RPV Embrittlement Monitoring and Prediction in Long-Term Operation

October 2021 EPRI MRP Technical Brief

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Presentation Outline*

- **Future Sources of High Fluence Capsule Data**
  - PWR Coordinated Reactor Vessel Surveillance Program (CRVSP)
    - MRP-326, Revision 1
  - PWR Supplemental Surveillance Program (PSSP)
    - MRP-412
- **Review of Prior EPRI MRP Conclusions from the November 2019 ACRS Meeting**
  - Potential to impact plant Pressure-Temperature (P-T) limit curves

*Note that BWR Units have an NRC approved Integrated Surveillance Program (ISP) for up to 60 years for the U.S. BWR Fleet (BWRVIP-86, Rev. 1-A). The implementation plan for Subsequent License Renewal (SLR) has also been accepted by NRC, with the highest BWR Unit projected *not* to exceed the threshold for fluence of 6×10^{19} n/cm^2 (E>1.0 MeV) as described in this report (BWRVIP-321-A). See Slide 12 for more details.

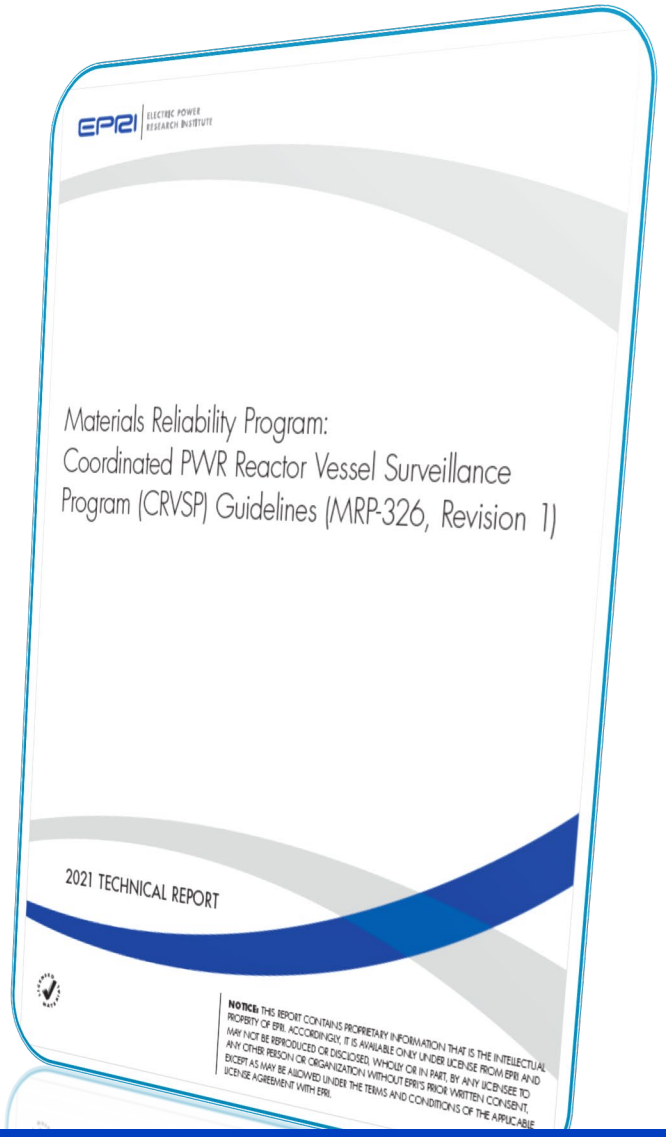
Update to the CRVSP, MRP-326, Revision 1

Coordinated PWR Reactor Vessel Surveillance Program (CRVSP)

