14 June 2016

M E M O R A N D U M

To: Simon Sheng
From: Mark Kirk
cc: Jack McHale
Dave Rudland

Subj: Specification of FAVOR analyses to support BTP 5.3 Evaluation

Based on our conversations of the last few weeks I have prepared a run specification for FAVOR. You have agreed to this in our e-mail exchange (last dated 13 June 2016 at 0753). The purpose of this e-mail is to formally document the run specification that I will pass onto Terry Dickson at ORNL.

This memorandum addresses the following six topics:

1. Objective & scope of this assessment
2. Assumptions
3. Bounding material conditions to analyze
4. Loadings to analyze
5. Evaluation paths
6. Detailed FAVOR run specification

1. Objective & scope of this assessment

Simply Stated: Perform an assessment, bounding through 80 years of operation, of the risk-significance of the BTP-5.3 $RT_{NDT(u)}$ estimation errors for normal operating conditions in the RPV beltline.

In More Detail: For the beltline region it is the intention of these analyses to bound the effect of any BTP 5-3-induced errors associated with $RT_{NDT(u)}$ estimation. If the risk-significance of these errors proves to be small this will indicate that there is no risk-justification to make licensees take account of the error in setting their current P-T limits. If risk significance is found then some portion of the operating fleet will be affected, and more refined analyses will be needed to better identify this effect.

Also Note: Significant areas not covered by this assessment include

- Impact of BTP 5-3 error on compliance with PTS rules (10CFR50.61, 10CFR50.61a)
- Impact of BTP 5-3 error on steels in the nozzle region

These topics need to be addressed by other analyses not described in this memorandum.

Also, regardless of the outcome of this analysis there is a need to place into the public record information now available to the NRC Staff concerning the inaccuracy of the BTP 5-3 estimates of $RT_{NDT(u)}$ so that these errors do not become part of future reactor vessel integrity assessments.

2. Assumptions

Within the context defined in Section 1, this assessment is further defined by the following conditions and assumptions:

- Only shallow surface breaking flaws are assessed (i.e., flaws on the vessel ID whose depth extends just below the clad-to-base metal interface) because these have been identified as being more limiting to plant operations than embedded flaws when subjected to normal operating conditions. Consistent with past FAVOR analyses, the flaw density and aspect ratio distributions sampled are detailed in NUREG/CR-6817
- In a normal FAVOR analysis, the different "major regions" of the beltline (that is, the different welds, plates, and forgings) would be modeled as having region-specific input values of Cu, Ni, and $RT_{NDT(u)}$; these values would be treated as means and sampled using normal FAVOR protocols. For conservatism and simplicity in this analysis the entire beltline is modeled as having the same input values of of Cu, Ni, and $RT_{NDT(u)}$.
- Still need to analyze welds as having residual stress even though they are modeled as having plate or forging properties.
- The peak fluence in the RPV beltline is set at the input fluence value defined in Section 3. Azimuthal and axial variation follow the FAVOR fluence model for the reactor vessels specified in Section 6. (One reactor vessel model of each type, BWR and PWR, is used in this assessment. These models are selected from models already constructed by the Oak Ridge National Laboratory.)
- For the embrittlement trend curve (ETC):
    - The ETC used to generate loading inputs is that found in Revision 2 of Regulatory Guide 1.99 because the analyses described herein is of P-T limits, and the Reg Guide 1.99 ETC is conventionally used for P-T limits. In this assessment the Reg Guide margin term used when credible surveillance data is not available will be adopted.
    - The ETC used within the probabilistic FAVOR model will be the trend curve adopted in 10 CFR 50.61a. This ETC provides a better agreement with available surveillance data than does that found in Revision 2 of Regulatory Guide 1.99.
- The RVID2 database is used to select conditions that define the bounding plants. Because information provided by EPRI in report MRP-401 indicates that all plants that used BTP 5-3 are not reflected in RVID2, this search for bounding plants is not restricted only to materials for which BTP 5-3 was known to be used.

3. Bounding material conditions to analyze

Per our conversations we have agreed that these analyses should, as a 1st cut, examine an end-of-SLR (subsequent license renewal) condition. If we can show limited risk impact after 80 years of operation the analysis results should bound all lower amounts of radiation exposure.

