



Primary Coolant System ASME Design by Analysis

Kyle Francis (Walsh)

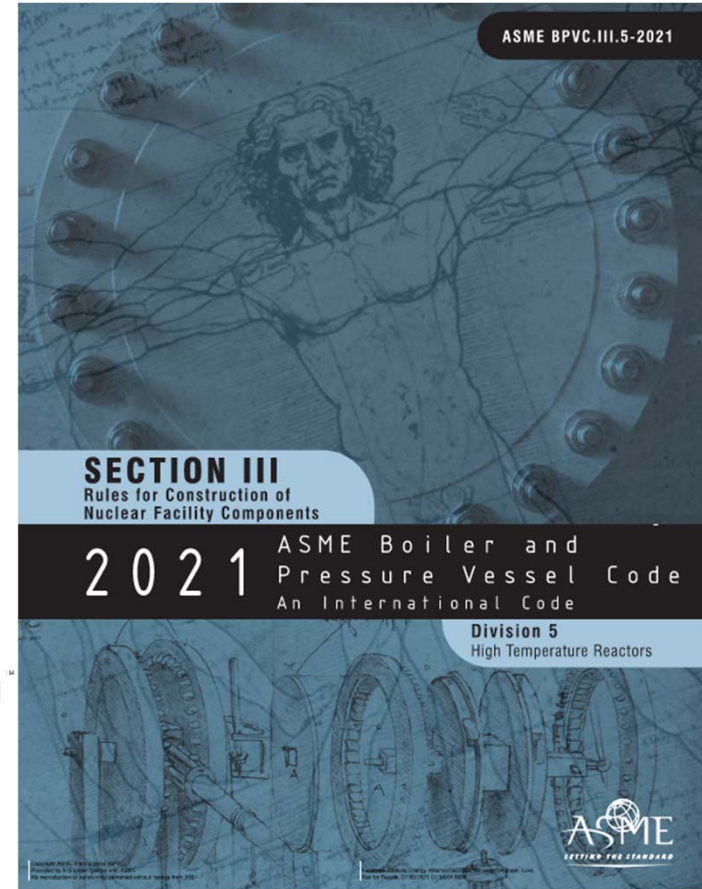
Cody Hale (INL)

Collaborators: INL, Walsh, LANL, ANL



Design Basis

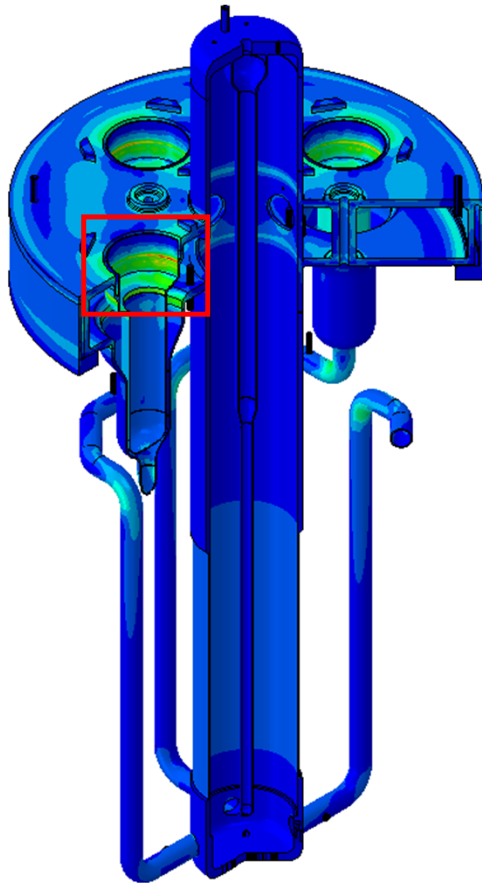
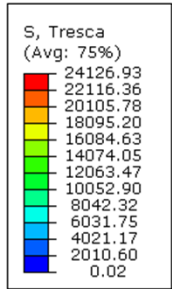
- ASME BPVC Section III Division 5 Subsection HB Subpart B for Elevated Temperature Service of Class A Components
 - Class A metallic pressure boundary components
 - Service loading temperatures > 800°F (425°C)
 - Elastic analysis approach
- Analysis Software Roadmap



