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# Risk-Informed Extension of the Reactor Vessel In-Service Inspection Interval

Westinghouse-PWR Owners Group

CEOG Task 2008, 2059

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## **Risk-Informed Extension of the Reactor Vessel In-Service Inspection Interval**

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## LIST OF ACRONYMS AND ABBREVIATIONS

ADV	Atmospheric dump valve
AFW	Auxiliary feedwater
ART	Adjusted reference temperature
ASME	American Society of Mechanical Engineers
B&PV	Boiler and Pressure Vessel
B&W	Babcock & Wilcox
BV1	Beaver Valley Unit 1
CCDP	Conditional core damage probability
CDF	Core damage frequency
CE	Combustion Engineering
ECT	Eddy current examination
EFPY	Effective full-power year
EOL	End of life
EPRI	Electric Power Research Institute
FENOC	FirstEnergy Nuclear Operating Company
FCG	Fatigue crack growth
FP	Failure probability
FSAR	Final Safety Analysis Report
GQA	Graded quality assurance
HPI	High-pressure injection
HUCD	Heat-up and cool-down transient
HZP	Hot-zero power
IEF	Initiating event frequency
IGSCC	Intergranular stress corrosion cracking
ID	Inner diameter
ISI	In-service inspection
IST	In-service testing
LBLOCA	Large-break loss-of-coolant accident
LERF	Large early release frequency
LOCA	Loss-of-coolant accident
MBLOCA	Medium-break loss-of-coolant accident
MSIV	Main steam isolation valve
MSLB	Main steam line break
MT	Magnetic particle examination
NDE	Non-destructive examination
NMC	Nuclear Management Company
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
OC1	Oconee Unit 1
OD	Outer diameter
ORNL	Oak Ridge National Laboratory
PFM	Probabilistic fracture mechanics
PNNL	Pacific Northwest National Laboratory
POD	Probability of detection

**LIST OF ACRONYMS AND ABBREVIATIONS (cont.)**

PRA	Probabilistic risk assessment
PT	Liquid penetrant examination
PTS	Pressurized thermal shock
PVRUF	Pressurized Vessel Research User Facility
PWR	Pressurized water reactor
PWROG	PWR Owners Group
QA	Quality Assurance
RAI	NRC Request for Additional Information
RCP	Reactor coolant pump
RCS	Reactor Coolant System
RG	NRC Regulatory Guide
RI-ISI	Risk-informed ISI
RPV	Reactor pressure vessel
RT <sub>NDT</sub>	Reference nil-ductility transition temperature
RV	Reactor vessel
RV ISI	Reactor Vessel In-service Inspection
RVID	Reactor vessel integrity database
SBLOCA	Small-break loss-of-coolant accident
SER	NRC Safety Evaluation Report
SG	Steam generator
SRP	Standard Review Plan
SRRA	Structural Reliability and Risk Assessment
SRV	Safety and relief valve
SSC	Structures, systems, and components
TH	Thermal hydraulics
TWCF	Through Wall Cracking Frequency
UT	Ultrasonic examination
VT	Visual examination
<del>WOG</del>	<del>Westinghouse Owners Group</del>

## EXECUTIVE SUMMARY

The current requirements for the inspection of reactor vessel pressure-containing welds have been in effect since the 1989 Edition of *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code*, Section XI, as supplemented by Nuclear Regulatory Commission (NRC) Regulatory Guide 1.150. The manner in which these examinations are conducted has recently been augmented by Appendix VIII of Section XI, 1996 Addenda, as implemented by the NRC in an amendment to 10CFR50.55a effective November 22, 1999. The industry has expended significant cost and man-rem exposure that have shown no service-induced flaws in the reactor vessel (RV) for ASME Section XI Category B-A, or B-D, or B-J RV welds.

The objective of the methodology discussed in this report is to provide the technical basis for decreasing the frequency of inspection by extending the Section XI Inspection interval from the current 10 years to 20 years for ASME Section XI Category B-A and B-D, and B-J RV nozzle welds. Specific pilot studies have been performed on the Westinghouse, Combustion Engineering, and Babcock and Wilcox reactor vessel and NSSS designs. The results show that the change in risk associated with eliminating all inspections after the initial 10-year in-service inspection satisfies the guidelines specified in Regulatory Guide 1.174 for an acceptable change in risk for large early release frequency (LERF).

This conclusion is applicable to all Westinghouse, Combustion Engineering, and Babcock and Wilcox reactor vessel designs given that the applicable individual plant parameters are bounded by the critical parameters identified in Appendix A.



## 1 INTRODUCTION

The current requirements for the inspection of reactor vessel (RV) pressure containing welds have been in effect since the 1989 Edition of *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code*, Section XI [1+], as supplemented by the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.150 [22]. The manner in which these examinations are conducted has been augmented by Appendix VIII of Section XI, 1996 Addenda, as implemented by NRC in an amendment to 10CFR50.55a effective November 22, 1999 [33]. The industry has expended significant cost and man-rem exposure by performing the required examinations that have shown no service-induced flaws in the RV for ASME Section XI Category B-A or B-D or B-J RV nozzle welds. The current code criteria for the selection of examination areas and the frequency of examinations is not be an effective way to expend inspection resources.

The objective of this study was to verify that a reduction in frequency of volumetric examination of the RV full-penetration welds could be accomplished with an acceptably small change in risk. The methodology used to justify this reduction involved an evaluation of the change in risk associated with extending the 10-year in-service inspection (ISI) interval for three pilot plant bounding cases based on the calculated difference in the frequency of RV failure. RV failure was defined for this study to be the extension of a crack all the way through the RV wall. The difference in frequency of RV failure was evaluated using RG 1.174 [44] to determine if the values met the specified regulatory guidelines. The intent was that licensees can then use the results of this bounding assessment to demonstrate that their RV and plant are bounded by the generic analysis, thereby justifying a plant-specific extension in the RV weld inspection interval.

This study followed the approach specified in ASME Code Case N-691 [55], which provides guidelines for using risk-informed insights to increase the inspection interval for pressurized water reactor (PWR) vessel welds.

## 2 BACKGROUND

The original objective of the ASME B&PV Code, Section XI [1+] ISI program was to assess the condition of pressure-containing components in nuclear power plants to ensure continued safe operation. If non-destructive examination (NDE) found indications that exceeded the allowable standards, examinations were extended to additional welds in components in the same examination category. If NDE found indications that exceeded the acceptance standards in those welds, then the examinations were extended further to similar welds in similar components, etc.

With respect to the method defined in this report, 100 percent of the present examination areas will be retained. The methodology is limited to justification of a reduction in the frequency of examination, i.e., increasing the time interval between inspections.

The original examination interval of 10 years was based on “wear-out” rate experience in the pre-nuclear utility and petrochemical process industries. As with some other Section XI ISI requirements, with no indications being found in the vessel welds under evaluation in this report, these inspections are decreasing in value with increasing industry experience to rely upon. The U.S. NRC has granted a number of exemptions to inspections for other areas and components (e.g., piping [66], reactor coolant pump motor flywheels [77], etc.) based on experience and man-rem reductions. This has been attributed to the combined design, fabrication, examination, and Quality Assurance (QA) rigor of the nuclear codes, and more careful control of plant operating parameters by the utilities.

A critical component of the justification of the interval extension is a fracture mechanics evaluation of the reactor vessel, which shows that flaws, if they do exist, would not grow to a critical size if the inspection interval is increased to more than 10 years. This can be demonstrated by selecting critical areas of the reactor vessel for the evaluation such as the beltline, flange, and outlet nozzle regions. These locations are known to be areas of primary concern and are currently considered in ASME Section III, Appendix G [16] evaluations for protection against nonductile failure of the reactor vessel. As part of this study, a deterministic fracture mechanics evaluation of limiting locations in a typical geometry for a RV identified that the beltline region was the critical location with respect to the potential for growth of fatigue cracks. Fatigue crack growth is recognized as the primary degradation mechanism in the carbon and low alloy steel components in PWR Nuclear Steam Supply System (NSSS), that could contribute to any potential growth of existing flaws in the component base materials and weld metals.

Fatigue can be defined as repeated exposure to cyclic loading resulting from a variety of operating conditions or events (e.g. heatups, cooldowns, reactor trips). Design basis documents provided descriptions of the conditions that would contribute to cyclic fatigue. This information was used to identify and define the frequency of occurrence for each of the events that was considered when determining the potential for fatigue crack growth.

A technical consideration critical to success was the application of risk-informed assessment techniques to substantiate the deterministic fracture mechanics flaw growth evaluation. Risk assessment techniques provided a means to quantify and calculate cumulative results from contributing mechanisms and uncertainties associated with the critical parameters. A probabilistic fracture mechanics (PFM) methodology was used to consider the distributions and uncertainties in flaw numbers, flaw sizes, fluence, material properties, crack growth rate, stresses, and the effectiveness of inspections. The PFM

methodology was also used to calculate the change in the frequency of RV failure due to a change in inspection interval. This change in RV failure frequency was used to evaluate the viability of such an inspection interval change. Recognized guidelines for evaluating the change in failure frequencies are provided in RG 1.174 [44] and the NRC risk assessment developed in conjunction with the current pressurized thermal shock (PTS) evaluations [8][8, 927, 43].

