyrnyauz deposit of wolfram and molybdenum. Stratigraphy: 0-260m, glacial/fluvial sediment; 260-3835m, pink and grey granite; 3835- 4000m, leucogranite. Pleistocene intrusion. Add borehole drilling details in future	43.402678,42.932167	Approximate area only; in area between Black Sea and Caspian Sea; area shown is village area marked Tyrnaus; well is located 1.5km SW outside town of Tyrnauz (near Tyrnyauz Deposit); requires location verification	471, 576a, 582, 582a, 582d, 585a	43.402678	42.932167

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3.16	Tyumen SG-6: Tyumenskaya	Russian Federation (R&D)	Yamal-Nenets autonomous district / YaNAD, Russian Federation (Tyumen Oblast has administrative jurisdiction of Yamal Nenets)	TD in 1994	7502m, 24612'	Sedimentary basin; SG-6 drilled thick Permo-Triassic section, but did not penetrate to basement (basement of Paleozoic age in area). Alkali effusive rocks of the Permian-Triassic trappean formation / Siberian trap rock equivalents encountered ~5500m bgl. Associated with Urengoi–Koltogory rift. *Add drilling details in future*. See NEDRA (Reference 582b) states SG-6 and SG-7 were drilled near axis of Ob Paleorift basin; SG-7 (En Yakhinskaya) borehole was drilled (spud 2000; TD 2013+?; not same as well SG-7 above) at the Bolshoi Urengoi field, at Pestsovyi Swell, 160 km northwest of the SG-6 borehole); ; more precise location information was classified (M. Westphal et al., 1998, Geophys. J. Inter. 134:254-266}. Note reference 582b is incorrectly numbered in Rev 0 References as 282b and has been changed in Revision 1, herein. Also see https://helion-ltd.ru/drilling-mud-technologies/	66.001, 78.001	Location conflict problem. Questionable approximate locations: 67.305976,76.904297 approximate area only from larger maps only; For SG-7 67N 76E guessed as map described, 50km east of Nizhnii Urengoi gas field; Urengoi field in Wikipedia.org located at 66.1°N, 76.9°E; used 66N,78E, but incorrect. {One reference has it ~66N,78.5E. Requires verification of location and well name; see comments. Location for Village of Tyumen, Tyumen Oblast, Russia, 57.178379, 65.521042, is far from guessed location	582, 582a, 582b, 582e	66.001	78.001

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3.17	Saatly SD-1: Saatly deep SD-1 borehole	Azerbaijan (former USSR)	Azerbaijan	1965; spud prelim hole, 1971 to 1974; continued 1977	8267m, 27123'; drilled depth	R&D, Crustal Study: Crystalline basement study was one objective of area investigation; expected Mesozoic intrusive units as encountered in area wells. Well drilled in Kura Depression; depth also reported to be 8267m and 8324m TD. SD-1 was second well drilled for USSR deep well program; SD-1 drilled on the buried uplift of basement rock, Middle Kura Depression; well penetrated nearly 5 km of Jurassic/Cretaceous volcanic units from ~3.6km to ~8.2km TD; some clastic deposits; deeper basement structure expected to be composed of Mesozoic age stocks and metamorphic units and older altered crustal units, but those were not encountered when drilling terminated. The Kura depression separates the Greater and the Lesser Caucasus. Original proposed TD was 15000m. From 1971-1974, preliminary well drilled to 6240m. SD-1 penetrated: 0-~2000m, Cenozoic clastic sequence; mixed clastics and carbonaceous units, ~2000m – 2830; 2830-3529m, mixed sediment and volcanic units of Cretaceous/Jurassic age; 3529- ~8230m TD, volcanic units. Mesozoic / Cenozoic sequence of flysch and Molasse type sequence. Add drilling details and verify depth / inconsistencies in future	39.921718,48.370657	approximate area only	582a, 585, 585b, 585c, 585d	39.921718	48.370657

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3.18	Krivoy Rog, SG-8	Ukraine (USSR, NEDRA R&D)	Ukraine	Spud 1984; 1986; 1993	6600m; 21653'; alt. earlier TDs reported: 3600m, ~5000m in 1991, and 5432 m 1993; deepened to 6.6km	R&D, Crustal Study: aka SG-8, USSR scientific drilling program borehole drilled in Ukraine, East European Platform, Precambrian shield area; Archean to Early Proterozoic (1.3-3.6 Ga) basin included iron-bearing formations of Krivbass basinal feature; entire well drilled in basement formations. In 1987, pilot hole at 3500m, 8.5" diameter; SD-8 deepened as 11.6" hole to 5432m in 1993; planned TD was 12,000m TD, but not reached. Stratigraphy: 0-2351m, Gneiss and metasedimentary units; 2351m-TD, deformed complex sheared metamorphic units. Reported deepened to 6.6km.	48.001, 33.22	Approximation; alternate, 47.873295,33.462639 approximate area only; 15km NW of town of Krivoy Rog, ~48.00, 33.22; See SKB TR92-39	471, 576a, 582a, 582c, 582d, 585	48.001	33.22
3.19	Otokumpu / ODB, Outokumpu R2500	ODDP, GTK (Geological Survey of Finland); ICDP, International Continental Scientific Drilling Program	Outokumpu mining area, North Karelia Region, Finland	2003-2005 drilling operations and construction phase; testing to 2010; spud, 2004	2516m; 8265'; TVD 2497m	R&D, Crustal Study: ODB / Outokumpu Deep Borehole, R-2500 is deepest drilled in Finland; NEDRA cooperation for drilling. Deep Drilling Project of the Geological Survey of Finland / GTK; partial support from ICSDP. Outokumpu Cu mine discovery in 1910; borehole is located proximal to the Outokumpu polymetallic deposit; Reference 584. Geology: Outokumpu Palaeoproterozoic metasedimentary schists / gneiss, igneous and ophiolite-related sequence; imbricated overthrust terrane, dominated by ~1.92–1.90 Ga old metaturbidites, emplaced over a basement complex consisting of late Archean gneisses and a thin Palaeoproterozoic cover; TD in pegmatitic granitic rock; deep cores generally 60-80mm and ~100mm; drilling goal achieved with 22cm (8.66") diameter hole (Reference 584, p. 153) to TD; not an example of large diameter deep drilling, but good example of drilling in complex Precambrian age crystalline basement sequence. See also http://tupa.gtk.fi/raportti/arkisto/q10_2_2007_29.pdf ; http://outokumpu.icdp-online.org/	62.717777, 29.061918	Approximate area only; 62° 43' 02.63" N, 29° 03' 55.01"E; Sysmajarvi; located 2.5 km SE of Outokumpu; alt. location Ref. 583, 584 guess is used; see Geol. Surv. Finl. Spec. Paper 51, 2011 (GTK); also, location from https://www.icdp-online.org/projects/world/europe/outokumpu-finland/details/	487, 583, 584, 584a, 584b, 585	62.717777	29.061918

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3.20	Soultz-sous-Forets, GPK3	France, GEIE EMC, Groupement Européen d'Intérêt Economique "Exploitation Minière de la Chaleur"	Alsace, France	1995-2003, production complex	~5091 m, 16702',GPK3, 2001-2005 ; GPK2, 1992-2000, TD ~ 4955m; GPK1, 1992-1997, TD ~ 3600m; GPK4, 2001-2005, TD ~4982 km; and EPS1, 1997, TD ~2227m;	Geothermal Project: European project; 3 enhanced geothermal system well series or cluster (GPK 2, 3, and 4); bottom hole diameter 9.625". Upper Rhine Graben, an asymmetrical Cenozoic graben floored by Hercynian basement complex with Mesozoic sequence on basement. GPK1 and EPS1 wells were exploration deep wells; Soultz granite is "reservoir" for EGS system; Cenozoic/Mesozoic sedimentary units to ~ 1.2 km depth; sediment rests upon basement intrusive granitic crystalline sequence to TD; hole paths slightly deviated. Intrusion age ~327-334mya for granitic host. Formerly Hot Dry Rock, HDR program; now referenced as Enhanced Geothermal System complex. Hydraulic stimulation of fractures; power production tested in ~2008; scaling and sulfide mineral deposition challenges with system	48.931064, 7.866523	Facility location, well complex	474, 478, 479, 487, 489, 514, 517, 519-522, 603; 603a; hole diameter data for GPK-2 also in references 523, 524	48.931064	7.866523

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3.21	KTB HB	German Continental Deep Drilling Program; KTB, Kontinentale Tiefbohrprogramm der Bundesrepublik	Windischeschenbach, Bavaria, Germany	1987-1989, guide hole; 1990-1994, main hole	9,101 m; 29859' TD	R&D, Crustal Study: Deep, large bore drilling project, the "Kontinentale Tiefbohrprogramm der Bundesrepublik Deutschland (KTB); temperature was more than 500 °F (260 °C) at total depth. Two holes: pilot guide hole, Vorbohrung, KTB-VB = 4000m TD, 6" diameter. Main test hole, Hauptbohrung KTB-HB = 9101m TD in 1994; 6.5" diameter at TD reported for KTB-HB; 14.75" diameter at 6000m, and set 13-3/8" casing in a 14-3/4" hole to a depth of 6,000 m. Hole diameter at 7784m and 8328m reported as 12.25". Drilled Bohemian Massif within shear zone; metamorphic / paragneiss, metabasites; granitic. Recognize Paleozoic / Variscan age orogenic event-associated structures. The well provided analog information used for planning, siting and characterization of the Forsmark area borehole, underground research laboratory, and nuclear waste repository (analog references 561-565), in particular, the evaluation of deep borehole disposal used by Swedish Nuclear Fuel and Waste Management Company, SKB, Svensk Kärnbränslehantering AB; see Table 2 of this study, Forsmark Repository site area.	49.815328,12.120396	49°48′55″N 12°07′14″E precise location; Near Windischeschenbach; validated with Google maps	470, 474, 478, 479, 490, 490a, 502-506; 505a, 517, 562, 565, 567, 582a, 585, 585a, 585b, 586, 603; analog 561-565; hole diameter data also in references 523, 524; nuclear waste disposal analog studies, see Reference 188a	49.815328	12.120396
3.22	Gross Schoeneck: underground laboratory	GFZ / GeoForschungs Zentrum	Brandenburg State, Germany	~2000	~4400m, 14436'	Geothermal R&D: Borehole and research center; in situ geothermal laboratory, Gross Schoenebeck; 8.5" hole 3840m-4375m reported; discrepancies on total depth; TD in Early Permian pre-Zechstein Rotliegend Formation, sedimentary and older volcanic units of the North German Basin; deepened in phased manner	52.903820, 13.601646	Located ~50km N of Berlin	507-509	52.903820	13.601646

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3.23	Urach 3	FIP, Future Investment Program, German Fed. Gov. supported	Bad Urach, District of Reutlingen, Baden-Württemberg State, Germany; in Swabian Alps	1977/1978; 1992-1997	~4445m, 14583'; 3300m in 1978; deepened, sidetracks maximum ~4445m TD; ~ 14583'; deviated	Geothermal Project: Mesozoic (largely Triassic and Jurassic) and Permian sedimentary units occur to 1604m bgl; @1604m bgl encounter crystalline Variscan gneiss of Black Forest basement, Moldanubian Domain; fractured crystalline rocks reported 1604m to TD. Test area for hot dry rock geothermal system. Reported 7" casing to 3320m; 5.5" diameter hole at TD; redrill / sidetrack details 3488m – 4445m could be added in future revision to this survey data; hot dry rock project.	48.506822, 9.373690	Approximate area;	478, 479, 510-518; 603	48.506822	9.373690
3.24	Gravberg #1; ST3	Vattenfall (government energy company, Swedish State Power Board); Gas Research Institute	Siljan Impact, near Mora, Dalarna County, central Sweden	1986-1989, 1990	~6800m, 22,300' for ST3 deep hole; TVD ~6.7km bgl for sidetrack hole	Oil and Gas R&D, basement as methane source: Drilled in NE part of Siljan Ring Impact Structure as gas exploratory deep borehole; within Precambrian Shield, Sweden. Feature formed by Devonian ~362Mya (alt 376mya) impact structure in 1.7 Ga basement granitic rock, Dala Series granites (reference 569); deep gas enriched in H2, He and N; stagnant water for millions of years residence time at depth. "Shocked" Proterozoic granite and diabase; dolorite dikes produced geophysical anomaly penetrated by Gravberg hole. Approximately first 4km drilled depth with ~12"/0.3m hole; TD in 1988; sidetrack 2 TVD 6394m; sidetrack 3 drilled to TD ~6.8km/ 6957m TD: bottom hole diameter reported 6.5". {See also Stenberg-1 deep well, drilled 1991/92; ~6.5km TD, KTB, Das Kontinentale Tiefbohrprogramm der Bundesrepublik Deutschland later drilled the Stenberg borehole nearer center of crater; both wells test Thomas Gold's theory of abiotic origin of hydrocarbons}. Swedish Deep Drilling Program (SDDP) conducted additional work in Siljan area. Reference 566a for recent related proposed studies	61.144510, 15.004786	Approximate area location. Gravberg well is located several km NE of ring center; nearer community of Gravberg, 61.144510, 15.004786; ring center ~ N 61° 2', E 14° 52'; or 61.033333, 14.866666, and closer to Sternberg well location; Mora and Gravberg are in Dalarna County	470, 471, 478, 479, 490, 490a, 564, 565; 566, 566a, 567-570; 585, 585b, 603; hole diameter data also in references 523, 524	61.144510	15.004786

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3.25	COSC #1	International Continental Scientific Drilling Program (ICDP), Swedish Research Council, Geological Survey of Sweden (SGU)	Near Town of Are, Jämtland County, Sweden	Spud #1 well in 2013; completed in 2014	~2495.8m ; ~8189'	Basement R&D: Collisional Orogeny in the Scandinavian Caledonides / COSC. Located near Paleozoic age Baltica and Laurentia collision zone; structure and tectonic exploratory R&D deep borehole (ICDP drill site 5054-1-A); study of Seve Nappe Complex; Lower Seve Nappe, with alternating layers of felsic calcsilicate/ gneisses and amphibolites; mylonitic 1700-2300m; mafic rocks were encountered at about 2314 m and a transition from gneissic to lower-grade metasedimentary rocks occurs around 2350 m; well located near abandoned copper mine at Fröå. COSC #2 well planned (2014) and intended to penetrate subjacent to Seve Nappe basement complex; hole diameter at TD, TBV; update progress on COSC #2 planned for 2.5km TD, end drilling remains TBD	63.401629, 13.202926	Reference 571 location 63.401629, 13.202926; Approximate area estimated from maps provided; estimated from ref. 572a, #1 well shown south of road in area indicated ; #1 is located near Åre, and #2 borehole near Järpen in western Jämtland	571, 572, 572a	63.401629	13.202926

