

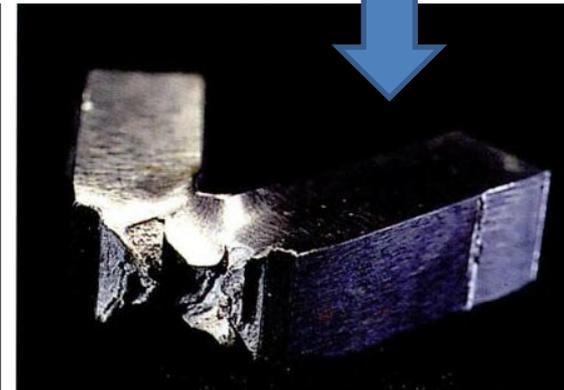
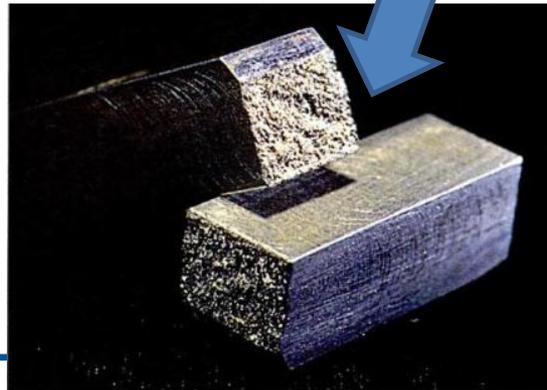
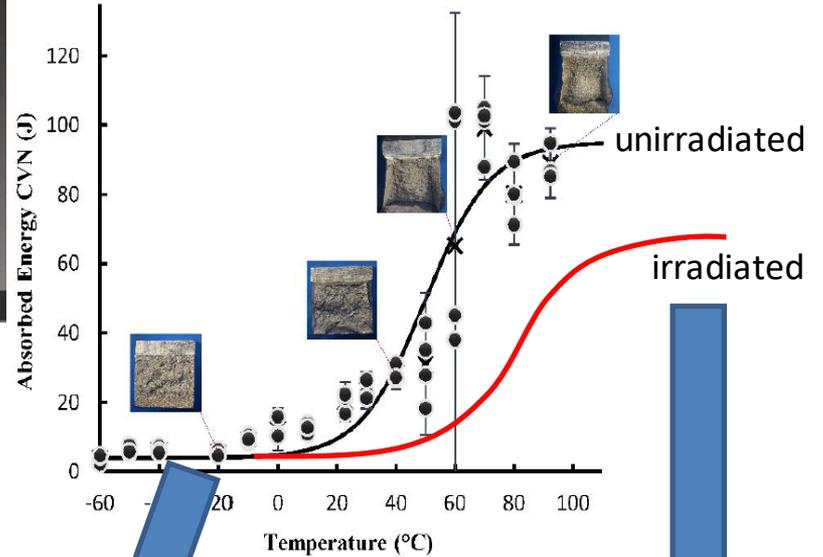
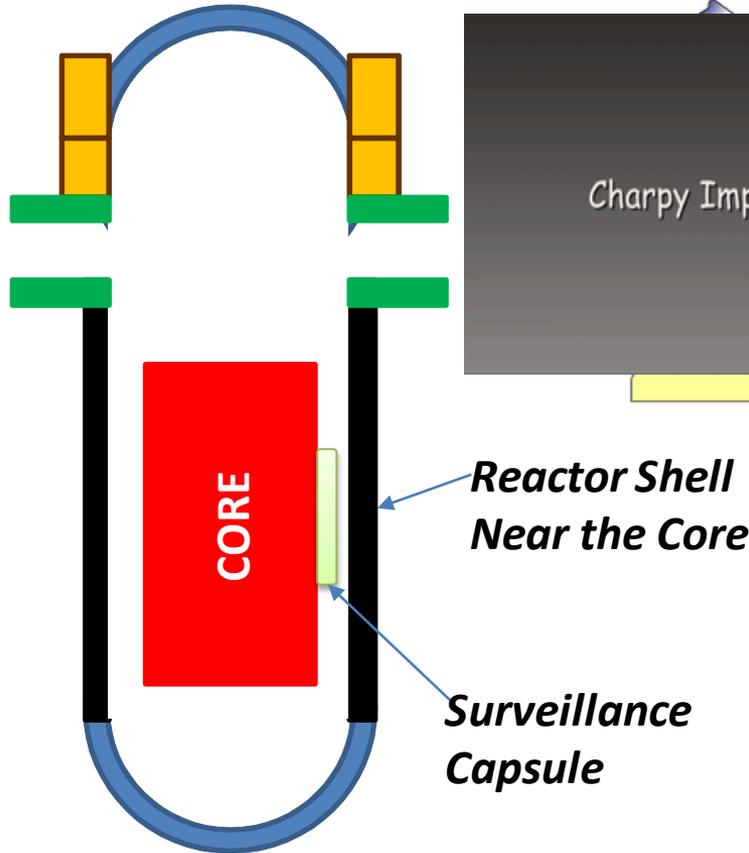
RPV Embrittlement – Monitoring and Prediction

