DUPIC FUEL FABRICATION IN SHIELDED FACILITIES IN KOREA

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ABSTRACT

The DUPIC(Direct use of spent PWR fuel in CANDU reactors) fuel cycle is to directly refabricate the CANDU fuel from spent PWR fuel materials by thermal and mechanical processes without wet reprocessing process. The concept was proposed and termed DUPIC in joint research program between the Korea Atomic Energy Research Institute(KAERI), Atomic Energy of Canada Limited (AECL) and the US Departments of State in 1992. The DUPIC fuel cycle has many advantages over direct disposal or wet reprocessing and MOX fuel cycle in terms of proliferation resistance, reduction of spent fuel accumulation and uranium resource utilization, etc.

Since the material in the DUPIC fuel fabrication process is highly radioactive due to no separation of uranium, plutonium and fission products, which is an intrinsic characteristic of the DUPIC process, all fabrication and characterization processes should be performed remotely in highly shielded hot cell facilities. KAERI has developed the remote fuel fabrication equipment and has successfully completed the installation of them in the shielded facilities, called DFDF(DUPIC Fuel Development Facility), at KAERI in early 2000. Based on the fuel fabrication technologies, including powder treatment, pelletizing and laser welding, KAERI has successfully fabricated DUPIC fuel pellets and elements with various design specifications to evaluate the performance of DUPIC fuel through irradiation tests at the HANARO research reactor. This paper describes KAERI's progress in DUPIC fuel fabrication.

I. INTRODUCTION

In 1992 Korea, Canada, and the US Departments of State cooperated on a study for the dry recycling of PWR fuel into CANDU reactors in Korea. Seven dry recycling options were examined. These options, involving only mechanical and/or thermal processes, can be referred to collectively as DUPIC fuel cycle options. Of these options, the OREOX (Oxidation and REduction of OXide fuel) option was chosen as the most promising method for the DUPIC fuel cycle, considering technical feasibility and safeguards, etc. Currently, based on this study, the experimental verification program is being implemented in tripartite cooperation. It will demonstrate OREOX technology on a laboratory scale, including remote fabrication of DUPIC fuel for irradiation testing and irradiation of DUPIC fuel elements in research reactors[1,2].

The DUPIC fuel fabrication processes can be divided into powder preparation, pelletizing, element and bundle fabrication. The decladed spent fuel material is treated by an OREOX process to obtain resinterable powder. Once the powder is prepared, the DUPIC fuel fabrication processes are similar to the conventional CANDU fuel fabrication except it should be performed remotely in shielded hot cell facilities[3]. The optimum conditions for the OREOX, pelletizing and end cap welding processes were established. About 25 equipment have been developed for the remote fabrication of DUPIC pellets and elements, and the hot cell facilities were refurbished for remote fuel fabrication. By utilizing the developed equipment and technology, several DUPIC fuel pellets and elements have been successfully fabricated since early 2000. The fabricated DUPIC fuel generally satisfied the current specification of CANDU fuel, and they were irradiated at the HANARO research reactor for performance evaluation.

2. DUPIC FUEL FABRICATION TECHNOLOGY

The DUPIC fuel fabrication processes can be divided into powder preparation, pelletizing, element and bundle fabrication. Powder preparation, which is considered as the most critical process for producing resinterable powder, is comprised of several processes such as disassembling of spent PWR fuel assemblies, decladding of spent PWR fuel rods, and OREOX processing of the decladded fuel material. Once the feed-stock material is prepared by the powder preparation processes, the pellet and element manufacturing processes are almost the same as the conventional powder/pellet route in CANDU fuel fabrication. The overall DUPIC fuel fabrication processes are shown in Figure 1.

2.1. OREOX Process

The OREOX process is composed of a repetition of oxidation and reduction steps to convert irradiated fuel pellets into a powder that is used to make DUPIC fuel pellets. During this process, UO_2 is oxidized to U_3O_8 and reduced back to UO_2, with about a 30 % volume change due to the phase transformation(from cubic to orthorhombic). This change in volume breaks the pellet up into a powder and produce microcracks to increase the specific surface area. The optimum conditions for oxidation and reduction are determined as 450℃ in air and 700℃ in an Ar-4%H_2 atmosphere, respectively. Figure 2 shows the powder produced by the OREOX process using spent PWR fuel. After the final stage of reduction, the powder is subjected to passivation treatment at 80℃ in an Ar-2%O_2 atmosphere for 4 hours.

In order to increase sinterability further, extensive powder milling, such as attrition milling is also utilized to make the powder finer and reactive. Once the resinterable powder is prepared, the rest of the fabrication process is very similar to the conventional powder-pellet route for the manufacturing of CANDU fuel.

