DEVELOPMENT OF HOT CELL FACILITIES FOR DEMONSTRATION OF ACP

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ABSTRACT

The research and development of effective management technologies of the spent fuels discharged from power reactors are an important and essential task of KAERI. In resent several years KAERI has focused on a project named "development and demonstration of the Advanced spent fuel Conditioning Process (ACP) in a laboratory scale." The Facility for ACP demonstration consists of two Hot Cells and auxiliary facilities. It is now in the final design stage and will be constructed in 2004. After construction of the facility the ACP equipments will be installed in Hot Cells. The ACP will be demonstrated by some simulated spent fuels first and then by spent fuels.

INTRODUCTION

The major goal of the R&D projects for the management of the spent fuel is to enhance environmental friendliness, cost viability, proliferation resistance as well as to maximize use of natural resources. The worldly recognized approach to meet these criteria is the "Dirty Fuel and Clean Waste" concept. This concept is the innovative technology to generate electricity and to minimize the wastes for deep geologic disposal by combination of dry processing and subsequent transmutation of long-lived nuclides of transuranic elements into rather shorter ones. Development efforts are currently under way in the United States and Japan, prominent leaders in the field. Technology gained from the R&D project will be applied for conditioning the spent fuel for deep geological disposal, and for advancing key fundamental technologies for the next generation fuel cycle concepts.

The spent fuel, the essential by-product of the electricity by the nuclear power reactors, is a highly radioactive waste, if it is discarded. However, it could be a valuable asset if it is effectively recycled. Therefore, the development of methods for effective management of the large amount of the spent fuel is an important and essential task of KAERI when the technology is viewed from the economical view point, the effective recycling of the asset, and the environmentally friendly treatment of the spent fuel. KAERI focuses on the project 'Development of Advanced Spent Fuel Management Technology', that is, the development and demonstration of the advanced spent fuel management process in a laboratory scale (see Fig.1 and 2) [1]. This technology involves the process of the reduction of uranium oxide by a lithium metal in a high temperature molten salt bath. The successful implementation of this project will provide a promising solution for the effective management of spent fuel, and contribute to the establishment of a nuclear fuel cycle technology which is proliferation resistant and cost effective.

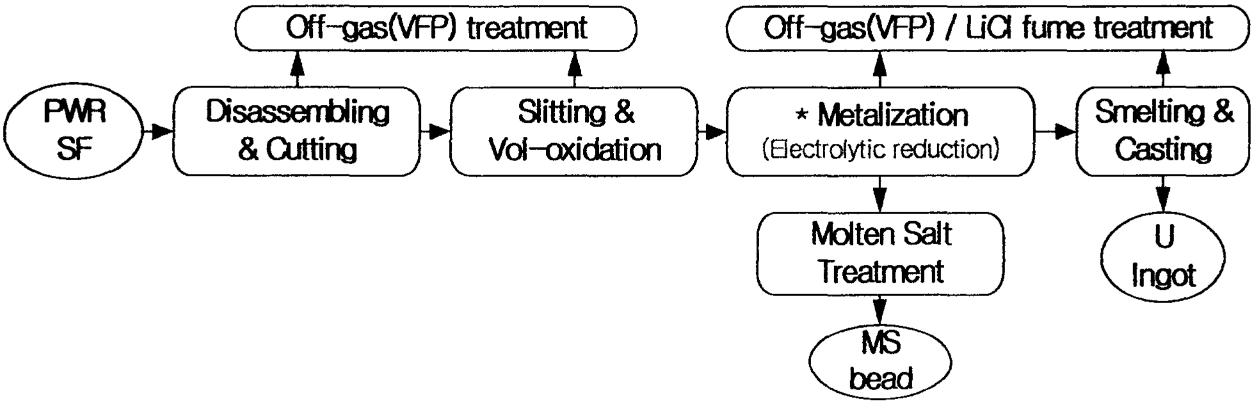


Fig. 1. Process Block Diagram for ACP.

