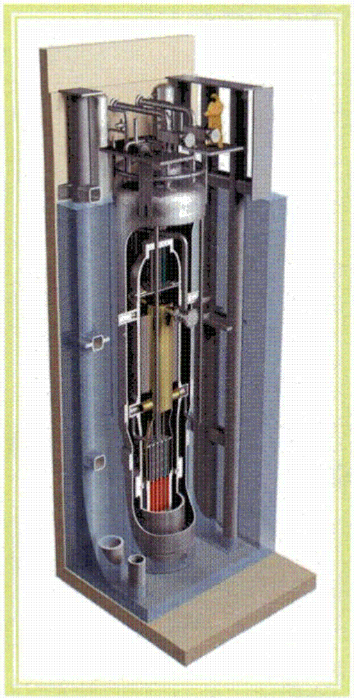
LO-0316-22069

Enclosure 1:

"Spent and New Fuel Storage Design," PM-0216-21760-NP, Revision 0, nonproprietary version

NuScale Nonproprietary

Spent and New Fuel Storage Design



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Acknowledgement & Disclaimer

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Agenda

- Meeting purpose
- Design parameters and layout
- Spent fuel storage rack
  - seismic analysis
  - criticality analysis
  - thermal hydraulic analysis
- New fuel storage rack
  - seismic analysis
  - criticality analysis
- Metal matrix composite characteristics
- Material evaluations
- Coupon surveillance program
- Summary

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Abbreviations

Abbreviation	Definition
ALE	Arbitrary-Lagrange-Eulerian
FA	fuel assembly
FEA	finite element analysis
GDC	general design criteria
ISRS	in-structure response spectra
NFS	new fuel storage
SFP	spent fuel pool
SFS	spent fuel storage
SSE	safe shutdown earthquake

Meeting Purpose

- Inform the NRC about the NuScale design approach for the new and spent fuel storage
- Discuss the methodology for completing seismic, criticality, and thermal hydraulic analysis pertaining to the spent fuel storage racks and new fuel storage racks
- Receive NRC staff feedback

Spent Fuel Storage

- **Design parameters and layout**
- Spent fuel storage rack
  - seismic analysis
  - criticality analysis
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Design Parameters

- NFS and SFS rack design meets NUREG-0800, SRP 9.1.1 and 9.1.2
- SFS rack design meets NUREG-0800, SRP 3.7.1 Subsection II.1.B.ii, Option 2 and ASCE/SEI 43-05 requirement
- NFS racks design meets Appendix D of NUREG-0800 Section 3.8.4 requirements

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Design Parameters

- All primary stresses in the new and spent fuel racks satisfy the limits in Section III, Subsection NF, Class 3 of ASME BP&V Code
- Design, fabrication, and examination of racks are in accordance with guidance from NF-3000 (design), NF-4000 (fabrication), and NF-5000 (examination)
- New and spent fuel racks are designed to withstand normal and postulated dead loads, fuel drop loads, loads resulting from thermal effects, and loads caused by a safe shutdown earthquake (SSE)

Design Parameters

- New and spent fuel storage racks maintain the stored fuel assemblies in a subcritical configuration using flux traps and fixed neutron absorbers during all credible storage and handling conditions in accordance with general design criteria (GDC) 62 and 10 CFR 50.68
  - k_{eff} must not exceed 1.0 when flooded with unborated water and maximum reactive fuel at a 95% probability and a 95% confidence level
  - k_{eff} must not exceed 0.95 when flooded with minimally borated water and maximum reactive fuel at a 95% probability and a 95% confidence level
  - if optimum moderation occurs with the racks loaded with maximum reactive fuel and filled with low-density hydrogenous fluid, the $K_{95/95}$ corresponding to this optimum moderation must not exceed 0.98

