# Preliminary Criticality Calculation on Conceptual Deep Borehole Disposal System for Trans-metal Waste during Operational Phase

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## 1. Introduction

To improve utilization of uranium resources and to reduce radio toxicity and volume of radioactive waste, pyro-processing that is connected with fast reactor is under development. However, there are uncertainties in commencement time of fast reactor operation and degree of utilization of trans-uranium and other element in the radioactive waste from pyro-processing. Deep borehole disposal (DBD) of waste containing trans-uranium elements and other elements from pyro-processing could be considered an alternative option.

The primary function of any repository is to prevent spreading of dangerous materials into surrounding environment. In the case of high-level radioactive waste repository, radioactive material must be isolated and retarded during sufficient decay time to minimize radiation hazard to human and surrounding environment. Sub-criticality of disposal canister and whole disposal system is minimum requisite to prevent multiplication of radiation hazard. In this study, criticality of disposal canister and DBD system for trans-metal waste is calculated to check compliance of sub-criticality.

## 2. Methods and Results

### *2.1 Assumptions and Specifications of wasteform, canister and disposal borehole*

To calculate criticality of conceptual DBD system, assumptions below are used.

- Reference spent fuel has initial enrichment of 4.5 wt.% and discharge burn-up of 55 GWd/MtU
- Elementary composition of trans-metal waste is composed of all elements from pyro-processing waste except salt and gas waste
- Disposal borehole can contain about 1500 disposal canister. Canister can contain one 2nd container which can contain one wasteform and one 1st container.
- Disposal borehole pitch is assumed to be 50 m.
- Temperature of each component are assumed to have the same temperature and cross section libraries at this temperature are adopted on account of insufficient temperature distribution data, though exact temperature and cross section libraries must be applied properly to get reliable results.

Specifications of wasteform, container, canister, and disposal borehole are listed in Table 1.

Table1. Specifications of waste, canister and borehole

| | Specification |
|---|---|
| Waste | - Size: 300*375 mm (L)<br>- Weight: 490 kg<br>- Initial decay heat: 590 W<br>- Initial radioactivity: 1.25E5Ci |
| 1st container | - Inner size: Ø 320*410 mm (L)<br>- Outer size: Ø 340*470 mm (L)<br>- Thickness of cylinder: 10 mm(t)<br>- Material: stainless steel<br>- Weight: 70 kg (empty) |
| 2nd container | - Inner size: Ø 350*490 mm (L)<br>- Outer size: Ø 370*550 mm (L)<br>- Thickness of cylinder: 10 mm(t)<br>- Material: stainless steel<br>- Weight: 90 kg (empty) |
| Canister | - Inner size: Ø 380*1,120 mm (L)<br>- Outer size: Ø 400*1,250 mm (L)<br>- Thickness of cylinder: 10 mm(t)<br>- Material: stainless steel<br>- Weight: 200 kg (empty) |
| Borehole | - Size: Ø 430*5,000,000 mm (L) |

### *2.2 MCNP modeling*

MCNP version 5 is used to calculate criticality of canister and conceptual DBD system. Figure1 represents geometry of canister model (left side of figure) and DBD system model (right side of figure) adopted in MCNP criticality analysis.

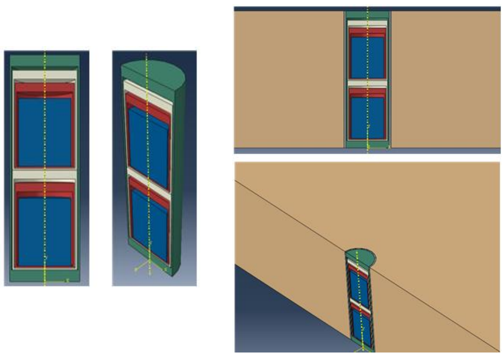

Figure1.MCNP model of canister and DBD system

Nuclides considered to calculate criticality are listed below. Many nuclides are omitted and substituted to uranium by reason of its low concentration. ENDF B-VII cross section tables are used for most nuclides except some nuclides.

