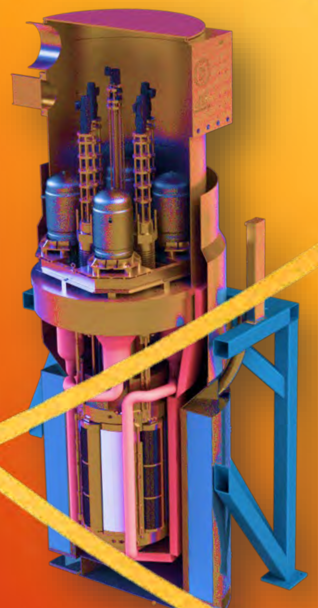
(Microreactor Applications Research, Validation & EvaLuation), 2024



MARVEL

Microreactor Prototype

Sponsored by DOE-NE 5

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2021 ASME Section III, Division 5

- **ASME Section III, Division 5, Subsection HBB**
  - Class A equivalent to Class 1 in Section III, Division 1
    - MARVEL PCS is a Class A pressure vessel
- **HBB Design Methods for Class A Components**
  - Design methods based on elastic analysis results provide conservative bounds (sometimes very conservative) to guard against failure modes
    - Intended as “screening” tools
    - Rely on stress classification, linearization, etc. (not easily integrated with finite element methods)
  - Design methods based on inelastic analysis results provide more accurate but much more complex to implement
    - Complex inelastic material models
    - High computational time

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2021 ASME Section III, Division 5 Cont'd

- **MARVEL will use the allowable Code Cases for Elastic-Perfectly Plastic (EPP)**
  - Use different allowable stresses as pseudo yield stress in EPP finite element analysis to determine different bounding characteristics for different failure modes
  - Intended as simplified "screening" tools in place of elastic analysis methods
  - No stress classification
  - Any geometry or loading
  - Simpler to implement
    - Based on finite element results, no linearization

EPP Design Check	EPP Code Case
Primary Load	N-924
Strain Limits	N-861
Creep-fatigue	N-862

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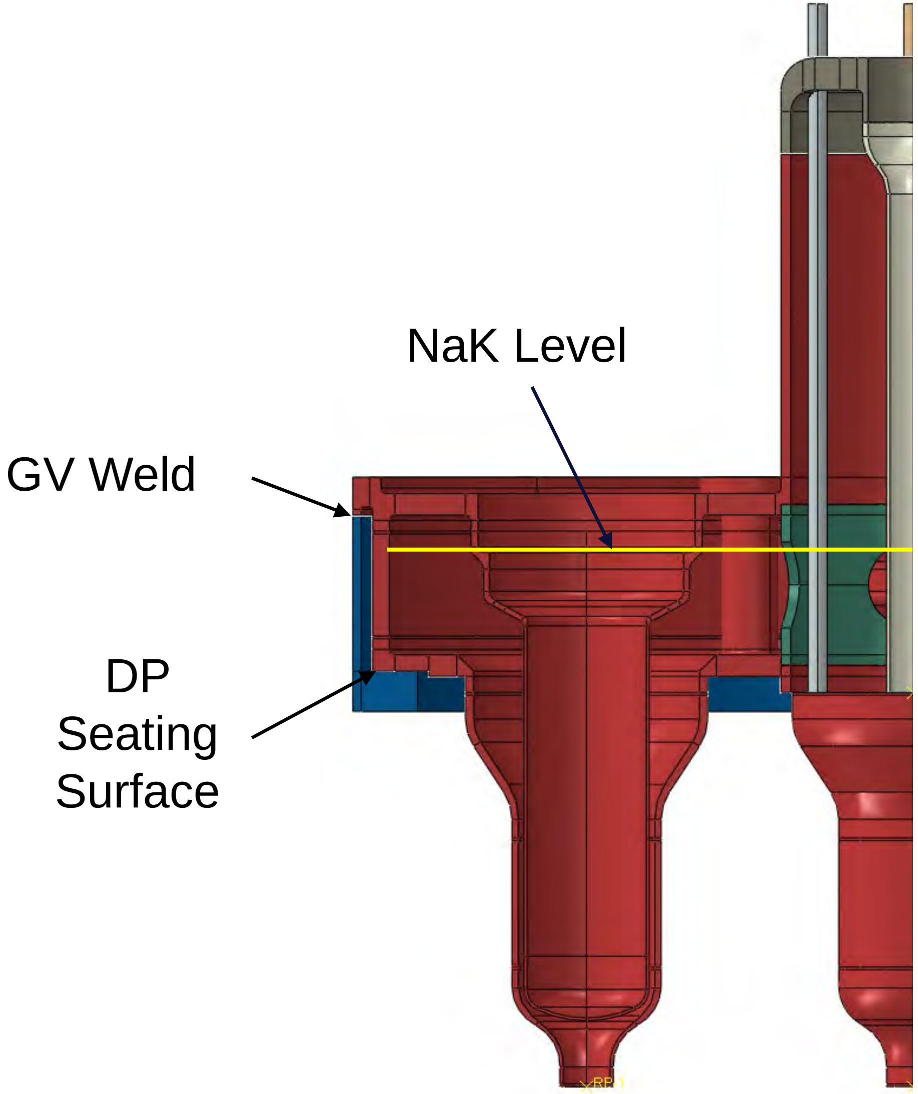
Trouble Areas