Significant work is on-going in the nuclear industry to investigate the impacts from PTS or "off-normal" plant transients that may be outside the current design basis. These transients are commonly understood to present the most severe challenge to RV structural integrity. The NRC effort to address PTS has identified FirstEnergy Nuclear Operating Company's (FENOC's) Beaver Valley Unit 1 (BV1), Nuclear Management Company's (NMC's) Palisades, and Duke Energy's Oconee Unit 1 (OC1) as the representative plants based on geometry and embrittlement for the Westinghouse, Combustion Engineering (CE), and Babcock and Wilcox (B&W) PWR designs. These are the primary PWR manufacturers in the U.S. and were evaluated by the NRC and Oak Ridge National Laboratory (ORNL) as part of the NRC PTS Risk Study [8][8, 9][27, 43].

This report summarizes the results from an evaluation of the extension of the inspection of ASME Section XI [14] Examination Category B-A and B-D welds in the reactor pressure vessel (RPV) and Category B-J welds to the RV nozzle from the current requirement of every 10 years to an extension of 20 years. It demonstrates that for the pilot plant reactor vessel geometry and fabrication history, any potential change in risk when the inspection interval is extended meets the change in risk evaluation guidelines defined in RG 1.174 [44]. The evaluation documented in this report considers FENOC's BV1 as the Westinghouse pilot plant. NMC's Palisades Plant and Duke Energy's OC1 are the respective Combustion Engineering (CE) and Babcock and Wilcox (B&W) pilot plants for this evaluation. To apply the results of this report to non-pilot plants, it must be shown, using the tables contained in Appendix A that the pilot plant evaluations for the respective design bound the non-pilot plant.

The following paragraphs address the current Section XI ISI requirements for PWR RV welds under consideration for the proposed extension. The following topics are included:

1. Reactor Vessel In-Service Inspection (RV ISI)
2. Location-specific ISI data from participating plants
3. The man-rem exposure and other costs of RV weld inspection
4. Generic RV weld experience at various plants
5. Development of the ISI interval extension methodology
6. Pilot plants
7. Safety impact

## 2.1 REACTOR VESSEL IN-SERVICE INSPECTION

Since its beginning, ASME B&PV Code, Section XI [14] has required inspections of weld areas of reactor vessels and other pressure-containing nuclear system components. The selection of inspection locations was based on areas known to have high-service factors and additional areas to provide a representative sampling for the condition of pressure-containing nuclear system components. While weld and adjoining areas were specified, it was recognized that the volumetric examination of the weld and adjoining base material would result in a significant degree of examination of the base metal.

## Examination Volumes

Initially, for longitudinal and circumferential welds in a reactor vessel shell, Section XI required examination of 10 percent of the length of longitudinal welds, and 5 percent of the length of circumferential welds. Welds receiving exposure in excess of specified neutron fluence would require an inspection of 50 percent of the length. The 1977 Edition of Section XI increased the examination of RV welds from 5 or 10 percent of the length to 100 percent, with all welds examined in the first 10-year interval. Subsequent intervals required 100 percent examination of specified circumferential and longitudinal welds. The 1989 Edition of Section XI [14] extended the examination to include all welds.

There has been no report of structural failure or leakage from any full-penetration weld being addressed in this report in a PWR RV shell, globally. In volumetric examinations of these welds in ISIs performed in accordance with the requirements of Section XI (and RG 1.150 [22]), flaws identified in the original construction have been detected and were acceptable under Section XI requirements. These flaws have been monitored and to date, no growth has been identified. There has been no evidence of in-service flaw initiation in these welds.

## Examination Approaches

The preceding discussion of RV welds addresses the Category B-A, RV seam welds of Table IWB-2500-1 of Section XI. Category B-D, RV nozzle welds and nozzle inner radius, and Category B-J RV nozzle-to-piping welds are also included in this evaluation.

The ultrasonic examinations (UTs) of these RV welds, as of the 1996 Addenda of Section XI, were conducted in accordance with Appendix I, I-2110. This Addenda requires Appendix VIII inspections for:

- Shell and head welds, excluding flange welds
- Nozzle-to-vessel welds
- Nozzle, inside radius region

## Precedent for Change

There have been a number of revisions (often by ASME Code Case) to the Section XI ISI program that have eliminated or reduced the extent of examinations and tests based on successful operating experience and analytical evaluation. Examples of ASME Code Cases applicable to the RV and its piping connections include:

- N-481 [109] Associated with cast austenitic pump casings. This was the first example of substituting an analysis plus a visual examination (VT) for a volumetric examination, for a Class 1 component.
- N-560 [1140] Permits a reduction in the examination of Class 1 Category B-J piping welds from 25 to 10 percent, provided a specified risk-importance ranking selection process is followed. This was a substantive reduction of an established Class 1 examination.

- N-577 [12+4] Provide requirements for risk-informed ISI of Class 1, 2, and 3 piping. The cases provide different methods to achieve the same objective. This was the first use of the plant probabilistic risk assessment (PRA). Both methods have received extensive implementation in the U.S. and in several other countries in Europe and Asia.
- N-578 [13+2]
- N-613 [14+3] Reduces the examination volume of Category B-D nozzle welds in adjacent material from 1/2 shell thickness to 1/2 inch. This permits a significant reduction in qualification and scanning time.
- N-552 [15+4] Permits computational modeling for the qualification of nozzle inner radius examination techniques, in lieu of qualification on a multitude of configurations.
- N-610 [16+5] Permits a  $K_{IR}$  curve in Appendix G, in lieu of a  $K_{IA}$  curve. Indirectly, this is beneficial to the pressure-temperature limit curve during plant startup.

Not all of the changes in Section XI, due to operating considerations, have led to a relaxation in inspection or evaluation requirements.

Over the past 10 years, there have also been a number of changes (often by code case) to the Section XI ISI program that have increased the extent of examinations and tests based on operating experience and analytical evaluation. The following examples of ASME Code Cases are limited to those applicable to the RV and its piping connections.

- N-409 [17+6] Introduced procedure and personnel qualification requirements for UT of intergranular stress corrosion cracking (IGSCC) in austenitic piping welds, a precursor to Appendix VIII, UT performance demonstration requirements.
- N-512 [18+7] Provided requirements for the assessment of RVs with low upper shelf Charpy impact energy levels.
- N-557 [19+8] Introduced requirements for in-place dry annealing of a PWR RV.

## 2.2 LOCATION-SPECIFIC ISI DATA FROM PARTICIPATING PLANTS

While it is known that the number of flaws found in RPV welds is very small, it is important to relate their number to the number of welds that have been examined over the past 30 years with no evidence of the development of service-induced flaws.

To develop location-specific ISI data from nuclear plants, ISI data on the RV weld categories noted above were gathered in a survey [20+9]. This information focused on service-induced flaws. It did not address the detection of original fabrication flaws, unless the flaws had grown due to service conditions. The response to this survey is summarized in Table 2-1.

No. of Plants	Total Years of Service Prior to Survey	ASME Weld Category / Item	No. of Welds in Category	Welds with No Flaws	Welds with Flaws	Means of Detection <sup>1</sup>	Cause of Flaw/Failure
14	301	<b>B-A</b>					
		Shell, B1.10	112	112	0		
		Head, B1.20	105	105	0		
		Shell-to-flange, B1.30	16	16	0		One plant reported 3 indications that may be just scratches.
		Head-to-flange, B1.40	16	16	0		One plant reported 3 indications that may be just scratches.
		<b>B-D</b>					
		Nozzle-to-shell, B3.90	102	102	0		
		Nozzle inside radius B3.100	102	102	0		
		<b>B-F</b>					
		Dissimilar metal, B.5.10	84	84	0		
		B5.30	32	32	0		
		<b>B-J</b>					
		Piping, B9.10	64	64	0		
		<b>B-K</b>					
		Welded attach, B10.10	4	4	0		
		<b>B-N</b>					

<b>No. of Plants</b>	<b>Total Years of Service Prior to Survey</b>	<b>ASME Weld Category</b>	<b>No. of Welds in Category</b>	<b>Welds with No Flaws</b>	<b>Welds with Flaws</b>	<b>Means of Detection<sup>1</sup></b>	<b>Cause of Flaw/Failure</b>
		Vessel interior, B13.10	34	34	0		
		Interior attach.-beltline, B13.50	6	6	0		
		Other interior attach., B13.60	53	53	0	VT-3, UT, ECT	One plant reported crack arrest holes drilled in core barrel.
		Core support struct., B13.70	41	5	0		

Note 1: VT = Visual Inspection, UT = Ultrasonic Inspection, ECT = Eddy Current Inspection

## 2.3 EXPOSURE AND COST REDUCTION

Data was gathered on CE and Westinghouse plants related to the cost of a typical RV ISI outage, as well as the cost of the exposure affecting the involved personnel [2049]. The objective of this effort was to investigate the exposure and financial aspects of the RV ISI. The results of the survey were tabulated based on the probability of a life extension program (60 years), and the potential savings were calculated with regards to a proposed extension of the RV ISI interval to 20 years. The radiation exposure cost is contingent on the utility and is typically \$15,000 to \$20,000 per man-rem. A summary of the results is presented in Table 2-2.

Probability of 20-Year Life Extension (%)		0%	50%	100%
Cost of Typical RV ISI Outage, \$	min	506,410	759,615	1,012,820
	max	7,680,000	9,600,000	11,520,000
	average	3,878,521	5,391,656	7,115,317
Dose of Exposure, Man-rems	min	0.2	0.4	0.6
	max	6.5	9.75	13.0
	average	1.66	2.32	2.98
Cost of Dose of Exposure, \$	min	2,492	4,984	7,476
	max	65,000	97,500	130,000
	average	20,611	28,856	37,101

As shown in Table 2-2, the savings associated with even the most conservative assumption, i.e., no life extension program (40 years) for any of the surveyed plants, are significant. The extension of the RV ISI interval to 20 years will save every unit an average of \$3,878,521 for the cost of the outage, and 1.66 man-rems of exposure.

