



# Flaw Tolerance per the ASME Code of CASS Piping at an M310 Plant

## Moment Discrepancies



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# Background

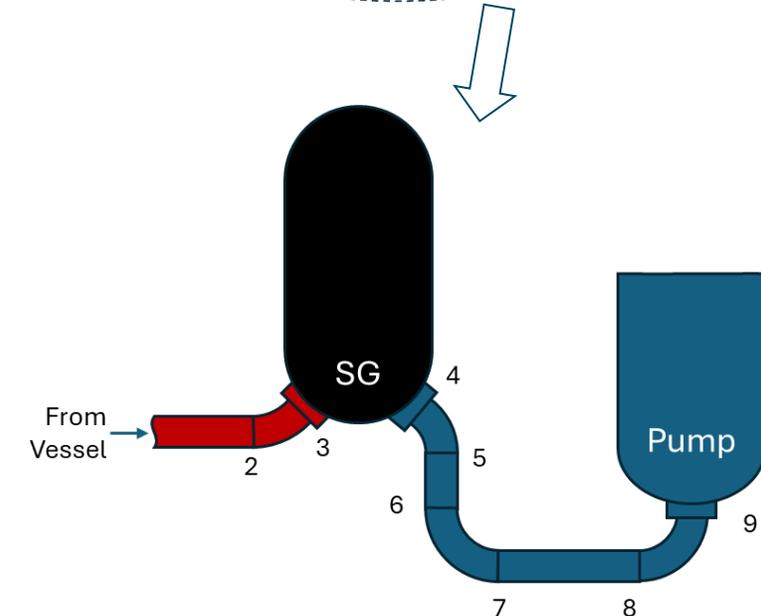
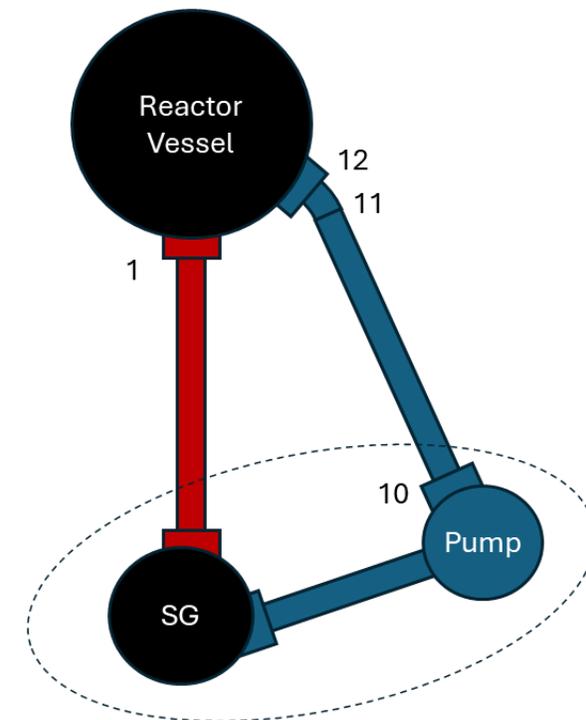
- Framatome-designed M310 plants are built to the French RCC-M Code and typically inspected per the French RSE-M Code
- ASME Boiler and Pressure Vessel Code, Section XI requirements for periodic volumetric examination of the similar metal welds in the main loop piping (IWB-2500 Category B-J) include a portion of the adjoining base metal within the examination volume
  - Equivalent RSE-M requirements (B 4810) are more limited in scope and volume
- Main loop piping in M310 plants is fabricated from Z3 CN 20-09 M, which is cast austenitic stainless steel (CASS)
- Because of the heterogenous microstructure of CASS material, a desired target flaw size for qualification of ultrasonic testing (UT) methods is a one-quarter thickness ( $1/4 t$ ) initial reference flaw
- A flaw tolerance evaluation is needed to justify the target flaw size for UT qualification and perhaps to justify a deeper target flaw size if necessary