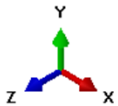
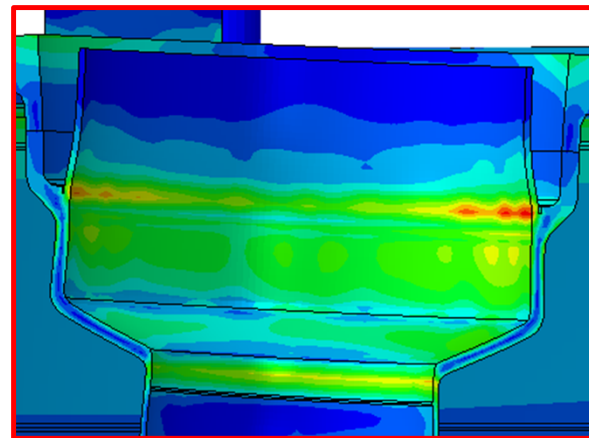
Operational Transients

Evaluation Type	Description	Pressure Input (psig)	Temperature Input	Number of Cycles
Design	-	55	1058°F (570°C)	N/A
Service Level A	Normal Operating Conditions	55	952°F (512°C) Max, Provided by CFD Analysis	156
Service Level B	Loss of One Stirling Engine	55	1051°F (567°C) Max, Provided by CFD Analysis	5
Service Level C	Unprotected Transient Over- Power (UTOP)	55	1128°F (609°C) Max, Provided by CFD Analysis	3
Service Level D	Seismic	55	Maximum Temperature from Service Level A	1

Service Level A Stress Intensity Contours



- Combined Primary and Secondary Stresses
- Maximum 24.1 ksi
- Maximum 19.6 ksi Primary Stress Only

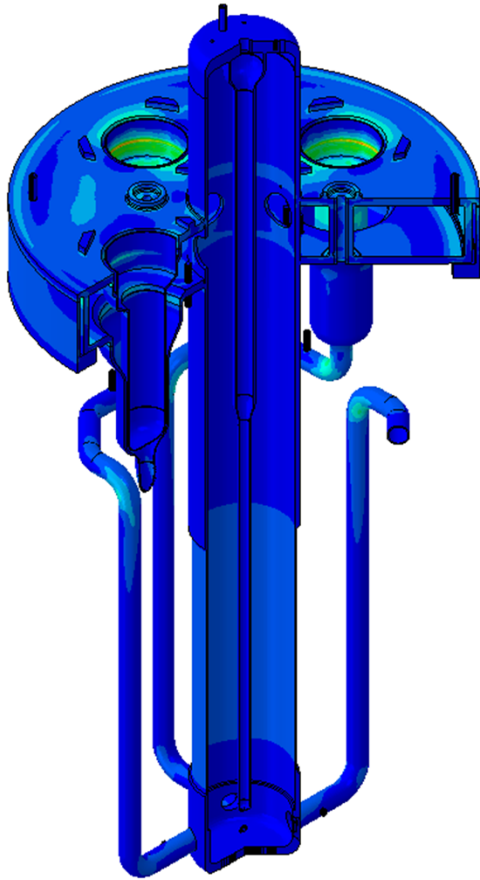
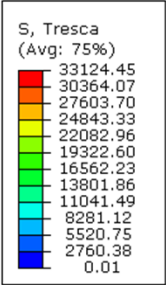


Combined primary and secondary stresses using PCS-Rev-C_R11 temperatures
 ODB: Combined-Stress-SS-C.odb Abaqus/Standard 2021.HF6 Thu Mar 02 09:38:03 Mountain Standard Time 2023
 Step: SS Primary and Secondary Loads, Steady state primary mechanical loads and secondary thermal loads that includes
 Increment 16; Step Time = 1.000
 Primary Var: S, Tresca

