Industry Risk-Informed Appendix G Program: Approach Summary and Results Status

NRC/EPRI MRP/BWRVIP Meeting
Rockville, Md.
October 9, 2008

Agenda

1. *ASME Code Guidelines & Regulatory Requirements*
   - ASME Section XI, Appendix G
   - 10CFR 50, Appendix G
   - Regulatory Guide 1.99, Rev. 2
   - Branch Technical Position 5.2
2. *Approach*
3. *Limiting Service Level A & B Events*
   - PWRs – Low temperature overpressure protection (LTOP)
   - BWRs – System leak test
3. *Status*
   - *Computational Results*
   - *Draft Revision to Section XI, Appendix G*

ASME Code Guidelines & Regulatory Requirements

1. *ASME Section XI, Appendix G*

- Provides guidelines to prevent brittle fracture of ferritic components in the reactor coolant pressure boundary.
- Applicable for Service Level A & B events.
- Is a non-mandatory ASME Code appendix.
- Defines pressure temperature limits (for the RPV shell region) using

$$2.0 \times K_{Im} + K_{It} < K_{Ic} \quad \text{normal operation}$$

$$1.5 \times K_{Im} < K_{Ic} \quad \text{leak testing}$$

- Specifies that LTOP system must be enabled at temperatures up to the greater of 200F or RT_{NDT} + 50F.

ASME Code Guidelines & Regulatory Requirements

2. *10CFR50, Appendix G*

- *10CFR50, Appendix G requires implementation* of ASME Section XI, Appendix G and *adds additional requirements for fracture prevention of the reactor pressure vessel.*

Additional Requirements in 10CFR50, Appendix G

Operating condition	Vessel pressure[1]	Requirements for pressure-temperature limits	Minimum temperature requirements
1. Hydrostatic pressure and leak tests (core is not critical):			
1.a Fuel in the vessel	≤20%	ASME Appendix G Limits	([2])
1.b Fuel in the vessel	>20%	ASME Appendix G Limits	([2]) +90 ° F([6])
1.c No fuel in the vessel (Preservice Hydrotest Only)	ALL	(Not Applicable)	([3]) +60 ° F
2. Normal operation (incl. heat-up and cool-down), including anticipated operational occurrences:			
2.a Core not critical	≤20%	ASME Appendix G Limits	([2])
2.b Core not critical	>20%	ASME Appendix G Limits	([2]) + 120 ° F.
2.c Core critical	≤20%	ASME Appendix G Limits + 40 ° F.	Larger of [([4])] or [([2]) + 40° F.]
2.d Core critical	>20%	ASME Appendix G Limits + 40 ° F.	Larger of [([4])] or [([2])+160°F]
2.e Core critical for BWR ([5])	≤20%	ASME Appendix G Limits + 40 ° F.	([2])+60°F

[1] Percent of the preservice system hydrostatic test pressure.
[2] The highest reference temperature of the material in the closure flange region that is highly stressed by the bolt preload.
[3] The highest reference temperature of the vessel.
[4] The minimum permissible temperature for the inservice system hydrostatic pressure test.
[5] For boiling water reactors (BWR) with water level within the normal range for power operation.
[6] Lower temperatures are permissible if they can be justified by showing that the margins of safety of the controlling region are equivalent to those required for the beltline when it is controlling.