Remarks by

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Reactor Vessel Embrittlement



RPV Integrity Regulations

Appendix A to Part 50 Criterion 31 – Fracture Prevention of Reactor Coolant Boundary

10 CFR 50.60 – Acceptance criteria for fracture prevention measures for normal operation

- Must meet Appendix G and H

10 CFR 50 App G

- ASME Sec XI App G
- PT limits: HU/CD (normal)
- Leak test
- Flange limits
- Upper shelf limits
- “must account for the effects of neutron radiation”

Regulatory Guide 1.99
Rev 2 – Radiation embrittlement of reactor vessel materials

10 CFR 50 App H

- Surveillance per ASTM E185-82
- Periodic monitoring based on 40-year life

10 CFR 50.66 - Requirements for thermal annealing of the reactor pressure vessel

10 CFR 50.61 - Fracture toughness requirements for protection against pressurized thermal shock events

- Prescriptive Embrittlement equation

10 CFR 50.61a – Alternate PTS rule

- Different Prescriptive Embrittlement equation

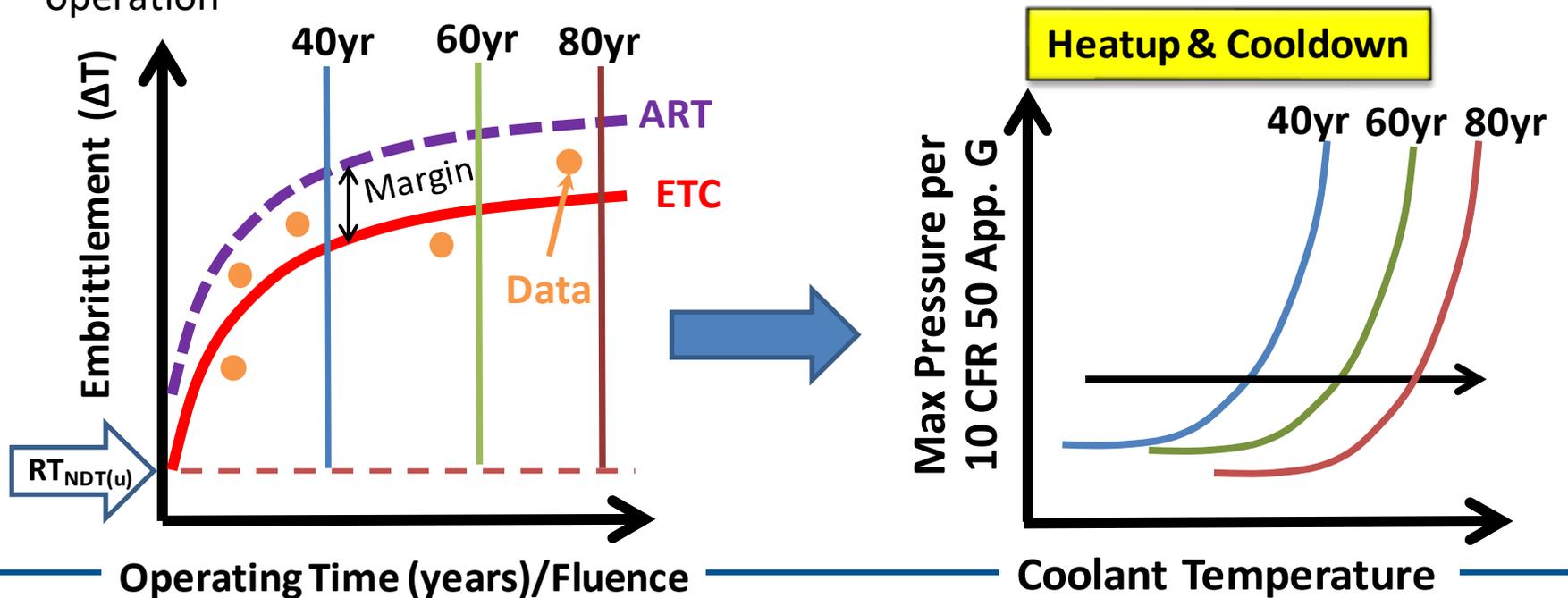
Embrittlement Trend Curve, May 1988, Fit based on 177 datapoints

