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Calculation of Material Flow in Pyroprocessing

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1. Introduction

This paper will include the calculation results of KAPF+ material flows. KAPF+(Korea Advanced Pyroprocess Facility Plus), concept-designed by KAERI, is a facility that can manufacture uranium and TRU, a raw material for SFR nuclear fuel, through the pyroprocessing of 400 tHM of PWR spent fuel per year. Here, TRU denotes mixed metal ingots of minor actinides such as Np, Am, Cm, and Pu[1].

The core process of the integrated Pyro-facility (KAPF+) is divided into three sectors as shown in the Process Flow Diagram in Figure 1, including the reception and storage of spent fuel, the front-end, and the Pyroprocess. The front-end process is a process in which the spent fuel that was emitted from light-water reactor power plants is received, dismantled, and cut, consisting of unit-processes such as dismantling of the assembly, fuel rod cutting, decladding and powdering, voloxidation, and waste disposal. The Pyroprocess consists of unit-processes such as electro reduction, electro-refining, electro-winning, removal of residual actinide, manufacturing of uranium and uranium-TRU ingots, and the recycling of salt-wastes[2].

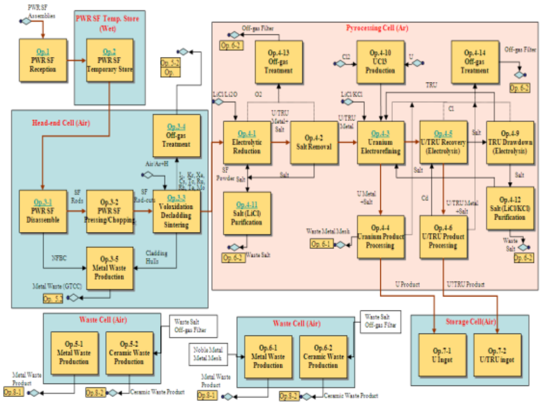


Figure 1. Pyroprocessing flow diagram

When looking into major process stages, the spent fuel is converted into metal during the Electro-reduction process, uranium is recovered in Electro-refining process, and the remaining uranium and TRU are recovered in an ingot state during the Electro-winning process.

The recovered surplus uranium is either recycled or disposed of as low-level waste, and U-TRU ingots are used as a raw material for SFR(Sodium-cooled Fast reactor) nuclear fuel.

The front-end process is implemented in an atmosphere of air, and the Pyroprocess is implemented in an atmosphere of argon gas where there exists virtually no air (≤ 50ppm or below) in order to suppress the oxidation reaction as required by the characteristics of the metal transformant[3].

2. Terms

2.1 Design criteria of Pyro-Facility

First, we need the design criteria for the concept design of the Pyro-Facility to calculate the material flows. The design criteria for the Integrated Pyro-Facility (KAPF+) are presented in Table 1 below.

Table 1. Main design criteria of Pyro-facilities

Capacity	Front-end : 400 tHM/yr, Temporary storage : 400 tHM/yr, Pyroprocessing : 200 tHM/yr/module x 2 module
Capacity factor	55%(200 day/year)
Life time	60 year
Raw material	PWR spent fuel
Products	- U, U/TRU metal ingot - Waste (ceramic, metal, etc)

The Integrated Pyro-Facility(KAPF+) was concept-designed in module form in consideration of a possible future expansion of the facility. The life-span of the facility was presumed to be 60 years. As for Pyroprocessing equipments, it is assumed that the equipment will be manufactured with materials that are more corrosion-resistant than those used at present. It is also assumed that the major processing equipment will be replaced by every 5~10 years. That is to say, the life–span of the processing equipment for handling high-temperature molten salt is assumed to be 5 years, and the life–span of other processing and handling equipment is assumed to be 10 years in consideration of the operability and maintainability of the processing equipment of concern. Also, in consideration of the repairability and job safety of the facility, the annual facility utilization rate of the processing equipment is assumed to be 55% (200 days).

2.2 Radioactive waste treatment

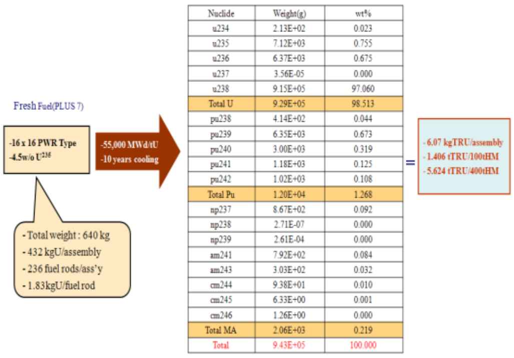
Radioactive waste generated at the site of the Integrated Pyro-Facility(KAPF+) should be mana-ged within the site until such time when it is transported to a separate storage or disposal facility.