The saving values associated with the less conservative assumption of the guaranteed life extension program (60 years) for any of the surveyed plants are considerably higher. The extension of the RV ISI interval to 20 years will save every unit an average of \$7,115,317 for the cost of outage, and 2.98 man-rems of exposure. The critical path outage time for RV inspections is approximately 3 ½ days. While this data was gathered for Westinghouse and CE designed plants, the savings for B&W designed plants are expected to be similar.

## 2.4 GENERIC REACTOR VESSEL WELD EXPERIENCE AT VARIOUS PLANTS

Section XI ISI requirements developed in the early 1970s were based on the detection of fatigue cracking in primary welds. This has not been substantiated by subsequent operating experience. Fatigue cracking in primary welds has not been a problem. Random sampling for the assessment of condition of pressure-containing components has not been effective; when leakage and other deterioration have been identified, it has been by examinations other than the Section XI ISI NDE.



Primary system failures/leakage have almost always been associated with dissimilar metal welds or control rod drive, bottom mounted instrumentation, or vent connections of the RV and its head. The latter connections are all partial penetration welds. They were not included in the survey, since the current effort does not propose to recommend changes to their present ISI interval requirements. Their examinations are not contingent on the removal of the reactor internals and the use of the RV inspection tool. Category B-F dissimilar metal welds, Category B-K welded attachments, and Category B-N interior attachment and support welds were not included in the inspection interval extension.

In many plants, the most highly stressed reactor vessel weld is the weld between the closure head flange and the dome. There have been no reports of degradation of this joint. This joint ranks quite low in its contribution to cumulative risk determined through typical PFM methods. Calculations [2120] have shown that flaw growth due to fatigue would be extremely small, so that even pre-existing flaws that clearly exceed the acceptance standards would not be subject to measurable growth.

## 2.5 DEVELOPMENT OF ISI INTERVAL EXTENSION METHODOLOGY

The ISI interval extension methodology is primarily based on a risk analysis, including a PFM analysis of the effect of different inspection intervals on the frequency of reactor vessel failure due to postulated PTS transients. Reactor vessel failure is defined for the purposes of this study as the point which a crack has extended all the way through the RV wall. The likelihood of reactor vessel failure is postulated to increase with increasing time of operation due to the growth of pre-existing fabrication flaws by fatigue in combination with a decrease in reactor vessel toughness due to irradiation. Credible, postulated PTS transients that could potentially lead to reactor vessel failure must be considered to occur at the worst time in the life of the plant. The PFM methodology allows the consideration of distributions and uncertainties in flaw number and size, fluence, material properties, crack growth rate, stresses, and the effectiveness of inspections. The PFM approach leads to a conditional reactor vessel failure frequency due to a given loading condition and a prescribed inspection interval. All locations of interest in the reactor vessel can be addressed in a similar way or, as in the case of this study, a bounding approach can be used to minimize the areas receiving a detailed evaluation.

A feasibility study was performed [2049] that showed that this fracture mechanics and risk methodology can be used to calculate the change in the frequency of reactor vessel failure due to a change in inspection interval and to evaluate the acceptability of the associated change in risk. The impact on plant safety from the change in risk presented in this study was based on the standards for risk-informed assessment as defined by RG 1.174 [44].

### 3 PILOT PLANT SUMMARY

The risk evaluations summarized in this report utilized the same pilot plants as used in the NRC PTS Risk Re-evaluation effort [8][27, 438, 9]. The NRC effort to address PTS risk identified FirstEnergy Nuclear Operating Company's (FENOC's) Beaver Valley Unit 1 (BV1), Nuclear Management Company's (NMC's) Palisades, and Duke Energy's Oconee Unit 1 (OC1) as the pilot plants. These pilot plant applications also used fleet-specific design transient data for the Combustion Engineering (CE) and Westinghouse designs. A typical generic heatup/cool-down transient was used for the Babcock & Wilcox (B&W) study. A study was also performed to determine the bounding location from among the applicable weld locations on a typical PWR reactor vessel. The results of all of these investigations are included in the following sections.

#### 3.1 BOUNDING LOCATION

The focus of the evaluations for reactor vessel inspection interval extension was on the beltline of the RV. To confirm that the beltline location represented the bounding location for the reactor vessel, all locations currently required for examination in the reactor pressure vessel (RPV) needed to be identified and considered. The beltline weld locations were found to be the bounding locations primarily due to irradiation induced change in the fracture toughness. This was consistent with the location assumptions used to support the NRC PTS Risk Study [8][8, 9][27-43]. Table 3-1 summarizes the current ISI requirements for RPV inspection as identified in Table TWB-2500-1 of the ASME B&PV Code, Section XI [1+]. While this table identifies all welds with Section XI inspection requirements, this report only addresses the ISI interval extension of the Category B-A and B-D and B-J welds.

<b>Table 3-1 ASME Section XI [14] ISI Requirements for RPVs (ASME Section XI, Table IWB-2500-1)</b>			
	<b>Item No.</b>	<b>RPV Location</b>	<b>Examination Requirement</b>
		<b>Pressure Retaining Welds in Reactor Vessel</b>	
B-A	B1.10	Shell Welds	Volumetric
B-A	B1.11	Circumferential	Volumetric
B-A	B1.12	Longitudinal	Volumetric
B-A	B1.20	Head Welds	Volumetric
B-A	B1.21	Circumferential	Volumetric
B-A	B1.22	Meridional	Volumetric
B-A	B1.30	Shell-to-Flange Weld	Volumetric
B-A	B1.40	Head-to-Flange Weld	Surface and Volumetric
B-A	B1.50	Repair Welds	Volumetric
B-A	B1.51	Beltline Region	Volumetric
		<b>Full Penetration Welded Nozzles in Vessels</b>	
B-D	B3.90	RPV Nozzle-to-Vessel Welds	Volumetric
B-D	B3.100	RPV Nozzle Inside Radius Section	Volumetric
		<b>Pressure Retaining Dissimilar Metal Welds in Vessel Nozzles</b>	
B-F	B5.10	RPV Nozzle-to-Safe End Butt Welds, NPS 4 or Larger	Surface and Volumetric
B-F	B5.20	RPV Nozzle-to-Safe End Butt Welds, Less Than NPS 4	Surface
B-F	B5.30	RPV Nozzle-to-Safe End Socket Welds	Surface
		<b>Pressure Retaining Welds in Piping</b>	
B-J	B9.10	NPS 4 or Larger	Surface and Volumetric
B-J	B9.11	Circumferential Welds	Surface and Volumetric
		<b>Welded Attachments for Vessels, Piping, Pumps and Valves</b>	
B-K	B10.10	Welded Attachments	Surface
		<b>Interior of Reactor Vessel</b>	
B-N-1	B13.10	Vessel Interior	Visual, VT-3
		<b>Welded Core Support Structures and Interior Attachments to Reactor Vessels</b>	
B-N-2	B13.50	Interior Attachments within Beltline Region	Visual, VT-1
B-N-2	B13.60	Interior Attachments Beyond Beltline Region	Visual, VT-3
		<b>Removable Core Support Structures</b>	
B-N-3	B13.70	Core Support Structure	Visual, VT-3

To confirm that the beltline was the limiting location, an assessment was performed using deterministic fracture mechanics that considered the following:

- Existence of 10-percent through-wall initial flaw
- In-service fatigue crack growth of the flaw due to normal plant operating transients
- 40 EFPY embrittlement throughout plant life
- Peak reactor vessel ID fluence assumed regardless of flaw depth, i.e., maximum embrittlement
- Design basis heat-up and cool-down transients
  - 500 cycles/40 years for CE NSSS
  - 200 cycles/40 years for Westinghouse NSSS
- 7 Weld Locations
  - Closure Head to Flange
  - Upper Shell to Flange
  - Lower Shell Transition
  - Bottom Head to Shell
  - Beltline
  - Inlet Nozzle to Safe End
  - Outlet Nozzle to Safe End

The study evaluated the effect of various ISI intervals by comparing the change in margins on ASME Code allowable flaw sizes for the respective locations. This approach was preceded by considering 3 iterative steps:

1. Select the first inspection interval,  $I_1$ , based on the growth of the assumed initial flaw to a fraction of the tolerable flaw size.
2. Perform the inspection. If no defects larger than the assumed flaw size are found, the second inspection interval,  $I_2$ , is the same as the first.
3. Continue subsequent inspections until actual flaws are detected that require repair or augmented inspections.

The results of the study are summarized in Figures 3-1 and 3-2. Inspection intervals were based on 10-, 20-, 30-, or 40-year inspection intervals over a 40-year plant life. Each reactor vessel location was evaluated by calculating the amount of crack extension that would occur due to fatigue crack growth over a 10-year period of operation. Each crack length was then evaluated for the maximum applied  $K_I$  from a transient. The ratio of the maximum allowable  $K_I$ , per the ASME Section XI [1+] Appendix A criteria, to the maximum  $K_I$  applied, was used as a measure of the margin a flaw in a given location has to the acceptance criteria. Note that in Figure 3-1 the margins on the acceptance standard are greater than 1, except for the beltline region axial and circumferential flaws. This indicates that all of the flaw sizes in other locations are acceptable with varying degrees of margin. The margin less than one for the beltline

locations is an indication that the assumed initial flaw size of 10-percent throughwall was greater than the acceptable flaw size. The other feature to note in Figures 3-1 and 3-2 is that, for each subsequent 10-year period that was evaluated, there was an insignificant change in the degree of margin for all of the locations. This observation was simply a reflection of the fact that the increments of fatigue crack growth of the flaws were so small that the applied  $K_I$  values were not changing. Therefore, the ratios of the applied to allowable  $K_I$  did not change. Though not shown in figures 3-1 and 3-2, the reactor vessel nozzle to shell weld was also evaluated and found to have a margin greater than that of the reactor vessel beltline axial and circumferential welds.