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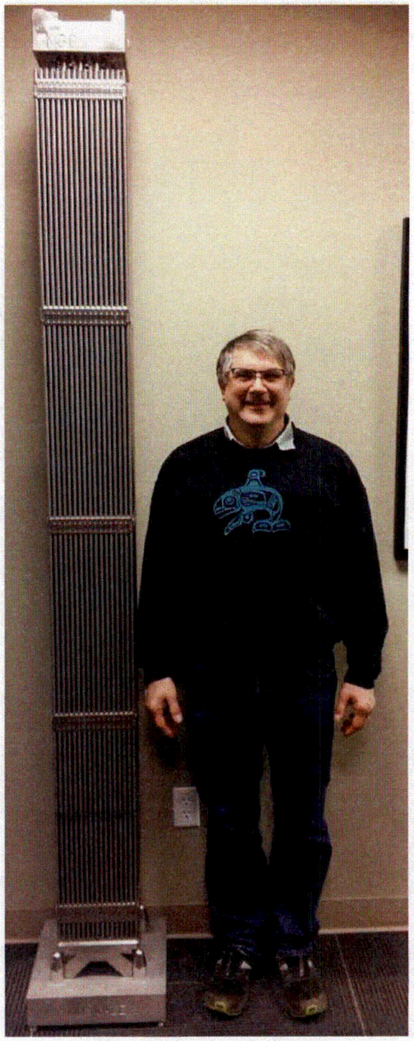
Design Parameters

- Fuel assembly (FA) drop event evaluation shows that the criticality geometry of the rack will not be compromised
- The peak fuel cladding temperature shall be maintained below the local saturation temperature for water at the top of the FA under all design conditions
- Racks are designed with no administrative controls for fuel loading
- Racks are free standing
- Fuel assemblies being stored in the racks should not be damaged

Fuel Assembly

FA overall length	94″
FA width and depth	8.426″
Active fuel length	78.74″
Number of fuel rods	264
Rod array	17 x 17
FA weight	830 lbs
Clad material	M5™



Typical 17 x 17 design with length scaled down to meet the NuScale reactor design.

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Spent Fuel Storage Structure

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Spent Fuel Storage Structure

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Spent Fuel Storage Structure

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Spent Fuel Storage Layout

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Spent Fuel Storage Layout

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New Fuel Storage Layout

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New Fuel Storage Layout

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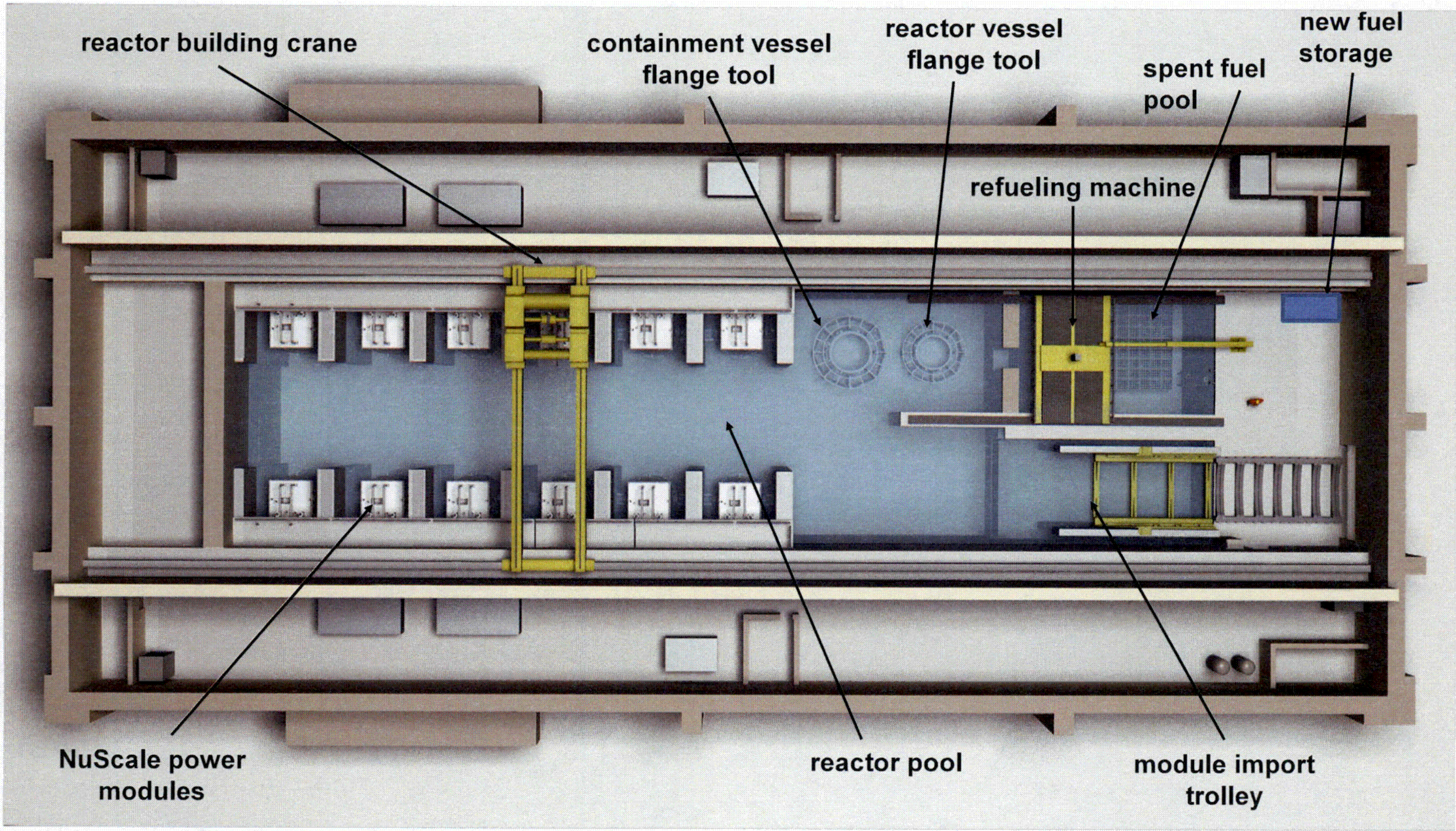
Reactor Building Overhead



