The Scope of Utility of Deep Borehole Disposal of Radioactive Waste

(as delivered)

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DBD has been considered for the disposal of spent nuclear fuel and now DOE is seriously contemplating an experimental program in support of DBD of “Smaller DOE-Managed Waste Forms.” For the disposal of “capsules” of Sr-90 and Cs-137, the principal contributions to the initial radioactivity die away with a half-life of 30 years, so in 1000 years the radioactivity of these isotopes is down by more than a billion. Engineered storage, particularly sub-surface storage, would be suitable, with provisions to handle the initial intense heat evolution. DBD disposal of these smaller waste forms has the advantage that it does not stress the performance of borehole isolation over millennia, but only over centuries.

My colleagues on this panel have provided estimates of projected dose from DBD although the comparison to projected dose from a geologic repository is difficult to make because it is dependent on the particular form and siting of the geologic repository and of the engineered containment.

I shall discuss the potential of DBD for excess weapon plutonium, for which there are some very specific questions of criticality and long-term isolation. The principal components of W-Pu are Pu-239 and Pu-240, with half lives of 24,000 and 6600 years, respectively.

For the disposal of spent fuel, the typical 1% Pu content provides challenging thermal problems for late times, but those problems are less severe for the disposal of excess W-Pu, simply because there is so much less of it. On the order of 40 MT of W-Pu is committed for disposal under the U.S.-Russia Plutonium Management and Disposition Agreement (PMDA), which entered into force on July 13, 2011—by conversion to MOX and burning in commercial power reactors, although the agreement allows, in principle, other forms of disposal.

The 76,000 MT of spent fuel considered for the Yucca Mountain repository would have some 700 MT of Pu, contributing a more than proportionally larger thermal power output, because much more of the reactor-grade Pu (R-Pu) is Pu-240.

DBD of excess W-Pu would start with metallic Pu from the weapon “pits” although in some approaches, it would be converted to hydride and then to oxide for disposal.

The creation of disposal volume in a deep borehole is far more costly than volume in a mined repository, and in any case repositories are for the most part thermally limited rather than volume limited. As described, heat generation is not the major problem for Pu-disposition. On the other hand, a Pu-bearing waste form of low density, containing a small concentration of Pu, would drive up the cost of the DBD approach because of the large volume to be disposed. Accordingly, I consider here the disposal of encapsulated metal—not pure Pu for an important reason, but perhaps Pu-U alloy, in which the uranium is depleted uranium—"DU."

The time horizon of concern for non-retrievability of the Pu is not just a few half-lives of Pu-239 (24,000 years), but much longer, because Pu-239 decays to U-235—an eminently weapon-usable fissile isotope with a half life of 704 million years. It is also true that 40 tons of U-235 is only about 1500 significant quantities (SQ) according to the IAEA, whereas that mass of W-Pu is 5000 SQ; but 1500 SQ is not negligible.

With a U-235 half-life of 704 million years, safety and security are a matter of concern for geologic time. As regards security, there is a big difference between direct-use fissile material such as HEU (greater than 20% U-235) and indirect use, such as LEU, that needs to be enriched before it can be used in a nuclear weapon.

Absent a good understanding that geochemistry will not result in the concentration of uranium beyond the geometrical configuration in which it is placed in the borehole, one might consider diluting the Pu with sufficient (depleted) uranium that after the Pu has decayed the uranium would be subcritical at all times and, of course, not directly exploitable by recovery of the material.

The disposition of weapon Pu is not a DOE-NE responsibility, but there is no reason for NNSA not to be aware of the cost and hazards of various options, even though they are not the frontrunners. It is now clear that a better understanding of options would have benefited the disposal program.
Many programs (and not only in DOE and NNSA) have suffered because there was insufficient exploratory analysis and research to identify a number of approaches and to determine their costs and benefits. It seems to me that DBD of excess W-Pu is one of these that should have been analyzed long ago, and merits analysis even now,

The system has to be safe during processing of the waste, encapsulation, presumably in high-strength steel for safety in handling and emplacement; during the emplacement and sealing of the borehole, including, probably, pulling the casing from the near-surface down to the beginning of the disposal zone.

A general question for DBD, of course, is whether it makes sense to pull the casing from the disposal zone as well. The corrosion and eventually dissolution of the steel casing adds a communication channel, but because the disposal zone is assumed to be uniformly packed with radioactive waste, making it all available at the shallow end of the DZ would not seem to increase the expected dose much above having access only to the material at the shallow end of the DZ. One approach is to have a highly perforated steel casing throughout the DZ so that grout or other filler will be in good contact with the rock of the borehole.