Fluence Information

To estimate fluence values characteristic of 80 years of operation information taken from a report recently published by ASTM is used[1]. That report included the graphic shown in Figure 1, which depicts the distribution of RPV ID fluences in the USA operating fleet following 40, 60, and 80 years of

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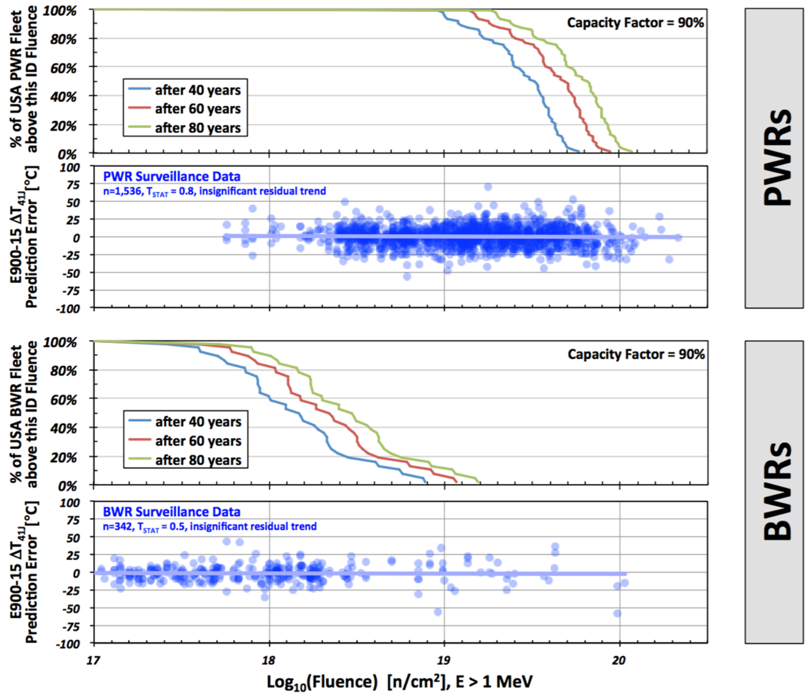
[1] Adjunct for ASTM E900-15, "*Technical Basis for the Equation used to Predict Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials*," 18 September 2015, ASTM International.

operation. The report stated that *"Comparison of the [RVID] fluences with more current information … demonstrated the following: (a) 73% of reported fluence values remain unchanged between 2000 and 2011, (b) for those fluence values that have changes they are, on average, 90% of the values reported in [RVID] in 2000."* Based on this information the following maximum fluence values are selected for the analyses conducted herein as being maximum (bounding) values characteristic of 80 years of plant operation:

PWRs	1×10^{20} n/cm^2 (E > 1MeV)
BWRs	1.4×10^{19} n/cm^2 (E > 1MeV)

Figure 3: Distribution of fluence values for various operating lifetimes for USA PWRs and BWRs.



Material Property Information

Plants having higher values of RT_{NDT} after irradiation have, all other factors held equal, a higher risk of vessel failure. Aside from fluence, which was just discussed, higher values of RT_{NDT} are promoted by (a) higher values of RT_{NDT} before irradiation occurs, along with (b) a greater sensitivity to radiation damage (that is, higher copper content, higher nickel content, and so on). The material in the fleet having the highest unirradiated RT_{NDT} does not necessarily have the most irradiation susceptible chemistry, so coupling these two factors to define a bounding set of conditions may not be realistic. For this reason, the bounding conditions for analysis were determined using the RVID2 database and searching for the plant with the highest RT_{PTS} value (estimated in RVID at 32 EFPY) in each of the four following categories:

PWRs with the beltline made of welded **plates**
PWRs with the beltline made of ring **forgings**
BWRs with the beltline made of welded **plates**
BWRs with the beltline made of ring **forgings**

This search led to the following

Beaver Valley Unit 1 is the bounding **PWR** with the beltline made of welded **plates**
Watts Bar Unit 1 is the bounding **PWR** with the beltline made of ring **forgings**
Oyster Creek is the bounding **BWR** with the beltline made of welded **plates**

Note that no operating BWR has its beltline made of ring forgings, so this analysis condition is eliminated.