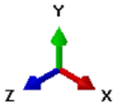


MRP Microreactor Program

Service Level B Stress Intensity Contours



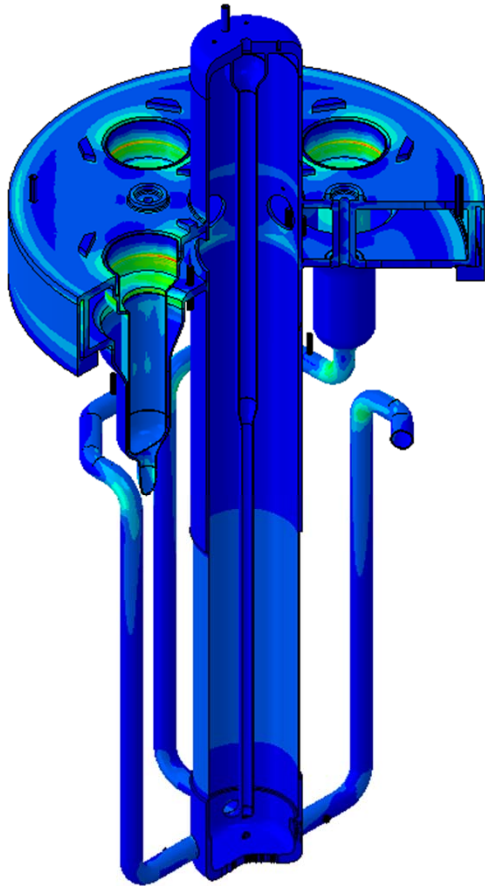
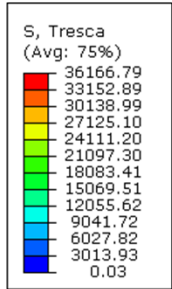
- Combined Primary and Secondary Stresses
- Maximum 33.1 ksi



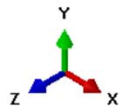
Primary and Secondary stress model from PCS-Rev-C_R11-LOHS temps from CFD
 ODB: LOHS-Combined-Stress-SS-B.odb Abaqus/Standard 2021.HF6 Wed Mar 01 19:15:07 Mountain Standard Time 2023
 Step: SS Primary and Secondary Loads, Steady state primary mechanical loads and secondary thermal loads that includes
 Increment 16: Step Time = 1.000
 Primary Var: S, Tresca



Service Level C Stress Intensity Contours



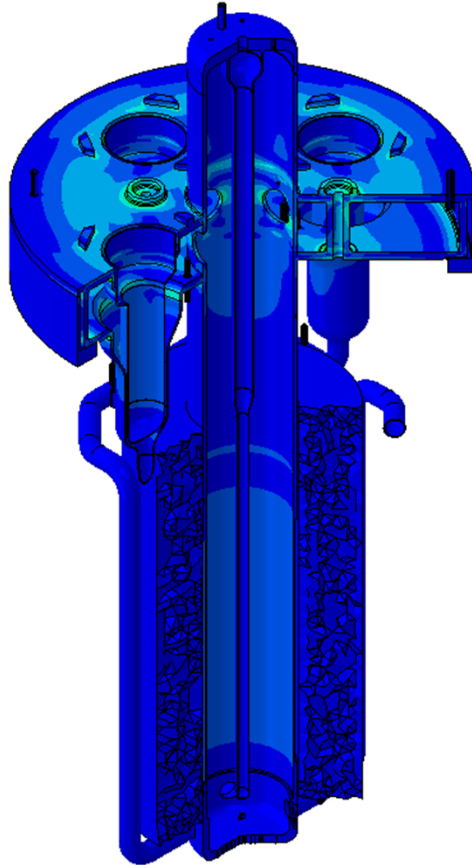
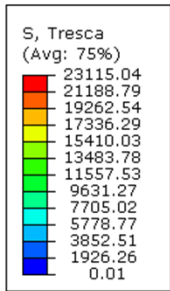
- Combined Primary and Secondary Stresses
- Maximum 36.2 ksi



