NRC / ORNL Work on Risk-Informing 10 CFR Part 50 Appendix G

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Public Meeting
17th April 2007 – Rockville, MD – Westinghouse Offices

Outline

- **Level of effort**
- **10 CFR Part 50 Appendix G requirements, and resultant project scope**
  - **HU/CD**
  - **Hydro test**
  - **Upper shelf energy**
- **Discussion of status of HU/CD modeling using FAVOR**
  - **Terry (FAVOR results)**
  - **Mark (illustration of how results could be use in a rule)**

Level of Effort

FY	ORNL py	RES py	NRR py
05	~½	~0.1	-
06	~¾	~0.1	-
07	~½	~¼	tr.
08	~1	~½	~0.1
09	~1	~½	~½
10	~½	~¼	~½

June 2008: RES transmits initial tech basis to NRR for review and comment.

Appendix G to Part 50

(Fracture Toughness Requirements)

- **Scope**
  - **Ferritic materials of**
  - **The reactor coolant pressure boundary (including bolting) of**
  - **Light water nuclear power reactors**
- **Incorporates by reference**
  - **ASME SC XI Appendix G**
- **IV – Fracture toughness requirements**
  - **Reactor vessel (beltline) Charpy energy**
  - **P-T & T_{min} reqts. for reactor vessel**
    - ✓ **Depend on loading (i.e., on applied stresses)**
      - ➢ **Hydro / leak test**
      - ➢ **Normal operating / anticipated operational occurrences (HU/CD)**
    - ✓ **Depend on presence of fuel & core criticality (i.e., on margins)**
    - ✓ **Vessel may be limited by flange RT_{NDT} if flange RT_{NDT} is highest**

Appendix G to Part 50

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      - ➢ Normal operating / anticipated operational occurrences (HU/CD)
    - ✓ Depend on presence of fuel & core criticality (i.e., on margins)
    - ✓ Vessel may be limited by flange RT_{NDT} if flange RT_{NDT} is highest

Scope includes **entire** pressure boundary

ASME Code addresses **entire** pressure boundary (Beltline, head, nozzles)

FT reqts. apply **only** to vessel beltline

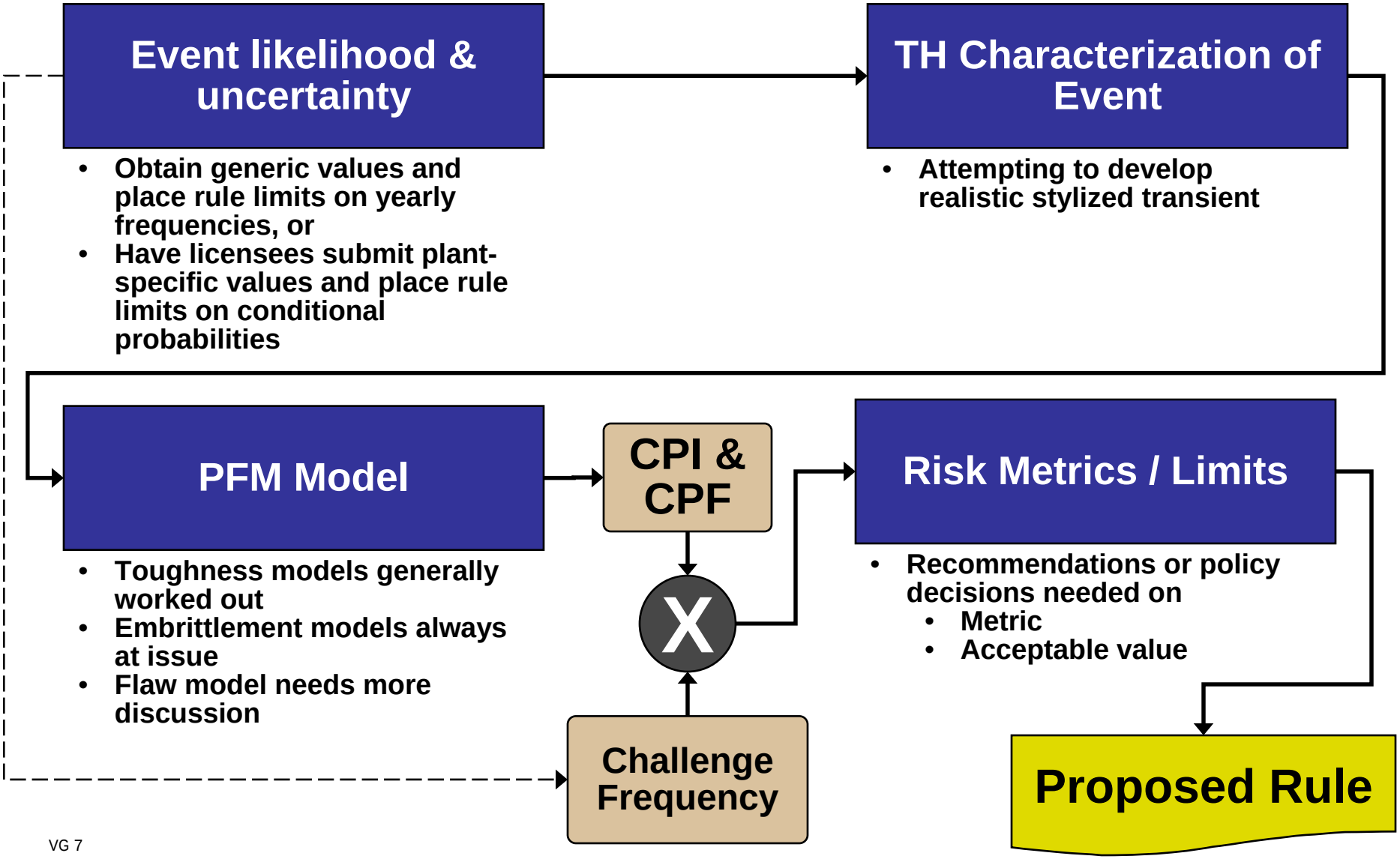
10CFR50G reqts. **supplement** ASME SC-XI App. G

Fracture Toughness Requirements of 10 CFR Part 50 Appendix G

- **Heat up / cool down limits**
  - **Pressure and temperature limits as a function of RT_{NDT}**
- **Hydro test limit**
  - **Temperature limit (pressure is specified) as a function of RT_{NDT}**
- **50 ft-lb upper shelf energy requirement**
  - **Expressed independent of RT_{NDT} requirements**
  - **A thought regarding revision options**
    - ✓ **Eliminate as an explicit requirement (because it depends on RT_{NDT})**
    - ✓ **Retain independent requirement but justify adoption of lower value**

HU/CD Limits

(Same Process Applies to Hydro Limits w/ Simpler TH)



Review of ORNL / NRC Studies Regarding Risk-Informing ASME Section XI Appendix G

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Computational Sciences and Engineering Division
Oak Ridge National Laboratory

Mark EricksonKirk
Office of Nuclear Regulatory Research
United States Nuclear Regulatory Commission

Meeting at NRC Headquarters
April 17, 2007
Rockville, Maryland

A Goal of Current NRC Research Is to Derive a Technical Basis for a Risk-Informed Revision to the Current Requirements of Appendix G to 10 CFR Part 50 in a Manner That Is Consistent With That Used to Develop the Risk-Informed Revision to the PTS Regulations

Overview of Presentation

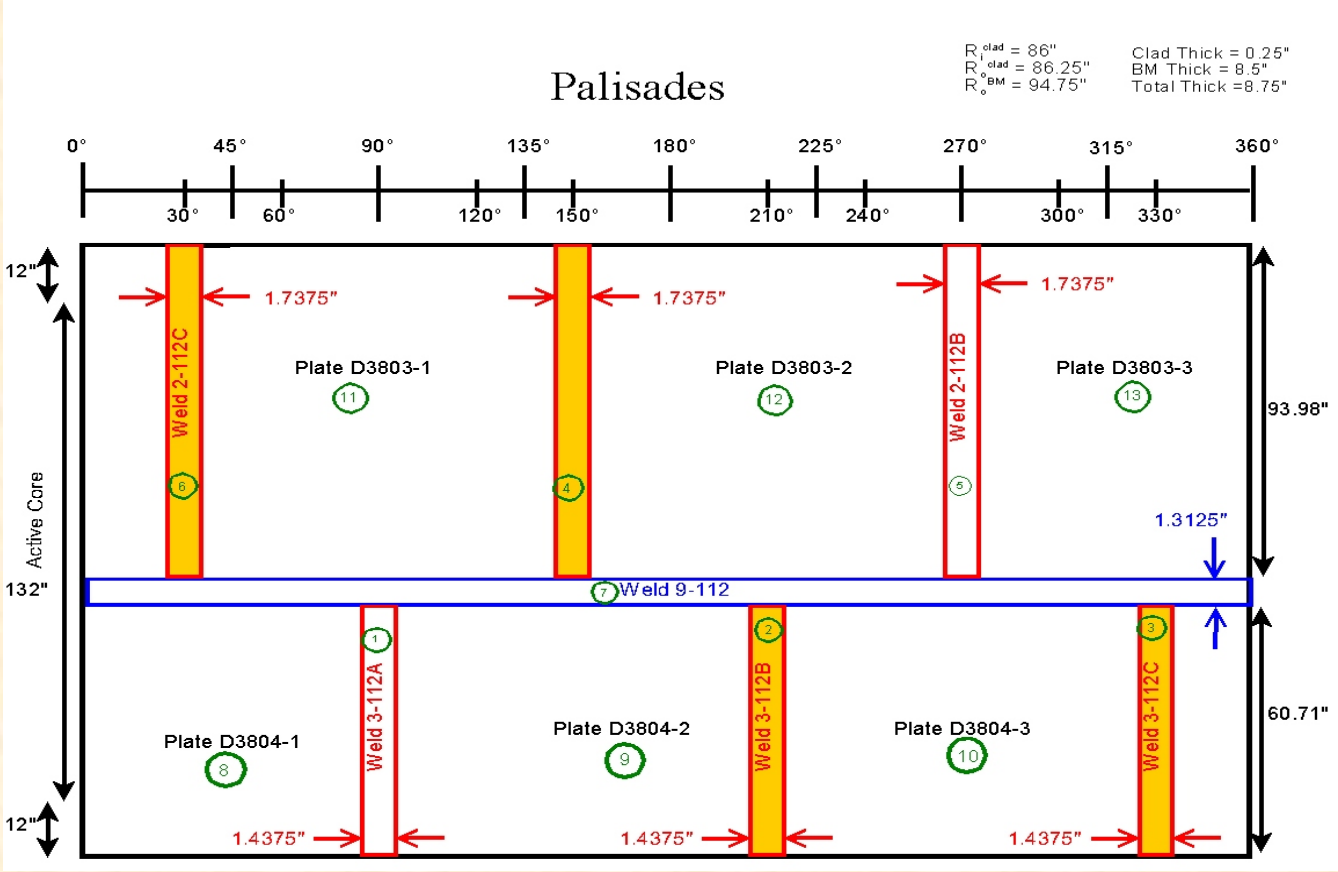
- **Previous work on cool-down transients**
- **Previous work on heat-up transients**
- **Rationale for cool-down always being limiting relative to heat-up ?**
- **Parametric study on stylized (but realistic) cool-down transients**

Review of previous work on cool-down transients

Scoping PFM analyses for normal operation cool-down transients associated with reactor shutdown were performed for Palisades since it was the most limiting RPV in the PTS re-evaluation (axial welds are the most highly embrittled RPV regions)

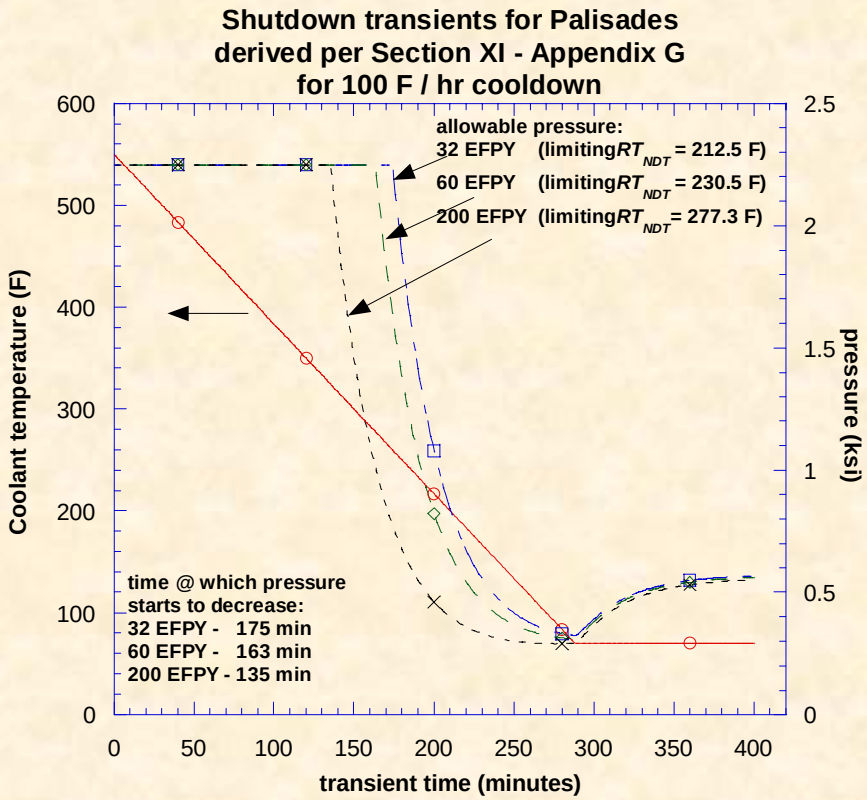
Note that all postulated flaws are embedded flaws