Table 1 summarizes the information presented in this section.

Table 1. Bounding material property information to use in the FAVOR analyses

		Beaver Valley 1	Watts Bar 1	Oyster Creek
Information from RVID2	Reactor Type	PWR	PWR	BWR
	Product Form	PLATE	FORGING	PLATE
	Beltline ID	LOWER SHELL B6903-1	INTERMEDIATE SHELL 05	LOWER SHELL G-307-5
	Unirradiated RT_{NDT} [°F]	27	47	3
	Unirradiated RT_{NDT} method	BTP 5-3	PLANT SPECIFIC	PLANT SPECIFIC
	Copper [weight percent]	0.2	0.17	0.27
	Nickel [weight percent]	0.54	0.8	0.53
	Phosphorus [weight percent]	0.01	0.012	0.019
	σ_Δ [°F]	17	17	17
	RG1.99R2 Chemistry factor [°F]	141.8	132	173.85
BTP Uncertainty	$\sigma_{(U)}$ [°F]	20	60	20
	Margin = $2\sqrt{\sigma_{(U)}^2 + \sigma_\Delta^2}$	52	125	52
Information from Fig. 1	80 Year Fluence [n/cm^2, E > 1 MeV]	1E+20	1E+20	1.4E+19
At 80 years on ID	fluence factor	1.51	1.51	1.09
	Irradiated RT_{NDT} [°F]	242	247	193
	Irradiated RT_{NDT} plus margin [°F]	294	372	246
At 80 years at ¼T	fluence factor	0.94	0.94	0.68
	Irradiated RT_{NDT} [°F]	160	171	121
	Irradiated RT_{NDT} plus margin [°F]	212	295	173

4. Loading conditions to analyze

Previous analyses have indicated that certain loading conditions are more risk-significant than others. Accordingly, in the analyses described herein attention is focused on the most risk-significant loadings, which are as follows:

- In PWRs only normal cooldown loadings are assessed. This includes the following two conditions
    - Limit-state cooldowns that follow the limits imposed by Appendix G to Section XI of the ASME Code at a cool-down rate of 100 °F/hr.
    - "Actual" cooldowns based on a limited sampling of plant records available to the NRC.
- In BWRs both normal cooldown loadings and operating pressure leak tests are assessed
    - Cooldowns

        - Limit-state cooldowns that follow the limits imposed by Appendix G to Section XI of the ASME Code at a cool-down rate of 100 °F/hr.
        - "Actual" cooldowns that follow the saturation curve.
    - Operating pressure leak tests
        - Limit-state leak tests that follow the limits imposed by Appendix G to Section XI of the ASME Code at a cool-down rate of 40 °F/hr.
        - A leak test following the procedures followed at an operating BWR.

In these analyses it should be noted that the NRC's state of knowledge regarding the variability inherent to "actual" loadings is quite limited.

- For PWRs, a set of ≈50 cooldowns was provided by the industry some years ago. The reactors in which these loadings occurred is unknown, as is the embrittlement state of the reactors at the time the loading occurred. A set of four of these loadings is used for FAVOR analysis.
- For BWRs, physical considerations require heat-up and cool-down to follow the saturation curve. Also, a leak test transient compliant with plant procedures was developed some years ago by Gary Stevens and will again be used.

These "actual" loadings are analyzed to provide anecdotal information concerning the differences in vessel failure risk characteristic of loading along allowed limits versus loading that is more characteristic of actual operating conditions. In the event the estimated vessel failure risk for the limit state loadings is excessive the information obtained from these analyses of "actual" loadings will provide an indication of the possible benefit to be gained from performing more detailed, and more realistic, analyses.

