A preliminary study on the radiation dose distribution in the pyroprocess hot cell environment

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1. Introduction

Nuclear energy has been the effective alternative to fossil fuels considering the growing energy demand and public concern about carbon dioxide emission. However there are issues to be still solved for the stable use of nuclear energy. The management and disposal of spent fuels are one of the important issues [1].

Pyroprocessing is the promising technology for treatment of spent fuels. Because it is based on the collective recovery of TRU, it has an advantage in proliferation resistance compared to conventional aqueous processes [2]. Development of pyroprocessing has positive effects to the public through reduction of the high-level radioactive waste and the effective use of energy resources.

In Korea, Korea Atomic Energy Research Institute (KAERI) has researched pyroprocessing since 1997. The engineering scale integrated inactive pyroprocess facility (PRIDE) was constructed and test operation has been performed [3]. A study on the preliminary conceptual design and cost estimation for a larger-scale model facility is in progress[4].

The safeguards are essential in the pyroprocessing facility for proliferation resistance. To establish the reliable safeguards, the preliminary studies on radiation resistance requirements, assessment of the safeguards system applicability, and shielding of the safeguards equipment are required. Therefore, first of all, the radiation flux and dose distribution in hot cell environment have to be studied. The previous studies [5, 6] focused on the neutron flux at the pyroprocessing however they are limited to the individual unit process.

In this study, the flux and dose distribution of neutron and gamma-ray in the hot cell environment of the pilot pyroprocessing facility are investigated. Based on the simplified material flow of pyroprocess, the material distribution model is established. And using the established material flow model, the neutron and gamma-ray flux are investigated by MCNP6 simulation.

2. Simulation Modeling

Figure 1 shows the simplified flow of pyroprocessing. The main processes are electrolytic reduction, cathode processing, electrorefining, and electrowinning. The used spent fuel assemblies are disassembled and cut. Through decladding and pretreatment, cladding is mechanically removed and fuel rods are converted into proper form for the following process step. Gaseous fission products are removed at this stage.

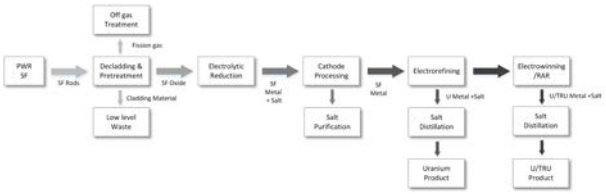

Fig. 1. Flow diagram of pyroprocessing.

The electrolytic reduction converts this spent fuel of oxide form into the metallic form. The oxides soluble in a molten salt (LiCl) are removed whereas the U, TRU, and RE oxides remain in the metallic product. The remained salt in the metal product is removed by the cathode processing. At the electrorefining stage, uranium is collected on the cathode and recovered by the salt distillation. Finally, the residual U and TRU in the salt are extracted at the electrowinning and residual actinide recovery (RAR) stage.

Based on the flow of pyroprocessing, the material flow and radionuclides composition at the major stages are calculated for 1 MTU of fresh fuel. The calculated composition is used for the material card specification in the MCNP6 simulation.

The initial simulation was performed with the composition of metal fuel alloy (weight percent of 65% uranium, 20% TRU, 5% rare earth fission products, and 10% zirconium) in order to compare with the previous study [5]. It is noted that the composition will be modified with the calculated radionuclides composition model of pyroprocessing flow.

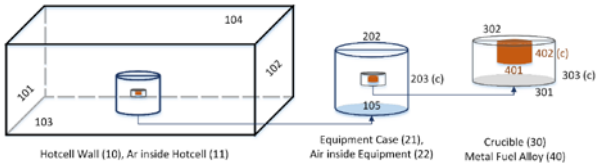

Fig. 2. Schematic diagram of the geometry for the initial simulation.

The geometry for the initial simulation is shown in Figure 2. The dimension of a hot cell were 40m length, 8m width, and 10m height. The hot cell was filled with Ar gas and had walls of 15cm thick concrete. In the initial simulation, the metal fuel alloy (U/TRU product)

after the fuel fabrication was described only. The other processing stages will be also described additionally until the presentation.

The processing equipment and metal fuel alloy were designed as well as the previous studies [5, 6] at this time. The metal fuel alloy was assumed as the cylinder of 7.4cm diameter and 5cm height. It was contained in a crucible whose dimension are 12.4cm diameter and 10cm height. The metal fuel alloy and crucible were in a steel cylinder of 5cm thickness, 4m diameter, and 3m height. The geometry will be updated with the consideration of each unit process during the further detailed modeling procedure.

