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SMR-160 – RPV Neutron Embrittlement Methods

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[Not Export Controlled]

Agenda

- Introductions
- Purpose & Outcome
- Discussion of neutron embrittlement methodology
- Discussion of planned surveillance program
- Questions
- Open Forum

Purpose & Outcome

Purpose

- Provide SMR's plans to:
  - Use unique methodology to predict neutron embrittlement
  - Justify use of that methodology
  - Execute a surveillance plan to validate results

Outcome

- Obtain feedback from NRC staff on this approach

Refresher from February Meeting

- SA-508 Grade 3 Class 2 base material, [[[redacted]
  - [redacted]]]
  - Low alloy steel weld material
- Cold leg/irradiation temperature [[[redacted]]]
- Maximum estimated neutron fluence [[[redacted]]]
  - Fluence calculations based on RG 1.190 framework
  - Flux at RPV surface [[[redacted]]]
  - Fluence for 40 years (38 EFPY) is [[[redacted]]]

Refresher from February Meeting

- RG 1.99 applicable for ≥ 525°F; not appropriate for SMR-160
  - Temperature dependence not considered

Alternative industry standards:

- ASTM E900 – includes a temperature-dependent term
  - Irradiation temperatures 491 – 572°F ⟶ $\Delta T_{41J} = f(\mathrm{Cu}, \mathrm{Ni}, \mathrm{Mn}, \mathrm{P}, \Phi, T)$
  - SMR considered using this formula with a separate temperature factor
- EPRI – MRP-462
  - Considers test reactor data and adds flux term

$$\Delta T_{41J} = f(\mathrm{Cu}, \mathrm{Ni}, \mathrm{Mn}, \mathrm{P}, \Phi, T, \varphi)$$

Temperature plays a significant role in the extent of neutron embrittlement

- Two main types of damage generally agreed upon:
  - Cu-rich clusters (N/A – low Cu)
  - "Matrix damage" (enhanced by solute clustering – Ni, Mn)

- Matrix damage is worse at low temperature
  - Less energy for diffusion
  - Reduced self-annealing of damage

Temperature dependence in industry standards

- All data used by industry correlations is >480°F
- [[[redacted]
- [redacted]]]

[[[redacted]]]

[redacted]

SMR-160 Embrittlement Approach

- [[[redacted]
- [redacted]]]

[[[redacted]]]

[redacted]

SMR-160 Embrittlement Approach

[[[redacted]]]

Results of Design Assumptions

[[

[redacted]

[redacted]

]]

SMR-160 Surveillance Program

- 10 CFR 50 App H requires surveillance program
  - References ASTM E185-82 for most requirements

- ASTM E185-82 requirements are not ideal for SMR-160
  - Requires tracking of welds in addition to base metal
  - Low lead factors (1-3) provide data slowly

- SMR intends to follow all other App H requirements

Considering replacing weld metal specimens with additional base metal (BM)

- [[[redacted]
  - ✓ [redacted]
  - ✓ [redacted]
  - ✓ [redacted]
- [redacted]
- [redacted]]]

Specimens

ASTM E185-82	Proposed
BM Charpy	BM Charpy
Weld Charpy	BM Charpy (2nd set)
BM tensile	BM tensile
Weld tensile	BM tensile (2nd set)
	Fracture toughness (some capsules)

High lead factors (LF) generate data quickly

- ASTM E185-82 recommends LF of 1-3
- E185-21 recommends LF below 5
  - Recommends validation method (e.g., correlation monitor) for LF > 5
- [[[redacted]]]
  - Recent NRC publication:
    "In practice, the testing of correlation monitor material has demonstrated variability… which has limited the practical use of the data."
  - Japan and Germany allow LF of 10 and 12, respectively
  - [[[redacted]]]

Lead Factor and Withdrawal Schedule

[[

[redacted]

[redacted]

]]

Proposed ISP – 2-unit site

Specimens (each capsule)

Units 1 & 2
BM Charpy – RPV 1
BM Charpy – RPV 2
BM tensile – RPV 1
BM tensile – RPV 2
Fracture toughness – RPV 1 or RPV 2

[[[redacted]]]

Upper shelf energy is not a significant concern

- Requirements from 10 CFR 50 App G:
  - > 75ft-lbs @ BOL
  - > 50 ft-lbs @ EOL
- Typical BOL value for SA-508 Gr 3:
  - >100 ft-lbs is expected, 150 ft-lbs not uncommon
- Typical USE reduction for low Cu steel is <<50%
  - [[[redacted]]]
  - Will be validated by surveillance data
  - Considering adding a PO requirement that USE exceed 100 ft-lbs

SMR does not plan to obtain K_{IC} data from three heats of material before construction

