REFURBISHING ACPF FOR PYROPROCESSING TECHNOLOGY DEVELOPMENT AT KAERI

K.H. KIM, S.N. YU, B.S. PARK, S.H. KIM, J.K. LEE, I.J. CHO, D.H. AHN
Nuclear Fuel Cycle Technology Development Division, Korea Atomic Energy Research Institute
989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057 – Korea

ABSTRACT

The Korea Atomic Energy Research Institute (KAERI) has been developing an engineering-scale pyroprocessing technology in a mock-up test facility of PRIDE (PyRoprocess Integrated inactive Demonstration facility). The full-spectrum of this technology development using depleted uranium or surrogates is being demonstrated in an inert atmosphere of PRIDE. Currently, the Advanced spent fuel Conditioning Process Facility (ACPF) at KAERI is being refurbished to demonstrate an electrolytic reduction process of pyroprocessing using spent nuclear fuel. One of the major ACPF refurbishments is to construct an additional inert atmosphere cell inside of the air atmosphere cell of ACPF. This paper describes on-going refurbishing activities and the current status of ACPF. The constructed argon cell with auxiliary equipment and devices and remote is also demonstrated.

1. Introduction

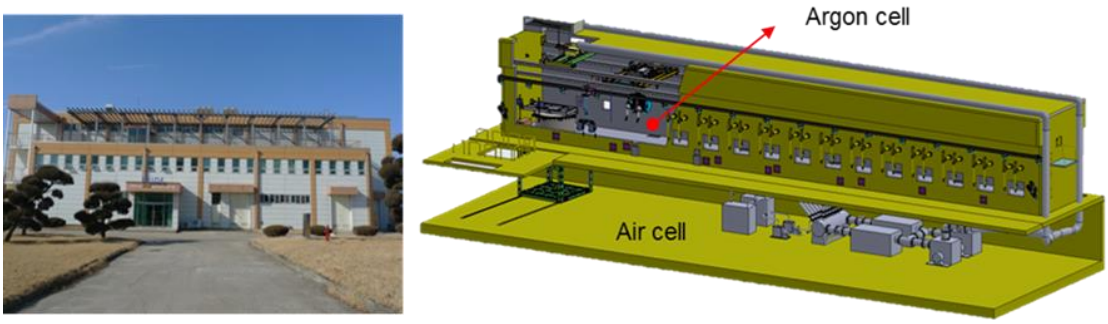
Pyroprocessing is a technology that refines nuclear materials from spent nuclear fuels using an electrochemical method. This pyroprocessing technology, which is considered one of the promising options for future nuclear fuel cycles in Korea, is being developed at the Korea Atomic Energy Research Institute (KAERI). The pyroprocessing that we consider mainly consists of five processes: head-end, electrolytic reduction, electro-refining, electro-wining, and waste salt treatment. This technology development should be conducted in an argon atmosphere owing to its characteristics.

KAERI has two facilities for developing pyroprocessing technology: a mock-up test facility, called the PyRoprocess Integrated inactive DEmonstration facility (PRIDE) [1] and the Advanced spent fuel Conditioning Process Facility (ACPF). In 2012, PRIDE was constructed to demonstrate the full-spectrum of the engineering-scale pyroprocessing technology development using depleted uranium or surrogates in an argon gas atmosphere. The engineering-scale processing equipment and auxiliary devices for all of the above five processes were designed, fabricated and installed in the PRIDE argon cell. All of the processing equipment was tested and evaluated from the remote operation and maintenance viewpoints from the design stage to the fabrication before putting into service at the argon cell of PRIDE. Currently, PRIDE is under normal operation conducting experimentation using depleted uranium or surrogates for pyroprocessing technology development.