Combined primary and secondary stresses for SS UTOP at 130kW (1.52x nominal power)
ODB: UTOP-Combined-Stress-SS-C.odb Abaqus/Standard 2021.HF6 Fri Mar 03 16:46:03 Mountain Standard Time 2023
Step: SS Primary and Secondary Loads, Steady state primary mechanical loads and secondary thermal loads that includes
Increment 10; Step Time = 1.000
Primary Var: S, Tresca



Service Level D Stress Intensity Contours



- Maximum 23.1 ksi Primary Stress Intensity
- 0.377 g Seismic Accelerations
- Passes all rules for Level D Service Limits under conservative loading



Static equivalent $x_z=0.377$ g and $y=-0.377$ g
ODB: Seismic-Stress-XZ-SS-B.odb Abaqus/Standard 2021.HF6 Fri Mar 03 00:57:20 Mountain Standard Time 2023
Step: SS Seismic and Primary Loads, Steady state seismic with primary mechanical loads that includes a constant bound
Increment 16: Step Time = 1.000
Primary Var: S, Tresca

ASME Section III Division 5 Code Calculations



ASME Section III, Division 5, Subsection HBB

- Subsection HBB
 - Applicable to all Class A metallic components at elevated temperature
 - $> 800^{\circ}\text{F}$ for 316
 - MARVEL PCS is a Class A component
- Provides limits for various aspects of the Design
 - Design Conditions
 - Design Pressure and Temperature
 - Service Level Conditions
 - Normal operating and off-normal (accident) conditions
 - Deformation-Controlled Quantities
 - Applicable to Service Level A, B, and C Conditions



ASME Section III, Division 5, Design Tool

- Provided by NRC, developed under contract with ANL
- Consists of various python scripts to check the various Design/Service Level Limits
 - 5 Ratcheting Tests
 - 9 Creep-Fatigue Tests
- Tool implements Elastic analysis method
- Time dependent temperature and stress results
 - Results are input to an Excel template
 - Metadata – Case name, Service level, Transient time, Number of Cycles
 - Temperature Data
 - Primary Stress Data
 - Local Primary Stress Data
 - Secondary Stress Data
 - Peak Stress Data



ASME Section III, Division 5, Design Tool

- Sample Input for an Individual Stress Classification Line (SCL)

