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A Feasibility Study on the Safeguardability of a Reference Pyroprocessing Facility

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1. Introduction

An MSSP (member-state support program for agency safeguards) Project for the "Support for the Development of a Safeguards Approach for a Pyroprocessing Plant" was contracted by IAEA and the Republic of Korea in July 2008. As a result of the research that was performed in the first year, a reference pyroprocessing facility (REPF) concept was determined [1]. In this paper, analysis of possible MBAs and KMPs, identification of possible operator measurement systems, and operation and MUF simulation has been carried out based on the REPF.

2. Conceptual Design of a Safeguards System

2.1 Analysis of Possible MBAs and KMPs

An MBA is established for the accurate evaluation of the material balance, and it has been determined based on criteria that include the possibility of containment/surveillance to ensure the integrity of material flow measurement, simplicity for the application of safeguards, and effort to measure the key measurement point (KMP) [2]. The five MBAs determined as most desirable, consisting of the front end of the process (MBA-1), the pyroprocess (MBA-2), U ingot (MBA-3), TRU ingot (MBA-4), and product and waste storage (MBA-5), were established, as shown in Fig. 1. MBA-1 and MBA-2 were divided at the homogenization process that was added for nuclear-material accountancy. MBA-3, 4, and 5 include storages for the wastes generated in MBA-1 and 2, and the U and TRU ingots. As the KMP in the MBA is a point for determining the nuclear-material flow or inventory in the unit process, it was determined through the minimization of process interference and the simplicity of accountancy. The type of nuclear material in the MBA is shown in Table 1.

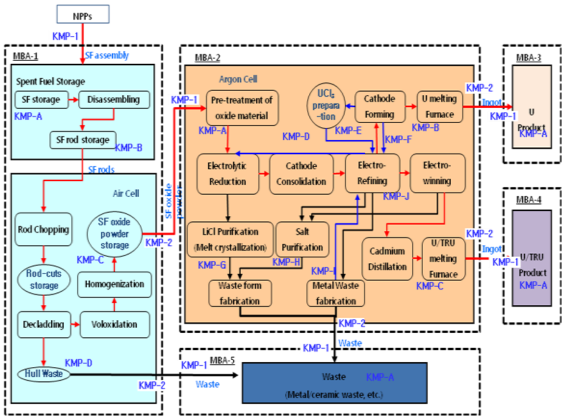

Figure 1. Establishment of MBAs and KMPS.

Table 1. MBAs in the REPF

MBA	Description	Type of Nuclear Material Contained
1	- Spent-fuel storage - Storage and disassembly of spent-fuel assembly - Chopping, decladding, and homogenization of spent fuel from MBA-1	- Items: . SF assemblies and rods . Rod cuts - Bulk: . SF oxide powder
2	- Main pyroprocess - High-temperature oxidation, electrolytic reduction, electrorefining, electrowinning, waste treatment	- Bulk: . SF oxide powder . SF oxide granule/ pellets, metal, TRU
3	- U ingot storage	- Bulk: U metal ingot
4	- U/TRU ingot storage	- Bulk: U/TRU metal ingot
5	- Waste storage	- Bulk: waste (metal/ceramic waste, etc.)

2.2 Possible Measurement System

A measurement system was established to realize the near-real-time-accountancy-(NRTA)-applied non-destructive assay (NDA), which has many advantages with respect to the analysis time, equipment, human resources, and ease of sampling. Destructive assay (DA) was also applied to the three important KMPs to increase the accuracy of accounting. Considering the time required for the analysis of DA, a three-step method was suggested. First, the DA samples are obtained at the three important KMPs, and the samples are analyzed through the DA method. Second, NRTA is continuously performed through the NDA equipment at the three important KMPs, while the DA samples are analyzed. Third, the NRTA based on NDA is updated and corrected by comparing the NDA values with the DA values.

It is assumed that a spent-fuel assembly is converted to small (approximately 500 kg) particles through a decladding and low-temperature oxidation process, and the homogenization process is continued in a mixing device for homogenization until the preset degree of homogeneity is reached. This operation is performed once per about 11 days. If 500 kg spent fuel is set as one batch, 20 batches can be treated per year. Five samples of about 5 g spent-fuel powder are collected from the spent-fuel mixed powder and are measured with the use of the unified NDA equipment.

