Safeguarding Pyroprocessing Related Facilities in the Republic of Korea (ROK)

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Abstract. Pyroprocessing technology, as one form of electrochemical recycling process, is being investigated by a number of countries as a promising strategy to the sustainable development of nuclear energy production and management of spent nuclear fuel. The Republic of Korea (ROK) has been developing technical aspects of pyroprocessing since 1997. To date, the ROK has established three pyroprocessing related facilities at the Korea Atomic Energy Research Institute (KAERI) site.

The IAEA's safeguards system provides the international community with credible assurances regarding a State's fulfilment of its safeguards obligations. Developing safeguards approaches for pyroprocessing facilities in a State is an integrated process consisting of acquisition path analysis establishment and prioritization of technical objectives (TO) and identification of applicable safeguards measures.

This paper presents the basic principles of safeguards implementation at pyroprocessing related facilities in the ROK which takes into account the specific nature of the process and the nuclear materials involved, and it outlines how new monitoring equipment has been tailored for safeguards purposes. The need for robust safeguards to be applied to pyroprocessing facilities requires the IAEA to develop new measures/techniques to complement the more traditional safeguards measures such as containment and surveillance (C/S). As an example, a bus bar system has been designed and developed to support evaluation of the facility operators' declarations by monitoring the electrical current supplied to the electro-reduction and the electro-refining equipment.

1. Introduction

Pyroprocessing (or electrochemical recycling) in the nuclear fuel cycle is a process utilizing electrochemical methods to separate uranium (U) and plutonium (Pu), together with minor actinide elements from fission products elements according to their chemical potentials. The process takes place in high temperature molten salts/molten metal media, instead of aqueous solutions. The process is characterized by group actinide recovery (no separated Pu in process streams) and relatively low product purity (low decontamination factors of fission products).

Pyroprocessing technology is being investigated by a number of countries (including: European Union, India, Japan, ROK, Russia, United States) as a promising strategy to the sustainable development of nuclear energy production (eventual fuel fabrication for fast reactors) and management of spent nuclear fuel (possible minimizing of high-level waste) [1]. However, pyroprocessing has not yet been implemented on an industrial scale and, to date, only limited laboratory-scale and engineering-scale including experimental/demonstration facilities are operating. This means that flow sheets and equipment used may vary depending upon purposes. For example, for the purpose of treating LWR spent fuel (oxide fuel) the core pyroprocessing technology includes: fuel assembly chopping, decladding/vol-oxidation, electro-reduction, electro-refining and /or electro-winning, cathode processing and waste treatment process. For the purpose of metal spent fuel (e.g.

EBR-II) treatment the vol-oxidation, electro-winning and electro-reduction steps are not included. The whole process produces U metal ingot and uranium/transuranium (U/TRU) metal ingot as final products accompanied by two types of waste forms: ceramic/salt waste and metal waste.

The safeguards approach (SG approach) defines the actions the IAEA (the Agency) takes at the State, site and facility level to meet its objectives. It also sets safeguards equipment requirements and pragmatic implementation factors. This means that relevant and effective safeguards measures should be identified to provide:

- Verification of the non-diversion of declared nuclear material from a facility,
- Confirmation of facility operation as declared,
- Support for a conclusion on the absence of undeclared materials or activities in the State as whole (when an additional protocol is in force).

Nuclear material accountancy as a basis for non-diversion, comprehensive evaluation of all safeguards relevant information about a State and consequent implementation of safeguards based on State-level approach allow meeting the requirements listed above.

This paper presents the SG approach implemented at the pyroprocessing related facilities in the ROK.

2. Basic principles of safeguards implementation at pyroprocessing facilities

In case of pyroprocessing facilities, application of a robust SG approach requires that the Agency measure/verify Pu and U inventories at strategic points and to keep the continuity of knowledge of both nuclides during the process flow. Due to the nature of the pyroprocess (e.g. Pu and U products remain partially mixed with fission products), the existing safeguards techniques might not be sufficient. This implies that development of new measures/techniques to complement the traditional safeguards measures such as C/S and nuclear material accountancy may be required. [1]

Currently, the preparation/implementation of a SG approach for pyroprocessing facilities is realized in two ways: for the already existing facilities and for future engineer/commercial scale pyroprocessing facilities, as presented in Fig.1. Development of an effective SG approach for the future industrial pyroprocessing facilities presents several challenges to the Agency. In this regard, the Agency cooperates with the United States support programme, conducts consultations with other Member States, works with international technical experts and consultants to identify suitable monitoring instruments and develop process models and relevant safeguards procedures.

