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Perspectives of Small Modular Advanced Reactor Used Fuel Management in Canada

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Outline

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- Current Status of Used Fuel Management in Canada
- Introduction of Small Modular Advanced Reactors (SMARs)
- Expected Used Fuel from SMARs
- Potential Requirements in Future Used Fuel Management
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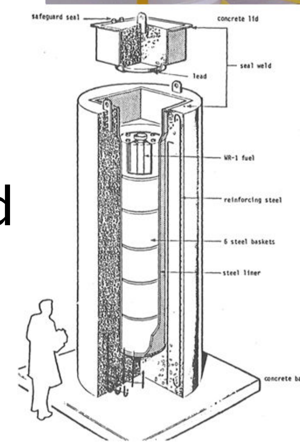
Background

- Canada has been on a unique path to design and use Pressure Tube – Heavy Water Cooled and Moderated Reactors (PT-HWR) with natural uranium fuel for nuclear energy generation – registered as CANada Deuterium Uranium (CANDU®).
- CANDUs are also built in in Argentina, China, India, Pakistan, Romania, and South Korea.
- Used CANDU fuel management is similar to Light Water Reactors (LWRs): initial cooling in water pool and above-ground dry storage.
- An open or once-through fuel cycle was considered more economically and has been adopted, with direct disposal of used nat. U fuel in Canada.
- Used fuel disposal in Canada is the responsibility of Nuclear Waste Management Organization (NWMO).
- A deep geological repository (DGR) is pursued but designed solely for disposal of used CANDU fuel bundles.

Status of used fuel management in Canada: Storage

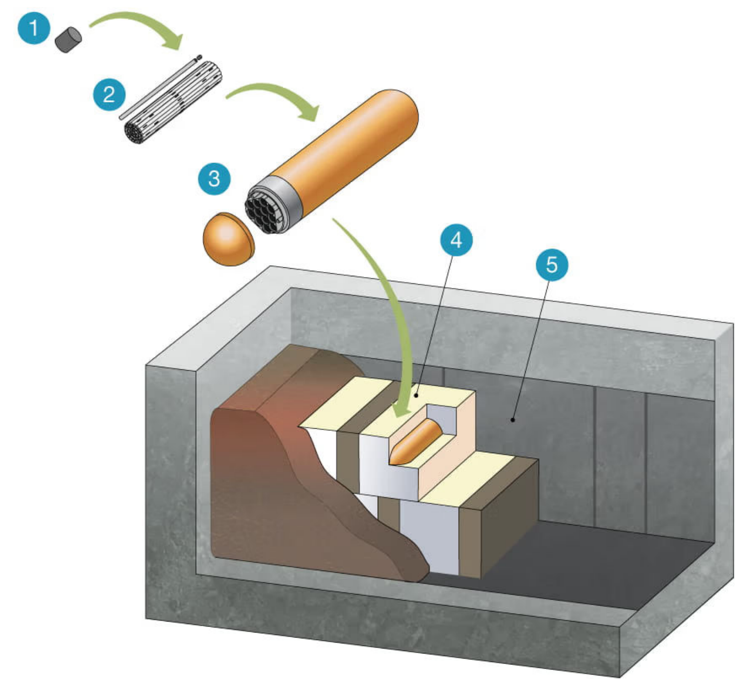
- Most used fuels including research reactor fuels are in dry storage.
- Ontario Power Generation – Dry Storage Containers (indoor).
- AECL Concrete Canisters (outdoor, used at AECL/CNL, and CANDU-6 fuel at Point Lepreau Generating Station). Used before MACSTOR™.
- AECL – MACSTOR™ (an outdoor structure used by Point Lepreau and Gentilly-2 generating stations and also in China, Romania, and South Korea).



Status of used fuel management in Canada: Disposal

NWMO:

1. Adaptive Phased Management: the containment and isolation of Canada's used fuel at a new repository site.
2. A Site Selected: Wabigoon Lake Ojibway Nation (WLON) and the Township of Ignace.
3. Multiple barrier system.
4. Started discussion of siting approach for next deep geological repository (ILW and non-fuel HLW).



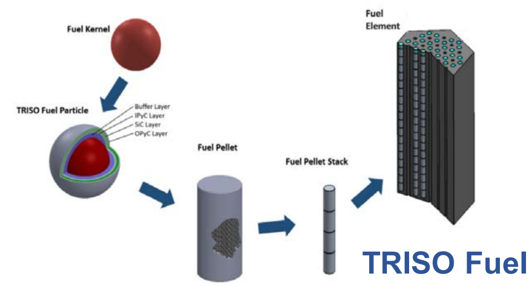
Multiple barrier system

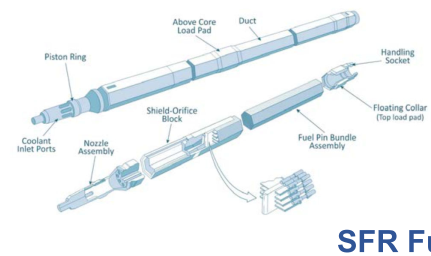
Introduction of Small Modular Advanced Reactors

