CR3MP
Crystal River 3 Middle Package
2nd NRC Meeting

DOCKET NO. 71-9393
EPID L-2021-NEW-0003

ORANO DECOMMISSIONING SERVICES, LLC,
ORANO FEDERAL SERVICES, LLC, *and*
ACCELERATED DECOMMISSIONING PARTNERS, LLC

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ADP Accelerated Decommissioning Partners, LLC

5/25/2021

Agenda

- Introductions
- CR3MP Authorized Contents
- CR3MP Type B Design
- Preferred Operational Steps
- Licensing Strategy
- Safety Analysis updates
    - Structural Evaluation
        - **Design/Brittle Fracture**
        - **Drop Testing**
    - Containment Evaluation
        - **Drop Testing**
        - **Puncture Testing**
    - Thermal Evaluation and Pressure
    - Shielding Evaluation and Hydrogen
- Project Schedule Timeline
- Wrap Up Discussion

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Introductions

Orano Federal Services

- **Chris Backus, Licensing Support**
- **Phil Noss, Licensing Manager**
- **Armando Merlin, Project Technical Lead**
- **Dan Wick, Structural Analysis Support**
- **Erik Gonsiorowski, Thermal/Shielding Analysis Support**

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- **Matt Lucas, Deputy Manager - Nuclear Decommissioning Strategy & Operations**
- **Donald R. LeFrancois, VTYRS Deputy PM/Advisory Engineer**
- **Dirk Bender, Nuclear Decommissioning Project Engineer VY & CR3 Reactor Segmentation**
- **Arthur Niemoller, CR3 Segmentation / Packaging Engineer**
- **Adam Mancini, Waste Management Advisory Engineer**

Advanced Decommissioning Partners, Crystal River 3

- **Craig Miller**
- **Phyllis Dixon**
- **Mark Van Sicklen**

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- **Peter Vescovi, Technical Lead for Part 71 Packaging Design and Licensing**
- **Jason Heineman, Transportation Project Engineer**
- **Mike Valenzano, Sr. Project Manager**

WCS

- **Matt Hooper, WCS**

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CR3MP Authorized Contents

CR3 Decommissioning

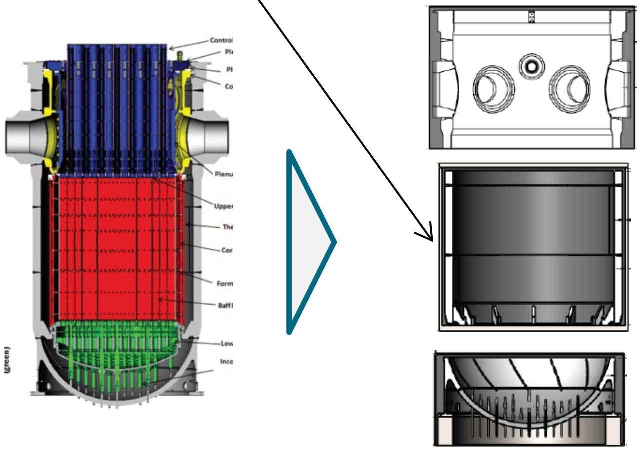
- **Accelerated Decommissioning Partners LLC (ADP)**

Reactor Vessel (RV) and Internals removal, grouting, and segmentation

- **All Greater than Class C material is removed for on-site storage, with waste contained in the middle package representing Class B and C waste as classified by 10 CFR 61.55**
- **The remaining RV Internals will be re-arranged within the RV**
- **The RV and Internals will be grouted and severed in three large sections**
- **The three sections will be packaged**

Middle Package is the Type B package (CR3MP)

Middle Package compliant with 10 CFR 71.41(d)



The Middle Section is the one of interest for today’s discussion – the top and bottom shipments will use IP-2 packages

CR3MP Authorized Contents

Details of the Reactor Vessel Internals Middle Section:

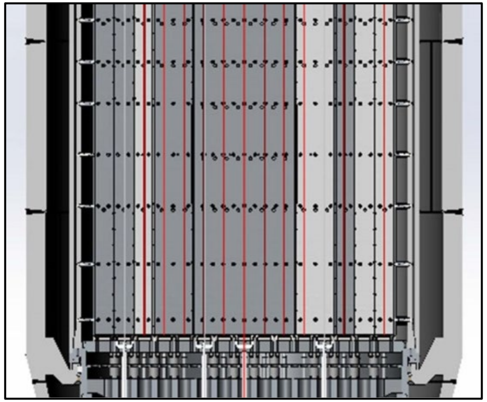
- **The bottom of the Plenum Assembly and Core Support Shield**
- **The Lower and Upper Grid Assembly**
- **The Thermal Shield and the Surveillance Specimen Holder Tubes**
- **Control Rod Guide Tube Assemblies**

Physical Properties:

- **Weight of Reactor Vessel Middle Section with internals is approximately 420,000 pounds and with grout 590,000 pounds**
- **Conservative Contents Weight: 645,000 lbs**
- **Height ~163”, Diameter ~188”**

Radiological Properties:

- **Mostly driven by activated material (>99%) with a total activity prior to RV segmentation of 38,000 Ci among which 20,700 Ci are of Co-60**
- **Dispersible contamination is limited to about 48 Ci among which 15 Ci are Co-60**