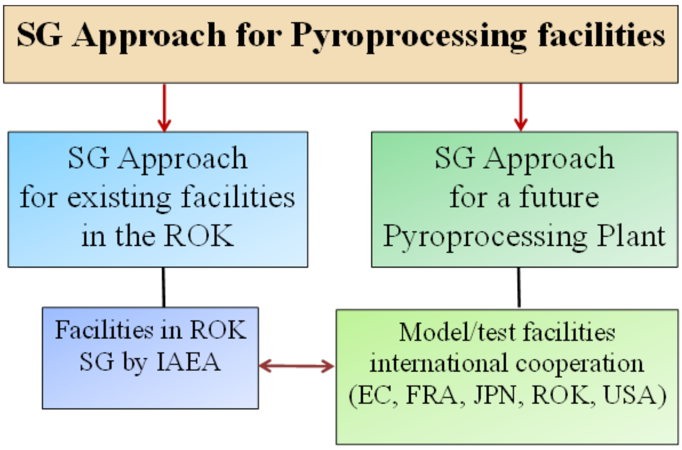


FIG.1. Safeguards implementation for Pyroprocessing facilities

3. Pyroprocessing in the ROK

The ROK has been developing all technical aspects of pyroprocessing since 1997. Pyroprocessing is the leading technology option for solving the ROK's near-term spent fuel storage limits (spent fuel recycling and reducing nuclear waste). It has been estimated that on-site spent fuel storage limit in the ROK will be reached from 2016. [2], [3]

The ROK is involved in several international projects related to pyroprocessing technology including close collaboration with the Agency in generic SG approach development.

In 2008, the Pyroprocessing Working Group was established with professionals from the IAEA and the ROK to support development of a SG approach for a pyroprocessing plant. The ROK was working closely with the Agency under the ROK's Member State Support Program to develop a model SG approach for a reference engineering-scale pyroprocessing facility (REPF). REPF design is part of the IAEA's effort to develop an effective SG approach for pyroprocessing facilities (Safeguards-by-Design). As a result of the project: a model design information questionnaire (DIQ), a model Facility Attachment (FA) and a model SG approach were prepared.

In January 2011, the ROK signed an agreement with the United States to conduct a feasibility study on pyroprocessing (10-year Joint Fuel Cycle Study (JFCS) project). The IAEA was invited to be an official member of the Safeguards and Security Working Group under the JFCS in November 2011, and the invitation was accepted.

3.1 Pyroprocessing related facilities in the ROK

To date, the ROK has established three pyroprocessing related facilities at the KAERI site:

PRIDE – **P**yro-p**r**ocess **I**ntegrated Inactive **De**monstration Facility

ACPF – **A**dvanced Spent Fuel **C**onditioning **P**rocess Demonstration **F**acility

DFDF – **D**UPIC **F**uel **D**evelopment **F**acility

3.1.1 Pyro-process Integrated Inactive Demonstration Facility (PRIDE)

PRIDE is an engineering-scale R&D facility, handling non-irradiated depleted uranium (DU) and surrogates to develop and test key technologies for pyroprocessing prior to the development and construction of an engineering-scale facility. The data obtained from this facility will be used to evaluate the feasibility of an engineering scale pyroprocessing facility. [2] [3]

The facility consists of a maintenance chamber connected to a large-sized argon cell. The process involves the following main steps: vol-oxidation of feed material, electrolytic reduction, electro-refining, electro-winning, UCl_3 preparation; and waste salt treatment.

The designed annual throughput is up to 10 t-U/ year of DU to be processed. The PRIDE facility is in testing operation with salts and it is under preparation to start tests with DU at the beginning of 2015. It has received the initial batch of feed material. Normal operations will start in 2017.