ASME Code Guidelines & Regulatory Requirements

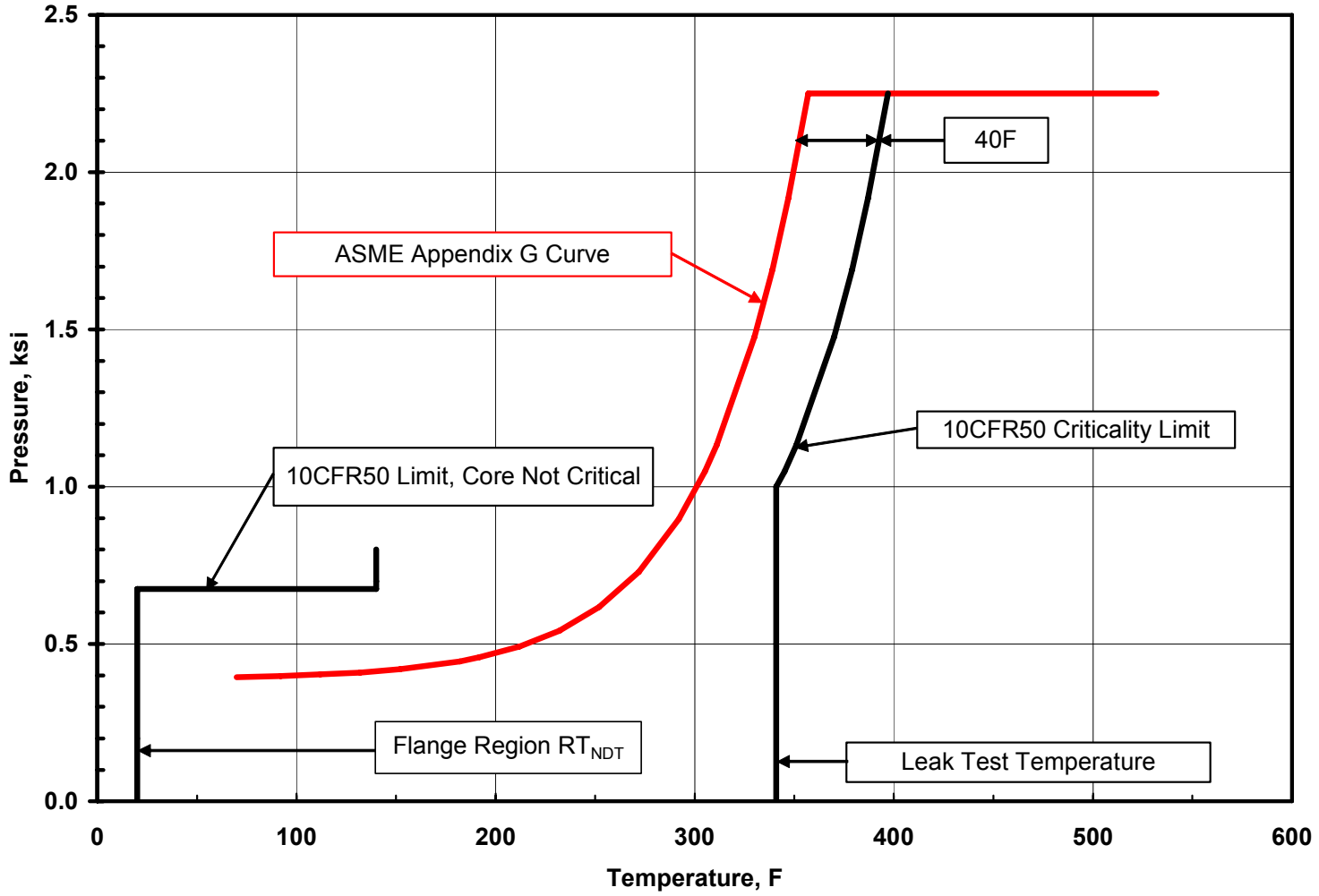
3. *Regulatory Guide 1.99, Rev. 2*

- Provides guidelines for assessing the effect of neutron irradiation on the fracture toughness of ferritic steels. The irradiation effect is described by an adjustment to RT_{NDT}.
- Provides guidelines for assessing the effect of uncertainty for the irradiation damage model. This uncertainty is described by an added margin to the adjusted RT_{NDT},
- Adjusted $RT_{NDT} = RT_{NDT(u)} + \Delta RT_{NDT}$ + Margin

4. *Branch Technical Position 5.2*

- Specifies that the LTOP system must be enabled at temperatures up to RT_{NDT} + 90F.

Illustration of Limits in Appendices G of the ASME Code & 10CFR50 for a PWR



Scope and Application of the Risk-informed Approach

- Scope of industry effort is to add an optional section to ASME Section XI, Appendix G for constructing risk-informed heat-up and cool-down curves.
- Maintain the current ASME Section XI Appendix G method.
  - It is anticipated that many operating plants may still use the conventional Appendix G method.
    - This will reduce the regulatory and licensee burden.
- Nozzles will be assessed using deterministic evaluation procedures and criteria being developed by the ASME WG OPC.

Risk-informed Approach

- The risk-informed margin is obtained based on the relationship
  - ➢CPF x EF x SO ≤ Acceptable Failure Frequency,

  where
    - CPF is conditional probability of vessel failure, and is determined from PFM analyses,
    - EF is the is the frequency of normal operating startup or shutdown.
    - SO is the conditional probability that the event will exceed the system operational constraints and reach RI- P/T limits
    - The failure frequency is <<1E-6 per operating reactor year.