2.2. Pelletization

The prepared powder is precompacted and granulated to improve the flowability of powders. The granules are mixed with zinc stearate for lubrication, and finally compacted to the specified green pellets. The green pellets are sintered at 1700℃ in an Ar-4%H_2 atmosphere for 4 hours. All sintered pellets are subjected to a final grinding operation to control the diameter and the surface finish. This is done by dry grinding method.

The effects of the compaction pressure and sintering temperature on the quality and the density of the sintered pellets were analyzed, and the optimum pelletizing conditions were established. The macrography of the sintered DUPIC pellets is shown in Figure 3.

2. 3. End Cap Welding

Although tungsten inert gas(TIG) welding method is widely used for welding an end cap in a hot cell, laser welding was chosen for the welding of DUPIC fuel element because of its ease in alignment of welding specimens and remote operation and maintenance. The laser generator and control modules are located outside the hot cell, and only the welding chamber is located inside the hot cell. The generated Nd:YAG laser of 500 watts is transmitted into hot cell through an optical fiber for welding the Zircaloy end caps and cladding tube.

The optimum conditions of laser welding were established. The welding quality, such as microstructure of the weld area and welding defects, was satisfactory. Figure 4 shows the DUPIC elements produced by laser welding method in the hot cell.

2.4. Characterization

Due to the high radioactivity of DUPIC fuel material, it is very difficult to have extensive characterization of the products in the process and have immediate feedback for process optimization. The dimensions and density of the pellets were measured by precision dimension measurement tools and an electronic balance. Also the immersion density of a pellet was measured and compared with the geometric density to get some ideas on the amount of open pores in the pellet. The chemical compositions and homogeneity of the powder were determined by a chemical analysis on a sampling basis. The microstructure of the pellets was observed by an optical microscope and the electron probe microanalysis system. The soundness of the end cap welding was checked by the helium leak test and observation of microstructures of the weld area. A micro-focus X-ray radiography system was developed for the precise inspection of the end cap weld area, but it was used just for the out-cell experiment for the qualification of the welding process parameters.

3. FABRICATION FACILITIES AND EQUIPMENT

Part of the existing hot cell facilities, that is, PIEF(Post Irradiation Examination Facility) and IMEF(Irradiated Material Examination Facility), were used for DUPIC fuel fabrication. The hot cell used for the main fabrication campaign of DUPIC fuel was the IMEF M6 hot cell, called DFDF(DUPIC Fuel Development Facility), which is a 2 m deep, 23 m long, 1.1 m concrete shielding wall with 10 working windows. However, as the hot cell facilities were built for the general purpose of post irradiation examination, some refurbishment such as modification of the rear door for the padirac system and supply of the electric power has to be performed.

About 25 equipment for the remote fabrication of DUPIC fuel element were developed and installed in the hot cell. As long as commercial equipment is available, it is purchased and modified for hot cell use from the viewpoint of easy remote operation and maintenance. The equipment was designed to be modular and remotely operable by the master-slave manipulator. The mechanical parts of the equipment were located inside the hot cell, while the electronic parts were separated to be installed outside the hot cell in order to avoid degradation of performance of the equipment due to radioactivity. The equipment layout of the DFDF is shown in Figure 5.

4. DUPIC FUEL FABRICATION

Following small-scale hot cell experiments at PIEF to characterize DUPIC powder/pellet using actual spent PWR fuel, a main DUPIC fuel fabrication campaign was started to fabricate the DUPIC fuel pellets and elements for the irradiation test at a research reactor. Up to now, a total of 5 kg of spent PWR fuel which has undergone a nominal burnup of 35,500 MWD/MTU and was discharged in 1986 was fabricated into DUPIC fuel pellets and elements.

On the basis of the process conditions developed by the DUPIC powder/pellet characterization study, DUPIC pellets and elements for the irradiation test were successfully fabricated remotely. The DUPIC fuel pellets have in general satisfactory characteristics in terms of dimensions, density, microstructure and homogeneity of composition. Also, the developed equipment have been operated well for remote operation and maintenance. However, there are some areas for further improvement, such as obtaining a higher pellet density and improving the surface roughness of pellets after dry centerless grinding, etc. The quality of laser welding of end caps was also satisfactory. The fabricated DUPIC elements were loaded in the HANARO research reactor for the first irradiation of DUPIC fuel in Korea in May 2000. They were discharged after a short term irradiation test of about 1,800 MWD/MTU with successful behavior, and the post irradiation examination for the performance evaluation is under way.