RV with RVI cross-section prior to repackaging

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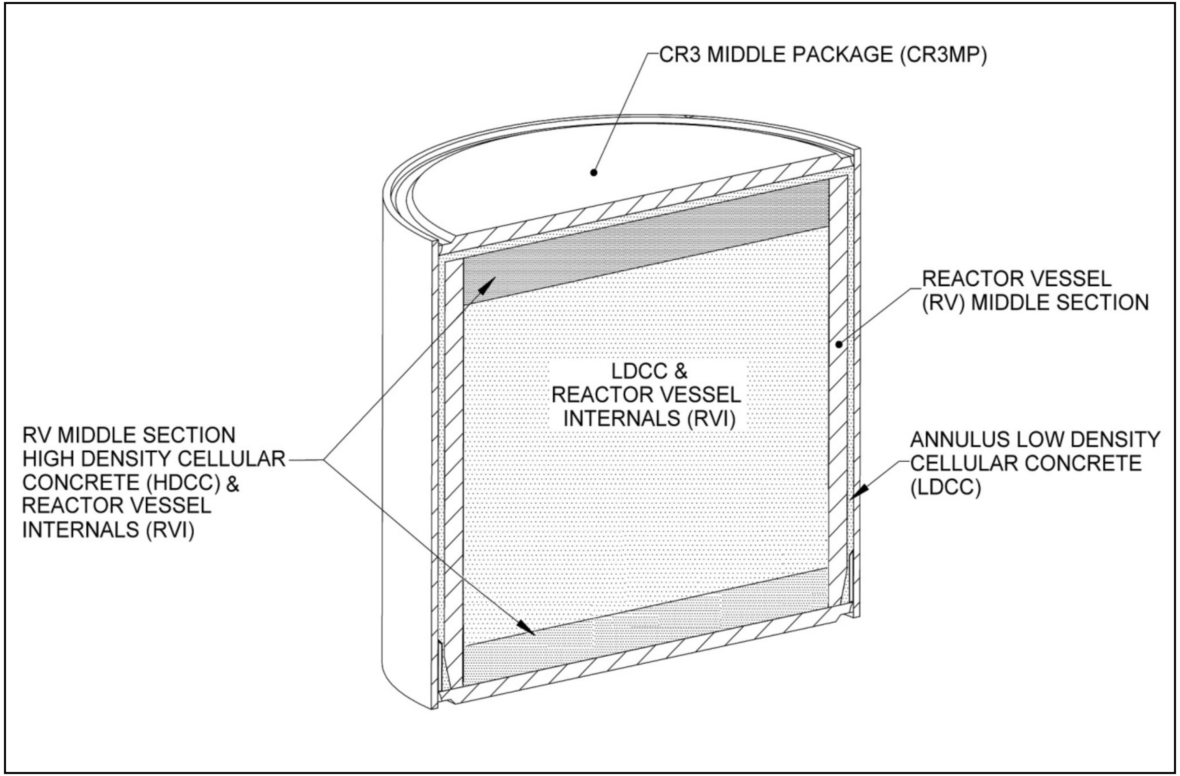
CR3MP Type B Design

Package Basics:

- **No Removable Seals/Closures, No Leakage Rate Testing**
- **No Impact Limiters**
- **Package Annulus is Grouted**
- **Fissile Exempt**
- **Package profile: 178.13-in. tall x 200.25-in diameter**
- **3-in. thick side shell**
- **Welded Bottom and Top Closure Covers (6-in. thick top, 6-in. thick bottom)**
- **Approx. 3-in of grout on sides/top**
- **Total gross weight: ~860,000 lb.**



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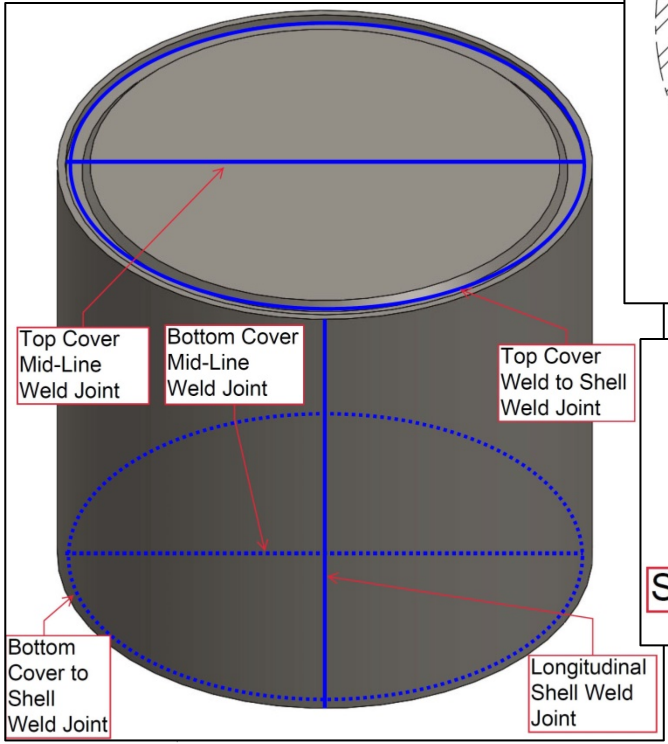
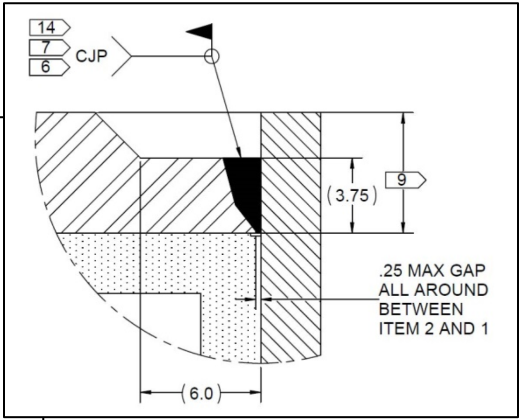
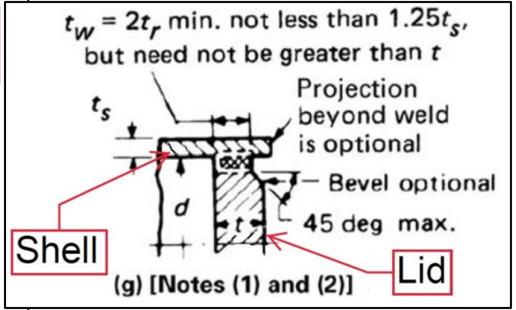
CR3MP Type B Design

Welds:

- **Base Material ASTM A516, Grade 70**
- **Longitudinal shell joints and base and lid flat joints to be double V-groove welds**
- **ND-3351.3 Category C joint connecting the flat (both top and bottom) covers to the package shell**
- **Will meet fabrication requirements of ND-4243 with joint geometry per Figure ND-4243-1(j)**
- **Besides VT inspections, NDE includes 100% UT volumetric inspection of the final weld joint, MT/PT on root pass, routine MT/PT, and MT/PT on final pass**







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Preferred Operational Steps

No crane lifts are involved

- **Expensive mobilization**
- **Eliminate package lug design**
- **Maintain Part 71 configuration**

1. Self Propelled Modular Transporter (SPMT) used for movements of packages
2. Package rests on vertical stands to facilitate SPMT use
3. Package securement with over the top lashing and blocking (no direct connections)

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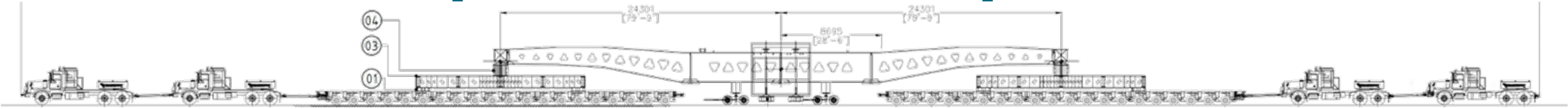
Preferred Operational Steps



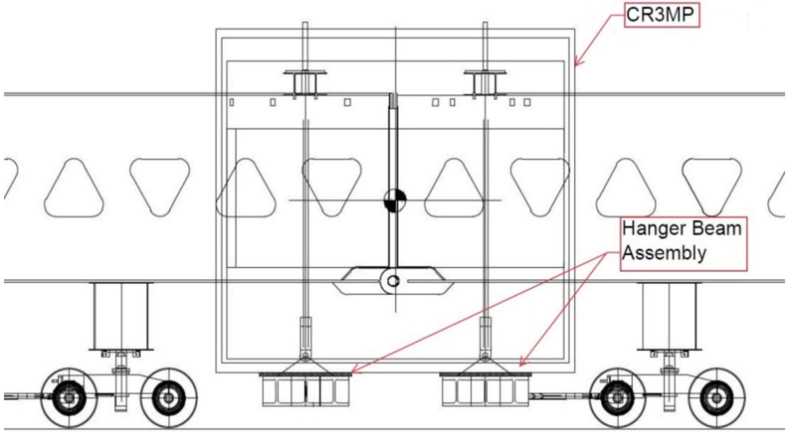
4. Possibly convert Hanger Beam Assembly into a Package Skid for Heavy Haul Trailer (HHT)

5. SPMT picks up package and moves to HHT loading site lowering package onto HHT Hanger Beam Assembly (possible use of gantry jacking system to engage skid)

6. HHT transport to Disposal Site (WCS)

7. SPMT lifts package/skid off HHT, moves to disposal cell

8. SPMT lowers package onto Disposal Stands (may push/pull package into position instead of stands)



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Licensing Strategy

NRC Reg. Guide 7.9 for Standard Application Format and Content

Safety demonstration by computer analysis or simple arithmetic

- **No scale testing or direct package comparisons**
- **Use precedents as appropriate (West Valley, LaCrosse)**

Type B Package meeting all applicable requirements of 10 CFR 71

- **Special Package Authorization (SPA) [10 CFR 71.41(d)]**
- **One-time Use Package Evaluation**
- **Where not practicable, will show equivalent safety per 10 CFR 71.41(d)**
- **No exceptions or exemptions will be requested**

Structural: Design/Brittle Fracture

Design Criteria

- **ASME BPVC, Section III, Division 1, Sub-Section ND Criteria (ND-3000 – Design). NRC RG 7.6 stress limits**
- **Load combinations per NRC Reg. Guide 7.8**

Fracture toughness considerations per NRC Reg. Guide 7.12 establishing minimum fracture toughness criteria

- **Maximum Nil Ductility Transition (NDT) temperature determined using the method of NUREG/CR-6491.**
- **A516, Grade 70 metal NDT determined using ASTM E208 drop weight testing (approx. -25°F)**
- **Requirement ≤ -19°F at Lowest Service Temperature (LST) of 0°F**

Recommended Welding Criteria (NUREG/CR-3019)

- **Per NUREG/CR-3019, Table 2, weld metal will meet the requirements of ND-2400 using Charpy V-notch testing to the LST.**

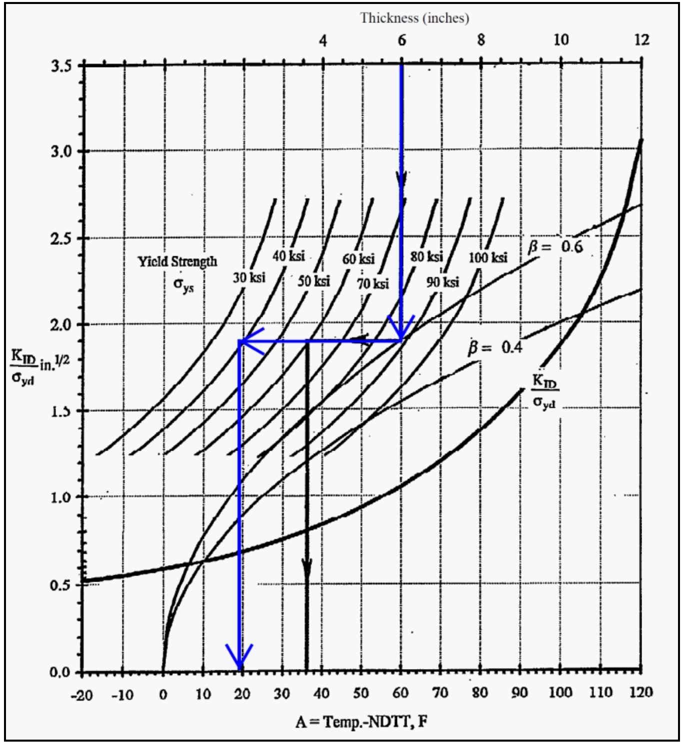


Figure 1 from NUREG-6491

Structural: Drop Testing

NCT and HAC Drop tests are simulated using the FEA code LS_DYNA

- **Drop orientations consist of bottom end, side and CG over corner**
- **The drop pad used for the simulations is an unyielding body (rigid material)**
- **The HAC drop cases include an additional 1 foot to account for accumulated NCT damage**

Acceptance criteria incorporate ASME B&PV Code Section VIII, Division 2 tri-axial strain relations.