Risk-informed Approach

- The risk informed margin will be determined by finding the margin that will result in CPF x EF $\leq$ 1E-6/yr when the reactor operates up to P/T limits determined from the RI equation

$$K_{Im} + K_{It} < K_{IC}.$$

- Values of CPF were determined from the FAVOR software, version 06.1, Rev2. (cool-down) and FAVOR-HT (heat-up).

Why This Approach?

- Easy to understand and implement.
- Does not require changes to the current Code fracture mechanics equations.
- Does not require a change in the assumed reference flaw size.
- Maintains easy to use Code computational procedures.
- Risk informed approaches have been used in other nuclear applications.

ASME Code, Section XI, Appendix G

1. *P/T limits for shell regions away from discontinuities*
   - $M_p \times K_{Ip} + K_{It} < K_{Ic}$
   - $K_{Ip} = M_m \times p \times R/t$
   - $K_{It} = 0.953 \times 10^{-3} \times CD \times t^{2.5}$; $0.893 \times 10^{-3} \times HU \times t^{2.5}$
   - $K_{Ic} = 33.2 + 20.734 \times EXP[0.02(T - RT_{NDT} - M_{RTNDT})]$,
   - T = temperature at tip of the reference flaw (t/4 or 3t/4)
   - Irradiated $RT_{NDT} = RT_{NDT(u)} + \Delta RT_{NDT}$ at the tip of the reference flaw (t/4 or 3t/4)
   - M_{RTNDT} = margin added to RT_{NDT}.

ASME Code, Section XI, Appendix G

2. Operation and Flaw Conditions
   - Heat-up – Limiting of inside surface flaw with K_{It} =0, and outside surface flaw
   - Cool-down – Inside surface flaw
   - Axial and circumferential flaws

3. RI Equation for assessing risk-informed P/T limits
   - $p = \{33.2 + 20.734 \times EXP[0.02(T - RT_{NDT} - M_{RTNDT})] - K_{It}\} \times \{t/R\} \times \{1/M_p\} \times \{1/M_m\}$,
   - *Where* M_{RTNDT} *and* M_p *are risk adjusted margins on* RT_{NDT} *and pressure, respectively.*

