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Spent Fuel Pool Modeling and Analysis with MELCOR

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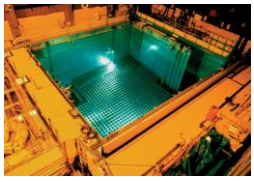
U.S. Spent Fuel Pools (SFP)



- Spent fuel rods stored in spent fuel pools under at least 20 ft of water
- Typically ~ 1/3 to 1/2 of fuel in reactor replaced with fresh fuel every 18-24 months
- Spent fuel stored in pools for a minimum of 5 years

Spent Fuel Safety

- SFPs were originally designed for limited storage of spent fuel until removed off-site
- Safety of spent fuel in pools achieved primarily by maintaining water inventory, geometry, and soluble boron (pressurized water reactors only)
- Drain down could lead to uncovered fuel, heat-up, and the release of radionuclides

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SFP Accident Analysis

- Complete Loss-of-Coolant Accident
  - Draining to uncover the bottom of the racks
    - Air circulation patterns
    - Air oxidation
      - More energetic
      - Pre- and Post-Breakaway
    - Little or no hydrogen
    - Enhanced Ru release
- Partial Loss-of-Coolant Accident
  - LOCA or boil-off with no or a late uncovery of the bottom of the racks
    - Steam generation
    - Steam oxidation/steam starvation
    - Hydrogen combustion
    - Potential late air oxidation after uncovery of bottom of racks

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SFP MELCOR Models

- New records (SFP-BWR, SFP-PWR)
  - Rack component introduced in M1.8.5 version RO to model heat transfer within a ring and also from ring to ring (a ring is usually a collection of assemblies)
- Thermal radiation modeling
- Decay heat modeling
- Radionuclide modeling
- Air oxidation modeling (ANL data)
- Hydraulic resistance model

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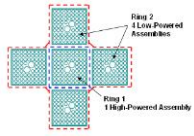
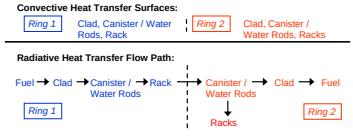
Thermal Radiation Modeling

- MELCOR thermal radiation considerations
  - Only one Rack component
  - Rack transfers heat between rings
  - Rack also exists interior to ring
  - Generalized radiation model
    - Ring-to-ring view factor/area
    - Rack surface area





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Decay Heat/Radionuclide modeling

- MELCOR models fission product release and transport (all relevant phenomena including aerosol dynamics and deposition by various mechanisms are included)
- SCALE/ORIGEN analysis to characterize decay power and radionuclide masses for all assemblies. Most recent offload dominates SFP power.
- SFP accident analysis involves fuel assemblies with multiple shutdown times
- Control system developed to track the releases from fuel in each ring. The non-dimensional release fractions together with actual inventories are used as input for consequence analysis (required by MACCS2)

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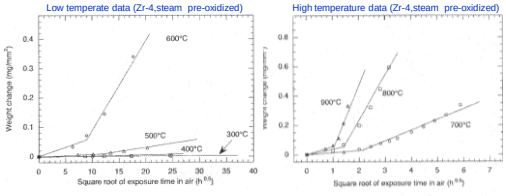
Oxidation Model

- MELCOR models oxidation of Zircaloy (cladding and channel boxes) by steam and air
- Steam oxidation model uses standard parabolic kinetics
  - Urbanic-Heidrich correlation with mass transfer limitation under low oxidant concentration
- Air oxidation model based on the ANL experiments
  - NUREG/CR-6846, "Air Oxidation Kinetics for Zr-Based Alloys"
  - Breakaway timing is a function of temperature modeled using a lifetime rule



Hydraulic Resistance Model

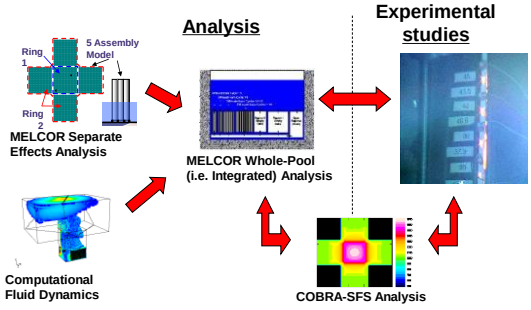
- MELCOR models flow between control volumes using constitutive relationships that specify form losses (K) and wall friction losses (fL/D)

$$\Delta P = \frac{1}{2}\rho v^2 \left(f\frac{L}{D} + K\right)$$

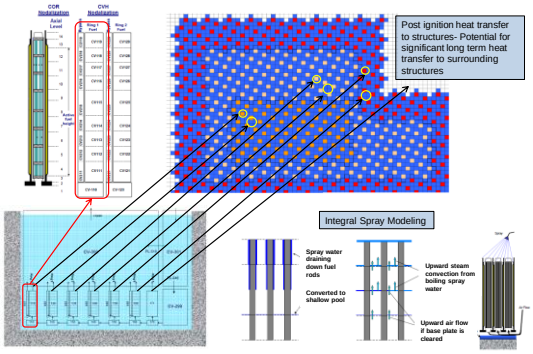
- The laminar friction factor, f, is a function of Reynolds number and S_{LAM} which is a user-specified MELCOR input parameter and can be prescribed based on the SNL experiments
  - NUREG/CR-7144, "Laminar Hydraulic Analysis of a Commercial Pressurized Water Reactor Fuel Assembly," (Jan. 2013)

$$f = S_{LAM}/Re$$

Use of MELCOR for SFP Analysis



Integral SFP MELCOR Model



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MELCOR Application to SFP Scoping Study

- Two conditions to be considered:
  - Representative of the current situation for the selected site (i.e., high-density loading and a relatively full SFP)
  - Representative of expedited movement of older fuel to a dry cask storage facility (i.e., low-density loading)
- Consider situations with effective and ineffective accident mitigation
- Elements of the study include
  - Seismic and structural assessments based on available information to define initial and boundary conditions
  - SCALE analysis of reactor building dose rates
  - MELCOR accident progression analysis (effectiveness of mitigation, fission product release, etc.)
  - Emergency planning assessment
  - MACCS2 offsite consequence analysis
  - Probabilistic considerations

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Conclusion

- Improved SFP MELCOR modeling informed by experimental data leads to more realistic accident progression and source term
- MELCOR modeling approach is the right tool for SFP accident analysis since all severe accident phenomena are represented in an integral manner (i.e., fuel degradation, fission product release and transport, hydrogen combustion)

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