The second irradiation test of DUPIC fuel elements has been started at the HANARO research reactor from early June 2001, which will be taken for about 8 months with a target burnup of 7,000 MWD/MTU[4].

5. SUMMARY

The DUPIC fuel cycle has recently attracted a growing interest as an innovative concept in terms of a proliferation resistant fuel cycle for reusing spent PWR fuel in a CANDU reactor without wet reprocessing.

The DUPIC fuel fabrication campaign is progressing well on schedule. KAERI has successfully developed the remote fuel fabrication equipment and technology for the fabrication of prototypical DUPIC fuel. Based on this, several DUPIC fuel elements for irradiation tests at the HANARO research reactor have been fabricated and irradiated for the experimental verification of DUPIC fuel performance.

ACKNOWLEDGMENTS

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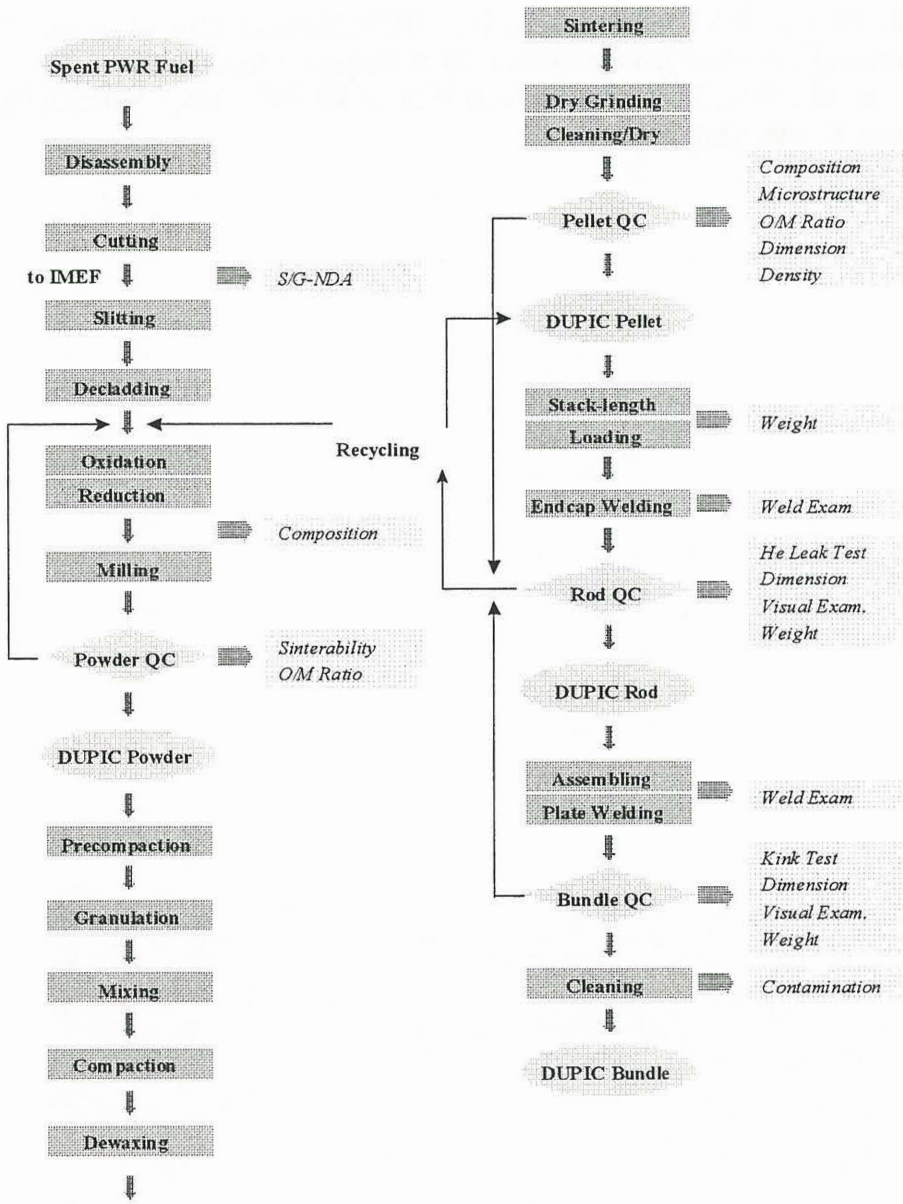