360 degree rollout of Palisades Reactor Pressure Vessel

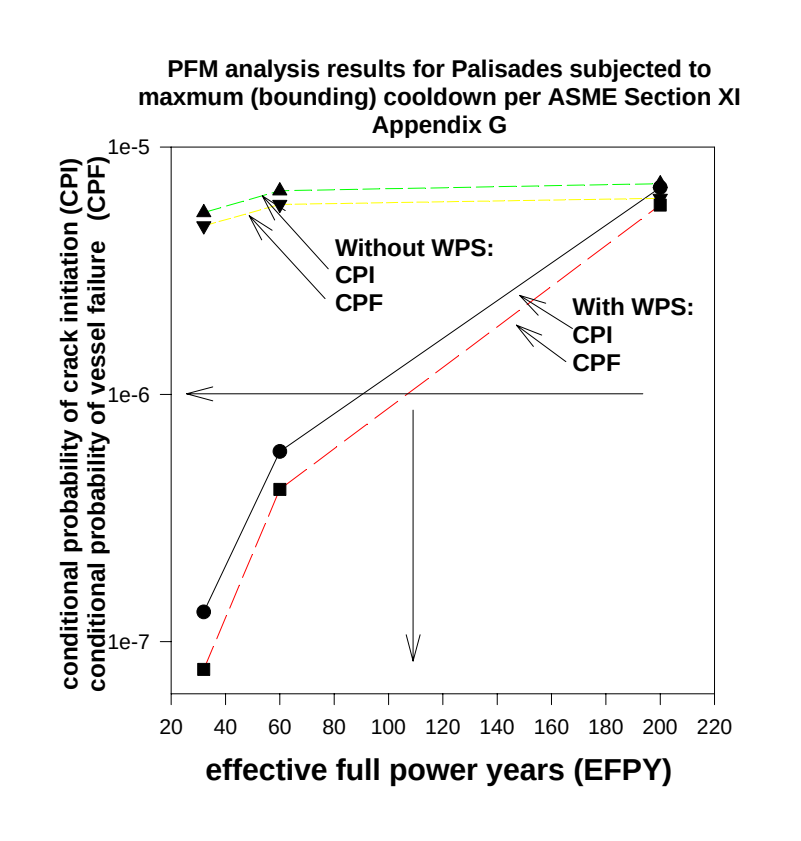


Scoping PFM analysis results for bounding cool-down transients are in compliance with proposed new acceptance criteria (for PTS) of 1.0e-6 failed RPVs per reactor operating year for over 100 EFPY

Bounding cool-down transients for Palisades per Section – XI Appendix G

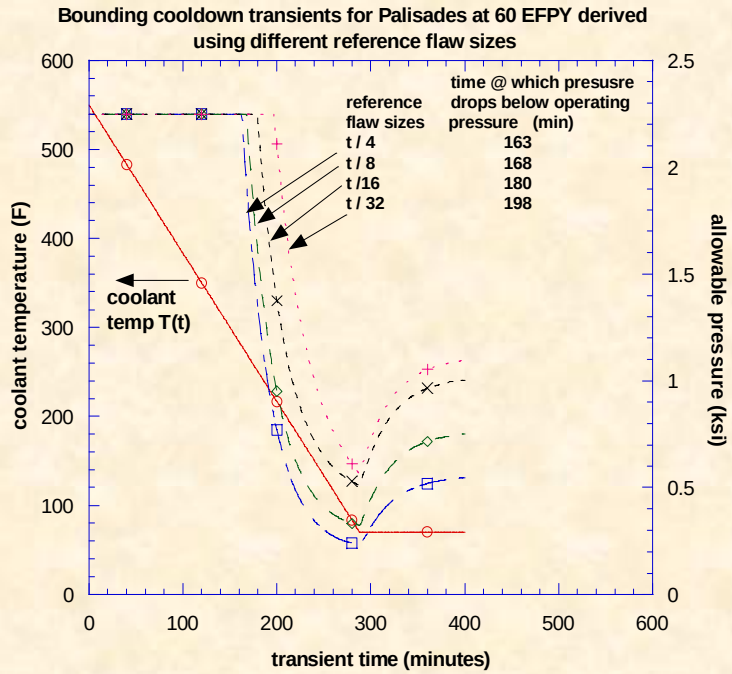


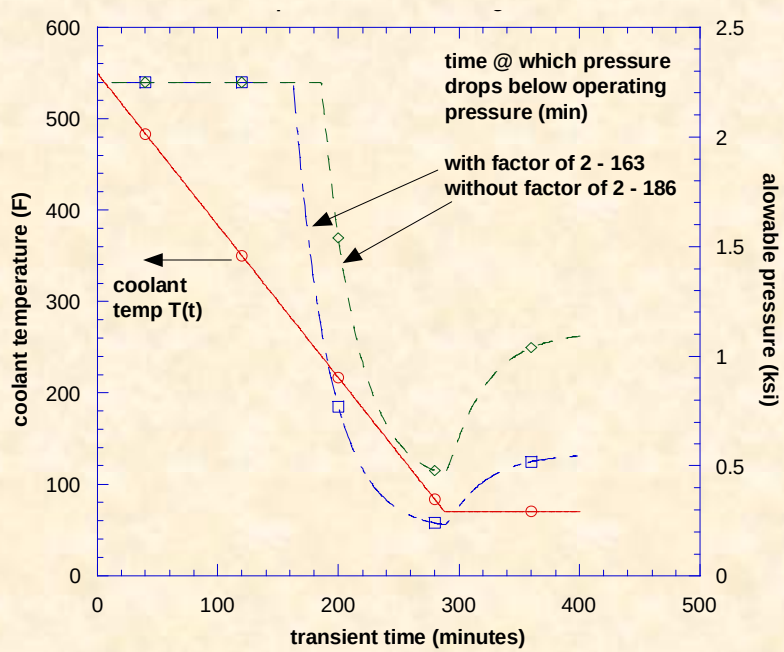
CPI and CPF computed with and without WPS



Previous analyses explored possible different approaches to relaxing the current prescriptive deterministic method of Section XI – Appendix G

e.g., Remove factor of 2 and modification of reference flaw size in derivation of allowable pressure

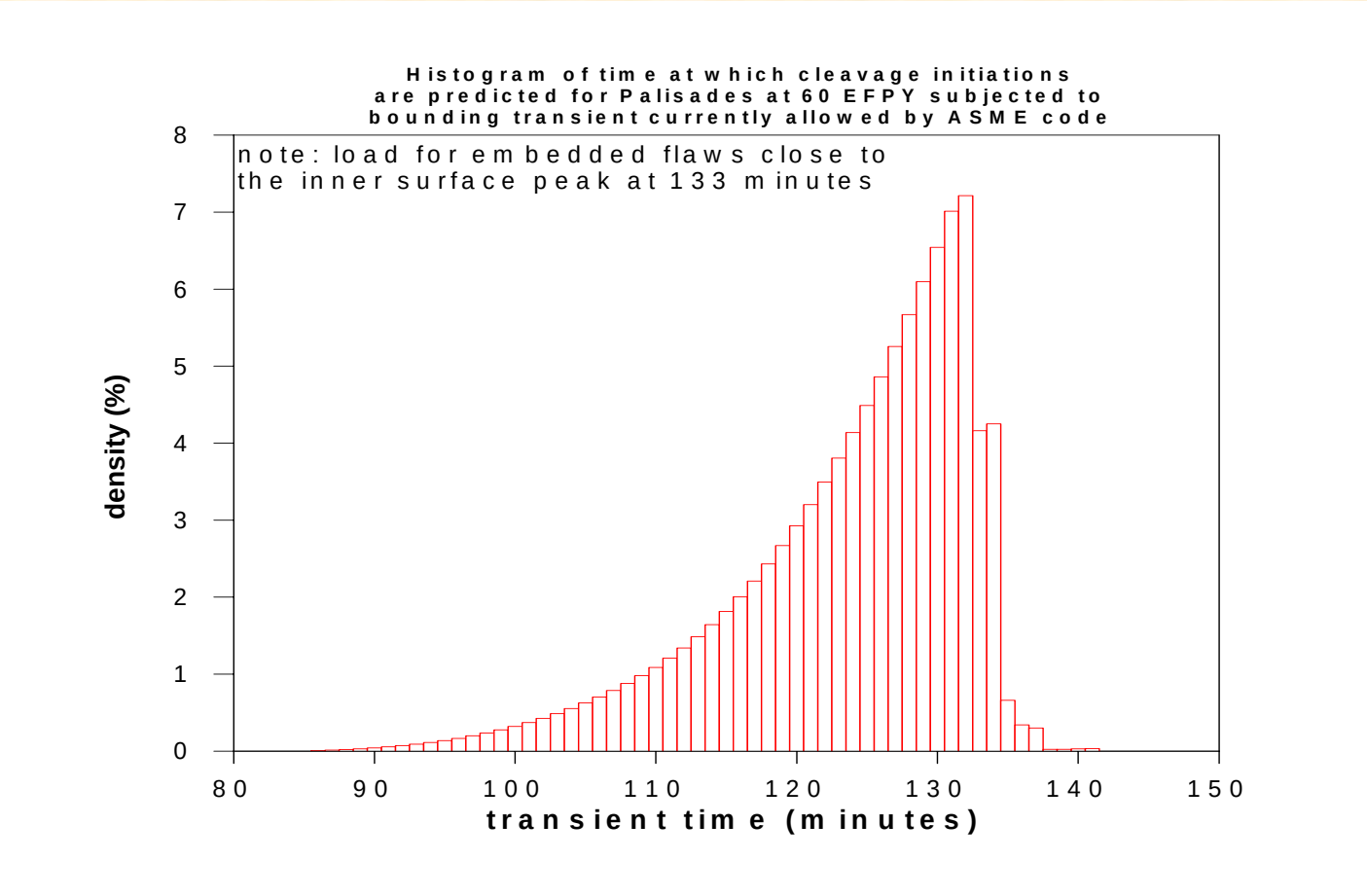




The result of the relaxations was to allow the pressure to hold at steady state (operating) pressure to a later transient time

These Relaxations Do Not Increase the Risk. i.e., do not Impact PFM Solutions, Since All Initiations and Failures Are Predicted to Occur Before the Transients Diverge (Different Pressure Hold Times)

All crack initiations are predicted to occur in first 142 minutes of transient; load peaks at 133 minutes for embedded axial flaws close to inner surface of RPV

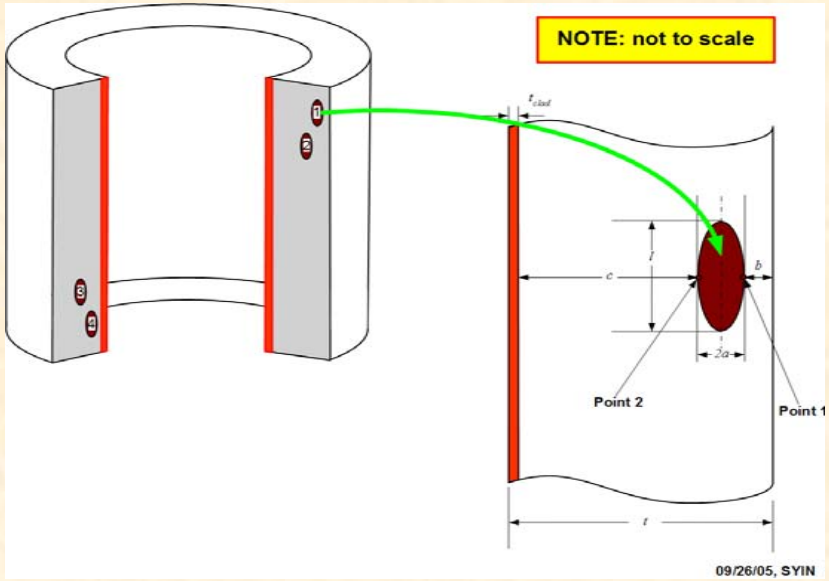


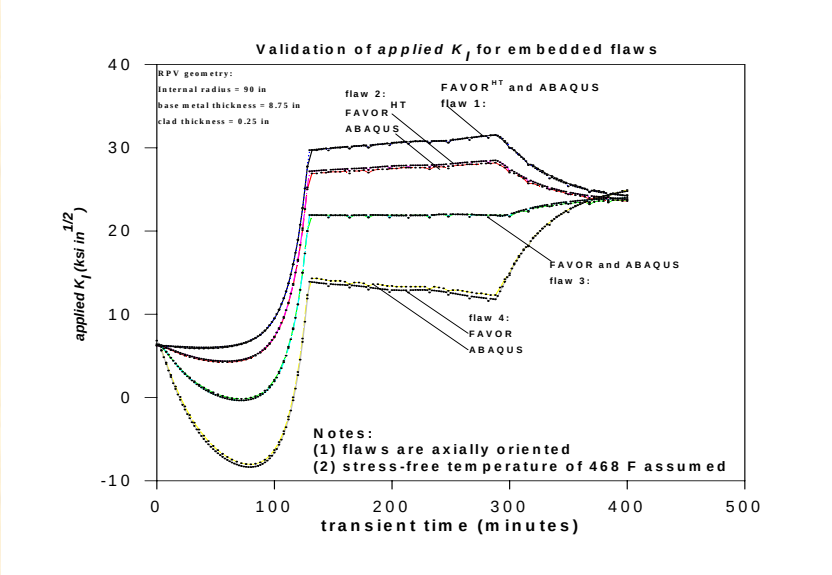
Review of previous work on heat-up transients associated with reactor startup

FAVOR^{HT} Has Been Developed to Calculate Crack Initiation Probabilities for Heat-Up Transients Such as those Associated with Reactor Startup

- During cool-down transients associated with reactor shutdown, tensile stresses tend to open existing cracks on or near the RPV inner surface
- During heat-up transients associated with reactor startup, tensile stresses tend to open existing cracks on or near the RPV outer surface
- Previous versions of FAVOR designed for analysis of cool-down transients (fracture mechanics of flaws on or near RPV inner surface)
- Initial version of FAVOR^{HT} developed to address deterministic and probabilistic fracture mechanics of embedded flaws near RPV outer surface
- Initial version of FAVOR^{HT} calculates conditional probability of <u>initiation,</u> for embedded flaws near outer surface, due to cleavage fracture, but without capability of through-wall crack propagation
- A major requirement for the development of FAVOR^{HT} was to have a validated computational methodology for calculating applied K_I for embedded flaws near the RPV outer surface

The implementation of the methodology into FAVOR^{HT} for calculating applied *KI* for embedded flaws near the RPV outer surface has been validated by successfully comparing FAVOR and ABAQUS solutions



