AECL'S PROGRESS IN DUPIC FUEL DEVELOPMENT

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ABSTRACT

Previous papers described progress in choosing a fabrication route for the DUPIC (Direct Use of Spent PWR Fuel in CANDU®) fuel cycle [1], details of the OREOX (Oxidation Reduction of Oxide fuel) process, and preliminary results of out-cell and small-scale in-cell experiments [2]. AECL's project to develop the DUPIC fuel cycle has now progressed to the stage of fabricating DUPIC fuel elements for irradiation testing in a research reactor. Because of the high radiation fields around the spent PWR fuel, all work is being done in hot cells.

The equipment used for fabrication of the DUPIC fuel elements is described in this paper. The commissioning, in-cell installation and current status of the fabrication process are also described and plans for the completion of this phase of the DUPIC project are outlined. The goal of this phase of the project is demonstration of the technical feasibility of the DUPIC fuel cycle.

INTRODUCTION

Atomic Energy of Canada Limited (AECL), the Korea Atomic Energy Research Institute (KAERI) and the United States Departments of State and Energy (USDOS/USDOE) are involved in a joint program to develop a process for the Direct Use of spent PWR fuel in CANDU reactors (DUPIC). A phased approach has been followed in developing this process. Phase I was a paper study of seven different methods of reconfiguring spent pressurized-water reactor (PWR) fuel to make it compatible with CANDU reactors. The final recommendation from Phase I was to pursue the OREOX option [1], a process in which irradiated fuel pellets are broken up into a powder that is then fabricated into CANDU pellets, elements and bundles.

Phase II is the Experimental Verification of the feasibility of using the OREOX process to fabricate DUPIC fuel and irradiation testing of this fuel in a research reactor. In this phase, AECL is focusing on powder and pellet technology development, and KAERI is setting up for fabrication of both pellets and, eventually, full bundles.

The AECL program is comprised of three fabrication tasks:

- small-scale experiments on actual spent PWR fuel in the hot cells at the Chalk River Laboratories (CRL),
- larger-scale out-cell experiments using SIMFUEL[1] as a surrogate for PWR fuel, and
- fabrication of DUPIC fuel elements for irradiation testing in a research reactor. These irradiations will be used to assess the performance of DUPIC fuel under CANDU conditions.

BACKGROUND

Small-scale in-cell experiments at CRL have been completed. Pellets meeting CANDU specifications for density (as a percent of the theoretical density of the fuel - between 95 and 98%) were fabricated successfully [2]. Fission-product releases during the process were quantified, and technology for trapping volatile cesium was demonstrated.

In out-cell experiments using SIMFUEL, kilogram quantities of SIMFUEL pellets were processed into pellets meeting CANDU specifications, using the OREOX process. Some decladding techniques were also demonstrated.

The in-cell fabrication campaign in the Whiteshell Laboratories (WL) Shielded Facility (SF) hot cells is currently in progress.

DUPIC PROCESS

A flow chart of the DUPIC process is shown in Figure 1. The process is as follows:

- spent PWR fuel is removed from the cladding, and subjected to the OREOX process (described later) to reduce it to a powder.
- Powder conditioning, in the form of milling, is used to increase powder sinterability.
- Powders are then pressed into pellets, and sintered to a final density between 95% and 98% of the theoretical density of the fuel.
- After sintering, the pellets are centreless ground to final diameter and surface finish (using dry grinding only), formed into stacks and loaded into elements.
- Elements are sealed by tungsten inert gas (TIG) welding and finally assembled into bundles.

The OREOX process uses the oxidation, reduction and reoxidation of UO_2 to convert irradiated fuel pellets into a powder that can be used to reconstitute fuel pellets. Under reducing conditions, UO_2 is the stable form; under oxidizing conditions, U_3O_8 is the stable phase. In transforming from UO_2 to U_3O_8, the matrix undergoes a phase transformation (from cubic to orthorhombic) with an associated change in density and, as a result, a change in volume (by 32%). This change in volume causes the matrix to

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[1] SIMFUEL is UO_2 fuel pellets fabricated from fresh UO_2 with stable chemicals added to simulate fission products. The presence of fission product elements affects the processing characteristics of the fuel.

develop microcracks, and successive oxidation and reduction eventually breaks the pellet up into a powder. It has been determined that the optimum number of oxidation and reduction cycles is three.