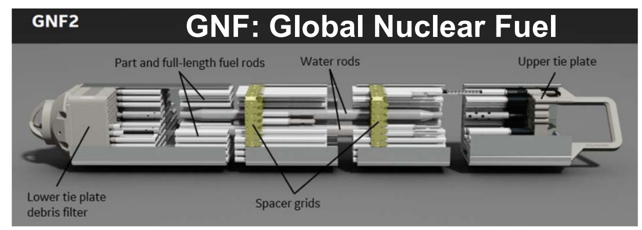
- Small Modular Advanced Reactors (SMARs) are currently promoted, because of its potentially low upfront construction cost and inherent passive safety features in Canada, for grid and off-grid energy applications.
- Governments and private industries jointly released "Small Modular Reactor Roadmap" and "Small Modular Reactor Action Plan".
- Introduction of SMARs represents a drastic shift from the CANDU only scenario in Canada.
- SMARs require **enriched uranium fuels and/or transuranic fuel** that was made from materials recovered by reprocessing of used U fuel.
- SMAR fuels are in various chemical forms instead of UO_2 CANDU fuel.
- Questions are **on their compatibility** with CANDU UO_2 fuel DGR.

SMAR Fuel Types

1. TRISO fuel (HTGR, MMR®, eVinci®): Graphite block + SiC or graphite compacts + fuel particles (SiC coating, pyrolytic carbon coatings, HALEU UCO, UN, or UO_2 fuel kernels).
2. Sodium-cooled fast reactor fuel (SFR, ARC-100): U-Zr alloy HALEU fuel.
3. Boiling Water Reactor fuel (BWRX-300): GNF2 LEU fuel assemblies.
4. Molted fluoride salt fuel: LEU UF_4+Be_2F+NaF.
5. Molten TRU Chloride Salt Fuel (SSR-W): used TRU processed WATSS to recycle TRU with the generation of vitrified FPs and Minor Actinides.







WATSS: WAsTe to Stable Salt.
SSR-W: Stable Salt Reactor – Waste Burner (a Molten Chloride Salt Fast Reactor).
GNF2 – Global Nuclear Fuel generation 2

Potential Requirements in Future Used Fuel Management: Treatment or Conditioning

Based on the current practice of oxide fuel direct disposal (once-through):

1. TRISO fuel: extract fuel compacts from graphite blocks to remove the volume.
2. U-Zr alloy fuel: clean surface residual Na (minimum); converting metal to oxide for disposal if required.
3. LWR LEU fuel assemblies: likely no treatment required; similar to conventional BWR used fuel.
4. Molten fluoride salt fuel: convert fluorides to oxides for disposal.
5. For cladded fuel, cladding must be removed for conversion.
6. Potential release of a significant amount of fission products during high temperature processing for oxide formation.
7. For a once-through fuel cycle, no single-solution can fit all.

Potential Requirements in Future Used Fuel Management: Recycling

1. A combination of SSR-W and WATSS process: Recycle TRU (mainly Pu); vitrified FPs, U, and residual transuranic (TRU) actinides (Np, Am, Cm).

2. Advanced Recycling Technologies:
    1. Use aqueous processing technologies to recover mixed Pu+U or grouped transuranic metals (TRU) and U for recycling with or without the separation of fission products such as Tc, Cs, Sr, and lanthanide elements, etc.
    2. Use molten chloride salt pyro-electrochemical processing to recover grouped transuranic metals (TRU) and U+Pu for recycling.
    3. Recover TRU with Fluoride Volatility for recycling.
    4. Vitrify waste stream from the above recycling technology application: vitrified waste (glass waste form).

Potential Requirements in Future Used Fuel Management: Recycling

What are needed for used fuel recycling:

- Require advanced aqueous processing technologies to be implemented for TRU recovery.
- Require pyro-processing engineering and scale-up development for demonstration with used fuel.
- Improved reactor technology to burn TRU elements.

Direct benefits for waste disposal:

1. It is possible for the used fuel recycling to have a single vitrified waste heading to a DGR, which can be classified as intermediate level.
2. Most non-glass waste streams from the used fuel recycling can be disposed of at low-level waste disposal facilities.

Potential Requirements in Future Used Fuel Management: Alignment with Policies

- Natural Resources Canada recently released Integrated Strategy for Radioactive Waste (ISRW): surface disposal for low-level waste; deep geological disposal for intermediate level waste.

Alignment with Polices:

1. The CANDU used fuel DGR continues by NWMO.
2. NWMO started the discussion of siting approach for next DGR (ILW and non-fuel HLW).
3. Used fuel recycling can facilitate the acceptance of waste from recycling SMAR used fuel into the second DGR, where no used fuel will need DGR disposal.
4. Fast reactors may be needed for improved burning of TRU elements.

Conclusions

1. Canadian government supports the applications of SMARs as tools to combat global climate change.
2. Provincial governments and industry committed to collaborate to facilitate SMAR deployment and coordinate waste management while observing the regulations and policies.
3. CNL conducts research to support both government policy and decision makings and nuclear industry needs.
4. A 'radioactive waste management' theme program has been established under the AECL's federal science and technology program. The program pivots towards development of enabling technologies for backend fuel cycle and waste management.

Questions

CNL provides research & support to industries

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