Temperature Input

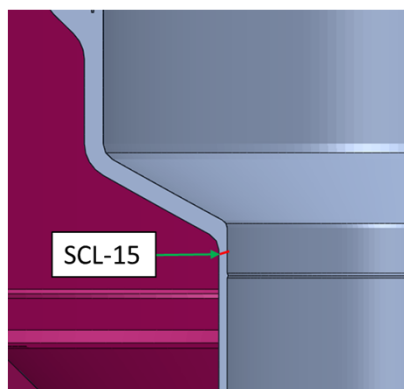
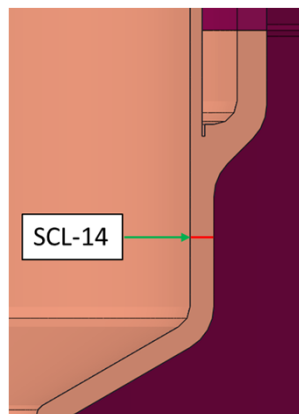
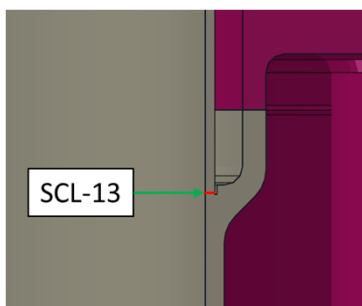
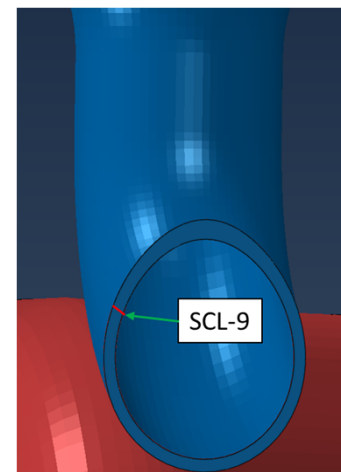
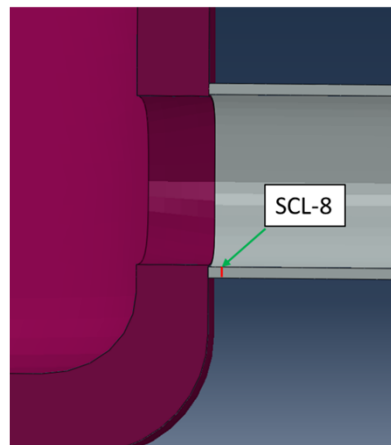
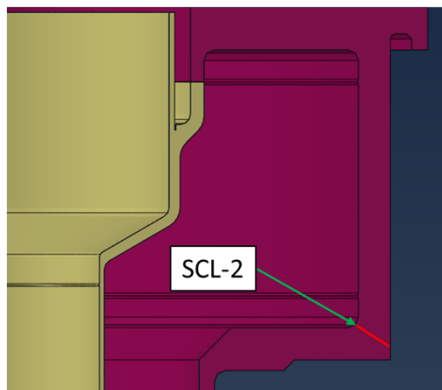
Time	Position	Temperature
0	0.000	427
0	0.025	427
0	0.050	427
0	0.075	427
0	0.100	427
0	0.125	427
1	0.000	442.3544444
1	0.025	442.3544444
1	0.050	442.3544444
1	0.075	442.3538889
1	0.100	442.3533333
1	0.125	442.3527778
71	0.000	442.3544444
71	0.025	442.3544444
71	0.050	442.3544444
71	0.075	442.3538889
71	0.100	442.3533333
71	0.125	442.3527778
72	0.000	427
72	0.025	427
72	0.050	427
72	0.075	427
72	0.100	427
72	0.125	427

Stress Input

Time	Position	XX	YY	ZZ	YZ	XZ	XY
0	0.000	-0.02496	15.1525	22.5087	-0.00474	6.8E-06	0.14283
0	0.025	-0.05304	13.9208	22.242	-0.004	3.2E-06	0.15485
0	0.050	-0.10962	12.7269	21.9777	-0.00326	-2E-06	0.15477
0	0.075	-0.22322	11.6084	21.7183	-0.00251	-1.1E-05	0.13049
0	0.100	-0.31835	10.4992	21.4669	-0.00176	-1.7E-05	0.10448
0	0.125	-0.40424	9.39452	21.2195	-0.00101	-2.3E-05	0.07759
1	0.000	-0.03464	13.3303	22.2204	0.96433	-0.00288	0.12209
1	0.025	-0.06062	12.1393	21.8756	1.00258	-0.00281	0.13019
1	0.050	-0.11395	10.9819	21.5323	1.04031	-0.00256	0.12761
1	0.075	-0.22199	9.89132	21.192	1.077	-0.00192	0.10365
1	0.100	-0.31292	8.81923	20.8622	1.11511	-0.00136	0.07921
1	0.125	-0.39528	7.75631	20.5378	1.15394	-0.00084	0.05452
71	0.000	-0.03464	13.3303	22.2204	0.96433	-0.00288	0.12209
71	0.025	-0.06062	12.1393	21.8756	1.00258	-0.00281	0.13019
71	0.050	-0.11395	10.9819	21.5323	1.04031	-0.00256	0.12761
71	0.075	-0.22199	9.89132	21.192	1.077	-0.00192	0.10365
71	0.100	-0.31292	8.81923	20.8622	1.11511	-0.00136	0.07921
71	0.125	-0.39528	7.75631	20.5378	1.15394	-0.00084	0.05452
72	0.000	-0.02496	15.1525	22.5087	-0.00474	6.8E-06	0.14283
72	0.025	-0.05304	13.9208	22.242	-0.004	3.2E-06	0.15485
72	0.050	-0.10962	12.7269	21.9777	-0.00326	-2E-06	0.15477
72	0.075	-0.22322	11.6084	21.7183	-0.00251	-1.1E-05	0.13049
72	0.100	-0.31835	10.4992	21.4669	-0.00176	-1.7E-05	0.10448
72	0.125	-0.40424	9.39452	21.2195	-0.00101	-2.3E-05	0.07759



