Status and Prospect of Safeguards By Design for the Pyroprocessing Facility

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Abstract.

The concept of Safeguards-By-Design (SBD), which is proposed and developed by the United States and the IAEA, is now widely acknowledged as a fundamental consideration for the effective and efficient implementation of safeguards. The application of a SBD concept is of importance especially for developmental nuclear facilities which have new technological features and relevant challenges to their safeguards approach. At this point of time, the examination of the applicability of SBD on a pyroprocessing facility, which has been being developed in the Republic of Korea (ROK), would be meaningful. The ROK developed a safeguards system with the concept of SBD for Advanced spent fuel Conditioning Process Facility (ACPF) and DUPIC Fuel Development Facility (DFDF) before the SBD concept was formally suggested. Currently, The PRIDE (PyRoprocess Integrated Inactive Demonstration) facility for the demonstration of pyroprocess using 10 ton of non-radioactive nuclear materials per year is being constructed in the ROK. The safeguards system for the facility has been designed in cooperation with a facility designer from the design phase, and the safeguards system would be established according to the future construction schedule. In preparing the design of Engineering Scale Pyroprocess Facility (ESPF), which will use spent fuels in an engineering scale and be constructed in 2016, a research on the safeguards system for this facility is also being conducted. In this connection, a project to support for development of safeguards approach for a reference pyroprocessing facility has been carried out by KAERI in cooperation with KINAC and the IAEA through an IAEA Member State Support Program (MSSP). When this MSSP project is finished in August, 2011, a safeguards system model and safeguards approach for a reference pyroprocessing facility would be established. Maximizing these early experiences and results, a safeguards system of ESPF based on the concept of SBD would be designed and developed.

1. Introduction

Pyroprocess technology is currently being developed, all over the world, and the Republic of Korea (ROK) is one of the most active states to realize it for the near future [1]. It is focused on securing the sustainability of nuclear energy by improving proliferation resistance, economic efficiency, environmental friendliness, and resource utilization of a back-end nuclear fuel cycle. The international community's confidence should be secured for the realization of pyroprocess technology. The safeguards approach, however, has not been established yet, especially from the view point of nuclear material accountancy technology. Due to the nature of the process, pyroprocess has various kinds of process material form, and the composition of Pu and U isotopes included in the process material is not homogeneous. The existing nuclear material accountancy technology for a wet reprocessing facility is hard to apply because of the large quantity of gamma-ray radiation which is emitted from the fissile products in process material. A study to develop material accounting methods and demonstrate the safeguardability for a pyroprocess facility is needed through analyzing and evaluating nuclear material flow, accountancy of pyroprocess, and the measurement uncertainties of accounting equipment.

The application of a Safeguards-By-Design (SBD) concept is now widely acknowledged as a fundamental consideration for the effective and efficient implementation of safeguards. At this point of time, the examination of the applicability of SBD on a pyroprocessing facility would be meaningful. The ROK constructed a safeguards system along with the construction of Advanced spent fuel Conditioning Process Facility (ACPF) since 2003 and keeps the investigation for applying the SBD concept for the pyroprocess facility. In this study, the main features of the safeguards development by the ROK for the pyroprocess are
reviewed and discussed.

2. R&D Experiences for Safeguards System for Pyroprocess

2.1 Technology Development for Nuclear Material Accounting

A passive neutron-based non-destructive assay (NDA) technology has continuously been developed and investigated for the pyroprocess nuclear material accounting system. The ACP Safeguards Neutron Counter (ASNC) for the nuclear material accounting for electrolytic-reduction uranium and process materials of the ACPF is one of the representative results [2]. A verification test using spent fuel rod-cuts was performed with experts from the IAEA and Los Alamos National Laboratory (LANL) in 2007. The results were generally good, and above the rest, the most satisfying results were that this could measure spent fuels to Triplet for the first time in the world and this also has full capability of remote operation and maintenance in a hot-cell.