- NaK Level
  - 2 in. below Top Plate
  - Creates large thermal discontinuity near structural discontinuity
- GV Weld
  - 0.5 in. Argon gap between GV and PCS
  - Thermal constraint since PCS sits on GV



Trouble Areas Cont’d

Transient Selection History

- Multiple transients for both startup and shutdown have been attempted
  - 1 hr, 9 hr, 16 hr, and 20 hr startups have been tried while also applying various temperature hold points to allow time for heat conduction to take place. Also looked at using the heaters to heat the reactor up to a certain temperature before turning on nuclear power
  - Scram shutdown with Stirlings pulling max heat out, controlled shutdowns of varying times with various hold points
- None of these transients were able to pass the ASME Creep-Fatigue Code Case.

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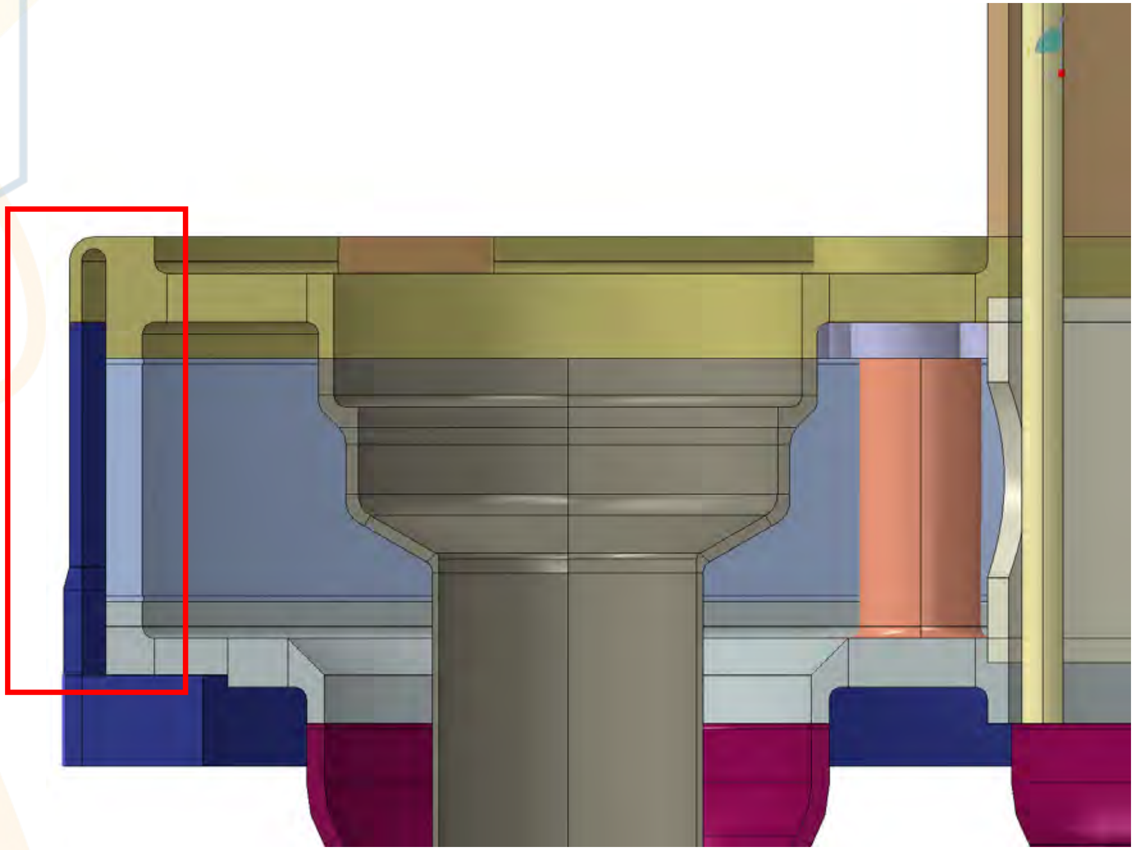
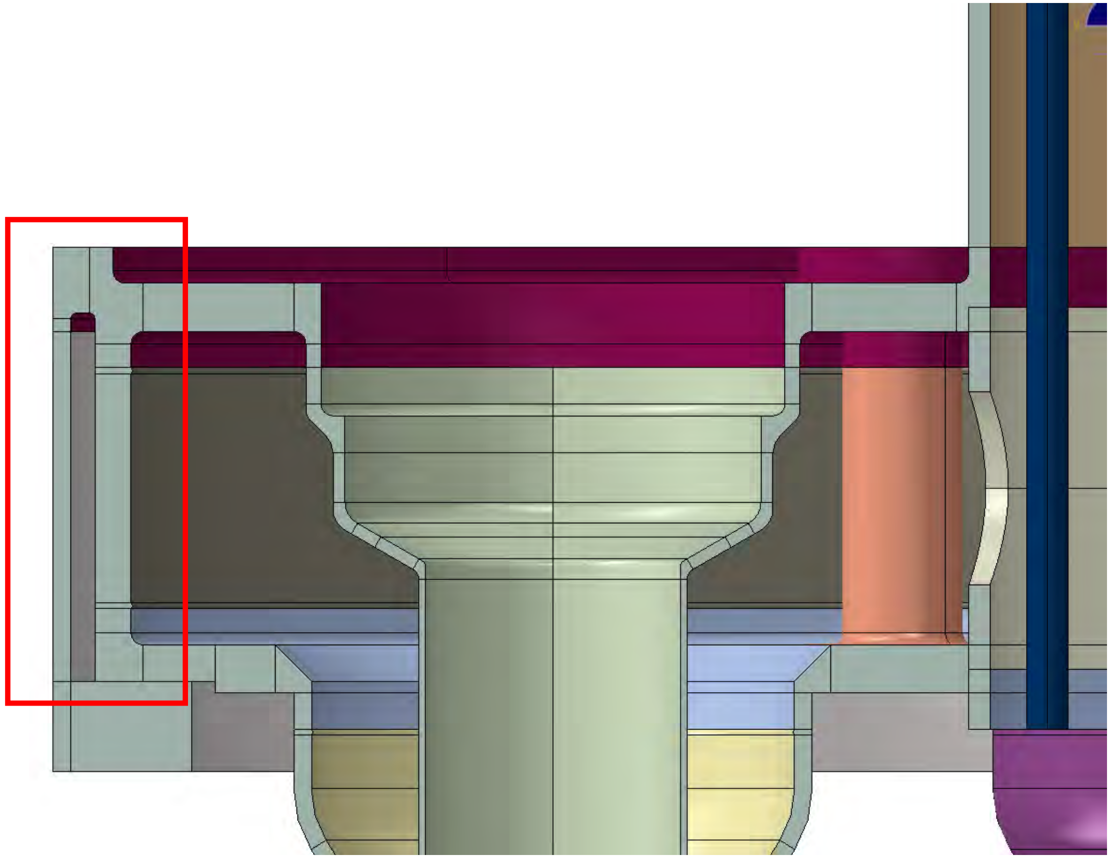
GV-PCS Weld Connection Changes