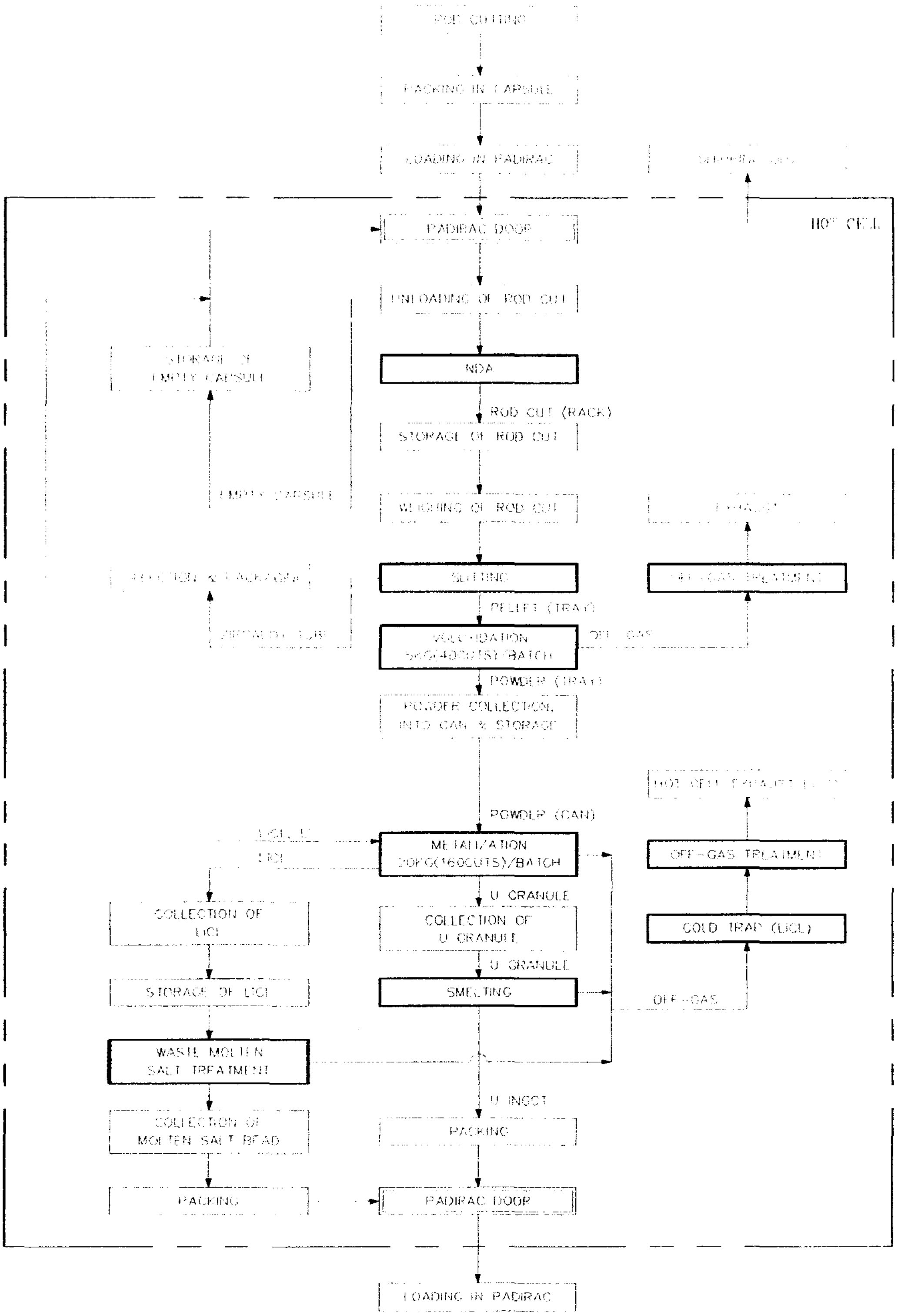


Fig. 2. Process Flow Diagram for ACP.

ACP HOT CELLS

For the demonstration of the ACP technology several Hot Cells in which spent fuel can be treated safely are needed, but KAERI does not have proper Hot Cells for ACP demonstration. Therefore, KAERI has decided to use the Future Hot Cell Line in IMEF(Irradiated Material Examination Facility) after some modifications. The ACP Hot Cells should have proper functions and facilities for the demonstration of the ACP. The inner dimension of this facility is 11 m length x 2 m depth x 4.55 m height.

2.1 Location

ACP Hot Cell Line will be located in the basement in IMEF by refurbishment of the Future Hot Cell Line (see Figure 3). IMEF is a hot cell facility for post irradiation examination on fuel and structural materials irradiated at a material test reactor named HANARO in KAERI.

Fig. 3. A photographic view of the Future Hot Cell Line in IMEF.