# Project Objective and Approach

- **Objective:** Demonstrate, using ASME Section XI methodologies, that a flaw detectability depth of 25% the wall thickness would result in acceptable flaw tolerance evaluation results for the large-diameter main loop piping at a M310 plant
- **Approach:** The project is being performed in two phases
  - For this Phase 1, inputs needed to perform a flaw tolerance evaluation were gathered for two M310 units, implications of material and mechanical loading on allowable flaw size were assessed deterministically, and an example fatigue crack growth calculation are performed
  - For Phase 2:
    - The remaining flaw growth cases will be evaluated,
    - PFM methodologies will be employed for locations not meeting deterministic criteria (or to illustrate how PFM can be used to extend the assumed evaluation time period or increase the target flaw depth), and
    - Results documented as an EPRI report

# Scope and Geometry

- Assess all large-diameter CASS components (straight pipe segments, elbows, and reactor coolant pump nozzles) within the main loop piping at two units using the M310 design
- Each of the 3-loops of the M310 design has four segments of CASS straight pipe and five CASS elbows
  - All are fabricated from Z3 CN 20-09 M
- There are twelve (12) piping butt welds adjoining CASS in the reactor coolant main loop—see figure at right
  - These butt welds are subject to periodic UT in a plant inspected per ASME Section XI requirements
  - Outside diameters from 826.4 to 973.6 mm
  - Thicknesses from 64 to 93.1 mm
- As in the recent EPRI MRP-479 report, CASS branch piping nozzles are excluded from the project scope
  - The inclined branch nozzles for the subject M310 design are CASS
  - Branch lines may also included CASS valve bodies
  - Including the branch lines in the scope of the flaw tolerance evaluations would require substantial additional effort as the design loads for the branch lines are distinct from those for the large-diameter main loop piping



# Mechanical Piping Loads

- To find the allowable flaw size, the mechanical piping loads\* need to be known for each service level at each location, as considered in the design basis:
  - Internal pressure (primary), deadweight (primary), pressure expansion (primary), thermal expansion (secondary\*\*), operating basis earthquake (OBE) inertial loads (primary), safe shutdown earthquake (SSE) inertial loads (primary), and loss of coolant accident (LOCA) pipe break loads (primary)†
  - For the subject plant, the design seismic events (either OBE or SSE) have no associated seismic anchor movement (SAM) loads (secondary)
  - The three reactor loops are nominally identical, so the design load information is generic to the three reactor loops
- In Category 4, the piping design basis considered loads from a break in one of three locations:
  - Main loop LOCA on the same leg as the analysis node (“Same Leg”)
  - Main loop LOCA on a different leg of the same loop (“Other Leg”)
  - Main loop LOCA on a different loop (“Other Loop”) concurrent with the SSE (seismic) loads

Type	RCC-M Category	ASME Service Level	Pressure	Temperature	Dead-weight	Pressure Expansion	Thermal Expansion	OBE (1/2 SSE)	SSE	Pipe Break
Design	1	Design	Design	Design	DW			OBE		
Normal	2	A	Normal	Normal	DW	Normal	Normal	OBE		
Upset		B	Upset	Upset	DW	Upset	Upset	OBE		
Emergency	3	C	Emergency	Emergency	DW					6-inch Branch
Faulted	4	D	Faulted	Faulted						Same Leg
Faulted	4	D	Faulted	Faulted					SSE	Other Leg
Faulted	4	D	Faulted	Faulted					SSE	Other Loop

\* N-838 and §XI, App. C assume that mechanical axial forces on piping are negligibly small compared to bending and pressure loads (C-2500)

\*\* Unlike App. C, N-838 does not differentiate between primary and secondary loads

† U.S. plants have generally eliminated LOCA loads from their main loop piping design basis by demonstrating leak before break

