Conf-9503166--1

UCRL-JC-120593
PREPRINT

Regulatory Issues for Deep Borehole Plutonium

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This paper was prepared for submittal to Fluor Daniel
Lawrence Livermore National Laboratory
Livermore, CA
March 29, 1995

March 1995

Lawrence Livermore National Laboratory

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White Paper

Regulatory Issues for Deep Borehole Plutonium Disposition

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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 regulatory issues for 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. This white paper discusses the regulatory issues.

Regulatory issues concerning construction, operation and decommissioning of the surface facility do not appear to be controversial, with existing regulations providing adequate coverage. It is in the areas of siting, licensing and long term environmental protection that current regulations may be inappropriate. This is because many current regulations are be intent or by default specific to waste forms, facilities or missions significantly different from deep borehole disposition of excess weapons useable fissile material. It is expected that custom regulations can be evolved in the context of this mission.

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

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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 repository currently being considered.

THE DEEP BOREHOLE DISPOSITION CONCEPT

The deep borehole disposition concept involves placement of excess materials in the bottom portion of one or more holes drilled into deep rock formations which have no significant history of hydrologic communication with the accessible environment. A host rock would be sought which is stable tectonically, hydrologically,thermally and chemically. Lithostatic loads at depths of several kilometers should limit fracture opening and free void volumes which could provide water flow paths. Any water which is present should be ancient and perhaps even conate, or emplaced at the time of rock formation. These features provide strong evidence that the water has not communicated with the accessible environment and is not expected to in the foreseeable future. Thus, the "deep" in deep borehole refers not to a specific depth, but to that depth at which the desirable host rock conditions can be found. Given such conditions, the safety demonstration would focus on understanding and mitigating any flow pathways and driving forces for migration introduced into the site by construction, emplacement operations, closure and sealing and by the small amount of thermal perturbation from radionuclide decay.

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.

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.

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. It should be determined as soon as practicable whether this material would be managed under DOE 5820.2A Radioactive Waste Management, and if so, what amendments are appropriate. The author suggests that this, or a similar custom Order, would provide the framework for evolution of appropriate regulations. Because most of the uncertainties concern siting, licensing and long term isolation and safety, rather than operational safety, we will divide our discussion into these two categories: operational and post-closure. We begin with a brief perspective on the operational period regulations.

Operational Regulations for the Surface Facility

Regulations governing transportation, packaging, storage and handling of radioactive materials, and construction, operation and decommissioning of the surface facilities are not very controversial. Existing regulations, orders and codes should adequately cover these activities.

Transportation and packaging

Transportation of radioactive materials to the facility would probably be covered by 49 CFR 173.7 for U. S. Government material, with 49 CFR Subpart I for radioactive material. Packaging should conform with 10 CFR 71. Transportation would probably also conform to IAEA Safety Series #6, with additional requirement for plutonium shipping given in 10 CFR 71. Safeguards and security regulation pertaining to shipment of plutonium are given in 10 CFR 73.25 to 73.27. Modification of several of these requirements may be appropriate for immobilized forms.

Construction and operation

Facility development would likely conform to standard DOE design, procurement and construction orders such as: DOE 4700.1 Project Management System, DOE 5700.6B Quality Assurance, and DOE 6430.1 General Design Criteria. Handling of radioactive materials, worker safety, environmental protection and public health might involve a collection of requirements including: DOE 5630 series regarding safeguards and security, 10 CFR 20 Radiation Protection, 10 CFR 835 Occupational Radiation Protection, 40 CFR 141 and 142 National Primary Drinking Water Regulation and Implementation. It is likely that provisions of 40 CFR 191 Environmental Radiation Protection for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes will apply to the operations.

Rather than trying to be comprehensive here, we have attempted to illustrate our belief that all phases of the surface operations can be accommodated within existing guidance, with modifications as appropriate.

Siting, Licensing, and Long Term Safety Regulations

Because concentrated, separated fissile material in significant quantities has never been considered for direct disposition before, many 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.

It is useful to consider the possible status of excess weapons-usable fissile material. Plutonium by itself is not either low-level waste (LLW) or high-level waste (HLW) as defined by regulation. It certainly is transuranic, but does not fit the common description of transuranic waste (TRU) which includes items that have been contaminated as a result of activities associated with the production of nuclear weapons such as rags, equipment, tools, contaminated sludges and residues. Significant quantities of concentrated plutonium also do not readily fit within the WIPP Waste Acceptance Criteria for TRU disposal. To meet the WIPP criteria, weapons usable plutonium would require dilution down into millions of barrels for emplacement as contact handled waste, or thousands of containers for remote handled waste which would consume much of the currently proposed capacity of the facility. This cursory analysis suggests that direct disposition of surplus fissile material might create a custom category or sub-category of waste.

We would like to examine three regulatory topics for potential application to a deep borehole facility: Siting, Licensing and Environmental Protection. In doing so, it is important to bear in mind the purpose of these regulation: to provide a quantitative measure of comparison for adequacy in regulatory proceedings regarding the ultimate safety of the facility. The fundamental safety argument for the borehole is emplacement in old stable rock with little mobile water and no hydraulic communication with accessible water.