1.2 Design requirements

The maximum radioactivity retained in ACP hot cells and design basis of hot cell containment were decided as shown in Table 1 & 2.

Table 1. The Basis of Radioactivity Source Term.

Materials	Radioactivities (Ci)
1 Batch of Spent Fuel (20 kg-HM)*	9,930
4 batches of Uranium Ingots (80 kg-HM)	14,740
4 batches of H-3, Kr-85(fission gas) [having long half lifes]	560
2 batches of Waste molten salt	12,220
Total	37,450

- 3.5 % enrichment, 43,000 MWD/MTU burnup, 10 years cooling

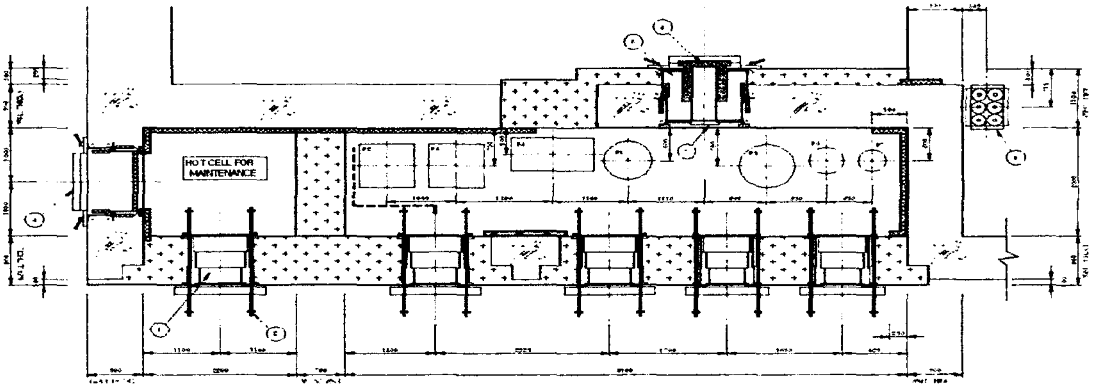
Table 2. The Design Basis of Hot Cell Containment.

Items	Contents
Type of Hot Cell	α-γ seal type with air environment
Shield Design	Operation area(7000 zone) : 0.01 mSv/hr Maintenance area(8000 zone) : 0.15 mSv/hr [Korean regulation guide : 1 mSv/week]
Shield Reinforcement	Opening parts on front wall : Heavy concrete 90 cm Heavy concrete 80 cm wall : Steel plate 4 cm
Leak Rate	4 vol. %/day at –30 mmAq
Differential Pressure	- 27 ~ -30 mmAq
Air Exchange Rate	15 ~ 20 times/hr
Manipulation Device	Seal type MSM (9~12 kg) Telescopic Manipulator (~ 15 kg) In-cell crane (~ 1 ton)
Shielding Windows	Double seal in connection parts with frame, cover glass, hot cell liner Cover on hot side and cold side

1.3 Layout

Figure 4 shows the floor plan of ACP Hot Cells. The ACP facility consists of two Hot Cells, one is for the process equipment and the other is for maintenance of process and handling equipments. These Hot Cell facilities, the same as other hot cells of IMEF, are designed to minimize radiation exposures and potential for contamination of personnel. In IMEF, four zones of control such as green, blue, amber, and red, are identified. Green zone is always clean areas and includes offices, meeting room, and clean side of change room. Blue zone is a usually clean area and includes the cold laboratories, corridors to the laboratories, and Hot Cell working areas. Amber zone, usually called the intervention area, is a rear area of Hot Cells and it is normally contamination-free zone. But it is recognized and accepted that contamination may be encountered. Red zone is normally a contaminated zone such as the interior of Hot Cells, hoods and glove boxes.

Fig. 4. Layout of ACP Hot Cells.



1.4 Radioactive Material Transfers

The radioactive material in PIEF (Post Irradiation Examination Facility) will be transferred to the ACP Hot Cells. During this transferring works the ACP hot cell design should permit movement of radioactive materials into and out of the facility without passing through normally clean areas in IMEF and without significant radiation exposure to the staff. The shielded casks (Padirac casks) in PIEF will be used for handling radioactive materials for ACP. Figure 5 shows the roots of the transferring cask from PIEF to ACP Hot Cells in IMEF.

