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Key Observations on the Deep Borehole Disposal of Spent Fuel

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1. Introduction

As a potential option for long-term isolation of spent fuel at cost-competitive with mined repositories, deep borehole disposal has been proposed. We have reviewed the deep borehole disposal concept development.

For the bounding analysis of this report, waste is envisioned to be emplaced as fuel assemblies stacked inside drill casting that are lowered, and emplaced using off-the-shelf oilfield and geothermal drilling techniques, into the lower 1-2 km portion of a vertical borehole ~45 cm in diameter and 3-5 km deep, followed by borehole sealing.

2. Review of the Deep Borehole Disposal Studies

Thermal, hydrologic, and geochemical calculations suggest that radionuclides in spent fuel emplaced in deep boreholes will experience little physical reason to leave the borehole/near borehole domain. The vast majority of radionuclides, and the fuel itself, will be thermodynamically stable and will therefore resist dissolution into borehole fluids, or movement into and through the adjacent rocks. Thermal-hydrologic calculations indicate that, except for an early window extending from the time of emplacement to ~ 150 years post-emplacement (in the borehole), and ~ 600 years (to the top of the basement), there will be no vertical fluid flow to transport radionuclides towards the surface. Vertical transport velocities in the early flow window will be between 0.1 (basement) and 0.7 (borehole) m/yr. This means that total vertical fluid movement in, and adjacent to, deep borehole disposal zones should not exceed roughly 100 meters. In the absence of advection, chemical diffusion cannot move radionuclides from boreholes through discontinuous, stagnant, and density-stratified waters over distances much greater than about 200 meters in the 1,000,000 years needed for the vast bulk of the radioactivity to decay away. Simplified and conservative performance assessment calculations indicate that radiological dose to a human receptor via the groundwater pathway would be limited to a single radionuclide (^{129}I) and would be negligibly small, ~10 order of magnitude below current criteria. [1]

The canisters use standard oil drilling casings. The inner diameter is 315.32mm in order to accommodate a PWR assembly with a width of 214mm. At five meters tall, each canister holds one PWR assembly. The canister thickness is 12.19mm, with an outer diameter of 339.7mm. A liner can extend to the bottom of the emplacement zone to aid in retrievability. The liner has an outer diameter of 406.4mm and a thickness of 9.52mm. The standard drill bit used with a liner of this size has an outer diameter of 444.5mm.

Sample calculations were performed for a two kilometer deep emplacement zone in a four kilometer deep hole for the conservative case of PWR fuel having a burnup of 60,000 MWd/kg, cooled ten years before emplacement. Tensile and buckling stresses were calculated, and found to be tolerable for a high grade of steel used in the drilling industry.

In the thermal analysis, a maximum borehole wall temperature of 240^0C was computed from available correlations and used to calculate a maximum canister centerline temperature of 337^0C, or 319^0C if the hole floods with water. [2]

Table I below shows what studies have been conducted so far in the area of the deep borehole disposal.

Table I: Studied Items

1	Thermal Effects on Hydrologic Environment - Heat conduction - Thermally driven hydrologic flow - Groundwater pumping and dilution above the borehole disposal system
2	Chemical Environment - Radionuclide solubility - Radionuclide sorption
3	Emplacement Process
4	Short & Long Term Environment of the Borehole
5	Canister Design - Diameter, height, material
6	Stress Analysis -Tensile & compressive stress of the waste string during the emplacement process - Thermal stress on the borehole wall

7	Thermal Analysis - Fuel assembly homogenization - Calculation of the canister centerline temperature - Parametric study of temperatures in the borehole system
8	Economics - Daily rig cost - Total drilling operation cost for a single hole - Estimation of current costs for drilling

KIGAM(Korea Institute of Geoscience and Mineral Resources) has conducted development of exploration, evaluation, and investigation techniques deep drilling technology to 2386m with the purpose of utilization of geothermal energy in Pohang, Korea.[3] The first geothermal power station of Korea broke ground in 2012,and plans to drill to 5km by 2015. This experience can be applied to the deep borehole disposal study.

3. Key Observations

3.1 Thermal Analysis

Two things should be accounted for in the thermal analysis conducted. The role of axial cooling should be analyzed. In reality, some heat would travel away from each borehole. At first axial cooling would occur in both directions, but due to the vertical thermal gradient, most of the cooling would be toward the surface of the earth. Also, the vertical thermal gradient inside the borehole due to convection needs further analysis.

3.2 Plugging

After filling a borehole with waste, it will need to be plugged to prevent radionuclides from reaching the biosphere via the borehole. In May of 1980, a workshop was held in Columbus by the OECD Nuclear Energy Agency and the United States Department of Energy. The workshop proceedings were published with a title "Borehole and Shaft Plugging".[4] The workshop addressed plugging of mined geologic repositories and boreholes in basalt and rock salt. Bentonite, cement based sealants, and cement grout were addressed as part of the proposed plugging system. A similar analysis should be performed for plugging boreholes in granite.

3.3 Performance of Disposal Canisters

The durability of the proposed canister made of oil drilling casings needs be upgraded. On the time scale of up to a million years required for disposal safety assessment, the canisters would fail quickly if they do not have a proper protective coating. The use of corrosion resistant materials should allow the engineered barriers to be sufficiently long lived to make a useful contribution to safety.[5] However, the canisters do not need to last such a long time if the natural barrier and plugging perform properly as the primary barrier to minimize radionuclide migration to the biosphere. An analysis should be performed to assess a variety of canister failure scenarios.

3.4 Coupled Modeling Analysis

The coupled thermal-hydrologic-chemical-mechanical behavior of the borehole and disturbed region during the thermal pulse, and in the presence of density-stratified waters, should be modeled more accurately.

3.5 Performance of Multi-Borehole Arrays

Modeling of both the detailed thermal-hydrologic-chemical-mechanical behavior and the full-system performance of multi-borehole arrays should be undertaken, consistent with an assumption that a regional borehole disposal facility could entail an array of 10-100 individual boreholes. Such investigations could elaborate on the potential for cross-hole effects, and help determine minimum inter-holes distances.

3.6 Site Selection

A detailed study would be required to identify suitable locations for repository. The political process could also be analyzed.

4. Conclusions

Deep boreholes represent another form of deep geologic disposal that may offer benefits. However, this concept is less well understood than disposal in a mined repository and requires further exploration.

REFERENCES

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