MOX FUEL FABRICATION AT AECL

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ABSTRACT

Atomic Energy of Canada Limited's mixed-oxide (MOX) fuel fabrication activities are conducted in the Recycle Fuel Fabrication Laboratories (RFFL) at the Chalk River Laboratories. The RFFL facility is designed to produce experimental quantities of CANDU® MOX fuel for reactor physics tests or demonstration irradiations. From 1979 to 1987, several MOX fuel fabrication campaigns were run in the RFFL, producing various quantities of fuel with different compositions. About 150 bundles, containing over three tonnes of MOX, were fabricated in the RFFL before operations in the facility were suspended. In late 1987, the RFFL was placed in a state of active standby, a condition where no fuel fabrication activities are conducted, but the monitoring and ventilation systems in the facility are maintained.

Currently, a project to rehabilitate the RFFL and resume MOX fuel fabrication is nearing completion. This project is funded by the CANDU Owners' Group (COG). The initial fabrication campaign will consist of the production of thirty-eight 37-element $(U,Pu)O_2$ bundles containing 0.3 wt% Pu in Heavy Element (H.E.) destined for physics tests in the zero-power ZED-2 reactor.

An overview of the Rehabilitation Project will be given.

INTRODUCTION

AECL's MOX fuel program was started more than thirty years ago. The program consisted of two components:

- irradiation testing and post-irradiation examination (PIE) of various types of MOX fuel, and,
- development of MOX fuel fabrication technology.

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Irradiation testing and PIE of MOX fuel is still continuing at AECL; it has gone from early multi-element tests to recent multi-bundle demonstration testing. This paper discusses the second component of AECL's MOX fuel program, i.e., MOX fuel fabrication.

HISTORY OF THE RFFL

Start-Up

Various forms of fuel containing plutonium have been handled by AECL at its Chalk River Laboratories (CRL) since 1960. Research activities were conducted in glove boxes between 1960 and 1970, including the development of MOX fuel fabrication technology, measurement of physical properties, production of fuel samples for experimental irradiation, etc. In 1970, a decision was made to re-model the plutonium laboratory and install new facilities, to focus on MOX fuel fabrication technology. Installation of the new facilities was complete by 1975 [1]. The facility, collectively referred to as the Recycle Fuel Fabrication Laboratories (RFFL), is designed to produce experimental quantities of alpha-active fuel such as MOX for reactor physics tests or demonstration irradiations.

The Fabrication Process in the RFFL

Subject to special precautions because of the presence of Pu (e.g., essentially all operations are done inside glove boxes), the processes employed in the RFFL follow conventional natural UO_2 practice. The fabrication line was designed for the production of sealed individual fuel elements, starting from UO_2 or ThO_2 powders as the major component and PuO_2 or $^{233}UO_2$ as the minor component.

The fabrication process adopted in the RFFL is outlined in Fig. 1. Weighed amounts of the starting oxide powders are mixed either in single-stage or double-stage blending, the latter being used for more dilute mixtures to achieve better homogeneity. After blending, the MOX powder is pre-pressed using an isostatic press, to convert the mixed powder into compacts, which are, in turn, fed into a granulator. The resulting free-flowing granules are then suitable for final pressing into green pellets using a single-cavity hydraulic press.

The green pellets are loaded into a batch furnace, where sintering is done in a dilute hydrogen cover gas. Sintered pellets are then centreless ground to a specified diameter and surface finish. The pellets are washed and then dried in warm air. Acceptable pellets are loaded into empty sheaths that already have one end cap welded and all appendages brazed in place (these sub-assemblies are supplied by commercial fabricators). The second end cap is welded to the loaded sheath using a tungsten inert gas (TIG) welding system. The sealed elements are then helium leak-tested, scanned for surface alpha contamination, and, if required, assayed by neutron interrogation. Following assay, the elements are ready for bundle assembly.

Previous Fabrication Campaigns

From 1979 to 1987, several MOX fuel fabrication campaigns were run in the RFFL, producing various quantities of fuel with different compositions [1]. As listed in Table 1, the first campaign consisted of producing fifteen $(U,Pu)O_2$ fuel bundles containing 0.5 wt % Pu in H.E. Later, about 1.3 tonnes of $(Th,Pu)O_2$ fuel (over 1630 elements) were produced, with a range of compositions from 1.8 wt % to 2.3 wt % Pu in H.E. The last campaign was particularly challenging, since it involved the fabrication of 1350 elements containing 1.4 wt % ^{233}U in H.E. The challenge is due to the presence of ^{232}U, which has a gamma-active daughter [2].

