Improve the Understanding of Environmental Impacts and Waste of SMR Operations in Support of the Pan-Canadian SMR Roadmap Activities

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PROJECT

Knowledge Gaps

1. Potential new waste streams to Canadian jurisdictions
2. New radionuclides that are not well studied in Canadian ecosystems

Objectives

- Parameters for assessing ecological and human health risk from Small Modular Reactors (SMR) in the Canadian environment.
- Estimates of low- and intermediate-level waste (LILW) streams from SMR operation, fuel cycle and decommissioning
- Strategy for graphite waste
- SMR fuel processing and stabilization options

Alignment

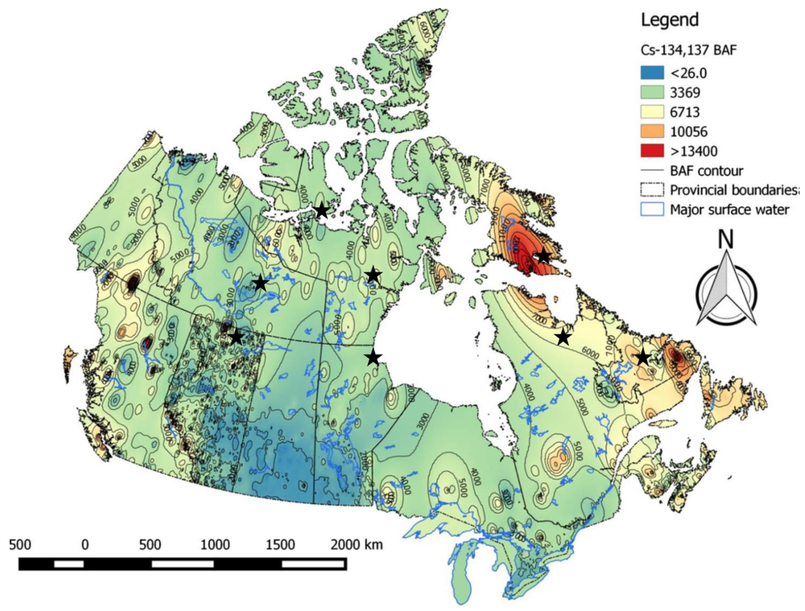
Aligns with Government Priority to "Overcome the challenges of powering off-grid communities and contribute to CO_2 emission reduction in Canada"

Stakeholders NRCan, CNSC, ECCC, Health Canada

ENVIRONMENTAL IMPACT STUDIES

Planning for Arctic Research (Year 1)

Planning for arctic field research in summer 2021 is underway, utilizing the results of Brinkmann and Rowan (2018) for aquatic ecosystems as a template for ecological risk and site selection. Preliminary field sites for 2021 are identified with black stars.



- Areas with high risk include southern Baffin Island, Ungava Bay and eastern Labrador. Areas with moderate risk include Baker Lake, Slave Lake (NWT) and Churchill (MN), with lower risk at Cambridge Bay and Wood Buffalo National Park.
- A draft research plan was submitted to the Nunavut Research Institute in June (**milestone, June 2019**). A final proposal to obtain a research license will be submitted following community approval (Iqaluit, Cambridge Bay and Baker Lake).
- Permits are not required for Churchill (Manitoba), Labrador, Ungava Bay and Wood Buffalo National Park.
- Slave Lake requires a research license from Northwest Territories.

WASTE STREAMS

Calculating N-activation Waste Streams (Year 1)

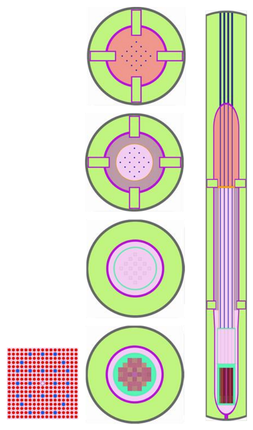
Neutron activation calculations to determine waste streams for five SMR technologies:

1. Integral Pressurized Water Reactor (iPWR)
2. High Temperature Gas-cooled Reactor (HTGR)
3. Molten Salt Reactor (MSR)
4. Lead-cooled Fast Reactor (LFR)
5. Sodium-cooled Fast Reactor (SFR)

N-activation Methodology:

Coupling neutron fluxes and spectra with neutron nuclear reactions and decay

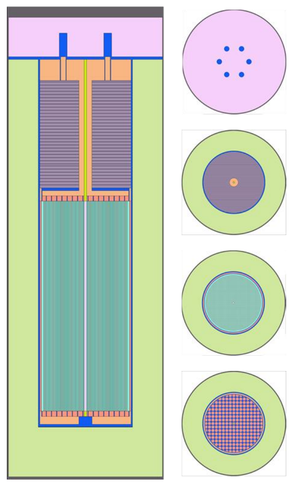
1. Neutron fluxes and spectra SERPENT v.2: 3-D continuous-energy Monte Carlo particle transport code
2. Time-dependent isotope concentrations activities: ORIGEN (Oak Ridge Isotope Generation code) v2.2 on neutron transmutation, fission, and decay



iPWR (NuScale Data)
- *160 MWth*
- *2-year operation cycle 60-year life*
- *<5% wt% U235 in UO2*
- *Light water coolant and moderator*

Neutron activation waste components:

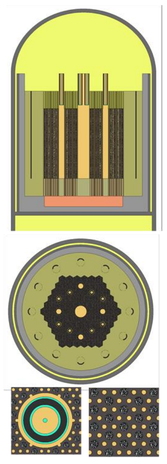
- ✓ Containment vessel
- ✓ Reactor pressure vessel
- ✓ Reactor internal structures
- ✓ Control and shutdown rods
- ✓ Steam Generator
- ✓ Pressurizer
- ✓ CRDM



