Integrity Assessment of CANDU Spent Fuel During Interim Dry Storage in MACSTOR

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Outline

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- Dry storage conditions in MACSTOR
- Safety requirements and target criteria
- Sheath integrity assessment
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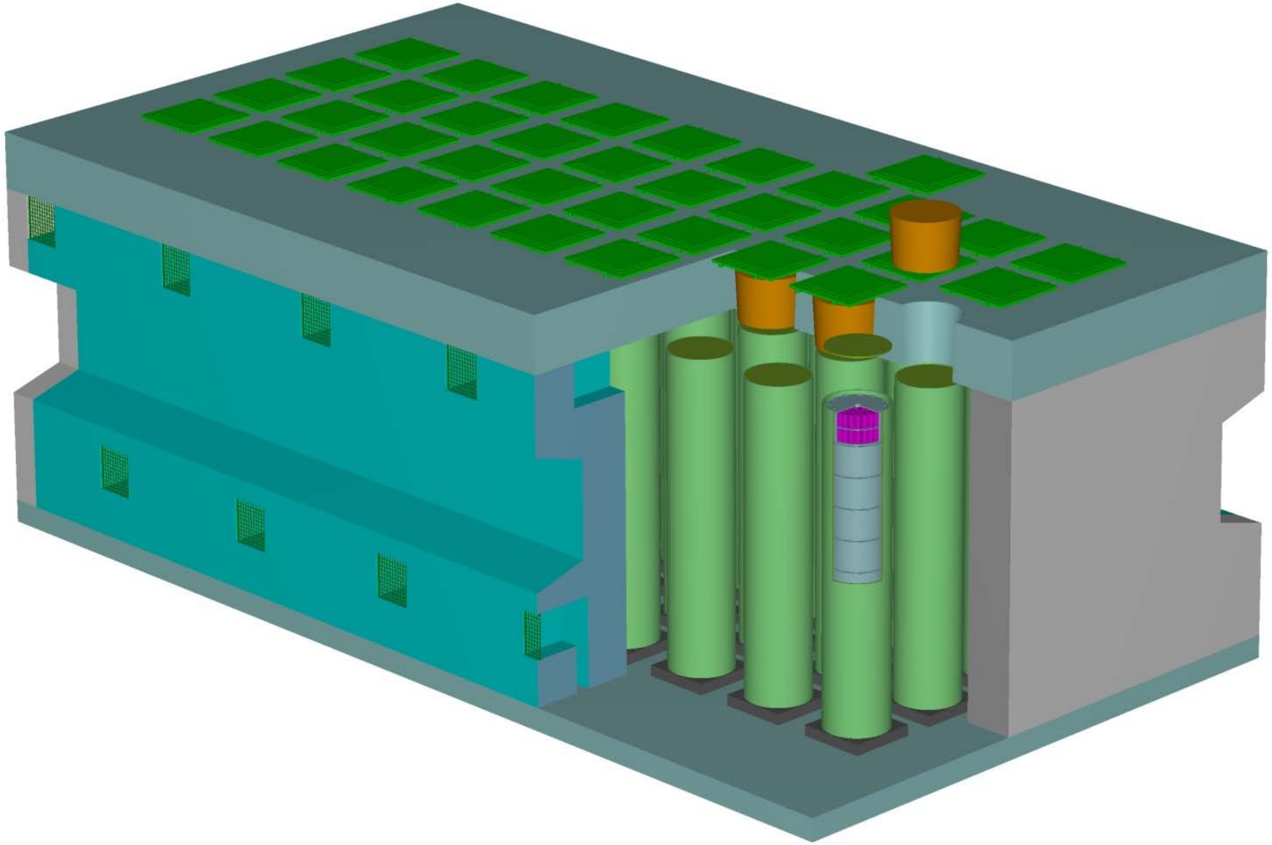
About AECL

- A Canadian Crown Corporation formed in 1952
- An operator of extensive nuclear research facilities
- A supplier of research reactors and CANDU power reactors
- R&D on spent fuel dry storage technology since 1970’s

Modular Air Cooled STORage (MACSTOR-200 at Gentilly-2, Quebec)