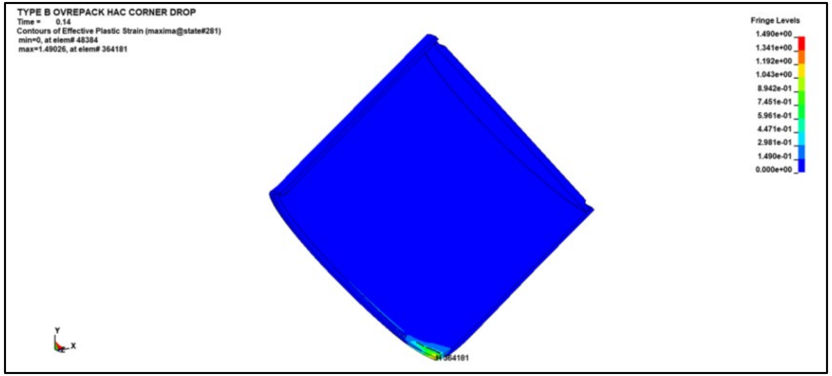
- **A 38% uniaxial limit is derived based on equations in Table 5.7 of the Code Division and the Minimum Properties from ASTM A516**
- **A 22% tri-axial limit using Equation 5.6 is derived from the uniaxial limit and assumes a balanced uniaxial tension as the worst case scenario**
- **Conservatively welds are set to erode at an effective strain of 19%**
- **Acceptance of the Base metal relies on ensuring the tri-axial limit is not exceeded.**

Structural: Drop Testing

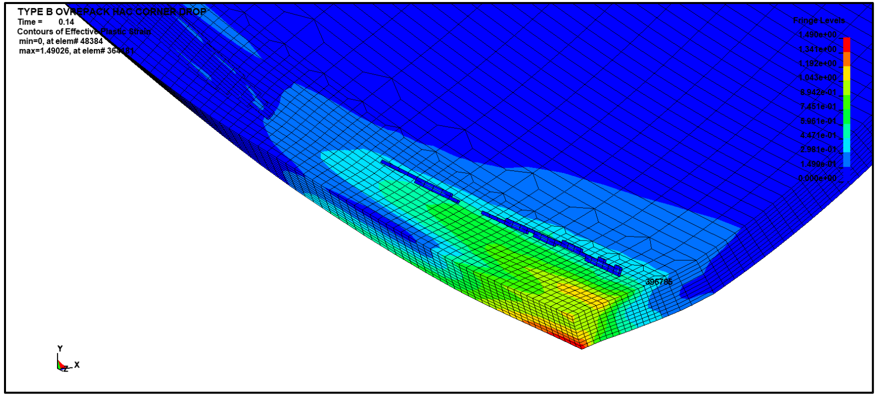
The preliminary results show:

- **The maximum plastic strain in the NCT drops is below the strain criterion of 22%**
- **NCT corner drop case shows partial weld failure due to compressive strain, but through-failure does not occur**
  - The damage appears to be due to compressive forces on the weld joint and no opening occurs
- **HAC side and corner drop cases show that the plastic strain in the closure weld exceeds 19% over limited regions**
  - Weld erosion in the model appears as the weld joint is squeezed in between the lid and the shell-indicating compressive failure
  - The gap is due to the erosion of the elements and quickly closes

The next step is to show that even with the weld erosion, any HAC release remains below the maximum A2 Limits



