

## NAYGN McMaster Chapter Nuclear Case Competition 2026: Nuclear Reprocessing



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### Abstract

The NAYGN (North American Young Generation in Nuclear) McMaster Chapter is a student led organisation at McMaster University that supports NAYGN, a non-profit organization founded in 1999 dedicated to empowering the next generation of nuclear professionals. NAYGN McMaster Chapter organized this case competition for undergraduate students to provide them with the opportunity to engage in problem-based learning while tackling current issues in the nuclear industry. This competition fosters collaboration, thoughtful discussion, and innovation, while also offering participants the chance to grow personally and professionally. This year's theme was nuclear reprocessing, and teams were asked to choose a nuclear reprocessing technique and discuss how it could be implemented in Canada. After a round of written submissions, the top eight teams presented their research to a panel of judges at the NAYGN Nuclear Case Competition Expo. The judges selected the top four team, whose abstracts have been published in this abstract booklet. If you would like to learn more about NAYGN McMaster Chapter or the NAYGN Nuclear Case Competition, please visit our Instagram page (@naygn\_mcmaster), or email us ([naygn@mcmaster.ca](mailto:naygn@mcmaster.ca)).

**Keywords:** undergraduate research; nuclear reprocessing; nuclear chemistry; case competition

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### Conference Abstracts

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## **First Place**

### **Implementing Co-Extraction Reprocessing at Darlington Nuclear Generating Station**

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Given the projected increase of fuel bundle waste storage, implementing Co-Extraction (COEX) reprocessing of spent fuel from the new BWRX-300 reactor for recycling in CANDU-6 reactors at the same Darlington site could shift Canada's fuel cycle landscape. The COEX process is an advanced aqueous reprocessing method developed by the French Alternative Energies and Atomic Energy Commission (CEA) in collaboration with AREVA, designed for light water reactor (LWR) spent fuel such as boiling water reactor (BWR). Derived from the PUREX process, COEX ensures that uranium and plutonium remain together in a mixed stream at all stages rather than separating pure plutonium to accomplish a proliferation barrier. In this process, spent fuel is dissolved in nitric acid to form a solution of plutonium Pu(III) and uranium U(IV). Next, Pu and U are coprecipitated in oxalic acid to allow the recovery of the mixed elements in the same solid phase. To produce the end-product, the mixed oxalate is heat-treated to create a mixed oxide (MOX) fuel. According to Atomic Energy of Canada Limited (AECL), CANDU reactors are suited for implementing advanced fuel cycles and can burn MOX fuel derived from reprocessed LWR fuel without major modifications of the reactor. MOX fuel rates were found to be comparable to natural uranium at the Bruce A station. AECL studies demonstrate that irradiated MOX can be handled and stored using the same systems already used in standard Canada Deuterium Uranium (CANDU) fuel. This compatibility contributes to financial feasibility as few changes to the CANDU fuel channels and cooling systems are necessary, however, costs associated longer dry storage requirements and more robust fuel packaging to account for increased radiation will incur. Large investments will be needed to develop COEX reprocessing facilities at Darlington, with 800 tHM/yr plant costing roughly \$12 billion from 2014 estimates at comparable French facilities. As the COEX process uses an integrated reprocessing and recycling site, and leverages existing PUREX industrial equipment, financial viability can be argued considering the savings on long-term fuel storage, mined uranium and transportation due to the proposed domestic integration. The proposed COEX reprocessing method only utilizes material already sanctioned within Canada's current regulatory nuclear framework. Spent BWRX-300 fuel is defined as a regulated "nuclear substance" under Section 2 of the Nuclear Safety and Control Act (NSCA). Under OPG's CNSC licence, the Darlington New Nuclear Project is already permitted to possess and store this spent fuel. However, to implement a COEX reprocessing facility, a separate Class I nuclear facility licence under the NSCA would be required. Currently, reprocessing is not conducted in Canada, but federal radioactive-waste policy states that reprocessing is "not presently employed," meaning COEX would require policy evaluation but is not prohibited. As a non-nuclear-weapon state under the Nuclear Non-proliferation Treaty (NPT), Canada must implement IAEA safeguards for all nuclear material. The COEX process supports these obligations by avoiding production of separated plutonium streams, and locating reprocessing at Darlington would further improve safety by limiting the transport of high-activity spent fuel.