# Mechanical Piping Loads: Comparison vs. Stress Report

- Piping moments available from two sources: a document with a full listing of moments at each node, and the Unit 1 and 2 reactor coolant piping stress analysis report (SAR)
  - Nodal moments provided for (Category 1 [design], Category 2, and Category 4), including at all 12 welds
  - Piping SAR lists Category 3 and Category 4 moments as input to RCC-M Equation (9) for the middle of the 5 elbows and the 6 ends of the piping legs; results of RCC-M Equation (9) are also provided for Category 1, Category 3 and Category 4
- For Category 1 and 4, compared moments from the two sources and the resulting Equation (9) stresses
  - The results of Equation (9) in the SAR for the 6 piping ends can be reproduced by assuming the moments listed in the SAR (when available)
  - However, the moments in the SAR appear to be inconsistent with the nodal moment data in some cases
- Resolution of these discrepancies is needed as the SAR does not include resultant moments for some of the locations and load cases within the project scope
  - We need to apply the data in the nodal moment document to complete inputs for Phase 2

**The discrepancies should be resolved to set needed moment inputs for Phase 2**

# Equation (9) Results in SAR

- The SAR includes sufficient information to show that the moment implied by the piping design Equation (9) matches the moment cited in the SAR when the moment value is listed:
  - The data cover most of the third and fourth operating conditions for each of the six piping segment ends

$$B_1 \frac{PD_o}{2t} + B_2 \frac{M_i D_o}{2I} \leq \alpha S_m \quad \text{Eq (9)}$$

- The SAR does not include needed moment data for some operating conditions, as well as for all the operating conditions for the other six locations within the project scope