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3.26	Basel 1	Geopower Basel AG	Basel, Switzerland	2006-2009	5009m; 16434'	Deep Heat Mining Project (DHM): Geothermal system boreholes: Diameter at TD, 251mm (9.875"); located at the intersection of the southern end of the Upper Rhine Graben and the Jura mountains.; granite rock matrix; drilled to 5,009 m depth and cased to 4,629 m bgl; borehole with upper sequence of 2,400 m Tertiary, Mesozoic and Permian sediments. The top granite encountered at 2,426 m; no metamorphic units encountered. Geothermal system testing induced seismic activity. Concerns about induced seismicity resulted in the cancellation of project in 2009. In Otterbach area Deep Heat Mining Project, Basel, geothermal exploratory test wells DHM-1 drilled 1999 to 1537m; DHM-2 drilled in 2001 to 2755m. Basel 1 enhanced geothermal system well (9 7/8ths" hole diameter through most of basement; bottom ~100m with 8.5" hole) completed in 2006 at ~5km depth penetrating ~2.5km sedimentary and ~2.5km of crystalline rock associated with Rhine Graben (Paleogene rift basin, deformed in Neogene synchronous with thrust units of Jura); Variscan age basement.	47.5840, 7.5970	North part, N of City of Basel, plant area location, ~47.5766, 7.600	470, 474, 487, 487a	47.5840	7.5970
3.27	CCSD-1	Chinese Continental Scientific Drilling Project, China	Donghai County, Jiangsu Province, China	2001-2005?	5158m; 16923'	Basement R&D: Deep borehole in granite; Chinese Continental Scientific Drilling Project; cored; 2001-2005; drilling technology advances; cored and reamed hole to depth. Dabie-Sulu region of eastern China. Donghai County (Donghai Xian), Jiangsu Province; Dabie-Sulu UHPM ultrahigh-pressure Metamorphic belt; Gneiss, eclogite, amphibolite, etc. Triassic Metamorphism with extensional deformation in Cretaceous. Final borehole diameter 6.25", 157mm at TD; included drilling of 2 pilot holes (PP1, PP2; 426m, 1028m depth bgl) and CCSD-1, main hole; see reference 496, 500a.	34.405984,118.672340	Approximate area location; 34º24'36"N, 118º40'12"E from Ref. 498. Alternate approximate area location 34.552, 118.763. Well is located in Maobei Village of Donghai County/ Lianyungang City, Jiangsu Province (south of 34.41,118.67)	492, 493; 494-499, 499a, 500, 500a, 501	34.405984	118.672340

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3.28	Gwangju: Geothermal	Hanjin D&B Company	Gwangiu, Republic of Korea	~2012-2013; +?	~3500m, 11483'; in 2015. Planned 7km TD	Geothermal study, granitic rock: 2012 and 2014 programmatic and reference design information for deep borehole disposal concept provided in references 523, 524. ROK also has active Enhanced Geothermal program with several deep boreholes drilled in granitic rock, e.g.: 1) Pohang EGS Pilot Site, PX-1 well drilled in 2013 to 4127m depth by Korea Institute of Geoscience and Korea Institute of Geoscience and Mineral Resources and was the deepest well drilled in ROK; granite encountered ~2200 mbgl; 2) Gwangju project, Hanjin D&B Company drilled one of the deepest wells in granite, target 7 km TD, located in Gwangju. Okchon fold belt; drilling plutonic (batholith) granites of Upper Proterozoic and the more recent Bulguksa granites of Cretaceous age; in 2015, depth ~3.5km, planned TD ~7km. (Reference the KURT URL and test complex for wells and associated disposal study); in 2015 drill reached 12,000' using water hammer drill machine with 10x drilling speed of conventional technology. Current status requires further literature review.	35.155833, 126.834444	Approximate area location: Gwangiu 35° 9' 21", 126° 50' 4"	523, 524, 524a, 524b	35.155833	126.834444

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.29	Shin-Takenomachi	METI / Ministry of Economy, Trade and Industry; aka Japan National Oil Corporation (JNOC)	Niigata Prefecture, Japan	1993	6310m; 20702'	Oil and Gas well: Japan has several very deep exploration holes, constructed by METI (the Ministry of Economy, Trade and Industry) in the 1990s (but no very deep disposal R&D hole exists), e.g.: Shin-Takenomachi (1993; oil and gas well, then the deepest well in Japan) to 6,310 m, with 8.5" diameter vertical hole at TD and a bottom temperature of 197 C. Other deep wells in 1990s include 1) Mishima (1992; oil and gas well) to 6,300 m with a bottom temperature of 226 C; 2) Higashi-kubiki (1989-1990; oil and gas well) to 6,001 m, cased to 5000 m at about 24.4 cm OD and uncased below 5000m with 8.5" diameter hole to TD. Shin-Takenomachi and Mishima wells drilled in Niigata Basin between cities of Niigata and Nagaoka. Basinal section penetrations in wells are Miocene to recent age clastic / clay sediments. Need more literature search for granite crystalline holes in Japan not associated with the URL sites. Some information on Japan crystalline sites are discussed in this study, Tables 1, 2, and 4 (mines, URLs, and underground physics laboratories). Japan is assessing borehole disposal and more conventional mined geologic disposal.	37.814084, 138.893859	Approximate area location for basin area between cities of Niigata and Nagaoka	481, 492-493; 523, 524, 524c, 524d	37.814084	138.893859

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3.30	NNSS: Nuclear Weapons Tests, Plowshares	DOE: U.S. Department of Energy; NNSA/ National Nuclear Security Administration; successors to AEC / Atomic Energy Commission	Nevada National Security Site / Nevada Test Site; Nye County, Nevada, USA	~1950 to 1992; mission changed 1992 with underground nuclear test cessation; Emplacement holes; other drilled holes	~183m - 670m TD (~600'- 2200'+); other deeper holes	Large Diameter Borehole Drilling: AEC pioneered large diameter borehole drilling for emplacement of weapons capsules at depth; capabilities / demonstrations using deep and large diameter borehole for weapons and Plowshares activities. Over 500 holes drilled for weapons tests on NNSS / NTS and other locations; ~450 holes drilled >48" diameter, with TD>500'. Most holes 48"- 144" diameter; many in range of ~70"-120" diameter were drilled for nuclear capsule and large diameter test equipment and capsule emplacement @ depths ~1.5km . A few NNSS tests were conducted in granitic rock, e.g., Climax (discussed below); most NV test site holes were drilled in alluvium and tuff. Hundreds of holes and tunnel complexes were constructed during underground test period ending in 1992. Deep large diameter holes may still be available for testing (e.g., in Climax area), but most are in use (hydrologic monitoring test program, DOE EM). Examples of deep large diameter holes drilled off NTS/NNSS in 1960s/70s Plowshares Program sites are included in table: 1] Gasbuggy, 2] Rulison, 3] Rio Blanco, and 4) Cannikin / Amchitka test; Plowshares Program cancelled in 1975; geospatial display of DOE LM non-NNSS tests, see http://gems.lm.doe.gov/#	37.155939,-116.043091	37°07′N 116°03′W, general area only. For Plowshare locations: NNSS / NTS	470, 553, 553a, 554-559, 558a, 559g	37.155939	-116.043091

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3.31	Gasbuggy : Plowshare Operation	AEC / U.S. Atomic Energy Commission (now Department of Energy / DOE)	Rio Arriba County, New Mexico, USA	~1967; testing to 1976	~1293m, ~4242'	Large Diameter Borehole Drilling, Fracture Test: Planned well GB-E for 28" hole to ~4350' reamed to 28" hole to TD after drilled pilot hole for test (AEC developed heavy duty rigs such as Parker Drilling Rig No. 114 to drill large diameter deep boreholes); weapon assembly emplacement and detonation at 4227'; 29 kiloton device; fracking technology test to enhance natural gas (and liquids) production from sandstone and argillaceous sedimentary rock. Plowshare Operation Program (`1961-1973 active), outgrowth Atoms for Peace concept; Plowshare cancelled in 1975; test within Late Cretaceous age Pictured Cliffs Sandstone and at top layers of the Lewis Shale, San Juan Basin; currently managed by DOE LM / Legacy Management; referenced as Nevada Offsite Test along with other Plowshares tests included here in table (e.g., Gasbuggy, Rulison, Rio Blanco, Amchitka / Cannikin, Faultless / CNT, Gnome)	36.6778°, -107.2089°	T29N, R4W	555, 558, 558a, 559, 559a, 559b, 559c	36.6778	-107.2089
3.32	Rulison: Rulison Test: Plowshare Operation	AEC / U.S. Atomic Energy Commission, Department of Energy / DOE	Rulison, Garfield County, Colorado, USA	1968/1969	~ 2652m; ~8700' TD; test ~>8500'; ~8700'	Large Diameter Borehole Drilling, Induced Fracturing: Borehole R-EX drilled smaller diameter to TD. Borehole R-E for emplacement with 15" hole from 800-8700'; detonated a ~43-kiloton nuclear device ~8,426' underground to produce commercially viable amounts of natural gas; one of several "fracking" technology tests drilled for AEC Plowshares Program / outgrowth AEC Atoms for Peace concept; Plowshare cancelled in 1975. Test within Late Cretaceous age Mesa Verde Group, Piceance Creek Basin; see reference 559h	39.405278, -107.948528	S25, T7S, R95W	555, 558, 558a, 559, 559d, 559h	39.405278	-107.948528

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3.33	Rio Blanco: Rio Blanco Project: RB-E-01 Test, Plowshares Operation	AEC / U.S. Atomic Energy Commission, Department of Energy / DOE	Rifle, Rio Blanco County, Colorado, USA	1972/1973	2398m; 7869' TD; ~6700' test	Large Diameter Borehole Drilling, Induced Fracturing: 15" diameter hole from ~ 850' to 6990'; TD 7869'; fracking / fracture technology test; simultaneous detonations of three 33 kiloton nuclear devices at 5838', 6230', and 6689'; test to enhance natural gas (and liquids) production; Plowshares Program / outgrowth AEC Atoms for Peace concept; Plowshare cancelled in 1975; RB was last test of Plowshares Program; detonation in the Late Cretaceous age Fort Union and Mesa Verde (Williams Fork) Formations, Piceance Creek Basin, Colorado; see reference 559i	39.7935, -108.3674	Northwest of Rifle, CO.; Sec. 14, T3S, R98W; Google and DOE LM show site 39.7935, -108.3674; Google and LM location is on north side of Fawn Creek, ~ 1km SE of location on map layer; verify	555, 558, 558a, 559, 559e, 559f, 559i	39.7935	-108.3674
3.34	Climax SFT: Climax Spent Fuel Test / CSFT	U.S. Department of Energy, Nevada National Security Site; Nevada Test Site	Nye County, Nevada, USA	1978-1983; facility closed in 1990s	~420m, ~1378' bgl; SFT test level	Nuclear Waste Disposal URL / R&D: Climax Spent Fuel Test (CSFT / SFT-C) and complex located south of closed Climax mine. Access for SFT via 1960s borehole shaft (U-15a) and tunnel system; Climax underground facility was used for both weapons and spent fuel and thermal testing within Cretaceous "crystalline / granitic" quartz monzonite (near contact with granodiorite, age ~104mya). Depth SFT at 420m bgl; CSFT intended to demonstrate safe emplacement, storage and retrieval of SNF canisters, study response of natural and engineered systems to waste in granite environment (see reference 553a). Refurbished Piledriver shaft used for initial access. For test, also drilled to 420m / ~1378' bgl, a 0.76m diameter shaft (cased with .51m O.D. pipe for canister access to and from test level in tunnel ~1400'bgl); assemblies for thermal test encapsulated in 14" diameter canisters; successful test. Precursor heater test conducted in facility 1977-78. Climax test area is site of 3 nuclear weapon effects tests (~1961-1966), Hard Hat (1962), Tiny Tot (1965), and Piledriver (1966); Climax granite tests were first non-tuff hardrock underground tests conducted to examine mechanical response / seismic characteristics of crystalline rock response to nuclear event. Closed	37.22352, -116.05895	NNSS Area 15; NNSS / NTS, near closed Climax silver mine; level 1400 references depth of ~1400' bgl; shaft location, referenced as borehole U-15a; Test Area ~ = 37°13'24"N 116°3'33"W, 37.223333, -116.059167; shaft U- 15a Hard Hat, 37.226262, -116.059315; Climax Mine located north of test area = 37°14'9"N 116°3'13"W, 37.235833, -116.053611	470, 474a, 553, 553a, 559g, 603	37.22352	-116.05895

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.35	Faultless: Faultless Test, wells UC-1; UC-3, UC-4	AEC/DOE; Atomic Energy Commission, Department of Energy	Central Nevada Test Area / Site, Hot Creek Valley, Nye County, Nevada, USA	1967, 1968	998m, 3275' TD, UC-1; ~1680m, 5512' TD, UC-4; 1477m, 4846' TD, UC 3; ~998-1680m; 3275' - 5512'.	Weapons Test, Geologic R&D: Faultless Test well UC-1 wellbore, 3m diameter drilled shallow casing for nuclear test well; 72" hole to 400' bgl; 400'-3275', 42" diameter borehole. Stratigraphy: 0-2400' bgl consisted of alluvium; 2400' to 3275' is tuff. (SGZ emplacement hole) Purpose of calibration test was to check suitability of area structure and stability as future test site; aka, Project Faultless; results proved area unsuitable for testing; device yield of ~200 to 1,000 kilotons; TD in zeolitized tuff; event / capsule set at ~3200' bgl. Site formerly known as CNTA, the Central Nevada Test Area; test proved site not stable enough for underground testing program; reference borehole diagram found in reference 557b. Reference 474 indicates well UC-4, deepest hole with TD ~5500' (1.68km) and 120" largest diameter hole drilled at TD. Other area larger diameter deep hole is UC-3, a 4846' TD, 120" borehole with 54" casing to 4782'	38.63421, -116.21622		470, 557, 557a , 557b, 558, 558a, 559	38.63421	-116.21622
3.36	Gnome: Gnome test	AEC/DOE; Atomic Energy Commission, Department of Energy	Eddy County, New Mexico, USA	1961	~370m, 1216'shaft	Test in tunnel off shaft within evaporitic sequence at 1184' depth. First test in Plowshares Program; Permian age Salado Formation (salt); 10' diameter vertical shaft drilled to 1216' bgl; horizontal tunnel at 1116'; reference 558b	32.26298°, -103.86592°	~8.4 miles SW from WIPP; Section 34 Township 23 South, Range 30 East, New Mexico Principal Meridian	558, 558a, 558b	32.26298	-103.86592

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3.37	Cannikin UA-1: Amchitka, Cannikin Nuclear test, UA-1	AEC: DOE; Atomic Energy Commission, Department of Energy	Amchitka Island (Aleutians), Bering Sea, Alaska, USA	1969-1970, test preparation; event, November, 6, 1971	~1874 m; ~6,150'	Weapons Test: Depth issue TBV; alternate TD mentioned is 1905m / 6150'/ 6250' bgl. Drilled "shaft", 2.28m / ~7.48' / 90" diameter borehole; ~5 megaton atomic weapon test at ~1790m bgl; this was largest underground test conducted by USA. Volcanic arc / forearc setting associated with Aleutian subduction zone; Aleutian Islands, Amchitka Island. Rock sequence primarily consists of basaltic units of submarine origin. See reference 602a.	51.469988, 179.106330	Located at southern margin of Bering Sea, northern margin of Pacific Ocean, Amchitka Island	470, 474; 478, 479, 557; 558, 558a, 596-602, 602a	51.469988	179.106330
3.38	Cajon Pass	DOSSEC / Drilling, Observation and Sampling of the Earths Continental Crust; NSF/USGS	San Bernardino County, California, USA	1986; 1987-1988	3510m, 11515' TD	Geology / rock mechanics R&D: Well drilled ~4km from San Andreas Fault area as geomechanics test well; penetrates late Neogene basin clastic units on crystalline basement. Borehole is 6.25" diameter at TD; 7 5/8ths" casing from 5494'-11380', 8.5" hole; DOSSEC borehole study; encountered relatively unaltered granite below ~1000'; ideal for mechanical test, granodiorite and gneiss; very low permeability, healed fractures, isolated zones of formation water with little vertical mixing evident from geochemical investigations; more basic igneous composition and foliations from 1450m - 2073m; granodiorites, tonalites, monzogranites and gneisses present ~2100-3500m. AKA Federal 2-26; API #07120060, https://secure.conservation.ca.gov/WellSearch/, 34.321498, -117.47953	34.322103, -117.478165	Approximate area location and alternatives; reported location of well ~34º18'52", 117º28'38"W, but pad seems to be north of this location; on margin of SW Mohave Desert; USGS reports location as Sec26, T3N, R6W, SBB&M, San Bernardino County, California; verify location	478, 479, 567, 603, 607, 607a, 607b, 608	34.322103	-117.478165