Illustration of Risk-informed Margins for PWR Normal Operation

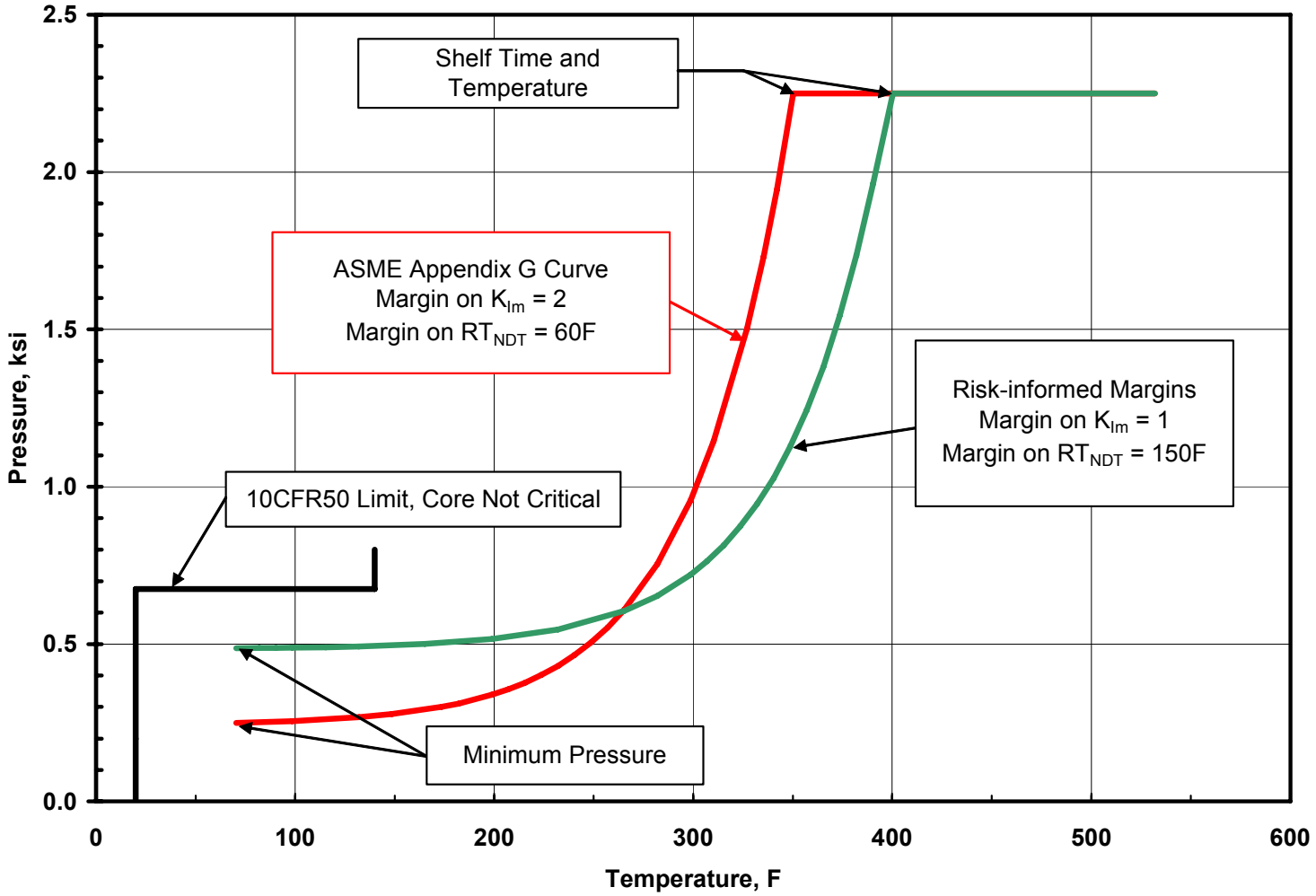
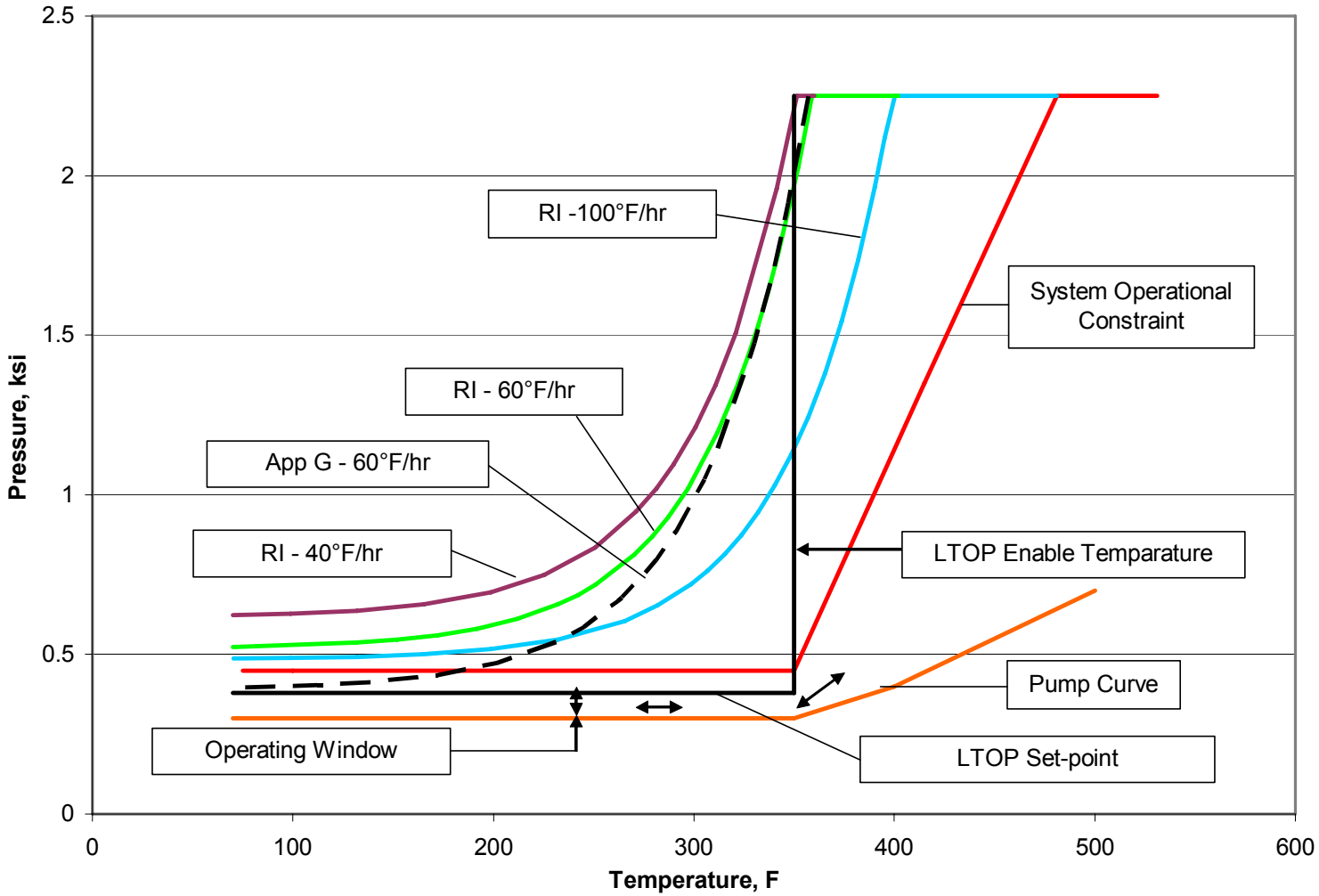