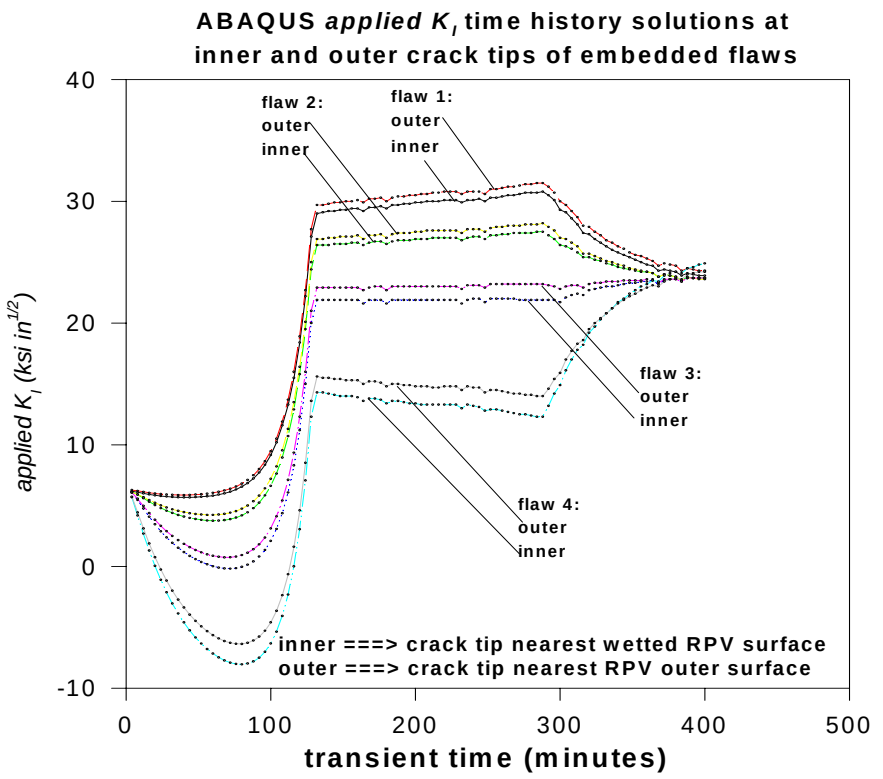


flaw model number	c (mm)	b (mm)	depth (2a) (mm)	length (mm)	largest difference in ABAQUS and FAVOR (ksi in$^{1/2}$)
1	189.55	12.7	20	80	0.18
2	126.05	76.2	20	80	0.35
3	69.85	132.4	20	80	0.27
4	6.35	195.9	20	80	0.53

FAVOR^{HT} performs fracture analysis at crack tip nearest the RPV outer surface

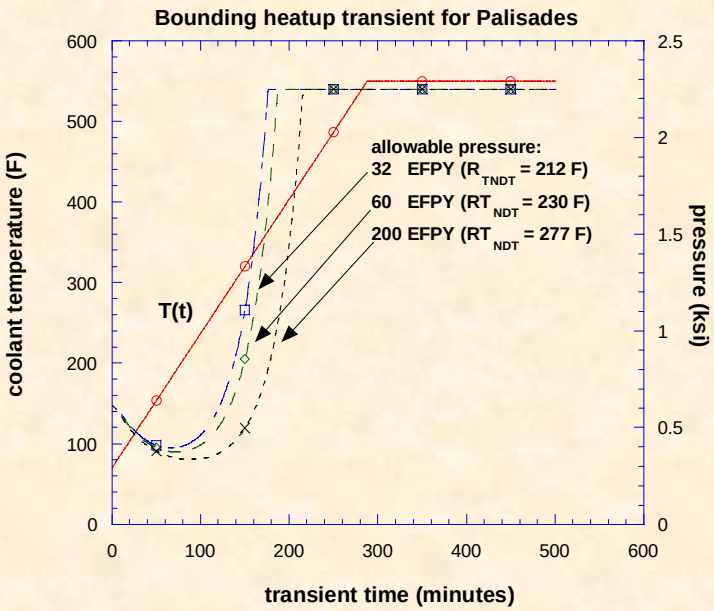
Competing effects: embrittlement decreases from inner surface to outer surface and temperature increases from inner to outer surface (for heat-up)

For cases examined in detail: outer crack tip has higher K_I / K_{Ic} ratio



PFM scoping studies for heat-up transients associated with reactor startup performed with FAVOR^{HT} indicate very small probability of cleavage fracture

Also, no ductile tearing, as initiating mechanism predicted

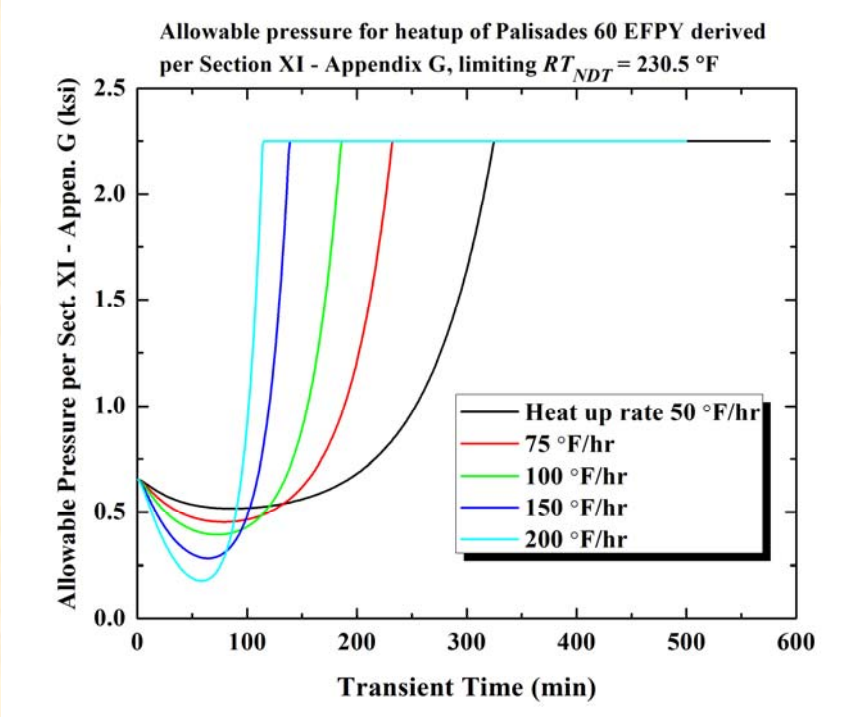


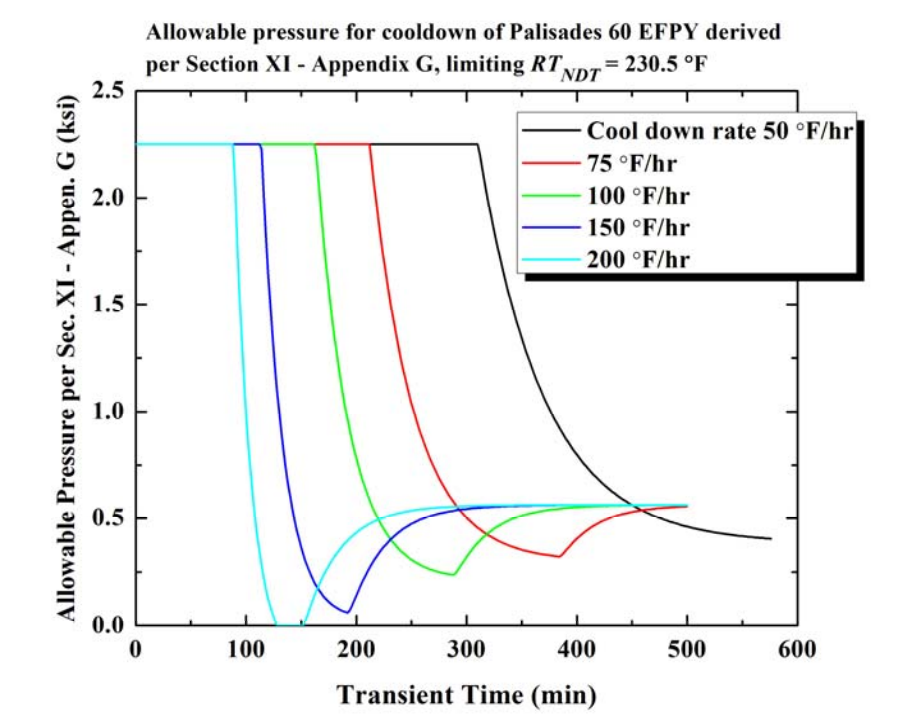
EFPY	*FAVHT CPI due to flaws in outer 3/8 t*	*FAVPFM CPI due to flaws in inner 3/8 t*	**Total**
32	0.0e+0	0.0e+0	0.0e+0
60	7.32 e-11	0.0e+0	7.32 e-11
200	6.33e-10	0.0e+0	6.33e-10

Preliminary Evaluation of the Potential for Deterministic Elimination of Heat-up transients Associated with Reactor Startup

(by demonstrating that cool-down transients always pose a greater risk than heat-up transients)

The prescriptive deterministic fracture methodology in ASME Section XI – Appendix G was applied to derive allowable pressure for a range of cool-down and heat-up rates

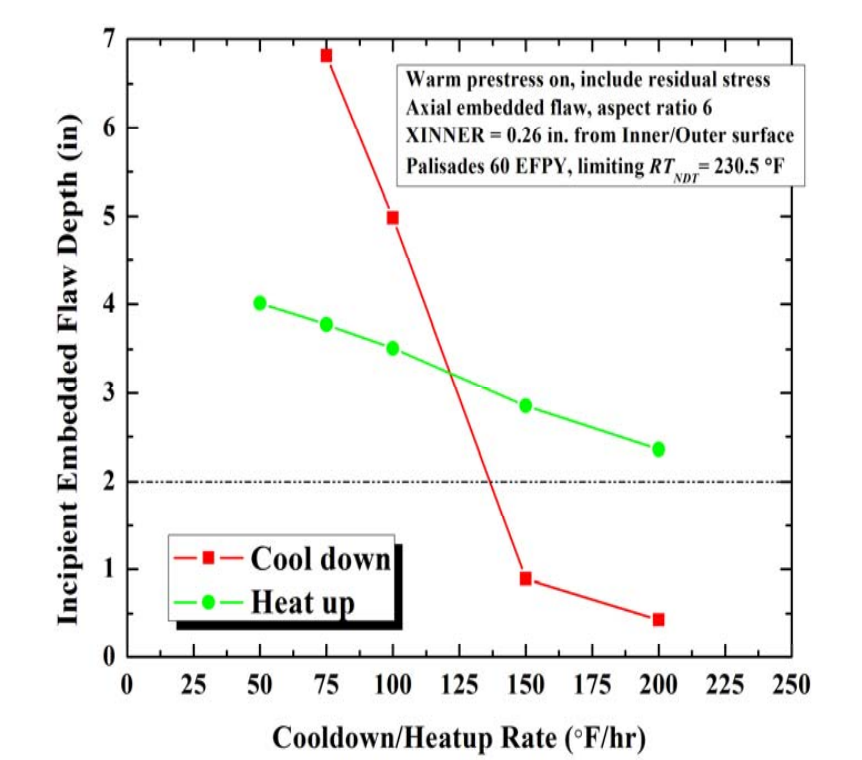




Deterministic minimization option 1: for embedded flaw, given inner crack-tip RT_{NDT} and through-wall flaw location, find the incipient flaw depth, i.e. the minimum embedded flaw depth such that the applied K_I driving force is tangent to the Weibull "a" parameter of the K_{Ic} distribution, i.e. solve for the minimum flaw depth that would have a non-zero conditional probability of crack initiation.

(1) Theoretically, heat-up is more limiting than cool-down for cool-down / heat-up rates < ~ 125 F / hr; however, incipient embedded flaw depths > 3.0 inches. The maximum postulated embedded flaw depth ~ 2.0 inches.

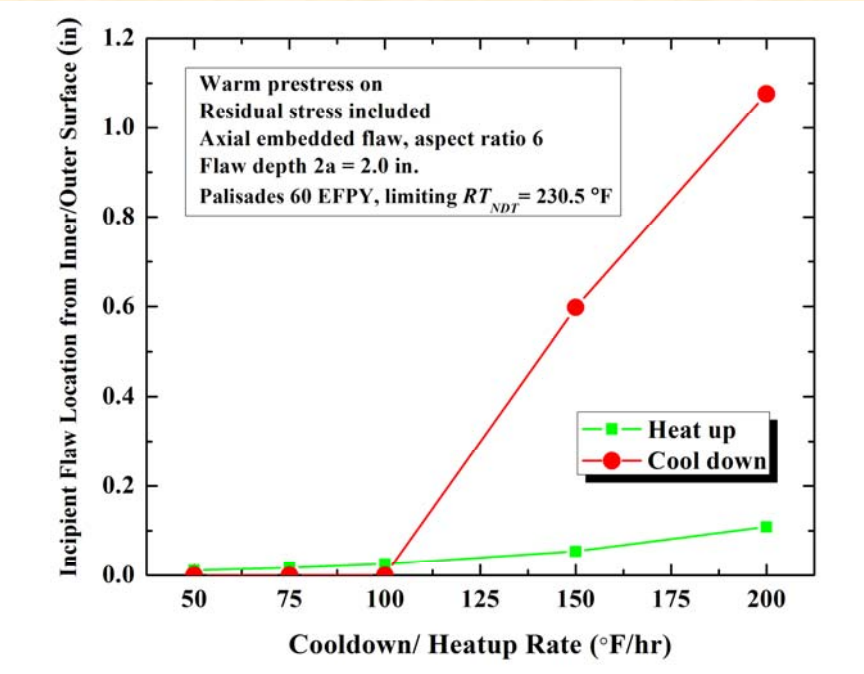
(2) Minimum incipient embedded flaw depth for heat-up transients is greater than maximum postulated depth.

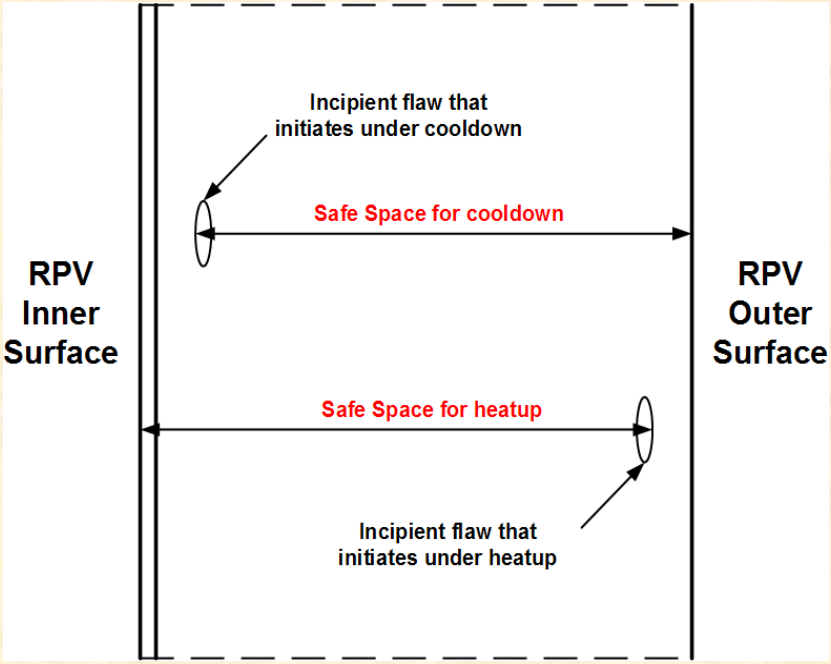


Deterministic minimization option 2: for RPV containing embedded flaw of specified depth, length, and inner-surface RT_{NDT}, locate the incipient through-wall location, I.e., the maximum distance (from the RPV inner surface for cool-down and RPV outer surface for heat-up) such that applied K_I driving force is tangent to the Weibull "a" parameter of the K_{Ic} distribution, i.e. solves for the maximum thru-wall distance of inner flaw tip flaw that would have a non-zero conditional probability of crack initiation.