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3.39	SAFOD	ICDP; USGS, NSF (Pilot well); SAFOD, by EarthScope, NSF, USGS	Near Parkfield, Monterey County, California, , USA	2004-present. 2004-2008; main hole drilled. Pilot hole drilled 2002. Main hole testing expected to continue to 2023	~3214m, ~10544' (testing); 3965m DTD, phase III; ~1.5 km vertical, ~1.8 km inclined ~60 degrees; TVD San Andreas Fault ~2.7km; TD 3965m	Geology R&D: San Andreas Fault Observatory at Depth (SAFOD), Earthscope, near Parkfield; ICDP pilot hole drilled vertically in 2002 to 2.2km; pilot hole was drilled from same pad as SAFOD well; SAFOD observation well penetrates San Andreas Fault. Phase 1 in 2004 drilled Neogene Santa Margarita and ~1.5km vertically in Salinian granitic unit; Phase 2 in 2005; 8.5" hole directionally drilled with TVD bgl ~2.7 km depth; Phase 3 with sidetracks drilled and completed in 2007 DD ~3.5km (?); instrumentation in 2008. Below DD ~2km, Phase 2 and 3 portion of borehole entered exited granite and entered Great Valley clastic sequence in sidetrack hole section. Reported depth differs with phased drilling program; have not confirmed the TD that may be drilled depth while shallower depths may be TVD;TD is to be verified; Zoback et al. (Reference 608a, Table 3) indicates log runs to ~3965'MD; verify	35.974028,-120.552425	Approximate area location; ICDP coordinates 35° 58' 26.5" N, 120° 33' 8.73" W, 35.974039, -120.552431	608a, 608b, 609, 609a	35.974028	-120.552425
3.40	Fenton Hill	Los Alamos National Laboratory and US Dept. Energy	Sandoval County, New Mexico, USA	1975-1987	3000m - 4400m, 9842'-14435' {~3km (2 wells), ~4km, ~4.4km}	Geothermal R&D: Well series for enhanced geothermal investigations; diameter wells at TD reported at 8.75", 9.87". Located on the southwest flank of Valles Caldera, NM. Volcanic Miocene to recent exposed rock suite coincident with Jemez lineament; GT-2 well drilled in 1974 to ~2.98km (2.93km TVD); EE-1 drilled in 1975 to ~3.1km TD; EE-2 drilled in 1980 to ~4.4km; EE-3 drilled in 1981 to ~4km. General well stratigraphy, 0-750m, Cenozoic volcanics and sedimentary units; ~750m-1750m, Precambrian gneiss; wells to total depth mixed gneiss, mafic schist, and granodiorite and mixed igneous / metamorphic units with metavolcanic sequence.	35.879804, -106.674903	Well field area	478, 479, 602-604, 604a, 605, 606; hole diameter data also in references 523, 524	35.879804	-106.674903

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.41	IDDP-2	Iceland Deep Drilling Project (IDDP) Consortium and DeepEGS	Reykjanes peninsula, Reykjanes geothermal field, Southwest Iceland, Iceland	2016, 2017	4659m / 15285' DTD reached in January, 2017; 5000m planned TD; TVD ~4500m for completed well	The IDDP Consortium has included the Iceland National Energy Authority, numerous other geothermal, drilling industry companies, R&D partners (e.g., U.S. universities; contributions from ICDP and U.S. NSF; EU R&D groups) for drilling IDDP-2 with HS Orka / others; planned TD of 5km with estimated bottom temperature near 500oC; in 2016, group re-enters and deepens ~2.5km deep existing hole RN-15. RN-15/IDDP-2 was at 4626m depth 12/21/2016, with 8.5" hole; reached 4659m in January 2017 and appeared to cease drilling given bottom hole conditions met criteria. The IDDP-1 was drilled in NE Iceland at Krafla caldera in 2009; planned 5km borehole but encountered magma ~2104m depth with 12.25" bit. Reference 603c	63.825772, -22.680672	Power Plant area, 63.828879, -22.692544; approximate area IDDP-2 location provided near power plant; location area of IDDP-1 ~ 65.717402, -16.758250, closer to 65.716231, -16.763414; see http://www.sciencedirect.com/science/article/pii/S037565051300045X and http://iddp.is/ . Spud location IDDP-2 near 63.827557, -22.678446	603b and links; 603c	63.825772	-22.680672
3.42	San José: mine rescue shaft	CMSE, San Esteban Mining Company	Atacama Region (Desert), Copiapó Province, Chile	Operations since 1889; Rescue of miners, 2010	~700m, 2300'	Rapid Drilling, Large Diameter hole in Crystalline Rock: San José copper–gold mine (aka mine (Chile / Copiapó Mine Rescue 2010) event and rescue of miners; rescue capsule used to extract the 33 men was the *Fénix 2*, a device 54 centimeters (21 in) in diameter; rescued miners from level at ~2300' (~688 meters (2,257') bgl with multiple retrievals (33) of personnel. First successful rescue hole / shaft drilled (diameter ~21") in just days using Schramm T130XD rig. Access to miners via 5km spiral access tunnel system was failure. Ore occurs within diorite cut by mesothermal Au/Ag veins. Mine area in operation for over 125 years; copper sulfide vein deposits; mine operations closed in 2010	-27.160203°, -70.496778°	27°9′36.7″S 70°29′48.4″W	525, 525a	-27.160203	-70.496778

3.43	Other Examples of Deep / crystalline basement Drilling Programs					**Examples of other International R&D Drilling Programs and Operators: 1) SKB PASS PROJECT**, Sweden: completed = Swedish Nuclear Fuel and Waste Management Company (SKB) project on alternative systems (performance) study - SKB. Project on Alternative Systems Study (PASS) Final Rpt., 10/1992. SKB Technical Rpt. TR 93-04. 1993; Svensk Kärnbränslehantering, Swedish Nuclear Fuel and Waste Management Co., SKB; Ref. 561. 2) **NEDRA / Russia** = Scientific Industrial Company on Superdeep Drilling and Comprehensive Investigation of the Earth's Interior; 3) **NIREX / UK:** for nuclear waste repository site investigations; 1989-1997; Ref. 471a for NDA cores, data set created by BGS; drilling near Sellafield (Cumbria) and Dounreay (Caithness); Nuclear Industry Radioactive Waste Executive became UK Nirex Limited, then integrated as UK Nuclear Decommissioning Authority (NDA), 2007; in 1990s, drilled boreholes ~2km deep with 6.25" diameter at TD. 4) **SWEDEN: DGE**/ Dept. Engineering Geology holes #1 and #2; geothermal / hydrologic study, Lund, Scania, Sweden; 2002-2003, #1, TD ~3702m, 17.5" diam. at TD in basement. Basement top ~2000m bgl; gneiss, gneissic granite (Refs. 487, 560)			NIREX: 470, 471, 576a, 472-492; 560-565; DGE, 487, 560, 586			
3.44	**Selected United States Deep Water Drilling Engineering; Deep Vertical and Extended Reach Examples**											

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location information	References	Approx. Latitude	Approx. Longitude
3.45	Tiber: Tiber Prospect, Oil Field	BP / British Petroleum	Keathley Canyon Block 102 (BP), Gulf of Mexico, USA	2009	~10685m; ~35,055’	Oil and Gas - Offshore Deep Water and Deep Drilling: Field discovery using Transocean Deepwater Horizon rig prior to drilling the BP Macondo prospect. Reported 35,050’ vertical depth and 35,055’ (10685m) feet measured depth (MD), or more than six miles drilled, while operating in 4,130’ (1260m) of water; drilled ~31000’ below mudline (to be verified). One of deepest vertical wells drilled at the time. TD in Lower Tertiary; Paleogene production from deep water / turbidite sands; reservoir seals, deep water claystones; reported 5.5” diameter hole for deeper sections of well. Several billion barrel discovery; suspended operations after Macondo accident	26.878333° -93.268333°	Approximate area location; discovery located 300 miles ESE of Corpus Christi, TX; location taken from https://en.wikipedia.org/wiki/Tiber_Oil_Field , noted in references 550, 551	550, 551; 475	26.878333	-93.268333
3.46	Macondo: BP Macondo	BP / British Petroleum	Mississippi Canyon Block 252, Gulf of Mexico, USA	2009, 2010	5596m; 18,360’	Oil and Gas - Offshore Deep Water and Deep Drilling: BP / Transocean Deepwater Horizon, Macondo Prospect: drilling, accident, consequences, and remediation measures with extensive documentation are not included herein. Reported 9 7/8ths” casing set to 18304’ / 18126’ (verify, TBD); also reported 8.5” hole to TD@18360’; water depth ~5000’; TD in Neogene deep water clastic sequence	28.736667, -88.386944	Location information taken from Reference 552, https://en.wikipedia.org/wiki/Macondo_Prospect. Directional drilling efforts and final well control demo of capabilities, limitations	552	28.736667	-88.386944

Table #. Item #	Well / Borehole	Operator / Owner	Location	Year, Operations / other	Total Depth	Comments: e.g., Hole Diameter, Bit Size, Casing, Cost, Geology	Approximate Latitude / Longitude	Approximate Location: area or alternative location	References	Approx. Latitude	Approx. Longitude
3.47	Perdido: Perdido Project	Shell / Royal Dutch Shell Group	Alaminos Canyon Block 857, Gulf of Mexico, USA	Discovery well / field in 2002; first production, 2010	~5486m, ~ 18,000 bsl. Drilling ~up to 9000' below sea bottom; TD wells ~ 18,000 bsl	Oil & Gas - Offshore Deep Water / Deep Drilling: Ultra-deep water facility / production hub platform. Perdido (prod., 2010) was world's deepest offshore platform facility with ~2,450m (8,000') depth water, but now surpassed by Stones facility. Perdido associated field production wellheads approaching ~10,000' water depth; complex production / management operation; Perdido intended for development of the Great White, Silvertip and Tobago fields. Production from Paleogene units deformed in late Paleogene / early Neogene of "Perdido fold belt"; "foldbelt" result of large scale downslope mass displacement; sediments are late Cretaceous to Eocene with deformation in Oligocene /early Neogene; productive units up to 9,000' below sea bottom; brecciated carbonate rock (Cretaceous) and Paleogene turbidites provide primary production. Casing and bit size require added literature review.	26.128889,-94.898056	Approximate area location provided for Perdido, from https://en.wikipedia.org/wiki/Perdido_%28oil_platform%29	Perdido, 549, 549a; Stones / Cardamom, 545-548; extended reach drilling, 470, 474, 475, 491	26.128889	-94.898056
3.48	Other Gulf of Mexico					Oil & Gas - Offshore Deep Water / Deep Drilling: Other deep water engineering examples of note are: 1) Shell Stones Project, Walker Ridge block 508, Stones 2 well with TVD 28,560' and Stone 3 to total depth of 29,400' in ~9500' water depth with reservoir at ~17,000' below mud line. 2) Shell Cardamom: Garden Banks Block 427, discovered in 2010; ~800m water; field well drilled ~6.4km (below mudline) and hole directionally drilled from Auger Platform with TD ~5km from platform; reservoir sub- salt		Multiple locations for examples of extended reach, deep water drilling	549a		
3.49	Other: Uraguay, India, Russia				Deepest water depth and horizontal reach drilling	Deepest and longest reach wells: 1) Sakhalin-1 project wells, in 2012, Z-44 well, MD 12376m, world extended reach record at time; 2) Raya-1, Uraguay, record water depth 2016 at ~3,400 m / 11,156'; and 3) India former world water depth record, ONGC well # 1-D-1, 3174m water depth.		Highly approximate area locations: 1) Sakhalin project fields, 52.9633, 143.4937; 2) Raya-1, -36.1062, -52.8947; 3) ONGC well # 1-D-1, 16.6359, 83.1591	475, 475a-c		

Table 4 – (Physics Facilities) Selected Physics Underground Research Laboratories (URLs) and Facilities; Existing, Proposed, Candidate, Former R&D Facilities and Former Candidate Sites

Table #. Item #	Facility, Site, Candidate or former Candidate Site	Country	Responsible Party (Managing, Funding, Constructing)	Date: Planning, Operations, Activity	Depth	Characteristics, access, geology, other	Location, Latitude and Longitude	Additional or Alternative Location Information	References	Approx. Latitude	Approx. Longitude
4.1	Baksan: BNO / Baksan Neutrino Observatory	Prielbrusye, Kabardino-Balkarian Autonomous Republic, Russian Federation	INR, Institute for Nuclear Research; Russian Academy of Sciences, RAS	1966 and 1977 both years reported as start facilities construction and test activities; ; modern phase tests since 1998	~300-2300m / 984' - 7546' bgl; zone testing reported. Estimated maximum potential depth 3500m bgl	(Crystalline) First purpose built neutrino laboratory; entrance elevation ~1700m; Mt Andyrchi rises to ~4200m elevation; two parallel horizontal tunnel access; 4000m of adit with instrumented sites (Reference 650, ~4400 mwe in tunnel); within area of highest mountains of Caucasus, e.g., Mt. Elbrus. Geology: Noritic crystalline rock within test area; Neogene phase in closure of Tethys seaway with ongoing collision of Eurasian / India subcontinent plates.	43.275556, 42.690278	Beneath Mount Andyrchi, North Caucasus, southern Russia; see Wikipedia.org ; located in and proximal to town of Neutrino about 10 miles from Tyrnauz facility; verified, google maps location	611, 612, 618, 618a, 619, 638, 639, 650. Tabulated information in Table 4 is derived from multiple sources and data; see general references 610-622 for much of source information for Table 4 sites	43.275556	42.690278