HAC Corner Drop Maximum Strains



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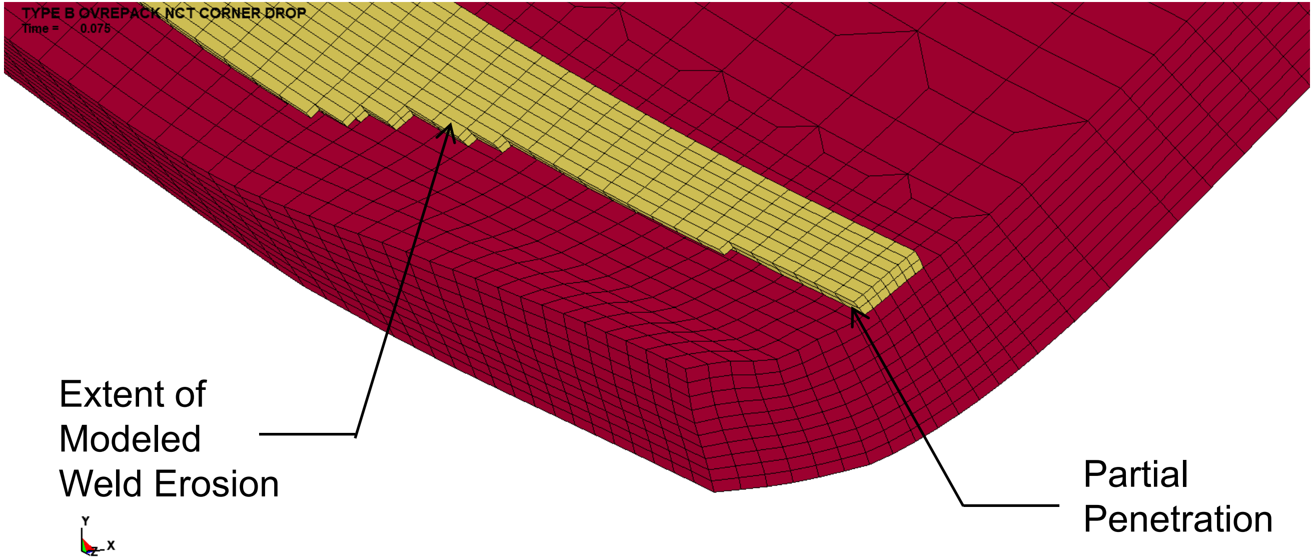
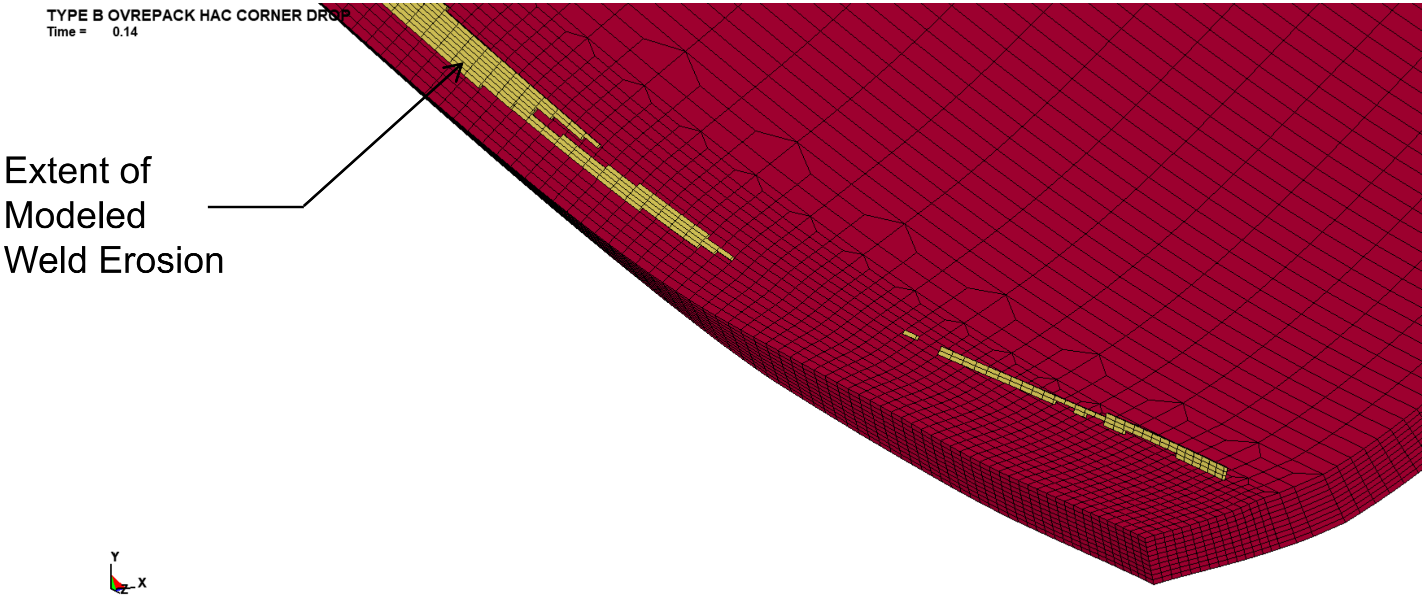
Structural: Drop Testing

NCT Model Closure Weld Erosion



Structural: Drop Testing

HAC Model Closure Weld Erosion



Containment Evaluation: Drop Testing

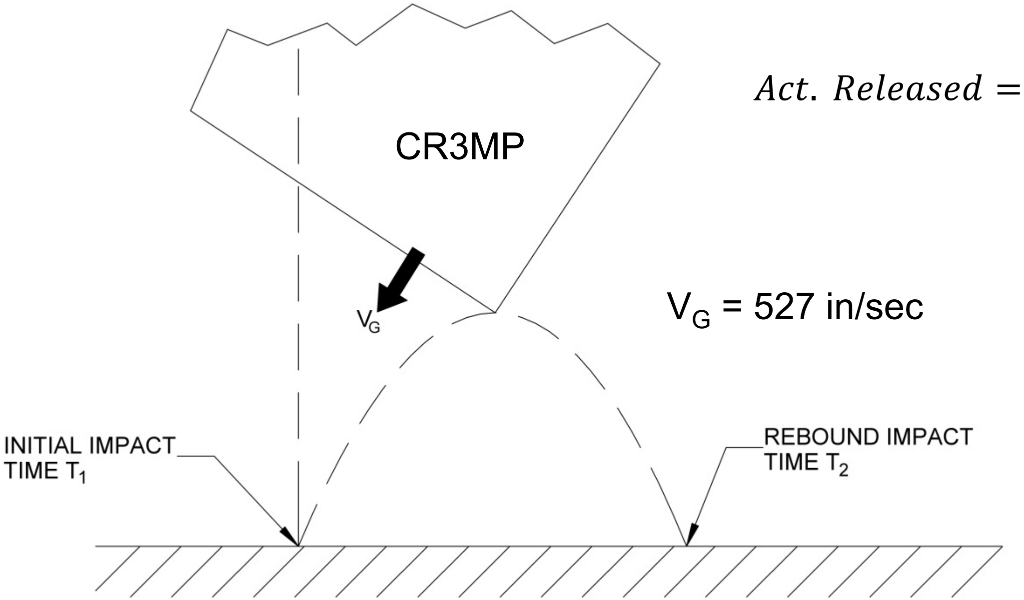
Containment Criteria per 10 CFR 71.51

- Under NCT, no loss of activity exceeding 10^{-6} A2 per hour
- Under HAC, no loss of activity exceeding one A2 per week

Calculation of Activity Loss in HAC Free Drop (no loss under NCT)