License Renewal

- Regulations are unchanged; surveillance program addressed in guidance
- Aging Management Program XI.M31, “Reactor Vessel Material Surveillance”
 - Continues reliance on Appendix H program using ASTM E185-82
 - GALL Report (NUREG-1801, Rev. 1) for license renewal (40 to 60 years)
 - “shall have at least one capsule with a projected neutron fluence equal to or exceeding the 60-year peak reactor vessel wall neutron fluence prior to the end of the period of extended operation”
 - Describes use of reconstituted specimens and use of operating restrictions (neutron flux, spectrum, irradiation temperature, etc.)
 - GALL-SLR Report (NUREG-2191) for subsequent license renewal (60 to 80 years)
 - “withdrawal and testing of at least one capsule . . . with a neutron fluence of the capsule between one and two times the peak neutron fluence of interest at the end of the subsequent period of extended operation” – or data from a prior tested capsule
 - Specifies – “it is not acceptable to redirect or postpone the withdrawal and testing of that capsule to achieve a higher neutron fluence that meets the neutron fluence criterion for the subsequent period of extended operation”

Monitoring and Prediction of Embrittlement

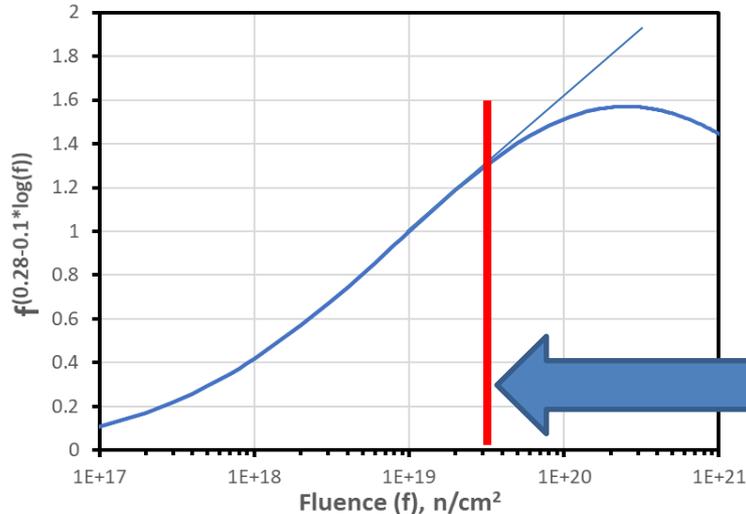
- Embrittlement Trend Curve (ETC) provides estimates of change in fracture toughness (ΔT or ΔRT_{NDT}) as a function of fluence
- Surveillance capsule testing provides monitoring to ensure ETC predicts plant specific behavior properly
- Together they are used to determine pressure-temperature (PT) limits for normal operation