(1) Again, heat-up is more limiting than cool-down for cool-down / heat-up rates < ~ 100 F / hr, I.e, has smaller amount of "safe RPV wall space".

(2) Cool-down more limiting than heat-up for cool-down / heat-up rates > ~ 100

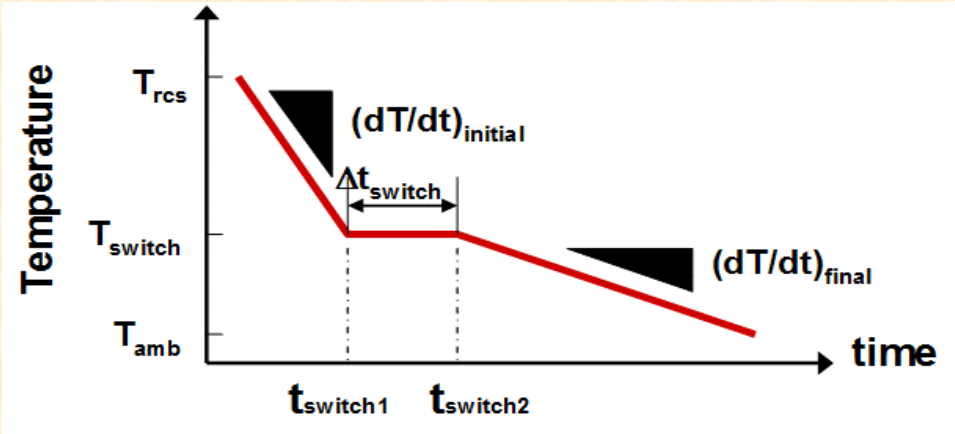


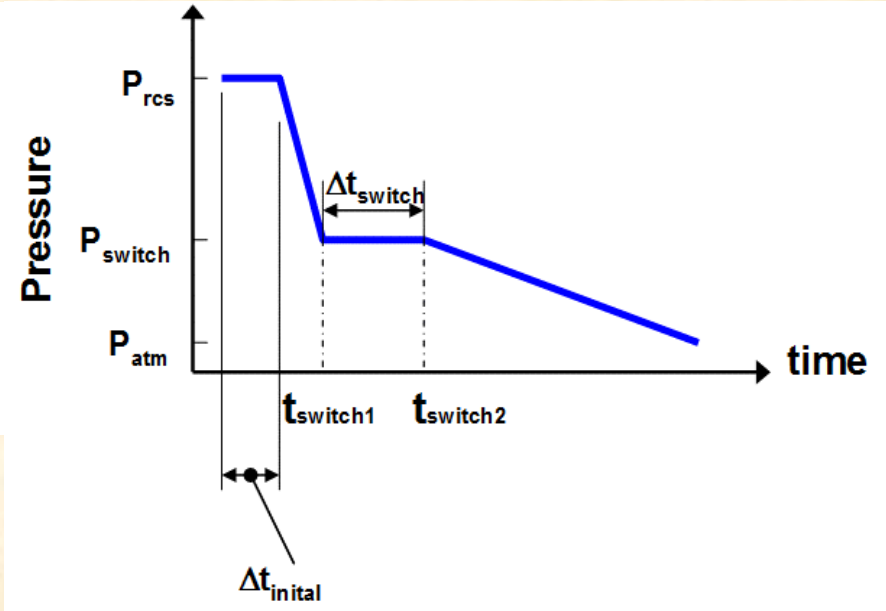


Review of recent work on PFM scoping analyses of parameterized cool-down transients associated with reactor shutdown

Cool-down transients associated with reactor shutdown were parameterized in terms of:
cool-down rates: $\{(dT/dt)_{initial}, (dT/dt)_{final}\}$,
plateau temperature and pressure $\{(T_{switch}), P_{switch})\}$,
duration for which pressure and temperature remain at plateau (Δt_{switch}),
and "hold time for pressure" $\Delta t_{initial}$

Motivated by previous Westinghouse work





Assumptions:

(1) Plateau pressure P_{switch} = 1.0 ksi

(2) $t_{switch1}$, $t_{switch2}$, and Δt_{switch} are identical for P(t) and T(t)

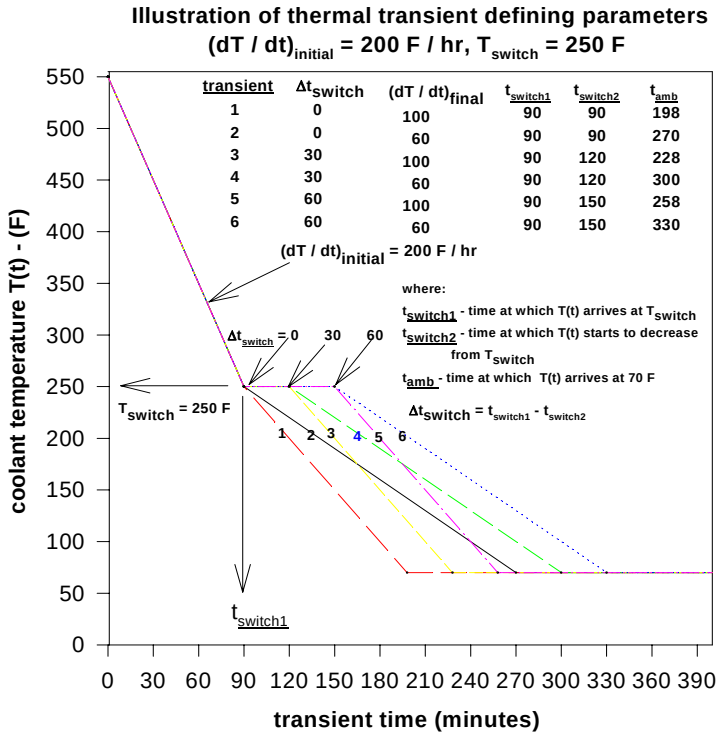
The initial phase of the PFM scoping analyses was performed for Palisades at 60 EFPY with the 06.1 version of FAVOR for 360 permutations of parameters

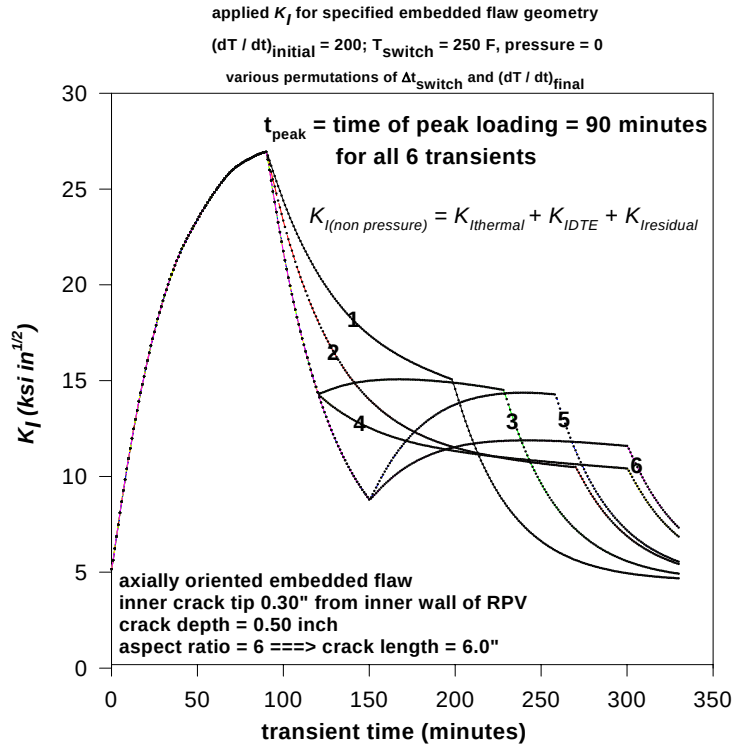
5	2		4	3			3		
$(dT / dt)_{initial}$	$(dT / dt)_{final}$		T_{switch}	Δt_{switch}			$\Delta t_{initial}$		
400	60	100	212	0	30	60	0	30	60
400	60	100	250	0	30	60	0	30	60
400	60	100	300	0	30	60	0	30	60
400	60	100	350	0	30	60	0	30	60
300	60	100	212	0	30	60	0	30	60
300	60	100	250	0	30	60	0	30	60
300	60	100	300	0	30	60	0	30	60
300	60	100	350	0	30	60	0	30	60
250	60	100	212	0	30	60	0	30	60
250	60	100	250	0	30	60	0	30	60
250	60	100	300	0	30	60	0	30	60
250	60	100	350	0	30	60	0	30	60
200	60	100	212	0	30	60	0	30	60
200	60	100	250	0	30	60	0	30	60
200	60	100	300	0	30	60	0	30	60
200	60	100	350	0	30	60	0	30	60
100	60	100	212	0	30	60	0	30	60
100	60	100	250	0	30	60	0	30	60
100	60	100	300	0	30	60	0	30	60
100	60	100	350	0	30	60	0	30	60

For the cases examined thus far,

When WPS is included in the model, PFM solutions are invariant with respect to Δt_{switch} and $(dT / dt)_{final}$ because the effect of Δt_{switch} and $(dT / dt)_{final}$ occur after maximum loading

therefore: PFM solutions are functions of $(dT/dt)_{initial}$, T_{switch}, and $\Delta t_{initial}$

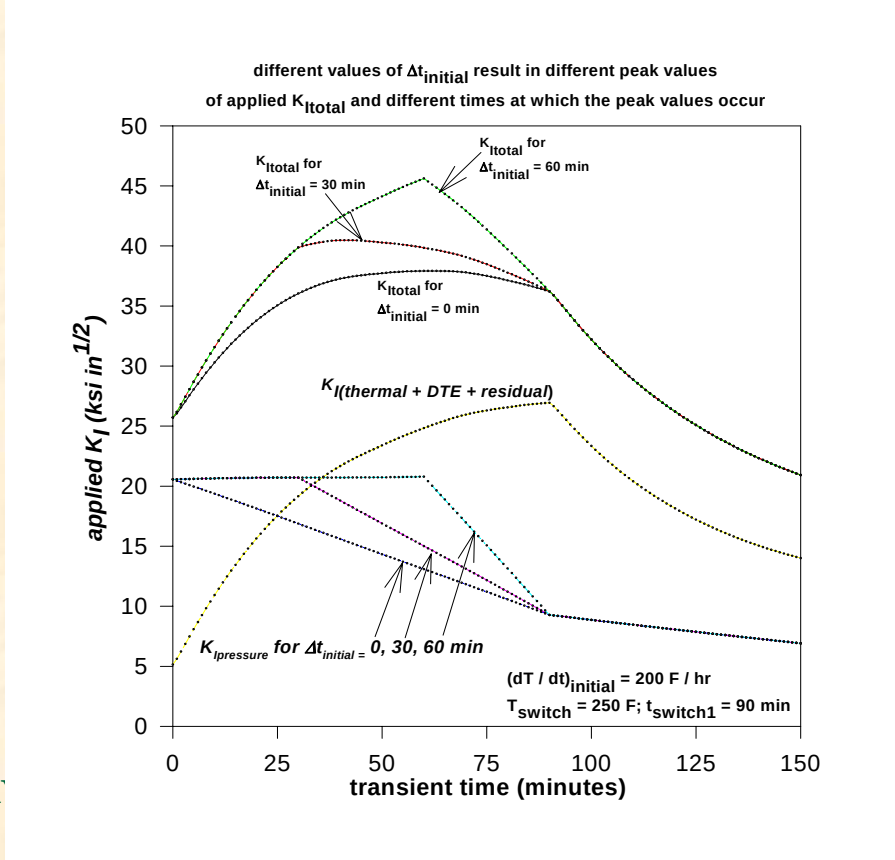




There is a complex interaction between $(dT/dt)_{initial}$, T_{switch}, and $\Delta t_{initial}$ that determines the time t_{peak} and magnitude of peak loading $KI(t_{peak})$

For a given pair $\{(dT/dt)_{initial}, T_{switch}\}$
$\{t_{peak}, KI(t_{peak})\}$ are uniquely determined as a function of $\Delta t_{initial}$

The second phase of the PFM scoping analyses for parameterized cool-down transients concentrated on a more detailed variation of $\Delta t_{initial}$