These results confirmed that the beltline was the limiting location and that the change in fatigue crack growth increment for RPV flaws was insignificant relative to the inspection interval. While a specific number of design basis heat-up and cool-down transients was not analyzed for B&W designs in this bounding location assessment, it is reasonable to expect that the conclusions of this assessment would also be applicable to B&W plants due to similarities in the RV and NSSS designs.

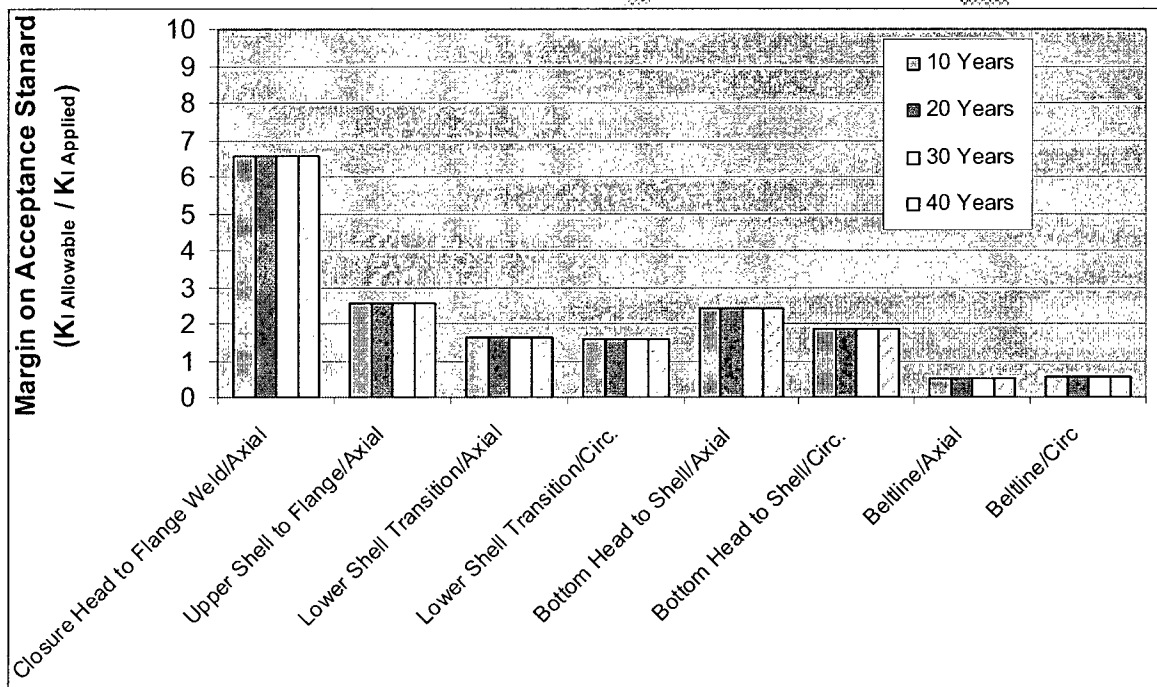


Figure 3-1 Comparison to Acceptance Criteria – Minimum Margins Code Allowable

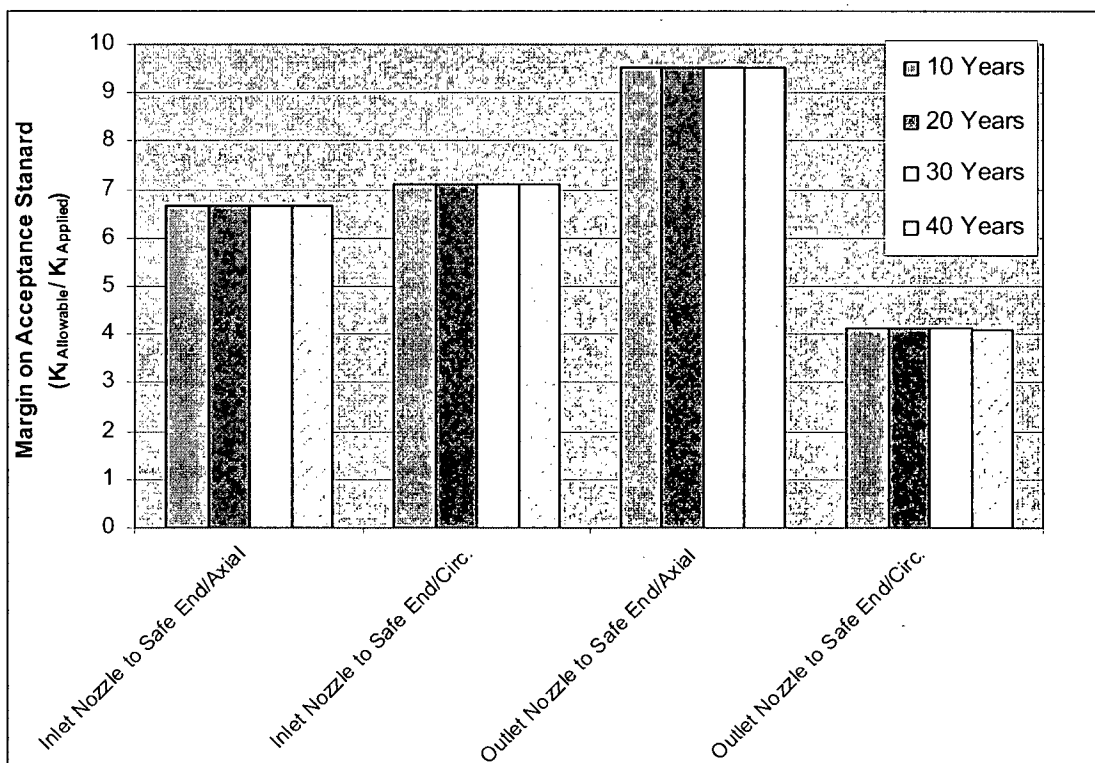


Figure 3-2 Comparison to Acceptance Criteria – Minimum Margins Code Allowable

### 3.2 BASIS FOR RISK DETERMINATION

As indicated in ASME Code Case N-691 [55], the application of risk-informed insights from PFM and risk analyses can be used to justify an increase from 10 to 20 years in the requirements of Section XI, IWB-2412 for the inspection interval for the examination of Category B-A and B-D welds in PWR reactor vessels, and Category B-D welds to the RV nozzles. The guidelines in Regulatory Guide 1.174 provide the basis for an acceptable change in risk resulting from an extension in inspection interval. As the basis for determining the change in risk, the inputs to the RV PFM and risk analyses included the following:

#### Accident Transients and Frequency

ASME Code Case N-691 [55] states that it is necessary to define a complete set of accident transients that can be postulated to realistically result in RV failure and their frequencies of occurrence. As previously mentioned, PTS events are viewed as providing the greatest challenge to PWR RPV structural integrity. For this reason, the pilot plant applications in this report used the PTS transients and frequencies from the NRC PTS Risk Study [8][27, 438, 9]. As part of the NRC study, probabilistic risk assessment (PRA) models were developed for each of the pilot plants using plant specific information [21, 22, 2322, 23, 24]. These PRA models included an event-tree analysis that defined both the sequences of events that are likely to produce a PTS challenge to RPV structural integrity and the frequency with which such events can be expected to occur. The typical sequence of concern was cool-down and depressurization due to the initiating event, followed by repressurization due to high-pressure safety injection or charging. Historically, a small-break loss-of-coolant accident (SBLOCA) with low decay heat has been the

sequence identified as a major contributor to PTS risk. However, other events considered included a large break in the main steam line upstream of the main steam isolation valves, a double-ended main steam line break (MSLB) upstream of the main steam isolation valves (MSIVs), small steam line break downstream of the MSIVs, and excessive feedwater flow, all with the reactor coolant pump (RCP) shutdown and multiple failures of the operator to take remedial action.

The PTS Risk Study utilized the plant specific PRA models to determine the possible sequences which could result in a PTS event for each of the pilot plants. Due to the large number of sequences which were identified, it was necessary to group (i.e., bin) sequences with like characteristics into representative transients that could later be analyzed using thermal-hydraulic codes. This resulted in 178 binned sequences for OC1, 118 for BV1, and 65 for Palisades. Thermal-hydraulic analyses were performed for each of these bins (i.e., representative transients) to develop time histories of temperature, pressure, and heat transfer coefficients [2425]. These histories were then input into the PFM analysis to determine conditional probability of reactor vessel failure for each transient. From this analysis, it was determined that only a portion of the transients contribute to the total risk of RPV failure, while the remainder have an insignificant or zero contribution. The transients which were identified to be contributors to PTS risk were then used for the PFM analysis in the PTS study and for the pilot plant studies in this report. Consistent with the PTS Risk Study, 61 transients were analyzed for BV1, 30 for Palisades, and 55 for OC1 in this study on the impact of extending the RV ISI interval. Details of the transients are provided in Appendix D for BV1, Appendix H for Palisades, and Appendix L for OC1.

