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The MUF of a Pilot-Scaled ACP Facility and Its Sensitivity

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Abstract

The Advanced Spent Fuel Conditioning Process (ACP) have been developed at the Korea Atomic Energy Research Institute (KAERI) as an alternative for the effective conditioning of spent fuel for long-term storage or/and eventual disposal. This paper addresses the safeguardability of a pilot-scaled ACP facility and its sensitivity analysis. For this, a conceptual process and its material flow are analyzed using experiences from conventional fuel cycles, and measurement methods and their uncertainties are assumed for calculating MUF (Material Uncounted For) standards deviation (SD). We concluded from the preliminary analysis of the MUF SD that the pilot-scaled ACP facility with capacity of 30 MTHM/year can meet the International Atomic Energy Agency (IAEA) safeguards goals.

1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing the Advanced Spent Fuel Conditioning Process (ACP), so-called the electrolytic reduction process, which involves the process of the reduction of uranium oxide by lithium metal in a high temperature molten salt bath. In order to support the program, the safeguardability study of the ACP concept has been carried out as the joint research project by KAERI and the Los Alamos National Laboratory (LANL) since the year 2002.

This study deals with the safeguardability of the ACP and their sensitivities. Especially, the effects of facility throughput and MB (Material Balance) period on the MUF (Material Uncounted For) standard deviation are examined. The approach for safeguardability and its sensitivity analysis employed in this study is shown in Fig. 1. First reference facility such as throughput, availability and batch size and the characteristics of the reference fuel such as burnup and cooling time are assumed. Second, MBAs (Material Balance Areas) and KMPs (Key Measurement Points) of the pilot-scaled ACP facility are defined considering the general domestic and IAEA (International Atomic Energy Agency) safeguarding principles. With those parameters, material flow for each sub-process and KMP is estimated. And then the MUF SD for the reference facility is calculated with assumption of measurement methods and their measurement uncertainties in order to see if the reference facility can meet the IAEA target value. Finally, the sensitivities for facility throughput and MB period are examined.

2. Reference Facility Concept

The reference facility concept consists of six major sub-processes. They include dismantling of the fuel assemblies, and decladding of the Zircaloy cladding, thermal oxidation of UO_2 to the form of U_3O_8, reduction of the oxide fuel to metals using a suitable reductant in a molten salt, smelting of metallized fuel and casting of metallized fuel in a form that is suitable for interim storage and deposition. The key process of the facility, electrolytic reduction process, is well described in other reference [1].

It is assumed that a pilot scale ACP facility has a capacity of 30 MTHM/year and batch size of 100 kgHM. The facility is a physically stand-alone facility, and administratively isolated from the reactors and interim spent-fuel storage facilities. A basic specification of the conceptual ACP facility to be evaluated is summarized in Table 1. The facility availability is assumed as 60 %, which is equivalent to 219 full operating calendar days per year. The facility consists mainly of three parts: spent fuel handling area (spent fuel disassembling and rod extraction), main hot cell (decladding, reduction, smelting, casting etc.), and a metal ingot handling area (loading metal rods into storage cask and temporary storage).

The reference spent fuel used in the ACP facility is Yong-Gwang Unit 1 & 2's 17×17 standard PWR spent fuel assemblies with burnup of 45,000 MWd/MTU and a minimum 10 years of cooling time after discharge from the reactor. The reduction rate of the fuel is assumed to be 99.8% for all actinide. It is also assumed that this facility operates 220 days/calendar year and closes the material balances once every 3 months (or once after 54 days of operation).

3. Material Control and Accountability

This facility is considered as three MBAs: spent fuel handling area, main processing area (bulk handling area) and metal storage area. The facility operator does material accounting based on some declared values for feed materials; destructive chemical analyses for mixed oxides; and NDA measurements for U metals, recyclable scraps, and disposable waste streams. The IAEA verification is preceded by a shutdown and cleanout of the bulk handling area and all the fuel material to be verified should be stored in storage KMPs. The facility closes material balances once every three months and plans to have the IAEA inspections coincide with this schedule for plant shutdown, cleanout, and material balance closing.

Material accountancy requires quantitative knowledge of the material, 1) present in the material balance area at the beginning and ending of the accountancy period and, 2) transferred into and out of the area during the period. Concrete results require characterization of the process operations and related material flows. It is also necessary to characterize the accounting system, facility measurement procedures, and related uncertainties.

Inventory for the bulk-handing area and their measurement methods assumed in this study are shown in Table 2. The destructive assay (DA) and Non-Destructive Assay (NDA) measurements for plutonium concentration are used on a batch basis. Their measurement uncertainties are referred to ITV (International Target Value) 2000 recommended by IAEA [2].

4. Results

The MUF is defined as the difference between the measured inventory and what is expected to be in the inventory based on the previous inventory and measured flows into and out of the process. The MUF SD can be calculated from general error propagation theory. The probability of detecting the loss of a given quantity of material, which is associated with MUF SD, depends on the measurement and sampling uncertainty. The IAEA detection goal for Pu is to detect a loss of one SQ (Significant Quantity) with 95% detection probability and a 5% false alarm probability. To achieve this goal, σ_{MUF} must satisfy $3.3\sigma_{MUF} < 8kgPu$, $\sigma_{MUF} < 2.424kgPu$.