5. Evaluation paths

Figure 2 depicts the three analysis paths that will be followed for each condition (condition = combination of material properties, loading, & flaw size) assessed. The three paths are each enclosed by a dotted box. Depending on the different means used to estimate RT_{NDT} (green boxes) and the different FAVOR models (orange boxes) different estimates of CPF (grey round-corner boxes) are produced. Comparison of these CPF results tells us different things (see purple boxes at the bottom of the figure). For completeness this figure depicts analyses with the version of FAVOR that captures more accurately the BTP error (these are designated as Path B* and Path C*); see Figure 3. However, consistent with our discussions, analysis along Paths B* and C* are not part of the current analysis request of ORNL; these analyses will be done later.

Figure 2: Evaluation Paths.

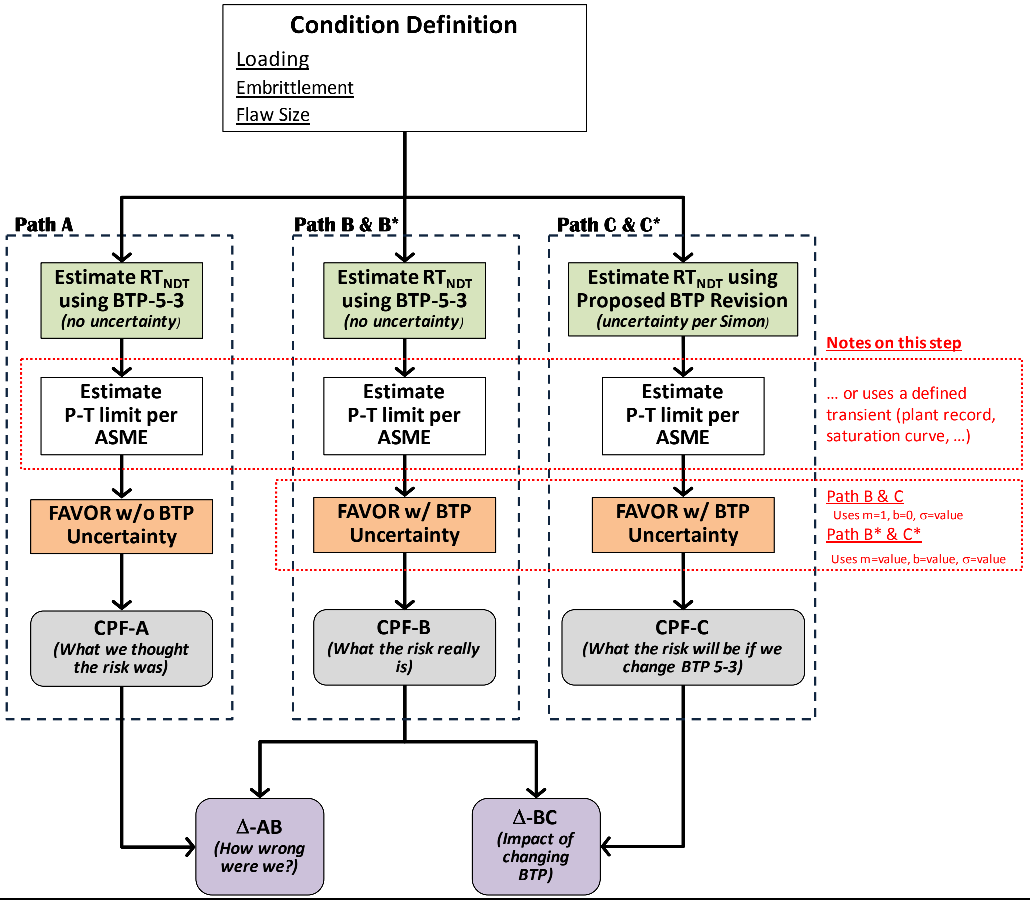
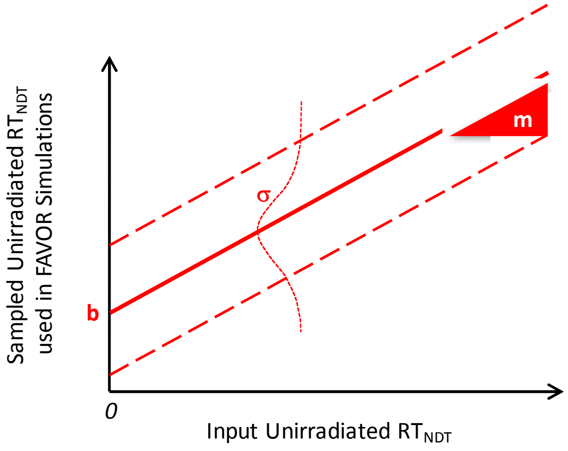


Figure 5: Definition of m, b, and σ.