ACPF was constructed in the basement of the Irradiated Materials Examination Facility (IMEF) at KAERI in 2005. ACPF, an alpha-gamma type hot-cell, is operated in an air atmosphere. This hot-cell has two cells: a maintenance cell for repairing damaged equipment or devices and a process cell for conducting process experimentation. As of 2015, KAERI has been refurbishing ACPF to demonstrate an electrolytic reduction process of pyroprocesing using spent PWR (Pressurized Water Reactor) nuclear fuel in an argon atmosphere. One of the major features of the ACPF refurbishment is to construct an additional argon cell inside of the ACPF process cell with an air atmosphere. An additional argon cell is being constructed inside of the process cell of ACPF for a pyroprocessing technology development of the electrolytic reduction process. Relevant remote handling systems and an argon supply system are also being implemented to make the argon cell more functional.

2. Overview of PRIDE

PRIDE was constructed in 2012 by refurbishing the aged ADU (Ammonium Di-Uranate) conversion facility located at the KAERI site. Figure 1 shows a photograph of the constructed PRIDE outside and the elevation view of the PRIDE graphical model. PRIDE is a three-story building composed of an air cell positioned on the first floor and an argon cell constructed through the second and third floors. As shown in Figure 2, the air cell is a personnel accessible area, where various utility systems and air-atmosphere processing equipment are installed. The argon cell is a major process cell and has a configuration of 40.3 x 4.8 x 6.4 (LxWxH) m with 6-mm-thick stainless steel walls and a 10-mm thick stainless floor. This argon cell is normally operated at a temperature of 25 to 40 ^{O}C and a pressure of -50 to -20 mmH_2O. The impurity levels of oxygen and moisture inside the cell are controlled at below 50 parts per million (ppm). The argon cell is equipped with various types of equipment and systems necessary for operation, i.e., cell equipment mounted on the cell structure, remote handling systems movable for performing remote operation and maintenance of processing equipment inside the cell, and in-cell monitoring systems for monitoring and identifying in-cell conditions or situations in real-time during cell operation [2].



a) outside   b) Isometric section view of inside

Fig 1. The constructed PRIDE

The major cell equipment of the PRIDE argon cell includes twenty-two viewing windows (seventeen on the front wall and five on the rear wall), small and large transfer lock systems, gravity tubes, feed-throughs, cell lights, and an argon utility system. Remote handling systems installed in the argon cell include an in-cell overhead crane, a blister, master-slave manipulators (MSMs), and bridge transported dual arm servo-manipulators (BDSM) [2]. These remote handling systems make processing equipment and auxiliary devices remotely operable and maintainable inside the cell. A pair of MSMs (HWM A110, Germany) was installed above the left- and right-hand sides of each front viewing window workstation. Thus, a total of thirty-four MSMs were installed on the front wall of the cell. In-cell monitoring systems consist of in-cell cameras and various types of sensory devices. The in-cell was equipped with a total of twelve cameras including a 3D camera to provide in-cell information or situations. Various types of sensory devices such as O_2 concentration analysers, moisture analysers, pressure sensors, temperature sensors, and temperature liner sensors were installed inside the cell to identify the in-cell conditions.

A total of thirteen pieces of engineering-scale processing equipment for pyroprocessing technology development were installed inside the PRIDE argon cell after completing the remote operability and maintainability of the processing equipment in the mock-up of PRIDE. Currently, the integrated processes of electrolytic reduction, electro-refining, electro-wining, and waste salt treatment using depleted uranium are under normal operation in the PRIDE argon cell. The head-end process is conducted in the air cell located on the 1st floor.

3. ACPF Refurbishment

3.1. Overview of ACPF

ACPF constructed in 2005 is an alpha-gamma type hot-cell with an air atmosphere and was used to demonstrate an electrolytic reduction process using natural uranium until its refurbishment was initiated. ACPF consists of two cells: a maintenance cell and a process cell. The maintenance cell was designed and constructed to repair processing equipment or devices damaged or broken in-situ during cell operation, and has a configuration of 2.2 x 2.0 x 3.4 (LxWxH) m, where the height was measured from the in-cell floor. The process cell with a configuration of 8.1 x 2.0 x 3.4 (LxWxH) m was occupied to conduct process experimentations. The wall of the hot-cell was made of 0.9 m of heavy concrete to keep the dose rate less than 0.01 mSv/h in the operating area. ACPF has five shielding window workstations. Each window workstation was equipped with a pair of MSMs. ACPF was also equipped with other remote handling systems to provide remote handling capabilities over the entire in-cell. These remote handling systems are a bridge-transported servo-manipulator, a 1-ton in-cell overhead crane and a gate crane. A bridge-transported servo manipulator that traverses the length and width of the in-cell ceiling and moves in a vertical direction was no longer used by completely removing it from the in-cell during the refurbishment of the cell.