From the MUF SD analysis, it was indicated that the σ_{MUF} of the reference case is 1.29kg of plutonium. This means that our reference facility can meet the typical IAEA detection goals because the MUF standard deviation is much less than the IAEA limit. From the results of the sensitivity analysis, as shown in Fig. 2 and Fig. 3, we found out that the facility throughput and material balance period are directly proportional to total facility MUF. These figures also shows that break-even values to meet the IAEA target goal for capacity and MB period are about 57 MTHM and 5.7 months, respectively.

At this research stage, most of the process data cannot be clearly defined. Therefore, a preliminary conceptual design to examine the safeguardability of the ACP facility is based on the open literatures for a similar process. Some modifications will be needed as more reliable information on the technical parameters becomes available.

References

[1] C.S.Seo et. al., "A Study on the Electrolytic Reduction of Uranium Oxide in a LiCl-Li2O Molten Salt", Korean Nuclear Society Spring Meeting, Gyeong Ju, May 2003.

[2] Aigner, H., et al. (2001), International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Materials, STR-327, IAEA.

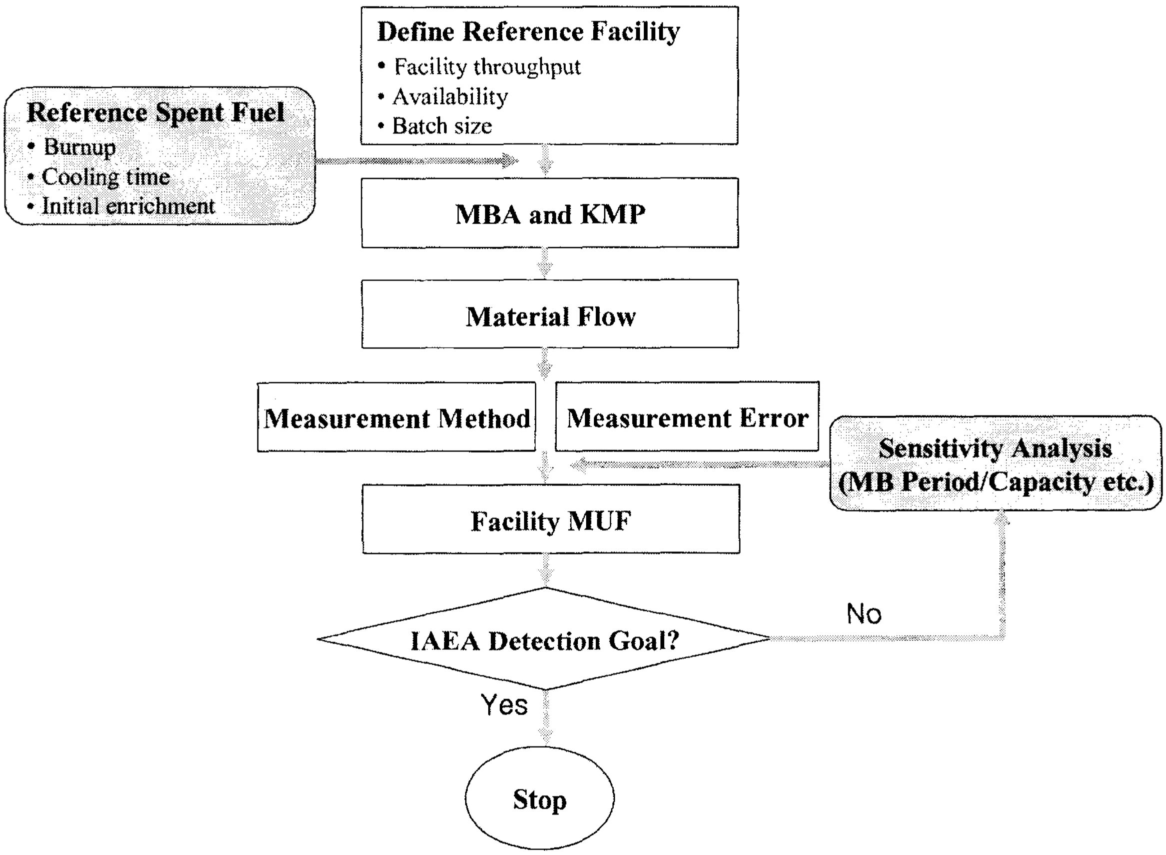

Fig. 1. Approach for Safeguardability Analysis

Table 1 Basic Specifications of Pilot Scale ACP Facility

Target fuel	Korean Yong-Gwang Unit 1 & 2's 17x17 standard PWR spent fuel assemblies with a minimum of 10 years of cooling time after discharge from the reactor.
Facility throughput	30 MTHM/y (approximately 0.45 MT-Pu/y)
Facility availability	60% plant production availability (i.e., equivalent 220 full operating calendar days/year)
Impurities in product	2 wt% of products (low decontamination product)
Main process of the facility	Electrolytic reduction process (reduction rate: 99.8% for all actinides)