- Materials Issue Being Addressed:
  - Optimize the U.S. PWR surveillance capsule withdrawal schedules to increase the amount of high-fluence ($f > 3.0 \times 10^{19}$ n/cm^2) surveillance data which can be used to inform development of embrittlement trend correlations (ETCs) applicable for RPV operation to high fluence (60+ years).
- Objectives of the Project
  - Revision 0 (2011): Review the reactor vessel surveillance programs (RVSPs) of the operating U.S. PWR fleet and recommend changes to selected RVSP withdrawal schedules in order to increase the amount of high fluence surveillance data by 2025.
  - Revision 1 (2021): Review of how we did, what has occurred, what's left to do, and when it is most likely to happen across the US fleet
- Updates to the evaluation include
  - Evaluated capsules withdrawn since 2011
  - Future capsule pull schedules
  - Capsule fluence values
  - Analysis of closed (or to be closed) plants

Update to the CRVSP, MRP-326, Revision 1

- Current high fluence capsule withdrawal results
  - 16 out of 30 CRVSP Capsules are tested or planned to be tested
  - There are 14 remaining CRVSP Capsules
    - Half of these are not planned to be tested (i.e., due to plant shutdown) or will be delayed beyond 2025
- Summary of available high fluence data
  - 48 U.S. capsules have been tested at $f > 3.0 \times 10^{19}$ n/cm^2
    - 4 of these are $f > 8.0 \times 10^{19}$ n/cm^2
  - By 2025, the remaining 7 planned CRVSP capsules will be tested at $f > 3.0 \times 10^{19}$ n/cm^2
    - 2 of these are predicted to be $f > 8.0 \times 10^{19}$ n/cm^2
- PSSP withdrawal schedule update
  - Farley 1 Capsule P to be withdrawn in Spring 2027
  - Shearon Harris Capsule P in Fall 2028



There are no NEI 03-08 requirements of any kind associated with this report revision

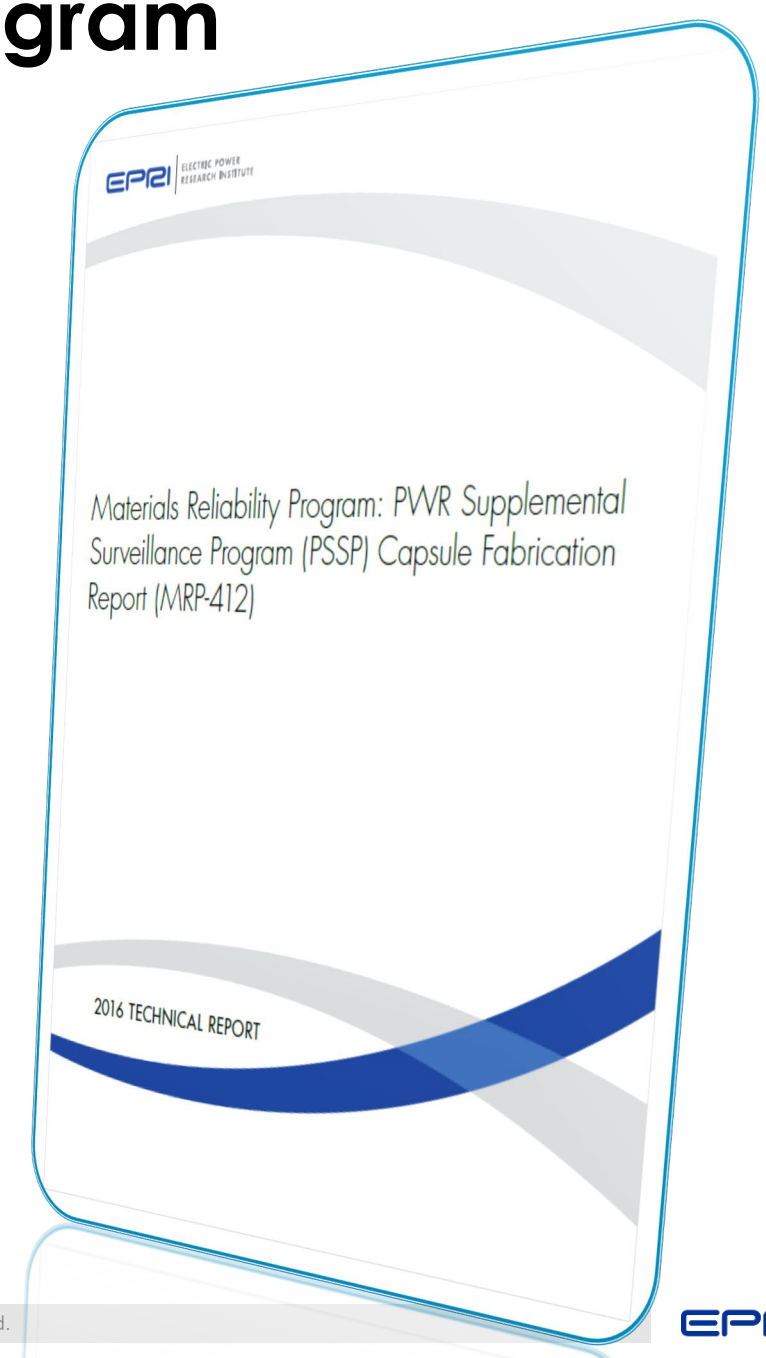
PWR Supplemental Surveillance Program (PSSP)

