Disposal Density Analyses based on the Spent Fuel Cooling Time for a Deep Geologic Repository Design

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1. Introduction

The purpose of HLW disposal is not only to isolate the HLW from human environment but to delay the leaked radioactive materials to human environment. Extremely high and long-time scale radioactivity of HLW led to the idea of deep geological repositories in stable geological formations. Deep geological disposal remains the most preferred option for the safe management method of high-level radioactive waste in several countries, including Republic of Korea.

A deep geologic repository concept for the disposal of spent fuels from reactors involves emplacing heat-generating, disposal containers with spent fuels at a depth ranging between 500 to 1000 m in a plutonic rock mass. Further delaying spent fuels disposal results in further decay of the radioactivity, in turn, reducing the intensity of the heat source of the waste.

In this study, various disposal pit/tunnel spacing have been derived through thermal analysis for the repository satisfying the thermal requirement according to the spent fuel cooling times. And, the correlations between spent fuel cooling times and the disposal area are reviewed. From this review result, an optimized spent fuel cooling time is derived.

2. The concept of disposal system

2.1 Thermal design

Geological disposal considers multi-barrier, the natural barrier and engineered barrier. However, because the natural barrier has a lot of uncertainties, the engineered barrier concept which is composed of spent, canister, buffer, backfill, etc. is implemented to establish the reliability of safety.

The temperature requirements of the buffer to maintain the temperature below the 100˚c is major limitations for underground repository layout to maintain the integrity of the repository system.

2.2 Unit disposal area

The concept of the unit disposal area considering the area between disposal tunnel and disposal pit spacing is set up as shown in Fig 1. Therefore, overall scale of the repository can be estimated by multiplying the unit disposal area and the number of disposal packages. From economical point of view, it is desirable to set up the disposal tunnel spacing and the disposal pit spacing so that the repository area can be minimized and the disposal density can be high.

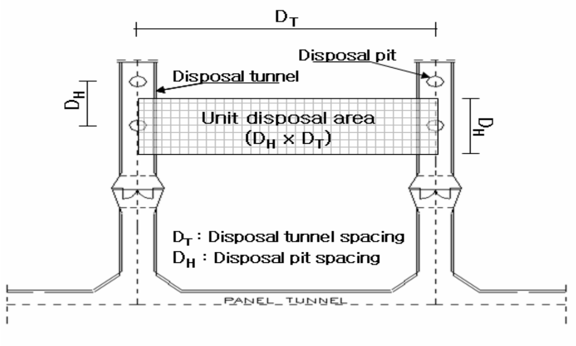

Fig. 1. Concept of Unit Disposal Area

3. Heat analysis of the repository system

3.1 Analysis model

A model for the thermal analysis of the geological repository implemented 3-dimension quarter model is shown in Fig. 2. That's because the number of the disposal tunnels and the disposal pits are emplaced in parallel with the same spacing and the geometrical shape. As shown in figure 2, horizontal boundary of the upper and the lower part of the model considered 500m to both parts enough not to be effected by the radioactive material. Also the radioactive decay heat which affects around the disposal pit is written according to the decay heat history by spent fuels cooling times, and the equation is as follows.

$$P(t) = 14548.7 t^{-0.76804} \quad (30 \le t \le 10^6)$$

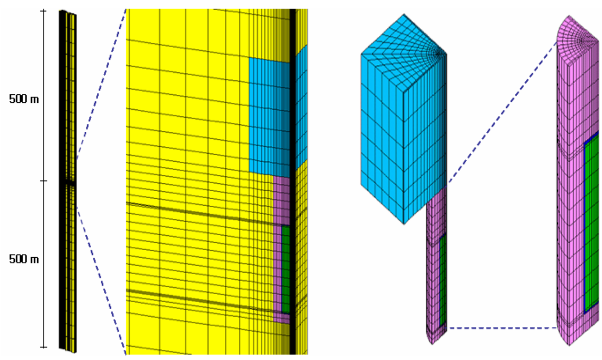

Fig. 2. The repository model for the heat analysis.

3.2. Initial and Boundary condition

Both vertical sides and the bottom part are set up adiabatic in the boundary conditions of the symmetric model for the heat analysis of the repository. The initial conditions are set up with the assumptions that the temperature of the underground water under the surface is 15˚c and 3˚c rises for each 100m depth. Also density, thermal conductivity and specific heat were used as the material properties of the rock, buffer, backfill and canister and the computer code used for this analysis was the heat module of NISA ver. 12.

4. Analysis results by cooling times

Thermal analysis is performed with the disposal tunnel and disposal pit spacing satisfying the temperature requirements of the buffer blocks according to 30, 40 50, 60, 70 and 80 years of cooling times. Analysis results according to the spent fuel cooling times and disposal pit/disposal tunnel spacing are listed in table 1. Also, the Unit disposal, the disposal density in term of uranium, and the thermal load according to the cooling time of the spent fuels are shown in Fig. 3.

Repository area, volume and, therefore, related excavation and sealing/backfilling costs can decrease if designers take advantage of the increasing age of spent fuels prior to disposal as shown in the table. The practical time limit of increasing the cooling time of spent fuels is about 50 years, beyond which no significant reduction in repository area, volume and direct cost can be achieved.

Table 1. Thermal Behavior according to the Spent Fuel Cooling Time

Cooling time	Tunnle spacing	Hole pitch	U. diposal area	T. load (W/M2)	U density (KgU/M2)
30	40	12	480	4.04	3.67
40	40	6	240	6.52	7.33
50	35	5.4	189	6.99	9.31
60	35	4.8	168	6.85	10.48
70	35	4.5	157.5	6.50	11.17
80	35	4.3	150.5	6.02	11.69

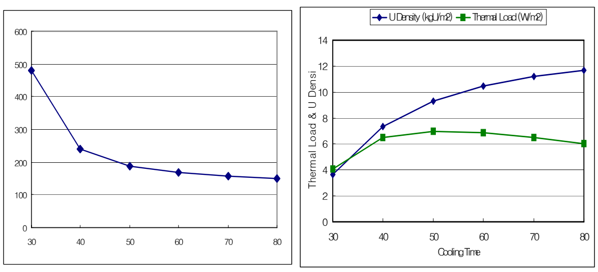

Fig. 3. Unit disposal area, disposal density and thermal load with cooling time

5. Conclusions and future plans

Various spent fuel cooling times and the disposal tunnel/pit spacing is set up to estimate the scale of HLW geological disposal facilities and the layout for corresponding spent nuclear fuels and the thermal integrity of the disposal system is analyzed in this research. Moreover, the mutual effects of the components are reviewed by using the analysis results and the concept of layout advantageous from safety and economical point of view is derived which is stated as follows.

The brief analysis for an example of a repository shows that the repository volume and area can be significantly reduced (e.g., approximately by a factor of two) by increasing the cooling time of spent fuels from 30 to 50 years prior to disposal. This could allow a reduction in direct excavation and backfill material costs and may simplify locating a repository. Beyond a spent fuels cooling time of about 50 to 70 years, depending on the specifics of the waste emplacement method, no further significant reductions in volume and costs can be realized.

The results from this research are expected to be implemented in the design of the HLW underground repository emplacement. Furthermore, more detailed analysis for the real site characteristics data is required to minimize any uncertainties of the future site.

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