As part of the NRC PTS Risk Reevaluation Program, a study was performed to determine the applicability of the pilot plant detailed analyses to the remainder of the domestic PWR fleet. This "Generalization" Study [2526] examined the results from the three detailed pilot plant studies (BV1, Palisades, and OC1) and identified a set of plant design and operational features considered to be important in determining whether or not certain types of overcooling scenarios are significant contributors to PTS. These features were then analyzed for five additional plants and compared to the features of the pilot plants. These five plants included the following:

- Salem Unit 1 (Westinghouse 4-loop plant comparable to Beaver Valley Unit 1)
- TMI Unit 1 (B&W plant comparable to Oconee Unit 1)
- Fort Calhoun (CE plant comparable to Palisades)
- Diablo Canyon (Westinghouse 4-loop plant comparable to Beaver Valley Unit 1)
- Sequoyah Unit 1 (Westinghouse 4-loop plant comparable to Beaver Valley Unit 1)

They were chosen for the generalization study on the basis of:

- having a high reference temperature metric ( $RT_{PTS}$ ), which reflects their potential sensitivity to PTS,
- further demonstrating the applicability of the pilot plant analyses to the remainder of the fleet for the nuclear steam supply system (NSSS) vendors, and
- including plants having different limiting materials (i.e., welds, plates, and forgings).

It was determined in the generalization study that there were no differences in plant features that from a PRA, thermal hydraulic, and PFM standpoint would be expected to cause significant differences in the through wall cracking frequencies due to the postulated PTS scenarios. It was further concluded through the generalization study that the pilot plant results at a comparable embrittlement level could be applied to the remainder of the domestic PWR fleet.

### Operational Transients and Cycles

ASME Code Case N-691 [55] states that the operational transients that contribute to fatigue crack growth and the number of cycles occurring each year must be identified. Typically, the start-up (heat-up) and shut-down (cool-down) events are the dominant loading conditions as seen in ASME Code Section XI, Non-Mandatory Appendix A [14] calculations for fatigue crack growth of an existing flaw.

For the purpose of the pilot plant studies in this report, an 80-year life for fatigue crack growth was used. This 80-year life envelopes plants seeking to obtain license extensions to 60 years and provides an additional margin of conservatism. The design basis transients for the pilot plants were reviewed and it was determined that the greatest contributor to fatigue crack growth for the pilot plants is heat-up and cool-down. Each transient represents a full heat-up and cool-down cycle between atmospheric pressure at room temperature and full-system pressure at 100-percent power operating temperature, and thus envelopes many transients with a smaller range of conditions. For the pilot plant evaluations, 7 heat-up and cool-down cycles per year were used for Westinghouse plants (BV1) and 13 cycles were used for CE plants (Palisades) to bound all the design basis transients for the respective PWR plant designs in each fleet. Based upon available information, 12 cycles were used for Babcock and Wilcox plants. For any B&W plant using the results of this WCAP to extend the reactor vessel ISI interval from 10 to 20 years, including the pilot plant (OC1), the fatigue crack growth for 12 heatup/cooldown transients per year will have to be verified to bound the fatigue crack growth for all design basis transients.

It is important to note that most plants' operational histories indicate that they will not reach this number of design transients by end of life (EOL) (80 years). However, this calculation was performed as a bounding analysis and the number of design transients was used rather than the number of operational transients so that plants with operational histories different than those of the pilot plants would be enveloped.



## Initial Flaw Distribution

ASME Code Case N-691 [55] requires credible flaw distributions for a PWR reactor vessel. Significant work by Pacific Northwest National Laboratory (PNNL) and the NRC was performed to more completely specify the initial flaw size distributions and their densities for input into the NRC PTS Risk Study [8][27, 438, 9]. This work focused on making detailed destructive and non-destructive measurements of fabrication flaws in nuclear grade RPV welds and plates. Whenever possible, this experimental evidence was used exclusively or given the greatest "weight" in establishing the flaw distributions. In cases where experimental evidence was not sufficient, physical models and expert opinion were used to supplement the experimental evidence in establishing the flaw distributions. For the NRC PTS Risk Study, flaw distributions were developed for embedded flaws in welds, plates (includes forgings), and inner surface breaking flaws.

The weld flaw distribution was based on the highest densities of the Shoreham reactor vessel and the largest sizes of the PVRUF vessel. The embedded flaws are distributed evenly through the thickness of the weld. Flaws are postulated only in the same orientation as the weld. The flaw distribution represents a blended combination of weld types with 2% of the welds assumed to be repair welds, which have the largest flaw sizes.

Empirical evidence to support a plate flaw distribution is much more limited than that for welds. For this reason, the density for flaws of depths less than 6mm is 10% of that for weld flaws, while the density for flaws of depth above 6mm is 2.5% of that for weld flaws. Half of the simulated flaws are assumed to be axially oriented while the other half are assumed to be circumferentially oriented.

For weld and plate flaws, the pilot plant studies for the RV ISI interval extension study used the flaw distributions from the NRC PTS Risk Study directly. These densities are input into the FAVOR Code PFM analyses as flaw density files, P.dat (plate-embedded flaws) and W.dat (weld-embedded flaws). This is discussed further in the "PFM Computer Tool and Methodology" section.

The inner-diameter of the RPV is clad with a thin layer of stainless steel. Lack of inter-run fusion can occur between adjacent weld beads, resulting in circumferentially oriented cracks (the cladding in the RV is deposited circumferentially). However, none of the cracks discovered in the PNNL studies had broken through the cladding layer on the inside surface of the RV. Therefore, for the NRC PTS Risk Study [8][8, 927, 43], the BVI and Palisades evaluations used multi-pass cladding with no surface breaking flaws. Multi-layer cladding is assumed to have no surface breaking flaws due to the small likelihood of two flaws aligning in two different weld layers. The OCI pilot evaluation used an assumed surface flaw completely through the cladding with a density of  $1/1000^{\text{th}}$  of the embedded flaws through the vessel wall.

For this investigation on the impact of extending the RV ISI interval it is important to consider the effects of fatigue crack growth. Due to the fact that embedded flaws do not grow significantly due to fatigue, for the pilot plant studies, the presence of surface breaking flaws with an initial flaw depth equal to the cladding thickness was postulated. Therefore, for the pilot plant evaluations to bound all the plants of the same design, single-pass cladding was conservatively assumed. The initial flaw size and distribution was input into a fatigue crack growth and ISI analysis to determine a surface flaw density file after any inspections (ISI). Surface flaw density files were created to simulate two cases. The first case simulated inspections performed on a 10 year interval as currently required by the ASME Code. The

second case simulated a single inspection performed after the first 10 years of operation with no subsequent inspection. These surface breaking flaw density files are then input into the PFM analysis as surface breaking flaw density file S.dat. The methodology for determining the flaw depth and density included in this file is described in the section on PFM and Computer Tool Methodology. Cladding details for the pilot plants are identified in Appendices B, F, and J.

### Fluence Distribution

ASME Code Case N-691 [55] requires that the fluence distribution versus operating time, both axial and azimuthal, be based on plant-specific or bounding data for the current operating time and extrapolated as applicable to the end of the current 40 year license or for license renewal to 60 years.

For the pilot plant evaluations in this report, the input fluence distributions were taken directly from the NRC PTS Risk Study [8][8, 927, 43]. For the NRC PTS Risk Study, a series of neutron transport calculations were performed to determine the neutron fluence on the inner-wall of the pilot plant RPVs. The modeling procedures were based on the guidance contained in NRC Reg. Guide 1.190[27]. The models incorporated pilot plant specific geometry and operating data. The fluence for  $E > 1$  MeV was calculated as a function of the azimuthal and axial location in the inner reactor vessel wall. The fluence was extrapolated from the current state point to various effective full-power years (EFPYs) assuming a linear extrapolation of the most recent operating cycles.

The fluences used in the RV ISI interval extension evaluations were for 60 EFPY for BV1 and Palisades and for fluences at 500 EFPY for OC1 to envelope license extension. 500 EFPY were used for OC1 rather than 60 EFPY because it is recognized that it is not the most embrittled RV in the B&W fleet. The use of 500 EFPY for OC1 should bound the embrittlement of the most highly embrittled RV in the B&W fleet when evaluated against the parameters identified in Appendix A. Representative fluence maps for BV1, Palisades, and OC1 at 32 EFPY can be found in Appendices B, F, and J, respectively. While the magnitude of the fluence on these maps correspond to 32 EFPY rather than the 60 EFPY and 500 EFPY used in the pilot plant evaluations, the contour of the fluence relative to the reactor vessel weld layout still applies.

### Material Fracture Toughness

ASME Code Case N-691 [55] states that the material fracture toughness of the limiting beltline plates and weld materials need to be based on the following plant-specific data:

- Physical and mechanical properties of the base metal, clad, and welds (e.g., copper and nickel content) and their uncertainties.
- Initial reference nil-ductility transition temperature ( $RT_{NDT}$ ), including uncertainty
- $\Delta RT_{NDT}$  due to radiation embrittlement, versus time and depth, including uncertainty
- Fracture toughness versus time and depth, including uncertainty

These reactor vessel material properties for the BV1, Palisades, and OC1 pilot plants evaluated in this report are identified in Appendices B, F, and J, respectively.