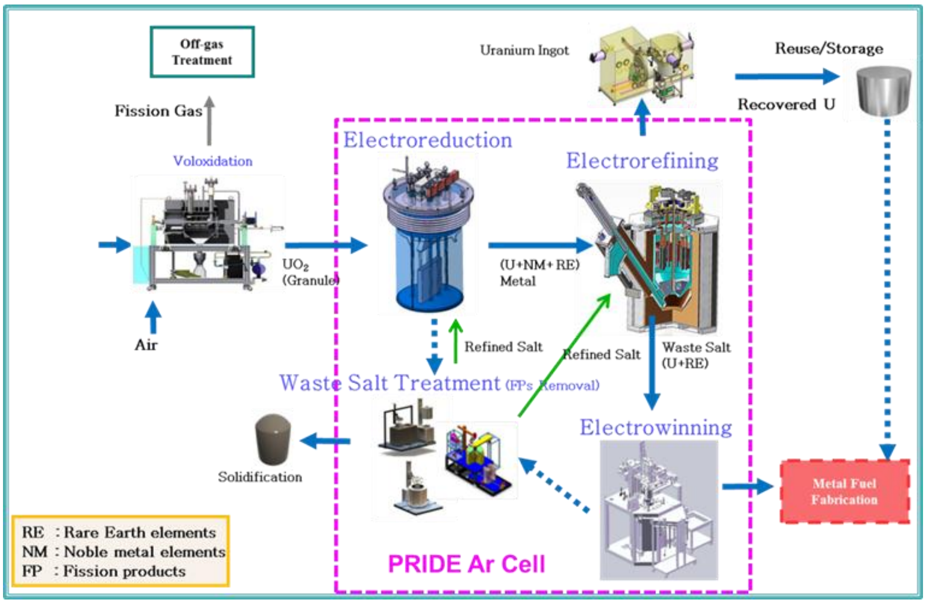


FIG.2. Pyro-process Integrated Inactive Demonstration Facility

3.1.2 Advanced Spent Fuel Conditioning Process Demonstration Facility (ACPF)

ACPF is an R&D facility consisting of two concrete hot cells (one containing an argon compartment) for research into the electrolytic reduction process. The ACPF process involves only one step: electrolytic reduction of oxide into metal form in the argon compartment.

The ACPF operation is divided into two steps:

— Cold test - (on-going) with un-irradiated natural and depleted uranium as nuclear material involved in test; and,
— Hot test – (time not defined yet) which will involve up to 10 kg-U of feed material from DFDF (PWR irradiated fuel rod cuts after vol-oxidation process in form of low density pellets or granules).

3.1.3. DUPIC Fuel Development Facility (DFDF)

DFDF consists of one concrete hot cell used for the technology development of the DUPIC (Direct Use of Pressurized Water Reactor Fuel in CANDU) fuel fabrication as well as for vol-oxidation of irradiated PWR fuel rod cuts to produce feed material (granules and low density pellets) for the electrolytic reduction process in ACFP. During the vol-oxidation process, volatile fission products are removed and trapped, e.g. Cs-137 is significantly reduced.

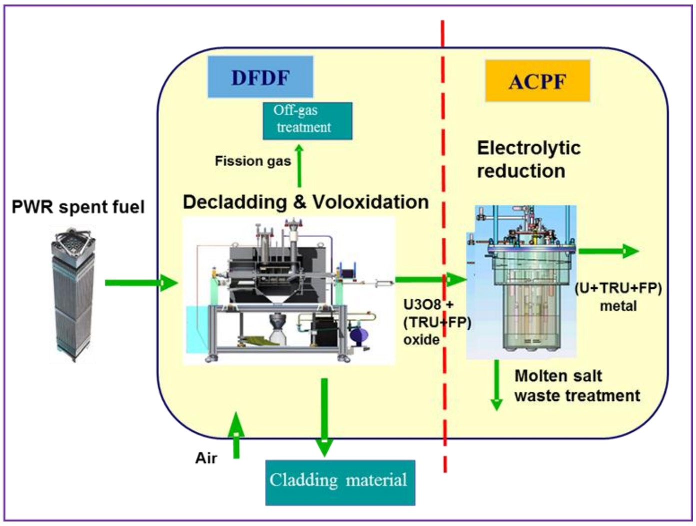


FIG. 3. Relation between the Advanced Spent Fuel Conditioning Process Demonstration Facility and DUPIC Fuel Development Facility

4. SG approach at pyro-related facilities in the ROK

The SG approach for pyro-related R&D facilities in the ROK, takes into account the specific nature of the process and that the nuclear material involved is less than 1SQ at each facility in relation to the acquisition path analysis for the ROK. It has been designed and implemented to meet the safeguards TOs of the State-Level SG Approach (SLA) for the ROK. TOs are established to identify possible safeguards measures which may cover an acquisition pathway and to fulfil the following State-level safeguards objectives (A, B and C):