Active neutron coincidence counter has also been developed as one NDA method for accounting nuclear materials in a pyroprocess [3]. Even though there should be more efforts to reduce the measurement errors and verification using relevant process materials, the accounting measurement techniques for a spent fuel management process will be expanded and have a high confidence by combining with other conventional non-destructive assay methods.

Database of the expected nuclear material accounting values had been established by using the calculation codes in consideration of radioactivity, Cm ratio, alpha-neutron reaction, and neutron emission as function of burn-up also. The gamma-ray spectroscopy measurement system is also one main NDA technique for KAERI to investigate for measurement of pyroprocess materials. Consequently, the results can be utilized as basic materials needed in preparing guidelines for establishing a nuclear material accounting method of the next pyroprocessing facility in large scale and in constructing a verification system of the IAEA.

2.2 Advanced Surveillance System and Remote Monitoring Technologies

An appropriate surveillance system and neutron coincidence counters for ACPF were developed and adjusted from the design phases of the facility [4]. An integrated surveillance system for ACPF safeguards including neutron monitors, surveillance cameras, and movement detection and text message sending functions were developed and installed in the ACPF. Performance tests with the data transmission system were also conducted.
Regarding with remote monitoring features, KAERI conducted several related research activities on the ACPF safeguards system. The feasibility of remote monitoring using Virtual Private Network (VPN) technology was tested and the surveillance data was transferred to the central monitoring station via VPN. By transmitting the monitoring information of the ACPF surveillance system to the IAEA and Sandia National Laboratory (SNL) of the U.S. via the Korea Institute of Nuclear Non-Proliferation and Control (KINAC) every day, we have improved the international nuclear transparency for a pyroprocessing facility. This safeguards system was utilized not only for nuclear material accountancy and monitoring of the pyroprocess, but also as reference materials for constructing a safeguards verification system of the IAEA.

2.3 Safeguardability Analysis and Preliminary Evaluation for Pyroprocessing Facilities

KAERI and LANL have collaborated on a safeguards study for a conceptual design of large-scale pyroprocess facility since 2006. In this study, the safeguardability of a pilot-scaled Korean Advanced Pyroprocessing Facility (KAPF) was assessed. The main processes, including voloxidation, electrolytic reduction, electro-refining, and electro-winning, were analyzed, and the sub-processes and material flow of the conceptually-designed KAPF were analyzed. MBAs and KMPs were designed and identified for material accounting for the main processing. The continuous association of Pu with Cm would present measurement options, but the Pu/Cm inseparability argument would have to be proven. Based on the sigma-MUF evaluation results with assumed facility features and a proposed safeguards system throughout the KAPF, it was concluded that a safeguards system could be designed to meet the IAEA’s comprehensive safeguards objective. Several additional considerations to enhance the safeguardability of the KAPF were also made. The safeguardability assessment conducted in this study is applicable to throughputs of about 100 MTHM/yr or less.

A preliminary conceptual design of a safeguards system for a 10 ton/year-scale ESPF, and analysis of its sigma-MUF were investigated. It would be necessary to homogenize nuclear material powder to account pyroprocess nuclear materials accurately, and there was suggested the developing of a 'Unified NDA System' for the pyroprocess NDA equipment in order to reduce systematic uncertainties and interruptions to process operation. A computer code for analyzing the safeguardability of pyroprocess facility was developed and being modified [5].

3. International Collaborations

3.1 Collaboration to Develop Advanced NDA Technologies

KAERI collaborated with the U.S. national laboratories for fuel cycle and safeguards technology R&D through various frameworks such as Work For Others, I-NERI program, Permanent Coordinating Group collaboration, and KAERI-10 program since the early 1990s. As a collaboration result, the establishment and enhancement of the ACPF safeguards system, development of neutron NDA equipments for accounting system, safeguardability assessment for pyroprocess facility were performed as described earlier sections. Other cooperation for advanced NDA technologies is also actively proceeding.