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4.2	Boulby: BUL / Boulby Underground Laboratory (aka Boulby - Palmer Laboratory)	Yorkshire, England, United Kingdom	Imperial College; Zeplin Research Program; Cleveland Potash (Israel Chemicals Ltd., subsidiary) owner / mine operator; Institute of Underground Science, oversight of testing under Science and Technology Facilities Council and ICL	Modern potash production, 1973; Underground Laboratory testing since 1987; main test phase start in 2001	~1000m - 1440m; 3281'-4724' bgl; testing @ ~1.1km bgl, 2805mwe	(Salt) Boulby Mine: Potash, sylvite, polyhalite and salt mine; rock-salt and potash produced; two access shafts to ~1150m bgl, and 5.5m diameter; ~1000 km (620 miles) underground tunnels; inner tunnel access to 1440m (~4593' bgl) mined depth; 1100m bgl ~=2805mwe, Ref.650; UK deepest mine; Late Permian (Zechstein salt basin age) evaporites overlain by Mesozoic age clastic basin deposits (e.g., Bunter Sandstone), >~250 mya. Physics testing ~1100m bgl; study of dark matter, cosmic rays, muons, other	54.5534, -0.8245		611, 612, 617-619; 620-621, 621a; 650; 715-722	54.5534	-0.8245
4.3	Gran Sasso: LNGS / Laboratori Nazionali del Gran Sasso.	L'Aquila, Abruzzo Region, Italy	Italian Istituto Nazionale di Fisica Nucleare (INFN)	1968-1984, first tunnel construction; second tunnel completed 1995; testing since 1987; 1989 major URL test phase initiated	~1400m; 4593' bgl	(Dolomite / Limestone) Largest URL in the world; two ~10km road tunnel access; up to 1400m bgl; neutrino and astroparticle physics R&D; ~3200-3800mwe (reference 650 states 3500mwe). Geology: carbonate (limestone and dolomite) units of Apennine Mountains; Gran Sasso Mountain area, the highest peak in the Apennine mountain belt. Late Miocene-Pliocene deformation and mountain building; Mesozoic-Neogene shelf carbonates (limestone) developed near transition to basinal argillaceous clastic sequence. Compressional regional structures formed with detachment and rotation. Large 20m caverns excavated for testing, ~1500m bgl in carbonate rock	42.419831, 13.517228	Located between L'Aquila and Teramo; mid-tunnel location 42.454,13.576; Assergi, town near SW tunnel entrance, 42.419831, 13.517228, INFN external facilities	611, 612, 618, 619, 621, 621a, 622, 645, 646, 650; general references 610-617; 725 (=97);	42.419831	13.517228

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4.4	Canfranc: LSC / Laboratorio Subterráneo de Canfranc	Canfranc, Huesca Province, Aragon, Spain	University of Zaragoza , operator; Consortium of the Spanish Ministry of Education, Science and Innovation	Since 1980's; 1985 early test phase old facility; 2010 recent phase tests new facility	~250m – 850m; 820'-2789' bgl; access to maximum depth 850m bgl	(Carbonates) Early tests in mid 1980s in abandoned 8.6 km (access train station) Somport rail tunnel; 1988, small test facility; new opportunities since road tunnel with rooms excavated between old rail (built 1915-1925) and new road tunnels for R&D constructed since 2005; 2450mwe; recent testing ~850-900m bgl; tunnel access also by new Somport Auto Tunnel (construction 1994-2002); abandoned rail tunnel now serves as an emergency lane for car Tunnel of Somport and Canfranc laboratory ; Ref. 650, ~ 2450 mwe. Geology: Pyrenees Mountain URL; under Mount Tobazo; Paleozoic limestone bedrock; main phase mountain building during Paleogene (~35 mya); Paleozoic (often carbonates) rest on Variscan basement; tunnels and test locations largely within Devonian age carbonates (limestone)	42.75065° -0.51460°	Located under the Pyrenees mountain El Tobazo (elevation ~1850m); Spanish side of the Aragon Pyrenees; rail station location 42.75065°N -0.51460°W. Alternate locations are the Spain, canfranc station 42.747446, -0.515338, and France, tunnel 42.818194, -0.560990; near Spanish-French border adjacent to Somport Highway tunnel	618, 618a, 619, 620, 621, 621a; 636, 637, 637a; 650; general references 610-617, in particular, 611, 612,	42.75065	-0.51460

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4.5	Modane: LSM / Laboratoire Souterrain de Modane	Modane, France (Frejus Roadway Tunnel between France and Italy)	Le Centre National de la Recherche Scientifique / CNRS, and CEA /Commissariat à l'Energie Atomique	Operations since 1982; constructed 1979-1981;	~1200-1700m, 3937' - 5577' bgl testing; ~1700m overburden	(Calc-Schist, "crystalline " metamorphic) Access via Frejus roadway tunnel, the tunnel route Fréjus / Savoie (aka Fréjus Underground Laboratory in Frejus tunnel); Laboratory located adjacent to tunnel beneath Frejus Peak (Mont); depth >4000mwe, average 4800mwe; reference 621 states it is the deepest of facilities testing; reported test area ~4000-4800mwe in reaches of thickest overburden; in 2012, constituted thickest overburden of EU laboratories. LSM is situated within the Piemonte zone and characterized by calc-schist with a phyllitic facies (highly schistose) and a carbonate facies (reduced schistocity); exhumed Alpine Cretaceous / Paleogene high pressure subduction complex	45.189951, 6.684824	Location provided along tunnel route to SE of Modane. Site is near Italian-French border (Cottian Alps) adjacent to the Fréjus Highway tunnel connecting villages of Modane, France and Bardonecchia, Italy; Modane in town laboratory location, 45.189951, 6.684824 shown on google maps	611, 612, 617, 618, 618a, 619, 620, 621, 621a; general references 610-616; 644, 644a; 650	45.189951	6.684824
4.6	Bas Bruit : LSBB / Laboratoire Souterrain Bas Bruit / Low Noise Underground Laboratory	Rustrel, Department Vaucluse, Provence, France	University of Nice and Research consortium	2009 instrumentation	~518m; 1699' bgl (maximum vault depth; ~1500mwe)	(Carbonates) ~3.9km galleries and horizontal tunnel access to vaults; karstic area located in Cretaceous (Neocomian and Aptian) carbonate platform deposits of the Albion Plateau; associated with area of the Fontaine-de-Vaucluse aquifer composed of fractured carbonate rock; with artificial galleries constructed for testing in primarily unsaturated karst terrain; modified former military zone and underground facility from cold war era	43.935169, 5.485182	Approximate tunnel area location; located within nature park of the Luberon; alternate surface location for entrance ~ 43.92865°, 5.48705°; 43.928611, 5.486944	621; 642, 643	43.935169	5.485182

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4.7	SUL / Solotvina Underground Laboratory	Zakarpattia Oblast, western Ukraine	INR / Institute for Nuclear Research, Kiev; constructed by the Lepton Physics Department (LPD) of the INR; under the Ukrainian National Academy of Science	since 1984, but currently closed	~430m; 1411' bgl (~1000 mwe)	(Salt) Access via salt mine shaft to ~430m; may not be in operation currently; reportedly domal (verify); located within the Transcarpathian trough; mine was closed in 2013 due to environmental concerns, salt contamination of stream and ground water in area; basinal salt deposits formed in Eocene and Miocene. Solotvina formerly was salt mine of Aknaszlatina, Hungary; Zakarpattia Oblast formerly aka Transcarpathian Oblast	47.960021, 23.873187	Transcarpathian region, western Ukraine; Solotvina (translation, salt wine; named for salt mine of area); town of Solotvino salt lake located at ~ 47.955556, 23.871111; used as approximate locale for facility, un-named salt mine location, 47.960021, 23.873187	618, 618a, 619; general references 610-617	47.960021	23.873187

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4.8	Kamioka: Kamioka Observatory	Kamioka-cho, Gifu (Kamioka-Mozumi mine, Hida-city, Gifu), Chubu Region, Honshu Island, Japan	Institute for Cosmic Ray Research, Univ. Tokyo	Since 1983	~800-1000m; 2625' - 3281' bgl; ~800m bgl to max. ~1000m bgl	(Crystalline) Kamioka (Ag, Pb, Cu, and Zn) Mozumi zinc mine, skarn ore replacing limestone. Atotsu tunnel road access for area mine; Kamioka Underground Observatory now referenced as Kamioka Observatory. Selected tests by name include: KAMIOKA Nucleon Decay Experiment, and Super KamiokeNDE; KamiokaNDE ~1,000 m underground of Mozumi Mine of the Kamioka Mining and Smelting Co. Reference 650 states 2700mwe for mine test level; other sources state ~2400mwe; Mozumi / Kamioka mine area for testing; was once largest Zn mine in East Asia; ~1.7km tunnel road access to laboratory; mining ceased in `2001; 20m and 40 m span caverns for testing in Hida metamorphic unit rocks at ~1000m bgl; gneiss, Paleozoic age metabasite and granitic rock	36.427549, 137.299978	Kamioka, Mount Ikeno, 36.4267°N 137.3117°E ; more likely location area 36.427549, 137.299978; mine area also 36.352994, 137.319909; illustrated on Wikimapia.org beneath Mt. Ikeno showing tunnels and experiments; also Reference 657a	611, 612, 618, 618a, 619, 621a; 622, 637a, 650, 655; 656, 657, 657a-660; general references 610-617	36.427549	137.299978

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4.9	Oto-Cosmo : OTO / Oto-Cosmo Observatory	Oto-Tentsuji tunnel, Nara Prefecture, Japan	Osaka University	~1996	<467m; 1532' bgl; maximum ~467m bgl (~1400mwe)	(Lithology TBV) Access in association with unused rail tunnel; near center of 5 km stretch of Oto-Tentsuji rail tunnel of Goshin Line; Reference 655a	34.344097, 135.746014	Approximate location information: tunnel between Oto Village and Nishiyoshino Village, Nara Prefecture); but Oto and Nishiyoshino merged with Gojo in 2005; location of area uncertain; approximate location placed (Google maps) arbitrarily E of Gojo 34.344097, 135.746014	611, 612, 618, 618a, 619, 622; 651- 655, 655a; general references 610-617	34.344097	135.746014
4.10	Y2L: Yangyang Laboratory	Gangwon-do / Kangwondo Prefecture, Republic of Korea	Korea Middleland Power Co., Yangyang Pumped Storage Power Plant (tunnel); Korea Science and Engineering Foundation	2016, KIMS detector installation	~700m; 2296' bgl	(Lithology TBV) Yangyang Underground Research Laboratory (Y2L) with access by road tunnel near Yangyang Pumped Storage Power Plant; associated with 1) KIMS (Korea Invisible Mass Search) ; reference 650 states 2100mwe; 2 km tunnel access by car; http://dmrc.snu.ac.kr/english/main_e.html ; and http://dmrc.snu.ac.kr/english/media/science070706.pdf	38.0163, 128.5467	Beneath Mt. JeomBong, one source at 38.041394, 128.594164 seems off location; Power Station Pumped Storage Power Plant located at 38.0163, 128.5467	611, 612, 618, 618a, 619, 621a; 650, 655, 661, 662; general references 610-617	38.0163	128.5467

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4.11	INO: India-based Neutrino Observatory	Near Pottipuram village, Theni district, Tamil Nadu state, India	MOU for operations, Tata Institute of Fundamental Research (TIFR) and others	TBD; construction delays; (MoEF) grants environmental clearance, March 2018; Reference 641d	~1200m - 1300m; 3937' - 4265' bgl (planned depth)	(Crystalline / Charnockitic granite) Purpose built facility planned with ~ 2km tunnel for access. Construction was expected to start in 2015. Reference 650 states 3500 mwe for mine test level; planned 7.5m wide and 2.1 km long access tunnel. Geology: TBD	9.956046, 77.283598	Location - approximate area location; surface facilities near Pottipuram, Bodi West Hills, Theni District (Ref. 641). Refs. 611, 612 discuss former location in Masinagudi, 11.564516, 76.635963; site location changed; Refs. 621b, 640b, 641 show location used herein. Wikipedia.org INO, 9°58′N 77°16′E; on Google.map at ~9.956046, 77.283598. (http://www.ino.tifr.res.in/ino/faq.php#projectlocation, Figure 2; Refs. 640a, 641, notes)	618, 618a, 619, 621a, 621b; 640, 640a, 640b, 641, 641b, 641d; general references 610-617; 650	9.956046	77.283598

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4.12	Kolar: Kolar Gold Fields	Kolar Gold Fields, Kolar District, Karnataka State, India	BEML / BGML (Bharat Gold Mines Limited), mine operator; mines closed; earlier physics experiments Tata Institute of Fundamental Research (TIFR), Mumbai, Osaka City University, Japan and Durham University, UK	~1960-1992 for main physics research; testing reported as early as 1951; mining since bronze age or earlier	~3200m; 10499' bgl (>15000' bgl mining operations ; testing ~10500' [3.2 km] bgl; ceased operations, 1992, mine closure)	(Crystalline / metamorphic) India underground physics testing (cosmic ray / muon, neutrino experiments) from 1960s-1990s in the KGF (e.g., KGF / Kolar Gold Fields' Champion Reefs Mines, ~10500'bgl; Gifford Shaft neutrino experiment in 1965); had very deep test capabilities; detectors emplaced ~2.3 km bgl; mine closed and neutrino particle experiments ended in 1992; all district mines closed in 2003; recent plans to reopen; KGF area includes deepest mining in Asia, up to ~17000' bgl; surface mining since 6000 ybp; first mine shaft in 1875; (Champion is one of world's deepest mines). Geology: Deccan Plateau, within the Kolar Schist Belt, 2.7Ga old; associated with a 2.5Ga suture zone within Dharwar Craton; schists / amphibolites cut by vein Au mineralization; ore veins with thin zone of alteration in adjacent host rock	12.939266, 78.255652	Approximate location for Kolar Gold Fields town, Kolar Gold Fields, Bangarpet Taluk, Kolar District, Karnataka state, India 12.961736°N 78.270721°E (Reference 641a, 641c); Champion Reef mine used for experiments near Andersonpet; Champion Reef mine approximate area location 12.940458, 78.259388	612, 614, 615, 641a, 641b, 641c	12.939266	78.255652

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4.13	SNOLab	Creighton Ni/Cu mine, Sudbury Neutrino Observatory / SNO, Sudbury, Ontario, Canada	Vale Ltd., INCO mine operator	1984-1990 planning and construction; see earlier discussion of Creighton Mine in tables; underground mine operations since 1901/1906; discovery in 1856; Cu, Ni, sulfide ore	~2000 - 2073m, ; 6562' - 6801' bgl (in 2008, mined access to ~7800' (2377m) bgl)	(Crystalline: igneous / metamorphic) SNO / SNOlab: In Creighton Ni / Cu Mine; #9 vertical shaft access to ~2073m (~6800') bgl; was deepest single continuous drop shaft, deepest metals mine in N America; now surpassed by LaRonde. Refs. 650, 667, up to ~6000mwe. Geology: crystalline rock; mined along fault zone. Meteor impact on ~2.5Ga basement at ~1.85Ga associated with generation of the granophyre and norite-gabbro of 3km thick Sudbury Igneous Complex (SIC); impact structure deformed to ~72kmx27km during Penokian and Grenville orogenies (~1.8Ga, 1.1 Ga); post-impact sedimentary fill with Whitewater Group superjacent to SIC; Archean / Paleoproterozoic basement fractured from impact. Mining induced seismic event monitoring. Cavern at ~2km bgl for testing	46.471639, -81.186619		611, 612, 618, 619, 621a, 622; 650; 667-673; general references 610-617. Same as Item 1.10, herein	46.471639	-81.186619