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Spent Fuel Storage

- Design parameters and layout
- Spent fuel storage rack
  - **seismic analysis**
  - criticality analysis
  - thermal hydraulic analysis
- New fuel storage rack
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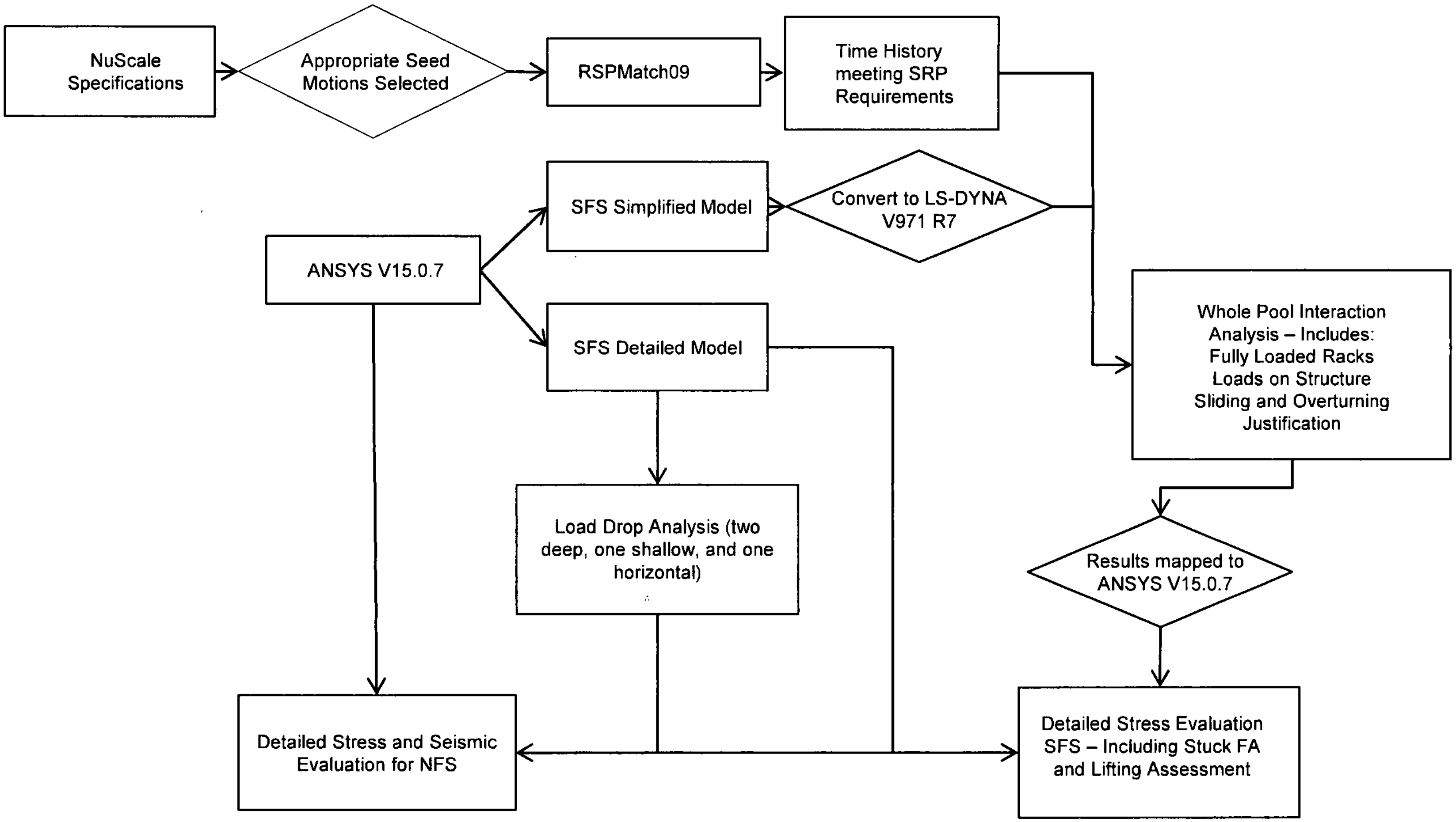
Seismic Analysis Road Map