○ Trans-metal waste
- $^{16}$O, $^{17}$O, $^{18}$O, $^{147}$Pm, $^{151}$Pm, $^{154}$Eu, $^{234}$U, $^{235}$U, $^{236}$U, $^{238}$U, $^{238}$Pu, $^{239}$Pu, $^{240}$Pu, $^{241}$Pu, $^{241}$Am, $^{243}$Am, $^{244}$Am

○ Stainless steel 321
- $^{12}$C, $^{28}$Si, $^{29}$Si, $^{30}$Si, $^{32}$S, $^{33}$S, $^{34}$S, $^{36}$S, $^{46}$Ti, $^{47}$Ti, $^{48}$Ti, $^{49}$Ti, $^{50}$Ti, $^{50}$Cr, $^{52}$Cr, $^{53}$Cr, $^{54}$Cr, $^{54}$Fe, $^{56}$Fe, $^{57}$Fe, $^{58}$Fe, $^{58}$Ni, $^{60}$Ni, $^{61}$Ni, $^{62}$Ni, $^{64}$Ni

○ Ca-bentonite
- $^{16}$O , $^{17}$O, $^{18}$O, $^{27}$Al, $^{28}$Si, $^{29}$Si, $^{30}$Si, $^{28}$Si, $^{40}$Ca, $^{42}$Ca, $^{44}$Ca, $^{54}$Fe, $^{56}$Fe, $^{57}$Fe, $^{58}$Fe

○ Granite
- $^{16}$O , $^{17}$O, $^{18}$O, $^{23}$Na, $^{27}$Al, $^{28}$Si, $^{29}$Si, $^{30}$Si, $^{28}$Si, $^{39}$K, $^{41}$K, $^{40}$Ca, $^{42}$Ca, $^{44}$Ca, $^{54}$Fe, $^{56}$Fe, $^{57}$Fe, $^{58}$Fe

### *2.3 Results*

Figure2 represents calculated criticality of canister and DBD system and sensitivity of criticality for temperature. The black line and red line stand for results of canister model and DBD system model respectively. Calculated criticalities at every temperature are under sub-criticality and comply with its safety limit ($k_{eff}$ <0.95). Criticality tend to decrease when system temperature increase due to reduced cross section.

Calculated criticalities at room temperature of canister and DBD system are 0.34986 and 0.37784 and its standard deviations are 0.00032 and 0.00033. Criticality of canister and DBD system at 600K become 0.34713 and 0.37436 with standard deviation of 0.00032. Considering expected temperature of canister and DBD system, criticalities of canister and DBD system are expected to become 0.34932 and 0.37618 approximately.

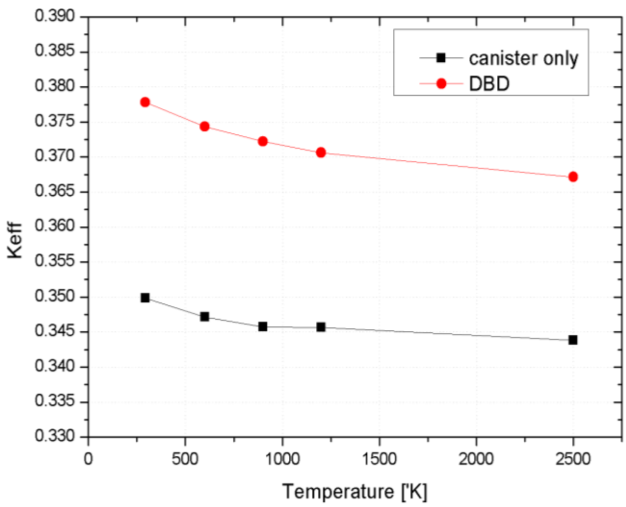


Figure2. Calculated criticality of canister and DBD system

## 3. Conclusions

Preliminary calculation on criticality of conceptual deep borehole disposal system and its canister for trans-metal waste during operational phase is conducted in this study. Calculated criticalities at every temperature are under sub-criticalities and criticalities of canister and DBD system considering temperature are expected to become 0.34932 and 0.37618 approximately.

There are obvious limitations in this study. To obtain reliable data, exact elementary composition of each component, system component temperature must be specified and applied, and then proper cross section according to each component temperature must be adopted. However, many assumptions, for example simplified elementary concentration and isothermal component temperature, are adopted in this study. Improvement of these data must be conducted in the future work to progress reliability. And, post closure criticality analyses including geo, thermal, hydro, mechanical, chemical mechanism, especially fissile material re-deposition by precipitation and sorption, must be considered to ascertain criticality safety of DBD system as a future work.

## REFERENCES

[1] Los Alamos National Laboratory, MCNP – A General Monte Carlo N-Particle Transport Code, Version 5 LA-UR-03-1987, 2003

[2] Dennis Mennerdahl, Review of the Nuclear Criticality Safety of SKB Licensing Application for a Spent Nuclear Fuel Repository in Sweden, SKB, 2012, pp.18-32