Illustration of Limiting Service Level A PWR Condition (LTOP)



Results Summary for Palisades Cool-down

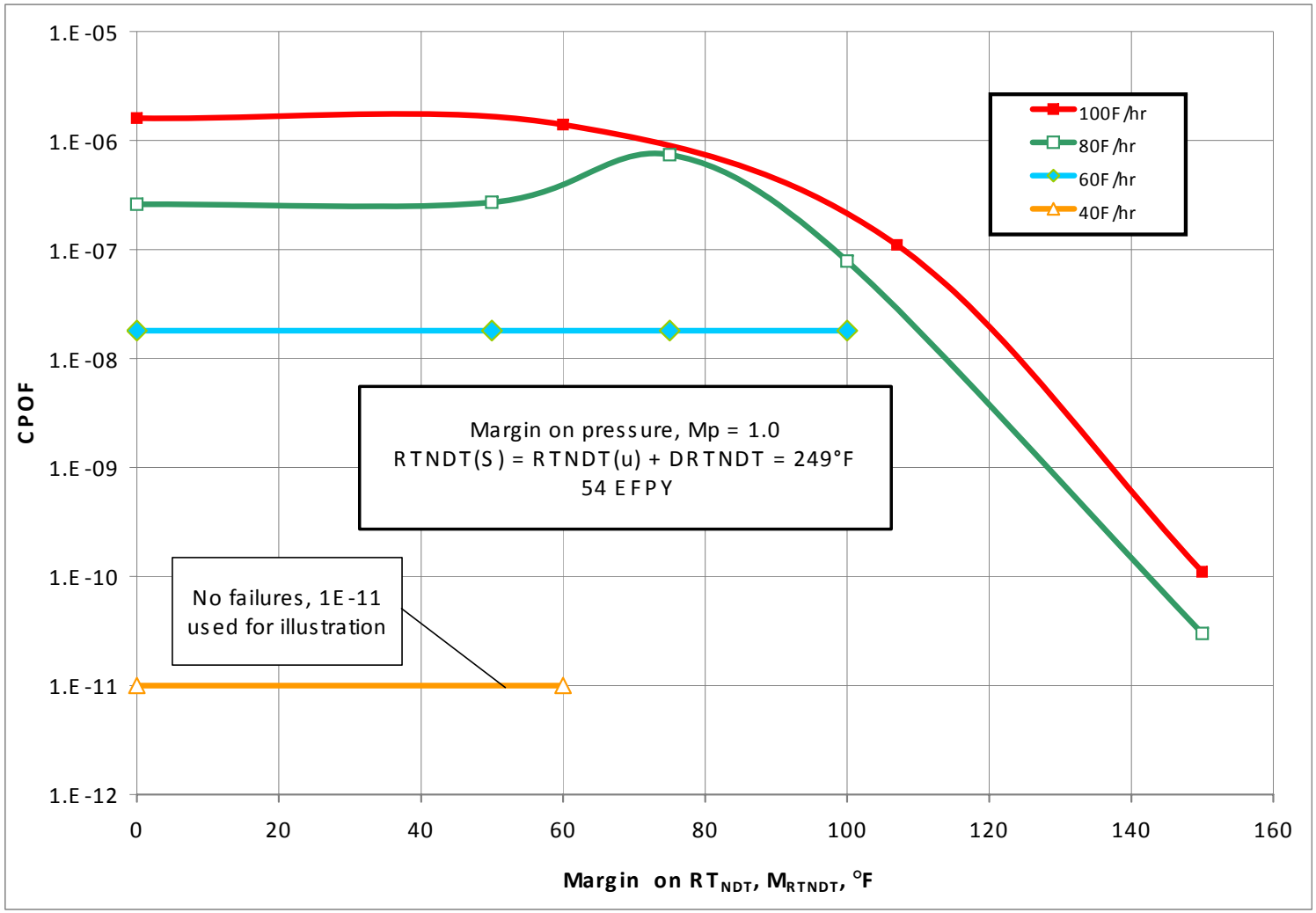


Illustration of Limiting Service Level A BWR Condition (Leak test)