Unless the integrity of the encapsulation of the Pu-U alloy can be guaranteed for 50 ky or more, one needs to be concerned about geochemical separation of Pu from the corrosion products of the alloy, and its possible criticality, or the criticality of the resulting U-235 decay, because if the Pu decays in a separate location from the initial diluent uranium, the U-235 could itself be concentrated chemically and provide a nuclear chain reaction with moderated neutrons, depending on the composition of the rock.

So these are the questions—to what extent can the integrity of the engineered capsules (steel for strength surrounded by copper or gold perhaps) be guaranteed for 50,000 years or more, and to what extent can the resulting LEU be guaranteed against criticality with thermal neutrons because of neutron absorbers in the rock? And can such criticality cause problems at the surface?

We have the experience of the natural reactors of Oklo (Gabon), in which primordial LEU (probably in the range of 3% U-235) became critical with the relatively pure water of the environment in Gabon some 2 billion years ago. Here I note only that the reactors operated for some 100,000 years, self-regulating at a power on the order of 100 kW, probably in a kind of percolator mode, consuming a good fraction of the fissile material, just as do power reactors in our society. What would be the impact at the surface of such a reactor at a depth of 3km in granite? It would be good to have significant analysis, including the influence of inert-gas fission products.

Rather than providing here examples of criticality calculations of (0.03 Pu: 0.97 DU) capsules in a small borehole, or a similar mixture of oxides in a larger borehole, I ask for long-overdue[1] support for responsible analysis and publication, performed perhaps by MIT and Sandia, to better understand the utility of Deep Borehole Disposition of excess plutonium—whether of weapon origin or not, and not only of U.S. origin. It is in the security and environmental interest of all of the world's inhabitants to reduce the nuclear-weapon threat posed by stocks of civil or military plutonium.

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[1] Twenty years after the discussion of DBD of plutonium in the National Academies report, "*Management and Disposition of Excess Weapons Plutonium,*" Pp. 247-255 (available at http://www.nap.edu/catalog/2345.html).

Instead of adding the details of package design and criticality calculations for disposal packages of 3%Pu:97% depleted uranium (DU) metal, or that same composition converted to less corrodible oxide, I summarize remarks that I have made during the sessions.

1. Under the reducing conditions at 3-5 km depth favored for nuclear waste disposal packages, the steel containers as well as steel well casing may corrode[1] within a few years, liberating hydrogen bubbles that will proceed through buoyancy up small cracks within the borehole complex and the engineered seals. This needs to be analyzed; and in instances where it is not precluded, the transport of radioactive material gases and particulates should be estimated, including the scrubbing of the entrained radioactivity by the large surface area of the tortuous path.

Counterintuitively, taking measures to increase the local porosity of the crystalline rock in the disposal zone so that the waste can access a cylinder of 5m diam centered on the borehole, rather the borehole itself of 43cm diameter, might eliminate the formation of

[1] *"The deep borehole concept. A conceptual model for gas generation and gas transport,"* by Bertil Grundfelt, James Crawford, Kemakta Konsult AB, May 2014

hydrogen bubbles and the resulting transport via buoyancy, and it would not increase the overall transport through nominally unfaulted rock.

1. The seal concept of Rockmelting appears vulnerable to the shrinkage-produced cracks in the rock surrounding the melted and refrozen rock, as well as to the microporosity in that surround rock associated with the 573°C α-β transition in quartz.
2. If a satisfactory technical approach is found for the experimental wells and for the definition of a disposition program, it will be carried out by individuals and contractors with human and corporate properties and tendencies. The tens of billions of dollars in damages and fines paid by BP and its associates for consequences of the deficiencies in cementing, testing, and other inadequacies; and the outright cheating by VW on its emissions control software are only two examples that mandate that DOE or whatever agency carries out disposition activities must have and must exercise current insight into the detailed conduct of the program.
3. Finally, is the concept of multiple barriers optimum for a deep-borehole-disposal program? If seclusion by dense saline fluid at depth is effective and sure, is it worthwhile to investigate and to invest in lesser engineered barriers other than casing removal and nominal seals on the well? Waste package emplacement would be accompanied by the supply of dense saline fluid in the disposition zone to maintain from the start the density gradient barrier, BUT flow of water along faults in the disposal zone can convey dissolved or suspended waste to large distance horizontally. Even if such flow cannot lead to the surface in the vicinity of the borehole because of the fluid density, the acceptability of spreading of waste to large distance at a depth of 3-5 km must be evaluated.