3.2. ACPF Refurbishment

The purpose of the ACPF refurbishment is to demonstrate an electrolytic reduction process using spent nuclear fuel in an argon atmosphere of the ACPF hot-cell. The refurbishing scopes of ACPF mainly include the ACPF hot-cells, the operating area, and the service area, shown in Figures 2 and 3 [3]. As to the refurbishment of the ACPF hot-cell, old in-cell structures, utilities lines and cell equipment and devices were decontaminated by reducing to ALARA (As Low As Reasonably Achievable) before they were dismantled and disposed of.

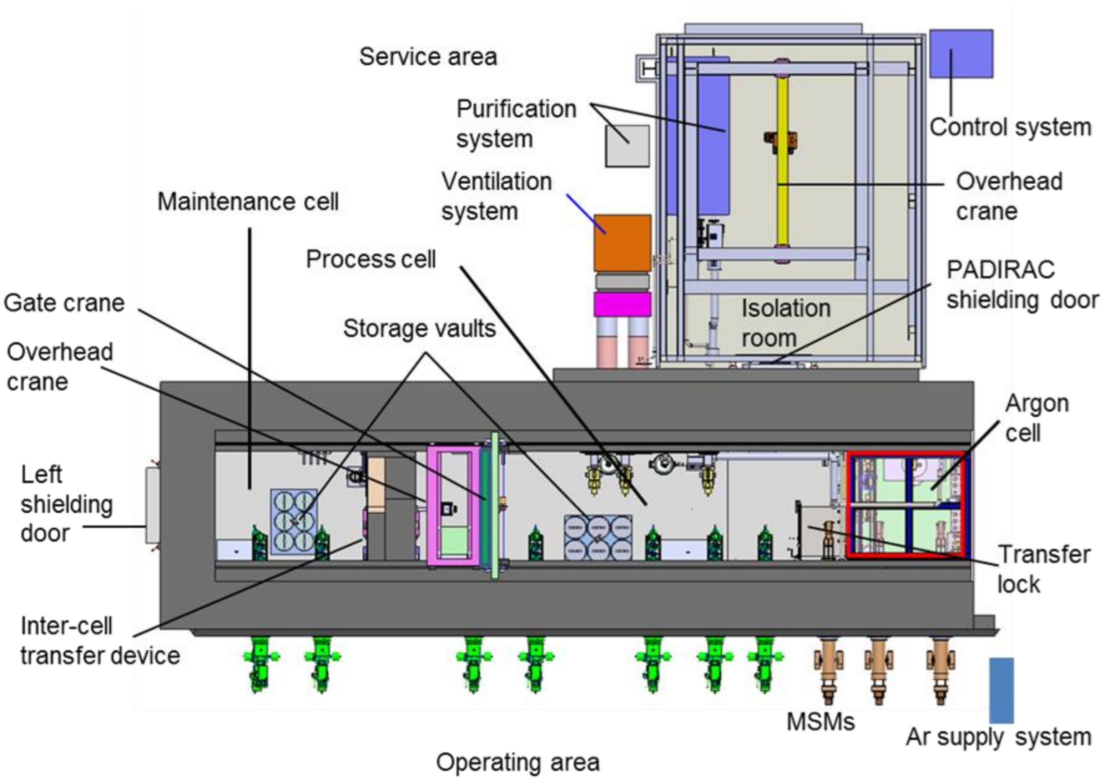


Fig 2. The top view of the ACPF being refurbished

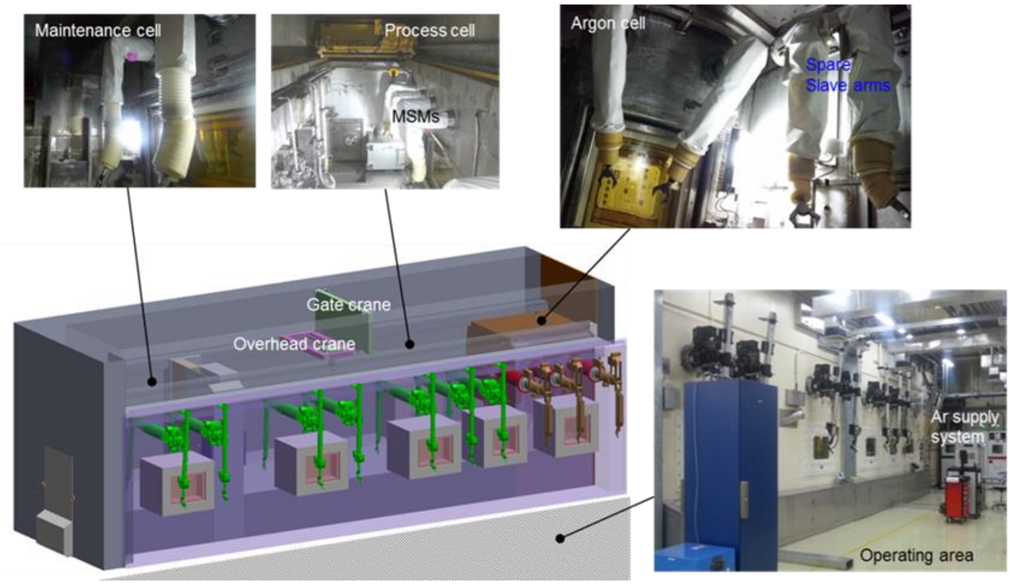
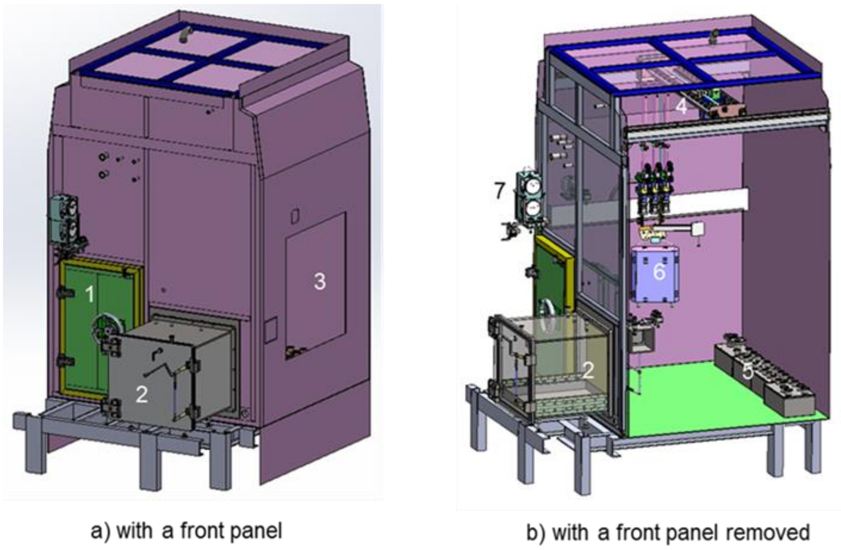


Fig 3. An isometric view and photographs of the ACPF being refurbished



1: Entrance door, 2: Transfer lock system, 3: Shielding window, 4: Overhead crane, 5: Feed-throughs, 6: Cell light, 7: Temperature and pressure sensors

Fig 4. A graphical model of the ACPF argon cell constructed inside the process cell

