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DISPOSITION OF EXCESS FISSILE MATERIALS IN DEEP BOREHOLES

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ABSTRACT

As a result of recent changes throughout the world, a substantial inventory of excess separated plutonium is expected to result from dismantlement of U.S. nuclear weapons. The safe and secure management and eventual disposition of this plutonium, and of a similar inventory in Russia, is a high priority.

A variety of options (both interim and permanent) are under consideration to manage this material. The permanent solutions can be categorized into two broad groups: direct disposal and utilization. Plutonium utilization options have in common the generation of high-level radioactive waste which will be disposed of in a mined geologic disposal system to be developed for spent reactor fuel and defense high level waste. Other final disposition forms, such as plutonium metal, plutonium oxide and plutonium immobilized without high-level radiation sources may be better suited to placement in a custom facility. This paper discusses a leading candidate for such a facility; deep (several kilometer) borehole disposition.

The deep borehole disposition concept involves placing excess plutonium deep into old stable rock formations with little free water present. The safety argument centers around ancient groundwater indicating lack of migration, and thus no expected communication with the accessible environment until the plutonium has decayed.

Conceptual design studies have been prepared to serve as the basis for assessing the feasibility of deep borehole Pu disposition, and to allow comparison to other options in a systematic way. Issues of concern include the regulatory, statutory and policy status of such a facility, the availability of sites with desirable characteristics and the technologies required for drilling deep holes, characterizing them, emplacing excess plutonium and sealing the holes. Input data has been developed for a programmatic environmental impact statement (PEIS). This PEIS, along with the conceptual designs and analyses will serve as the basis for a decision on which concept(s) to pursue for plutonium disposition.

BACKGROUND

In the aftermath of the Cold War, the Russian Federation and the United States are reducing defense requirements at an unprecedented rate, resulting in the mixed blessing of having to manage substantial quantities of weapons-usable fissile materials coming from dismantled weapons and deactivated facilities and processes. These stocks of material could threaten national and international security if they are not properly managed to preclude proliferation as well as environment, safety, and health consequences. President Clinton's September 1993 Non-proliferation Policy

Directive included a commitment to a comprehensive review of plutonium disposition options. His subsequent January 1994 joint summit statement on non-proliferation with President Yeltsin also committed experts from both countries to joint studies of options for the long-term disposition of fissile materials.

Since then, the U. S. Department of Energy has established an Office of Fissile Materials Disposition (MD), and serves as the lead support agency for the U. S. Interagency Working Group focused on this issue. Both the current U. S. scope of work for fissile materials disposition as well as plans for joint studies with Russian experts include tasks related to geologic emplacement of these materials in deep boreholes. A recent review of the plutonium management issue by the National Academy of Sciences recommended further assessment of several options. The deep borehole was considered less developed and not clearly understood, but the potential for easier, quicker or cheaper implementation led to a recommendation for further study. The deep borehole was considered primarily for direct emplacement of plutonium without first utilizing its energy content as a nuclear fuel. Utilization concepts fission some of the plutonium in a reactor or accelerator target and result in a waste stream which qualifies as high-level radioactive (HLW) waste. Since such wastes (in the U.S.) are specified for disposal in a mined geologic repository system to be developed for spent commercial reactor fuel and processed defense high level waste they are not considered for deep borehole disposition. Another option recommended for consideration by the NAS study is incorporation of the excess plutonium into the vitrified defense high-level waste designated for mined geologic disposal. The deep borehole is the only fissile disposition alternative to the HLW respoitory currently being considered.

Screening of Disposition Options

A wide range of potential alternatives exists for disposition of the fissile materials determined to be excess to U. S. national security needs. In order to husband limited resources for assessing the efficacy of specific approaches, evaluation criteria were developed by a "screening" committee to enable a preliminary screening process to establish a reasonable range of alternatives for further evaluation. These criteria were reviewed with and by a wide spectrum of "stakeholders" in an effort to establish a robust and well-balanced basis for assessing disposition options. An extensive set of possible disposition options were weighed against the following criteria: resistance to theft or diversion by unauthorized parties; resistance to retrieval, extraction, and reuse by host nation;technical viability; environment, safety and health compliance; cost effectiveness; timeliness; fostering progress and cooperation with Russia and other countries; public and institutional acceptance; and any additional benefits. The screening process includes two steps: a) evaluating each option to identify any "fatal flaw" which would disqualify the option based on failing a specific criterion, and b) examining the remaining options against all of the criteria to identify candidates for elimination based on dominance by other options or low overall performance.