Objective A: Detection of Undeclared Nuclear Material and Activities in the State as a Whole

Objective B: Confirmation of the Absence of Undeclared Production or Processing of Nuclear Material at Declared Facilities and Locations (Misuse of Declared Facilities)

Objective C: Confirmation of the Absence of Diversion of Declared Nuclear Material

4.1. Selected safeguards measures for safeguards implementation

To address the TOs in the SLA, the following components have been selected for the safeguards implementation:

(1) In Field Verification Activities [4]:

(i). Routine inspections: e.g. physical inventory verification and random interim inspection**.** During the inspections the following measures are implemented: nuclear material accountancy**,** utilisation of C/S measures, destructive analysis, and non-destructive analysis (NDA)

(ii). Design Information Verification (DIV)

The design information of each facility provided by the ROK is re-examined, at least once a year, in the light of any changes, which might have a bearing on currently applied safeguards. DIV is performed periodically or when the Agency considers it necessary, according to the annual implementation plan (AIP) for the ROK. The objectives and activities performed during the visits are described in a DIV plan.

(iii). Complementary Access (CA) [5]

(iv). Environmental Sampling

Environmental samples may be taken at any location at the pyro-related facilities, during routine/ad hoc/special inspections, DIVs or CAs based on information evaluation and/or in accordance with the AIP for the ROK.

The baseline environmental samples for PRIDE facility were taken in the argon cell and in the process room on the first floor during the expert team visit in August 2012, described in Section 4.2. Additionally, environmental samples were taken inside hot cells for the ACPF and DFDF facilities during the same visit as a baseline for the facilities after the respective reconstruction/maintenance activities were completed.

(2) Headquarters (HQ) Activities:

(i). Material balance evaluation, performed at the facility and State level

(ii). Analysis of all available information: e.g. information collected during field activities, evaluation of the information provided with DIQ, advanced declarations (annual and monthly), operational facility information (quarterly), additional protocol declarations, open source information, satellite imagery, trade analysis, etc.

4.2. Expert team mission to KAERI pyroprocessing related facilities

In connection with declared construction status of the PRIDE facility, and in view of significant modifications at the ACPF and DFDF facilities, an Agency expert team on pyro-processing was sent to KAERI in August 2012 with the main objective of performing the first full DIV at pyroprocessing related facilities. During conduct of the DIV activities, special attention was placed on baseline establishment of the essential equipment list for the PRIDE , ACPF and DFDF facilities; discussing safeguards accountancy requirements, measures and approach in support of drafting the FA for PRIDE; performing a site survey for the Agency NDAs and possible C/S installation or modification in support of safeguards implementation at the ROK pyro-processing related facilities; and sharing perspectives on the ROK's provision of the operator's process information/camera data sharing for remote transmission to the IAEA HQ in Vienna.

The information collected during the visit was discussed during several technical meetings of the expert team members after return to the HQ. As the results of the information evaluation, baseline documentation for the future DIVs was established (e.g. essential equipment lists and detailed essential equipment working papers) and the recommended equipment to be used/ installed as well as the possible C/S at all three pyro-related facilities under the current SG approach were determined.