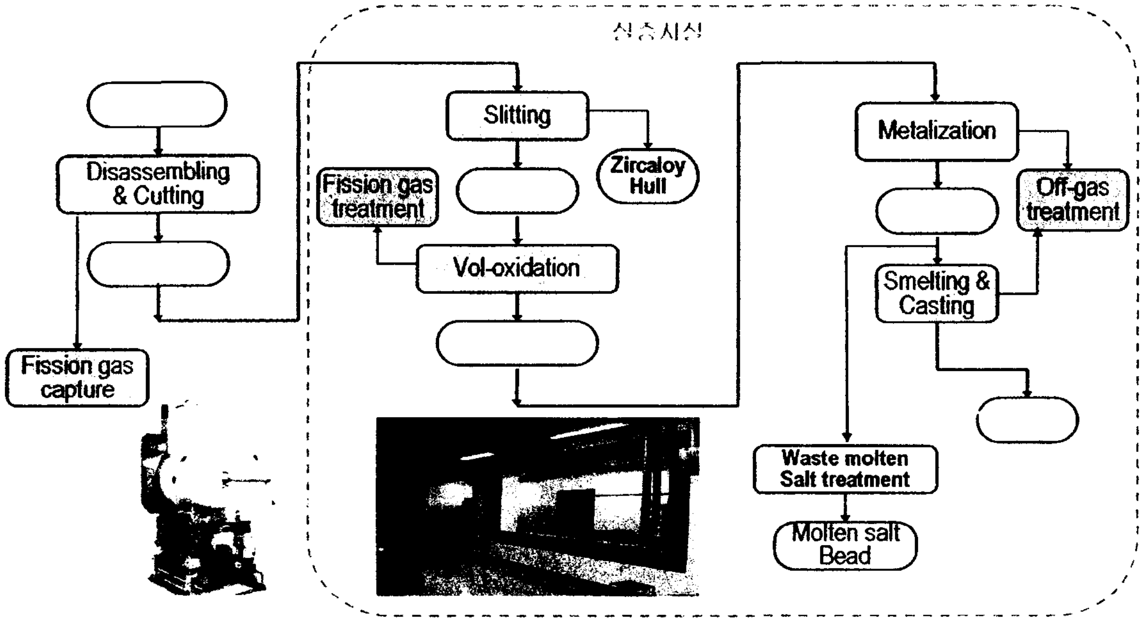


Fig. 5. Radioactive Materials Flow Diagram.

2.5 Safety Analyses

2.5.1 Process Safety

ACP chemical process treats high level radioactive materials and chemically toxic materials in hot cell. Process safety should be considered for the proper and safe operation of ACP. There are four kinds of hazards that may be associated with process safety for ACP [2].

1) Radiation risk produced by radioactive materials

2) Chemical risk produced by radioactive materials

3) Plant conditions which affect the safety of radioactive materials and thus present an increased radiation risk to worker. For example, these might produce a fire or an explosion, and thereby cause a release of radioactive materials or unsafe process condition.

4) Plant conditions which results in an occupational risk, but not affect the safety of radioactive materials. For example, there might be exposure from the chemically toxic materials and other hazards. Especially, the chemical explosion in hot cell could disperse radioactive materials, just as the radiation environment could make it more difficult to respond to hazardous chemical spill or leak.

The process safety requirements to prevent these hazards should be considered in the design of hot cell facilities. The process safety requirements established for safe operation of ACP are described in Table 3.

Table 3. Process Safety Requirements.

Classify	Contents
General Considerations	- Hazard evaluation and design against various failures - Design to prevent succeeding to severe failure by primary failure - Double monitoring and control of important process parameters - Pressure balance between process equipments and off-gas system
Considerations by Process Characteristics	- α-γ sealed type hot cells - Design to prevent leakage and flying away of U_3O_8 powder from process reactor - Design for removal of volatile fission products and LiCl fume in clean-up system - Design to prevent clogging of off-gas line (Pressure build-up : monitoring and control of pressure)

2.5.2 Radiation Shielding Safety

Working area in front of Hot Cell will be designed to help keep all radiation exposure as low as practicable. In the design step of the facilities, the source term of the material being handled should be carefully considered in the shielding design. For handling of spent fuel, shielding for neutrons, as well as for gamma rays, may be needed. Figure 6 shows the photon spectrum of ACP source term. Dry type lead glasses will be installed for viewing inside of ACP Hot Cells. Table 4 indicates the reinforcement methods for each wall of ACP Hot Cells for a conservative radiation shielding safety against ACP source term.