PWR Supplemental Surveillance Program (PSSP)

- Materials Issue Being Addressed:
  - Additional high-fluence ($f > 5.0 \times 10^{19}$ n/cm^2) surveillance data is needed to inform development of embrittlement trend correlations (ETCs) applicable for RPV operation to high fluence (60+ years).
- Objectives of the Project:
  - Fill projected gaps in the tested surveillance capsule database
  - Inform future ETCs using actual RPV surveillance materials from commercial PWRs (not test reactor data)
- End game: Irradiate two supplemental surveillance capsules for ~10 total years before withdrawal, testing, evaluation and publication of capsule test reports
  - These two surveillance capsules have 288 Charpy Specimens from 27 unique plates, forgings and welds
  - The data generated from these capsules will ultimately yield 24 new transition temperature shift results and 3 additional upper shelf energy results
    - Fluences levels of the to be evaluated specimens will range from ~4.5E+19 up to ~1.2E+20 (n/cm^2)

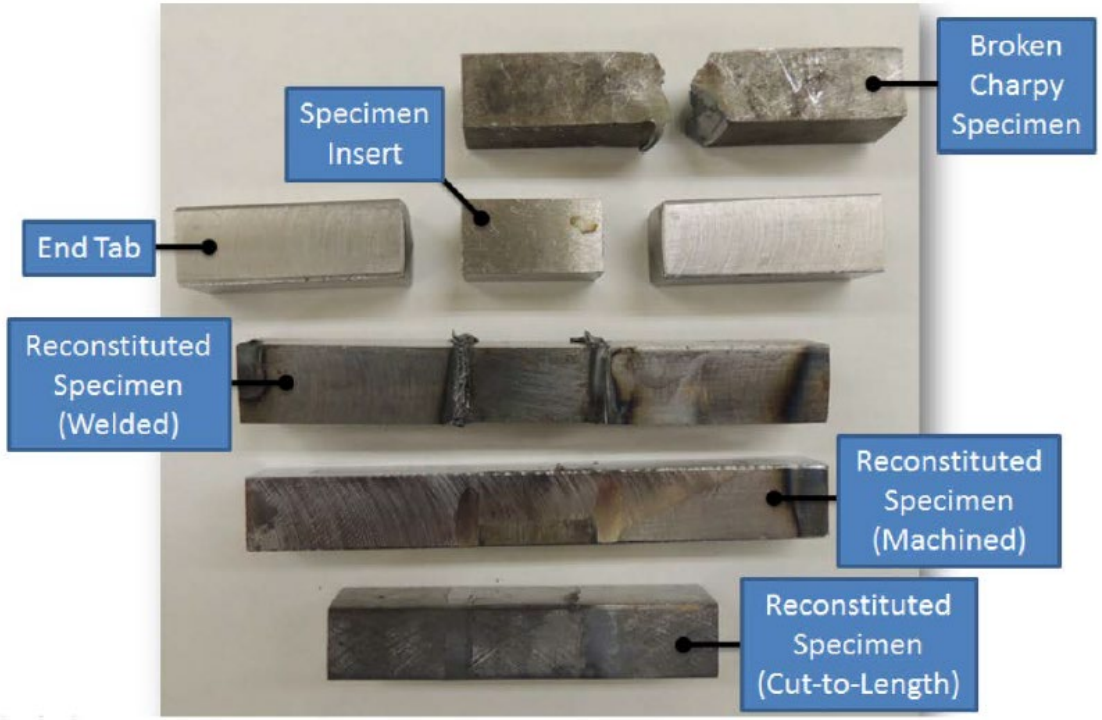
PWR Supplemental Surveillance Program

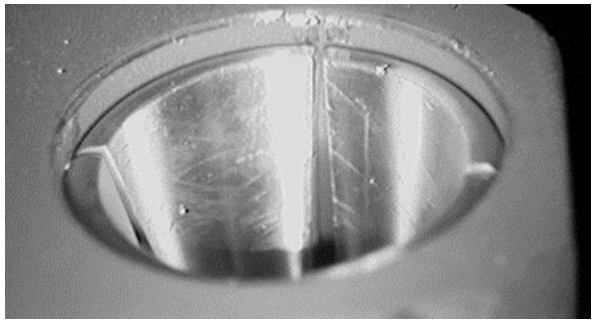
- Project History
  - Program designed and fabricated 2 supplemental surveillance capsules containing previously-irradiated, reconstituted PWR materials
  - EPRI MRP sponsored the fabrication of these 2 surveillance capsules:
    - ALA-P; 14 materials (Host: Farley 1), inserted October 2016
    - CQL-P; 13 materials (Host: Shearon Harris), inserted April 2018
  - MRP-412 (PSSP Capsule Fabrication report) was published in 2016



PWR Supplemental Surveillance Program

- Current Project Status and Timeline
  - Farley 1 Capsule P to be withdrawn in Spring 2027; Shearon Harris in Fall 2028 per MRP-326,R1
  - Testing of surveillance capsules and data evaluation in 2028-2030
  - Anticipated Project Deliverable Date:
    - Capsule report within ~18 months of each capsules' withdrawal date (2 reports total)
  - Data evaluation and impact on future ETCs in 2030-2032