Embrittlement due to irradiation in RPV steels occurs due to matrix hardening and age hardening [8][27, 438, 9]. Based on the physical insights into these hardening mechanisms a relationship between material composition, irradiation-condition variables, and measurable quantities such as yield strength increase, Charpy-transition-temperature shift, and toughness-transition-temperature shift was established for the NRC PTS Risk Study [8][8, 927, 43]. Furthermore, a quantitative relationship was developed from the database of Charpy shift values generated in domestic reactor surveillance programs. The Eason and Wright irradiation shift model was developed by fitting this data. This model is used in the FAVOR Code [28] for the NRC PTS Risk Study [826] and the RV ISI interval extension pilot plant studies to calculate the shift and irradiated reference temperature as a function of time.

The results of the significant work at ORNL, the NRC, and within industry to more completely specify the distribution on fracture toughness and its uncertainty for the NRC PTS Risk Study [8][8, 927, 43] are included in the FAVOR Code which is used for the pilot plant studies for RV ISI interval extension. The FAVOR Code includes fracture toughness models which are based on extended databases of empirically obtained  $K_{Ic}$  and  $K_{Ia}$  data points and include the effects of the statistical bias for direct measurement of fracture toughness (Master Curve Method). Furthermore, the FAVOR Code [28][26] uses the latest correlation on irradiated upper shelf fracture toughness.

It should be noted that along with the inspection of a weld, there is a specified amount of base metal inspected. In the FAVOR Code evaluation, if a flaw is placed within a weld that is adjacent to a more highly embrittled plate, the flaw is assigned the embrittlement characteristics of the plate rather than the weld and is assumed to fracture and propagate in the direction of the plate.

The NRC has proposed that through wall cracking frequency (TWCF) can be correlated to the embrittlement index (reference temperature) of the reactor vessel components. The correlation for determining plant specific TWCF based on the plant specific data mentioned can be found in Reference 27 439. This correlation takes into consideration the contribution to TWCF for each of the most limiting plate, axial weld, and circumferential welds. These individual TWCF contributions are then weighted based on experimental pilot plant data and summed to determine a total reactor vessel TWCF. For application to other plant reactor vessels, the plant specific TWCF must be equal to or less than the values used for the applicable pilot plants evaluated in this report (see Appendix A) at 60 EFPY.

### **Crack Growth Rate Correlation**

ASME Code Case N-691 [55] requires that the basic physical models for fatigue crack growth due to operational transients (e.g., heat-ups, cool-downs, normal plant operating changes, and reactor trips) including the effects of uncertainties, be used for the PFM analysis. Also used are the basic physical models for crack growth during these transient events (i.e., the change in applied stress intensity and the corresponding change in flaw size) for the surface breaking flaws and their uncertainties.

The pilot-plant studies in this report included a probabilistic representation of the fatigue crack growth correlation for ferritic materials in water that was consistent with the previous and current models contained in Appendix A of the ASME Code, Section XI [14]. These correlations represented the

behavior of the ferritic reactor vessel materials for all domestic PWRs. This probabilistic representation was consistent with that used by the NRC-supported pc-PRAISE code [2928] and the NRC-approved SRRA tool for piping-risk informed ISI [3029].

### Cladding and Residual Stresses

ASME Code Case N-691 [55] requires that the residual stress distribution in welds and the cladding stress and its temperature dependence due to differential thermal expansion be considered. For the pilot plant studies for RV ISI interval extension, the residual stress distribution through the wall was taken from the NRC PTS Risk Study [8][8, 927, 43] and is described in the FAVOR Code Theory Manual [2628]. This distribution is shown in Figure 3-3. The stress profile was determined for the NRC PTS Risk Study through experiments in which a radial slot was cut in a longitudinal weld in a shell segment from an actual RPV and the deformation of the slot was measured after cutting. Finite element analysis was used to determine the residual stress profile from the measured deformations. The cladding stress used in the pilot plant studies was taken from the NRC PTS Risk Study. The cladding temperature dependence due to differential thermal expansion was based on a stress-free temperature of 468 488°F, which is consistent with that used in the NRC PTS Risk Study [88, 927, 43].

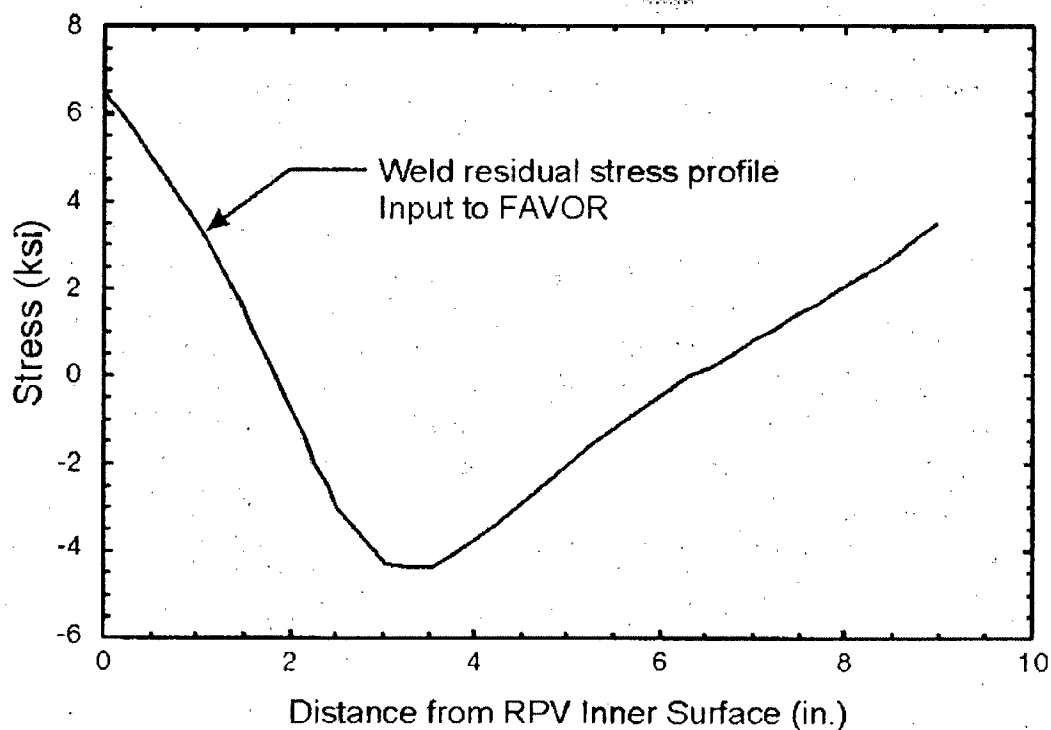


Figure 3-3 Weld Stress Profile

### Effectiveness of ISI

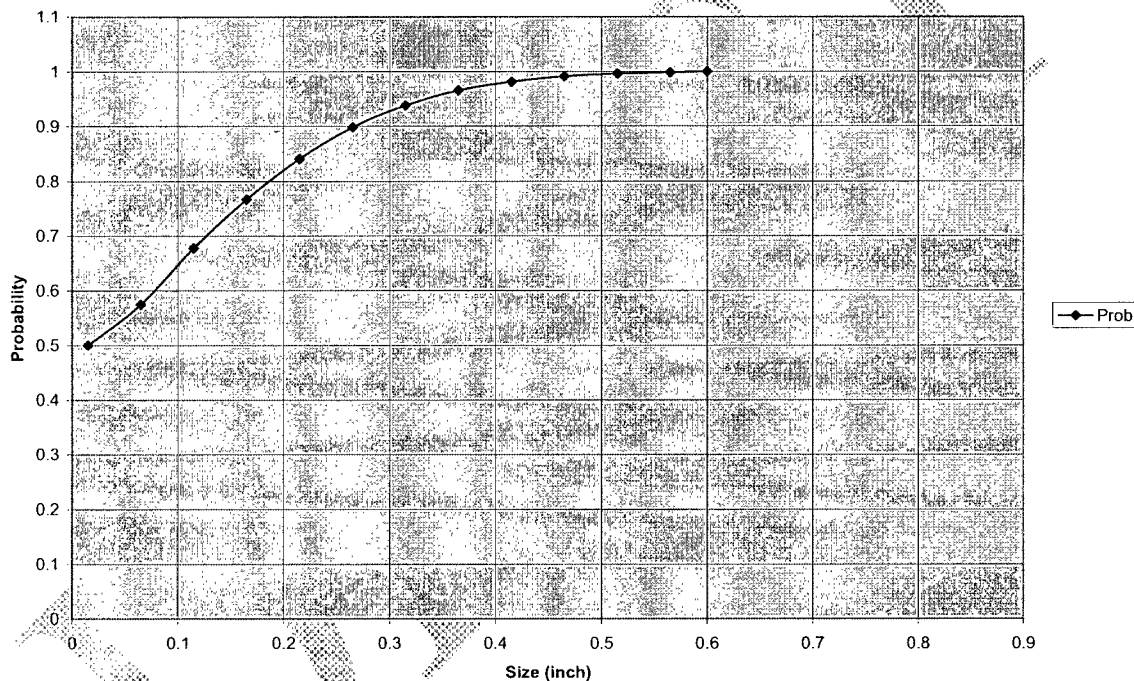
The essential requirement for an effective volumetric examination in ASME Code Case N-691 [55] is that it be conducted in accordance with Section XI Appendix VIII [14] or RG 1.150 [22].

The following effects also need to be considered along with the change in ISI interval:

- Extent of inspection (percent coverage)
- Probability of detection (POD) with flaw size
- Repair criterion for removing flaws from service

The POD should correlate to the respective examination method for the RV weld of interest.

The basis for the probability of flaw detection used in the pilot plant studies for the RV ISI interval extension was taken from studies performed at the EPRI NDE Center on the detection and sizing qualification of ISIs on the RV beltline welds [3130]. Figure 3-4 shows the probability of detection with respect to flaw size used in the pilot studies in this report.



