CANDU FUEL:

Evolution towards Optimal Performance

CANADIAN NUCLEAR LABORATORIES FUEL SCIENCE & TECHNOLOGY

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EXTENDED ABSTRACT

In 2015 September, Canadian Nuclear Laboratories (CNL; formerly AECL) was restructured as a government-owned, contractor operated (GoCo) national nuclear laboratory. The private-sector consortium operating CNL is the Canadian Nuclear Energy Alliance, which is comprised of CH2M, Fluor, WS Atkins, SNC-Lavalin and Rolls-Royce. Atomic Energy of Canada Limited (AECL) continues as a small government organization that oversees the laboratory contract, functioning as an interface between CNL and the Government of Canada.

Canadian Nuclear Laboratories is mandated by the Government of Canada to conduct nuclear fuel research and development under its Energy and Safety and Security programs. The Energy Program positions Canada and the world to meet future nuclear energy needs, particularly in the area of advanced fuel cycles. The Safety and Security Program promotes nuclear emergency preparedness and response capability, and includes studies on fuel behaviour during abnormal and accident conditions. These programs position CNL to deliver on federal government needs for innovation in nuclear fuel science and technology (S&T) and to provide support to the nuclear industry on a commercial basis. Collaboration with other nuclear S&T institutions and universities, both domestic and international, is integral to CNL leveraging its S&T commitments and intellectual property to maximize benefits to Canada and the world.

This plenary session presentation reviews programs and capability at CNL relevant to CANDU fuel technology. Highlights of nuclear fuel S&T initiatives undertaken by CNL are presented, in addition to the available capabilities that position CNL to extend the services of the laboratories to the nuclear industry for commercial use. This includes advanced fuel cycle development, fabrication technology, fuel performance assessment, safety-related testing, computer modelling and materials behaviour.

Advanced fuel cycle development includes $(U, Pu)O_2$ (mixed oxide; MOX) and thoria-based fuels involving various technologies, facilities and capabilities, including:

- Fuel Fabrication Technology (Recycle Fuel Fabrication Laboratory (RFFL) and Chalk River Advanced Fuel Technology Laboratory (CRAFT))
- Reactor Physics (ZED-2 Reactor)
- Thermalhydraulics Testing (MR3 Freon Loop)
- Irradiation Testing (NRU)
- Post-Irradiation Examination (PIE in Hot Cells)
- Materials Properties Characterization
- Performance Modelling
- Reprocessing Technology
- Safety-Related Testing (including Defected Fuel Behaviour)

Canadian Nuclear Laboratories has > 40 years experience developing MOX fuels. Fabrication technology for MOX fuel is well established and irradiation testing and PIE is on-going. Canadian Nuclear Laboratories has recently initiated a project to model MOX fuel behaviour and documented a safety testing roadmap for advanced fuels, including MOX.

Canadian Nuclear Laboratories has > 55 years experience developing thoria-based fuels, including ThO_2, (Th, U)O_2 and (Th, Pu)O_2. Most recently, CNL has initiated the Thoria Roadmap Project, which includes eleven S&T areas spanning the front- and back-end of various thoria-based fuel cycles (for cylindrically-clad fuel operating in water-cooled reactors). S&T needs and "gaps" have been identified, along with a plan ("roadmap") to identify gaps. Significant progress has been made to address identified gaps in recent years [1].

The fabrication technology for (U, Pu)O_2, ThO_2 and (Th, U)O_2 fuels is well established and has been demonstrated in various irradiation tests. Additional fabrication development is required for (Th, Pu)O_2 fuel. During 2014, (Th, Pu)O_2 fuel pellet fabrication trials were conducted in the RFFL, achieving homogeneous microstructures and demonstrating control over grain size and Pu distribution [1]. This was accomplished using various powder blending methods and sintering times.