Currently in FAVOR

- m=1 always
- b=0 always
- σ can be input

I've ask Terry to create a version of FAVOR where

- m can be input
- b can be input
- σ can be input

6. Detailed FAVOR Run Specification

Based on the information provided in the preceding sections, Tables 2 and 3 describe the cases to run in FAVOR for, respectively, PWRs and BWRs.

Table 2: FAVOR analyses of PWRs using the Beaver Valley Model.

			<u>Input Values / Conditions for FAVOR</u>							<u>$RT_{NDT(u)}$ Uncertainty Model in FAVOR</u>		
Analysis Case Description	**Evaluation Path**	**Product Form**	**Cu**	**Ni**	**$RT_{NDT(u)}$ [°F]**	**End SLR Fluence [n/cm^2]**	**$\sigma_{(u)}$ [°F]**	**$\sigma_{(\Delta)}$ [°F]**	**Loading**	**m**	**b**	**$\sigma_{(u)}$ [°F]**
Limit Cooldown Plate	A	Plate	0.2	0.54	27	1E+20	0	17	100 °F/hr ASME allowable cooldown	1	0	0
	B	Plate	0.2	0.54	27	1E+20	0	17		1	0	20
	C	Plate	0.2	0.54	27	1E+20	20	17		1	0	20
Limit Cooldown Forging	A	Forging	0.17	0.8	47	1E+20	0	17		1	0	0
	B	Forging	0.17	0.8	47	1E+20	0	17		1	0	60
	C	Forging	0.17	0.8	47	1E+20	60	17		1	0	60
Actual Cooldown Plate	A	Plate	0.2	0.54	27	1E+20	0	17	each of 4 *"actual"* cooldown records	1	0	0
	B	Plate	0.2	0.54	27	1E+20	0	17		1	0	20
	C	Plate	0.2	0.54	27	1E+20	20	17		1	0	20
Actual Cooldown Forging	A	Forging	0.17	0.8	47	1E+20	0	17		1	0	0
	B	Forging	0.17	0.8	47	1E+20	0	17		1	0	60
	C	Forging	0.17	0.8	47	1E+20	60	17		1	0	60

<u>Note</u>: For further analysis details see the "assumptions" listed in Section 2 of this document.

Table 3: FAVOR analyses of BWRs using the Oyster Creek Model.

			<u>Input Values / Conditions for FAVOR</u>							<u>$RT_{NDT(u)}$ Uncertainty Model in FAVOR</u>		
Analysis Case Description	**Evaluation Path**	**Product Form**	**Cu**	**Ni**	**$RT_{NDT(u)}$ [°F]**	**End SLR Fluence [n/cm^2]**	**$\sigma_{(u)}$ [°F]**	**$\sigma_{(\Delta)}$ [°F]**	**Loading**	**m**	**b**	**$\sigma_{(u)}$ [°F]**
Limit Cooldown Plate	A	Plate	0.27	0.53	3	1.4E+19	0	17	100F °F/hr ASME allowable cooldown	1	0	0
	B	Plate	0.27	0.53	3	1.4E+19	0	17		1	0	20
	C	Plate	0.27	0.53	3	1.4E+19	20	17		1	0	20
Saturation Cooldown Plate	A	Plate	0.27	0.53	3	1.4E+19	0	17	cooldown on saturation curve at 100 ° F/hr	1	0	0
	B	Plate	0.27	0.53	3	1.4E+19	0	17		1	0	20
	C	Plate	0.27	0.53	3	1.4E+19	20	17		1	0	20
Limit Leak Test Plate	A	Plate	0.27	0.53	3	1.4E+19	0	17	Leak test per ASME, 40 °F/hr HU & CD	1	0	0
	B	Plate	0.27	0.53	3	1.4E+19	0	17		1	0	20
	C	Plate	0.27	0.53	3	1.4E+19	20	17		1	0	20
Plant Procedure Leak Test Plate	A	Plate	0.27	0.53	3	1.4E+19	0	17	Leak test per plant procedure	1	0	0
	B	Plate	0.27	0.53	3	1.4E+19	0	17		1	0	20
	C	Plate	0.27	0.53	3	1.4E+19	20	17		1	0	20

<u>Note</u>: For further analysis details see the "assumptions" listed in Section 2 of this document.