Detailed Model

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Simplified Model

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Model Comparison

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Model Comparison

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Target Response Spectra

- Enveloping ISRS of the SFP floor up to the 50′ EL provides loading to the racks that are controlled by impulsive loading
  - this approach is acceptable for seismic analysis of the SFS racks that are located on the basemat (24′ EL) and extend up to the 34′ EL

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Node Selection

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Response Spectra for the 24′ EL

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Response Spectra for the 50′ EL

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Enveloping ISRS

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SFS Time History Analysis

- Seven time histories were developed and analyzed
  - one time history that envelops in-structure response spectra (ISRS) for low- and high-frequency response spectra
  - four time histories that envelop the low-frequency response spectra
  - two time histories that envelop the high-frequency response spectra

Seed Motions

- Seed motions are extracted from NUREG/CR-6728
- RSPMatch09 is used to modify the input acceleration time histories so that the corresponding response spectra match that of the target spectra

TH. No.	Earthquake Name	Date	Mag.	Station	Dist. (km)	Site Condition	Azimuth (deg)	Dur. (sec)
1	Landers, California	6/28/1992	7.3	Lucerne	1.1	Rock	260	8.4
2	Landers, California	6/29/1992	7.3	Lucerne	1.1	Rock	345	8.4
3	Kocaeli, Turkey	8/17/1999	7.4	Arcelik	17	Rock	up	8.7

- All seed time histories have a time step size of Δt = 0.005 seconds
- The Nyquist frequency defined as $f_{Ny} = 1 / (2\Delta t) = 100$ Hz

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Seed and Target Response Spectra

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Computed/Target Spectral Ratio

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Acceleration, Velocity, and Displacement

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SFS Time History Analysis

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Power Spectral Density

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SFS Time History Analysis

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Whole Pool Analysis

- The simplified SFS rack model is used in the whole pool model
- Multiple SFS racks, concrete pool, water, and voids are modeled
- The ANSYS finite element mesh of the whole pool model is then converted to LS-DYNA input
- Seismic excitations in three orthogonal directions are applied simultaneously
- The time history solutions are performed for low- and high-friction factors (μ= 0.2 and 0.8) between leg plates and the pool liner

Whole Pool Model

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Whole Pool Model

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Whole Pool Model

- Whole pool model accounts for
  - fluid structure interaction between adjacent rack modules and between the racks and pool structure
  - structural nonlinearities due to rack sliding and rocking and impacting each other, global rack-to-rack, and rack-to-pool interaction effects
  - interaction between FA and rack tubes

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Fluid Structure Interaction

- SFS racks are modeled with a Lagrangian mesh
- Eulerian mesh is defined to follow the motions of the rigid concrete pool with the Arbitrary-Lagrange-Eulerian (ALE) reference mesh
- Void spaces are modeled where water elements can flow during the analysis
- Outward pressure 28.02 psi at the mid-height of the SFS racks is applied
- Outer surfaces of the fuel racks act as slave segments to Eulerian masters for the contact definition

Contact Definitions

- Three types of contact definitions that create the interaction between the fuel racks and concrete pool wall
  - contact force transducers
  - automatic surface-to-surface contact
  - automatic node-to-surface contact
- Structural nonlinearities due to rack sliding and rocking, impacting each other, global rack-to-rack, and rack-to-pool interaction effects
- Impact forces on resident fuel assemblies