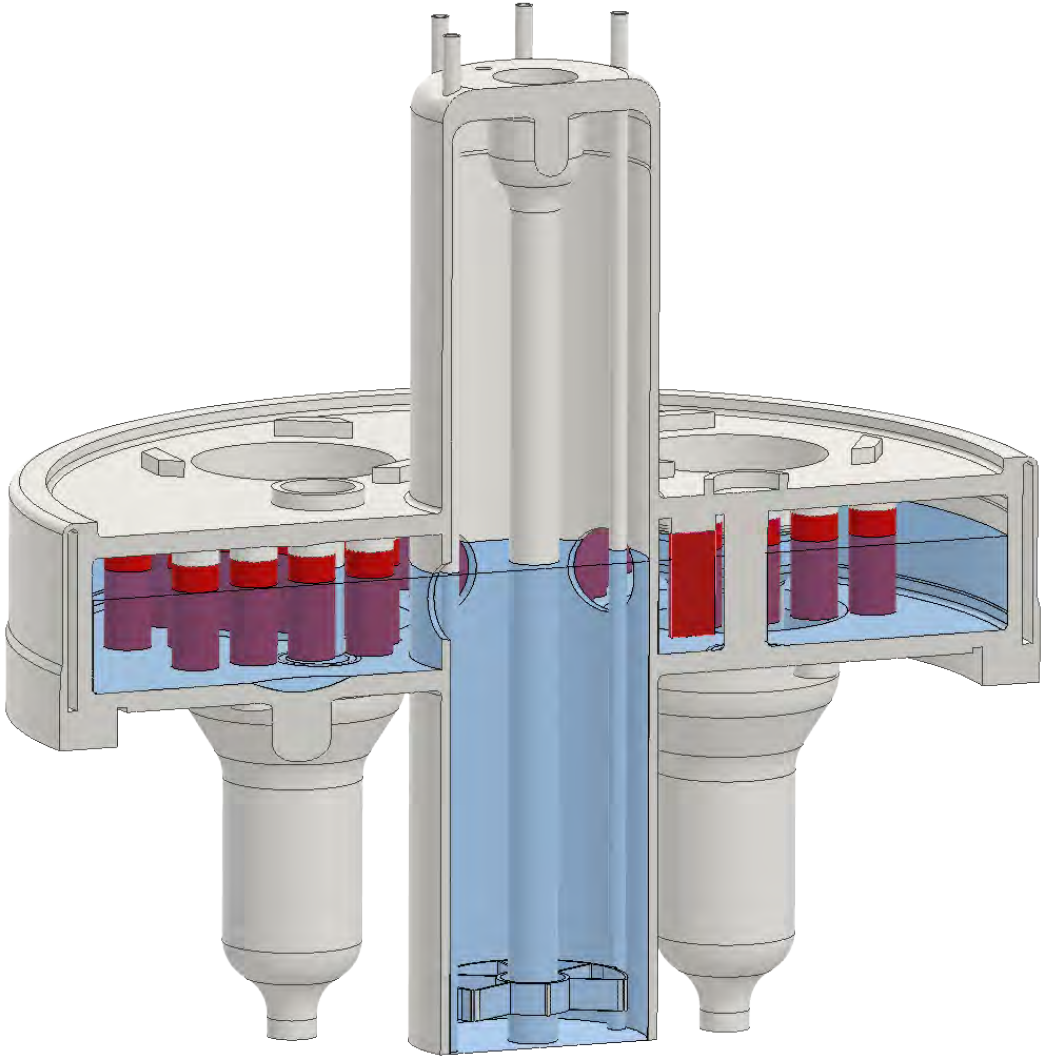


New Design



Old Design

Pin Fins for Increased Conduction



Preliminary Transients that Look Promising

- Startup
  - A 48 hr transient was established by using the CFD model and applying temperature hold points whenever the temperature difference between top and bottom plate reached ~50°C. This was a conservative bounds established by looking at previously run models and where they exceeded ASME limits.
- Shutdown
  - A 10 hr controlled shutdown to 350°C followed by a scram and immediate trip of Stirlings
    - 350°C limit was based on corrosion rate of secondary coolant
- Loss of One Stirling
  - Following a loss of one Stirling accident, steady state temperature only increases ~25°C, therefore, a scram is not necessary. The reactor will undergo a controlled shutdown similar to a normal shutdown.

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Design Loadings to be used going forward

Loading	Description	Number of Cycles	Status
Design	Design Temperature (570°C [1058°F]), Design Pressure (0.38 MPA [55 psig]), Design Mechanical Loads	N/A	Completed (passes ASME limits)
Service Level A	Normal Operating Conditions – Startup (48 hr), hot full power steady state, controlled shutdown over 10 hr to 350°C	156	Ongoing
Service Level B	Loss of Stirling Engine – Startup (48 hr), hot full power steady state, loss of on Stirling followed by a controlled shutdown to 350°C (same ramp rate as normal shutdown)	5	Ongoing
Service Level C	None	N/A	N/A
Service Level D	Unprotected Transient OverPower (UTOP), Seismic	1	Completed (passes ASME limits)

- **Scram Shutdown – All scram shutdowns will trigger an immediate trip of Stirlings which is then enveloped by a normal shutdown**
- **Scram Shutdown with failure of Stirling trip – This will be considered a Service Level D event and is enveloped by the UTOP**