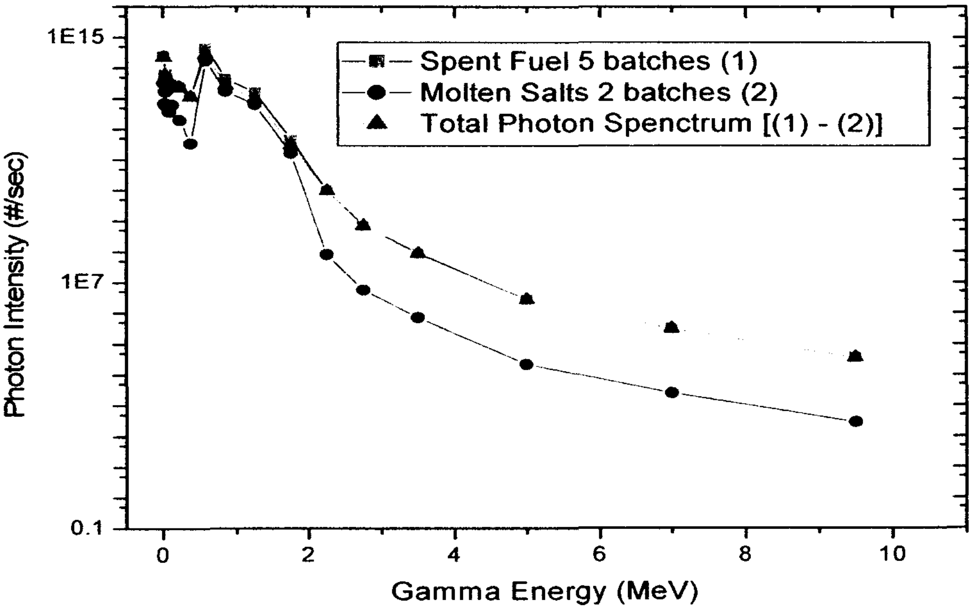


Fig. 6. Photon Spectrum of ACP Source Term.

Table 4. Reinforcement thicknesses of future hot cell line for satisfying the design criteria.

Location	Reinforcement Method
Front Wall	Heavy Concrete 90 cm
Rear Wall	Heavy Concrete 80 cm + steel 4 cm
Side Wall	Heavy Concrete 80 cm + steel 4 cm
Inter Cell Wall	Heavy Concrete 70 cm

2.5.3 Criticality Safety

The criticality safety by geometry is provided for designing process equipment, piping, and Hot Cell structures, etc. If the criticality safety can be maintained by limit of process handling mass and conservative calculations, the criticality design for ACP Hot Cells may not be considered. From the criticality analysis on ACP handling mass, it was found that the critical mass is about 50 kg in an accident condition. The ACP one batch size is 20 kg-HM. Even if double batches safety is considered, it is appeared the ACP process can satisfy the criticality safety.

2.5.4 Structural Safety

Seismic analysis for IMEF whole building block including ACP hot cells has been performed to verify the integrity of Hot Cell structure from a Design Basis Earthquake (DBE) and an Operating Basis Earthquake (OBE). Figure 7 shows the dx and dy displacements of ACP hot cells.

