Impact of Storage Period on Safe Geological Disposal of Spent Fuel

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Introduction

Geological disposal is the widely accepted method for safe disposal of Spent Fuel (SF) and high-level nuclear waste. In geological disposal, canisters containing SF/HWL are simply placed into boreholes in a geological formation deep underground, specifically selected for final disposal of nuclear wastes. The amount of waste that can be safely emplaced per unit area of the repository is defined as the disposal density, and it strongly depends on the characteristics (amount, isotopic composition, heat generation rate) of the waste. The isotopic composition and heat generation rate of SF change during the interim storage prior to disposal. This study aims to assess the effect of the length of interim storage period on the disposal density of SF in a geological repository.

Method

Heat dissipation from SF is one of the most important factors in the design of a geological repository, and it depends on the composition of SF. SF composition is a function of fresh fuel enrichment, burnup, reactor power and cooling time. Disposal density calculations have two major parts:

1. Determination of compositions and decay heat profiles of wastes: Utilizing the code MONTEBURNS, relevant compositions and decay heats of SFs discharged from a reference PWR are obtained for selected cooling times.

*MONTEBURNS is a Monte Carlo burnup code that links the Monte Carlo transport code MCNP with the radioactive decay and the burnup code ORIGEN2.*

2. Determination of disposal area through thermal analysis: Using the code ANSYS, thermal analyses are performed for a reference repository concept and disposal areas needed for SFs with different ages are determined by ensuring that thermal criteria limiting the canister surface temperature is satisfied.

*ANSYS is a finite element analysis software that can be used in modeling problems in wide range of engineering fields such as structural, thermal, mechanical, fluid dynamics, electrical.*

Results

• Disposal area needed to safely dispose one ton of SF (cooled for 40, 50, 60, 80 and 100 years) in the reference repository is calculated from the minimum distance between boreholes, distance between tunnels, and the amount of waste loaded into a canister.

Conclusion

• Results show that, as the cooling time prior to the disposal goes up, a significant reduction in the disposal density can be achieved.

• However, the constraints of mechanical nature to maintain the physical integrity of the disposal area during the operational period become important below a borehole spacing of about 4 m.

• To sum it up, for SF with 33000 MWd/t burnup from the reference PWR in this study, a cooling time of around 50 years prior to the final disposal represents a reasonable compromise.

Analysis (cont’d)

<table>
<thead>
<tr>
<th>Decay Heat Profile</th>
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<tr>
<td>SF Composition</td>
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<tr>
<td>SF discharged in the reference case consists of about 95% U-235 with Pu-239 and minor actinides. The U in SF contains around 0.85% U-233. About 70% of Pu in SF is composed of fissile isotopes, i.e., Z9% Pu-239 and 11% Pu-238.</td>
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In order to obtain heat generation rate equations for SFs with different storage periods (40, 50, 60, 80 and 100 years), which are to be used as heat-source terms in thermal analyses, a time-dependent decay heat curve is fitted to the sum of four exponential terms: Put’s formula [1]:

\[ Q(t) = \sum_{i=1}^{4} A_i e^{-\lambda_i t} \]

where Q is decay heat in W/His, t is time in years elapsed since the production of SF. Values of the coefficients to be used in Put’s formula are given in Table I.

Disposal Density Calculations

• Once SF is emplaced into the repository, temperatures of the repository components start to increase due to the heat generation.

• Increasing temperature affects many processes occurring in the repository, thus, during the repository design, it is necessary to investigate the resultant time-dependent temperature distributions and determine an appropriate density of placement.

• Thermal analysis is performed with the finite element code ANSYS to calculate time-dependent temperature distributions in the repository.

Reference Repository

• KBS-3 concept developed by SKB (Swedish Nuclear Fuel and Waste Management Company)

• SF is placed into copper canisters with a cast iron insert.

• The canisters are surrounded by bentonite buffer and placed vertically into holes excavated along parallel tunnels at a depth of 500 m in granite rock.

• The depth of a deposition hole is 7.5 m meters and its diameter is 1.75 m.

• Disposal tunnel diameter is 5.5 meters. The distance between the disposal tunnels is 40 meters.

Analysis (cont’d)

<table>
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<th>Reference Reactor</th>
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<tr>
<td>• 1000 MW PWR</td>
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<tr>
<td>• 5.9 weight percent (wt%) enriched UO2 fuel</td>
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<td>• 7000 MW/tU, discharge burnup</td>
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<td>• 1000 years trituration time</td>
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References