7. Summary of Results (this section was added on 28 October 2016)

As of this date FAVOR results are available for the PWR analyses specified in Table 2; the BWR analyses in Table 3 have not been started. These results were generated with a pre-release version of FAVOR Version 16.1[2]. Expanding a little on the analysis scope described in Table 2, both the Palisades and the Beaver Valley PWR models were used to explore the possible effect of different cladding thickness (the Beaver Valley model has a cladding thickness of 0.156-in. while the Palisades model has a cladding thickness of 0.25-in.).

Table 4 provides the results for the limiting cooldown transients (that is, a cooldown at a rate of 100 °F/hr following the ASME P-T limit curve) described in Table 2. The input values and $RT_{NDT(u)}$ uncertainty models for these analyses can be found in Table 2.

The information in Table 4 supports the following observations:

- Referring to the values in the yellow headed columns, as has been observed in previous FAVOR analyses, the ***conditional*** probabilities of crack initiation (CPI) and of vessel failure (CPF) can, in some situations, exceed a value of 10^{-6} when shallow surface breaking flaws are modeled. To convert these values to yearly vessel crack initiation or failure probabilities they would need to be multiplied by an estimate of the yearly frequency for a cooldown that closely follows the P-T limit curve.
- The values in the purple headed columns provide information on the effect of the uncertainty and/or imprecision in the BTP 5-3 estimates of $RT_{NDT(u)}$ on CPI and CPF values
    - As described in Figure 2, the ratio of results between evaluation paths B and A (**see entries labeled B/A, these appear as blue text**) indicate the factor by which current estimates of CPI and CPF (which do not account for the BTP uncertainty and/or imprecision) under-estimate the actual CPI or CPF. These factors range from almost unity (that is, barely any effect) to much larger values (in one case, ≈5x, in another, infinity). It should be noted that the reason for the result of infinity is that the modeling of the BTP uncertainty and/or imprecision changed the estimates of CPI and CPF from zero to finite values.
    - As described in Figure 2, the ratio of results between evaluation paths C and B (**see entries labeled C/B, these appear as green text**) indicate the factor by which the CPI or CPF would change if the current guidance of BTP 5.3 were modified to adopt values of $\sigma_{(u)}$=20 °F for plates and $\sigma_{(u)}$=60 °F for forgings (currently $\sigma_{(u)}$=0 °F for both product forms). These results fall into three categories:
        - Large decrease (C/B ≈ 0.1)
        - Small increase (C/B ≈ 1½-2)
        - Very large increase (C/B ≈ 1000)
    - In all cases the added margin ($\sigma_{(u)}$) shifts the time at which depressurization must occur to earlier in the cooldown transient then when no margin is used in calculation of the P-T loading curves that are input to FAVOR. This reduces the peak $K_{applied}$

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[2] The errors identified by the industry in FAVOR 15.1 had been fixed in the version of FAVOR done to conduct these analyses. However, the final suite of ORNL test cases and verification testing had not yet been completed when these analyses were conducted. Therefore, if these cases were re-run with the released version of FAVOR 16.1 there might be some differences in the results.

occurring early in the transient, but has no effect on the peak value of $K_{applied}$ occurring late in the transient. The late $K_{applied}$ peak is driven solely by the stresses generated by the mismatch in the coefficient of thermal expansion between the austenitic RPV cladding and the ferritic base material. If the reduction of the early (pressure-driven) peak $K_{applied}$ achieved by adding the $\sigma_{(u)}$ margin does not cause it to fall below the value of the late (coefficient of thermal expansion driven) peak $K_{applied}$ then the C/D CPI and CPF ratios will fall below unity. Otherwise these analysis shows that the C/D CPI and CPF ratios can increase, in some specific situations by a considerable amount.