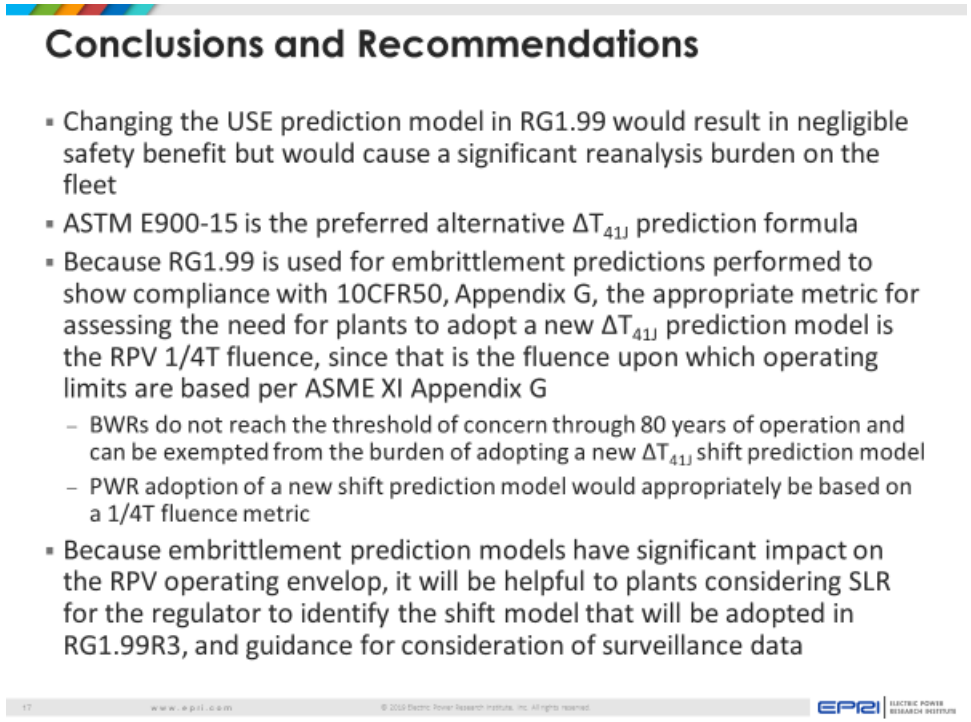


PSSP Capsule seated in its holder

Prior EPRI Conclusions on the Potential Revision of RG1.99R2

Conclusions from the EPRI Presentation to the ACRS in November 2019

- EPRI MRP previously presented on the potential revision of RG1.99R2 to the ACRS in Nov. 2019
- The conclusions from that meeting (shown at right) have not changed
- **If** a future revision to RG.199R2 is implemented, ASTM E900-15 remains the preferred ETC model (today)
- It is understood that for fluence values below 6E+19 n/cm^2, RG1.99R2 remains adequate for predicting RPV embrittlement
- The next slide details when certain plant designs will see that fluence level at 1/4T



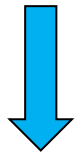
Conclusions and Recommendations

- Changing the USE prediction model in RG1.99 would result in negligible safety benefit but would cause a significant reanalysis burden on the fleet
- ASTM E900-15 is the preferred alternative ΔT_{41J} prediction formula
- Because RG1.99 is used for embrittlement predictions performed to show compliance with 10CFR50, Appendix G, the appropriate metric for assessing the need for plants to adopt a new ΔT_{41J} prediction model is the RPV 1/4T fluence, since that is the fluence upon which operating limits are based per ASME XI Appendix G
  - BWRs do not reach the threshold of concern through 80 years of operation and can be exempted from the burden of adopting a new ΔT_{41J} shift prediction model
  - PWR adoption of a new shift prediction model would appropriately be based on a 1/4T fluence metric