The typical Cm balancing approach for pyroprocess materials assumes that Cm remains un-separated from Pu in the process. Therefore, the Pu/Cm inseparability argument had to be proven. For real-time monitoring of the Pu/Cm ratio in process materials, joint studies for theoretical and experimental investigation of the feasibility of the Laser Induced Breakdown Spectroscopy (LIBS) technique [6] and high-resolution gamma-ray spectroscopy in combination with FRAM analysis code [7] are being conducted with U.S.

Direct measurement technology for fissile contents in process materials will play a critical role in safeguards approaches for pyroprocessing. Self-Interrogation Neutron Resonance Densitometry (SINRD) technology, which uses distinctive resonance absorption lines from U-235 or Pu-239 to determine the concentration of fissile contents in the nuclear materials, was investigated for nuclear material control and accountancy in advanced fuel cycle facilities. A joint study to develop a prototype SINRD system was
undertaken in PCG collaboration with LANL. For the amended task to develop an advanced NDA system for the pyroprocess facility, a Passive Neutron Albedo Reactivity (PNAR) counter was designed for a physics demonstration in cooperation with the LANL. The expected performance of the counter, with measurement uncertainties, and its applicability to pyroprocessing materials were also evaluated, and a hot-test will be performed in cooperation with the INL. PNAR counter would meet the design requirement for expected U/TRU samples.

3.2 Support Program for Safeguards Approach of a Pyroprocessing Plant

From the other aspect, research on the safeguards approach for a pyroprocess facility is also being conducted in cooperation with the IAEA. An Engineering Scale Pyroprocess Facility (ESPF), which will use spent fuels in an engineering scale (10 HM tons per year), is planned to be constructed by 2016. In connection with the facility safeguards design, a project to support for the development of the safeguards approach for a reference pyroprocessing facility was undertaken by KAERI in cooperation with KINAC and the IAEA through an IAEA Member State Support Program (MSSP). The collection and analysis of all the relevant information (characteristics of facility and materials, and flow sheet of the processes, etc.) on pyroprocessing facility concepts suggested by the U.S., Japan, and the ROK was completed in 2009. Three candidates for the reference pyroprocessing facility concept were suggested and reviewed, and the ESPF concept was determined to be the reference pyroprocessing facility in this MSSP project. For the next step, safeguards design and safeguardability analysis tasks will be carried out based on the reference pyroprocessing facility concept during the 2nd and 3rd years.

4. Summary

Technology development would be necessary to establish Pu inventory and track the inventory through the pyroprocess via the Pu/Cm ratio. Process monitoring of the pyroprocess would also be highly necessary to ensure there is no diversion. It would be imperative to investigate such process monitoring as a possible mean for a near real-time accountancy or an extra transparency measure in order to give the safeguards approach meaningful information about the process that could determine if the facility is operating as declared. Currently, the PyRoprocess Integrated Inactive Demonstration facility (PRIDE) is being constructed in the ROK. PRIDE is an engineering scale (10 ton/yr) pyroprocess demonstration facility and will uses un-irradiated materials (natural uranium and surrogate materials). To investigate a safeguards system including process monitoring technology and remote operability of the safeguards equipments, the safeguards system for the PRIDE facility was designed in cooperation with a facility designer from the design phase.

The accumulated experiences and technologies will be helpful for the development of NDA measurement equipments for engineering scale pyroprocess facilities which are going to be constructed in the future. The R&D efforts for the advanced C/S system will continue to stabilize and enhance the performance of the system with a remote monitoring capability. A safeguards system design and safeguards approach for a reference pyroprocessing facility would be established by completing IAEA support program in 2011. Maximizing these early experiences and results, a safeguards system of ESPF based on the concept of SBD will be designed and constructed, and it will contribute to increase the nuclear transparency for realizing the pyroprocess technology of the ROK, as well as to establish the safeguards technology for the pyroprocessing facility.

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References