Disposition options which survive this preliminary screening process will be more fully analyzed in support of the programmatic environmental impact statement (PEIS) on this subject (as well as the subsequent record of decision which will be based on factors beyond those considered in the PEIS.

Previous Consideration of Deep Borehole Disposition

Deep borehole disposition has been considered in recent decades for disposal of both hazardous and radioactive wastes. This concept received significant investigation in the 1970s for disposal of high-level radioactive waste (HLW) including spent nuclear reactor fuel (SNF). Several limitations in the concept for that particular mission led several nations to drop it in favor of a mined geologic facility. Examination suggests the reasons for rejecting deep borehole disposal of HLW and other wastes are not severe for a plutonium disposition mission, and may even become assets! A brief summary of these issues and their status for the plutonium disposition mission includes:

- Retrievability of HLW from a deep borehole would be difficult
  Difficult-retrievability may be desired for Pu disposition
- Volume of HLW would require many large holes
  Volume of excess Pu without added fission products is comparatively small
- Heat generation of HLW would limit hole capacity
  Heat generation of excess Pu is comparatively small
- Level of isolation required for LLW, ILW, TRU did not justify the cost
  There is a high priority on isolation of Pu to ensure against recovery and reuse
- Drilling technology limitations
  Drilling technology has improved

These considerations, and the desire to explore an option independent from the HLW repository program, have driven current interest the current deep borehole investigation.

DESIGN AND OPERATING CONCEPTS

To allow early comparison of deep borehole disposition to other options for weapons-usable fissile material disposition, preliminary operations concepts have been considered and simple conceptual designs prepared. These concepts are non-site-specific and include descriptions of surface facilities, drilling and emplacement facilities and as emplaced configurations for the disposition forms. A drawing of one current design example is shown in Figure 1 with a stepped borehole 4 km deep with emplacement in the bottom 2 km.

Desirable Site Characteristics

Generic site characteristics which would be desirable for such a facility have been developed. The primary considerations concern the subsurface emplacement zone, for which desirable characteristics include: long history of tectonic stability, limited open fracture/void space, any water present should be ancient and preferable conate, adequate thickness for emplacement, mechanical strength for hole integrity, gradual thermal gradient and benign geochemistry. Rock types which have been suggested for consideration include: plutonic/metamorphic "basement" rocks (e.g. granite), tuffs, evaporites (e.g. salt), sedimentary rocks (e.g. shales) and mafic lavas (e.g. basalt). Additional characteristics should include a lack of evident geologic resources to attract future drilling, access to transportation, surface water for drilling and reasonable distance from population centers.

Site characterization requirements have been considered to assess the ability of current technology to remotely determine the downhole conditions and properties using surface based methods. It is expected that adequate understanding can be obtained through the use of multiple characterization drillholes and extrapolation of existing techniques such as: continually cored sample holes, detailed well logging and cross hole testing.

Potential Disposition Forms

A wide range of disposition forms have been considered. It was desired to consider direct disposition of plutonium to see if the simplest and most direct disposition options were viable. As a alternative with potentially higher isolation performance and criticality control, disposition of immobilized forms have also been included. An early decision was made not to consider forms with radionuclides added to achieve a high radiation field as a deterrent to diversion. Most of the forms for other options have such characteristics, and both the radiation and thermal output would complicate the borehole operation. Preliminary design examples have been explored for disposition of plutonium metal, plutonium oxide and plutonium immobilized in glass, ceramic or metallic forms.

Surface Facilities

Preliminary surface facility layouts have been prepared against a set of functional requirements including: receiving from either rail or truck transport, processing as required, lag storage, waste management, material security, and operating personnel. Facilities have been sized for disposition of 50 metric tons of plutonium over a 10 year operational period. It is assumed that these materials will require active security until the hole is sealed and stemmed. It is also assumed that IAEA Safeguards will be applicable.