The fuel elements and bundles produced in the RFFL were used for test irradiations in NRU and for physics tests in the zero-power ZED-2 reactor. About 150 bundles, containing over three tonnes of MOX, were fabricated in the RFFL before operations in the facility were suspended. In late 1987, the RFFL was placed in a state of active standby, a condition where no fuel fabrication activities are conducted, but the monitoring and ventilation systems in the facility are maintained.

RFFL REHABILITATION PROJECT

Currently, a project to rehabilitate the RFFL and resume MOX fuel fabrication is nearing completion. This project is funded by the CANDU Owners' Group (COG) through Working Party 25. The initial fabrication campaign will consist of the production of thirty-eight 37-element $(U,Pu)O_2$ bundles containing 0.3 wt % Pu in H.E., destined for physics tests in the research reactor ZED-2 at CRL.

The scope of the project was defined by an initial feasibility study, complemented by two in-depth assessments:

1. A series of Fitness-for-Service studies, focusing on the facility's structure, services and process equipment, taking current standards and regulations into account, and
2. A Hazards and Operability (HAZOP) analysis, focusing on the safety aspects of operating the rehabilitated facility.

These assessments generated numerous recommendations for specific action. Major "hardware" actions included bracing the building to meet the most current (1990) National Building Code of Canada seismic standards, replacement of the Radiation Protection (RP) systems, addition of an alpha-in-air sampling system between the primary and secondary High-Efficiency Particulate Air (HEPA) filters in the exhaust train, and extension of the alarm display system.

The rehabilitation project also included a considerable "software" component, including extensive new and revised documentation, and staffing and training activities to re-staff the facility.

All activities were and continue to be done with extensive liaison with AECL's internal safety body (the Safety Review Committee, SRC) and with the Atomic Energy Control Board (AECB).

WHAT'S NEW IN THE RFFL

Process Equipment

The Fitness-for-Service review indicated that several items of process equipment should be replaced, including those for metallographic preparation and examination, and chemical analysis. New components were also brought in to update the capabilities of the facility. A new PuO_2 reception glove box was installed housing the can opener, which will be used to de-can welded PuO_2 containers both for the production line and for purposes of sampling and re-packaging. A master-mix high-intensity blender was acquired to enable a double-stage blending operation for dilute concentrations of MOX fuel. In addition to an exhaustive overhaul of all process equipment, new components, such as die sets for the press, controllers for the sintering furnaces, and a helium leak detector for weld inspection, were procured to update the fuel fabrication line.

Radiation Protection

Radiation protection in the RFFL follows current AECL standards and practices and is based on the following principles:

- Division of the facility into zones of progressively greater contamination hazard with personnel monitoring at each boundary on exit,
- Division of the staff into groups of progressively increasing qualifications, training and responsibility,
- Operation of a system of alpha CAMs (continuous air monitors), distributed through the facility and set to alarm at a pre-set level of airborne alpha activity,
- Operation with Personal Air Samplers (PAS) for all staff doing glovebox work in the facility. The PAS filters are analyzed daily as a routine, and as required, e.g., if an alpha CAM alarms.

The alpha CAMs that had been used in the facility during previous operation had their components replaced with state-of-the-art commercial units. This replacement afforded the opportunity to optimize the pattern of the sampling heads to optimize system resources and performance, particularly so far as response time to activity release is concerned. To this end, a quantitative air-flow study was conducted, using inactive tracer gas (SF_6), in the main fabrication room to determine

- the rate of dispersion of a release throughout the room, and
- the rate of decay of concentration at any given point.

Operations Quality Assurance

The RFFL is a licensed nuclear facility that comes under the AECL Nuclear Operations Quality Management Program. The program is based on the management principles and practices embodied in the CSA/CAN3-N286 series of standards. The development of the RFFL-specific Conduct of Operations Manual is in compliance with the requirements of the program.