FIGURE 1: DUPIC FUEL FABRICATION FLOWSHEET

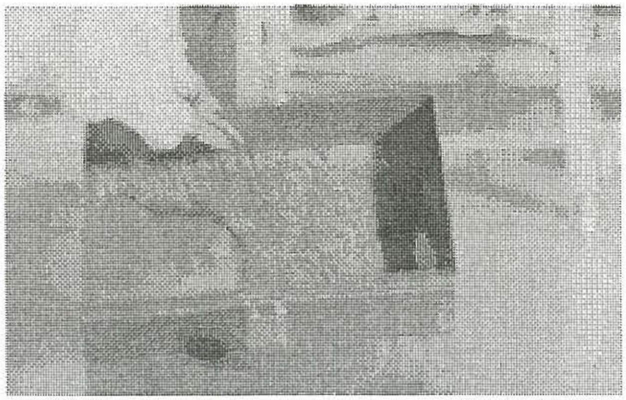


FIGURE 2 : POWDER PRODUCED BY OREOX PROCESS

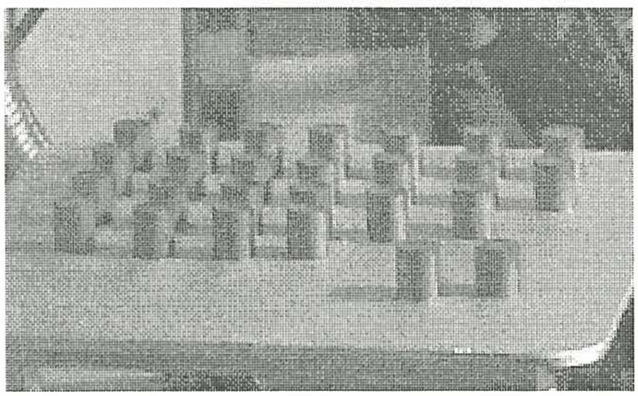


FIGURE 3 : SINTERED DUPIC PELLETS

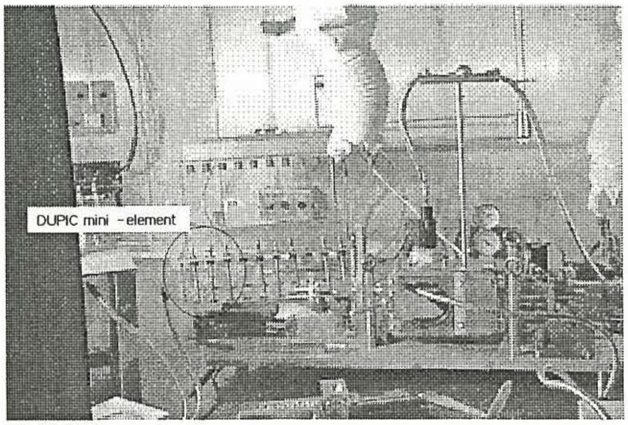
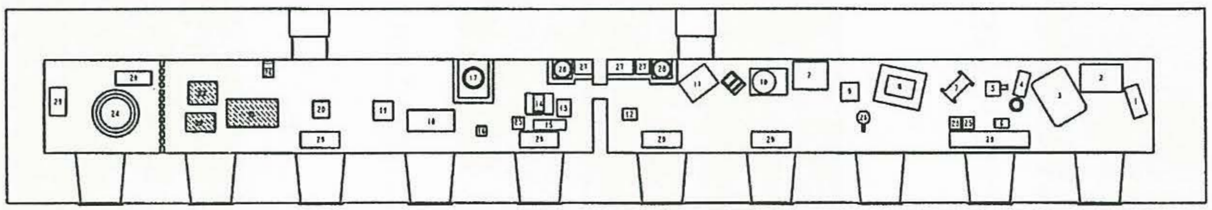


FIGURE 4 : DUPIC ELEMENTS WELD BY LASER WELDING

Layout of DUPIC Equipment at IMEF M6



1. Mill
2. Off gas Treatment System
3. OREOX Furnace
   (Oxidation & Dewaxing)
4. Mixer
5. Slitting Machine
6. Powder QC Equipment
7. Compaction Press
8. Centerless Grinder
9. Cutter
10. Sintering Furnace
11. Q.C - Furnace
12. Pellet Cleaner/Dryer
13. Pellet Loading Machine
14. Pellet QC Equipment
15. Pellet Stack Adjuster
16. Rod QC Equipment
17. S/G - DSNC
18. End Cap Welder
19. Helium Leak Tester
20. Mini - Element Assembly Machine
21. End Plate Welder
22. Bundle QC Equipment
23. Bundle Cleaner
24. Decon. Chamber
25. Balance
26. Vacuum Cleaner
27. Material Storage
28. Waste Storage
29. Ventilation Filter

: Equipment for Bundle Fabrication

FIGURE 5: EQUIPMENT LAYOUT OF DFDF