A typical temperature vs. time trace for an OREOX schedule is shown in Figure 2. In this case, it shows oxidation at 500°C and reduction at 700°C. Between oxidizing and reducing atmospheres, the furnace is purged with inert gas. It typically takes 60 h to complete a run. In the WL campaign, one OREOX run (with approximately 1 kg of spent PWR fuel) was completed in 3 d.

The photographs in Figure 3 show the dramatic change that takes place during the OREOX process. The top photograph is a crucible containing fresh SIMFUEL pellets. The bottom photograph shows the same crucible after the OREOX process. The volume of the fuel has increased by a factor of 5- to 10-fold.

An electron micrograph of the powder produced by the OREOX process using spent PWR fuel is shown in Figure 4. The solid white line is 10 μm long, so the powder is clearly quite fine, although not fine enough for pelletizing and sintering. This powder must be milled before it can be reconstituted into CANDU-quality fuel pellets.

FABRICATION CAMPAIGN

The campaign schedule is to complete the fabrication of DUPIC pellets and elements by 1997 September. A total of 4 kg of spent PWR fuel is available for the campaign. This fuel has undergone a nominal burnup of 28 MW·d/kg U, comparable to the reference PWR fuel for the DUPIC program, 35 MW·d/kg U.

FABRICATION EQUIPMENT

The OREOX furnace is a box furnace with a stainless steel retort, shown in Figure 5. The operating temperatures of the furnace and retort are 500°C under oxidizing conditions and 700°C under reducing conditions. Inconel trays are used to hold the pellets and powder in the retort during the OREOX process.

A hydraulic press is used to prepress and final press the powders (Figure 6). Although a hydraulic press is slower to operate than a mechanical press, it is simpler to operate and easier to control in-cell for small batch operations. Considerable experience was gained using a hydraulic press to make pellets in a hot cell during the small-scale hot cell experiments at CRL.

Sintering is done in a tube furnace, shown in Figure 7. The furnace has a horizontal alumina tube mounted in a box furnace, heated using molybdenum disilicide elements. The furnace is capable of reaching 1700°C. The sintering atmosphere is 4% hydrogen in argon.

Special fittings were designed and built to isolate the interior of the tube from the cell atmosphere yet allow easy access for loading and unloading using remote manipulators.

All fuel pellets must be subjected to a final grinding operation to ensure both a tight tolerance on the final outside diameter and the required surface finish. This is done using a centreless grinder, shown in Figure 8. A close-up view of the grinder is shown in Figure 9. Although all CANDU pellets are centreless ground, this is usually done using wet grinding. Wet processes are not allowed in DUPIC, so the grinder must be run dry. This requires that the grinder be outfitted with specially prepared grinding wheels. The grinder is rather large, and space limitations dictate that it will not be loaded into a hot cell until it is needed.

Once the pellets are ground, they are formed into stacks of the correct length and loaded into Zircaloy sheaths. The element is sealed by welding an end cap onto the loaded sheath. This is done by tungsten inert gas (TIG) welding. The TIG welder is shown in Figure 10. Figure 11, a close-up view of the TIG welder, shows an element sheath loaded in the welder chamber with an end cap in place. The tungsten electrode is also visible in this photograph.

TIG welding is a standard method used for welding in a hot cell, and AECL has considerable experience in making this type of weld and in its irradiation performance. The element is loaded in the horizontal chamber with the tube end and end cap projecting out the end. A bell jar is closed over the end, the apparatus is evacuated and back-filled with helium. An electric arc is struck, and a weld formed as the element is rotated under the electrode.

STATUS

The WL fabrication campaign is progressing very well. Equipment required for this stage of the campaign is now in cell. The PWR fuel has been removed from the sheaths. OREOX runs have been completed, the powder has been milled and is being fabricated into pellets.

SUMMARY

Both in-cell and out-cell experiments in Phase II of this project have been completed. The fabrication campaign is progressing on schedule and is expected to be completed in the fall of 1997. Irradiation of the DUPIC elements is scheduled to start in early 1998.

ACKNOWLEDGMENTS

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REFERENCES

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2. SULLIVAN, J.D., COX, D.S., "AECL's Progress in Developing the DUPIC Fuel Fabrication Process," Proceedings of the Fourth International Conference on CANDU Fuel, 1995 October 1-4, Pembroke, Canada.