With regard to MOX fuel performance assessments, several irradiation tests have been completed in the NRU and NPD reactors (reported at past CANDU Fuel Conferences). The BDL-419 MOX fuel test comprises fifteen 37-element geometry bundles irradiated over a span of more than 30 years. Recent work has included hot cell PIE on two BDL-419 bundles that achieved burnups of 500-900 MWh/kgHE, and studied high-burnup failure thresholds and the effect of coating type on the inner bore of the Zircaloy sheath [2]. Mixed-oxide fuel behaviour continues to be demonstrated as comparable to that of UO_2.

Thoria-based fuel performance assessments have included numerous past irradiation tests in the NRU, WR-1 and NPD reactors. These have included irradiation of ThO_2 and (Th, U)O_2 fuels to > 900 MWh/kgHE and (Th, Pu)O_2 fuel to > 1000 MWh/kgHE (reported at past CANDU Fuel Conferences). Recent efforts have focused on improved PIE of (Th, Pu)O_2 fuel, including autoradiography (to study the effect of Pu distribution on performance) and ceramography (to conduct microstructural studies) [1].

Safety-related testing includes behaviour of MOX and thoria-based pellets exposed to water/steam and oxygen. Normal operating conditions studies have included the analysis of fission product data for a defected (Th, U)O_2 fuel element irradiated in the X-2 loop of the NRX reactor. Canadian Nuclear Laboratories plans to conduct simulated accident tests using thoria-based and MOX fuel samples that have been trace-irradiated (to re-establish the short-lived fission-product inventory). These tests will expose fuel samples to various gaseous atmospheres at high temperatures (in a hot-cell environment) to study fission-product release [1].

Recently, CNL has collaborated with the Royal Military College of Canada (RMCC) to modify and existing UO_2 computer tool to model ThO_2, (Th, U)O_2 and (Th, Pu)O_2 (MPM-FAST) [1,3]. The MPM-FAST model was benchmarked against NRU test data and used to identify gaps in materials properties data. Canadian Nuclear Laboratories has also initiated a new project to model MOX fuel behaviour [4] and has conducted modelling studies on fuel and fuel channel deformation behaviour [5,6].

In 2013, CNL improved its material properties measurement capability by commissioning new laser flash equipment to measure thermal diffusivity of unirradiated fuel materials. This equipment was recently used to conduct thermal diffusivity measurements on (Th, U)O_2 fuels having various concentrations of UO_2 (from 0-100 wt.%). This was part of collaboration with the Transuranium Institute (Germany) where laser flash measurements made at both laboratories were compiled and compared [1]. Canadian Nuclear Laboratories has also conducted recent studies to determine thresholds for delayed-hydride cracking in Zr-4 fuel cladding as part of a coordinated research project initiated and sponsored by the IAEA [7].

Canadian Nuclear Laboratories has much to be proud of with regard to its past accomplishments, in addition to being confident in its future. As part of the new GoCo operation that initiated in 2015 September, CNL has developed a plan for renewal of its laboratories that will result in major infrastructure replacement and upgrades ("Vision 2026"). This will include a new Nuclear Materials & Fuels Research Centre to be built on the Chalk River site. This will be a world-class nuclear research facility that will replace existing hot cell and fuel laboratory facilities.

A major challenge facing CNL is the closure of the NRU reactor in 2018 March (mandated by the Government of Canada). Canadian Nuclear Laboratories intends to operate the U2 loop through 2018 March to continue fuel irradiation testing. Canadian Nuclear Laboratories is also working to position itself to continue irradiation testing (supporting fuel development) beyond NRU closure by developing partnerships and collaborations with organizations having fuel irradiation test facilities.

In conclusion, CNL has a rich history of fuel S&T development. We are proud of our past and confident in our future. Canadian Nuclear Laboratories is well positioned under its GoCo mandate to support the nuclear industry with regard to future nuclear energy needs and nuclear emergency preparedness and response. This is being accomplished in collaboration with both domestic and international partners and maintains CNL capability to support industry on a commercial basis. As part of its GoCo mandate, CNL has a vision for renewed laboratory infrastructure over the next ten years that includes a new Nuclear Materials & Fuels Research Centre.

References

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[6] M. Piro et al., "Investigation of Fluid Flow within a 37-Element CANDU Fuel Bundle in a Normal and Deformed Pressure Tube", presented at this conference.

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