Drilling, Emplacement and Sealing Technologies

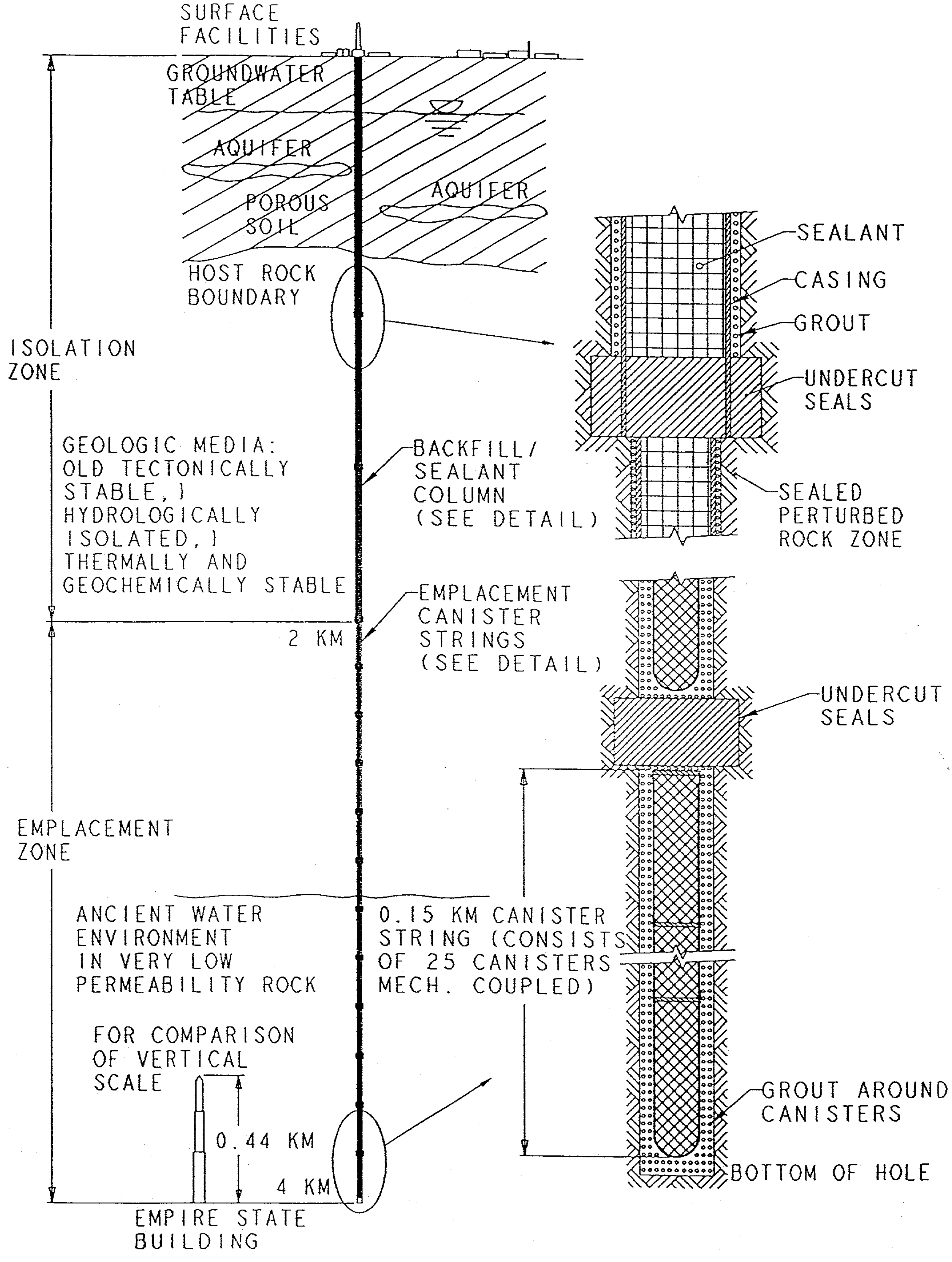
Technology of interest for drilling, emplacement and sealing can be found in underground nuclear weapon testing technology, deep geotechnical research drilling programs and in the mineral exploration industry. Preliminary evaluations suggest that drilling boreholes in suitable rock to depths of 4 to 6 km with usable bottom diameters of 0.5 to 0.75 m can be achieved with reasonable time and cost. Emplacement of canister strings weighing tens of tons can be accomplished with existing equipment. While we have not attempted to specify seal designs without site specific information, high integrity seal technology is available for a variety of applications.