- Because embrittlement prediction models have significant impact on the RPV operating envelop, it will be helpful to plants considering SLR for the regulator to identify the shift model that will be adopted in RG1.99R3, and guidance for consideration of surveillance data

What *surface* fluence = 6E+19 @ 1/4T and 3/4T?

- The chart at right was developed using the current fluence attenuation formula from RG1.99R2*
- It is understood that the 3-Loop Westinghouse design has the highest surface fluence at end-of-life
- SLR plants' most limiting surface fluence values are also summarized herein
- Only Plant 'A' will hit a 1/4T fluence of 6E+19 n/cm^2 for 80-years
  - This is currently predicted to occur well into the SLR operating period

Design	RPV Maker	Vessel T (in)	Surface Fluence Needed to Reach 6E+19 @	
			1/4T (E+19)	3/4T (E+19)
WEC 2-Loop	B&W/CE	6.5	8.86	19.3
WEC 3-Loop/Smaller CE	CE	7.875	9.62	24.8
B&W NSSS	B&W	8.44	9.96	27.4
WEC 4-Loop	RDM	8.45	9.96	27.5
WEC 4-Loop	B&W	8.5	9.99	27.7
WEC 4-Loop/Larger CE	CE	8.625	10.1	28.3
CE - Special	CE	8.79	10.2	29.2
CE - Sys80	CE	11.2	11.7	45



Plant	Design	EFPY	Surface Fluence (E+19)	Potentially Impacted?
A	WEC 3-Loop	72	10.8	at ~65 EFPY
B	WEC 3-Loop	68	7.26	No
C	Smaller CE	72	6.56	No
D	WEC 3-Loop	72	7.34	No
E	WEC 2-Loop	72	7.80	No
F	B&W	72	2.02	No

***BWR plants are not shown as they will *never* reach these fluence levels in any reasonable operational time-frame [BWR SLR Plant 70 EFPY surface fluence < 5E+18 n/cm^2]**