The Conduct of Operations Manual complements the AECL Nuclear Operations Quality Manual, and, together with the operating procedures, essentially comprises the QA documents that describe the system for assuring the quality of operations in the RFFL. The Manual describes the RFFL organization, responsibilities, processes and controls that demonstrate application of the principles and practices specified in the standard, CAN/CSA-N286.5-M87 Operations Quality Assurance for Nuclear Power Plants. It also describes how MOX fuel bundles are fabricated to the requirements of the CAN/CSA Z299.2 QA program standard. Thus the manual contains the full range of measures implemented to ensure both operational safety and product quality.

The Conduct of Operations Manual governs all activities and functions affecting the quality of operations in the RFFL. Quality, in this context, means the safe, reliable and effective performance of personnel and equipment associated with the fabrication of MOX fuels according to customer's specifications. This Manual applies to the operation and maintenance of fuel fabrication process equipment and all nuclear safety-related systems and components in the facility.

Nuclear Materials Accountability

Previous MOX fuel fabrication operations in the facility had been supported by a computer system known as INMACS (Integrated Nuclear Material Accountability and Control System), which combined the functions of both

1. Criticality avoidance (control of movement of materials to ensure that criticality limits are not exceeded), and
2. Inventory control (tracking and reporting of nuclear material inventories).

The INMACS hardware and software were obsolete at the time that the RFFL was put into active standby. As part of the Rehabilitation Project, a new system has been developed to meet all International Atomic Energy Agency (IAEA), AECB and AECL requirements for inventory control, and support Operations' responsibility for criticality avoidance. This system, RFFL Nuclear Materials Accountability System (RNMAS), has been developed in Microsoft Access® V2.0 in accordance with the software QA provisions of CAN/CSA-N286.7, running on a dedicated Pentium-based PC with dedicated data backup. The system uses graphical point-and-click operations, and predefined pick-lists to optimize user-friendliness (not a feature of INMACS). The system was designed and developed to conform to AECL policies, procedures and form standards. It is now being considered as a model for real-time site-wide nuclear materials accounting, including the possibility of central inquiry by means of encrypted data transmission, e.g., for monitoring for compliance with the Non-Proliferation Treaty.

Staffing and Training

The RFFL is a development laboratory rather than a full-scale production facility. As such, it has, in the past, been staffed by technicians with appropriate qualifications and experience. However, these staff are not now with AECL, and new technical staff have been recruited, evaluated and trained for the facility. This process followed a comprehensive training plan, which was developed in accordance with AECB-approved Company policies and practices.

The training plan included the following elements:

1. Extensive job/task analysis to determine knowledge and skills required.
2. Personal needs analyses for the job candidates to determine their training requirements relative to the knowledge/skills required.
3. Development of facility-specific training materials to complement existing generic courses.
4. Delivery of the training courses which included:
    - Nuclear Operations Training School (NOTS) for science fundamentals, equipment principles, and AECL generic policies and procedures,
    - Radiation Protection Training for Group 3, Group 2 and Group 1 training requirements,
    - Facility Specific Classroom Training for job-specific knowledge, and
    - On-Job Training to develop and evaluate operational skills.
5. Records are kept of the above actions so that the process can be verified and/or audited, e.g., by the AECB.

The end result of this structured training process is Company and AECB confidence that the RFFL staff have the capability to operate the facility efficiently and safely.

SUMMARY

AECL's MOX fuel fabrication activities are conducted in the RFFL at the Chalk River Laboratories. The RFFL facility is designed to produce experimental quantities of alpha-active (e.g., MOX) fuel for reactor physics tests or demonstration irradiations. From 1979 to 1987, several MOX fuel fabrication campaigns were run in the RFFL, producing various quantities of fuel with different compositions. In late 1987, the RFFL was placed in a state of active standby, a condition where no fuel fabrication activities are conducted, but the monitoring and ventilation systems in the facility are maintained.

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The initial campaign will consist of the production of thirty-eight 37-element $(U, Pu)O_2$ bundles containing 0.3 wt % Pu in H.E., destined for physics tests in the zero-power ZED-2 reactor.

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TABLE 1. Fuel Produced in the RFFL.

