Development of Pyroprocess Integrated Inactive Demonstration Facility


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Abstract

PRIDE (PyRoprocess Integrated inactive DEMonstration facility) has been developed in Korea as a cold test facility to implement the pyroprocessing technology. The important role of PRIDE is to integrate the whole unit process in one continuous operation to achieve the engineering-scale viability of pyroprocessing. This can provide valuable information to solve the interface problems involved in entire processes.

PRIDE consists of a large scale argon atmospheric cell, cell equipment, and utility systems. This paper introduces the major features of the PRIDE facility, such as an argon supply system, cell operating equipment, and a safety related system. In PRIDE, the key technology will be tested and demonstrated using depleted uranium with surrogate materials.

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1. Introduction

In Korea, nuclear power generation reached 31.3% of the total electric power generation in 2010, and is continually increasing, owing to the continuing growth of industrial demand and the shortage of other power generation resources. The spent fuels stored in power reactors have become a very serious national problem, as the total accumulated amount has almost reached full capacity. Moreover, the site securing for the interim storage of spent fuel has failed due to the strong objections of the local community and anti-nuclear demonstrations. Since spent fuel contains a considerable amount of fissile materials and toxic elements, a new advanced spent fuel treatment process which can remarkably reduce the toxicity and reuse the spent fuel with nonproliferation resistance has become an essential and urgent issue. Pyroprocessing is considered as an effective spent fuel...
management method which has environmental friendliness, cost viability, and proliferation resistance. Therefore, a demonstration is essential to realize the integrated pyroprocessing technology.

PRIDE (PyRoprocess Integrated inactive DEmonstration facility) has been developed in Korea as a cold test facility to support integrated pyroprocessing technology and equipment. It is aimed at integrating the whole process into one continuous operation to achieve the engineering-scale viability of pyroprocessing above the unit process concepts. This paper introduces the major equipment of the PRIDE facility, such as an argon supply system, cell operating equipment and other safety-related system and equipment.

2. Overview of PRIDE Facility

PRIDE is a three-story building as shown in the bird’s eye views in Fig. 1(a) and Fig. 1(b). The design works started in 2007 and the construction was completed in April 2012. PRIDE consists of a large scale argon atmospheric cell with a normal operation pressure between 99 to 99.9 kPa, various cell equipment and HVAC (Heating, Ventilation, and Air conditioning Control) and control systems to maintain the argon atmospheric conditions. As shown in Fig. 2, PRIDE consists of a large argon cell, a process apparatus, handling tools, BDSM (Bridge transported Dual arm Servo-Manipulator), transfer lock systems, an argon system, etc. The cell equipment in PRIDE has a full remote operation and maintenance concept. The process equipment for voloxidation, electrolytic reduction, electro-refining, electro-winning, etc. will be installed by August 2012. The maximum throughput of PRIDE is 10tU/y and possesses the capabilities necessary to develop and test high-temperature (~ 650°C) molten salt technology with a stringent inert atmosphere control and remote operation features.

3. Argon System

When designing a pyroprocessing facility, the challenging issue is handling reactive metals and hygroscopic chemicals. Therefore, a pyroprocessing facility needs an inert atmosphere with oxygen control and moisture concentration at ppm levels to meet the general challenges. Because the argon cell is operated in a closed loop, heat generated while operating furnaces and other heat sources in argon cell must be removed by circulating an argon cooling system to maintain at a slightly lower pressure than the occupied areas.

The feed-through systems, windows, and other devices are designed to keep the sealing tightness for the inert atmosphere and to satisfy the leak rate requirements of a large cell. To minimize the air leakage through seals at the installed equipment, all equipment is designed with argon-pressurized double seals. In-cell equipment and components must control nuclear safety hazards under normal and accident conditions.
3.1. Argon Atmosphere Cell

The primary purpose of argon atmosphere cell is to provide an inert-atmosphere area in which the fuel can be exposed to the cell atmosphere during pyroprocessing operations. For environmental control of argon in a mock-up cell in PRIDE, the argon system was designed to control to less than 15 and 40 ppm each moisture and oxygen level of the argon environment in the cell. The inner dimension of the argon cell is 40.4m × 4.8m × 6.4m, and the volume is about 1,200m³. The argon system consists of an argon supply unit, argon gas cooling and circulation unit, argon gas purification unit, and an argon pressure release unit as shown in the P&I diagram in Fig. 3. The details of the capacity are presented as follows.

The argon supply unit consists of a liquid argon storage, a vaporizer, and a pressure control device. The capacity of the liquid argon storage and vaporizer were designed as 3m³ and 320m³/hr. These design values are based on the fact that it takes 4 hours for a onetime filling of argon gas in the argon cell. At the initial charging stage, the argon gas is charged until the concentration of impurities in the cell falls below 200ppm.
The argon cell design was based on maintaining 15ppm water vapor and 40ppm oxygen in the cell atmosphere. The argon gas purification unit has the function to control impurities in argon gas caused by air contamination under normal operation and consists of a purifier and a compressor. The argon gas purification unit was designed to operate under the condition of more than 200ppm for moisture and oxygen and could be reduced to 55ppm (15ppm water vapor and 40ppm oxygen) within 12 hours after operation. The capacity of a purification unit was determined to be 200m³/hr.