Table 4: FAVOR results for cooldowns following P-T limits at a rate of 100 °F/hr.

		FAVOR Results				**Ratios of FAVOR results**			
		Beaver Valley geometry		**Palisades geometry**		**Beaver Valley geometry**		**Palisades geometry**	
Product Form	**Evaluation Path**	**CPImean**	**CPFmean**	**CPImean**	**CPFmean**	**CPI Ratios**	**CPF Ratios**	**CPI Ratios**	**CPF Ratios**
Plate	A	1.0E-05	3.6E-06	3.9E-08	1.2E-08	---	---	---	---
Plate	B	1.0E-05	3.8E-06	8.4E-08	6.4E-08	**B/A=1**	**B/A=1.1**	**B/A=2.2**	**B/A=5.3**
Plate	C	1.9E-05	5.2E-06	5.8E-09	4.9E-09	**C/B=1.8**	**C/B=1.4**	**C/B=0.1**	**C/B=0.1**
Forging	A	5.5E-06	1.8E-06	0.0E+00	0.0E+00	---	---	---	---
Forging	B	8.2E-06	3.7E-06	9.5E-07	7.5E-07	**B/A=1.5**	**B/A=2.1**	**B/A=∞**	**B/A=∞**
Forging	C	1.4E-05	4.8E-06	9.5E-04	8.3E-04	**C/B=1.7**	**C/B=1.3**	**C/B=1006.3**	**C/B=1104.1**

Table 5 provides the results for the "actual" cooldown transients. The input values and $RT_{NDT(u)}$ uncertainty models for these analyses can be found in Table 2. The four "actual" transients used as input to FAVOR occurred in operating PWR plants. These four represent only a tiny subset of the multitude of actual cooldowns that occur in PWRs. We do not have enough evidence at hand to characterize these four transients as being either "typical" or "bounding", all we can say for sure is that they occurred in PWR plants operated under NRC license.

Here results are provided only for evaluation paths "A" and "B." No analysis of evaluation path "C" was performed because these are actual loadings, so the possible addition of $\sigma_{(U)}$ margin to account for the BTP uncertainty and/or imprecision has no effect on these transients.

- Referring to the values in the yellow headed columns, while in most cases the estimated CPI and CPF values are quite low they do, as indicated by the red text, sometimes exceed a value of 10^{-6} for the conditions analyzed. The values that exceed 10^{-6} all are associated with the Palisades model, which has the thicker cladding, which causes the added stress due to coefficient of thermal expansion mismatch to be greater. To convert these conditional values to yearly vessel crack initiation amd failure probabilities they would need to be multiplied by an estimate of the yearly frequency for such a cooldown transient to occur. Given that these cooldowns have occurred in operating plants, and that plants cooldown in many cases once yearly, assumption of an event frequency of unity would not be unreasonable.

- The values in the purple headed columns provide information on the impact of the uncertainty and/or imprecision in the BTP 5-3 estimates of $RT_{NDT(u)}$ on these CPI and CPF estimates. As described in Figure 2, the ratio of results between evaluation paths B and A indicate the factor by which current estimates of CPI and CPF (which do not account for the BTP uncertainty and/or imprecision) under-estimate the actual CPI or CPF. These factors range from almost unity (that is, barely any effect) to much larger values (in one case, ≈80x). These largest B/A ratios (i.e., ≈ 80x) correspond, in general, to situations where the CPI and CPF are low. In the one case where a CPF value exceeds 10^{-6} the effect of the BTP uncertainty as represented by this analysis was to increase the value of CPF by ≈12x.

Table 5: FAVOR results for four actual PWR cooldowns.