MACSTOR-400



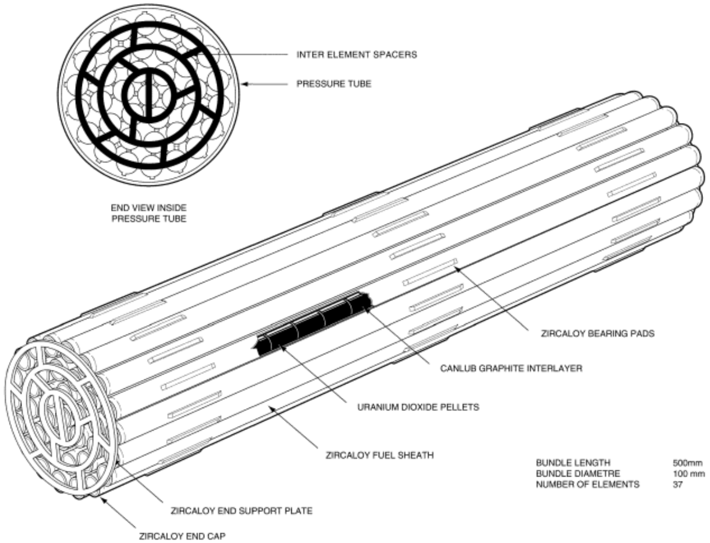
MACSTOR System

- Concrete monolith- simple construction
- Passive air cooling
- Retrievable fuel
- Multiple containments
- High storage density, low storage costs
- Low maintenance and worker exposure
- Flexible storage capacity (modularity)
- Proven technology

Spent Fuel from CANDU Reactors

- Natural uranium with Zr cladding
- Average burnup 7,800 MWd/tU
- 6 year pool storage
- Average decay heat load 6.08 w/bundle
- Only intact fuel bundles for dry storage
- Presence of non-intact fuel in MACSTOR discussed elsewhere

CANDU Fuel Bundle and Storage Basket



Dry Storage in MACSTOR

- 60 bundles in one SS fuel basket
- Hot-air dried and weld-sealed
- 10 baskets in one storage cylinder
- Storage cylinder equipped with gas monitoring system
- Maximum fuel temperature <150^{o}C
  - "Worst" loading conditions with high burnup fuel
  - First summer with warmest conditions recorded at site
- Maximum sheath hoop stress <4 MPa

Safety Requirements for Sheath Integrity

- **IAEA Safety Series No. 116 (Design of Spent Fuel Storage Facilities):**
  - *"The spent fuel cladding shall be protected during storage* ***against degradation that leads to gross ruptures****…" (Article 223)*
  - *"…the temperature of all fuel (and fuel cladding) in a storage facility* ***does not exceed the maximum temperature*** *recommended or approved by the national nuclear Regulatory Body for the type and condition of fuel to be stored." (Article 225)*

Safety Requirements for Sheath Integrity (Continued)

- **USNRC document NUREG-1536:**
  - *For each fuel type proposed for storage, the DCSS should* ***ensure a very low probability (e.g., 0.5 percent per fuel rod) of cladding breach*** *during long-term storage.*
  - *The design life of Dry Cask Storage System (DCSS) is restricted to 20 years*
- **Derived sheath failure limit for CANDU spent fuel:**
  - **1% per rod in 100 years dry storage in MACSTOR**

Integrity Assessment for Spent CANDU Fuel Stored in MACSTOR

- **Fuel temperature limit: 300 ^{o}C**
- **For storage in air at T< 300 ^{o}C** [1]**:**
  - **Creep rupture and external oxidation should not cause failure**
  - **Fatigue is not a limiting failure mechanism**
  - **Splitting of sheath by UO_2 oxidation is a limiting mode only with defected fuel**
  - **SCC is the limiting mode, with a failure rate of ~ 0.1% per rod over 100 years of dry storage**

[1] A.K. Miller et al.,*"Estimates of Zircaloy Integrity During Dry Storage of Spent Nuclear Fuel",* EPRI-NP-6387/1989

Integrity Assessment for Spent CANDU Fuel (Continued)

- **Failure rates predicted in [1] is based on database of US LWR spent fuel**
- **CANDU fuel is less susceptible to sheath failure:**
  - **exposed to lower concentration of the corrosive fission gas, and**
  - **subjected to a lower driving force (hoop stress)**
- **Hence, failure rate predicted in [1] is conservative for CANDU fuel**

Safety Margin Assessment

- Target sheath failure criteria is 1.0% per fuel rod in 100 years of storage
- At T=300°C, the sheath failure rate by SCC is ~ 0.1% per rod in 100 years of storage, 10 times lower than the target
- At T<=150°C the failure rate, is ~ 0.01% per rod in 100 years,100 times lower than the target criteria

Safety Margin Assessment (Continued)

- **The time-average fuel temperature is ~ 85°C, leaves a very large temperature margin of 215°C**
- **At T=85°C, a more realistic failure rate is 0.001% per rod in 100 years, 1,000 times lower than the target criteria**
- **As the spent CANDU fuel is less susceptible to SCC than the LWR fuel, the actual failure rate for the CANDU fuel would be even lower**

Summary

- **A very conservative temperature limit of 300°C is selected for CANDU spent fuel**
- **For intact fuel stored in air at T< 300 °C:**
  - **Creep rupture, external oxidation, fatigue and UO_2 oxidation are not a limiting failure mode**
  - **SCC is the only limiting mode but with a very low failure rate of ~ 0.1% per rod in 100 years**
- **At least 150°C of margin for the fuel stored in MACSTOR**
- **At least 3 orders of magnitude lower than the target limit based on NUREG-1536 for LWR fuel**

Thank You

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