Table 2 Inventory for the Bulk-Handling Area and Measurement Methods

Inventory KMP	Material Form	Pu(kg)	No. of Item	Accounting Method
A	Fuel Rods	0.91	60	Burnup, NDA
B	Powder (UO_2)	0.23	2	DA + weight
C	Cladding hull material	0.11	1	NDA
D	Powder (UO_2)	0.91	5	DA + weight
E	Powder residues (UO_2)	0.11	1	DA + weight
F	Powder (U_3O_8)	0.91	5	DA + weight
G	Salt waste	0.23	5	NDA
H	U ingot	0.91	5	NDA
I	Magnesia filter waste	0.11	1	NDA
J	U metal	0.91	5	NDA
K	Dirty metal scrap	0.23	2	NDA
Total		4.30	92	

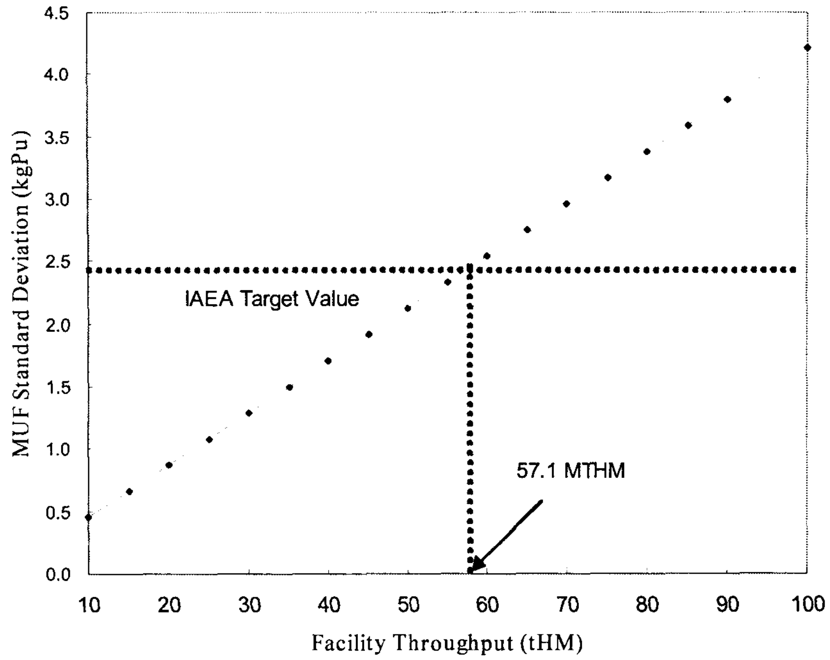

Fig. 2. Sensitivity Analysis for Facility Throughput
(batch size of 100kgHM, MB period of 3 months)

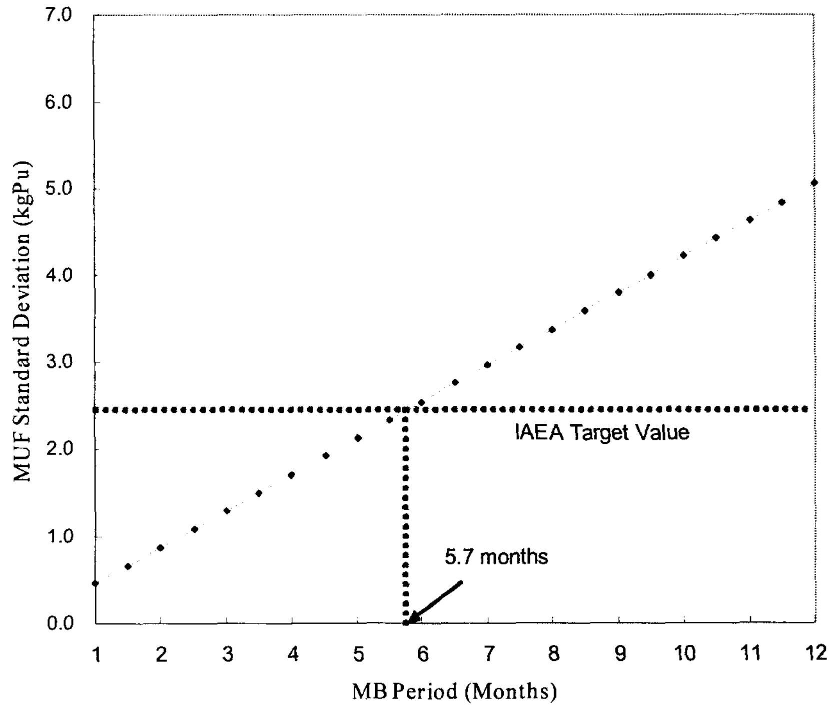

Fig. 3. Sensitivity Analysis for MB Period
(batch size of 100kgHM, throughput of 30 MTHM)