Piping Segment	Location Reactor Coolant Piping Location	Load Set Case RCC-M Load Set Category	ASME Service Level	Can result of RCC-M Eq (9) in the SAR be reproduced from the data in SAR alone?						
				Stress Report Eq (9) LHS (MPa)	Pressure P (MPa)	$B_1 PD_o/2t$	$B_2 D_o M_i/2I$	Primary $M_i$ Implied by Eq (9) Result ( $10^4$ m-N)	Primary $M_i$ Listed in Stress Report ( $10^4$ m-N)	Does moment implied by stress result match the moment listed?
Hot Leg	RV Outlet Nozzle	First	Design	104	17.23	55.972	48.028	151.7	N/A	N/A
Hot Leg	RV Outlet Nozzle	Second	A	N/A	16.00	51.976	N/A	N/A	N/A	N/A
Hot Leg	RV Outlet Nozzle	Second	B	N/A	17.23	55.972	N/A	N/A	N/A	N/A
Hot Leg	RV Outlet Nozzle	Third	C	78.575	19.50	63.346	15.229	48.100	48.100	Yes
Hot Leg	RV Outlet Nozzle	Fourth (same leg)	D	144.227	15.50	50.352	93.875	296.500	296.500	Yes
Hot Leg	RV Outlet Nozzle	Fourth (other leg)	D	156.783	18.80	61.072	95.711	302.299	302.300	Yes
Hot Leg	RV Outlet Nozzle	Fourth (other loop)	D	138.441	18.80	61.072	77.369	244.366	244.368	Yes
Hot Leg	SG Inlet Nozzle	First	Design	79	17.23	45.046	33.954	176.0	N/A	N/A
Hot Leg	SG Inlet Nozzle	Second	A	N/A	16.00	41.830	N/A	N/A	N/A	N/A
Hot Leg	SG Inlet Nozzle	Second	B	N/A	17.23	45.046	N/A	N/A	N/A	N/A
Hot Leg	SG Inlet Nozzle	Third	C	60.375	19.50	50.981	9.394	48.701	48.700	Yes
Hot Leg	SG Inlet Nozzle	Fourth (same leg)	D	115.270	15.50	40.523	74.747	387.497	387.500	Yes
Hot Leg	SG Inlet Nozzle	Fourth (other leg)	D	118.380	18.80	49.151	69.229	358.894	358.895	Yes
Hot Leg	SG Inlet Nozzle	Fourth (other loop)	D	118.480	18.80	49.151	69.329	359.412	359.413	Yes
Crossover	SG Outlet Nozzle	First	Design	109.5	17.23	45.046	64.454	334.1	N/A	N/A
Crossover	SG Outlet Nozzle	Second	A	N/A	16.00	41.830	N/A	N/A	N/A	N/A
Crossover	SG Outlet Nozzle	Second	B	N/A	17.23	45.046	N/A	N/A	N/A	N/A
Crossover	SG Outlet Nozzle	Third	C	61.764	19.50	50.981	10.783	55.902	55.900	Yes
Crossover	SG Outlet Nozzle	Fourth (same leg)	D	N/A	15.50	40.523	N/A	N/A	N/A	N/A
Crossover	SG Outlet Nozzle	Fourth (other leg)	D	161.834	18.80	49.151	112.683	584.165	584.168	Yes
Crossover	SG Outlet Nozzle	Fourth (other loop)	D	126.444	18.80	49.151	77.293	400.699	400.702	Yes
Crossover	Pump Suction	First	Design	79	17.23	53.243	25.757	106.2	N/A	N/A
Crossover	Pump Suction	Second	A	N/A	16.00	49.442	N/A	N/A	N/A	N/A
Crossover	Pump Suction	Second	B	N/A	17.23	53.243	N/A	N/A	N/A	N/A
Crossover	Pump Suction	Third	C	73.991	19.50	60.258	13.733	56.600	56.600	Yes
Crossover	Pump Suction	Fourth (same leg)	D	N/A	15.50	47.897	N/A	N/A	N/A	N/A
Crossover	Pump Suction	Fourth (other leg)	D	149.015	18.80	58.094	90.921	374.717	374.717	Yes
Crossover	Pump Suction	Fourth (other loop)	D	100.662	18.80	58.094	42.568	175.436	175.435	Yes
Cold Leg	Pump Discharge	First	Design	79.5	17.23	55.621	23.879	64.8	N/A	N/A
Cold Leg	Pump Discharge	Second	A	N/A	16.00	51.650	N/A	N/A	N/A	N/A
Cold Leg	Pump Discharge	Second	B	N/A	17.23	55.621	N/A	N/A	N/A	N/A
Cold Leg	Pump Discharge	Third	C	100.339	19.50	62.948	37.391	101.494	101.500	Yes
Cold Leg	Pump Discharge	Fourth (same leg)	D	163.111	15.50	50.036	113.075	306.934	307.000	Yes
Cold Leg	Pump Discharge	Fourth (other leg)	D	163.146	18.80	60.689	102.457	278.113	278.168	Yes
Cold Leg	Pump Discharge	Fourth (other loop)	D	106.514	18.80	60.689	45.825	124.389	124.404	Yes
Cold Leg	RV Inlet Nozzle	First	Design	79	17.23	52.221	26.779	79.1	N/A	N/A
Cold Leg	RV Inlet Nozzle	Second	A	N/A	16.00	48.493	N/A	N/A	N/A	N/A
Cold Leg	RV Inlet Nozzle	Second	B	N/A	17.23	52.221	N/A	N/A	N/A	N/A
Cold Leg	RV Inlet Nozzle	Third	C	93.951	19.50	59.101	34.850	102.899	102.900	Yes
Cold Leg	RV Inlet Nozzle	Fourth (same leg)	D	93.005	15.50	46.977	46.028	135.901	135.900	Yes
Cold Leg	RV Inlet Nozzle	Fourth (other leg)	D	193.535	18.80	56.979	136.556	403.195	403.197	Yes
Cold Leg	RV Inlet Nozzle	Fourth (other loop)	D	106.636	18.80	56.979	49.657	146.617	146.618	Yes

# Moment Comparison

- The moments listed or implied by Equation (9) in the SAR were compared to the moments determined using the data in Nodal Moment Document
  - Individual moments from the Nodal Moment Document were combined both through conservative summation of individual resultant moments and through vectoral addition (both approaches are permitted by the RCC-M design code)
- Where such comparison was possible, the moments were found to be in good agreement except for the following cases:
  - First operating condition for the steam generator outlet nozzle
  - Fourth operating condition (break on other leg or other loop) for all six piping segment ends
- In each case of fourth condition disagreement, the value from the Nodal Moment Document exceeded the moment value from the SAR
- The discrepancies are illustrated by the three examples on the following slide