- Limited weld failure is expected in two HAC drop orientations (not in NCT)
- LS-Dyna model will calculate circumferential extent and width of opening after metal spring-back
- Area of opening will be conservatively maximized
- LS-Dyna model will calculate the rebound period (time from first impact to second impact), rounded up
- During this time period, it will be assumed that grout exits the opening at the initial impact velocity of 527 inches/second
- 25% of the grout internal to the RPV is assumed to hold all of the dispersible activity
- The grout that exits will be solely the contaminated grout
- Current estimate is that less than one-half A2 of contamination will escape

Containment Evaluation: Drop Testing



V_G = 527 in/sec

$$Q_G = A \times V_G \times (T_2 - T_1)$$

$$Act.\ Released = \left(\frac{Q_G}{0.25 \times Q_{Total}} \times Dispersible\ Act.\right) \leq A_2$$

Where:

Q_G = *Quantity of grout released*

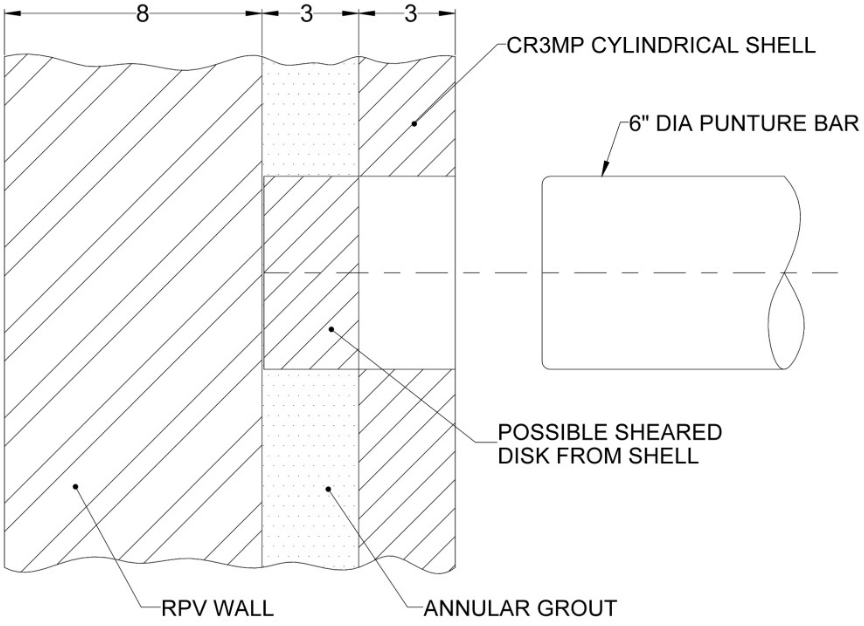
Q_{Total} = *Total amount of grout inside*

A = *Area of opening*

Containment Evaluation: Puncture Testing

Containment Related to the HAC Puncture Event

- **For puncture on closure ends, thickness is adequate to prevent perforation per Nelms equation**
- **For puncture on cylindrical shell, perforation may occur, however:**
  - Puncture bar is backed by massive RPV shell, preventing disturbance of interior grout located inside the containment boundary
  - Small opening can only release a small amount of uncontaminated grout in annulus



Thermal Evaluation

Modeling performed in ANSYS 19.2

- **2D axisymmetric (i.e. cylindrical)**
- **Simplified payload with components/decay heat concentrated at center**

Bounding heat loads

- **500 W decay heat**
- **24-hour averaged insolation loads (acceptable due to package size)**
- **Fire heat flux based on ASTM E2230-13 (10 CFR 71 fire radiation plus convection)**

Material properties

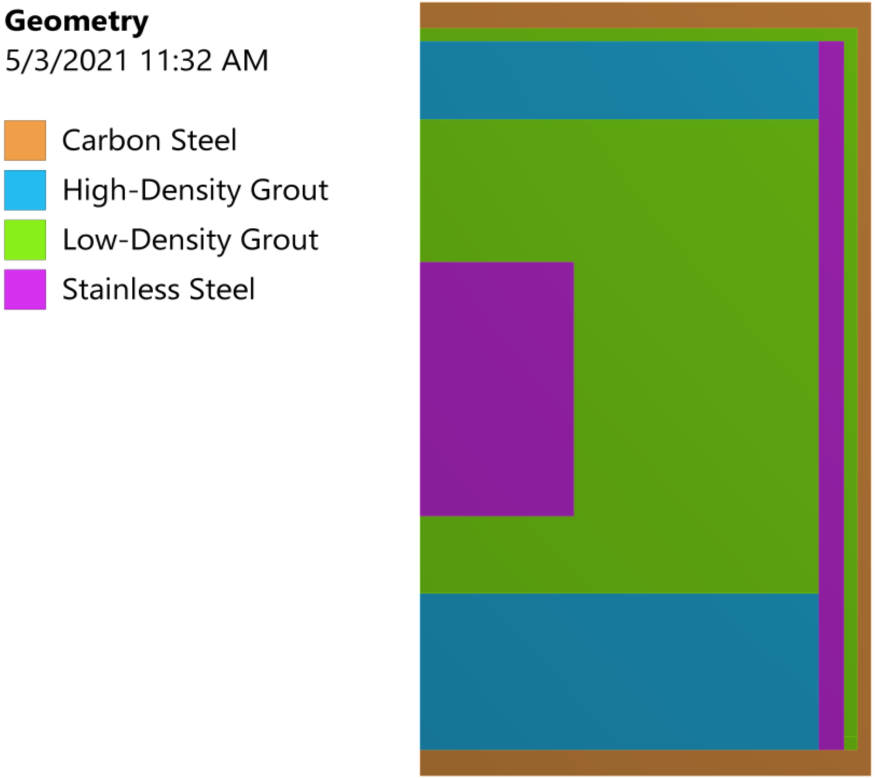
- **Steel per ASME BPVC**
- **Grout per ACI guidance on low-density cellular concrete and NUREG/CR-6900**