ART = Adjusted Reference Temperature

Underprediction of Embrittlement

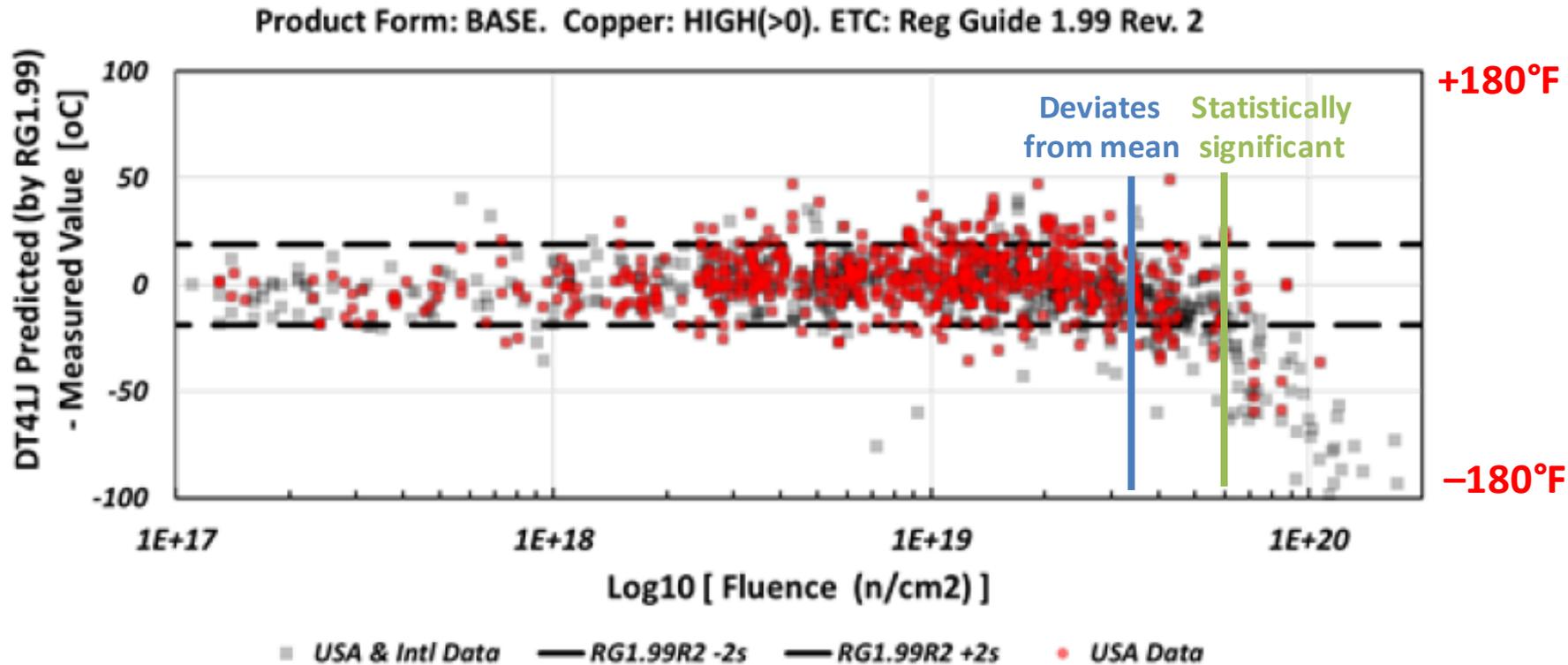
- Embrittlement Trend Curve in RG 1.99 Rev. 2 and 10 CFR 50.61 does not provide appropriate embrittlement estimates at high RPV fluence levels
 - Embrittlement Trend Curve, May 1988, Fit based on 177 datapoints
 - Fluence factor in the trend curve is not accurate at high fluence, because it provides non-physical “flattening” trend above $4\text{-}6 \times 10^{19} \text{ n/cm}^2$



- Surveillance data are fit to the fluence factor and can not provide good predictions of embrittlement at high fluence levels

Fluence function begins to “flatten”