Also, the Integrated Pyro-Facility was designed so as to minimize the amount of radioactive waste generated and to enable its physical control. That is to say, the Pyro- Facility was equipped with housing and ventilation facilities to ensure safe and efficient management of radioactive waste.

When looking into a recycling process using major nuclides, iodine and technetium should be separated and collected for burning in an SFR, and cesium and strontium should be separated and collected to be disposed of after long-term storage. The targets for radioactive wastes that still remain after separation and recovery are set at 1~0.1 % for iodine and technetium and 1 % or below for cesium and strontium.

2.3 Reference spent fuel

It is also assumed that the Integrated Pyro-Facility (KAPF+) is capable of receiving all spent fuel that has been cooled for 10 years or longer in a storage pool of the power plant after it is released from the light-water reactor. For spent fuel generated from all Korean PWRs as of now, the spent fuel from Yeong Gwang units #3 and #4 16x16 nuclear fuel with 4.5 wt% initial enrichment and 55,000 MWd/tU average burnup, has been selected as a reference fuel. The major characteristics of this reference fuel are shown in Figure 2.



Nuclide	Weight(g)	wt%
u234	2.13E+02	0.023
u235	7.12E+03	0.755
u236	6.37E+03	0.675
u237	3.56E-05	0.000
u238	9.15E+05	97.060
Total U	9.29E+05	98.513
pu238	4.14E+02	0.044
pu239	6.35E+03	0.673
pu240	3.00E+03	0.319
pu241	1.18E+03	0.125
pu242	1.02E+03	0.108
Total Pu	1.20E+04	1.268
np237	8.67E+02	0.092
np238	2.71E-07	0.000
np239	2.61E-04	0.000
am241	7.92E+02	0.084
am243	3.03E+02	0.032
cm244	9.38E+01	0.010
cm245	6.33E+00	0.001
cm246	1.26E+00	0.000
Total MA	2.06E+03	0.219
Total	9.43E+05	100.000

Figure 2. Characteristics of reference PWR spent fuel

3. Calculation results of material flow

Electro-winning is to be carried out once Electro-refining has been carried out approximately 20 times (batches). As for the recovery processing of salt, it should be carried out once after every 10 (batches) of Electro reductions. Also, the eutectic salt recovery rate in the LiCl-KCl oxidation/precipitation process and volatilization/condensation process was assumed to be 100%. Figure3 shows an approximated material balance diagram of an Integrated Pyro Facility (KAPF+) that pyroprocesses 400 tHM of PWR spent fuel per year.

The Integrated Pyro-Facility (KAPF+) produces 369.2 tU/yr of uranium ingots and 8.6 tHM of U-TRU-RE ingots per year. During these processes, it is assumed that 153.0 ton/yr of metal waste, 114.2 ton/yr(= 49.6 m³/yr) of ceramic waste from alkali metal and alkaline earth metal that processes the molten salt generated during the electro-reduction process, 32.1 ton/yr (= 10.0 m³/yr) of ceramic waste from rare earth elements that processes molten salt generated during the electro-refining and electro-winning processes, 12.9 ton/yr(= 17.2 m³/yr) of off-gas Cs + fly ash waste generated during a high temperature voloxidation process, 18.8 ton/yr(= 35.4 m³/yr) of iodine and technetium waste, and 3.7 ton/yr of ^{3}H+Kr+Xe wastes will be generated.

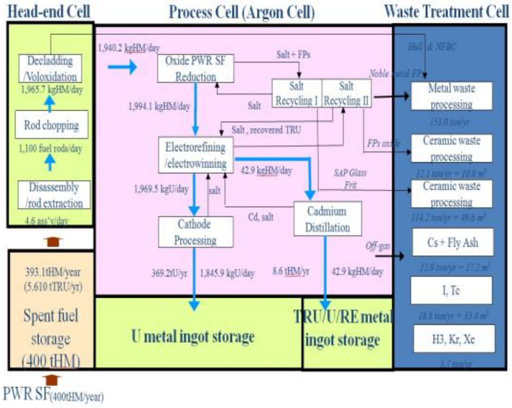


Figure 3. Material flow of Pyroprocessing facilities

4. Conclusions

To induce a material flow for the unit processes of the Integrated Pyro-Facility (KAPF+), quite a few assumptions have to be made. For example, 99.9% was selected for the decladding rate, which is the test value of DUPIC nuclear fuel obtained by KAERI.

However, since there is no commercialized Pyro-Facility yet, uncertainty regarding material balance of Pyro-Facility is quite large.

If technologies such as front-end technology, automatic Pyro operation, development of process materials, and waste recycling technology for a reduction of waste are further developed in an effort to minimize Pyroprocessing cost, it is expected that the accuracy of material flows in Pyroprocessing can be further improved.

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