The neutron and gamma sources were assumed as the isotropic sources distributed uniformly in the metal fuel alloy. The energy of neutron source was assumed by the watt distribution of ^{244}Cm in the MCNP6 and the energy of gamma source was defined based on the gamma ray histogram in the ORIGEN calculation.

3. Initial simulation result

The neutron and gamma flux have been obtained by the F2 surface flux tally and F4 cell flux tally in the MCNP6. The numbers in Figure 2 represent the used tallies.

As the surface tally, 4 sides of the hot cell (101, 102, 103, 104), the outer surface of the cylindrical equipment (105, 202, 203), the outer surface of the crucible (302, 301, 303), and the union surface of the metal fuel alloy (401, 402, 302) were defined. The cosine card was used to obtain the flux in the outward direction at the surfaces.

The cell flux was obtained for the walls of the hot cell (10), the Ar volume inside the hot cell (11), the equipment case (21), the air volume inside the equipment (22), the crucible (30), and the metal fuel alloy (40). The dose function (DF) card was also applied as well as the previous study [5]. The simulations were performed with the 10^6~10^8 particle histories.

In this study, the batch size was assumed as 6kg. The neutron and gamma generation rates at the U/TRU product are calculated with the ORIGEN simulation, and are 4.02 x 10^7 neutron/s· kg and 9.44 x 10^{12} gamma/s· kg. So that the calculated neutron and gamma generation rates at the U/TRU batch are 2.4 x 10^8 neutron/s and 5.66 x 10^{13} gamma/s.

Table I and II show the simulation results scaled with the neutron and gamma generation rates. The results for neutron show similar flux and dose rates in the previous study [5].

As shown in the table I and II, the neutron and gamma flux at the metal fuel alloy, crucible, processing equipment are very high so that they are enough to be monitored by the safeguards. If the other processes are performed in the same cell, these high flux can give significant damage to radiation detectors. From this reason, the further study which includes the other processes at the same time is required to assess the applicability of the safeguards and design of the shielding inside of hot cell. These results will be updated at the KNS presentation.

Table. I. The surface flux and dose rate for the 6kg batch size in the MCNP6 simulation.

Surface flux tally				
	Neutron		Gamma-ray	
Surface	Flux (n/cm^2 ·s)	Dose (mSv/h)	Flux (n/cm^2 ·s)	Dose (mSv/h)
Fuel alloy	9.51E+05	9.64E+02	5.47E+08	6.16E+03
Crucible	2.18E+05	2.24E+02	1.10E+08	1.33E+03
Equipment	1.20E+03	6.45E-01	3.80E+04	5.17E-01
Hot cell Surface long	8.74E+01	3.21E-02	2.13E+03	3.17E-02
Hot cell Surface short	3.57E+01	9.32E-03	4.36E+02	5.88E-03

Table. II. The cell flux and dose rate for the 6kg batch size in the MCNP6 simulation.

Cell flux tally				
	Neutron		Gamma-ray	
Cell	Flux (n/cm^2 ·s)	Dose (mSv/h)	Flux (n/cm^2 ·s)	Dose (mSv/h)
Fuel alloy	1.93E+06	1.93E+03	1.28E+09	1.42E+04
Crucible	4.49E+05	4.26E+02	1.99E+08	2.06E+03
Air inside equipment	3.37E+03	2.60E+00	8.39E+05	9.12E+00
Steel cylinder	1.92E+03	1.29E+00	1.55E+05	1.77E+00
Ar inside hot cell	1.62E+02	6.27E-02	3.44E+03	4.87E-02
Hot cell wall	9.07E+01	6.23E-02	7.90E+02	1.15E-02

4. Conclusion

In this study, the radiation flux and dose distribution in the hot cell environment of the pilot-scale pyroprocessing facility model is investigated preliminarily by the MCNP6 simulation. Based on the established material flow model, the material composition at each stage is calculated and used for the simulation. The simple hot cell structure and process batch size were assumed based on the previous studies. In the initial simulation result, the neutron and gamma flux from the U/TRU product are enough to be monitored by the safeguards. In the current simulation, the only U/TRU product fabrication stage is described but the other processes will be updated until the conference presentation.

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