Issue – ETC



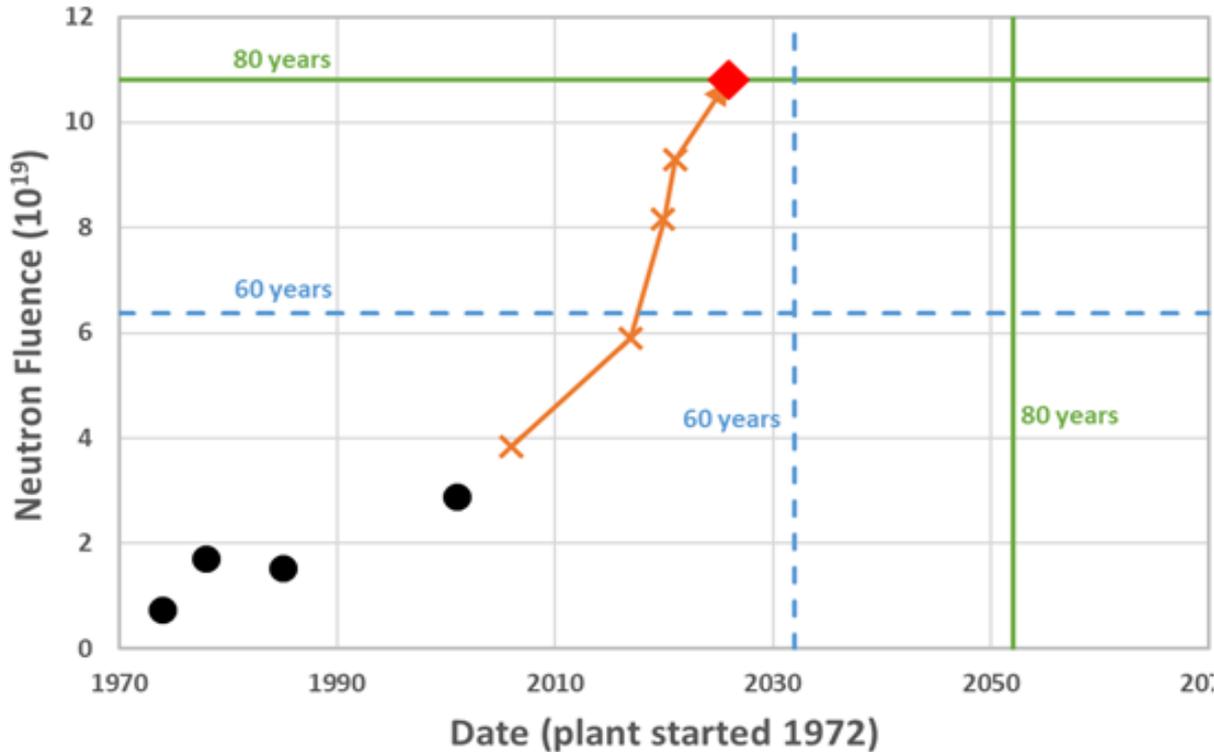
DT41J = ΔT_{41J} is a measurement of embrittlement representing the shift in transition temperature from brittle to ductile fracture at an impact toughness of 41J

Surveillance Capsule Delays

- Appendix H to 10 CFR Part 50 requires periodic monitoring of changes in fracture toughness caused by neutron embrittlement
 - ASTM standard (E185-82) allows final capsule fluence to be 2X RPV “design” fluence – plants change (intended 40-year) design fluence to current license length (e.g., 60 or 80 years)
 - ASTM standard (for 40 years) permits holding last capsule without testing
- Commission finding (“Perry decision” NRC Administrative Letter 97-04) that staff review of requests to change capsule withdrawal schedules is limited to verification of conformance with the ASTM standard (i.e., not based on technical or safety considerations)
 - Capsule withdraw and testing repeatedly delayed in some cases to achieve higher fluence

Issue – Appendix H

Performance Monitoring



Capsule withdrawal schedule changes include delays in both time and/or fluence

Many licensees have delayed capsules (time and/or fluence), some recent examples:

Plant	Capsule #	# of times delayed
Turkey Point	5	4
Robinson	5	2
Surry U1	5	2
Surry U2	5	2
North Anna U1	4	2
North Anna U2	4	2
St. Lucie U2	4	1
Point Beach	5	1

Not all plants have delayed withdrawal of capsules

Who is Impacted?