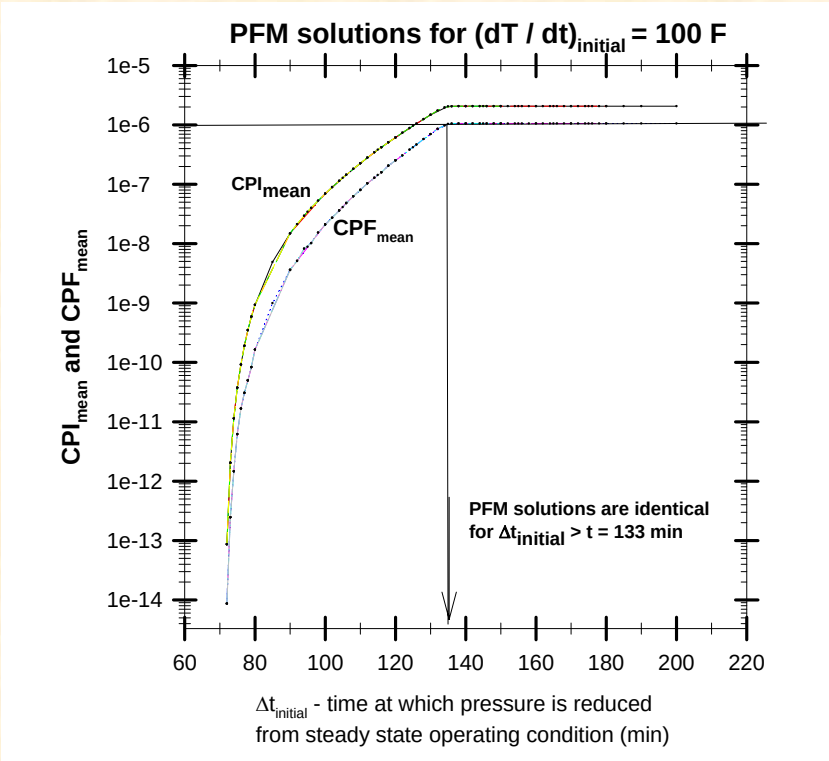


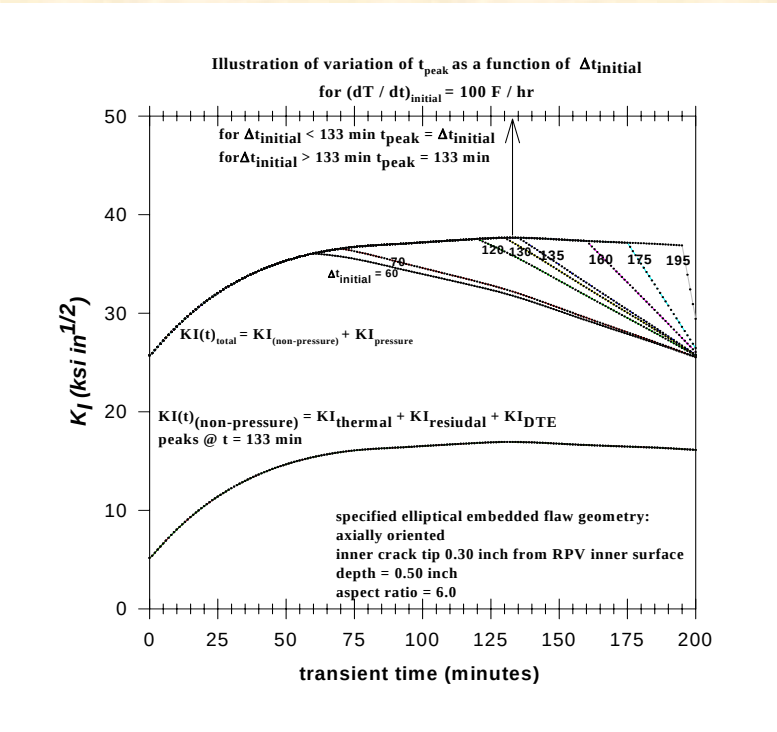
For $(dT/dt)_{initial}$ = 100 F / hr:

for $\Delta t_{initial}$ < 133 min, as $\Delta t_{initial}$ increases, t_{peak} , *$KI(t_{peak})$*, and PFM solutions increase

for $\Delta t_{initial}$ > 133 min, t_{peak} = constant = 133; therefore *$KI(t_{peak})$*, and PFM solutions = constant

Note: With WPS in the model, t_{peak} is the last transient time that can be used in the fracture analysis; therefore: *$KI(t_{peak} = 133)$* and *$T(tpeak = 133)$* produce identical results for all cool-down transients with $\Delta t_{initial}$ > 133 min





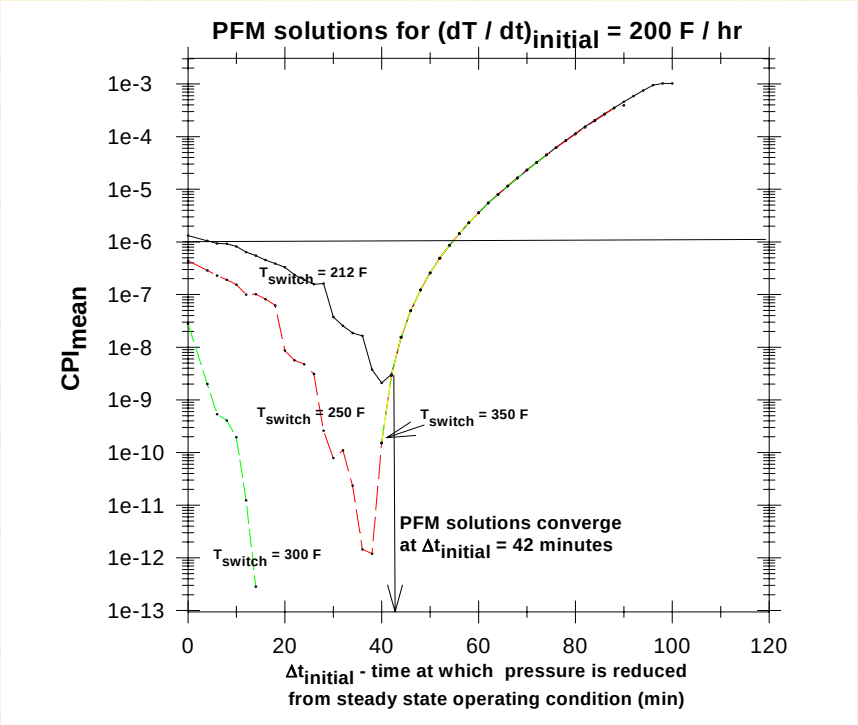
For $(dT/dt)_{initial}$ = 200 F / hr:

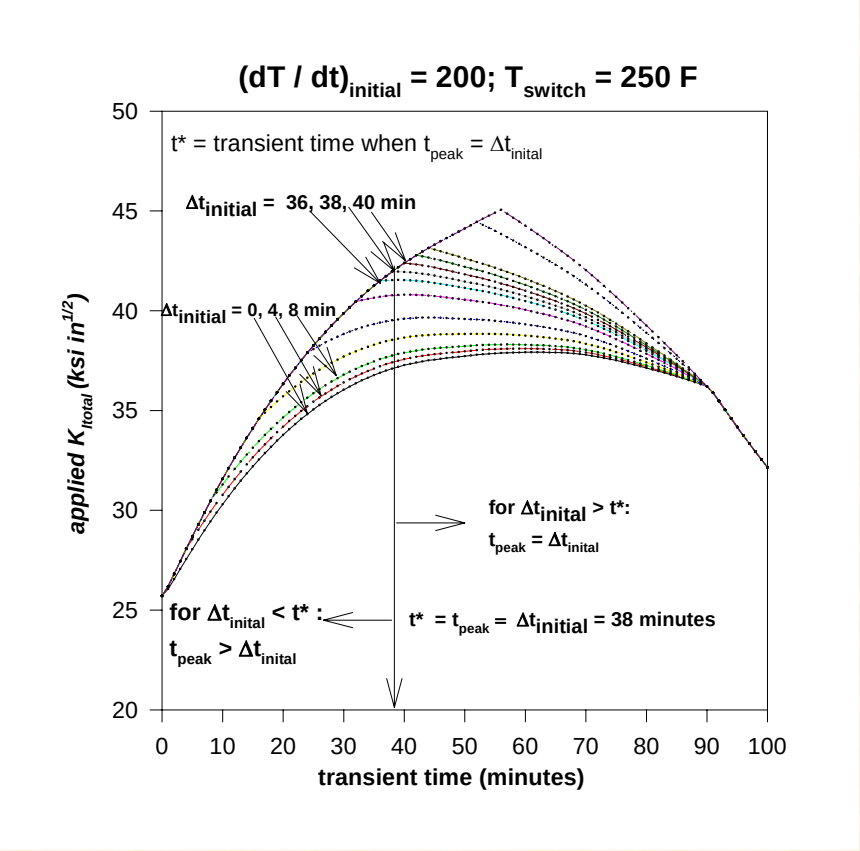
PFM solutions decrease for increasing Δtinitial up to
t* = earliest transient time at which t_{peak} occurs

PFM solutions increase for increasing $\Delta t_{initial}$ for $\Delta t_{initial}$ > t*

PFM solutions converge for various values of T_{switch} at $\Delta t_{initial} = t_{converge}$

(for mechanistic insight, see next slide, hopefully)

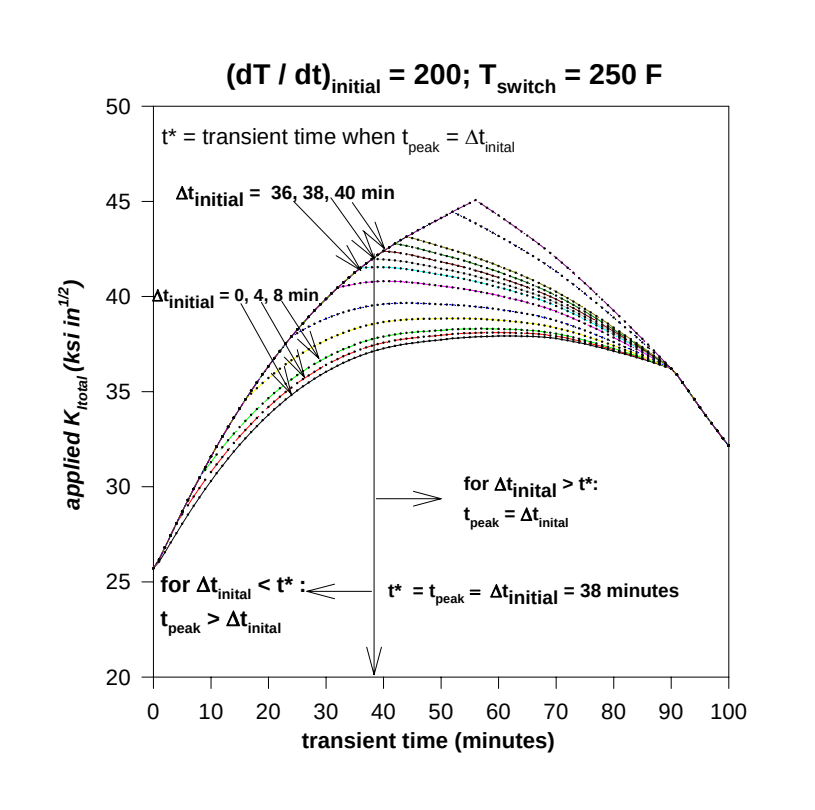




For $(dT/dt)_{initial}$ = 200 F / hr:

Initially, t_{peak} and PFM solutions decrease for cool-down transients with increasing $\Delta t_{initial}$ until $t_{peak} = \Delta t_{initial} = t^*$ = earliest transient time at which t_{peak} occurs

For cool-down transients with $\Delta t_{initial} > t^*$, $t_{peak} = \Delta t_{initial}$, PFM solutions increase



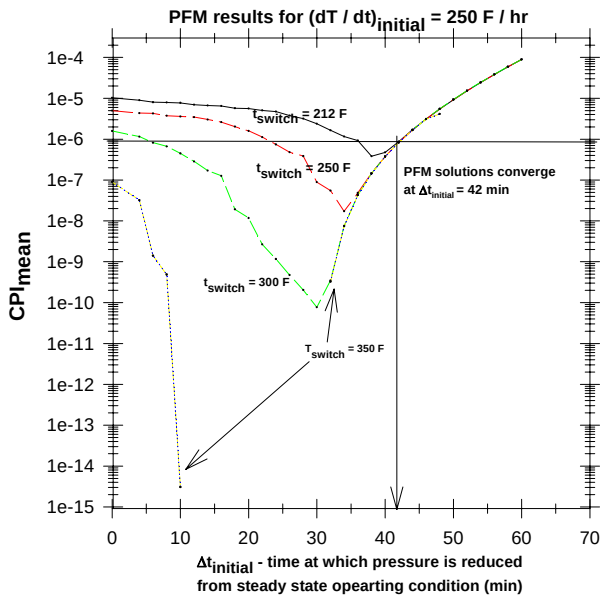
PFM trend for $(dT / dt)_{initial}$ = 200 F / hr
T_{switch} = 250 F, $t^* = t_{peak} = \Delta t_{initial}$ = 38

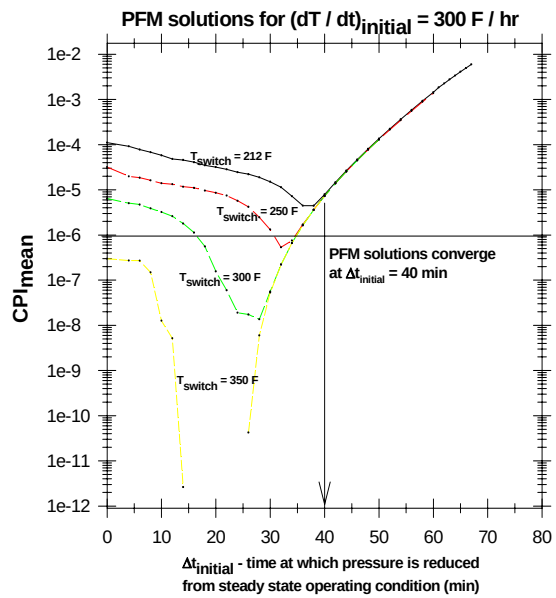
$\Delta t_{initial}$ (min)	CPI_{mean} [1]	CPF_{mean} [1]	t_{PEAK} [2] (min)	$K_I(t_{peak})$ [2] ksi in$^{1/2}$	$T(t_{peak})$ [2] °F
0	4.41E-07	4.41E-07	62	37.9	364.0
4	2.86E-07	2.86E-07	59	38.1	373.6
6	2.30E-07	2.30E-07	58	38.2	376.8
36	1.44E-12	1.44E-12	39	41.5	436.7
t* = 38	1.20E-12	1.20E-12	38	42.0	439.8
40	1.52E-10	1.52E-10	40	42.4	433.6
56	1.44E-06	1.44E-06	56	45.1	383.2
58	2.31E-06	2.31E-06	58	45.3	376.8
60	3.58E-06	3.58E-06	60	45.6	370.4
90	3.93E-04	3.36E-04	90	47.8	276.6

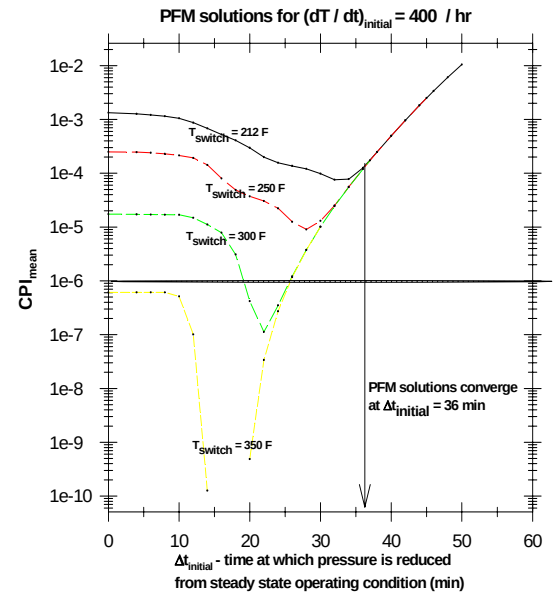
(1) Result is from PFM analysis
(2) Result is from deterministic analysis