Experiment	DATE	FUEL TYPE	QUANTITY
DP-12	1977-78	Natural UO_2	fifty 19-element bundles
BDL-419	1979-80	$(U, Pu)O_2$ with 0.5% Pu in HE	fifteen 36-element bundles
BDL-422	1981-83	$(Th, Pu)O_2$ with 1.75% Pu in HE	six 36-element bundles
BDL-430	1982	Natural ThO_2	one 36-element bundle
WR1-1012	1982	$(Th, U)O_2$ with 1.8% Pu in HE	two 21-element bundles
	1982	$(Th, Pu)O_2$ with 2.3% Pu in HE	two 21-element bundles
WR1-1010	1982-85	$(Th, Pu)O_2$ with 2.3% Pu in HE	1332 elements
BDL-432	1986-87	$(Th, U)O_2$ with 1.4% U-233 in HE	1350 elements

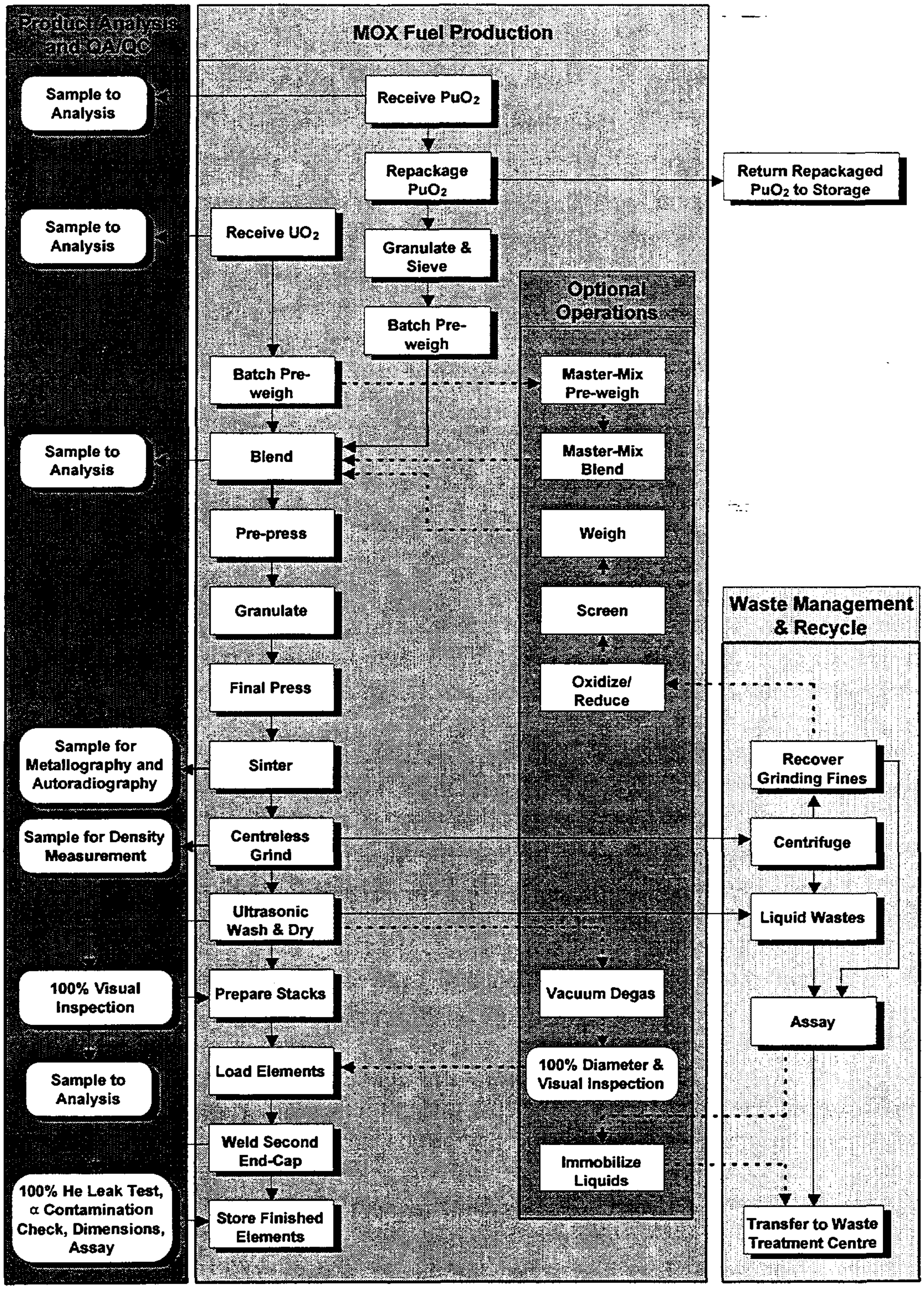

FIGURE 1. RFFL Fabrication Process Flowsheet.