Siting and site characterization

It has been suggested that site suitability guidelines such as those of 10 CFR 960 for the HLW repository program might be useful guidance for borehole siting. It is important to note that the HLW guidance was developed specifically for a mined geologic repository with human access for characterization, and for a facility for isolation of much more hazardous material than excess fissile material and with specific system and subsystem performance requirements. Many of the provisions of Part 960 may not be appropriate for the borehole facility. The intent of the guidance however could be used in formulating specific guidelines for siting and characterization of a borehole site consistent with the performance strategy for that facility. We would suggest care however that any such guidance be based on fundamental safety requirements and not deviate into a site characteristics 'wish list'. The DOE-MD borehole task does have an activity to consider potential site characteristics and the beneficial and adverse impacts which could result from them. The task will also survey potential characterization capabilities to estimate what can be learned about a borehole site. The results from these preliminary studies may provide a basis for defining site guidelines in the future. Such guidance would appropriately concentrate on the fundamental arguments for borehole facility safety: little free water present, what water is present has not migrated in geologic times, water is not expected to communicate with accessible or usable water in future geologic times, any flow paths or migration driving force created during facility construction, operation and sealing will not adversely affect this expectation.

Licensing

Licensing requirements are a key area where there are no clearly applicable regulations for the deep borehole. As was noted earlier, concentrated plutonium disposition forms meet neither the requirements for HLW or the normal criteria for TRU. It has been suggested that the HLW regulations of 10 CFR 60 Disposal of High-Level

Wastes in Geologic Repositories could be used, but upon inspection there are significant mismatches between these regulations and the borehole facility mission. Part 60 includes provisions for subsystem performance requirements on waste packages and the engineered barrier system which are inconsistent with the safety argument for the borehole. Part 60 mandates a retrievability period which is inconsistent with the goal of timely disposition of weapons-usable materials. The time frames of various requirements of Part 60 are based on the radionuclide decay characteristics of spent nuclear fuel (SNF) and defense high-level waste (DHLW), which is inconsistent with the borehole disposition forms. Provisions of Part 60 pertain to manned access of require access to the operations area which is inconsistent with borehole emplacement. Portions of Part 60 deal with thermal and radiation emissions from SNF and DHLW, which are inappropriate for plutonium. Portions of Part 60 dealing with criticality might be useable, but should be assessed in the safety context of the borehole concept. Finally, Part 60 was developed to assure safety of a much larger inventory of much more radioactive material in a facility much closer to the accessible environment than the borehole.

Safety compliance criteria for WIPP (40 CFR 194) were developed to comply with 40 CFR 191 and are based on the WIPP acceptance criteria which would not cover the weapons-usable disposition forms under consideration for the deep borehole unless they were partitioned and diluted. Further, the family of WIPP regulations was effectively customized in negotiating the land withdrawal act, and are specific to the WIPP mission, waste forms and location in bedded salt.

Both the HLW repository and WIPP provide useful precedent that governing regulations for licensing a plutonium disposition facility can and should be custom developed for the mission. It is likely that much of the intent and structure of the HLW and WIPP regulations would serve as useful guides in such development, providing that the specific technical provisions were kept relevant to the mission and safety strategy for the borehole disposition facility.

Environmental Protection

The core EPA regulation in question, 40 CFR 191 Environmental Radioactive Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste, should clearly apply to a facility for plutonium disposition. What is uncertain is just how. This regulation was remanded by court back to EPA for reconsideration several years ago. Review of potential revisions has been directed to the National Academy of Sciences by the Congress. In addition, several bills are currently pending in Congress which could further revise the details and application of Part 191. It appears in both WIPP and HLW applications, Congress and the courts are specifying the applicable portions on a facility specific basis. We suggest the assumption that Part 191 (or whatever follows it) will apply to the borehole facility, but that all portions might not be appropriate for the mission, disposition forms, performance strategy or location. In any event there will be a form of total system radionuclide hazard performance goals to be met, either as a release rate, dose rate or population risk, or a combination of these. We would expect that total system radionuclide protection standards would be applied at some point in the accessible environment, and not apply at the point of emplacement which is remote from the accessible environment and usable waters. To support this expectation, preliminary estimates for the ambient brines at a typical site predict 300 grams of total dissolved solids per liter of water, compared to a maximum of 10 grams per liter specified in Part 191 as an underground source of drinking water. We do however expect that safe drinking water standards (40 CFR 141,142) will apply to any useable aquifers, which could reside far above the emplacement region.

Other Regulations

There has been discussion as to the application of the Resource Conservation and Recovery Act (RCRA) to the disposition forms in a deep borehole. RCRA should only be a consideration if the form includes hazardous quantities of 40 CFR 261 listed materials, which we do not expect to be the case.

If regulations for licensing a HLW repository (10 CFR 60) do not apply to the deep borehole, then it has been suggested that perhaps the regulations for LLW (10 CFR 61) might apply. This is highly unlikely as plutonium is not LLW and Part 61 is intended to govern shallow land burial of short lived radionuclides.

Regulations exist to control deep well injection of hazardous materials, primarily 40 CFR 148. There has been debate on whether this regulation would apply to borehole disposal of solid radioactive materials. If it was found to apply to a deep borehole, a "no migration" waiver would be required, which requires showing expectation that the material will not migrate in 10,000 years. Significant precedent exists for issuance of such a waiver. We note that the fundamental safety argument of the deep borehole is that the water present hasn't migrated in geologic times and is not expected to in the forseeable future, the basic requirement for a waiver.

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. It is suggested that adequate regulatory coverage exists for the operational issues. For the licensing and long term environmental protection, it is suggested that current regulations are not entirely appropriate. Modification of and development from existing regulations in the context of the borehole safety basis could produce an adequate framework of regulations appropriate to deep borehole disposition of excess weapons-capable fissile materials. Ultimately, the regulatory stringency should evolve from predicted risk to the public and the environment, and compliance should be judged in comparison to other alternatives for plutonium disposition including the 'no action' alternative of extended storage.

ACKNOWLEDGEMENTS

Work performed under the auspieces of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.