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4.14	Soudan	Breitung Township, St. Louis County, Minnesota, USA	State of Minnesota Department of Natural Resources	1981 (early physics testing) to present); Fe ore mine; discovery ore and mining, 1882; mined 1882-1962; underground mining, ~1900-1962; testing through ~2015; Iron mine; tests terminated 2016 and facility closed	~700m; 2341' bgl (testing)	(Crystalline / granite and metamorphic) Soudan Underground (Research) Laboratory: in Soudan mine (closed mining) now located in Lake Vermilion-Soudan Underground Mine State Park; access by old mine shaft; slightly inclined, depth to ~700m and operations extended to ~2341' bgl; ~50 miles of subsurface excavations. Cooperative studies with Fermi Laboratory; test at ~713m bgl / 2090 mwe; deeper testing, Level 27, ~2300' bgl. Geology: Late Archean Granite with hematitic ore, ~ 2.7 Ga; Minnesota's Iron Range area, a Vermilion Range mine; associated metamorphic greenstone units. Ancient water chemistry and biological activity also covered in Table 1 references; MINOS test lost support; physics facility closed and decommissioning since 2016	47.819610, -92.241709	In state park; closed mine in the Iron Range; location verification with Wikimapia.org	611, 612, 614, 618, 618a, 619, 621a, 622; 723-726 (repeat references, 96-98); general references 610-617. Same as Item 1.25, herein	47.81961	-92.241709
4.15	Sanford: Sanford Underground Research Facility / SURF	Homestake (Gold) Mine, Lead, Lawrence County, South Dakota, USA	Barrick Gold, abandoned mine, former operator; testing operator South Dakota Science and Technology Authority, test management, Lawrence Berkeley National Laboratory	Mine discovery, 1876; mining operations ceased in 2001. Early physics tests in 1960s. Sanford Laboratory facility funded, 2006, implemented since 2011; ongoing testing since 2007	~200m-1478m; 656' - 4850' bgl (for testing projects); mine depth ~ >8000'	(Crystalline /metamorphic) SURF, previously aka Deep Underground Science and Engineering Laboratory (DUSEL). Located in currently non-producing Homestake Au mine; two shafts for test access. First solar neutrino detection, 1968 by Davis. Geology: 2Ga Early Proterozoic metasediments and meta volcanics; intruded and metamorphosed through ~1.8 Ga to 1.7 Ga. Greenstone belt / iron formation deposits - Poorman, Homestake (primary ore horizon, iron carbonates / silicates), and Ellison units; metamorphic disseminated and paleo-placer Au accumulations. Current testing in 4850' level (~4300mwe). Refs. 622,650 assert test levels ~ 4500mwe - 7000 mwe. Mine >6000' bgl flooded since ~2009. Facility chosen to be US (DOE/ NSF) DUSEL; later funded by Sanford. Facility rehabilitation, 2008-2017. See Table / Map Layer 1 (Mines).	44.352,-103.751	Black Hills, Homestake Gold Mine shafts for access; DUSEL facility surface location from Google.com/maps; see Yates, Ross, other key mine locations on wikimapia.org, Lead SD area with labels	618, 618a, 619, 621a; 622-627 (49-53); 628, 628a, 628b; 650; general references 610-617. Same as Item 1.14, herein	44.352	-103.751

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4.16	CUPP: Center for Underground Physics in Pyhäsalmi	Pyhäsalmi Mine, Pyhäjärvi municipality, Oulu Province, Finland	Inmet Mining Corporation (formerly) mine operator; (currently) First Quantum is owner / operator; CUPP funding from several sources	Underground mining since 1967 ("old mine", ~<1000m); deeper access ("new mine", ~1440m); physics testing since 2001	~980m; 3215' bgl (test access to ~980m bgl; mine works ~1000m-1444m bgl, ~4738' bgl)	(Crystalline / metamorphic) Pyhasalmi Cu/Zn pyrite mine to be closed by 2018/2019; new Timo Shaft to 1440m bgl for mine operations; old access shaft and new deeper shaft access; ventilation shaft; one spiral decline for access by car; reportedly is 2nd deepest mine in Europe and deepest European metal mine; 4000 mwe; physics test operations conducted; by 2005, testing limited to <1000m bgl; subsequent status TBD. Geology: Paleoproterozoic Island arc (2.0-1.8Ga) setting for origin of Savo Schist Belt, central Finland; formed as submarine syn-volcanic hydrothermal system with massive sulphide formed by replacement of host units; Savo Schist belt consists of meta-volcanics, meta-migmatitic gneiss / tubidite origin meta-sedimentary rocks; 1.87-1.89Ga volcanic and intrusive complex; sulphide mineralization within alteration halo. Also see site / Item 1.30	63.661077, 26.040931	Alternate approximate location, 63.658611, 26.041111	611, 612, 618, 618a, 619, 620; 707-714 (repeat of references 129-134); general references 610-617. Same as Item 1.30, herein	63.661077	26.040931
4.17	CJPL: China JinPing underground Laboratory	Sichuan Province, China	Ertan Hydropower Development Company (EHDC), tunnel construction and operations	Work initiated in 2009; completed construction in 2010	~1800-2400m / 5905' - 7874' bgl (testing); development in progress	("Crystalline" / metasediments, marble) Tunnel access up to 1400m bgl; neutrino and astroparticle physics R&D; note reference 647 and 649 indicate test ~2400-2500m bgl; reference 650 states ~7500mwe (other sources, ~6700mwe); EHDC envisioned two tunnels, ~ 17km long; construction status TBD. Induced microseismicity; EDZ enlarged; spalling issues	28.139440, 101.786038	Located under JinPing Mountain; along the Yalong River; adjoins JinPing Auto Tunnel; tunnels shown on wikimapia.org map. See presentations, TAUP, 2013, Ref. 619; Jianmin Li, 2015, Ref. 647a	618, 618a, 619, 621a; 647, 647a,648-650; general references 610-617. Reference 650a examines JUNO lab, China, but not included in map.	28.13944	101.786038

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4.18	ANDES: Agua Negra Deep Experiments Site	Chile / Argentina; Vicuna, Region de Coquimbo, Chile; Iglesia Department, San Juan Province, Argintina	ANDES / Underground Laboratory and the Latin American Consorsium for Underground Experiments / Consorcio Latinoamericano de Experimentos Subterráneos / CLES	planned to open in 2020; TBD	<1750m; ~5742' bgl (Maximum overburden ~1750m)	("Crystalline / Volcanic, volcaniclastic) Approximately 14 km road tunnel to be constructed connecting areas of Chile with Argentina. Road tunnel entrance portals 3,950m on Argentine side and 3,750m on Chilean side. Geology: sub vertical Permian-Triassic andesitic, basaltic, rhyolitic, and dacitic volcanic, volcaniclastic and pyroclastic rocks of the Choiyoi Formation overlain discordantly by Tertiary rocks of the Doña Ana Formation consisting of tuffs, volcaniclastic, pyroclastic and clastic sediments. Area outcrops of Permo-Triassic Choiyoi Group rock with intrusions of rhyolite, basalt and aplite dykes, sills and veins; located within the Rio Colorado reverse fault zone; Paleozoic basement is a complex of middle to early Paleozoic sedimentary, igneous and metamorphic rocks	-30.197943, -69.850534		618, 618a, 619, 621a, 663-666, 666a; general references 610-617	-30.197943	-69.850534
4.19	Huguenot : Huguenot Tunnel; proposed physics laboratory (South African Underground Laboratory / SAUL)	Paarl, Western Cape Province, South Africa	South African Underground Physics Project, consortium, R&D group	TBD; proposed	~300 - <700m; ~984' - 2297' bgl (Maximum ~700m bgl; tunnel with overburden thickness variation, reasonable average ~300+m overburden)	(Sedimentary; TBV) SA R&D group proposing underground physics / astrophysics laboratory; in ~3.9 km tunnel; dark matter investigations from southern hemisphere; granite and sandstone present / Table Mountain sandstone (SS), quartzitic of the Cape Supergroup, Cambrian/Ordovician rift basin fill sequence found resting on older granitic basement complex; Table Mountain (SS) is within the late Paleozoic Permo-Carboniferous age fold belt of the Western Cape Province; tunnel considered as option to deep mine activities; 2015, feasibility studies	-33.732484, 19.111133	Du Toitskloof Mountains; ~42 miles (~67km) ENE of Cape Town	679-681	-33.732484	19.111133

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4.20	SATREPS / NELSAM: Science and Technology Research Partnership for Sustainable Development; Natural Earthquake Laboratory in South Africa Mines	Moab / Khotsong mines, near Orkney / Klerksdorp, Gauteng Province, South Africa	Japan (JICA, Japan International Cooperation Agency) initiative, South African study support and cooperative R&D (CSIR, Council for Scientific and Industrial Research, South Africa, and CGS / Council for GeoScience, South Africa); AngloGold Ashanti, other	Start testing TBV; Moab / Khotsong 1st production in 2006; AngloGold Ashanti	~3000-3500m; 9843' - 11483' bgl (~3+ km bgl available for tests, multiple mines)	(Crystalline / metasedimentary) Deep mine seismic geophysical investigations; AngloGold Vaal River Operation, Klerksdorp; Kopanang, Great Noligwa, Moab/Khotsong mines; microseismic events, macro-events; strain meters; strong motion detectors, induced micro-seismic monitoring; Witwatersrand Basin, Precambrian metasedimentary sequence. NELSAM is successor project to DAFSAM. See mines Table 1 and references, and map layer; see Items 1.5, 1.6, 1.9, 1.11, herein	-26.984938, 26.801244	Vaal River Operations, near Klerksdorp: Moab/Khotsong Au and uranium mines, -26.984938, 26.801244; Kopanang, -26.982481, 26.741987; Great Noligwa, -26.959778, 26.785512; studies also included Goldfields Dreifontein mine	610; 682-687; 702-706	-26.984938	26.801244
4.21	JAGUARS / NELSAM /DAFSAM: JApanese-German Underground Acoustic Emission Research in South Africa; Natural Earthquake Laboratory in SA Mines; Drilling Active Faults Laboratory in South African Mines	Mponeng gold mine is near Carletonville, Northwest Province, South Africa	Japan, Germany, US, South African, and mining industry AngloGold Ashanti research effort	TBV; and ongoing	~3000-3500m; 9843' - 11483' bgl (~3.5 km for seismic studies; mine depth to >4 km bgl)	(Crystalline / meta-sedimentary) Deep mine seismic / geophysical studies; AngloGold's West Wits Operations area; Mponeng, Tau Tona, Savuka mines. Continuous seismic monitoring of micro- / macro-seismic events at 3.5 km depth bgl, Mponeng. Fault drilled in Tau Tona for DAFSAM project; Tau Tona, Western Deep NELSAM project tested at~3600m-3650m bgl to study Pretorius Fault examining seismogenic process at focal depth of earthquakes in mines. NELSAM is successor to DAFSAM. JAGUARS key mine is Mponeng. Temporary stations from PASSCAL / Program for the Array Seismic Studies of the Continental Lithosphere were deployed in TauTona / Mponeng. Geology: Gold bearing sediments of the Witwaterstrand Basin (2.7-2.9 Ga) disruted by ~2Ga Vredefort meteor impact creating a 300km wide ringed feature. See Table 1, and map, this study; see Items 1.1, 1.2, 1.3, 1.4, herein	-26.437057, 27.431744	West Wits Operations, near Carletonville: Mponeng mine, -26.437057, 27.431744; Tau Tona -26.415249, 27.427438; Savuka -26.420982, 27.404544; also monitor Dreifontain and Kloof	610; 688-701; 702-706 (several are repeats of 115-117, 108-112); reference 706 good for mine flooding discussion	-26.437057	27.431744

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4.22	WIPP: Waste Isolation Pilot Plant	Carlsbad, Eddy County, New Mexico, USA	U.S. DOE / Nuclear Waste Partnership - AECOM	1992, early testing, particle physics; 1999 and~2007-present, physics, WIMPS testing, 2010; 1999, first waste arrives at facility	~655m; 2149' bgl (~2000 mwe)	(Salt) Repository and physics testing: 3 vertical access shafts and ventilation shaft; salt repository, Permian age bedded salt, Solado Formation; main hoist cage 2.87x4.67x7.46m; inactive 2014-2016 due to incidents and repair; reaccess for operations, waste emplacement in resumes 2017; for history, see References 629a, 629b. Same as Item 2.65, herein	32.371667, -103.793611		619, 621a, 622, 629, 629a, 629b; general references 610-617, 622	32.371667	-103.793611
4.23	KURF: Kimballton Underground Research Facility	Giles County, Virginia, USA	Mine operator, Lhoist North America; Physics testing, Virginia Tech, Department of Physics	Laboratory facilities, 2007-present; limestone mined since 1945	~<701m; 2300' bgl (maximum, ~2300' bgl)	(Carbonate) In Kimballton Mine: Road tunnel ramp access to underground mine for high calcium limestone to make lime; >50 miles of drive-in drifts, `40'x20'; 40x26'; ~1700' bgl, 1450mwe (verify). Was contender for U.S. DUSEL. Current activity, Low Energy Neutrino Spectroscopy (LENS). Geology: in Paleozoic Middle Ordovician limestone (Five Oaks member of the Cliffield formation); located within the Butt Mountain Synclinorium and stacked thrust sequence	37.382149,-80.659583	North of Ripplemead, Virginia; Allegheny Mountains near western edge of the Appalachian Valley and Ridge Phsiographic Province; mine portal location approximate	727-736	37.382149	-80.659583
4.24	Morton Salt: Morton salt mine: (Fairport)	Fairport Harbor, Lake County, Ohio, USA	Morton / Morton-Thiokol mine operator; physics operations, Proton Decay Group: U. Michigan, U. Cal. Irvine, Brookhaven Laboratory	Detector operated 1981-1991; current status TBD; underground salt mined since 1959	~609m; 1998' bgl (~2000' bgl; mine also with horizontal tunnels under Lake Erie, ~ 2.5 miles from access point)	(Salt) Neutrino detector in pool (80'x70'x70') housed in room (150'x130'x110'); Paleozoic Silurian Salina Salt / Group; bedded salt	41.755394, -81.284720	East of Cleveland, OH	674-677; 733	41.755394	-81.284720

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4.25	Cargill Salt: Cargill salt mine	Whiskey Island, Cuyahoga County, Ohio, USA	Cargill	~1963; history TBV	518m; 1699' blb (~1700' below lake bottom, blb)	(Salt) Not a physics underground laboratory, but included as example of salt mine failure safety concern; salt mine operations suspended in 2013. Geology: Paleozoic Silurian Salina Group salt mine; bedded salt similar to Morton salt mine near Cleveland	41.493688, -81.718430	Located at mouth of the Cuyahoga River, Cleveland. Approximate mine business location verified with Google Map for Cargill Deicing	678	41.493688	-81.718430
4.26	Henderson mine	Clear Creek County, Colorado, USA	Freeport-McMoran	Ore disc. 1964; candidate DUSEL site (former)	<914m; 2999' bgl (down to ~ <3000' bgl)	(Crystalline: intrusive igneous, metamorphic) Was contender for U.S. DUSEL; ore deposit discovered in 1964; molybdenum mine; deposit consisting of a stockwork of small veins of molybdenite in rhyolite porphyries of Tertiary age that intrude into Precambrian Silver Plume granite; preparation for closure 2-4 years	39.771068, -105.845960	Located west of town of Empire	630, 631	39.771068	-105.845960
4.27	Mt. San Jacinto	Riverside County, California, USA		Candidate DUSEL site (former)	<2000m; 6562' bgl (~2000m bgl maximum; TBV)	(Crystalline) Was contender for U.S. DUSEL. Planned new purpose built 7-8 km horizontal tunnel >2k bgl; Peninsular Ranges Province; granitic plutonic Mesozoic batholith (Mt. San Jacinto is one of several DUSEL candidate projects closed)	33.814712, -116.679438		632, 633	33.814712	-116.679438
4.28	Icicle Creek	Chelan County, Washington State, USA	Univ. Washington	Candidate DUSEL site (former)	~1036m; 3399' bgl (~3400' for Pioneer Tunnel location)	(Crystalline / granite) Icicle Creek location under Cashmere Mountain was contender for U.S. DUSEL; eliminated in down-selection by NSF in 2005 due to proposal location change to Pioneer Tunnel; Homestake Sanford Laboratory selected (Icicle Creek and Pioneer Tunnel are terminated as DUSEL proposed projects); Pioneer Tunnel ~17 miles from Icicle Creek location in Cascades. Icicle Creek location subject to considerable local opposition	47.561246, -120.845839	Cashmere Mountain location is illustrated on map. Then a proposed study of 5.3 mile and ~3400' deep Pioneer Tunnel; Pioneer Tunnel entrance 47.715176, -121.145716; ceased study of both locations	634, 635	47.561246	-120.845839