## **Second Place**

### **Proposal for SMR Spent Fuel Reprocessing with UREX for Use in CANDU Reactors**

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Uranium Extraction (UREX) is a nuclear reprocessing technique modified from the Plutonium and Uranium Reduction Extraction (PUREX) process that utilizes a similar solvent-extraction process; however, it leaves potentially weapons-grade plutonium in an aqueous and unusable phase. Initially, in the scrub stage, the feed is dissolved in nitric acid, however, unlike PUREX, a complexing agent/reductant, acetohydroxamic acid (AHA), is added which reduces the plutonium. Then, diluted tributyl phosphate (TBP), is added. This causes uranium, as well as technetium to enter an organic phase, leaving plutonium as well as transuranic and fission products aqueous in the raffinate. The raffinate can further be purified in systems known as UREX+, if desired. The UREX product is considered a Natural Uranium Equivalent (NUE) which has been demonstrated in China to be viable fuel for Canadian Deuterium (CANDU) reactors. In France, Russia, and Japan, the spent fuel used in PUREX and UREX style reprocessing facilities is from light water reactors (LWRs). Canada currently has no LWRs, so the implementation of this method is reliant on utilizing the changes in infrastructure that will come with the recently announced Small Modular Reactor (SMR) Action Plan. SMRs use light water and their waste is compatible with LWR reprocessing techniques. All reagents used in UREX reprocessing are legal in Canada, and UREX has been developed to be proliferation

resistant due to the product not resulting in usable plutonium. While Canada mines, refines and exports uranium, they have no enrichment facilities and to operate their low enrichment uranium (LEU) powered research facilities, they rely on agreements with foreign parties. As a result, the LEU fuel for Canadian SMRs will be enriched in the United States or France, meaning, the Canadian uranium export and import rates will change because of the SMR Action Plan. An important consideration with SMRs is waste management, especially given that with refined fuel, they will generate high level, significantly hotter and more radioactive waste than CANDU reactors. One use for SMR waste would be the implementation of a UREX system to reprocess it into NUE fuel for use in CANDU reactors, ultimately resulting in less nuclear waste product from both kinds of reactors. For this to occur, a dedicated UREX reprocessing facility would need to be built. Based on models in the United States, it would require a multi-billion-dollar upfront investment, with final cost depending on the facility's size, which in turn relates to the expected growth of SMRs in Canada, and a mean cost of USD (2020) \$1350/kg of waste reprocessed. Relative to the estimated standard cost of USD (2017) \$15,600/MT of waste storage for LWRs—which corresponds to USD (2020) \$1693/kg—this indicates that on top of other benefits, UREX is potentially cost-effective. This ultimately evaluates the feasibility of using the UREX process to recycle SMR spent fuel into NUE for reuse in CANDU reactors, which could reduce waste long-term, and limit the risk of nuclear proliferation.

### **Third Place**

#### **Pyrochemical Partitioning & Transmutation in the Canadian Context: A Comprehensive Evaluation of the Niobium-Mediated Waste-to-Stable-Salt (WATSS) Process and Stable Salt Reactor (SSR-W) Implementation: A Research Study**

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The study examines the technical viability and socio-strategic implications of implementing the Niobium-Mediated Waste-to-Stable-Salt (WATSS) reprocessing technology coupled with the Stable Salt Reactor-Wasteburner (SSR-W) to close the Canadian nuclear fuel cycle. Processing the preexisting supply of natural uranium CANDU spent fuel at Point Lepreau, the proposed flowsheet starts with the OREOX (Oxidation-Reduction of Oxide fuel) head-end process. Conditioning the extant inventory of natural uranium CANDU spent fuel at Point Lepreau, the proposed flowsheet begins with a voloxidation step to convert the UO<sub>2</sub> into U<sub>3</sub>O<sub>8</sub> powder, followed by the OREOX (Oxidation-Reduction of Oxide fuel) head-end treatment. During these stages, the fuel is subjected to deliberately modulated thermal cycling that induces topotactic phase transformations. This transition, accompanied by a measurable crystallographic lattice dilation, generates internal shear stresses sufficient to autoclave and triturate the sintered fuel matrix. As microstructure fractures, entrained fission gases, including Kr, Xe, I species, and 3H are released and volatilized in a controlled manner before the material proceeds to the subsequent dissolution and molten salt contact steps. The core partitioning stage involves a pyrochemical extraction into a molten MgCl<sub>2</sub>-NaCl-KCl eutectic. Unlike magnesium-based reduction concepts, this employs metallic Niobium (Nb) as a precisely tuned redox mediator. Thermodynamic analysis and laboratory-scale developments confirm that Niobium's redox potential is calibrated to selectively chlorinate transuranics (Pu, Am, Cm) into the salt phase while suppressing the conversion of bulk uranium, which remains as a refractory oxide residue. The resultant product is an impure, actinide-bearing chloride salt. In contrast to Direct Use of spent PWR fuel in CANDU (DUPIC) fuel cycles, which aim for direct re-insertion into CANDU reactors, this chloride fuel form is incompatible with heavy-water reactor infrastructure, necessitating downstream utilization in the SSR-W. This 300 MWe fast-spectrum system adopts a "static fuel" architecture in which liquid fuel remains immobilized within vented containment tubes, enabling continuous removal of neutron-poisoning noble gases and mitigating operational risks associated with high-pressure, circulating salt systems. Techno-economic modelling projects a levelized cost of electricity (LCOE) of approximately \$44 USD/MWh, made viable by near-ambient-pressure operation and the incorporation of "GridReserve" thermal-buffering technology. Although the LCOE is competitive, deployment remains capital-intensive: roughly \$3 billion CAD for the first-of-a-kind unit. These costs are partially offset through strategic repurposing of existing infrastructure at the Point Lepreau site. The trajectory toward deployment will be shaped by a complex socio-political landscape. While the project aligns with Canada's non-proliferation framework through safeguards-by-design and the inherent proliferation-resistance of its self-protecting, impurity-laden fuel, it also encounters significant challenges with respect to Indigenous sovereignty and consent. Equity partnerships established with the North Shore Mi'kmaq District Council advance models of economic reconciliation, whereas the Wolastoq Grand Council has issued formal resolutions opposing the project on unceded territory, citing infringements of UNDRIP and concerns surrounding intergenerational stewardship of nuclear residues. Additionally, the absence of a validated immobilization matrix, such as