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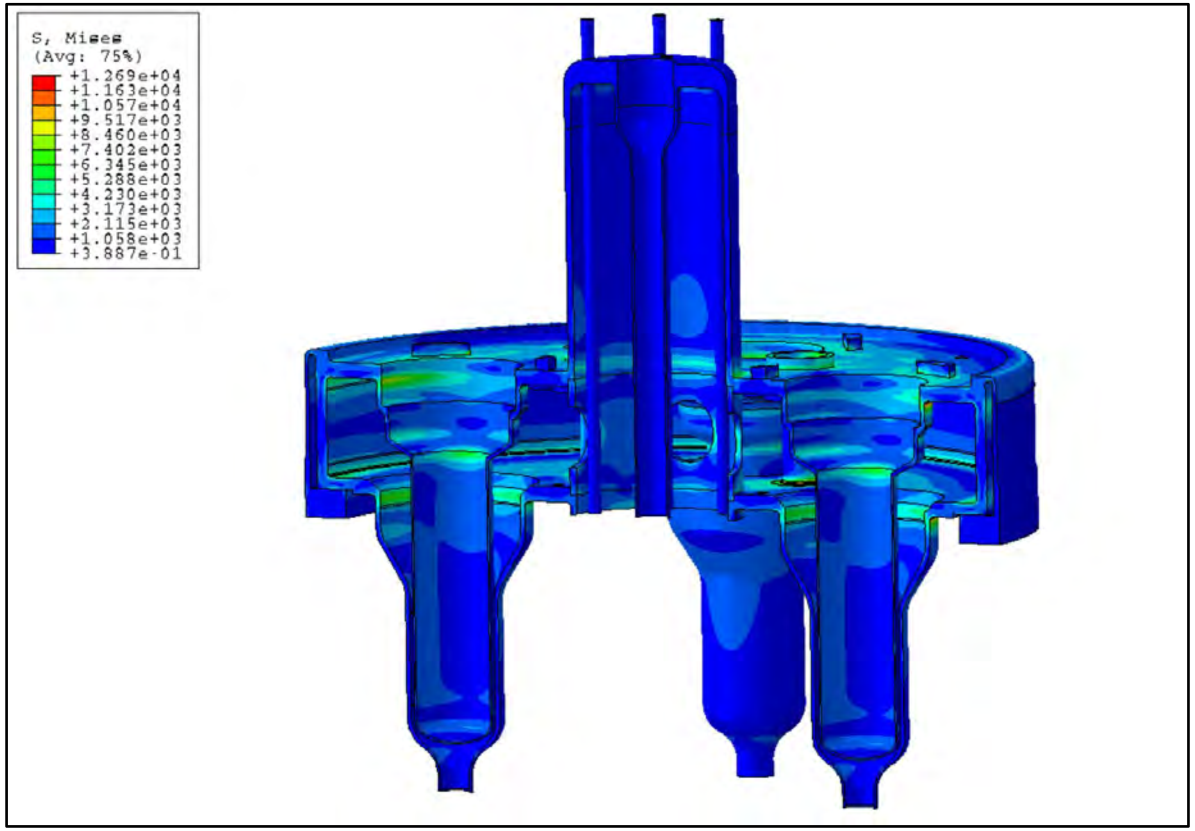
Design Limit Results

- **Code Case N-924 Design Limit Check using** $\sigma_{pseudoyield} = \sqrt{\frac{3}{4} * S_o}$



Buckling Analysis (HBB-T-1500)

- **HBB-T-1521 (Time-Independent Buckling)**
  - Load Factor = 3, Strain Factor = 1.67 (Design, SL-A, SL-B)
    - Flaw Shape = Eigenvalue Buckling Mode Shape
    - Flaw Depth = MMC from Drawings
    - Elastic-Plastic Model
  - Division 1, NB-3133 → Section II, Part D Charts
- **HBB-T-1522 (Time-Dependent Buckling)**
  - Load Factor = 1.5 (Design, SL-A, SL-B)
    - Flaw Shape = Eigenvalue Buckling Mode Shape
    - Flaw Depth = MMC from Drawings
    - Elastic-Plastic Model

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Buckling Analysis (HBB-T-1500) Results

Description	Time-Independent Allowable Pressure		Time-Dependent Allowable Pressure	
	psig	MPa	psig	MPa
IHX Pressure Boundary	*	*	214.5	1.48
Heater Rod	1762.4	12.15	2120.3	14.62
CIA Housing	478.1	3.30	487.5	3.36
Core Barrel	101.0	0.70	N/A**	N/A**

* Time-Independent calculations will be performed once temperature results are calculated.

** Core Barrel below limits provided in Figure HBB-T-1522-3 so Time-Dependent external pressure calculations not needed.

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