Product Form	Evaluation Path	Actual Loading ID	FAVOR Results				B/A Ratios of FAVOR results			
			Beaver Valley geometry		Palisades geometry		Beaver Valley geometry		Palisades geometry	
			CPImean	CPFmean	CPImean	CPFmean	CPI Ratios	CPF Ratios	CPI Ratios	CPF Ratios
Plate	A	1	6.8E-08	3.9E-11	7.8E-06	2.8E-08				
		2	1.4E-11	0.0E+00	4.8E-07	0.0E+00				
		3	2.7E-07	1.5E-10	3.5E-06	4.9E-07				
		4	3.4E-10	0.0E+00	8.3E-07	0.0E+00				
	B	1	7.0E-08	6.7E-11	8.1E-06	3.7E-08	1.0	1.7	1.0	1.3
		2	1.7E-11	0.0E+00	5.0E-07	0.0E+00	1.2	---	1.0	---
		3	2.7E-07	2.0E-10	3.8E-06	6.3E-07	1.0	1.3	1.1	1.3
		4	4.0E-10	0.0E+00	8.8E-07	0.0E+00	1.2	---	1.1	---
Forging	A	1	3.0E-08	3.6E-13	3.5E-06	9.5E-09				
		2	1.8E-12	0.0E+00	2.0E-07	0.0E+00				
		3	1.5E-07	1.6E-11	1.1E-06	8.5E-08				
		4	4.0E-11	0.0E+00	3.4E-07	0.0E+00				
	B	1	4.7E-08	3.0E-11	6.3E-06	4.6E-08	1.6	82.9	1.8	4.8
		2	7.8E-12	0.0E+00	4.5E-07	0.0E+00	4.4	---	2.2	---
		3	2.3E-07	8.9E-10	5.2E-06	1.1E-06	1.5	55.4	4.6	12.4
		4	2.0E-10	0.0E+00	8.7E-07	0.0E+00	4.9	---	2.5	---

Mark's Summary Thoughts, FWIW

- For cooldowns following the P-T limits
  - If Steve Dinmore can provide documentary support for a yearly event frequency of 10^{-3} or lower, then all of the "B" evaluation path transients falls comfortably below 10^{-6}/year.
  - The only difficulty I see in explaining these results is that the margin one might consider adding to account for the BTP uncertainty and/or imprecision can, in some cases, increase risk (dramatically). This will need to be explained.
- For "actual" cooldowns.
  - I think there is some difficulty with having CPF results that exceed 10^{-6}. Admittedly the degree of exceedance is small, but since we do not know how well the 4 transients modeled represent the entire population of possible cooldowns this result seems, to me, problematic.
  - Possible "fixes"
    - Fluence
      - We used 1×10^{20} to bound the PWR fleet at 80 years. Based on the same logic path and the data in Figure 3 we could reduce fluence to 8×10^{19} to represent 60 years. I do not, however, think this is a significant enough reduction to matter because we are analyzing high copper materials. High copper materials are usually close to embrittlement saturation at fluences considerably below 8×10^{19}. Thus the change in embrittlement between 8×10^{19} and 1×10^{20} is not so much.
      - Using plant-specific 60 or 80 year fluences could justify more substantial reductions of maximum fluence. The outcomes then become more plant specific, requiring a larger analysis matrix.
    - Chemistry
      - Likewise, we are using worst-case chemistry values. Plant-specific chemistry values could reduce the CPI and CPF values considerably. However, as with fluence, the outcomes then become more plant specific, requiring a more larger analysis matrix.
    - Loading
      - We have in our archives ≈50 cooldowns; we could analyze more of these to get a somewhat better understanding of the spread of CPI and CPF values expected for actual cooldowns.
- Overall
  A. I think the weakest point of this analysis is the actual loadings. We have in our archives ≈50 cooldowns; we could analyze more of these to get a somewhat better understanding of the spread of CPI and CPF values expected for actual cooldowns.
  B. We are also being overly pessimistic by using just a few values of chemistry and fluence to represent the entire fleet. However, without doing more analyses we cannot quantify this degree of pessimism.
  C. Finally, without having a complete view of where the BTP has been used in the fleet it is difficult to determine which plant-specific analyses to do.

D. The plant-specific aspects (items B & C) are perhaps more easily addressed by the industry. That said, before we ask for them to do more work I think we should better substantiate our findings regarding “actual” cooldowns.