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Remote Fuel Fabrication Technology learned from DUPIC Program

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1. Introduction

The DUPIC (Direct Use of spent PWR fuel in CANDU Reactors) concept was first proposed in a joint research program among KAERI, AECL and US DOS in 1991 [1,2]. The DUPIC technology, as its name implies, is to directly refabricate CANDU fuel from spent PWR fuel without any separation of the fissile materials and fission products. Thus, the DUPIC fuel material always remains in a highly radioactive state, which provides good proliferation resistant characteristics and great challenges in remotely fabricating a fuel.

This paper describes the lessons learned from the development of the DUPIC fuel fabrication technology in shielded facilities.

2. Development of Remote Fabrication Technology for DUPIC Fuel

Although the overall process of fabricating a DUPIC fuel is almost the same as that of fabricating CANDU fuel using natural uranium, there are fundamental differences between them as follows:

- The DUPIC fuel material contains not only uranium but also all the actinides and fission products.
- The DUPIC fuel fabrication process should be remotely performed in a hot cell because of its high radioactivity.

In order to remotely fabricate a DUPIC fuel, it is required to use a shielded facility, so called, a hot cell, for the protection of a high radioactivity and to develop process equipment for a remote fabrication of fuel products. It is also required to establish and demonstrate a remote fabrication process for a verification of the remote fuel fabrication technology.

2.1 Shielded Facility

Part of the existing hot cell facilities, that is, PIEF (Post Irradiation Examination Facility) and IMEF (Irradiated Material Examination Facility) at KAERI, were used for a DUPIC fuel fabrication. The hot cell used for the main fabrication campaign of the 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. This M6 cell was divided into two parts. The M6a cell was used for the fuel powder and pellet fabrication and the M6b cell for the fuel element and bundle. However, at first, as the hot cell facilities were built for the general purpose of a post irradiation examination, some refurbishment such as a modification of the rear door for a padirac system and supply of electric power was performed [3].

About 25 pieces of equipment for the remote fabrication of the DUPIC fuel element were developed and installed in the hot cell as shown in Figure 1. As long as commercial equipment was available, it was purchased and modified for a hot cell use from the viewpoint of an easy remote operation and maintenance. The equipment was designed to be modular and remotely operable by using a 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 for a minimal degradation of the performance of the equipment due to radioactivity.

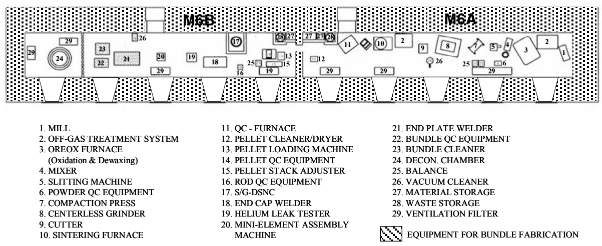

Figure 1. Layout of the remote process equipment for fabricating a DUPIC fuel element in DFDF

2.2 Remote Process Equipment

For the main fabrication campaign at DFDF, 25 pieces of equipment for the fabrication of DUPIC pellets and elements were developed and installed in a hot cell late 1999. From 1995 to 1996 the development of the design requirements and the conceptual design for the DUPIC fuel fabrication equipment were conducted in cooperation with AECL (Atomic Energy of Canada Limited) and ORNL (Oak Ridge National Laboratories) which have lots of experience in remote handling technology. Based on the results of the joint study, the detailed design and manufacture of the equipment were carried out according to the equipment development plan. And two off-gas treatment systems, one for the OREOX (Oxidation and REduction of OXide fuel) furnace and the other for the sintering furnace, were manufactured. The off-gas treatment system consists of several trapping units, heat exchanger and filter units. The piping and layout arrangements have been made by considering a remote accessibility. The developed equipment was tested all the function performances and moved to the mock-up cell to evaluate their remote operability. Considering the remote operation and maintenance in a hot cell, the operation procedures were set up and tested by using the manipulators in the mock-up cell. The troubles found during this test were fixed for an easy operation in a hot cell. After checking the remote operability, the equipment was installed in DFDF with the necessary auxiliary systems such as a cooling water line, a reaction gas piping line and maintenance tools, etc..

After completing the installation of the equipment in DFDF, a cold-test was carried out by using unirradiated natural UO_2 powders and process parameters established during the development experiments for the DUPIC fuel fabrication process. The cold-test run was successful, and showed that the installed equipment was acceptable [4]. Based on these results, the DUPIC fuel pellet and element fabrication experiment was fabricated using spent PWR fuel materials.