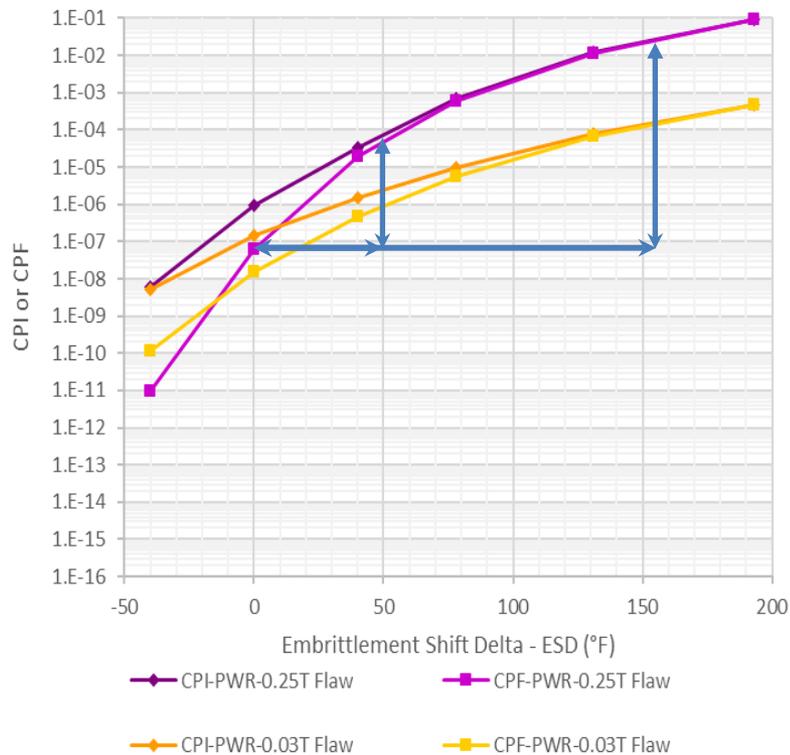
- Embrittlement underprediction

Percentage of Fleet Surpassing Fluence Levels			Percentage of PWRs Surpassing Fluence Levels	
Year/Fluence	6×10^{19} n/cm ²	8×10^{19} n/cm ²	6×10^{19} n/cm ²	8×10^{19} n/cm ²
60 years	6%	0%	9%	0%
80 years	22%	10%	34%	15%
100 years	30%	20%	48%	31%

- Lack of Surveillance Data
 - Any plant renewing license that chooses to delay last capsule