Similar PFM trend was found for $(dT/dt)_{initial}$ = 250, 300, and 400 F / hr as previously illustrated for $(dT/dt)_{initial}$ = 200

Note that for each $(dT/dt)_{initial}$; PFM solutions eventually converge for various values of T_{switch}, the value of $\Delta t_{initial}$ at which they converge is designated as $t_{converge}$

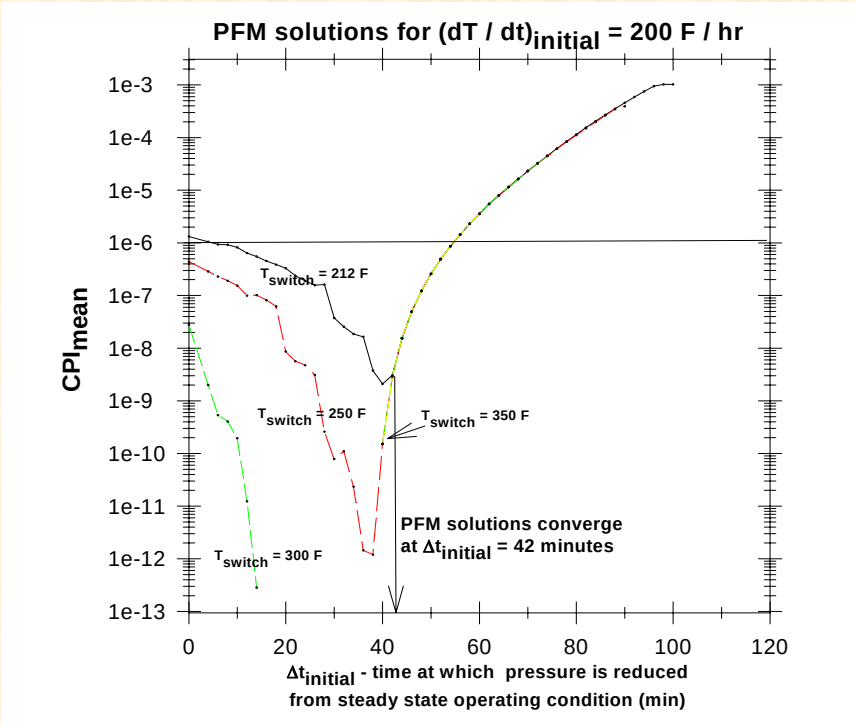


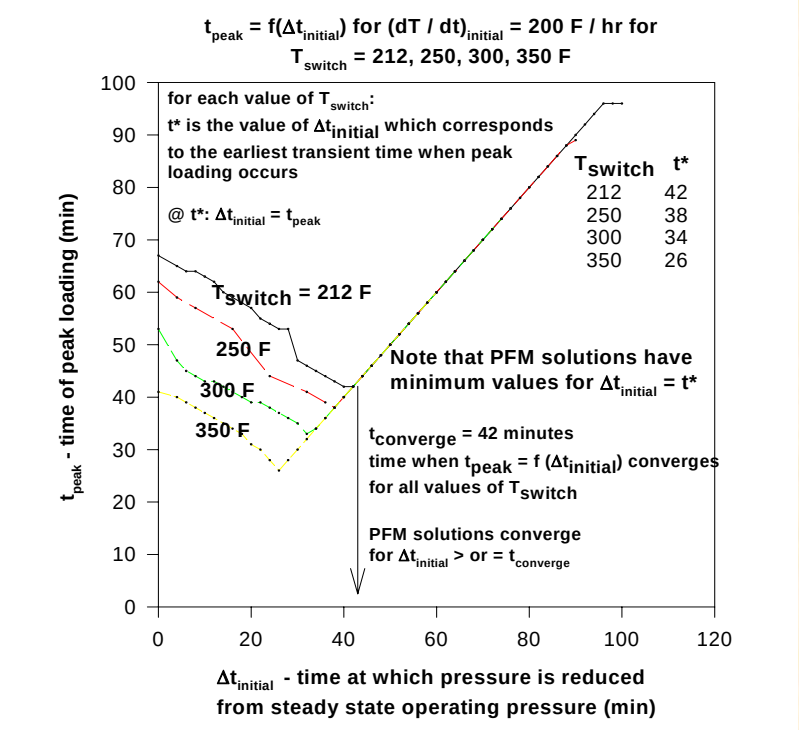




For each $\{(dT/dt)_{initial}, T_{switch}\}$ pair, there is a t*, which corresponds to the $\Delta t_{initial}$ that produces the earliest peak loading time t_{peak}

The largest value of t* corresponds to $t_{converge}$ after which the PFM solutions for a fixed $(dT/dt)_{initial}$ are identical for all values of T_{switch}





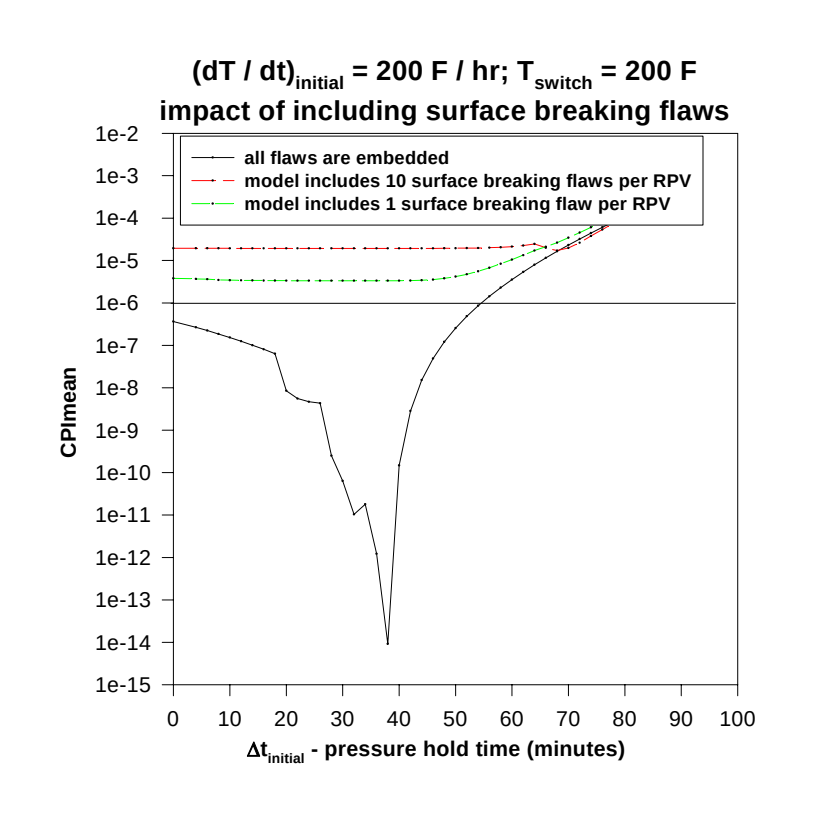
The results of the PFM scoping analyses are encouraging that the current requirements of Appendix G to 10 CFR Part 50 can be revised

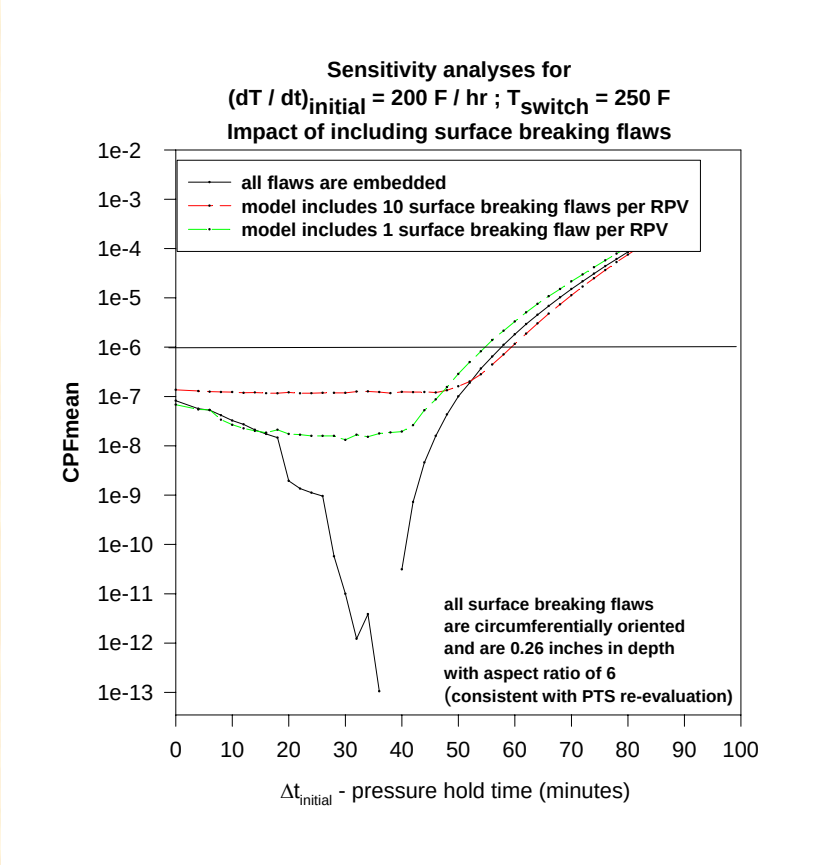
A large number of combinations of P(t) and T(t) can be used to cool-down Palisades at 60 EFPY and CPI_{mean} and CPF_{mean} remain below 1.0E-6

$(dT / dt)_{initial}$ °F / hr	T_{switch} °F	$\Delta t_{initial}$ interval for which $CPI_{mean} < 1x10^{-6}$ (minutes)	$\Delta t_{initial}$ interval for which $CPF_{mean} < 1x10^{-6}$ (minutes)
100	212	$\Delta t_{initial} < 125$	$\Delta t_{initial} < 133$
	250	$\Delta t_{initial} < 125$	$\Delta t_{initial} < 133$
	300	$\Delta t_{initial} < 125$	$\Delta t_{initial} < 133$
	350	$\Delta t_{initial} < 125$	$\Delta t_{initial} < 133$
200	212	$5 < \Delta t_{initial} < 54$	$\Delta t_{initial} < 57$
	250	$\Delta t_{initial} < 54$	$\Delta t_{initial} < 57$
	300	$\Delta t_{initial} < 54$	$\Delta t_{initial} < 57$
	350	$\Delta t_{initial} < 54$	$\Delta t_{initial} < 57$
250	212	$35 < \Delta t_{initial} < 42$	$28 < \Delta t_{initial} < 45$
	250	$22 < \Delta t_{initial} < 42$	$7 < \Delta t_{initial} < 44$
	300	$6 < \Delta t_{initial} < 42$	$\Delta t_{initial} < 44$
	350	$\Delta t_{initial} < 40$	$\Delta t_{initial} < 42$
300	212	None	None
	250	$30 < \Delta t_{initial} < 34$	$25 < \Delta t_{initial} < 36$
	300	$16 < \Delta t_{initial} < 34$	$6 < \Delta t_{initial} < 36$
	350	$\Delta t_{initial} < 34$	$\Delta t_{initial} < 36$
400	212	None	None
	250	None	None
	300	$19 < \Delta t_{initial} < 25$	$17 < \Delta t_{initial} < 27$
	350	$\Delta t_{initial} < 25$	$\Delta t_{initial} < 27$

A limited number of sensitivity analyses were performed to determine the impact of including inner-surface breaking flaws in the PFM model

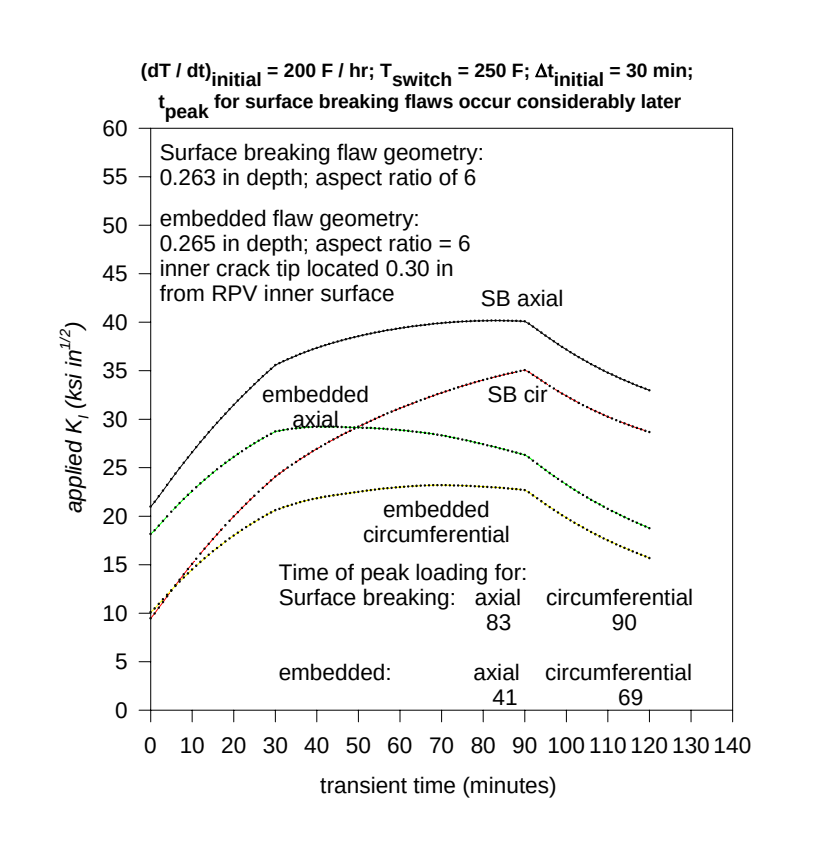
The sensitivity of the PFM results varies (increases) over several orders of magnitude as a function of $\Delta t_{initial}$





Inner surface breaking flaws obviously have a higher driving force than similar size embedded flaw

Also, t_{peak} occurs considerably later in the transient for inner-surface breaking flaws



Conclusions

Given the modeling assumptions used in these scoping analyses:

(1) When WPS is included in the model, the PFM solutions are invariant with respect to Δt_{switch} and $(dT / dt)_{final}$

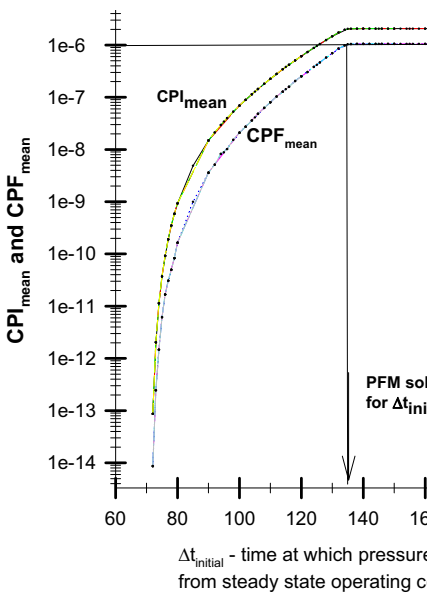
(2) Therefore, for an assumed value of P_{switch}, PFM solutions are a function of three variables: $(dT / dt)_{initial}$, T_{switch}, and $\Delta t_{initial}$.