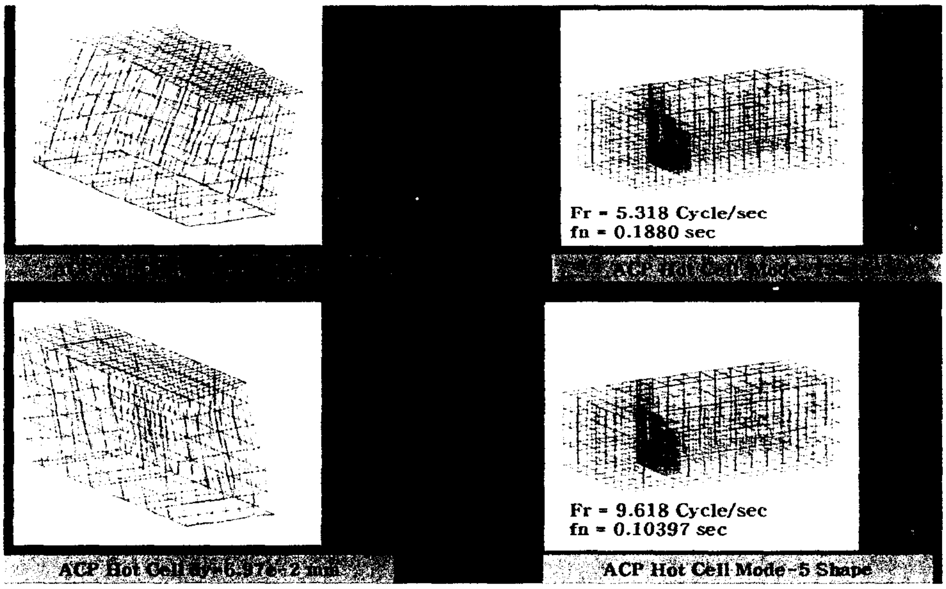


Fig. 7. Displacements of ACP Hot Cells from Seismic Analysis.

2.5.5 Environmental Safety

The ACP Hot Cells are an α-γ sealed type. The ventilation systems, which are a part of IMEF ventilation system, are designed to assure air flow from clean areas to more radioactive areas. A maximum pressure differential of -30 mmAq is maintained between Hot Cell inside and intervention area (Hot Cell rear area). Air changes at the rate of about 20 times/hr are recommended for Hot Cell inside. Figure 8 shows the filteration concepts of ACP and Table 5 shows the evaluation results of environment effects by the radioactive materials from ACP.

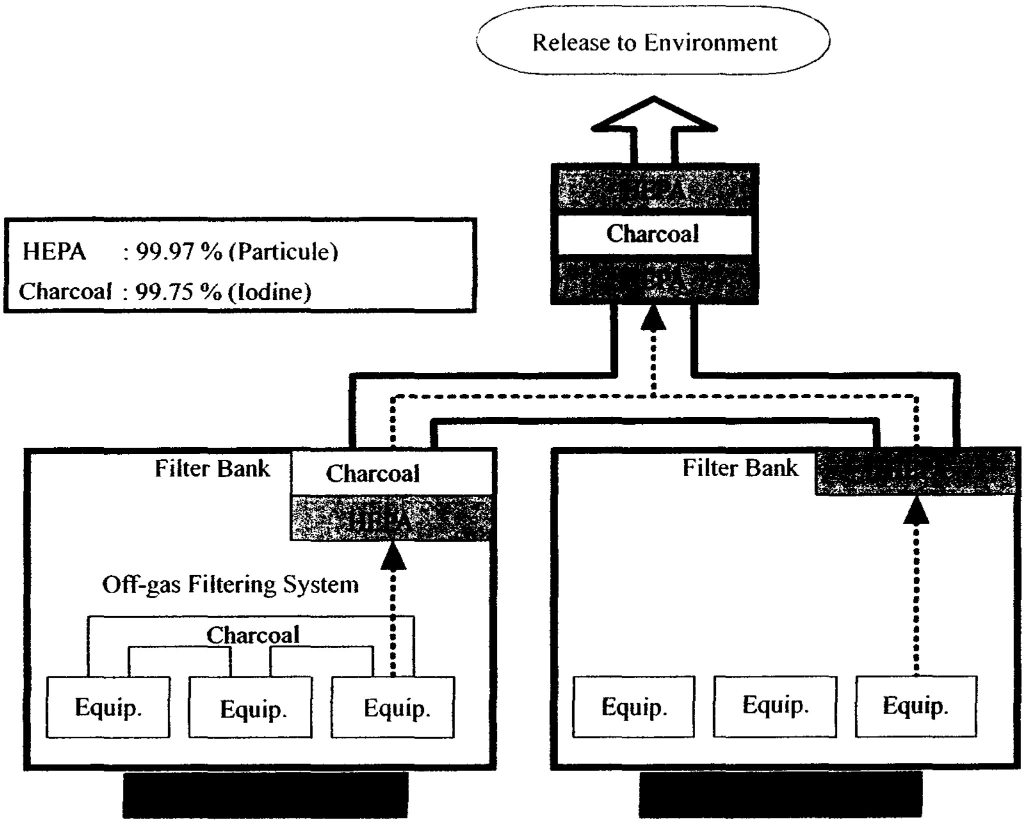


Fig.8.Off-gas Filteration System of ACP Hot. Cells

Table 5. Analysis Results of Environmental Effects by ACP.