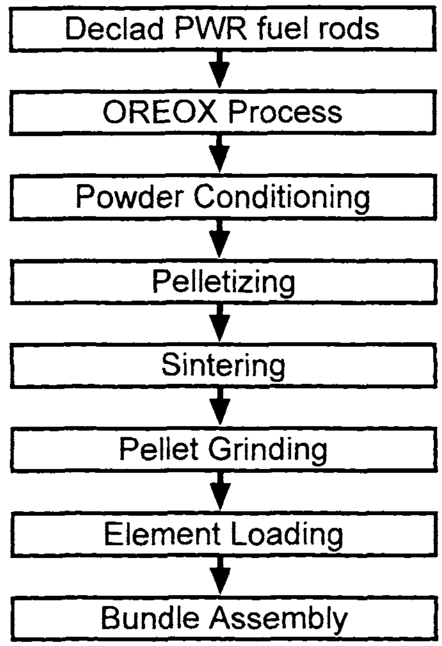

FIGURE 1: FLOW CHART OF THE DUPIC PROCESS

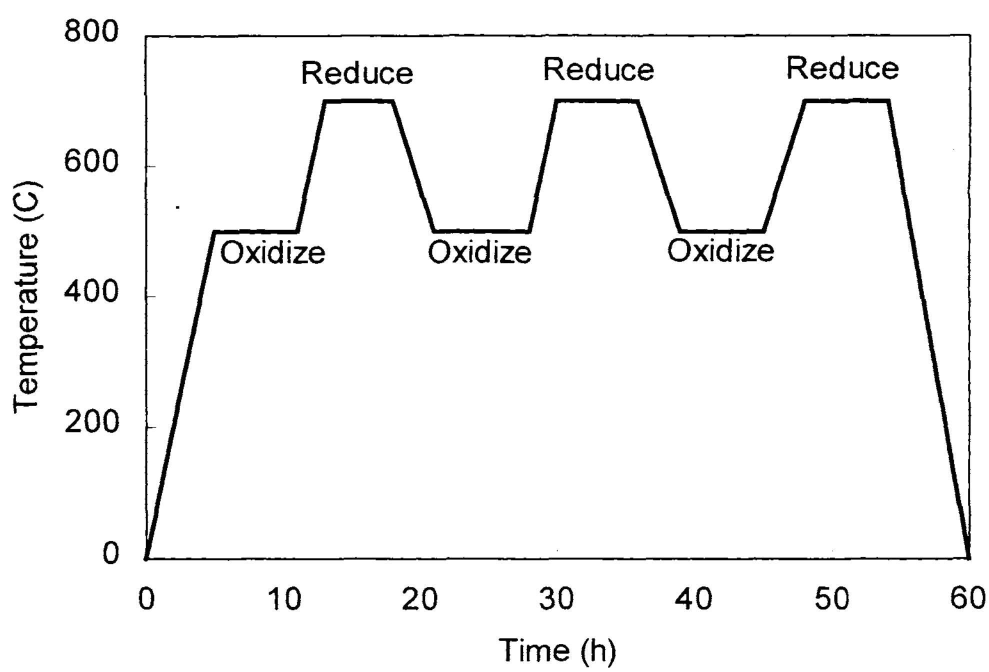

FIGURE 2: TYPICAL OREOX SCHEDULE

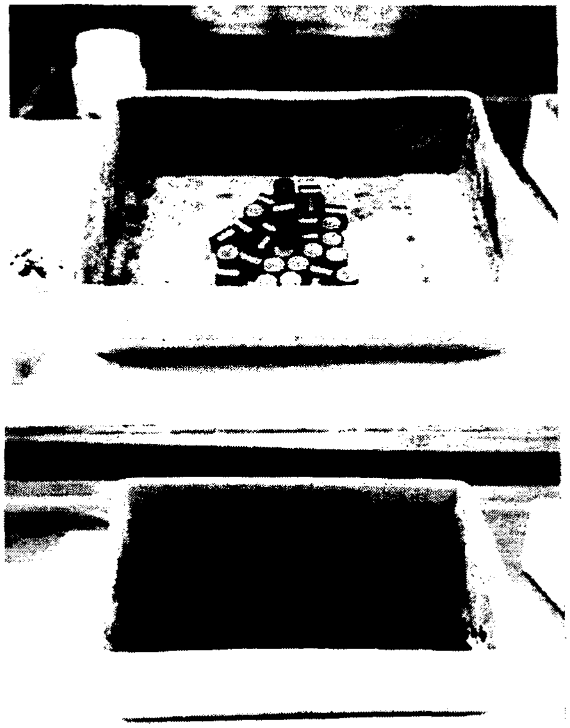

FIGURE 3: PHOTOGRAPHS OF A TRAY OF SIMFUEL PELLETS BEFORE AND AFTER THE OREOX PROCESS.