Location		Load Set Case		Comparison	
Piping Segment	Reactor Coolant Piping Location	RCC-M Load Set Category	ASME Service Level	Moment from SAR (10 <sup>4</sup> m-N)	Do moments match?
Hot Leg	RV Outlet Nozzle	First	Design	151.7	Yes
Hot Leg	RV Outlet Nozzle	Second	A	N/A	N/A
Hot Leg	RV Outlet Nozzle	Second	B	N/A	N/A
Hot Leg	RV Outlet Nozzle	Third	C	48.1	Yes
Hot Leg	RV Outlet Nozzle	Fourth (same leg)	D	296.5	Yes
Hot Leg	RV Outlet Nozzle	Fourth (other leg)	D	302.3	No
Hot Leg	RV Outlet Nozzle	Fourth (other loop)	D	244.4	No
Hot Leg	SG Inlet Nozzle	First	Design	176.0	Yes
Hot Leg	SG Inlet Nozzle	Second	A	N/A	N/A
Hot Leg	SG Inlet Nozzle	Second	B	N/A	N/A
Hot Leg	SG Inlet Nozzle	Third	C	48.7	Yes
Hot Leg	SG Inlet Nozzle	Fourth (same leg)	D	387.5	Yes
Hot Leg	SG Inlet Nozzle	Fourth (other leg)	D	358.9	No
Hot Leg	SG Inlet Nozzle	Fourth (other loop)	D	359.4	No
Crossover	SG Outlet Nozzle	First	Design	334.1	No
Crossover	SG Outlet Nozzle	Second	A	N/A	N/A
Crossover	SG Outlet Nozzle	Second	B	N/A	N/A
Crossover	SG Outlet Nozzle	Third	C	55.9	Yes
Crossover	SG Outlet Nozzle	Fourth (same leg)	D	N/A	N/A
Crossover	SG Outlet Nozzle	Fourth (other leg)	D	584.2	No
Crossover	SG Outlet Nozzle	Fourth (other loop)	D	400.7	No
Crossover	Pump Suction	First	Design	106.2	Yes
Crossover	Pump Suction	Second	A	N/A	N/A
Crossover	Pump Suction	Second	B	N/A	N/A
Crossover	Pump Suction	Third	C	56.6	Yes
Crossover	Pump Suction	Fourth (same leg)	D	N/A	N/A
Crossover	Pump Suction	Fourth (other leg)	D	374.7	No
Crossover	Pump Suction	Fourth (other loop)	D	175.4	No
Cold Leg	Pump Discharge	First	Design	64.8	Yes
Cold Leg	Pump Discharge	Second	A	N/A	N/A
Cold Leg	Pump Discharge	Second	B	N/A	N/A
Cold Leg	Pump Discharge	Third	C	101.5	Yes
Cold Leg	Pump Discharge	Fourth (same leg)	D	307.0	Yes
Cold Leg	Pump Discharge	Fourth (other leg)	D	278.2	No
Cold Leg	Pump Discharge	Fourth (other loop)	D	124.4	No
Cold Leg	RV Inlet Nozzle	First	Design	79.1	Yes
Cold Leg	RV Inlet Nozzle	Second	A	N/A	N/A
Cold Leg	RV Inlet Nozzle	Second	B	N/A	N/A
Cold Leg	RV Inlet Nozzle	Third	C	102.9	Yes
Cold Leg	RV Inlet Nozzle	Fourth (same leg)	D	135.9	Yes
Cold Leg	RV Inlet Nozzle	Fourth (other leg)	D	403.2	No
Cold Leg	RV Inlet Nozzle	Fourth (other loop)	D	146.6	No

# Example 1 (First Condition)

- Example 1: Steam generator outlet nozzle / First condition
  - The Equation (9) stress result is shown in the SAR (page 9 of Vol. 2) as 109.5 MPa
  - The implied primary moment is  $334 \cdot 10^4$  m-N
  - The first operating condition is understood to include the deadweight and seismic OBE mechanical piping loads
  - The data in the Nodal Moment Document show a total moment for these load sources of about  $231 \cdot 10^4$  m-N, which reflects a large disagreement
  - The above procedure showed good agreement for the other five piping segment end locations