[Under normal operation conditions]

Item	Regulation	Evaluation Result	%
Gamma Absorption in the Air (mGy)	1.0E-1	4.43E-4	0.44
Beta Absorption in the Air (mGy)	2.0E-1	5.02E-2	25.11
Effective Dose (mSv)	5.0E-2	5.35E-4	1.07
Skin Equivalent Dose (mSv)	1.5E-1	3.49E-2	23.23
Organ Equivalent Dose (mSv)	1.5E-1	6.44E-3	4.29 (Child, Thyroid)

[Under accident conditions]

Item		Radiation Dose (Sv)		
		Effective Dose (External)	Effective Dose (Internal)	Organ Equivalent Dose (Thyroid)
Regulation	10 CFR	0.25	0.25	3.0
	IMEF Facility Standard	2.5E-3	2.5E-3	3.0E-2
This study result		3.77E-5	4.76E-4	1.65E-3

2.6 Rad-waste Treatment

Rad-waste materials from ACP are two types; solid and gaseous ones. Used molten salt as a solid waste, will convert to beads inside Hot Cell for easy treatment. Gaseous effluents from all exhaust system in ACP will be cleaned by filtration and/or chemical scrubbing.

2.7 Radiation Monitoring System

Radiation monitoring system (Figure 9) will be installed in a working area in front of Hot Cells where abnormally high radiation dose rates could occur. These alarms from the monitoring system will provide prompt notices to the staffs if radiation conditions change substantially.

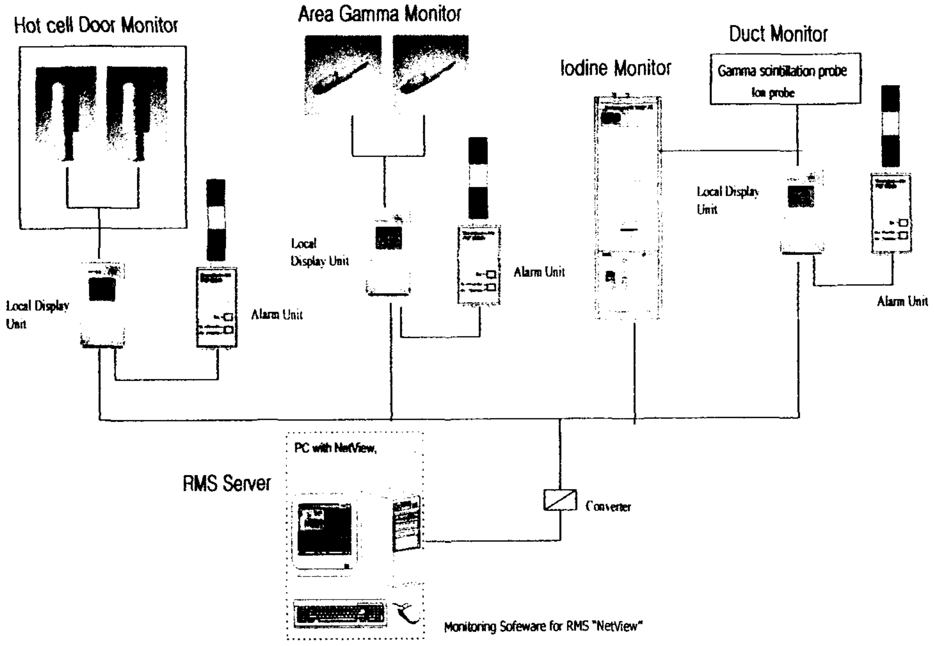


Fig. 9. Radiation Monitoring System for ACP Hot Cells.

3. SUMMARY

KAERI has been developing the advanced spent fuel conditioning process (ACP) which is the reduction process of uranium oxide by an electrolytic reduction method in a high temperature LiCl bath. The ACP Hot Cells for this process consist of one laboratory scale Cell Line and auxiliary facilities and are now under detail design stage. The Hot Cell Line consists of two air-sealed type Hot Cells and has a floor space of about 50 m^2. The equipment needed for the demonstration of ACP will be installed in Hot Cells after construction of the facility and the ACP will be tested by simulated spent fuel first and demonstrated by spent fuels finally.

REFERENCES

1. Y. J. Shin et. al, "Development of Advanced Spent Fuel Management Process," KAERI/RR-2128/2000 (2001).
2. NUREG-1601, "Chemical Process Safety at Fuel Cycle Facilities," (1997).