Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Study on the SF Treatment Technic for the SF Volume Reduction

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***Keywords:** Spent Fuel, SF Treatment, Volume Reduction, Economical efficiency evaluation

1. Introduction

The Nuclear power has produced lots of spent nuclear fuel (SNF). However, difficulties in managing SNF have hindered its sustainability as an energy source. Countries with nuclear plants worldwide have been working tirelessly to develop policies for SNF management and their implementation; however, they have faced significant challenges due to social acceptance issues among others. SNF management policies can be broadly categorized into direct disposal policy where SNF is stored temporarily before being directly buried underground, and recycling policy which involves processing SNF to reuse valuable nuclear materials contained within. Direct disposal countries consider SNF as waste while recycling nations treat it as future resources. Additionally, there are countries that haven't decided on a final policy yet, focusing instead on securing interim storage facilities to prepare for saturation of existing nuclear plant storage spaces under 'wait-and-see' policies. When SNF is recycled, major nuclear powers such as Japan, USA, France, and Russia are competing to develop advanced nuclear fuel cycle technologies like Japanese Next Generation System (NEXT), American Uranium Recovery by Extraction followed by French Coexistence (COEX), and Russian Dry Processing (DDP).

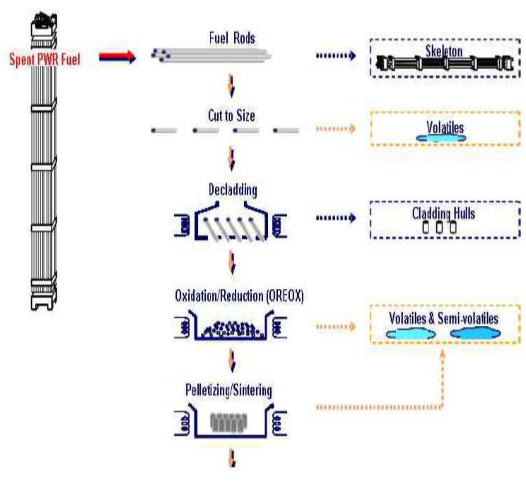

Figure 1. Process of OREX (DUPIC)

In this study, we defined the scope and boundaries of oxide reduction technology as an alternative for volume reduction in solid waste (SF). We then discuss major issues related to current oxidation technologies before conducting a legal review on oxide reduction facilities based on their characteristics. Furthermore, we analyze potential problems that may arise during facility introduction and licensing processes. Additionally, we conduct safety and economic analyses of oxide reduction technologies while examining their linkages with transportation, long-term storage, and disposal techniques.

2. Methods and Results

2.1 Safety performance evaluation

It should be provided for the sintered bodies in the status of eliminating volatile fission products such as xenon(Xe), krypton(Kr), iodine(I), cesium(Cs), and molybdenum(Mo) from spent nuclear fuel. It was assessed that large neutron absorption cross-section materials like Xe and Kr could be removed during this process. In previous studies, they considered producing them up to sizes of 20x10 cm or even 30x30 cm, assuming a density of uranium oxide (U3O8) at 8.38 grams per cubic centimeter. For one nuclear fuel assembly with 450 kilograms heavy metal (kgHM) and two nuclear fuel assemblies with 900 kgHM of spent nuclear fuel, spherical shapes were assumed under conservative calculations using an enrichment ratio of 4.5% for uranium-235. The evaluation results showed that criticality levels dropped below the threshold values, as shown in Table 1.

Table 1. Criticality for Air Oxidation Processes

Case(U_3O_8)	k-effective
450 kgHM	0.53345 ± 0.00086
900 kgHM	0.57551 ± 0.00076

The results of radiation evaluation are as followings,
① Long half-life and high mobility nuclear species, ② Short half-life and high heat nuclear species, ③ Various options for managing uranium grouped by their characteristics were studied to separate them according to their properties.

Physical separation of structural components through dismantling, extraction, and cutting: In the radioactive waste management process, metal structure waste such as aggregates of spent fuel and nuclear fuel cladding tubes are generated.

Separation of long-lived and highly mobile nuclear species using medium-high temperature treatment: During the preliminary processing at moderate temperatures and high temperatures, volatile/semi-volatile nuclear species are basically separated. The main volatiles in this step include long-lived and highly mobile nuclear species such as iodine (I), technetium (Tc), and high-heat nuclear species like cesium (Cs). They are collected and separated individually using filters.

2.2 Economical efficiency evaluation

Based on the unit facility cost of the DUPIC facility estimated in 1999 and converted to 2020 dollars, we can estimate that the cost is approximately $328 per kilogram U (KAERI/TR-8381/2020). This cost was calculated based on an assumed capacity of 400 metric tons uranium equivalent (MTU) per year for a 40-year operating period, including the manufacturing costs of CANDU nuclear fuel. However, these costs were adjusted by excluding the manufacturing costs of CANDU nuclear fuel.

Although the construction and operating costs of individual facilities are important, an overall approach considering the entire nuclear fuel cycle system is considered necessary as follows:

1. Benefits of replacing metal storage containers
2. Benefits from continuous operation
3. Changes in economic feasibility due to fluctuations in electricity prices
4. Economic benefits associated with disposal

2.3 Transportation, long-term storage, disposal

Regarding final solidification methods for treating and disposing of high-level radioactive waste filters containing volatile nuclides, there is a need for technological advancement in this area. In particular, demonstration and evaluation of solidification technologies for filters containing noble gases (Xe, Kr) and noble metals (Ru, Rh), which are expected to have relatively high mobility, would be necessary.

Therefore, although metallic structural materials are not considered high-level radioactive waste like spent fuel cladding, they may exceed concentration limits for Ni and Nb radionuclides, making their acceptance at interim or low-level radioactive waste repositories difficult. To reduce the burden of disposal, processing of metallic structural materials will be required, with options such as compaction and melting being utilized. Compression can potentially reduce initial volume by up to 7.6%, but further development and demonstration of volume reduction technologies will be needed. Additionally, considering recycling these metallic structural materials as sealants for oxide sintered bodies rather than disposing them as waste could also serve as an alternative approach to reducing the burden of disposal. In spite of initial reduce volume, the amount of total volume reduction would be reduced up to about 50%.

3. Conclusions

The oxide processing technology involves converting uranium dioxide (UO2) pellets to forms such as uranyl oxide (U3O8) by thermo-mechanically stripping off their cladding and removing volatile gases and highly radioactive nuclides released during this process. The powder is then sintered back into nuclear fuel form. In spite of initial reduce volume, the amount of total volume reduction would be reduced up to about 50%.

This allows for removal of high-heat producing radionuclides, thereby increasing storage efficiency; however, significant volumes of solid and gas waste will be generated in the process requiring disposal. Therefore, research on quantifying how much volume reduction can be achieved with oxide processing technology is needed along with safety performance and Economical efficiency evaluation.

REFERENCES

[1] Frank, S., "Waste Stream Treatment and Waste Form Fabrication for Pyroprocessing of Used Nuclear Fuel," Idaho National Laboratory, INL/EXT-14-34014, 2015.

[2] Federal Ministry for the Environment, “Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,” Nature Conservation and Nuclear Safety, 2020.

[3] Frederic J., “System and method for removing and consolidating the fuel rods of a nuclear fuel assembly,” U.S. Patent 5000906. 1991.

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