Conservative package puncture modeled for HAC

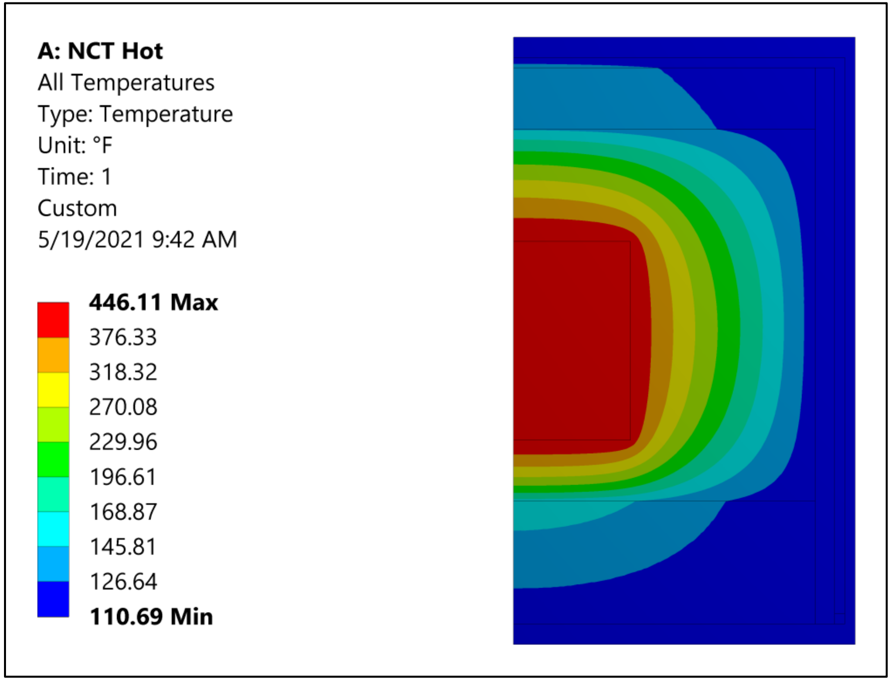
Thermal Evaluation

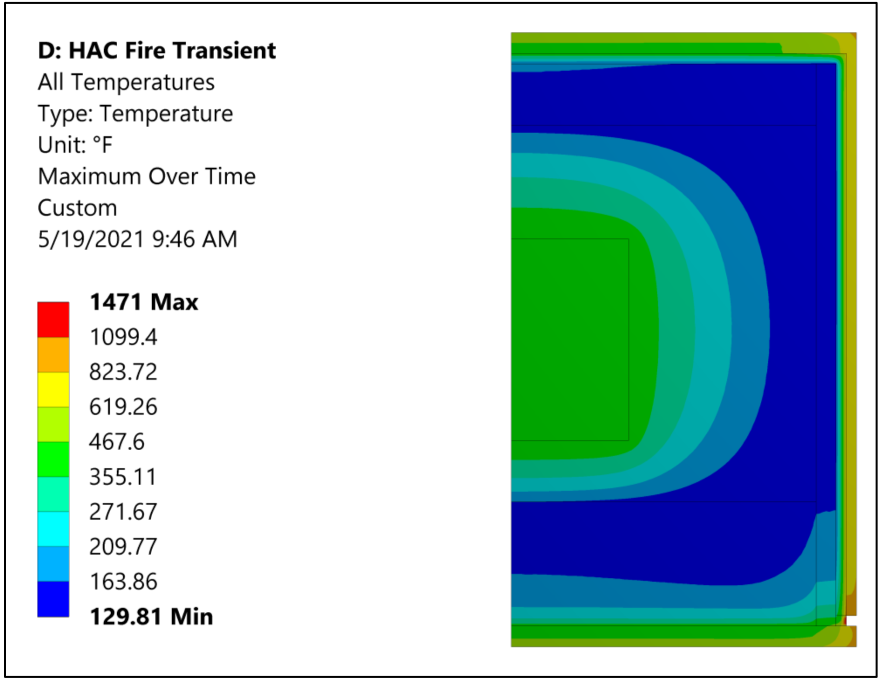
Results

- **Package, package surface, and payload components significantly below limits**
- **Acceptability of grout temperatures based on pressure calculations (no explicit temperature limit)**



Thermal Evaluation





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Evaluation of Internal Pressure

- Pressure will be generated from loss of moisture from grout as it warms due to decay heat, insolation, or fire heat
- Heat source is 500 W in the inner portion of the RPV
- Grout is mainly composed of calcium silicate and calcium hydroxide which hydrate on curing and may dehydrate with significant heating
- Fractional dehydration of calcium silicate is correlated as an Arrhenius function of the form:

$$\alpha = A \times e^{-\frac{E_a}{RT}}$$

Evaluation of Internal Pressure

- Moisture production is a function of grout density and temperature
- For each condition, temperature zones (in the form of concentric volumes) will be established and moles of water vapor released from each zone will be calculated
- Total moles of water vapor, plus initial air (from LDCC bubbles) will be heated to the average shell temperature and pressure calculated using the perfect gas law
- Resulting pressure will be used in structural calculation
- NCT pressure estimate is 11 psig
- HAC pressure estimate is 48 psig

Evaluation of Internal Pressure

Example:

Zone	Zone Volume	Grout Density	Zone Temperature	Moles water vapor released
1	V_1	$Dens_1$	T_1	n_1
2	V_2	$Dens_2$	T_2	n_2
3	V_3	$Dens_3$	T_3	n_3
Etc.	…	…	…	…

$$n_{H_2O} = n_1 + n_2 + n_3 + \cdots$$

$$P = P_0\left(1 + \frac{n_{H_2O}}{n_{air}}\right)\frac{T}{T_0}$$

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Shielding Evaluation

Modeling performed in MCNP6.2

- **RV/RVI geometry and sources modeled using voxel simplification**
- **Component geometry based on CAD models**
- **Activation sources based on Neutron Activation Analysis (NAA)**