**Figure 3-4 ISI Detection Probability**

For the pilot plant evaluations, examinations were assumed to be conducted in accordance with Section XI Appendix VIII [1+], so that Figure 3-4 could be used. Flaws that were detected were assumed to be repaired with the repaired area returned to a flaw-free condition. If the quality of inspection is not as good as assumed (e.g. ISI per Regulatory Guide 1.150) or the quality of the repair is less than 100 percent, then the result would be fewer flaws found and fewer flaws removed during repair, resulting in less difference in risk from one inspection interval to another. Therefore, the pilot plant studies conservatively calculated a larger potential difference in risk by maximizing the benefits of inspection.

### Impact of Other ASME Code Cases on RPV Inspection

While no ASME Code Cases have been found that directly overlap the actions included in ASME Code Case N-691 [55], there are related ASME Code Cases and “problem areas” that may affect implementation of the Code Case. ASME Code Cases that concern reactor vessel inspections but do not affect the applicability of the Code Case are identified in the following:

ASME Code Case N-697 [3234] addresses Examination Requirements for PWR Control Rod Drive and In-Core Instrumentation Housing Welds. It adds requirements for examination of in-core instrumentation housing welds greater than 2" Nominal Pipe Size to Examination Category B-O. If these UT or surface examinations of the housing weld inner surface were conducted from inside the RPV, they could result in examination intervals incompatible with effective implementation of N-691 [55]. However, these welds are not inspected from inside the RPV and, therefore, there is no impact.

A top priority in Section XI is to work with the Material Reliability Program Alloy 600 Issue Task Group to identify and incorporate changes needed in the examination of affected partial penetration and dissimilar metal welds. This could result in incompatible examination intervals for Examination Category B-F welds to reactor vessel nozzles, and dissimilar metal welds in Examination Category B-J not covered by Category B-F. A possible approach for some plants, where access permits, would be to examine these welds from the pipe outer diameter (OD) at alternate 10-year intervals, and from the inner diameter (ID) during the Case N-691 [55] examinations.

ASME Code Case N-700 [3332] addresses Examination Category B-K, surface examination of welded attachments. It permits examination of a single welded reactor vessel attachment each inspection interval.

ASME Code Case N-648-1 [3433] permits a VT-1 visual examination of a reactor vessel nozzle inner radius in lieu of a volumetric examination. Applicability of this Code Case would not be affected by the increased examination interval.

ASME Code Case N-624 [3534] provides for modification of the sequence of successive examinations. The increased examination interval would be applicable.

ASME Code Case N-623 [3635] permits deferral to the end of the interval of shell-to-flange and head-to-flange welds of a reactor vessel. The methodology of Case N-691 [55] would not be affected by application of this Code Case.

ASME Code Case N-615 [3736] permits ultrasonic examination as a surface examination method for Category B-F and B-J piping welds of 4" Nominal Pipe Size and larger. It would be compatible with the increased examination interval.

ASME Code Case N-613-1 [3837] reduces the nozzle weld examination volume of Examination Category B-D. It would be compatible with the increased examination interval.

ASME Code Case N-598 [3938] provides alternatives to the required percentages of examinations each inspection period. ASME Code Case N-691 [55] would increase the length of the inspection period but would not affect the percentage requirements.

### Impacts on Risk-Informed Piping ISI Programs

If the Category B-J piping welds to the RPV nozzles are included in a piping risk-informed inspection program, the impact on the piping program due to the extension in inspection interval must be evaluated per the requirements of ASME Code Case N-691 [5]. It must be determined whether extending the inspection interval for the Category B-J welds included in the risk-informed piping program will negatively impact (e.g., change the risk ranking of the piping segments) the piping program. If the program is negatively impacted, changes must be made to the program to address the impact.

For the pilot plant evaluations in this report, BVI does not have Category B-J welds to the RV and the RI-ISI for piping program is not impacted. For Palisades, the Category B-J welds to the RV were included in the RI-ISI piping program, but were selected as defense-in-depth examinations and not credited in the delta risk evaluation. Therefore, extending the inspection interval for these welds would not impact the RI-ISI program. OCl does not have a RI-ISI for piping program. Therefore, the extension of the inspection interval is not a concern for the OCl Category B-J welds in this regard.

### Probabilistic Fracture Mechanics Computer Tool and Methodology

For the pilot-plant applications of the PFM methodology, the failure frequency distributions for all postulated flaws in the RV were calculated using the latest version (0506.1) of the FAVOR code [2628]. The Fracture Analysis of Vessels – Oak Ridge (FAVOR) computer program was developed as part of the NRC PTS Risk Study [8][27, 438, 9]. It is a program that performs a probabilistic analysis of a nuclear reactor pressure vessel when subjected to events in which the reactor pressure vessel wall is exposed to time-varying thermal-hydraulic boundary conditions.

To run the FAVOR code, 3 modules (FAVLOAD, FAVPFM and FAVPOST) and various input files were required as shown in Figure 3-5. In the NRC PTS Risk Study [8][8, 927, 43], the effects of fatigue crack growth and ISI were not considered. However, to perform the risk evaluation for changing the inspection interval from 10 to 20 years, these effects were quantified. Program PROBSBFD (Probabilistic Surface Breaking Flaw Density) was developed to include these effects by modifying the surface-breaking flaw input file to FAVOR (S.dat) as shown in Figure 3-5.

The first module in FAVOR is the load module, FAVLOAD, where the thermal-hydraulic time histories are input for the dominant PTS transients. For each PTS transient, deterministic calculations are performed to produce a load-definition input file for FAVPFM (FAVPFS is also used in this analysis). These load-definition files include time-dependent, through-wall temperature profiles, through-wall circumferential and axial stress profiles, and stress-intensity factors for a range of axially and circumferentially oriented embedded and inner surface-breaking flaw geometries (both infinite and finite-length).

The FAVPFS module in Figure 3-5 is a modification of the FAVPFM module, which is the second module contained in the FAVOR code that was used in the NRC PTS risk study. The modification allows FAVPFS to have a 4 times finer depth distribution for surface breaking flaws in S.dat. The modification also reduces the output by printing only the first and last sub-region in each major region. The FAVPFS FAVOR module uses the input flaw distributions (e.g., S.dat, W.dat, and P.dat), the loads for the PTS events from the FAVLOAD module and fluence/chemistry input data at 60 EFPY (effective full-power years) to calculate the initiation and failure probabilities for each PTS transient.

The FAVPOST post-processor is the third module in FAVOR. It combines the distributions of initiating frequencies for the dominant PTS transients with the results of the PFM analysis (performed with the FAVPFS module) to generate probability distributions for the frequencies of reactor vessel crack initiation and reactor vessel failure. This module also generates statistical information on these distributions and the distributions for the conditional probabilities of reactor vessel crack initiation and failure for each PTS transient included in the risk analysis.

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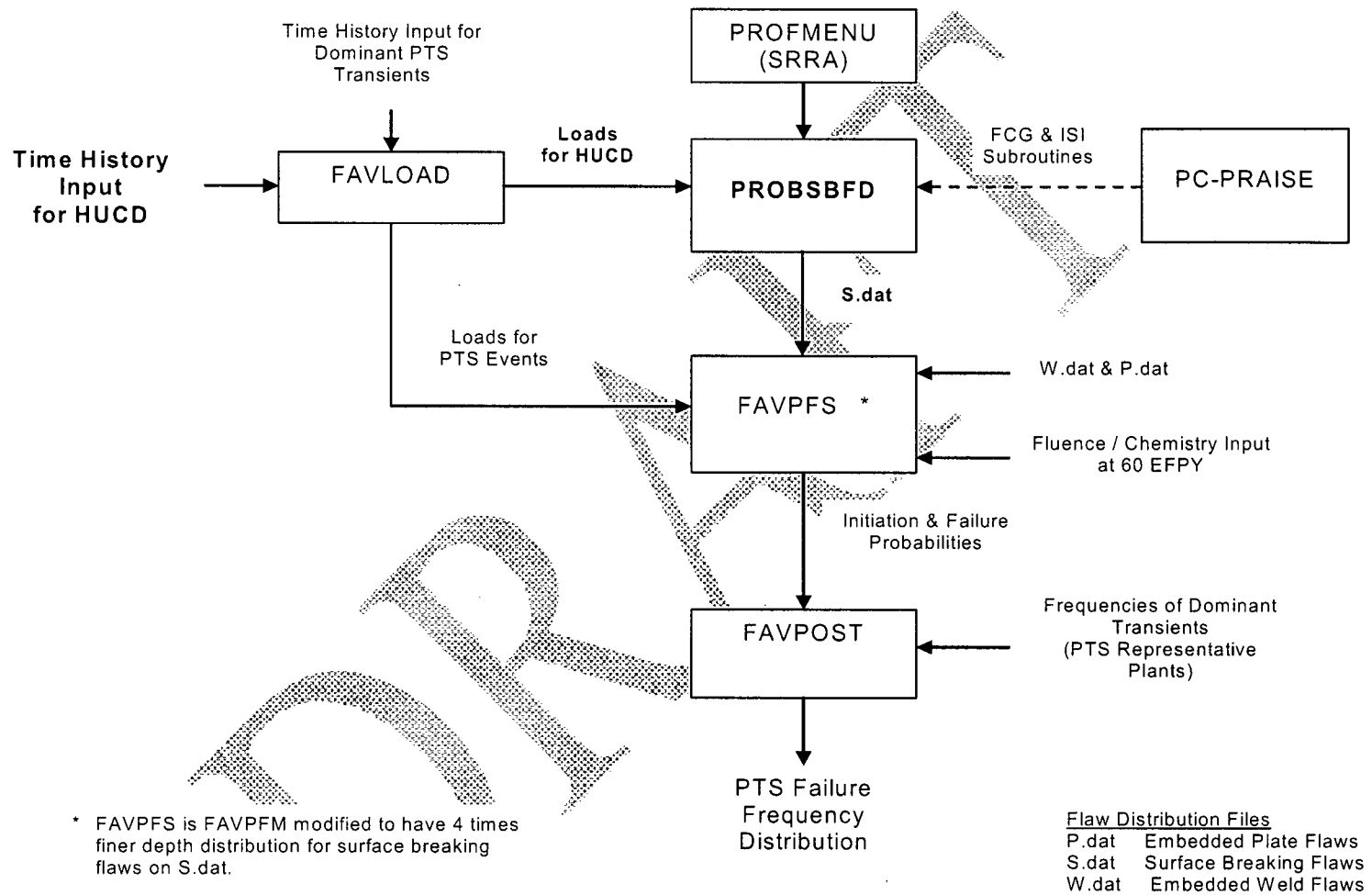