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4.29	SLANIC	Slanic, Prahova mines, Prahova County, Romania	IFIN-HH / Horia Hulubei National Institute of Physics and Nuclear Engineering	Physics testing since 2006 in Unirea mine, a mine level in Salina Veche mine; salt mined since 1938 from Unirea level until ~1970s	~208m; 682' bgl; ~560 m.w.e.	(Salt) Vertical shaft access; Miocene / Badenian Ocnele Mari evaporitic formation within Neogene age Tarcau Nappe; deformed salt basin deposits. Locally domal. Slanic Prahova's Unirea mine used in physics testing; testing in other mines also indicated	45.236360, 25.941699	Largest salt mine in Europe open to public access via elevator. 45º 14' 10.3" N / 25º 56' 30.2" E; 45.235311, 25.94125; Unirea	611, 612, 739, 740	45.23636	25.941699
4.30	SUNLAB: Sieroszowice Underground Laboratory	Polkowice / Sieroszowice mine; Polkowice / Sieroszowice near Kazmierzow, Polkowice County, Lower Silesia, Poland (near Lubin)	KGHM Polska Miedź, mine operator; partners with Institutes Nuclear Physics (Krakow and Warsaw), others; KGHM / Kombinat Gorniczo-Hutniczy Miedzi	Mined since 1962, 1977, Polkowice and Sieroszowice mines	~650-950m; 2133' - 3117' bgl (testing 900-950m and 650-700m may be planned; TBD). Mine shaft planned to 1216m bgl by KGHM)	(Sedimentary, salt) Proposed test location as of 2012; some indication anhydrite may be better unit for test. Vertical shaft access; copper / silver mining district. Other products include rock salt, clay. Depth to 900m ~=2200mwe; physics tests proposed to be conducted in associated salt cavern within bedded Zechstein salt unit; status TBV. Mined ore from shale-carbonate unit~300-900m bgl; district ore occurs ~ 600-1200m bgl in region. Basement consists of metamorphosed Proterozoic-Palaeozoic. Permian shale/carbonate ore unit within a Permo-Triassic sedimentary succession. Envisioned underground physics testing in Zechstein salt, other.	51.555833, 16.041667	TBV: verify location; Approximate location near 51.486861, 16.063179; location from photo of Sieroszowice mine (51.502321, 16.104269) is from Ref. 737a. Wikipedia.org also states 51.4651, 16.1020; but wikimapia.org shows Polkowice-Sieroszowice SW-1 Shaft (Copper Ore Mine) is 51.536274, 15.977558; Zalewska 2010 loc. 51.555833, 16.041667 verified	611, 612, 737, 737a, 738	51.555833	16.041667

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4.31	Stawell: SUPL / Stawell Underground Physics Laboratory	Stawell gold mine; Stawell, Victoia, Australia	Kirkland Lake Gold, owner operator of mine; testing supported by Victoria government, N Grampians Shire Council, U. Melbourne, the Australian Research Council's Centre of Excellence in Particle Physics	2015, government funding approved for SUPL; construction and testing to be initiated by 2016	~1025 m; 3363' bgl	(Crystalline- Metasedimentary / Metavolcanic) Decline ramp (~1.6km) for access by car or truck to test area planned for >1000m bgl, ~2900 mwe; additional test areas to be constructed. The Stawell Au field area occurs within the Stawell Zone, Lachlan Fold Belt. Ore zone occurs within Early Paleozoic (Cambrian) age fault-bounded units composed of volcanics, Cambrian turbidite deep water clastics, and volcaniclastic rocks; contact metamorphism in associated ore zones adjacent to Devonian age Stawell granite intrusive body. Kirkland Lake Gold announced (Ref. 741) the mining operations would be suspended; mine to enter a care and maintenance phase. According to Weekly Advertiser (Reference 741a), SUPL planned construction and testing are expected to be supported.	-37.075, 142.81	Location "area" verified with Google map and wikipedia.org. Wkimapia shows primary gold mine located at -37.06049, 142.8007	741	-37.075	142.81
4.32	Jaduguda: Underground Science Laboratory	Jadugora, Purbi Singhbhum district, state of Jharkhand state, India	Saha Institute of Nuclear Physics in Kolkata (testing); UCIL / Uranium Corporation India Ltd	Ore discovery, 1951; initial production 1957; UCIL production start 1967	~550m bgl physics testing; mine depth ~640m bgl	(Crystalline / metamorphic) Uranium mine (aka Jaduguda, Jadugoda or Jadugora): Access via 5m diameter vertical shaft. Underground facility for particle physics dark matter study. The planned construction of the India-based Neutrino Observatory (INO, Item 4.11, herein) has not materialized and India moved forward with underground science laboratory physics facility development in the Jaduguda mine. Uranium production with accessory sulphide minerals of copper, nickel, molybdenum and magnetite. Uranium mine within Singhbhum thrust belt and shear zone; strike-slip shears of Singhbhum orogeny. Ore host rocks are Archean age autoclastic conglomerate (formed by crushing, fracturing and brecciation) and quartz-chlorite-apatite-tourmaline-magnetite schist; fine grained uraninite minerals occur as disseminated grains and micro-veinlets in metasediments and metavolcanic rock suites.	22.652095, 86.346882	General area of UCIL facility	742, 743	22.652095	86.346882

Table 5 – (PITS): Deep Open Pit Mines

Table 5: (Pits) Compilation of some of the world's larger and deeper open pit mines.

Table #.Item #	Facility Name	Location, Country	Owner / Operator	Approximate Length	Approximate Width	Approximate Depth	Approximate Latitude / Longitude	Ore Mined; Status (Active, Inactive / Closed)	Other Information, Geology	References	Latitude	Longitude
Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.1	Aitik	Near towns of Gällivare and Sakajarvi, Norrbotten County, Sweden	Boliden AB	~2900m (9514' measured)	~1300m (4265' measured)	~450m (1476'); plans for final depth of 600m (1969') expected; North end of pit reached ~250m depth	67.066395, 20.950047	Copper mine: Open pit; Cu ores mined with silver and gold; discovered in 1930s; production, 1968; active	Ore is hosted by Paleo- to Mesoproterozoic metamorphosed Svecofennian sediments and intrusives surrounded by granitic intrusions, within a supracrustal metamorphosed shear zone of Precambrian age, ~ 1.9Ga; hydrothermal alteration & copper mineralization ~1.8Ga	750-755; 756-760	67.066395	20.950047
5.2	Betze-post	Eureka County, Nevada, United States	Barrick	~2200m / 7218' (reported); measured ~3.4km, 11155', 2.1 miles	~1500m / 4921' (reported); measured: ~2.21 km, 7251', 1.37 miles	>500m (1640')	40.981667, -116.378889	Gold mine: (Goldstrike mine) Betze-post Open pit; Carlin Trend, NV; ~1987 major production start for Goldstrike mine; part of the Goldstrike deposit area discovered in 1962; includes Betze-Post open pit and underground mines Meikle and Rodeo; active	The gold was epithermally deposited within Paleozoic (Early to Middle Devonian age) carbonate (Popovich Fm) or silicate sedimentary rocks in stages; hydrothermal deposits within lower plate units, sub-Roberts Mt. thrust. Age of intrusive events and mineralization 1) 159.3–154.6 My, Jurassic; 2) 38.3–37.8 Ma, Eocene, and possibly 3) Cretaceous. Within Nevada's Carlin Trend	750-755; 761-766; 766a-c	40.981667	-116.378889

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.3	Bingham Canyon	Salt Lake County, Utah, United States	Rio Tinto, Kennecott	~4400m (14500' estimated, Rio Tinto)	~4000m (13100', wikipedia.org)	~1200m (3937' depth reported by Kennecott; Wikipedia reports ~970m, 3180')	40.529166667, -112.15388889	Copper mine: Open pit; Cu ores mined with Au, Ag, and Mo; aka Kennecott Copper mine; active after extensive debris cleanup from landslide	Disc. 1848; porphyry copper deposit; production since 1906; deepest open pit mine in world; granite porphyry, major quartz monzonite porphyry intrusive events and mineralization phase. Paleogene Eocene age venation, dikes, mineralization and alteration complex (30-40My) hosted in Cenozoic intrusives and older altered Paleozoic units (skarns). Massive landslide, 2013	750-755a; 767-770	40.529167	-112.15388889
5.4	Boddington	North of Boddington, Western Australia, Australia	Newmont / AngloGold Mining	~1800m (5905'), north pit; south pit, 2030 m (6660') measured	~910m (2985') north pit; south pit ~1290m (4242') measured	~700m expected at completion	-32.73767, 116.3471	Gold, copper mine: Open pit; largest gold mine in Australia (two open pits); worked 1987 - 2009; reopens in 2009; pre-2001, old shallow bauxite mine with Au in deeper units. Currently active	Structure within the southwestern Yilgarn Craton; Saddleback greenstone belt (SGB), a fault-bounded sliver of Archaean volcanic and shallow level intrusive rocks, surrounded by granitic and gneissic rocks; two stages of mineralization @~2.6, ~2.7 Ga; additional later stage metamorphism.	750-755; 771-777	-32.73767	116.3471

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.5	Chuquicamata	Antofagasta Region, (Santiago), Chile	Codelco	~4300m (14107'); SYSGEO reports 4500m	~3000m (9842'); SYSGEO reports 3500m	~850m (2790'); SYSGEO reports 800m	-22.275, -68.902242	Copper mine: Open pit; aka "Chuqui"; operations since 1910; one of largest Cu mines in world (Cu/Mo); transition to underground mining in 2018 / 2019; active	Orebody is hosted by Chuqui Porphyry Complex; ore occurs in quartz veins and veinlets and with alteration minerals; hydrothermal mineralization; ~31-36Mya, Eocene / Oligocene granodiorite / monzogranite porphyry association; Paleogene to Mesozoic host units (volcanic / sedimentary) and older crystalline units of Paleozoic age; Cu enrichment 15-19Mya.	750-755a; 778-783	-22.275	-68.902242
5.6	Diavik	On island in Lac de Gras, Northwest Territories, Canada	Diavik, JV; Rio Tinto, Dominion Diavik Ltd.	~1740m (5709') measured max per pit; reported as 7km for area	~1000m (3280') measured for pit	?	64.489933, -110.256762	Diamond mine: Open pit; Lac de Gras kimberlite field; ~30km from Ekati mine; established 1994-95; first production, 2003. Pipes (4) include producing A154N, A154S, A418, and planned development of A21. Open pit mine, 2003-2012. Initiated and transitioned to underground mining ~2010-2012 in 3 of 4 pipes; located on island created with dikes, pumping. Active	Kimberlite pipes; intrude Archean age rock of Slave Province, Canada; kimberlite intrudes host granitic and metasediments of Archean; granites age ~2.5–2.7 billion years. Diamonds are as old as 3.3–3.5 billion years; kimberlites dated at ~55mya / Eocene age intrusions	750-755a; 784-788	64.489933	-110.256762

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.7	Ekati	Northwest Territories, Canada	Owner, Dominion Diamond Corporation (negotiating sale to Washington Companies); former owner was BHP Billiton	~600m (1969') for pit	~600m (1969')	?	64.715933, -110.619537	Diamond mine: Open pit; area discovery, 1991; several kimberlite pipes mined by open pit mining with operations start 1998; underground operations at several pipes continues; each pipe ~<0.7km diameter. Active	Kimberlite pipes; known earlier as NWT Diamonds project area, now referred to as Ekati Project Area. Panda pipe open pit developed first, 1998, and ceased surface mine in 2003; first commercial diamond mine in Canada. Other pipes in production since 2001, and initiated underground operations. Ekati pits are Koala, Koala North, Panda, and Beartooth. Misery pipe pit brought online in 2001; in 2017, Dominion with open pit production from Koala, Misery Main, Pigeon and Lynx pipes and Koala underground. Underground mining at Panda, Koala, Koala North in 2017. See Diavik's Eocene kimberlites; age of pipes in area range 45-62mya (Paleogene) intruding Archean basement complex. First NWT kimberlites discovered by Fipke and Blusson	750-755a; 789-793	64.715933	-110.619537

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.8	Escondida	Cerro Colorado area, Antofagasta Region (Atacama Desert), Chile	BHP Billiton / Rio Tinto	~3500m (11483' measured; ~3900m / 12795' also reported)	~2700m (8858')	~645m (2116')	-24.271242, -69.071388	Copper mine: Open pit; located south of Chuquicamata; Au, Ag, Cu mined since 1990; active	Porphyry copper deposits; two open-pits; Escondida North pit is 525m deep; Tertiary age porphyry copper Andean belt; Eocene-Oligocene quartz monzonitic / granodioritic intrusive stock hosted by Paleocene andesites; 3 hydrothermal alteration phases in mineralization; associated hydrothermal sulphide ores	750-755a; 794-798	-24.271242	-69.071388
5.9	Fimiston	Kalgoorlie, Western Australia, Australia	Barrick / Newmont JV, Kalgoorlie Consolidated Gold Mines (KCGM) operator	~3500m - 3800m (11483'-12467')	~1500m (4921')	~600m; expected by KCGM to be 700m deep when completed in 2019	-30.774722, 121.509444	Gold mine: Fimiston mine, Kalgoorlie Open pit, aka Kalgoorlie Super Pit; was Australia's largest open cut gold mine (nickel also produced) until 2016 when it was surpassed by the Newmont's Boddington gold mine. Super Pit construction starts 1989. Active	Ore occurs in sheared Golden Mile dolerite; Archean Norseman-Wiluna greenstone belt, Yilgarn block, Western Australia craton. Area quartz-felsic dikes dated at ~2.67Ga; similar age basic intrusives (sills) associated with alteration and mineral deposition, likely over long time period. Gold produced from area since 1893.	750-755a; 799-804	-30.774722	121.509444
5.10	Grasberg	Tembagapura, Mimika Regency, Papua province (Irian Jaya), Indonesia	PT Freeport Indonesia / Freeport McMoran (JV with Rio Tinto)	3058m (10032' measured; ~1.9 miles)	2253m (7392' measured; ~1.4 miles)	>550m (1804')	-4.059069, 137.113238	Cu / Gold mine: Open pit; gold, copper and silver ore mined; world's largest known gold reserves; area production since 1973; Grasberg production in mid-1980s; considered world's largest gold mine (pit). Active (some contract / production sharing issues with government in 2017)	Porphyry ore bodies and sulfide skarns at margins with Eocene clastics and carbonates forming surrounding sediment host; three phases dioritic intrusions; stockwork / veinlet controlled mineralization. Planned transition to underground mining in 2015; initiated deep underground mining plans and work in 2004. Historical political, environmental, contractual, and social issues evident	750-755a; 805-808	-4.059069	137.113238