A measurement method for each KMP was determined using the NDA method, considering the fact that the accounting values in such KMPs are the masses of U-235, Pu, and Cm. The process is as follows. First, the amount of Cm is measured using a passive-neutron-counting mode, and the whole amount of Cm is determined considering the weight of the mixed powder and sample. Second, the burn-up is determined via gamma spectrometry for the same sample. The amounts of Pu and U-235 are determined via ORIGEN simulation, with the determined burn-up value as an input value. Then the Cm ratios U/Cm ratio = U-235/Cm and Pu/Cm ratio = Pu/Cm are determined using the amounts of Cm, Pu, and U-235. Finally, the amounts of Pu and U-235 are determined by multiplying the Cm amounts with each Cm ratio.

3. Simulation and MUF Determination

The estimated measurement error was applied to the resulting value of the nuclear-material-flow calculation. The random, systematic, and total MUF uncertainties were calculated by applying the calculation formula of MUF uncertainty to the resulting value of the material flow of each nuclide, using the MUF parameter DB. The bulk measurement, sampling, and analytic measurement of the target nuclear material were traced in detail with the random and systematic errors during the material-balance period, to obtain the MUF uncertainty value. Considering the error propagation that occurred in the process, the measurement error variance of the target nuclear material by stratum, and its total value, were calculated [3, 4]. The uncertainty of the nuclear material that is generated in the pyroprocess was classified by random and systematic errors, and then the uncertainty of each nuclear material was determined and presented in a numerical value.

The calculation formula suggested in IAEA TECDOC-261 was used to determine the MUF uncertainty that could occur in the REPF. The reliability of the statistical test for the measured MUF depends on the uncertainty value of MUF, and the accurate handling of the error propagation by the error-of-measurement equipment, measurement order, manipulation, and material balance, and the reliability of the measurement error, are critical factors in the determination of MUF uncertainty. The Pu MUF uncertainty was calculated for MBA-2 when the REPF was operated under the conditions listed in Table 2. As the systematic errors of the SF powder and of TRU are the main factors of error propagation in the sigma-MUF evaluations, sensitivity analyses for these systems were conducted for some error ranges. Table 2 shows the results of the sensitivity analyses that were conducted for the TRU (Pu) products. When the systematic errors were assumed to be 1.0 and 1.5%, the Pu MUF uncertainty appeared to be less than 2.424 kg, the limitation was at the 95% detection probability, and the false alarm was 5%. As a result of the safeguardability evaluation for the conceptual design of the REPF using the proposed analysis technique, it seems that the designed safeguards approach can meet the typical IAEA detection goal for the REPF with a 10 tU/yr throughput if the safeguards system is established based on the given requirement of the measurement technique.

Table 2. MUF uncertainty determination

No	SF Powder (UO_2) Systematic Analysis Error-t_1	TRU Product Systematic Analysis Error-t_4	MUF Uncertainty (Pu)
1	1.0%	1.5%	2.340
2	2.0%	2.0%	2.576
3	3.0%	3.0%	3.643
4	4.0%	4.0%	4.750
5	4.0%	5.0%	5.341
6	5.0%	5.0%	5.874
7	7.6%	5.0%	7.500
8	5.0%	10.0%	9.178
9	7.6%	10.0%	10.294

4. Conclusion

Analysis of the MBA/KMP and measurement system, simulation of the pyroprocess, and Pu MUF uncertainty evaluation has been carried out based on the conceptual design of the REPF. As a result of the analysis of the safeguardability of the conceptual design of the REPF using the proposed analysis technique, it seems that the designed safeguards approach can meet the typical IAEA detection goal for the REPF with a 10 tU/yr throughput if the measurement system is established based on the given requirement of the measurement technique. It is necessary to improve the REPF design concept and its safeguards system in order to obtain a more optimized safeguardable pyroprocessing facility model.

Acknowledgement

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