One of the major features of the ACPF hot-cell refurbishment is to construct an additional argon cell inside of the ACPF process cell with an air atmosphere. The additional argon cell [4] was constructed inside of the far-most right-hand side of the process cell (air air). The more detailed graphical model of the constructed argon cell is also shown in Figure 4. This argon cell has one shielding window seen from an operating area and has a configuration of 1.7 x 2.0 x 2.7 (LxWxH) m, where the height was measured from 0.2 m above the base of the structure. The argon cell consists of an entrance door, a transfer lock system, feed-throughs, cell lightening, an overhead crane, and a pair of MSMs. An entrance door with a configuration of 0.6 x 1.0 (LxW) m was designed and fabricated to be firmly secured during the argon cell operation, and it will be never opened except for an emergency of the argon cell. A transfer lock system is a unique channel for connecting the argon cell and the air cell during the ACPF operation. This transfer lock system has a configuration of 0.6 x 0.6 x 0.6 (LxWxH) m and a maximum transferring capacity of 100 kg. Process materials, modularized components of processing equipment (electrolytic reduction equipment), and tools necessary for the in-cell (argon cell) experimentation are transferred to/from the inside (argon atmosphere) and outside (air atmosphere) cell through only this transfer lock system without breaking the in-cell tightness, keeping the allowable impurity levels below 1 ppm. Salt wastes generated from in-cell processing are also transferred from the in-cell (argon cell) to the out-of-cell (air cell) through this transfer lock system. Lightening in the argon cell is provided by one 250W metal halide lamp and one 100W three-wave lamp mounted on the lamp housing. The lamp housing is equipped with a detachable lamp receptacle with remotely detachable electrical connectors in which two lamps are installed. Utilities such as electricity and sensor signals are supplied from the out-of-cell (operating area) to the air cell through the penetrations. Utilities supplied to the air cell are then supplied to the argon cell through feed-throughs while keeping the tightness of the argon cell.

The argon utility system supplies argon gas into both the in-cell and an electrolytic reduction processing equipment. The argon utility system mainly consists of an argon supply system located at an operating area, a purification system, and a control system located at an isolation room, and HAPA filter system located inside the air cell. The purification system consists of six sub-modules: a circulation blower, a dry trap, a cooling system, a vacuum pump, oxygen and moisture sensors, and a dryer. The control system controls the impurity levels of oxygen and moisture, the temperatures, and the pressures required for the normal operation of the argon cell in real-time. The concentrations of oxygen and moisture inside the argon cell are required to remain equal to or less than 1 ppm during cell operation for the expected successful experimentation of the electrolytic reduction processing equipment installed inside the argon cell. In addition, the argon cell is required to be normally operated at a temperature of less than 38 ^{O}C and a pressure of -37 to -27 mmH_2O.

All of the processing equipment and devices located inside the argon cell require fully remote handling for operation, replacement, maintenance, and transportation. Remote handling systems installed in the argon cell are a 150-kg overhead crane and a pair of MSMs. A pair of MSMs installed above the left- and right-hand sides of the shielding window workstation of the argon cell are commercially manufactured costume-designed gas-tight manipulator systems (HWM A110, Germany), which consist of three pieces: a master manipulator, a through-tube equipped in a wall tube, and a slave manipulator. Each MSM has an effective handling capacity of 15 kg in any position within its workspace. These remote handling systems make the processing equipment and auxiliary devices remotely operable and maintainable inside the cell. Two spare slave arms were also installed in advance inside the argon cell for replacement in case the installed slave arms are broken or damaged. The in-cell information or situations are viewed and monitored through both a camera and a window. A camera with functions of pan, tilt, rotation, and zoom was installed inside the argon cell and can be remotely replaced by a new one when broken.