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.11	Hull-Rust-Mahoning	Hibbing, St. Louis County, Minnesota, United States	Hibbing Taconite Co.	5600m (18372', 3.5miles); (measured ~>6km for area mines complex on wikimapia.org)	2400m (7874', 1.5 miles); measured nearly ~2.5km for mine area on Google map and Wikimapia.org map	163m (535'); also reported as 180m deep	47.45219, -92.96052	Iron ore mines: Open pit; taconitic ore, Mesabi Range; initial production, 1895; small operation persists to present; much of mine area closed	Biwabik Iron-Formation, Paleoproterozoic, ~1.88 Ga, Mesabi Range ore belt	750-755; 809-813	47.45219	-92.96052
5.12	Kimberley	Kimberley, Northern Cape Province, South Africa	De Beers / DBCM (De Beers Consolidated Mines sold Kimberley mines, December, 2015 to Ekapa Minerals)	~540m (1772'); measured	~460m (1509'); measured	240m (787')	-28.739096, 24.758527	Diamond mine: Open pit; inactive, flooded; ceased surface operations over 100 years ago; operations 1871-1914; underground mining 1963-1990, nearby DeBeers mine; recently processing mining tailings in area. Cecil Rhodes enterprise	Kimberlite pipe pit dug by hand. Kimberlite is ~90My; intrudes basement 3.2-2.6Ga, Karoo Dwyka Glacial Shales (~300My), and Karoo dolerite sill (~180My) in Dwyka shale. Kaapvaal craton.	750-755a; 814-818	-28.739096	24.758527
5.13	Mirny (Mir)	Mirny, Sakha Republic (Yakutia, Eastern Siberia), Russian Federation	Alrosa	1200m (3937')	1200m (3937')	525m (1722'bgl)	62.529422, 113.993539	Diamond mine: Mir or Mirny Open pit; inactive since 2001; pit mined 1957-2001; pit closed in 2012. Mir kimberlite pipe exploited by subsurface mining since 2009. Active	Kimberlite pipe / diatreme; volcanic unit; diamond records two growth events ; older diamond core grew from subducted organic carbon 2.1 Ga; 0.9 Ga rim grew from mantle metasomatic fluid; diamond was exhumed from ~180 to ~120 km depths between the two growth stages; pipe formed ~360mya. Mine underground flooded, August 2017. Mir means Peace.	750-755a; 819-826	62.529422	113.993539

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.14	Muruntau	Kyzyl Kum Desert, Navoiy Province (Tamdy District), Uzbekistan (~17 miles ESE of Zarafshan)	Navoi Mining and Metallurgical Combinat (NMMC)	~3500m (11483')	~3000m (9843')	>600m (1969')	41.516667, 64.58333	Gold mine: Open pit; discovery ~1958 with operations in 1967; planned to ~650m - 1000m depth; active	Mine located within the Beltau-Kurama volcano-plutonic belt; large vein and stockwork systems hosted by older, competent metasediments [Besapan] and proximal to intrusive bodies or along the sheared zones; Mid-Late Paleozoic age mineralization; Kyzyl-Kum gold district within the Tien Shan belt)	750-755a; 827-831	41.516667	64.58333
5.15	Nanfen	Nanfen district, Benxi Prefecture, Liaoning Province, China	Benzi Iron and Steel Corp. / Benzi Steel	~3000m (9842')	~2000m (6562')	~500m (1640')to 750m cut slope	41.094892, 123.811032	Iron mine: "open pit"; planning activities for underground mine since 2011; largest iron mine in Asia; metamorphic sedimentary units of BIF in Neoarchean Anshan group; area mined located on hillslope with ~750m relief. Active	BIF (banded iron formation) hosted within Neoarchean middle Anshan Group; Archean BIF-hosted iron deposits; setting, subduction-related back-arc basin; Anshan Group strata are hosted between two phases of Archean granite, which have ages of about 3.0 Ga and about 2.45 Ga; Dayugou formation of Ashan Group 2.50 - 2.55 Ga; middle Anshan Group is made up mainly of amphibolites, amphibole-bearing gneiss and biotite leptynite, also interbedded with muscovite quartz schist, and chlorite quartz schist with BIF	750-755; 832-836	41.094892	123.811032

Item #	Name	Location	Owner / Operator	Length	Width	Depth	Latitude / Longitude	Ore Mined	Other Information	References	Latitude	Longitude
5.16	Udachny	Eastern Siberia, Sakha Republic, Russian Federation	Alrosa Udachnaya Mining Processing Division (UMPD)	1900m (6233'; measured)	~1400m (4593'; measured)	~630m (2067')	66.433333, 112.316667	Diamond mine: Open pit; discovery in 1955; production since 1971; open pit closed in 2015 with concurrent subsurface development (construction start in 2004) to 1450 m bgl expected; active	Kimberlite pipe(s); mined since 1971; part of the Daldyn-Alakit kimberlite field. Udachny means "Lucky". Age of two Kimberlite pipes, Devonian (~353-367mya); intruding Earlier Paleozoic, Ordovician limestones, and at depth, the 2 pipes separated by sediments / metasediments of Cambrian age	750-755a; 837-843	66.433333	112.316667
5.17	Berkeley	Berkeley mine, Butte, Silver Bow County, Montana	Anaconda Copper, 1955, initiated pit venture; Arco, 1977-1982	~2300m	~1700m	~540m	46.018505, -112.50951	Copper mine: also Pb, Zn, Mn, Au, Ag; pit operations initiated in 1955; mine closed in 1982; area mined since 1860s. Mine closed in 1982 and under remediation and monitoring since; filling with water	Laramide / Late Cretaceous age Butte quartz monzonite pluton of the Boulder Batholith suite; alteration of country rock and mineralization. Silver mined until 1955 in shaft and tunnels; copper mined after 1955 in open pit; mined copper-iron ore in central zone. Mine operations ceased and pit flooded; contaminated water issues are severe. Butte area underground mines are numerous; tens of miles of shafts exist along with ~2700 miles of tunnels. Flooding of underground mines upon closure was followed by fill of Berkeley pit with water / toxic water. Included as example of what can go wrong environmentally; remediation challenges	844-847	46.018505	-112.509514

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APPENDIX 1: Alphabetical Listings

Alphabetical Listing of Facilities for Each Table (1 to 5),
Including a
Crosswalk of Table 2 Facilities with Country and Chapters of Reference 167a

Alphabetical Listing of Facilities for Each Table: Appendix 1 (Alphabetical Listings) incorporates elements (table number and item number, "facility" name, country) of the five tables (Mines; Repositories, URLs, Sites; Boreholes; Underground Physics Facilities, deep open pit mines) sorted in alphabetical order by "facility" name (Column 2) for each table to aid in the use of the map layers and pop-up site attributes of facilities associated with each layer of the interactive map suite. For each of the alphabetically sorted tables presented in Appendix 1, the left column (Column 1) indicates the table number followed by the facility number for each site (name in Column 2) and country (Column 3) included in data tables by layer (Tables 1-5). In addition, Table 2 (Repositories, URLs, Sites) presents a cross-walk of country (Column 3) and alphabetized listing by facility or site (Table number. Name; Column 1) with the related chapter (Column 4) and or page numbers (Column 5) for country, site, or plans described in Reference 167a (*Fabishenko *et al*., 2016). Table 2, Column 5 also identifies pages within the Fabishenko *et al*. report related to disposal work for the country of concern.

*Faybishenko, B, and J. Birkholzer, D. Sassani, and P. Swift (editors). 2016. *International Approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation; Fifth Worldwide Review*, LBNL-1006984; Lawrence Berkeley National Laboratory, Sandia National Laboratories; https://www.osti.gov/scitech/servlets/purl/1353043 and at https://eesa.lbl.gov/wwr5/ (Reference 167a, herein)

Table A1-1: Alphabetical Listing, Deep Mines

Alphabetical Listing, Mines: Table 1, Map Layer 1		
Table. Item #	**Mine**	**Country**
1.27	Bergwerk Saar	Germany
1.29	Boulby	United Kingdom
1.10	Creighton	Canada
1.26	Crownpoint	United States
1.4	Driefontein	South Africa
1.31	Eagle	United States
1.22	East Rand	South Africa
1.9	Great Noligwa	South Africa
1.32	Hecla Star	United States
1.14	Homestake	United States
1.23	Kennedy	United States
1.8	Kidd Creek	Canada
1.11	Kopanang	South Africa
1.5	Kusasalethu	South Africa
1.21	LaRonde	Canada
1.13	Lucky Friday	United States
1.20	McArthur River	Canada
1.6	Moab Khotsong	South Africa
1.24	Mount Isa / Enterprise	Australia
1.1	Mponeng	South Africa
1.16	Oyu Tolgoi	Mongolia
1.15	Palabora	South Africa
1.19	Pumpkin Hollow	United States
1.30	Pyhäsalmi	Finland
1.34	Quincy	United States
1.17	Resolution	United States
1.3	Savuka	South Africa
1.28	Shaft No. 16	Czech Republic
1.25	Soudan	United States
1.7	South Deep	South Africa
1.12	Spring Hill	Canada
1.33	Sunshine	United States
1.2	TauTona:	South Africa
1.18	Xinhu mine:	China

Table A1-2: Alphabetical Listing and Cross-walk with Reference 167a (URLs, Repositories, Sites)

Alphabetical Listing and Cross-walk to Reference 167a: URLs, Repositories, Sites, Table 2, Map Layer 2				
Table. Item #	**Facility / Site Name / Candidate Site Name**	**Country**	**Country's Chapter #: International Approaches for Deep Geological Disposal of Nuclear Waste; Reference 167a**	**Other: International Approaches for Deep Geological Disposal of Nuclear Waste; Reference 167a**
2.26	Amélie	France	Chapter 8	NA
2.54	Äspö:	Sweden	Chapter 20	Page 4-10, 5-8, 5-21, 9-13, 19-7
2.30	Asse II	Germany	Chapter 9	Page 1-1, 1-5, 5-21
2.68	Avery Island	United States	Chapter 24	NA
2.36	Bátaapáti	Hungary	Chapter 10	NA
2.12	Bedrichov	Czech Republic	Chapter 6	NA
2.9	Beishan	China	Chapter 5	Page 1-4
2.8	Beishan / Xinchang	China	Chapter 5	Page 1-4
2.2	Belgium Repository	Belgium	NA	Page 1-16, 9-13, 11-2, 11-9, 15-12, 16-18, 21-19, 24-4, 24-6
2.21	Boletice	Czech Republic	Chapter 6	NA
NA	Brazil	Brazil	Chapter 2	Page 1-2, 5-21
2.19	Březový potok / Pačejov	Czech Republic	Chapter 6	NA
2.7	Bruce	Canada	Chapter 4	NA
2.13	Bukov	Czech Republic	Chapter 6	NA
2.72	Bulgaria	Bulgaria	Chapter 3	Page 1-3, 1-16
2.28	Bure / Meuse-Haute Marne	France	Chapter 8	Page 9-16
2.29	Bure area	France	Chapter 8	Page 9-16
2.66	Busted Butte	United States	Chapter 24	NA
2.70	BWIP / RRL	United States	Chapter 24	NA
2.6	CA Repos	Canada	Chapter 4	Page 1-3, 1-16, 2-10, 5-8, 11-2, 15-8, 15-9, 15-11, 21-19, 24-4, 25-1
2.20	Čertovka / Lubenec	Czech Republic	Chapter 6	NA
2.17	Čihadlo / Lodherov	Czech Republic	Chapter 6	NA
2.62	Climax	United States	Chapter 24	NA
2.14	Czech R: Repository Candidate sites	Czech Republic:	Chapter 6	Page 1-4, 1-6, 16-2, 16-3, 16-10, 16-20, 16-21, 21-19
2.69	Davis Canyon	United States	Chapter 24	NA
2.71	Deaf Smith	United States	Chapter 24	NA
2.75	Dekov	Bulgaria	Chapter 3	Page 1-3
2.3	Doel Nuclear Zone	Belgium	NA	NA
2.51	El Berrocal	Spain	Chapter 19	NA
2.24	Eurajoki	Finland	Chapter 7	NA
2.25	Fanay	France	Chapter 8	NA
2.55	Forsmark	Sweden	Chapter 20	Page iii, 1-10, 1-11, 15-9, 23-16, 24-6
2.31	Gorleben: URF	Germany	Chapter 9	Page 1-5, 22-13
2.56	Grimsel	Switzerland	Chapter 21	Page 1-1, 1-12, 4-10, 5-21, 6-14, 9-13, 19-3, 19-6, 19-7, 19-8, 19-11, 24-6, 24-14,
2.63	G-Tunnel	United States	Chapter 24	NA
2.1	HADES	Belgium	NA	Page 1-1,
2.15	Horka / Budišov	Czech Republic	Chapter 6	NA
2.40	Horonobe	Japan	Chapter 12	Page 1-7
2.16	Hradek / Rohozná	Czech Republic	Chapter 6	NA
NA	India	India	Chapter 11	Page 1-2, 1-6
2.11	Josef Stola	Czech Republic	Chapter 6	NA

2.58	Jura Ost	Switzerland	Chapter 21	Figure 21-3
2.38	Kamaishi	Japan	Chapter 12	NA
2.48	Kamenny	Russian Federation	NA	NA
2.76	Komarevo	Bulgaria	Chapter 3	Page 1-3
2.32	Konrad:	Germany	Chapter 9	Page 1-5
2.74	Kozloduy	Bulgaria	Chapter 3	Page 1-3
2.22	Kravi Hora	Czech Republic	Chapter 6	NA
2.42	KURT	Republic of Korea	NA (Chapters 12, 24)	Page 24-14,
2.5	Lac du Bonnet	Canada	Chapter 4	NA
NA	Latvia	Latvia	Chapter 13	Page 1-7
NA	Lithuania	Lithuania	Chapter 14	Page 1-7, 1-8, 1-16,
2.64	Lyons	United States	Chapter 24	Page 1-1
2.18	Magdalena / Božejovice	Czech Republic	Chapter 6	NA
NA	Mexico	Mexico	Chapter 15	Page 1-8
2.39	Mizunami / MIU	Japan	Chapter 12	NA
2.4	Mol Nuclear Zone:	Belgium	NA	NA
2.57	Mont Terri	Switzerland	Chapter 21	Page 1-12, 4-10, 19-3, 19-5, 19-8, 19-9, 24-14
2.33	Morsleben	Germany	Chapter 9	Page 1-5,
2.47	Nizhne-Itatsky, Telsky	Russian Federation	NA	NA
2.85	Novosilky	Ukraine	Chapter 23	Page 1-13
2.23	ONKALO	Finland	Chapter 7	Page 1-4, 4-10
2.49	PA Mayak	Russian Federation	NA	NA
2.35	Pécs	Hungary	Chapter 10	NA
2.60	RCF	United Kingdom	Chapter 22	NA
2.34	Repository	Germany	Chapter 9	NA
2.43	Repository	Republic of Korea	NA	NA (Chapters 12, 24); Page 1-16, 11-2, 12-16, 21-19, 24-14,
2.59	Repository Taiwan	Taiwan	NA	NA
2.61	Repository UK	United Kingdom	Chapter 22	Page 1-12, 1-16, 1-17, 9-4, 21-19, 24-4
2.41	Repository Japan	Japan	Chapter 12	Page 1-7, 1-16, 2-10, 2-22, 5-2, 9-13, 15-11, 15-12, 21-19, 24-4, 24-6, 25-2, 25-7,
2.81	Rimavska / Cerova	Slovakia	Chapter 16	Page 1-9,
2.10	Shaft 16	Czech Republic	Chapter 6	NA
2.78	Slovakia	Slovakia	Chapter 16	Page 1-9, 1-16
	Slovenia	Slovenia	Chapter 17	Page 1-9, 16-10,
	South Africa	South Africa	Chapter 18	Page 1-10
2.52	Spain URL / repository	Spain	Chapter 19	Page 1-10, 1-16, 2-10, 2-13, 9-13, 15-8, 15-11, 15-12, 21-19, 23-5
2.53	Stripa	Sweden	Chapter 20	Page 1-1, 5-21
2.37	Tono	Japan	Chapter 12	NA
2.27	Tournemire	France	Chapter 8	Page 9-13
2.79	Tribec	Slovakia	Chapter 16	Page 1-8, 1-9,
2.82	Ukraine	Ukraine	Chapter 23	Page 1-12, 1-16,
2.73	Varbitza	Bulgaria	Chapter 3	Page 1-3
2.80	Veporska /Stolicke	Slovakia	Chapter 16	NA
2.84	Veresnia	Ukraine	Chapter 23	Page 1-12
2.46	Verkhne-Itatsky	Russian Federation	NA	NA
2.65	WIPP	United States	Chapter 24	Page 22-13
2.50	Yeniseisky	Russian Federation	NA	NA
2.44	Yeniseisky site URL	Russian Federation	NA	NA
2.67	Yucca Mountain	United States	Chapter 24	Page 1-17, 15-12,
2.45	Yuzhny	Russian Federation	NA	NA
2.83	Zhovtneva	Ukraine	Chapter 23	Page 1-13
2.77	Zlatar	Bulgaria	Chapter 3	Page 1-3