SFS Whole Pool Analysis

- The results of the whole pool analyses are post-processed to determine
  - average acceleration of SFS racks
  - maximum rack sliding and uplift distances
  - differential displacements between rack modules
  - differential displacements between rack to walls
  - maximum floor reaction under one leg
  - friction loads transferred to the floor slabs
  - rack-to-pool wall contact forces
  - interaction forces between rack to rack
  - maximum reaction on a FA due to interaction with racks
  - uplift margin of safety
  - FA gap reductions

Impact Forces on Fuel Assembly

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SFS Stress Analysis

- Displacement time histories obtained at the nodal points from the whole pool model are mapped onto the detailed model of the bounding individual rack model to determine stress distribution on the rack members
- Tension, compression, shear, and bending stresses are checked
- Shear and bending stresses are checked using the square root of the sums (SRSS) of the horizontal and vertical components
- Welds are checked
  - all welds are full penetration welds

Fuel Assembly Drop

- FA drop analysis includes four independent fuel assembly drop scenarios onto a rack module
  - shallow drop (center strike) – FA drops in a vertical orientation, striking the top of the rack in center
  - deep drop (center strike) – FA drops through an empty storage cell and impacts the base plate center
  - deep drop (corner strike) – FA drops through an empty storage cell and impacts the base plate in the corner directly over the support leg
  - horizontal drop – FA in a horizontal orientation, striking the top of the rack in the center

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Fuel Assembly Drop

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Fuel Assembly Drop

- Buckling of the lead-in on top of the rack is expected
  - deformation does not affect main structural grid
  - deformation does not impact the poison plate
- Base plate deforms but does not shear

Stuck Fuel Assembly

- Analysis of a stuck FA stress is performed
  - maximum uplift is 1200 lbs
- Weld between fuel tube and upper grid checked
- Fuel tube compression checked
- Uplift of a stuck FA is acceptable

Spent Fuel Storage

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Upper Safety Limit

- From NUREG-6698, the upper safety limit is defined as

$$USL = K_L - \Delta_{sm} - \Delta_{AoA}$$

Where

- K_L = limiting k_{eff}, from the benchmark calculation
- Δ_{sm} = safety margin, defined administratively, (Δ_{sm} =0)
- Δ_{AoA} = area of applicability margin when extrapolation of benchmark applicability is required.

  Δ_{AoA} = 0 as determined by the benchmark

Criticality Assumptions

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Software and Benchmarking

- Software used
  - SCALE Version 6.1.3
  - KENO-V.a (Sequence CSAS5)
  - ENDF/B-VII, 238 group cross section library
- Software benchmarked in accordance with NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology"
  - benchmark bias = -0.00064, bias uncertainty = 0.00676 for 69 comparisons to critical experimental data

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Studies Performed

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Studies Performed

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Studies Performed

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Off Normal/Accident Conditions

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Off Normal/Accident Conditions

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Off Normal/Accident Conditions

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Summary

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Spent Fuel Storage

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Assumptions

- No credit is taken for heat loss through pool walls
- No credit is taken for evaporative cooling from the pool surface
- No credit is taken for convective cooling to ambient air
- Racks were simulated with porous media
- Axial pressure drop distribution was based on fuel testing data
- The k-ε turbulence model was applied throughout the pool
- The standard wall function was applied to gaps between the racks
- A buoyancy-driven model was applied to the bulk fluid in the pool
- A normal water level at the 94′ elevation was modeled

Thermal Hydraulic Analysis

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Temperature Contour at the Upper Surface

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Summary

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New Fuel Storage Racks

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NFS Model

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NFS Seismic Analysis

- Beam element components in the NFS rack ANSYS model are designed by linear elastic analysis
- Beam elements include the spacer tubes, the bumpers stiffening the middle band, and the wall brace
- The bumper is a built up member that acts as a stiffener to the middle band of the rack
- Fuel assemblies are not modeled in the ANSYS NFS rack model; impact of the fuel assemblies during a postulated seismic event are evaluated by estimating the kinetic energy of the fuel assembly.