As shown in Figures 2 and 3, the refurbished air cell of ACPF consists of a process cell and a maintenance cell. The process cell is occupied for providing the auxiliary means or devices necessary for the experimentation of an electrolytic reduction process to be conducted in the argon cell, while the maintenance cell is used to repair the damaged equipment or devices. The process cell includes three shielding windows; and the maintenance cell, one shielding window. A pair of MSMs was installed above each shielding window workstation. A 1-ton in-cell overhead crane and a gate crane traverse the air cell, and their electric cables were redesigned and rearranged owing to the in-cell structure refurbishment. The same cell lightening system applied to the argon cell was installed on the right-hand side of each shielding window inside the air cell. Spare lines for utilities such as pressurized air, argon gas, and electricity and electrical signals were installed inside the air cell so that, when necessary, they can be handled in a remote manner. There are two storage vaults inside the air cell: one inside the maintenance cell and the other inside the process cell. These storage vaults are installed below the floor of each cell and operated in an argon atmosphere. Salt wastes or other radioactive wastes generated from the argon cell processing are loaded into cylindrical drums, and drums lids are then closed. These drums with loaded wastes are transferred from the in-cell (argon cell) to the out-of-cell (air cell) through the transfer lock system. The transferred drums to the air cell are then stored inside the storage vault of an argon

atmosphere. Each storage vault can receive six waste-loaded drums. All of the transfers and storage of waste-loaded drums are conducted remotely using both MSMs and a crane. Object transfer between the maintenance cell and the process cell is achieved using an inter-cell transfer device. This transfer device is located at a tunnel penetrated through the wall between the maintenance cell and the process cell. Rectangular solid plate doors are located at each entrance side of a tunnel. These doors are fully counterbalanced and are opened or closed by lifting or lowering them in a vertical direction by MSMs with small force, respectively. Upon operation, one door is opened, and a transfer device is then pulled out of a tunnel. Objects are loaded into a transfer device, and a transfer device is then pushed into a tunnel. The door is closed, and the other door located at other side is then opened. A transfer device with loaded objects is pulled out of a tunnel, and then objects are unloaded onto the floor from the transfer device. All such relevant operations are conducted remotely using both MSMs and a crane. ACPF has two entrance doors to have access to the in-cell from outside of the air cell: one at the left-hand side of the maintenance cell seen from the operating area and the other at the isolation room (rear-side of the process cell), shown in Figure 2. The door located at the isolation room is the PADIRAC® shielding one. As the cell is active, all processing materials of spent nuclear fuels are transferred into the cell through only the transfer cask of the PADIRAC shielded door.
An isolation room located at the service area of ACPF was refurbished to improve the soundness and safety of ACPF. The left wall and windows seen toward the PADIRAC door were designed and constructed. The thicknesses of the steel plate shielding wall and the lead glass pane shielding window for the shielding capability were determined based on the calculation results of a calculation code, QAD-CGGP. The calculated thicknesses, which meet the allowable dose rate of 0.1 mSv/h behind the shielding wall, were 5 cm and 6 cm for the wall and window, respectively. Such a 5-cm-thick steel wall and two 6-cm-thick lead glass pane windows were constructed for the left side of the isolation room. In addition, an old jib crane was replaced by a 1-ton overhead crane to increase the handling capacity and workspace at a higher position.

a) outside b) inside

Fig 5. A refurbished isolation room of ACPF

An operating area of ACPF is a place where human operators control and manipulate all of the in-cell equipment or devices and conduct a processing experimentation in a fully remote manner. The operating area was refurbished from the facility function viewpoint. Utility lines of electricity, argon gas, and pressurized air were redesigned and rearranged. Penetrations located below the front wall were also rearranged for supplying the utilities to the in-cell. A new UPS system was installed, and the overall control systems including wireless hand-held controllers were modified from the viewpoint of security and convenience.

4. Summary

KAERI has been refurbishing ACPF to demonstrate an electrolytic reduction process of pyroprocessing using spent PWR nuclear fuel. The major feature of the ACPF refurbishment is to newly construct an additional argon atmosphere cell inside of the air cell of ACPF. The relevant cell equipment, devices, tools and utilities necessary for the refurbished hot-cells are also being modified or newly fabricated from remote operation and maintenance viewpoints. The refurbishment of ACPF will be completed by the end of this year from the facility viewpoint. Blank tests and remote handling tests of the refurbished ACPF hot-cells including the argon cell will be completed by early next year. Processing equipment installation in the argon cell of ACPF and salts tests will be followed.

5. References

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