Source term conservatively modeled as only Co-60

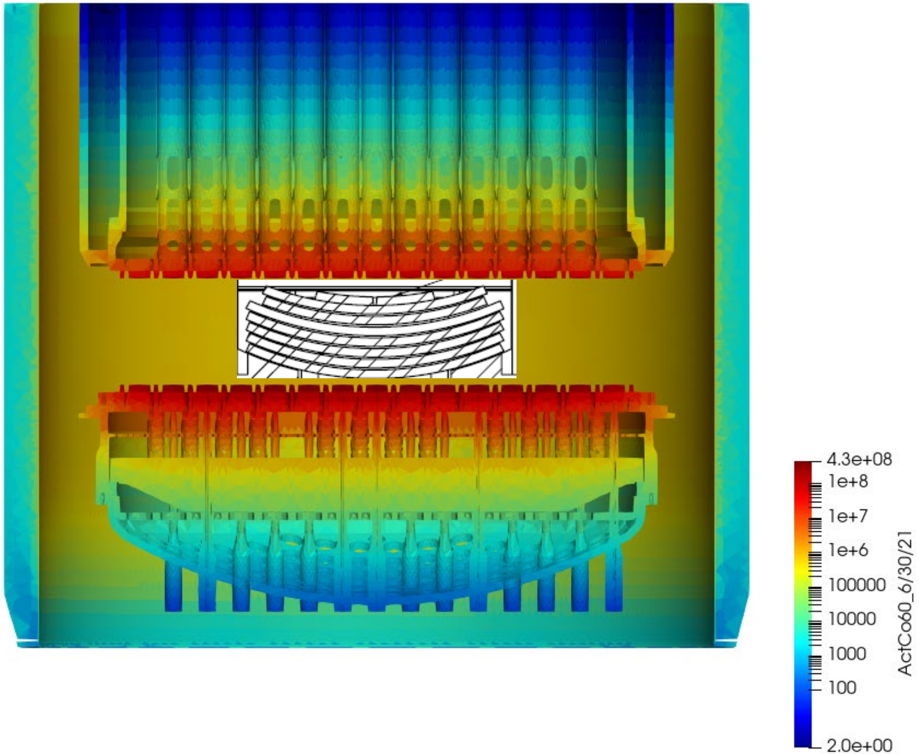
- **Other major isotopes are not significant gamma emitters**
- **No neutron sources**
- **Bounding 30,000 Ci Co-60 activation, ~50 Ci Co-60 contamination**

HAC damage modeled as significant loss of grout outside RV

Results

- **Dose rates ~1/10 of applicable limits**

Shielding Evaluation



Middle Package RV/RVI with Source Distribution

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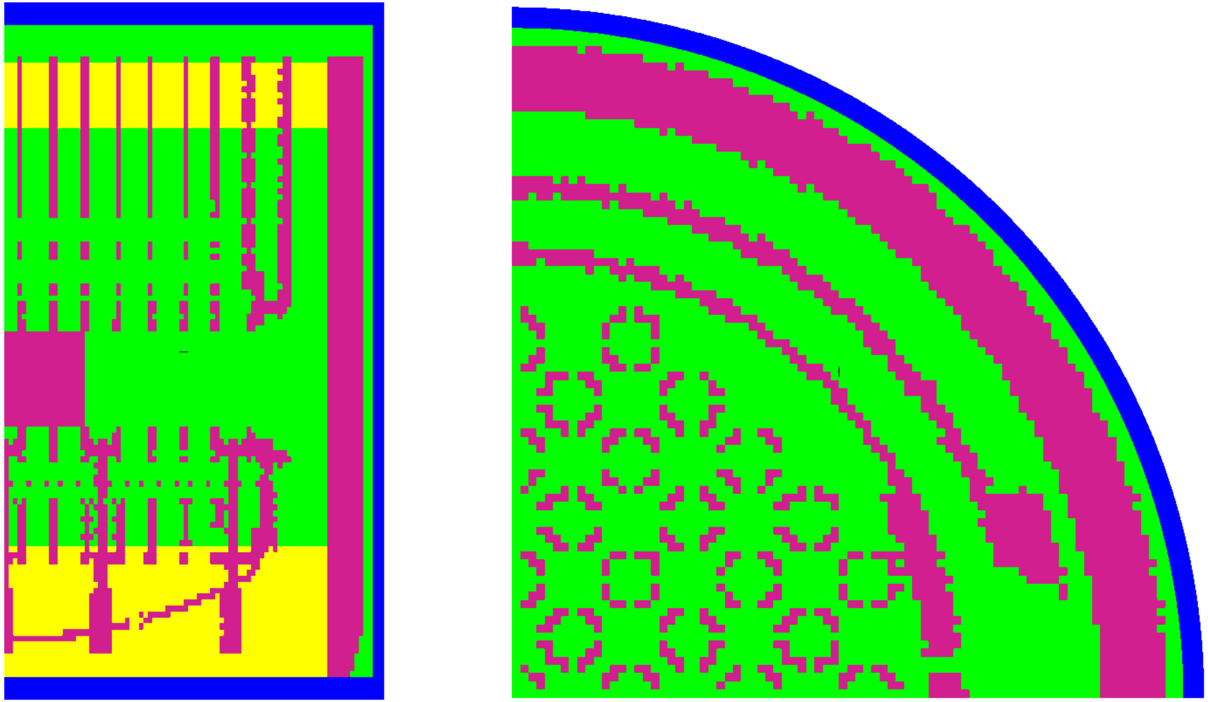
Shielding Evaluation

Axial

Radial



CR3MP MCNP Model (NCT)

Hydrogen

- Hydrogen from radiolysis of the moisture in the grout cannot accumulate due to lack of engineered void spaces within the package
  - **RPV internally, and space between RPV and package will be poured full within manufacturing tolerances**
  - **Grout may crack but will not settle, no voids in overall volume**
  - **From closure to disposal is not expected to exceed approx. 24 months**
  - **Thus hydrogen generation is not of concern**

Project Schedule Timeline

Submit SAR	July 2021
Request for RAIs	December 2021
RPV Package fabrication complete and delivery to Florida	January 2023
Shipment of RPV Package to WCS	July 2023

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WRAP UP DISCUSSION