Risk of Failure

PT100-100 Cooldown
ARTmax(PWR-no shift) = 260.7°F



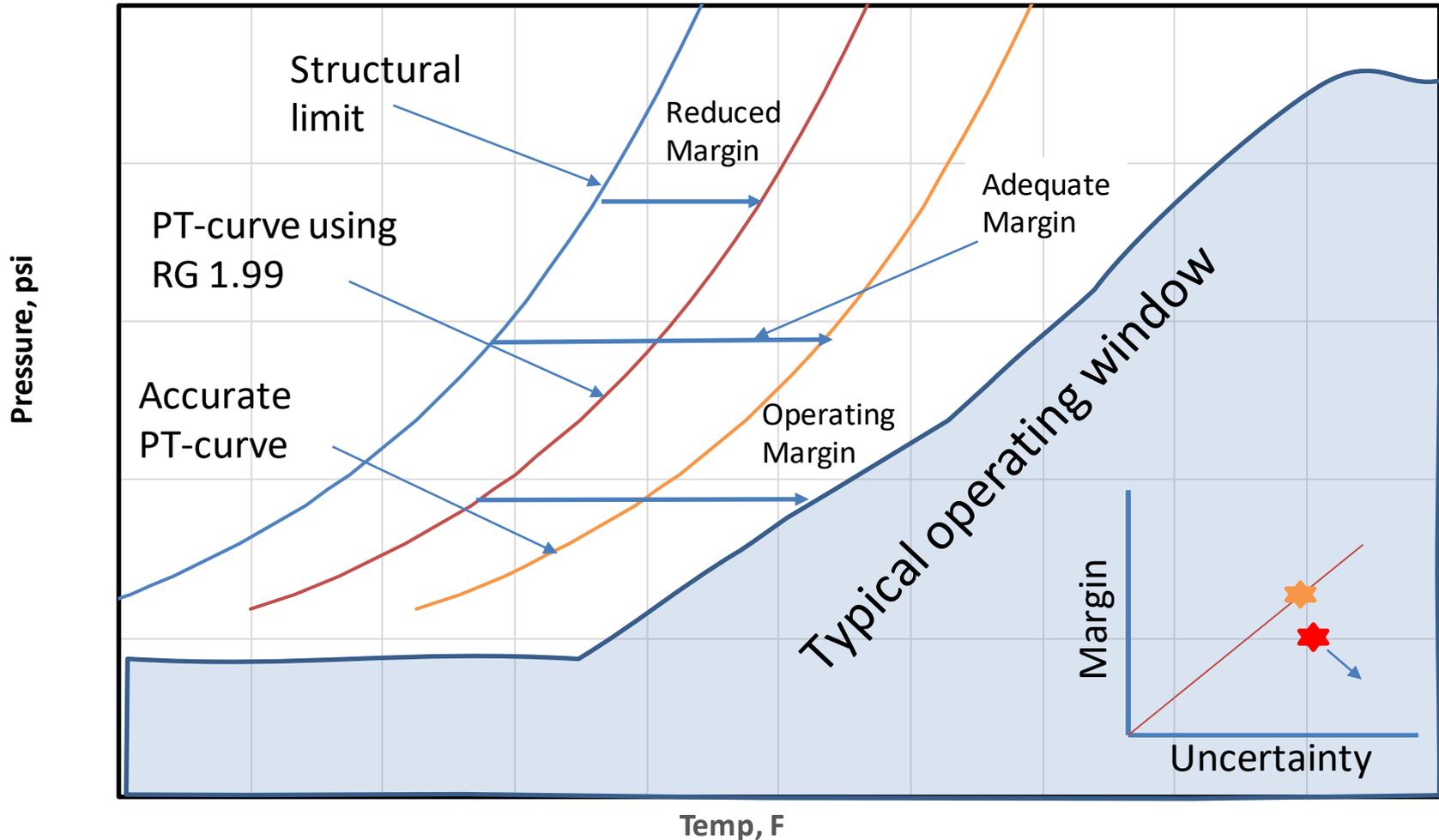
ESD represents the underprediction of ΔRT_{NDT}

Large Uncertainties:

- Unknown frequency of transient
- Actual plant fluence variations
- Are these analyses bounding?
 - Unknown plant-specific considerations
- How much protection do administrative and other operational limits provide against violating the PT limit?

“RG 1.99 Revision 2 Update FAVOR Scoping Study,”
 May 6, 2021, TLR RES/DE/CIB-2020-09, Rev. 1,
 ML21126A326

Safety Margins Illustration



Uncertainties increasing due to lack of surveillance, but margin is less due to embrittlement underprediction

Staff Goals

- Currently, regulations are sufficient for reasonable assurance of adequate protection against brittle fracture of vessel
- Staff wants to ensure continued reasonable assurance in long-term operation
 - Provide remedies for the identified issues with RPV surveillance requirements and embrittlement predictions, on a risk-informed, performance basis
- Do not impact those plants that are not adversely affected by the issues
 - Plant-specific surveillance data that covers end of license fluence level
 - Projected fluence at end of license $< \sim 3 \times 10^{19} \text{ n/cm}^2$

Next Steps

- Staff developed a rulemaking plan to ask the Commission for permission to initiate a rulemaking effort
- Once approved, staff will develop the technical basis for how to change to rule to correct these long-term issues

Questions?