SCL Examples

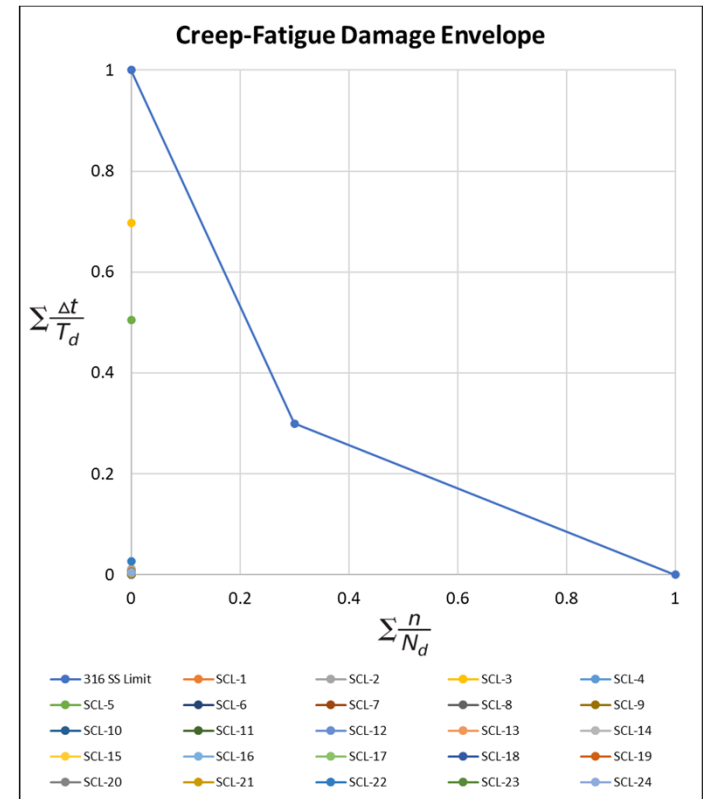


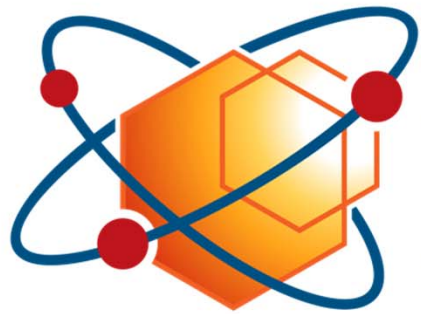
SCL Results (Design and Service Level Limits)

Evaluation Type	Code Section	SCL (Max D-C)	D-C
Design	HBB-3222.1(a)	SCL-12	0.36
	HBB-3222.1(b)	SCL-22	0.99
Service Level A	HBB-3223(a)	SCL-12	0.26
	HBB-3223(c) (eqn 4)	SCL-22	0.73
	HBB-3223(c) (eqn 5)	SCL-22	0.83
Service Level B	HBB-3223(a)	SCL-12	0.27
	HBB-3223(c) (eqn 4)	SCL-22	0.84
	HBB-3223(c) (eqn 5)	SCL-22	0.96
Service Level C	HBB-3224(a)	SCL-12	0.23
	HBB-3224(c) (eqn 9)	SCL-22	0.67
	HBB-3224(c) (eqn 10)	SCL-22	0.92

SCL Results (Ratcheting and Creep-Fatigue)

- All SCL's passed Test A-3 (HBB-T-1324)
- All SCL's passed strain range method (c) (HBB-T-1432(c)) and the creep damage method (HBB-T-1433 step 5 (a))
- All SCL's treated as welds





MRP Microreactor
Program