*Crossover Leg Connection to the Steam Generator - Region 3*

Condition	Design Value	Acceptable Value
<u>Design Condition</u> - Equation (9) value	109.5 MPa	$1.5 S_m = 158$ MPa

# Examples 2-3 (Fourth Condition)

- Example 2: Reactor vessel outlet nozzle / Fourth condition
  - The SAR explicitly lists (page 145 of Vol. 2) the primary moments for these cases as 302.3 and 244.4  $10^4$  m-N
- Example 3: Reactor vessel inlet nozzle / Fourth condition
  - The SAR explicitly lists (page 150 of Vol. 2) the primary moments for these cases as 403.2 and 146.6  $10^4$  m-N
- These fourth operating conditions with the break on other leg or on the other loop are specified to also include the seismic SSE mechanical piping loads
- The data in the Nodal Moment Document disagree with these SAR moments regardless of how the main pipe break and SSE loads are combined
- Whether or not the deadweight load is included cannot explain the discrepancies
- No other load sources could be identified as a potential explanation

REACTOR VESSEL OUTLET

WELD LOCATION	MI LEG NM	B1PDO/2I MPA	B2DDMI/2I MPA	EQ. 9 MPA	MAX. VALUE MPA
BROKEN LEG ( BREAK ON HOT LEG )	296.500	50.352	93.875	144.227	365.000 ( 1 )
UNBROKEN LEG ( BREAK ON CROSSOVER LEG OR COLD LEG )	302.300	61.072	95.711	156.783	333.000
UNBROKEN LOOP ( BREAK ON AN OTHER LOOP )	244.368	61.072	77.369	138.441	333.000

REACTOR VESSEL INLET

WELD LOCATION	MI LEG NM	B1PDO/2I MPA	B2DDMI/2I MPA	EQ. 9 MPA	MAX. VALUE MPA
BROKEN LEG ( BREAK ON COLD LEG )	135.900	46.977	46.027	93.005	315.000
UNBROKEN LEG ( BREAK ON HOT LEG OR CROSSOVER LEG )	403.197	56.979	136.556	193.535	315.000
UNBROKEN LOOP ( BREAK ON AN OTHER LOOP )	146.618	56.979	49.657	106.636	315.000

# Conclusions

- Verification of the application of the Nodal Moment Document within the SAR is important to ensure that the Phase 2 assessments reflect the piping design basis
  - The stress result of the piping design Equation (9) as applied in the SAR may be readily reproduced using the moment values explicitly listed in the SAR (where available)
  - However, a detailed comparison of the piping mechanical moments applied within the SAR versus the Nodal Moment Document reveals unexplained discrepancies
  - Application of the Nodal Moment Document is key to Phase 2 as the moments for many of the relevant locations and load cases are not documented in the SAR
- Because the SAR includes no reference to the Nodal Moment Document, the deviation raises the possibility that a different version of the Nodal Moment Document was used when the SAR was finalized

# Next Steps

- Resolve the discrepancies in the moments in the SAR versus the Nodal Moment Document
- If the discrepancies cannot be resolved, we suggest:
  - Apply the data in the Nodal Moment Document in the manner described in this presentation, with vectoral combination of individual loads for the second and fourth operating conditions
  - Document the discrepancies in the Phase 2 report
- Collect additional information available for the reactor coolant pump suction and discharge nozzle castings
  - We appreciate confirmation of the casting specification for those nozzles. As the pump nozzles are welded to CASS piping, the delta ferrite content of those pump nozzles is also relevant to our scope.
  - Could we also please get data on the casting-specific (i.e., CMTR) composition, delta ferrite content, and micrographs for each pump nozzle in both units (such as found in the piping EOMRs)? There is a total of six pump suction nozzles and six pump discharge nozzles, or 12 total pump nozzles in the two PWRs.
  - Our other Phase 1 information requests were previously resolved



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