(3) There is a complex interaction among $(dT / dt)_{initial}$, T_{switch}, and $\Delta t_{initial}$ which determines the time and magnitude of peak loading, which when WPS in included in the model, has a very significant impact on the PFM solutions.

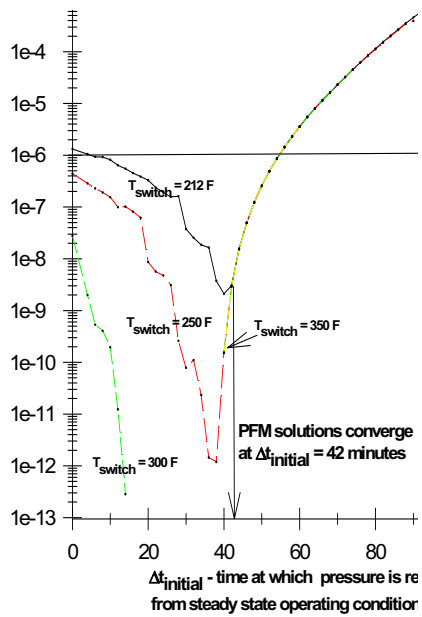
(4) Results of analyses are very sensitive to flaw distribution assumptions

Summary of Results from Cool-Down Parameter Study

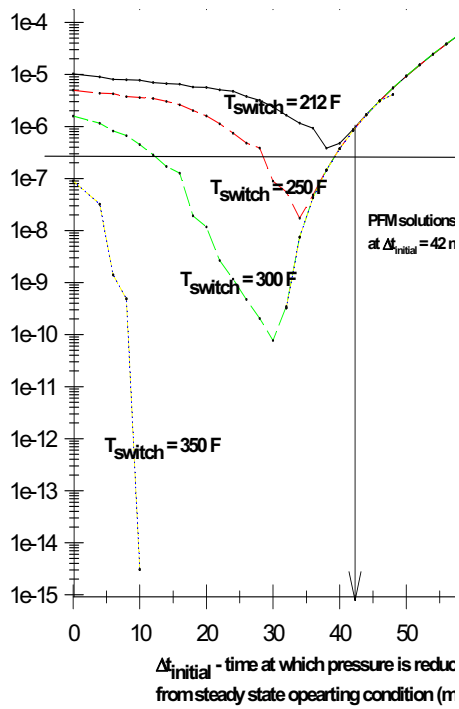
100°F/hr



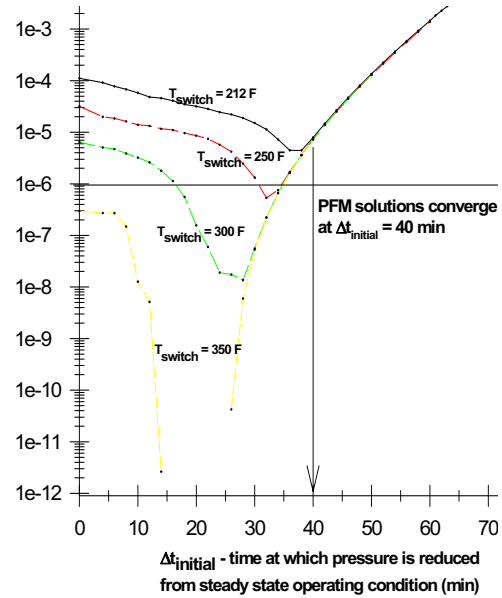
200°F/hr



250°F/hr

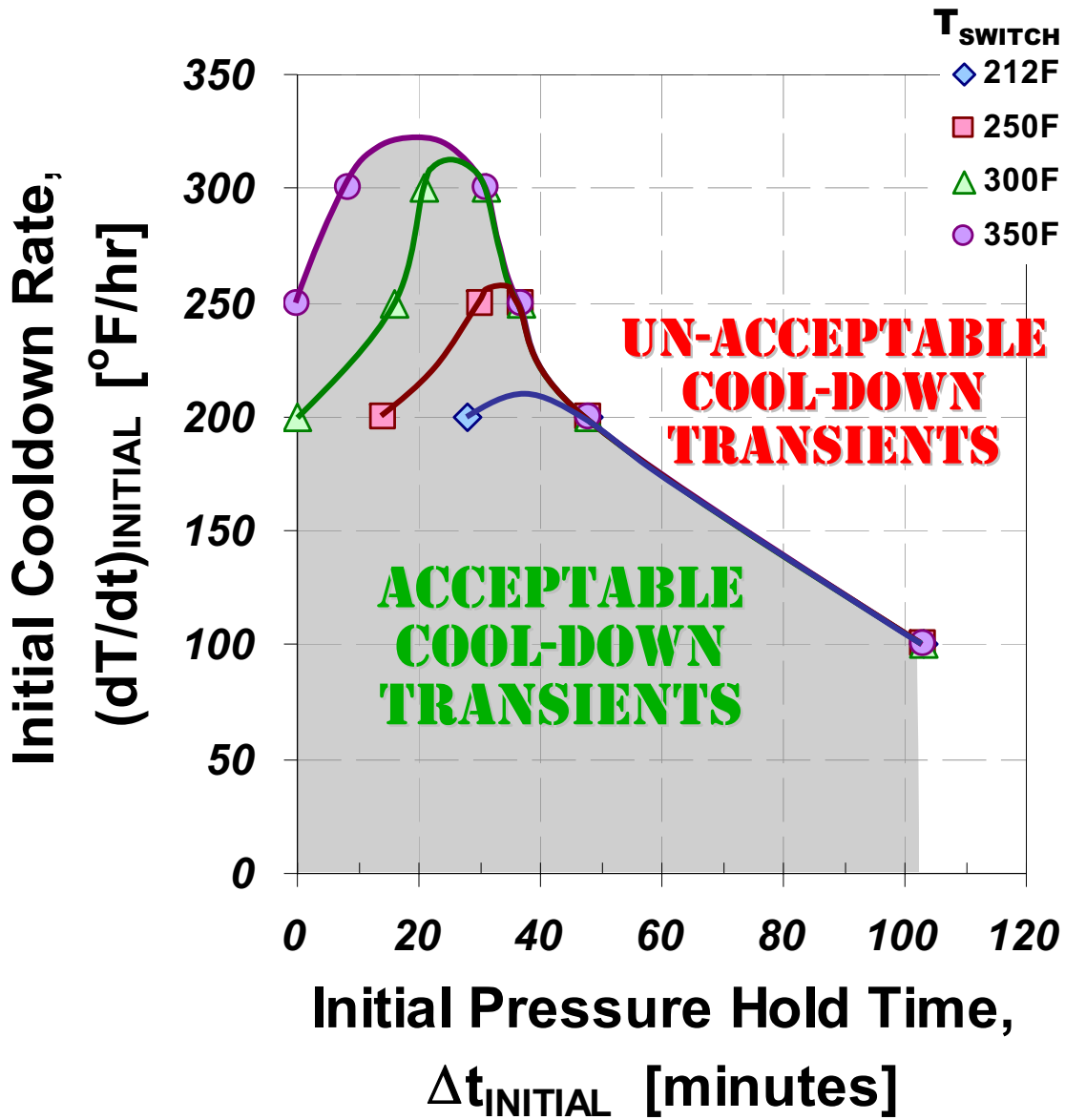


300°F/hr



Example of How These Results Could be Used

- For any specified acceptance metric (CPI, CPF, FCI, TWCF) these results can be used to define acceptable *vs.* un-acceptable cool-downs
- Given that
  - $P_{SWITCH} \leq 1000$ psi
  - $\Delta t_{SWITCH} \geq 0$ min
  - $(dT/dt)_{FINAL} \leq 100$ °F/hr
  - WPS is ON
  - Flaws as modeled



Industry Activities to Support on Risk-Informed Appendix G

Bill Server (ATI), Bruce Bishop, Nathan Palm, Ted Meyer (Westinghouse Electric Company)

NRC/EPRI MRP Meeting
Rockville, Md.
April 17, 2007

Industry Activities to Support Risk Informing ASME XI Appendix G

- Industry Proof of Concept Studies
  - ATI/Sartrex Approach — W. Server
  - Westinghouse/XGEN Approach — N. Palm
- Overall Plan/Schedule — T. Meyer

Proof of Concept Studies

- Two studies were funded by EPRI to evaluate potentially different approaches to apply risk informed methods for startup and shutdown transients in both PWRs and BWRs
- Ultimate goal is a deterministic, risk informed methodology for Appendix G of Sections III and XI of the ASME Code to define normal reactor startup and shutdown operational limits

ATI Consulting – Sartrex: Proof of Concept Study

- *BWRVIP-141: BWR Vessel and Internals Project, Risk Informed Approach for Calculating Reactor Pressure Vessel Heatup and Cooldown Operating Curves,* EPRI, Palo Alto, CA, 2005: 1011691.
- Details presented earlier at NRC meeting on 5/25/05
- Brief overview of approach and results presented here

Basic Approach

- Consistent with the PTS risk informed criterion, the risk informed margin is determined by finding the margin that will result in conditional probability of vessel failure (CPF) = 1E-6 when the reactor operates up to P/T limits determined from the current basic equation:

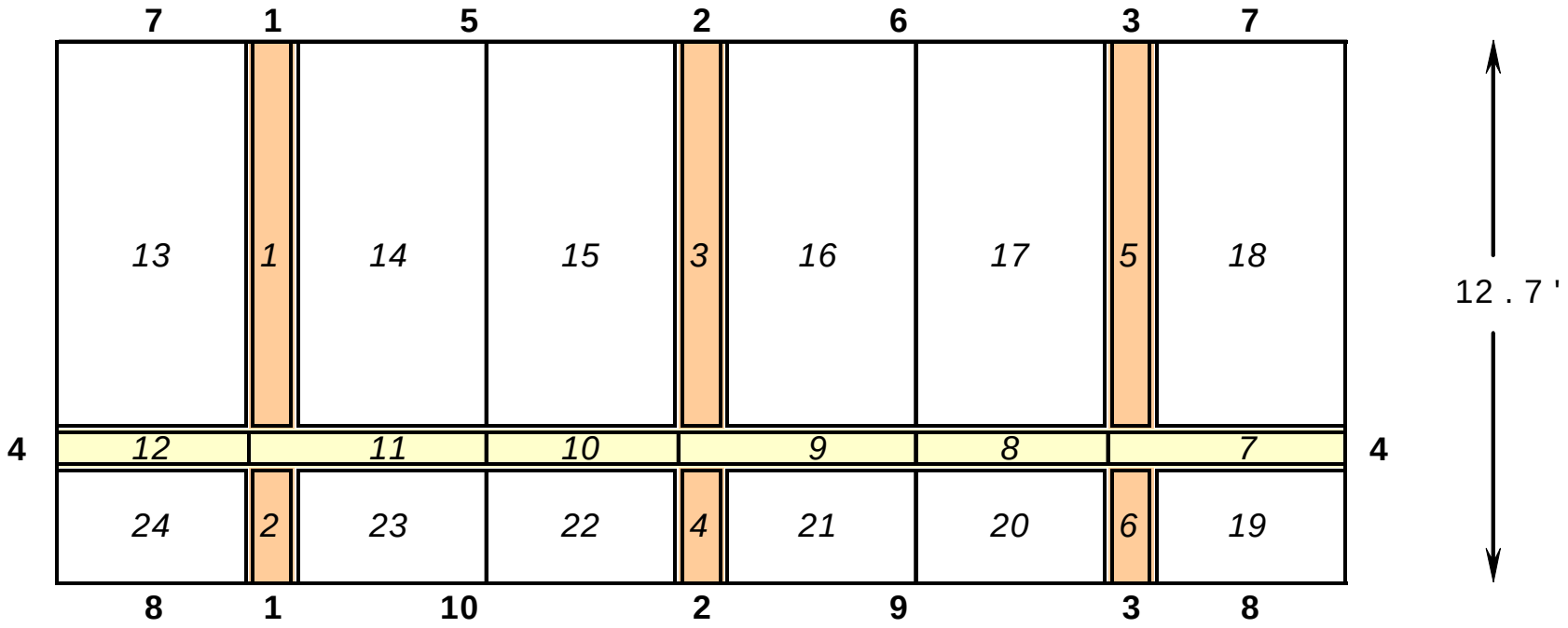
$$\text{Margin} \times K_{Im} + K_{It} < K_{IC}$$

- Values of CPF were determined using the FAVOR software, version 04.1, which was developed by ORNL for NRC Research

ATI Consulting – Sartrex: Why This Approach?