SAFETY CONSIDERATIONS

Preliminary safety considerations have been assessed, both operational and post-operational. The unique considerations for this facility would be the long term safety of the emplaced material.

Insert Figure 1 after this page

TYPICAL ARRANGEMENT OF DEEP BOREHOLE WITH EMPLACEMENT CANISTERS IN EMPLACEMENT ZONE



Long Term Plutonium Isolation

Permanent isolation of the material in the deep borehole relys primarily on the inherent characteristics of the geologic medium. The emplacement canisters are relyed upon only for operations and are not expected to isolate the material from the host rock. It is possible that some immobilized disposition forms would have significant long term performance in the down hole environment. If the site has suitable characteristics, then there no significant ambient natural transport pathways for radionuclide migration. Isolation demonstration then focuses on the potential for migration back up the stemmed and sealed borehole and on creation of potential vertical flow pathways in the host rock during drilling, operation, sealing or the postclosure thermal transient. The very high lithostatic load in both the host rock and the stemmed borehole are expected to limit fracture opening and free void space significantly. Any mobile water should have a high ionic strength, with a vertical density gradient sufficient to suppress any thermal buoyancy driving force. Periodic pressure or undercut seals would be used to interrupt new stress relief fractures created parallel the borehole. These are some of the key process which would require verification in a characterization program.

Criticality Control

Emplacement of large quantities of fissile material in a limited volume always raises criticality concerns. Several approaches are being studied for operational and long-term postclosure criticality control. Individual emplacement packages can be designed to contain criticality limited quantities of plutonium. Neutron absorbers can be incorporated into the disposition form and into the packing material surrounding the canisters. Fissile material can be physically dispersed throughout a matrix at concentrations which maintain sub-criticality. Combinations of these approaches are included on current design concepts. In addition, preliminary studies have considered the potential for reconcentration of fissile material in the geosystem, and whether any adverse consequences would be expected from post closure criticality.

REGULATORY AND LICENSING ISSUES

Perhaps the greatest current uncertainty in the feasibility of deep borehole disposition is the regulatory and licensing requirements for such a facility. Because concentrated, separated fissile material in significant quantities has never been considered for direct disposition before, current waste management regulations are not clearly appropriate for such a facility. Several existing or planned facilities may be useful as relative benchmarks to suggest regulatory stringency, including; the Greater Confinement Disposal Facility (GCDF) at the Nevada Test Site for disposal of gram quantities, the Waste Isolation Pilot Plant (WIPP) being developed for disposal of many tons of defense transuranic wastes near Carlsbad NM and the High-Level Radioactive Waste repository designed to emplace much larger quantities of plutonium incorporated in 70,000 tons of spent reactor fuel. WIPP is a useful precedent for developing a custom regulatory environment to assess a deep borehole facility because the hazard levels are similar and both are unique facilities. The fundamental safety argument for the borehole is emplacement in old stable rock with little mobile water and no hydraulic communication with accessible water. Some precedent exists for deep injection of hazardous material into waters which do not communicate with accessible waters, and this approach is central to feasibility of the deep borehole. Current plans are to initiate dialog with the NRC and EPA to consider possible regulation and licensing of such a facility.

CONCLUSION

The concept of deep borehole disposition of weapons-usable fissile materials is currently in a preliminary scoping assessment stage to allow comparison to other options for disposition of this material. Initial studies of technical feasibility, potential safety issues, and potential cost and schedule are encouraging. Numerous issues require further assessment, with regulatory implementation being the greatest uncertainty.

Figure 1 Conceptual design of a deep borehole facility for fissile material disposition.

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