Integral MSR (Terrestrial Data)
- *400 MWth*
- *Online fuelling 7-year life cycle*
- *<5% wt% U235 in NaF-BeF2-LiF as fuel and primary coolant*
- *Graphite moderator*

Neutron activation waste components:

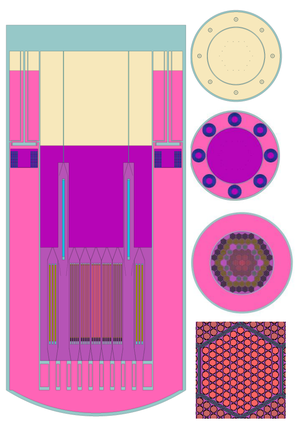
- ✓ Guard vessel
- ✓ IMSR core-unit:
- ✓ Reactor vessel
- ✓ Graphite moderator
- ✓ Shutdown rod
- ✓ Reactor structure
- ✓ Heat exchanger
- ✓ Secondary coolant
- ✓ pumps



MMR (USNC Data)
- *10 MWth*
- *one thru-cycle, 10 to 40-year lifetime*
- *TRISO fuel, 20-wt% U235 enriched UN[15]*
- *Monolithic fuel blocks*
- *Burnable poison Er_2O_3*
- *Helium coolant, graphite moderator, BeO reflector*
- *In-core control rods, outer control drums, shutdown rods*

Neutron activation waste components:

- ✓ Reactor pressure vessel, barrel, insulation
- ✓ Graphite blocks, reflectors
- ✓ Control and shutdown rods, and control drums



LFR (SEALER data)
- *8 MWth*
- *one thru-cycle, 27-year lifetime*
- *19.75-wt% U235 enriched UO_2*
- *Lead-cooled fast reactor (LFR)*

Neutron activation waste components:

- ✓ Reactor vessel, barrel, support structure
- ✓ Primary coolant pumps
- ✓ Steam generators
- ✓ Lead coolant
- ✓ Control rods, shutdown rods, reflector rods, shield rod, and ducts

Data collection for primary reactor components and physics models developed (shown in figures) for 4 of the 5 reactor types to be modelled.

Calculations have started to determine the waste inventory from neutron activation.

(**deliverable, Mar 2020)**

Graphite Waste Inventory

Graphite waste treatment technologies literature is being review to determine waste inventories, characteristics, and recycle technologies.

- 250,000 tons of i-graphite.
- Activation of atoms within the graphite structure include C-14, Cl-36 (long-lived) and H-3, Co-60 (short-lived). Activation of atoms deposited on the graphite surface will be C-14.
- There is potential for future re-use of graphite for for HTGR and Integral MSR.

(**milestone, Dec 2019**)

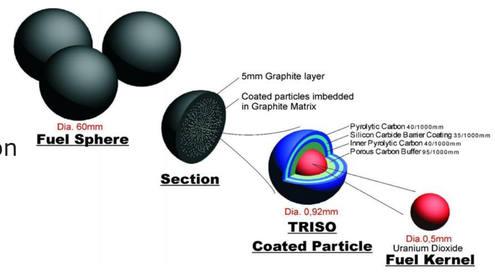
FUEL DISPOSAL AND LIFE-CYCLE WASTE GENERATION

Review of fuel disposal and life-cycle waste (Year 1)

- Fuel disposal and life-cycle waste generation for SMR are being reviewed, including investigation of dry processing for research reactor fuels, spent fuel and high level waste disposal technologies and possible processing methods for spent fuel types.

HTGR[b]

- Direct storage of TRISO
- TRISO encapsulation in glass



MSR[b,c]

- Electro-metallurgical process for stabilization
- CNL Reactor Fuels
- Conversion of metal and carbide fuels to oxides

Species	Units	Value
LiF	mole%	64.1 ± 1.1
BeF2	mole%	30.0 ± 1.0
ZrF4	mole%	5.0 ± 0.19
UF4	mole%	0.809 ± 0.024
Cr	Ppm (by mass)	64 ± 13 (range 35-80)
Fe	Ppm (by mass)	130 ±45
Ni	Ppm (by mass)	67 ± 67

NEXT STEPS (Future Years)

Environmental Impact Studies

- Sample soil, plants and water utilized by wildlife and people in sub-Arctic and Arctic regions of Canada to assess soil to plant transfer of radionuclides
- Measure dispersion in coastal marine areas of the Canadian Arctic for radionuclide fate and transport models
- Develop regional approaches for evaluating ecological and human health risk in Canada from SMR deployment
- Identify resilient and vulnerable regions, ecosystems and pathways for various SMR types

Waste Streams

- Improve estimates of LILW generation for SMRs
- Assess LILW waste management challenges and disposal requirements in the Pan-Canadian framework, including development of a strategy for recycling graphite waste

Fuel Disposal and Life-Cycle Waste

- Research and review of spent fuel characteristics and disposal technologies. Collect and summarize life-cycle waste data.
- Identify possible processing methods and develop plans for future experimental work
- Initial research into methods for conversion of SMR spent fuel to suitable fuel form for disposal in Nuclear Waste Management Organization (NWMO) repository.

References

a. Government of Canada, National Energy Board, Market Snapshot: Overcoming the challenges of powering Canada's off-grid communities, https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2018/10-01-1cndffgrdcmmnts-eng.html?=undefined&wbdisable=true

b. Compere, E.L.; et al. Fission product behavior in the Molten Salt Reactor Experiment, Oak Ridge National Laboratory Report No. ORNL-4865, 1975

c. IAEA Advanced Reactors Information System, https://aris.iaea.org/sites/MSR.html (accessed 8/15/2019)