glass-bonded sodalite, for long-term stabilization of chloride salt residues, represents a critical materials-science and regulatory gap in relation to eventual emplacement within Canada's Deep Geological Repository.

#### **Fourth Place**

#### **The Integration of Fluoride Volatility Processing and Moltex WATTS for Uranium and Plutonium Nuclear Fuel Reprocessing and Recycling in Current Canadian Industry: A Research Study**

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The potential of uranium reprocessing remains a critical area of investigation in Canadian nuclear power. As a promising pyrochemical reprocessing technique, the Fluoride Volatility Process (FVP) offers a compact, high-throughput, and aqueous-free method to electrochemically recover uranium from irradiated fuel. Following the transportation to the facility and initial handling, spent UO<sub>2</sub> oxide fuel from CANDU or LWR reactors are mechanically decladded and voloxidated in air/O<sub>2</sub> to produce U<sub>3</sub>O<sub>8</sub> powder. In the FVP stage, this powdered fuel is fluorinated with pure F<sub>2</sub> gas in a flame fluorination reactor, separating the volatile fluorides (UF<sub>6</sub>, and partially NpF<sub>6</sub>) from non-volatile actinide fluorides (PuF<sub>4</sub>, AmF<sub>3</sub>, CmF<sub>3</sub>). FVP generates three principal outputs: (1) high-purity UF<sub>6</sub>, which is subsequently converted to sinter-ready UO<sub>2</sub> powder; (2) concentrated PuF<sub>4</sub> residue for further recycling; and (3) solid/gaseous fission product waste, maintaining a non-aqueous process flow. For recycling, the PuF<sub>4</sub> residue can be integrated into Moltex Energy's Waste-to-Stable-Salt (WATSS) process. As the material is already in a salt form, it bypasses the oxidation-reduction pre-treatment and separation stages to enter the WATSS cycle during chloride extraction, producing molten PuCl<sub>3</sub>. Transuranics (TRUs) are subsequently alloyed to remove fission products and halogenated into a new salt phase to produce nuclear fuel for molten-salt systems such as Moltex's stable salt reactor-wasteburner (SSR-W). Recovery of >90% TRUs is achievable within 24 hours. FVP's dry fluorination and UF<sub>6</sub> chemistry circumvent aqueous streams and molten-metal steps, aligning with waste minimization policies under the Nuclear Fuel Waste Act. The CNSC licensed UF<sub>6</sub> Port Hope Conversion Facility demonstrates that the fluorination materials and chemistry used in FVP falls within established Canadian regulations. As FVP generates plutonium-bearing residues, CNSC's non-proliferation policies would apply, requiring enhanced safeguards such as strict reporting and monitoring of nuclear materials and regulatory compliance. Thus, FVP's permissibility depends on the proposed facility's ability to meet CNSC requirements for safety systems, plutonium management, and approved waste-management plans. In terms of infrastructure, Canada possesses the technical capability for early-stage FVP deployment. The Canadian Nuclear Laboratories (CNL) and McMaster University host high-temperature fluorination systems capable of withstanding volatile metal fluorides, extreme corrosion, and the elevated temperatures required for the FVP. CNL has demonstrated the hot-cell fluorination of irradiated fuel, providing evidence that the core chemical steps of the FVP can be executed within Canada's existing infrastructure. The resulting UO<sub>2</sub> is suitable for fabrication into CANDU-grade fuel pellets. While the potential for uranium reprocessing exists in Canada, scaling its deployment to support national demand would require significant expansion of hot-cell and fluorination infrastructure. A 2008 analysis estimated that FVP could be viable at <\$220/kg at 40 MWd/kg burnup. Rising uranium prices and positive public perception (~40% favorable), support the prospective economic feasibility of FVP deployment in Canada.

#### **Conflicts of Interest**

The authors declare no conflict of interests.

#### **Authors' Contributions**

NL, PH, CG: Served on the planning committee of the case competition and gave final approval of the booklet to be published.

AE: Founded the 1st annual NAYGN McMaster Chapter Nuclear Case Competition, served on the planning committee of the case competition, and gave final approval of the booklet to be published.

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