- Simple to understand and implement
- Maintains easy to use Code deterministic computational procedures
- Does not require changes to the current Code fracture mechanics equations
- Risk informed margins have been used in other industrial applications
- Utilizes risk informed approach applied to PTS re-evaluation

Simplified PFM Vessel Beltline Model

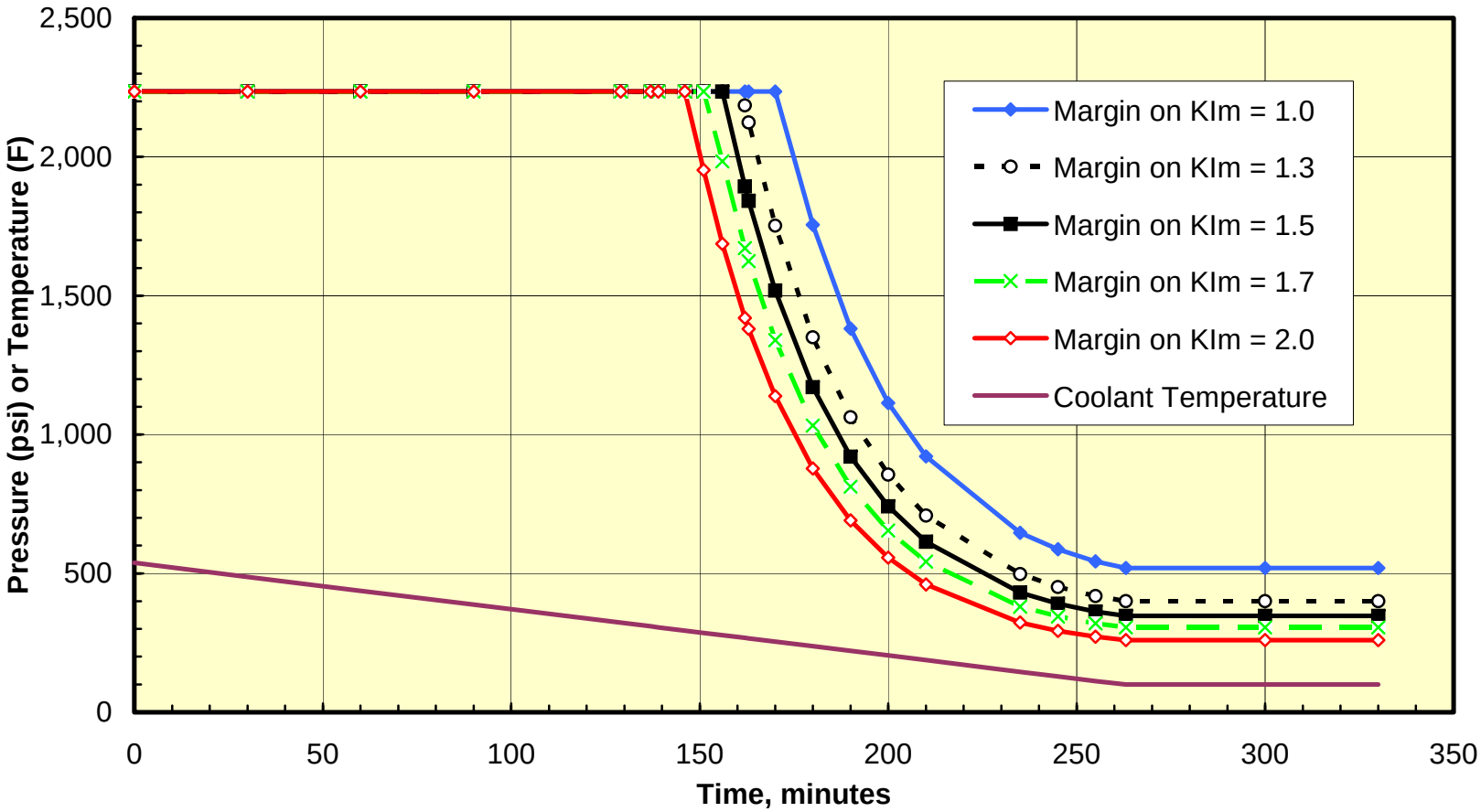


Summary of Beltline Conditions

Variable	PWR 1 EOL	PWR 1 EOLE	PWR 2 EOLE	BWR EOLE
Axial Weld $E\text{-}RT_{PTS}$	270	288	232	188
Circ Weld $E\text{-}RT_{PTS}$	259	274	243	83
Plate $E\text{-}RT_{PTS}$	231	247	173	219

$E\text{-}RT_{PTS}$ is the adjusted reference temperature at the vessel inner surface, where the ASTM E 900-02 correlation is used to predict irradiation damage

Example Cool Down Curves for E-RT_{PTS} = 270ºF and Cool Down Rate = 100ºF/hr



ATI Consulting – Sartrex: Summary of Results

$E\text{-}RT_{PTS}$	CR	App. G Allowable Pressure	Margin @ 1E-6	P @ 1E-6	Increase in Allowable Pressure
^{o}F	$^{o}F/hr$	psi	-	psi	%
270	100	260	2.0	260	0.0
270	100	260	1.27 (Optimized)	409	57
270	60	411	<1.43	>576	>40
288	100	246	<1.8	>273	>11
288	60	400	<1.5	>534	>34
232	100	323	1.45	446	38
232	60	455	1.05	866	90
188	100	329	1.0	658	100
270	0	636	1.0	1,271	100

Conclusions from Proof of Concept Probability Approach

- It is feasible to use a risk informed margin on K_{Im} to define a risk informed procedure for Appendix G
- The risk informed margin on K_{Im} to achieve an acceptable level of risk ranges from 1 (BWRs) to 1.5 (PWRs) at cool down rates up to 100 F/hr
- For startup a risk informed margin on K_{Im} of approximately 1 will achieve an acceptable level of risk
  - Significant increase in the PWR LTOP operating window
  - Significant increase for BWR heat up

Westinghouse- XGEN: Proof of Concept Study

- *MRP-143: Materials Reliability Program: Risk-Informed Revision of ASME Section XI Appendix G (Proof of Concept),* EPRI, Palo Alto, CA, 2005: 1009546.
- Details presented earlier at NRC meeting on 5/25/05
- Brief overview of approach and results presented here

Westinghouse – XGEN: Basic Approach

1. A range of possible operating conditions was determined from W HU/CD Feasibility Study
2. A new set of less conservative Appendix G factors was proposed
3. A set of limiting transients was determined
4. A representative RPV model was chosen – BV1
5. The limiting transients from 3 and RPV model from 4 were analyzed using FAVOR 04.1
6. The initiation frequency from 5 was compared to a conservative risk goal of 1.0E-06 per year
7. If initiation frequency < goal, proposed changes and concept are considered to be feasible

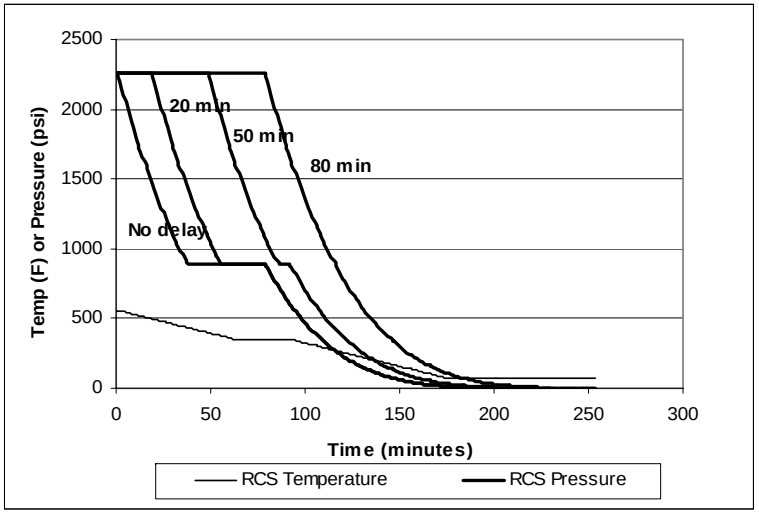
Westinghouse – XGEN: Accelerated HU/CD Feasibility Study

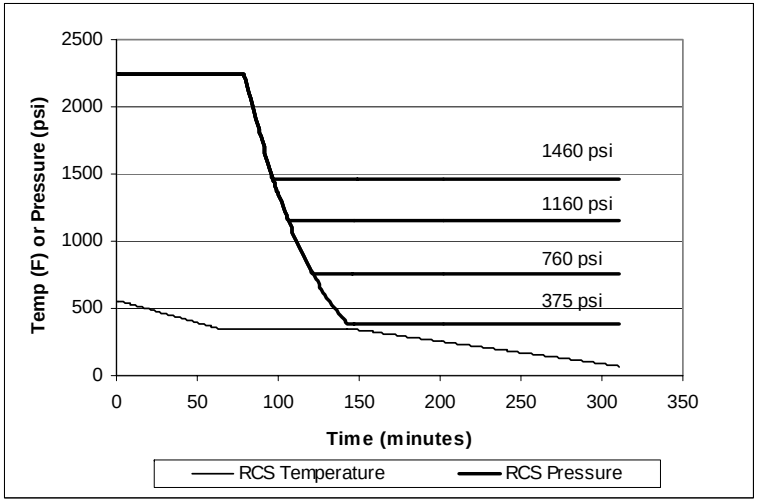
- 45 Years of operational data from 9 Westinghouse PWR plants was analyzed
- Study revealed departures from design basis cool-down assumptions
  - Pressure hold at beginning of cool-down
  - Step changes in temperature rather than constant rate
  - Temperature hold for alignment to Residual Heat Removal (RHR) System
- Investigated whether heat-up and cool-down limits could be relaxed both structurally and operationally (e.g. chemistry control)

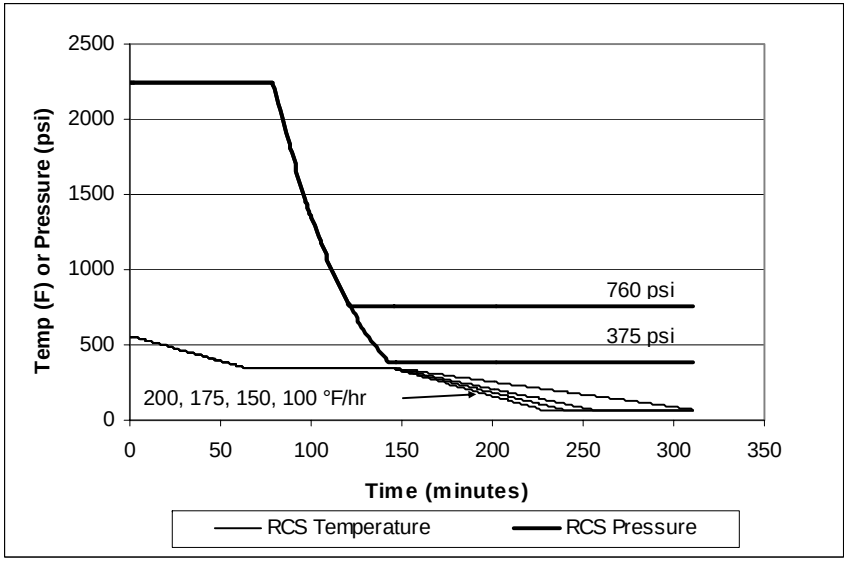
Westinghouse – XGEN: Studies to Determine Limiting Transients

- Goal is to find a transient for which K_I approaches K_{IC} so that when input into FAVOR the resulting frequency of initiation is close to risk goal
- Considered information from study on accelerated HU/CD
- Beaver Valley Unit 1 at 60 EFPY chosen for studies; Maximum RT_{NDT} = 332°F
- Frequency input file also created for each transient
  - Assumed cool-down frequency of one every 18 months (0.667/year) with a standard deviation of 1 month
- Frequency of initiation used for comparison to Risk Goal

Westinghouse – XGEN: Limiting Transients Considered







Westinghouse – XGEN: Summary of Results

Reactor Vessel Cooldown Transient	Frequency
A. Cooldown with 80 Minute Delay on Pressure and 1160 psi Minimum Pressure	2.55E-07/yr.
B. Cooldown with 80 Minute Delay on Pressure and 1460 psi Minimum Pressure	4.33E-07/yr.
C. Cooldown with 80 Minute Delay on Pressure, 375 psi Minimum Pressure, and 150°F/hr Cooldown Rate after RHR Initiation	3.83E-07/yr.
D. Cooldown with 80 Minute Delay on Pressure, 375 psi Minimum Pressure, and 175°F/hr Cooldown Rate after RHR Initiation	8.84E-07/yr.
E. Cooldown with 80 Minute Delay on Pressure, 375 psi Minimum Pressure, and 200°F/hr Cooldown Rate after RHR Initiation	2.06E-06/yr.
F. Cooldown with 80 Minute Delay on Pressure, 760 psi Minimum Pressure, and 150°F/hr Cooldown Rate after RHR Initiation	1.10E-06/yr.
G. Cooldown with 80 Minute Delay on Pressure, 760 psi Minimum Pressure, and 175°F/hr Cooldown Rate after RHR Initiation	2.83E-06/yr.

Westinghouse – XGEN: Conclusions

- Risk-informed methods provide flexibility to significantly relax the current Appendix G requirements for PWR Plants in 3 possible ways:
  - Eliminate margin term on RT_{NDT} and factor on pressure,
  - Reduce the assumed flaw size to 0.141T, or
  - Eliminate the margin term on RT_{NDT} and reduce the assumed flaw size to 3/16T
- Operational Flexibility can be obtained that can better justify some current operating practices and enable new practices
- Due to already existing large margin, proposed changes would also be acceptable for BWR Plants.

Overall Results from Proof of Concept Studies

- Both studies confirmed that a risk informed solution could be applied for both PWRs and BWRs to derive a deterministic approach similar to that currently being used
- Benefits from both Proof of Concept studies have been combined into a coordinated Phase 2 effort that is currently being initiated
- Details on the current overall plan and schedule are described next

Overall Plan and Schedule for Industry Activities

- Confirm FAVOR Version and Perform Computational Verification (July 07)
- Collect Analysis Input Data (April 07 to October 07)
- Perform Evaluations (October 07 to April 08)
- Submit ASME basis document to ASME XI Subcommittee (December 08)

Confirm FAVOR Version and Perform Computational Verification

- Define and Verify/Validate the FAVOR version that will be used by the NRC and the Industry to perform Appendix G cool down analyses.
  - Confirm FAVOR Version by 4/30/07
  - Complete computational verification by 7/2/07

Collect Analysis Input Data

- Materials Data
  - Identify candidate vessels to be used in Probabilistic Fracture Mechanics Analysis and Risk-Informed Methodology Development
- Flaw Distributions
  - Use flaw distributions evaluated in FAVOR V06.1
  - Confirm applicability of flaw distribution to BWR Vessels
- Components
  - Identify components other than the Reactor Vessel that might be impacted by changes in Appendix G

Collect Analysis Input Data - continued

- Events
  - Westinghouse database of ASME Service Level A and B events to define set of heat-up and cool-down events
  - Working with the PWR Owners Group Operations Subcommittee to define heat-up and cool-down transients and operational constraints

Perform Evaluations

- Deterministic Fracture Mechanics sensitivity and scoping analysis will be performed to determine the relative importance of key variables.
- Probabilistic Fracture Mechanics analyses will then be performed using the selected FAVOR version.
- Evaluate the impact of Risk-Informed Appendix G on components other than the Reactor Vessel
- Evaluate and identify any changes to ASME XI, Appendix E

Submit ASME basis document to ASME XI Subcommittee

- Develop the Technical Basis Document to justify implementing Risk-Informed Appendix G methodology in ASME XI
- Establish support for Risk-Informed Appendix G within pertinent ASME XI supporting groups
- Submit the Risk-Informed Appendix G to ASME XI Subcommittee and ballot within ASME