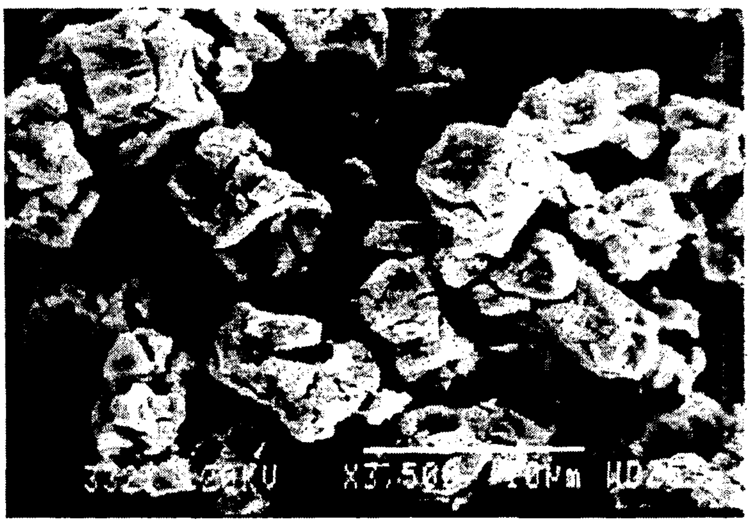

FIGURE 4: ELECTRON MICROGRAPH OF A POWDER PRODUCED FROM SPENT PWR FUEL USING THE OREOX PROCESS.

FIGURE 5: OREOX FURNACE

FIGURE 6: PELLET PRESS

FIGURE 7: SINTERING FURNACE

FIGURE 8: CENTRELESS GRINDER

FIGURE 9: CLOSE-UP VIEW OF CENTRELESS GRINDER SHOWING PELLET BETWEEN GRINDING WHEEL AND (SMALLER) REGULATING WHEEL

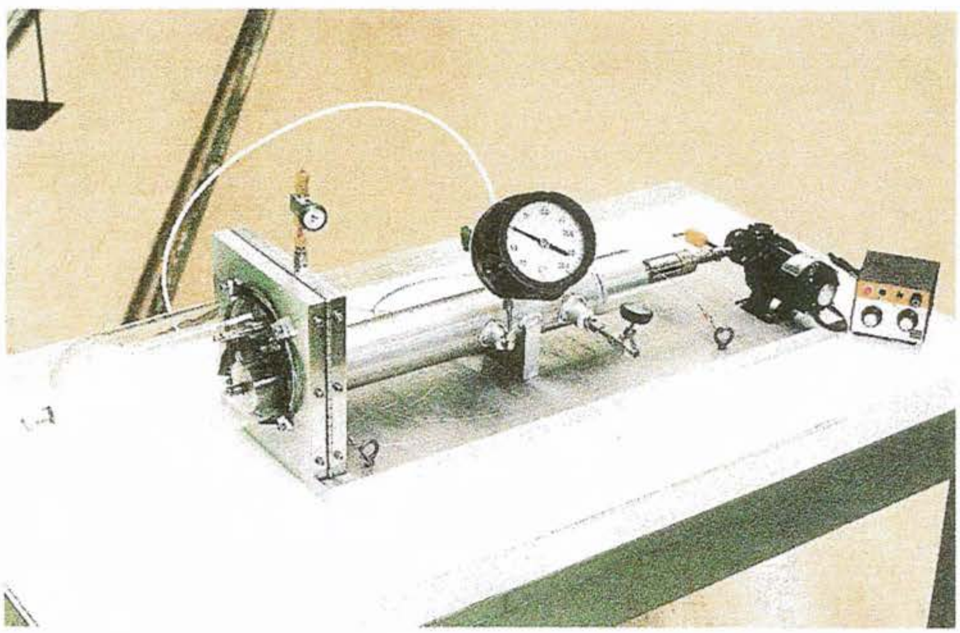

FIGURE 10: TIG WELDER

FIGURE 11: CLOSE-UP VIEW OF TIG WELDER SHOWING ELEMENT WITH END CAP IN PLACE AND TUNGSTEN ELECTRODE