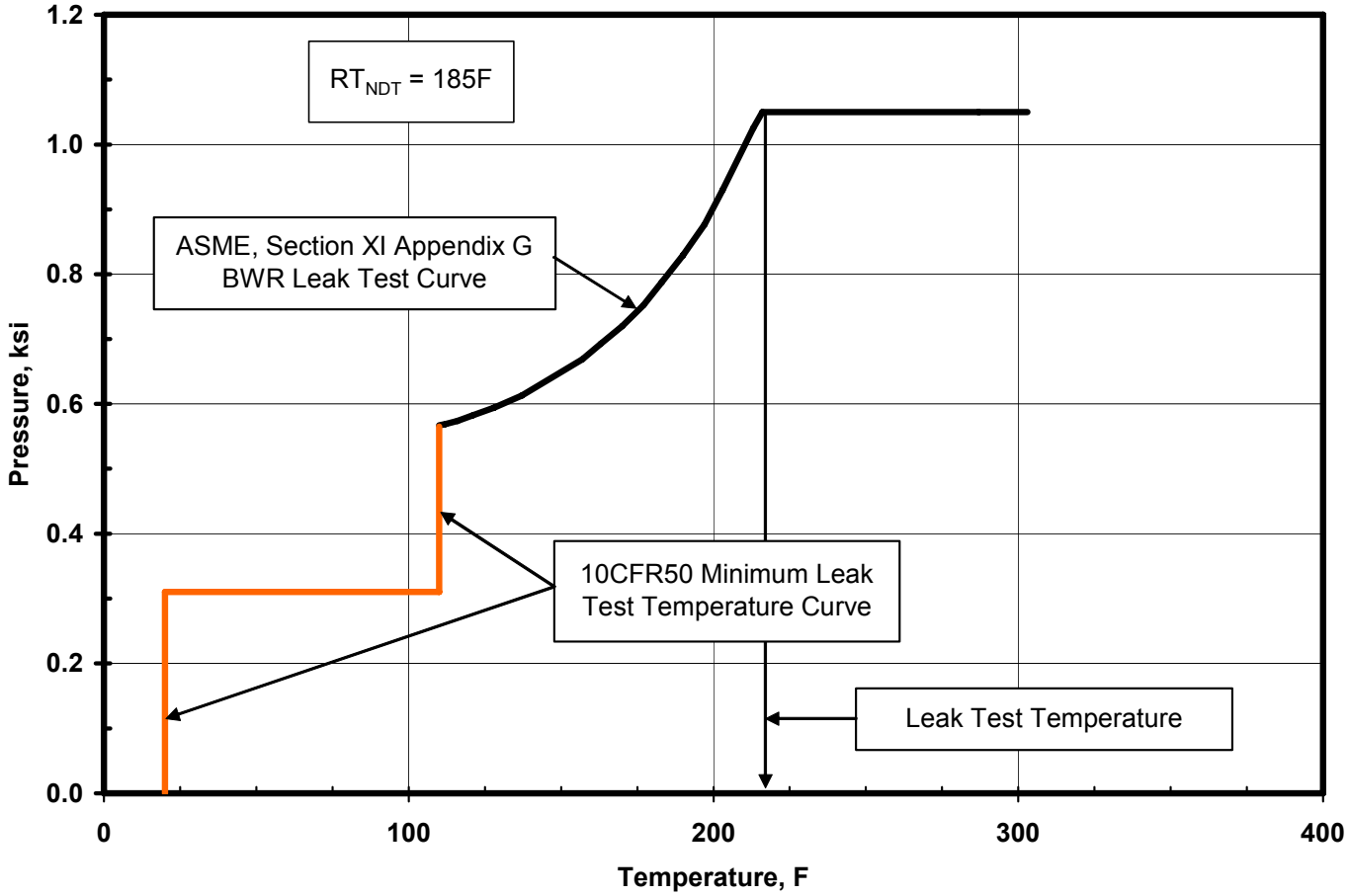
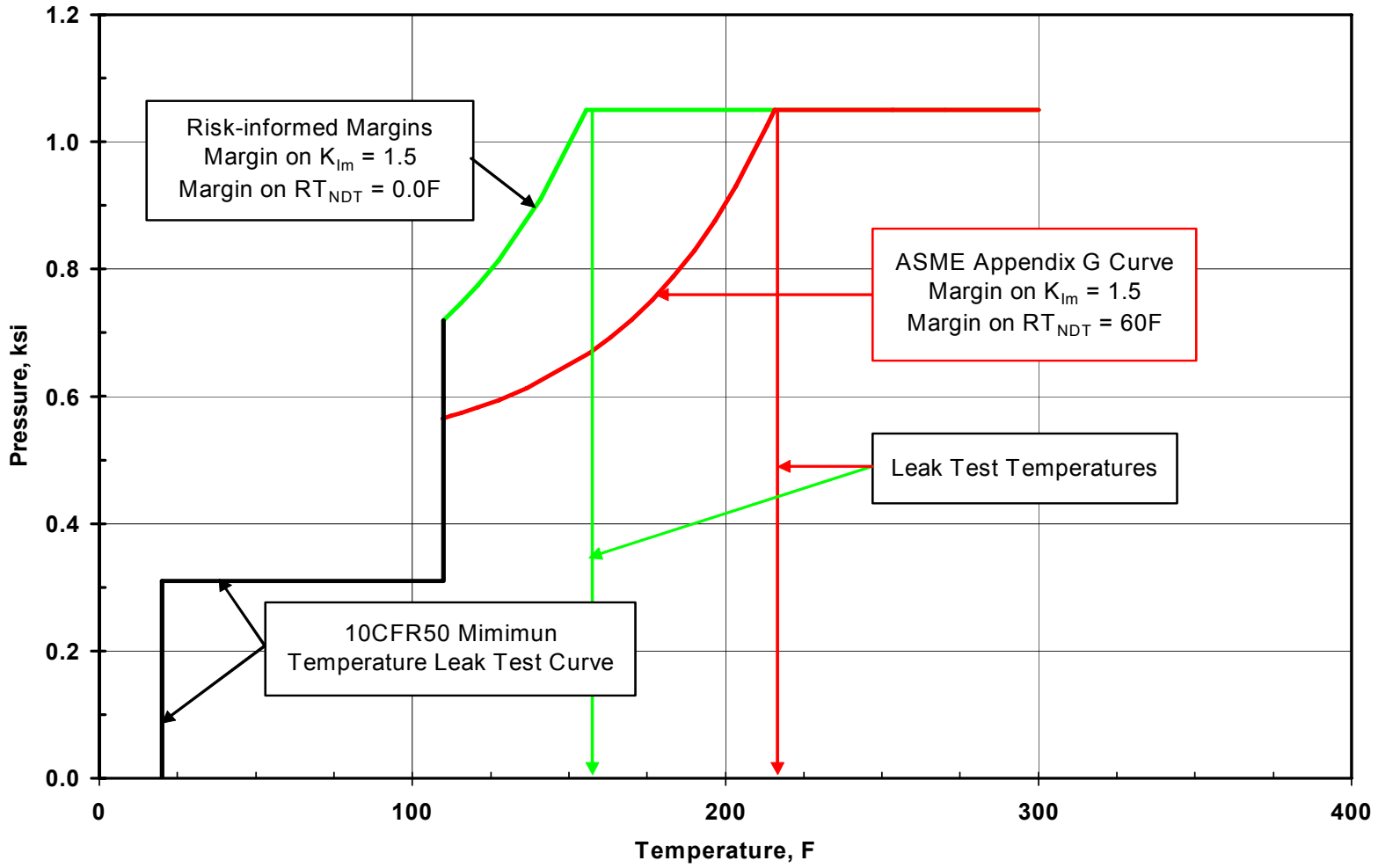
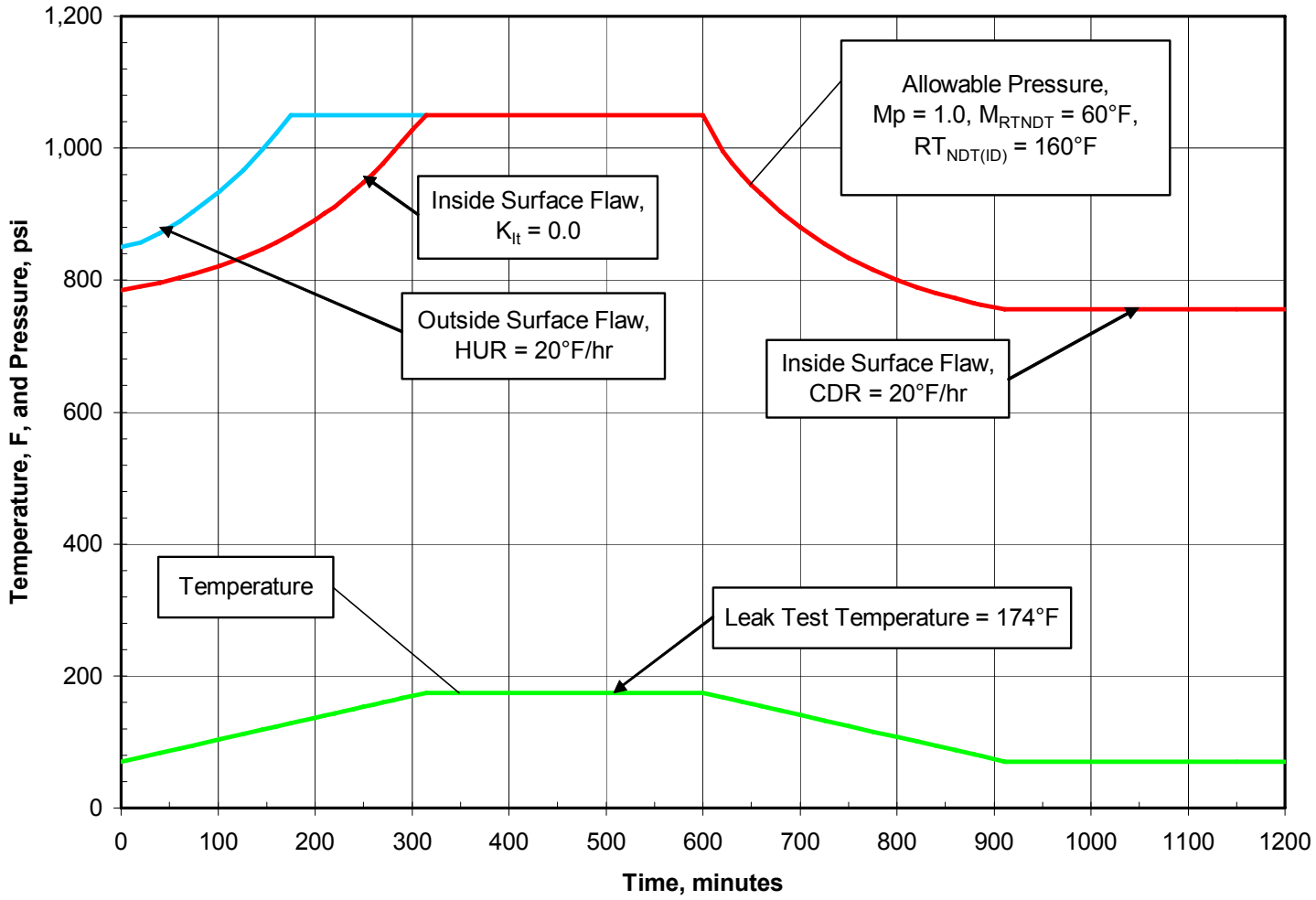


Illustration of Risk-informed Margins for BWR Leak Test



BWR Leak Test P/T Limits



Results Summary for BWR Leak Test

- CPOF = CPOI (FAVOR-HT) + CPOF (FAVOR)
- Cool-down and Heat-up Rate = 20°F/hr
- Mp = 1.0, M_{RTNDT} = 60°F: CPOF = 1.7E-7
- Mp = 1.5, M_{RTNDT} = 0°F: CPOF = 2E-7
- Leak test frequency approximately 0.5 – 0.7 per operating year.