NFS Seismic Analysis

- Since the rack is anchored to the wall, an envelope of the 4% damping spectral accelerations for nodes at 100′ EL and the elevation above, 125′ EL, is used to perform a single point response spectra analysis per the guidance of Regulatory Guide 1.92
- The attachment location to the wall is considered rigid

NFS Seismic Analysis

- Stresses in the new fuel rack meet their respective Level A and Level B stress limits for deadweight as defined in ASME Code Section III, Subsection NF
- Stresses for the new fuel racks meet the service level D accident condition criteria specified in Appendix D of SRP 3.8.4

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New Fuel Storage

- Spent fuel storage rack
  - design approach
  - seismic analysis
  - criticality analysis
  - thermal hydraulic analysis
- New fuel storage rack
  - design approach
  - seismic analysis
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NFS Criticality Analysis

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Abnormal Conditions

- Flooding with full density water
- Flooding with fire extinguishing foam
- Dropping an assembly on top of the rack in dry conditions
- Mechanical deformation of the rack during a seismic event under flooding conditions

NFS Criticality Analysis

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NFS Criticality Analysis

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New Fuel Storage

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Metal Matrix Composite Characteristics

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Metal Matrix Composite Characteristics

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Material Evaluation

- Design parameters and layout
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Material Evaluation

- Design requirements
  - metallic materials shall have a proven history in light water reactor environments
  - metallic materials shall be austenitic stainless steel or Ni-Cr-Fe alloys
  - metallic materials shall support a design life of 60 years
  - new fuel rack shall be designed for humidity ranging from 5% to 100% and temperatures ranging from 40°F to 212°F
  - spent fuel rack shall be designed for a normal operation water temperature of 100°F and a maximum water temperature of 212°F
  - all bolting material shall be corrosion resistant alloys
  - no coatings shall be used on any component that may come in contact with the fuel assemblies
  - spent fuel rack shall be designed for submersion in the water that meets the EPRI water chemistry guidelines

Material Evaluation

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Material Evaluation

- The most significant risk of degradation to the metallic materials used for the structural components is corrosion
- Materials specified takes credit for the successful operational experience of these materials in current light water reactor cores and SFPs
- Materials are used extensively in similar and more aggressive environments without experiencing any degradation due to pitting, intergranular, galvanic corrosion mechanisms.
- Since the water chemistry requirement will align with that used at LWRs, there is no reason to believe these corrosion mechanisms would pose a failure/degradation risk to the materials chosen.

Coupon Surveillance Program

- Design parameters and layout
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Coupon Surveillance Program

- In order to verify continued performance of the neutron absorber over the lifetime of the SFS racks, a surveillance program will be established in accordance with ASTM C1187
- Coupons shall be taken from the same production lot as that used for the construction of racks

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Coupon Surveillance Program

- Minimum of 12 coupons will be immersed in SFS racks in the SFP
  - at least one archive specimen will be retained, and not immersed in the pool for later comparison with the irradiated coupons
- Size of coupon will be large enough to obtain tensile test specimen (approx. 1″ x 8″), and ^{10}B density test specimen (approximately 2″ square)
  - the coupons should be located adjacent to freshly discharged irradiated fuel, in either an empty fuel compartment or in a space between

Coupon Surveillance Program

- At defined time periods (approximately 2, 4, 6, 8, 10,15, 20, 25, 30, 40 , 50, and 60 years) from first insertion of irradiated fuel in racks, at least one coupon shall be removed
- Acceptance criteria
  A. thickness increase due to general corrosion ≤ 20% compared to pre-immersion measurement
  B. pitting corrosion not exceeding a rating of A-2, B-2, C-2 per ASTM G46 para 6.2.1 is acceptable
     - pitting that exceeds this rating is acceptable if the area of greatest pitting satisfies criteria D below
  C. edge corrosion shall not reduce the coupon length or width by more than 1/16″
  D. ^{10}B areal density ≥ 95% of pre-immersion measurement

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Spent Fuel and New Fuel Storage

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Summary

- Spent fuel storage rack
  - seismic analysis demonstrates acceptable stresses for all rack components
  - SFS racks do not contact with the pool walls through sliding or tipping
  - maximum loads on the FA are less than the allowable loads and no FA damage is expected
  - criticality analysis demonstrates that a sub-critical configuration is maintained for all conditions evaluated
  - thermal hydraulic analysis demonstrates no nucleate boiling is expected in abnormal pool cooling scenarios

Summary

- New fuel storage rack
  - seismic analysis demonstrates all stresses are acceptable for all Level A, B, and D limits
  - criticality analysis demonstrates that a sub-critical configuration is maintained for all abnormal conditions

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sub-critical configuration }}2(a),(c)

- Coupon surveillance program will monitor the degradation of the poison plates

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Questions

- Questions / Comments
- Open discussion

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