- ASME Sec XI Appendix G:
  - For materials with Y.S. 50-90 ksi, the existing K_{IC} vs (T – RT_{NDT}) design curve may be used "provided fracture mechanics data are obtained on at least three heats of the material on a sufficient number of specimens to cover the temperature range of interest, including the weld metal and heat-affected zone" that exceed the curve
- SA-508 Gr 3, Cl 2 is well known
  - 2021 ASME code exempts it from this requirement
  - This includes the HAZ and associated weld metals

BACKUP SLIDES

[[[redacted]]]

[[[redacted]]]

[[[redacted]]]

[[[redacted]

[redacted]]]

MTR data compared to PWR and BWRs - from EPRI report

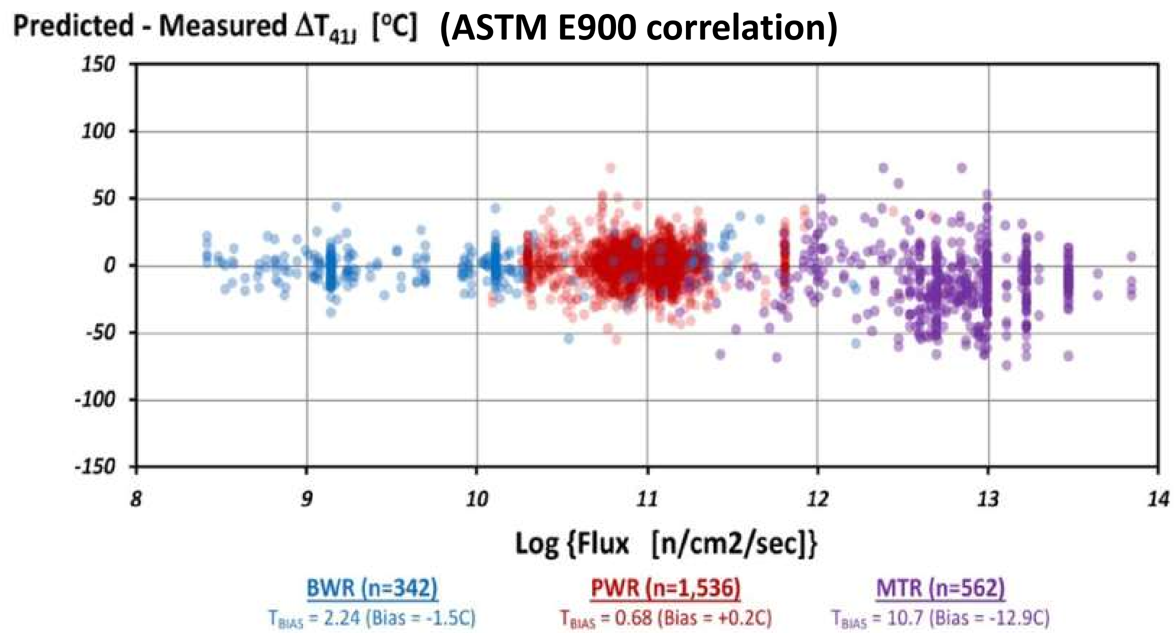

Figure 3-3
Data from the ASTM E10.02 PLOTTER [3] demonstrating a neutron flux effect in test reactor (MTR) ΔT_{41J} values, as evidenced by the 13°C bias in the ASTM E900-15 prediction error for the MTR (purple) data

- MTR data is conservative
- Flux effects from accelerated data over predict damage

ASME Sec XI Appendix G – 2021 Edition

(b) For materials with specified minimum yield strengths at room temperature greater than 50 ksi (350 MPa) but not exceeding 90 ksi (620 MPa), other than those in Table G-2110-1, Figure G-2210-1 (Figure G-2210-1M) may be used, provided fracture mechanics data are obtained on at least three heats of the material on a sufficient number of specimens to cover the temperature range of interest, including the weld metal and heat-affected zone, and provided the data are equal to or above the curve of Figure G-2210-1 (Figure G-2210-1M). These data shall be documented. If these materials of higher yield strengths [specified minimum yield strength greater than 50 ksi (350 MPa)] but not exceeding 90 ksi (620 MPa), including the materials in Table G-2110-1, are to be used in conditions in which radiation might affect the material properties, the effect of radiation on the K_{Ic} curve shall be determined for the material. This information shall be documented.

Table G-2110-1
Materials With Specified Minimum Yield Strength Greater Than 50 ksi (350 MPa) But Not Exceeding 90 ksi (620 MPa) Permitted to Use Figure G-2210-1 (Figure G-2210-1M)

SA-508 Grade 2 Class 2 (former designation SA-508 Class 2A)
SA-508 Grade 3 Class 2 (former designation SA-508 Class 3A)
SA-533 Type A Class 2 (former designation SA-533 Grade A Class 2)
SA-533 Type B Class 2 (former designation SA-533 Grade B Class 2)