The pyroprocess is operated in a high-temperature molten salt bath, and the heat emitted by the process equipments should then be removed to control the temperature in the cell by a cooling device with a circulation of argon gas. The cooling load was estimated to be 80kW, which is derived from the heat load of the process equipment, lighting, and circulation blower power. The circulation flow of argon gas was designed to be 12,000 m³/hr considering one circulation for 3 hours. The argon gas pressure release unit functions to control the pressure in a cell, and protects the cell structure from excess overpressure and under pressure (99.7 and 100.7 kPa). The argon gas pressure release unit consists of ventilation fans, seal pots and relief valves.

3.2. Operation Equipments for Argon Atmosphere Cell

The location of the PRIDE cell operation equipment is shown in Fig. 2. The major cell operation equipment consists of a large and small transfer lock system, feed-through system, gravity tube, MSM (Master and Slave Manipulator), windows, in-cell crane, cell lighting and so on. By using this equipment, the cell can be operated in a manner that prevents the leakage of air into the argon cell or argon out of the cell.

The transfer lock system is used to provide the means for transferring materials between the inside and outside of the argon cell. The small transfer lock system is used for the frequent transfer of small and light items. This lock system can be operated relatively rapidly and has a relatively small volume (420mm × 640mm × 1,144mm). This results in small argon losses per transfer. The large transfer lock system is used for less frequent transfers of large items and for volumes of material quantities too large for the small transfer lock system. It can transfer with a dimension of 2.2m in diameter, 2.2m in height, and maximum weight of 2.8ton. The attached toggle clamp at the upper lid can prevent leakage and can be remotely replaceable. The conceptual design model of the large and small transfer lock system is shown in Fig. 4.
An in-cell crane was designed by applying a special pick-up brush concept for easy maintenance. Thus, if the crane driving unit breaks, the crane trolley can be remotely separated from the main driving motor and replaced. The crane unit is presented in Fig. 5. A 2.8 ton capacity, bridge-type overhead crane is provided for the argon cell. The in-cell crane was designed with a drive speed of 1.2 m/s and lift speed of 1.7 m/s.

A feed-through system was designed to supply electric power or cooling water with the process utilities and operation equipment, which are installed in the argon cell, without argon leakage. A gravity tube is equipment used to put small components and tools into the argon cell. The tube consists of a 2-ball valve and flanges to prevent argon leakage. Finally, 17 viewing windows will be installed on the side, rear and front sections of the argon cell. The windows should be designed to have a clear view. Viewing windows can be replaced remotely, and double sealing is applied to prevents inward leakage of air. Fig. 6 shows the feed-through, gravity tube, and windows.

4. Safety Assessment

A safety evaluation for a hypothetical accident was carried out to ensure that the release of radioactivity into the environment is negligible, and the performance of an indoor argon flow for the argon cell has investigated by means of a CFD analysis. The aims of this analysis are to evaluate the influence of the process apparatus layout and argon cooling system with varying argon flow rates. In a normal operation, all generated heat in the argon
cell should be removed effectively by circulating argon gas, and there are no abnormally higher temperature regions through an ambient argon cell room temperature.

All significant processes and operations in the PRIDE facility will take place in the process apparatus, which is located in confined areas made of stainless steel walls, and radioactive contaminants in the argon cell will be released through the second stage HEPA filters in abnormal operation conditions. Therefore, it is expected that the abnormal operation of PRIDE facility presents no harm to the public, workers, or the environment. However, in the case of an accident, large amount of radioactive materials can be released into the environment. Therefore, several hypothetical accident cases such as breaches in an argon cell confinement boundary or an eruption or fire during the process, are considered to estimate the radiological dose at the site boundary. The radiological environment effects during accident conditions are negligible (about 0.2% of dose rate limits), but the second stages of HEPA filter system is recommended to minimize the release of radioactive materials.

5. Conclusions

PRIDE was developed to demonstrate an engineering-scale high-temperature molten salt system, interface technology involved in the unit process, and advanced safeguards technology with fully remote operation concepts. The innovative feed through, windows, and other devices are also satisfied to maintain the inert atmosphere and to satisfy the leak rate requirements of a large-scale inert cell.

PRIDE will support a near-term mission to evaluate and produce reliable data for scale-up issues of the pyroprocessing. In PRIDE, key technology will be tested and demonstrated using depleted uranium with surrogate materials, and system engineering studies containing a design study for facility and equipment, remote operation and maintenance technology, advanced safeguards technology, radioactive material transportation and so on will be enhanced through the PRIDE operation. The test results in this facility can provide valuable information to solve the interface problems involved in the unit process, operability, and feasibility of the entire process. It can also provide the design guidelines of the systems and equipment needed to support the process.

References