4.3. Equipment installed to support SG approach for the pyro-related facilities

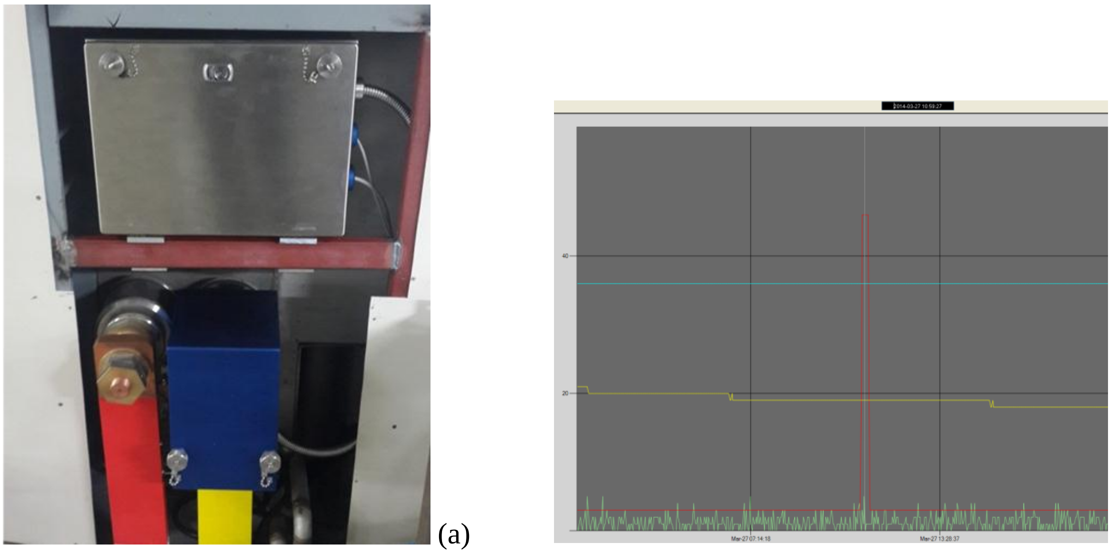
The demands for robust safeguards applied to pyroprocessing facilities require the IAEA to develop new measures/techniques to complement the more traditional safeguards systems. Based on the findings from the first full DIV and subsequent evaluation of the acquired information, a new unattended monitoring system (UMS) system, referred to as a bus bar monitoring system, has been designed and developed. The bus bar system, together with portal radiation monitors, were selected and installed in the PRIDE facility to support safeguards implementation in this facility.

(1) UMS Bus Bar Monitoring System

The system has been designed to support evaluation of the facility operator’s declarations (declared operating parameters and an indication of the processed material quantity) by monitoring the electrical current supplied to the electro-reduction and the electro-refining equipment.

Redundant current transducers are installed on the copper bus bars which supply the power to the electrolytic reducer and refiner. The output of the transducers is a DC voltage which is converted to a respective frequency (VFC) and connected to the Radiation Data Logger 1 (RDL1) pulse counter input. For review of the data, the pulse counter data is converted via the data collection software to a value representing the electrical current amperage. The system contains also He3 neutron detectors, batteries for external mains power loss, virtual private networking (VPN) hardware for secure external communications (e.g., data transfer, state-of-health monitoring) and it is installed within Sealable Tamper Indicating Enclosures (STIE).

Utilizing the RDL1 device, the system does not require a local data collection computer. The data are remotely directed via internet to the HQ Vienna. The data transfer is initiated from HQ.



(a) (b)

FIG. 4. UMS Bus Bar Monitoring System installed in PRIDE (a) and 50 Ampere Testing result (b)

(2) UMS Portal Radiation Monitors

The system supports confirmation of absence of irradiated nuclear material in the facility.

Each of the two neutron monitors installed in PRIDE contains He3 detectors, the RDL1 device, batteries for external mains power loss, VPN hardware for secure external communications (e.g., data transfer, state-of-health monitoring) and are installed within Sealable Tamper Indicating Enclosures (STIE).

The system utilizing radiation data logger does not require computer. This makes the system installed in PRIDE different compared to other currently operating portal radiation monitors. Local data are collected with a radiation data logger and transferred remotely to the HQ Vienna. Two locations were selected for the equipment installation – near the transfer hatch where material is brought into the argon cell and near the electrolytic refiner. Installation of the neutron monitoring equipment was completed below the floor of the argon operating cell as the floor is constructed with metal (non-neutron absorbing).

FIG.5. UMS Portal Radiation Monitor installed in the PRIDE facility.

5. Conclusion

The IAEA's safeguards system provides the international community with credible assurances regarding a State's fulfilment of its obligations. Safeguards based on the State-level approach and application of safeguards measures at the State, site and facility level have been applied to the pyroprocessing related facilities in the ROK taking into account the specific nature of the process and the nuclear materials involved.

With regard to the demands for robust safeguards applied to pyroprocessing facilities, the IAEA has developed specific measures/techniques. New equipment has been tailored for safeguards purposes (e.g., a bus bar system has been designed and developed to support evaluation of the facility operators' declaration by monitoring the electrical current supplied to the electro-reduction and the electro-refining equipment). New equipment will continue to be developed, tested and deployed in the future.

Based on the experience with safeguarding the pyroprocessing related facilities in the ROK and with the support of Member States, the Agency is well on the way to establish effective safeguards for future engineering/commercial scale facilities.

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