2.3 Remote Fabrication Process

For the development of DUPIC fuel fabrication technology, three experimental stages were taken according to the material types used in the experiments such as natural UO_2, SIMFUEL (Simulated Fuel) and spent fuel material [5].

As the first stage, natural UO_2 powder was used to investigate the unit process conditions for the DUPIC fuel fabrication. Especially, lots of experiments on the OREOX process were carried out to make ceramic grade powder suitable for a refabrication into sintered pellets. And the fabrication process flow for the DUPIC fuel was checked with the developed process flow. As a major result of this study, the milling process was very important for improving the powder properties and indispensable for making good quality pellets.

Based on these experimental results, the unit process and process flow developed for the DUPIC fuel fabrication were studied using SIMFUEL, which is unirradiated UO_2 blended with stable chemical additives to simulate the composition and microstructure of irradiated UO_2. A SIMFUEL fabrication process was established and the material properties of the fabricated SIMFUEL were studied. Then, DUPIC-SIMFUEL, which is the sintered pellet prepared by the DUPIC fuel fabrication process flow using the SIMFUEL pellet, was successfully fabricated. For the powder obtained from the OREOX treatment of SIMFUEL, the material properties were investigated. In addition, the effects of milling conditions on the powder and pellet properties were also investigated.

As the last stage to develop DUPIC fuel fabrication technology, an experiment was conducted at the PIEF #9405 hot cell with about 1 kg of spent PWR fuel to develop the optimum operating conditions for fabricating a DUPIC fuel pellet and to evaluate the DUPIC powder/pellet characteristics. Optimum operating conditions for the DUPIC fuel fabrication process were well developed and the results were used for establishing the process conditions for the main DUPIC fuel fabrication campaign in DFDF.

In parallel with the development of the DUPIC pellet fabrication technology, Nd:YAG laser welding technology was developed for the endcap welding of the DUPIC elements, and the operating conditions for a good quality weld were established.

For the verification of the process conditions developed and the performance of the equipment installed in DFDF, a cold-test was conducted using natural UO_2 powder from October 1999 to January 2000. Based on the results of the cold-test in DFDF, the detailed DUPIC fuel fabrication process flow was established.

3. Summary

The main DUPIC fuel fabrication campaign was started in DFDF using spent PWR fuel (G23 assembly discharged from Gori Unit #1 in 1986; burnup 35,502 MWd/tU) in 2000. The DUPIC fuel pellets and elements were successfully fabricated with satisfactory characteristics in terms of their dimensions, density, microstructure, homogeneity of the composition and weld quality. Also the developed equipment has been remotely operated successfully. Therefore, KAERI has successfully developed the remote fuel fabrication equipment and technology for the fabrication of DUPIC fuel. The DUPIC technology with the OREOX process offers a very high level of proliferation resistance and well meets the fuel concept pursued in the GEN-IV reactors, “Dirty Fuel and Clean Wastes”.

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REFERENCES

[1] P.G. Boczar, I.J. Hastings and A. Celli, Recycling in CANDU of Uranium and/or Plutonium from Spent LWR Fuel, AECL-10018, 1989

[2] J.S. Lee, K.C. Song, M.S. Yang, et al., Research and development program of KAERI for DUPIC (Direct Use of Spent PWR Fuel in CANDU Reactors), Proc. Int. Conf. and Technology Exhibition on Future Nuclear System, GLOBAL'93, Sept. 12-17, 1993, Seattle, USA

[3] K.H. Kim, J.J. Park, M.S. Yang, et al., Development of Equipment for fabricating DUPIC Fuel Powder, KAERI/TR-1328/99, 1999

[4] J.W. Lee, W.K. Kim, S.S. Kim, M.S. Yang and H.S. Park, DUPIC Fuel Fabrication in Shielded Facilities in Korea, Proceedings of the 7th CANDU Fuel Conference, Sep.23-27, 2001, Kingston, Canada

[5] J.H. Kim, K.H. Kang, B.G. Kim, Jae.W. Lee, J.W. Lee and M.S. Yang, Optimization of Powder/Pellet Fabrication for DUPIC Fuel, Proceedings of the 7th CANDU Fuel Conference, Sep.23-27, 2001, Kingston, Canada