Table A1-3: Alphabetical Listing, Deep / Large Diameter Boreholes

Alphabetical Listing: Boreholes, Table 3, Map Layer 3		
Table. Item #	**Well / Borehole**	**Country**
3.4	AZ St. A1	United States
3.26	Basel 1	Switzerland
3.5	Bertha Rogers 1-27	United States
3.1	Bighorn No. 1-5	United States
3.38	Cajon Pass	United States
3.37	Cannikin UA-1	United States
3.27	CCSD-1	China
3.34	Climax SFT	United States
3.25	COSC #1	Sweden
3.35	Faultless	United States
3.40	Fenton Hill	United States
3.31	Gasbuggy	United States
3.36	Gnome	United States
3.24	Gravberg #1	Sweden
3.22	Gross Schoenebeck	Germany
3.28	Gwangju	Republic of Korea
3.41	IDDP-2	Iceland
3.9	Innamincka / Habanero:	Australia
3.12	KOLA SG-3	Russian Federation
3.18	Krivoy Rog, SG-8	Ukraine
3.21	KTB HB	Germany
3.46	Macondo	United States
3.2	Madden 2-3	United States
3.6	Magoun 1	United States
3.30	NNSS	United States
3.43	Other / crystalline global	Global studies
3.19	Otokumpu	Finland
3.7	Paradox 1	United States
3.11	Paralana 2:	Australia
3.10	Penola / Salamander :	Australia
3.47	Perdido	United States
3.33	Rio Blanco	United States
3.8	RMA	United States
3.32	Rulison	United States
3.17	Saatly SD-1:	Azerbaijan
3.39	SAFOD	United States
3.42	San José mine	Chile
3.44	Selected USA GOM	United States
3.48	Selected USA Other GOM	United States
3.3	Shell 1 Government	United States
3.29	Shin-Takenomachi	Japan
3.20	Soultz-sous-Forets	France
3.45	Tiber	United States
3.15	Tyrnyauz:	Russian Federation
3.16	Tyumen SG-6:	Russian Federation
3.23	Urach 3	Germany
3.13	Ural SG-4	Russian Federation
3.14	Vorotilovo	Russian Federation

Table A1-4: Alphabetical Listing Underground Physics Facilities and sites

Alphabetical Listing: Underground Physics Facilities, Table 4, Map Layer 4		
Table. Item #	**Facility, Site,**	**Country**
4.18	ANDES	Chile / Argentina
4.1	Baksan	Russian Federation
4.6	Bas Bruit	France
4.2	Boulby	United Kingdom
4.4	Canfranc	Spain
4.25	Cargill Salt	United States
4.17	CJPL	China
4.16	CUPP	Finland
4.3	Gran Sasso	Italy
4.26	Henderson	United States
4.19	Huguenot	South Africa
4.28	Icicle Creek	United States
4.11	INO	India
4.32	Jaduguda	India
4.21	JAGUARS / NELSAM /DAFSAM	South Africa
4.8	Kamioka	Japan
4.12	Kolar	India
4.23	KURF	United States
4.5	Modane	France
4.24	Morton Salt	United States
4.27	Mt. San Jacinto	United States
4.9	Oto-Cosmo	Japan
4.15	Sanford	United States
4.20	SATREPS / NELSAM:	South Africa
4.29	SLANIC	Romania
4.13	SNOLab	Canada
4.14	Soudan	United States
4.31	Stawell	Australia
4.7	SUL / Solotvina	Ukraine
4.30	SUNLAB	Poland
4.22	WIPP	United States
4.10	Y2L	Republic of Korea

Table A1-5: Alphabetical Listing Deep Open Pit Mines

Alphabetical Listing: Deep and Large Open Pit Mines Table 5, Map Layer 5		
Table #.Item number	Open Pit Mine Name	Country
5.1	Aitik	Sweden
5.17	Berkeley	United States
5.2	Betze-post	United States
5.3	Bingham Canyon	United States
5.4	Boddington	Australia
5.5	Chuquicamata	Chile
5.6	Diavik	Canada
5.7	Ekati	Canada
5.8	Escondida	Chile
5.9	Fimiston	Australia
5.10	Grasberg	Indonesia
5.11	Hull-Rust-Mahoning	United States
5.12	Kimberley	South Africa
5.13	Mirny (Mir)	Russian Federation
5.14	Muruntau	Uzbekistan
5.15	Nanfen	China
5.16	Udachny	Russian Federation

APPENDIX 2: User's Guide to the GIS Global Survey Map Tool

http://gis.inl.gov/GlobalSurvey/

User's Guide GIS Map Site: http://gis.inl.gov/GlobalSurvey/

Appendix 2, constitutes the user's guide for the interactive map tool. The current map site is located at http://gis.inl.gov/globalsites/ . The application has been upgraded to a new JavaScript based GIS platform presentation (http://gis.inl.gov/GlobalSurvey) of the interactive tool and layers from the previous version.

Using SFWST Global Sites Survey Map: http://gis.inl.gov/GlobalSurvey/

Note: It may be better to use browser Google Chrome or Mozilla Firefox when accessing this site.

Go to http://gis.inl.gov/GlobalSurvey/

- Map with sites appears.
- To see the site location identifying labels, you must zoom in on map; when you zoom in on map, at ~1:40,000,000, the deep mine labels / identifiers appear. Continue zooming in and the remainder of site labels appear.

The map with color coded site symbols shows in the right 2/3rds of the frame. To the left side of the window, see grey panel with application tools: *Layers, Legend, Identify Features, Bookmarks*, etc., each with open/close button (a triangle) to the left of the word (Figure A2-1).

1) *Deep mine*, (multicolored hexagonal pins color coded by mine depth / approximate mine depth)
2) *Repositories / sites / URLs* (brown dots on map)
3) *Boreholes* (blue dots on map)
4) *Physics facilities* (green dots on map)
5) *Deep open pits* (purple dots on map)

Basemaps:

In the upper right corner of the map window, see a grey rectangle containing word "Basemaps". Select or click the rectangle to choose a basemap you find of value in your exploration of the tool. You are presented with ~7 choices for basemap to use including imagery, streets, topographic, hillshade and hybrids (i.e. streets and hillshade). It is recommended that the "satellite" view is used for the basemap but other basemaps may be a better orientation reference at different scales depending on user preference.

Layers:

Click triangle to the left of word "Layers". Two boxes appear next to the facility title and each layer title for the list of all 5 map layers. Make sure you place a check mark in each box just to left of layer name, and if you select or click the small box to the far left of the map and site titles, the site symbols appear on the map and equivalent of a legend is visible for symbols on map. Click the plus sign and make sure a check mark is in the right box next to each layer name or next to "all Layers". This activates database for each of the layers

Identify Facilities:

Click the triangle to left of word "Identify". You may select one layer or all layers on the map for activation. You may also Right Click with your mouse on the color assigned features on the map to get more information about the facility. Identify features on the map is available to you at any time. When you right click on the feature a pop-up window appears showing more information (attributes) about the specific feature. When clicking on a feature that is in close proximity to other features, you may get popup results for multiple features. When this is the case, you will see a ratio (i.e. "(1 of 3)") in the upper left corner of the popup indicating multiple features have been identified. Use triangle on upper right side to navigate to the the other identified features.

Facility Name Search:

Click the triangle to left of word "Facility Name Search". An open dropdown box will appear. You may click on the right side dropdown to get a list of facilities or begin typing the name of a specific facility in the blank space in the box. This will give you the most likely options. Once you select a facility, the map will change the extent to center on that facility and a pop-up window will appear showing the attributes of the facility selected.

Links to Report:

Through the hyperlinks in this tool, you may access the full report and key sections of the report in pdf format. Click on the link and the document should open in a new tab. If the document auto-downloads, a setting in your web browser will need to be changed. To make that change in Google Chrome:

1. Open *Google Chrome*.
2. Click on the *Menu* icon ( ) in the top-right corner of the Window.
3. Click *Settings*.
4. Scroll down to the bottom of the Settings window and click *Advanced*.
5. In the *Privacy and security* section, click *Content Settings*.
6. Scroll down and click the *PDF* documents option.

To change in Mozilla Firefox:

1. Go to *Tools* > *Options* (or *Firefox* > *Options*).
2. In the Options window, scroll down and select the *Applications* tab.
3. In the *Search* field, type *PDF*. You should find *Portable Document Format (PDF)*.
4. On the right handside you should find an *Action* column. Use that to select your favorite PDF reader. In order to view PDF files in Firefox, choose *Preview in Firefox*.

To change in Internet Explorer:

Make sure that the Adobe PDF browser add-on, AdobePDF.dll, is enabled.

1. Open *Internet Explorer*.
2. Select *Tools* > *Internet Options*.
3. Click the *Programs* tab.
4. Click the *Manage Add-ons* button.
5. Set the Show menu to "*Add-ons that have been used by Internet Explorer*."
6. Find and select *Adobe PDF Reader*.
7. Find and select *Adobe PDF Reader* and click *OK*.

Regional Extents:

Click the triangle to left of word "Regional Extents". A list of preset regional extents is now visible and you may select an extent that will change the extent of the map. You may also pan and zoom to a new extent and click Add Bookmark. This will save a new extent for use in a later session.

Measure:

Click the triangle to left of word "Measure". You may select from three options: Area, Distance, and Location. Once you select an option the units will appear to the right, and you may click on the units to change to the desired unit. After making your selections you can draw a polygon, line or points on the map. The units will appear in the left panel. Click on map at start point; double click to terminate drawing a line or polygon.

Print:

Click the triangle to left of word "Print". This tool allows you to print or save a copy of the current map extent, i.e., this prints or saves view of map area on screen, not the entire map.

Legend:

Click the triangle to left side of the word legend, and the layer symbols appear. Each map layer / facility type is assigned a color coded symbol; Deep mines layer has multiple colors assigned for infill of hexagonal symbol representing mine or shaft depth for the facilities in Table 1, Deep Mines and Shafts. You may leave the Legend open, or click the triangle to close it.

About:

To the right side of the top banner of the map, you can click on the *About* tool. This opens a stationary window on the map that provides helpful information about the site. Information is organized in tabular pages (Welcome (Abstract), Navigation, Tools, What's New). Hover the mouse over the name on the tabs and click. When finished, click X in upper right corner and you will return to the map.

Comments:

Accent marks present over letters and location data (degrees, minutes, seconds) symbols may have been replaced by other symbols or a question mark in pop-up panels for the sites. Most of these errors have been identified and corrected. Some may have gone unnoticed and remain in feature information in the panel for sites. The user should be aware of these possible errors in presentation material. Some international facility names use characters that are not found in the American English language and software code does not always translate those differences correctly.

Google maps may be more current in some remote areas when using satellite view. User may copy location from the report table (from the latitude and longitude column) or copy from information pop-up panel on map for a selected site. Go to Google Maps (https://www.google.com/maps/) and paste decimal location in search box.

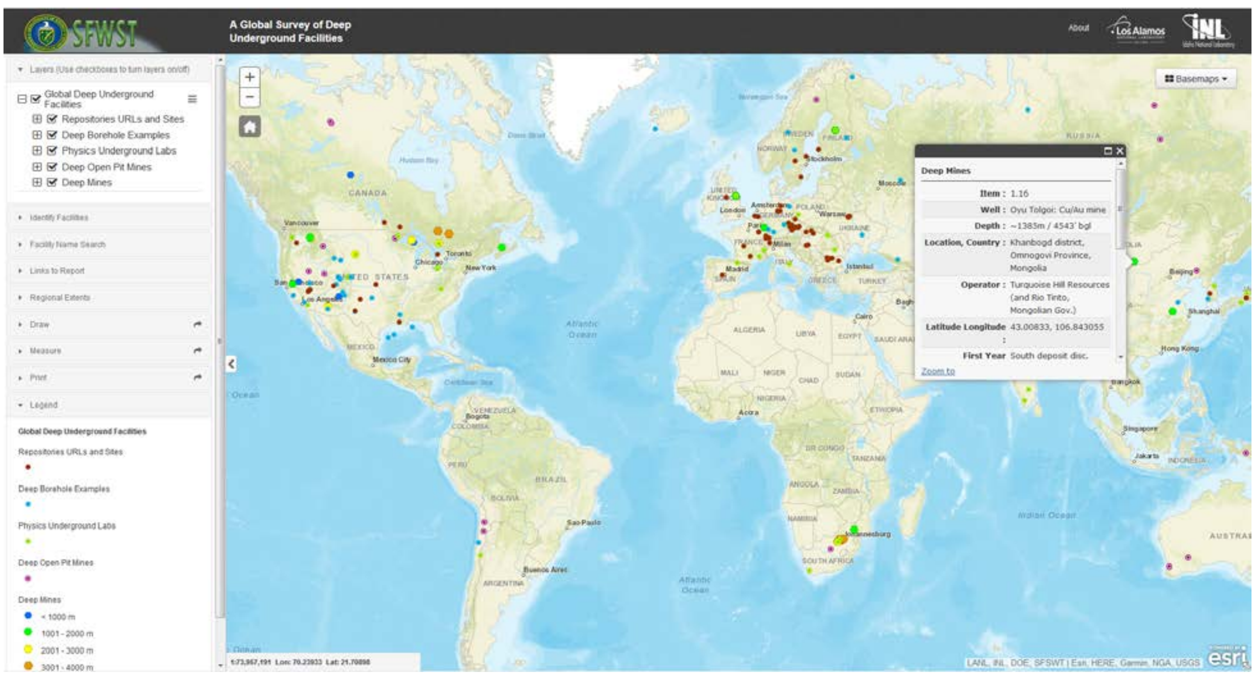

Figure A2.1: http://gis.inl.gov/GlobalSurvey/ Main page.

Important features for GIS map tool at this interactive map site. All layers are activated and visualized on start up. Tools to manipulate maps, layers, and information on found on left panel or top banner. Example site selected from "Deep Mines" layer; pop-up panel shows site name, number, and features from Table. Map layers color coded key appears for each layer and can be found in the Legend or using the Layers "+" button to the left of each layer to show symbology of layers. Deep Mines on map are color coded with hexagons by depth. Basemap selection allowed by clicking on grey rectangle in upper right of window. For beginning users, it is recommended to activate / select all layers and to use satellite view for base map.