Figure 3-5 Software and Data Flow for Pilot Plant Analyses

The PROBSBFD code was specifically developed for the RV ISI interval extension project and verified in accordance with the Westinghouse Quality Assurance requirements. This program utilizes the Westinghouse Structural Reliability and Risk Assessment (SRRA) library program, which provides standard input and output, including probabilistic analysis capabilities (e.g., random number generation and importance sampling). PROBSBFD was used to develop 1000 random surface breaking flaw distributions that fed into the FAVPFS module via an input file (S.dat is the default name). The loads were determined using the FAVLOAD module, for the input with time histories of temperature, pressure, and heat transfer characteristics for the operational transients (e.g., heat-up and cool-down) that could grow the initial flaws by means of fatigue. The applied stress intensity factor ( $K$ ) at various times and various depths through the reactor vessel wall were taken directly from the FAVLOAD output file and input into PROBSBFD (FAVLOADS.dat for PROBSBFD).

The beneficial effects of ISI were modeled in the same way as in the NRC's probabilistic analysis code pc-PRAISE [2829] and the SRRA Code [3029] used with the WOG/ASME piping risk-informed in-service inspection (RI-ISI) program. Specifically, only the flaws not detected during an ISI exam, at 10 years for example, remained. For example, if the probability of detection for the first inspection was 90 percent, then the flaw density was effectively multiplied by 10 percent for input to the next iteration. The effects of subsequent inspections, where the probability of detection was increased because the flaw was bigger (see Figure 3-4), could be either cumulative or independent.

For each of the 1000 simulations performed by PROBSBFD, the initial flaw depth and density were defined. Four aspect ratios, 2, 6, 10, and infinite, were considered. For each time-step and flaw-aspect ratio, the effects of ISI, the stress intensity factors, and the random crack growth were calculated. After all the time steps were completed, the distribution of flaw densities by depth and aspect ratio were written to a surface-breaking, flaw-distribution input file for FAVPFS, which was in the same format as the default S.dat file (see Figure 3-5).

### 3.3 RESULTS FOR THE WESTINGHOUSE PILOT PLANT: BV1

Reactor vessel failure frequencies were calculated for BV1 for two cases corresponding to the two surface flaw density files discussed in the section on "Initial Flaw Distribution". These cases were referred to as "ISI Every 10 Years" and "10-year ISI Only". As the names imply, the "ISI Every 10 Years" case simulates the current ASME Code required inspections while the "10-year ISI Only" case simulates a discontinuation of inspections after the first 10-year ISI. Statistically, the difference between the mean failure frequencies for the "ISI Every 10 Years" case and the "10-year ISI Only" case is insignificant. This is due to the fact that the difference between the mean values is less than the standard error for each of the cases. However, to calculate a change in risk for comparison to regulatory guidelines, a change in failure frequency was conservatively calculated based on the difference between an "Upper Bound" and a "Lower Bound." The Lower Bound was determined by subtracting 2 times the standard error as reported by FAVPOST from the mean value of the "ISI Every 10 Years" case. The Upper Bound was determined by adding 2 times the standard error as reported by FAVPOST to the mean value of the "10-Year ISI Only" case.

Elimination of ISI after the first 10-year ISI for the BV1 RPV results in a difference in failure (through-wall flaw) frequency of less than  $3.1 \times 10^{-9}$ . A summary table of the results of the evaluation are included in Table 3-2. The results reflect the maximum statistically calculated value for the potential change in risk at a number of reactor vessel simulations at which the Monte Carlo statistical analysis has reached a stable solution. The difference between the Upper Bound and Lower Bound represents the bounding difference between the 10-year inspection interval currently applicable under ASME criteria and elimination of all future inspections following an inspection within the first 10 years of operation.

This change in failure frequency is acceptable per the regulatory guidance discussed in Section 4.1. Transient input was based on design-basis transients and the transients used in the NRC PTS Risk Study [8, 97]. The input data included consideration of postulated life extension to 60 EFY. The FAVPOST outputs for the cases presented in Table 3-2 are presented in Appendix E. As previously mentioned in Section 3.1, BV1 does not have a Category B-J weld to the reactor vessel and the RI-ISI piping program is not impacted by the extended inspection interval.

10-Year ISI Only (Mean Value / Standard Error)	5.04E-09 / 2.54483E-10
Upper Bound Value	5.55604E-09
ISI Every 10 Years (Mean Value / Standard Error)	5.23440E-09 / 3.12289E-10
Lower Bound Value	4.61352E-09
Bounding Difference in Risk	9.4249E-1009

The mean effects of fatigue crack growth and ISI on the surface breaking flaw density for 1000 simulations are shown in Figures 3-6 and 3-7. These figures plot the flaw density as a function of the flaw depth for the cases of one initial 10-year ISI, a 10-year ISI interval, and a 20-year ISI interval. These

plots display the results for the 10-to-1 and infinite aspect ratio sizes. The PROBSBFD outputs used to generate these plots are included in Appendix C. The crack growth and density reduction due to ISI would both be reduced for the flaw length-to-depth aspect ratios of 2-to-1 and 6-to-1 also considered in the pilot plant study.

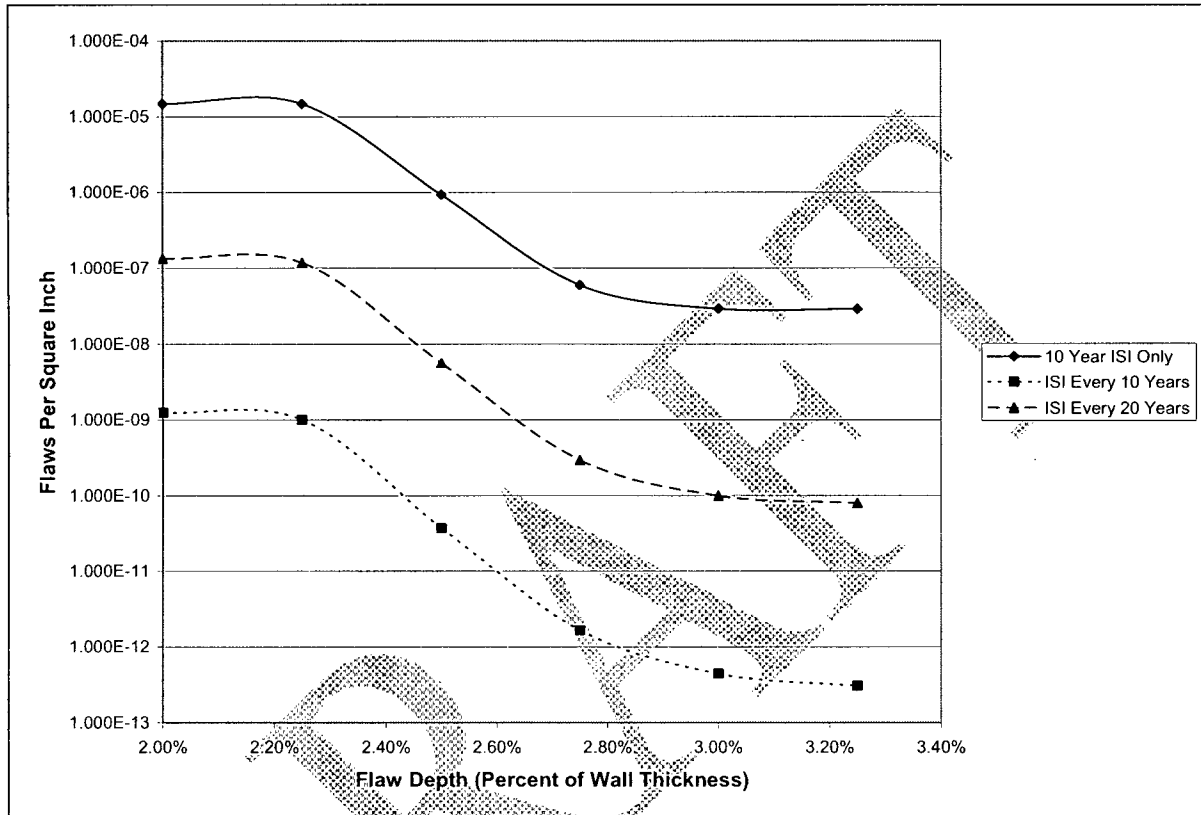


Figure 3-6 Growth of Flaws with an Aspect Ratio of 10 for BV1

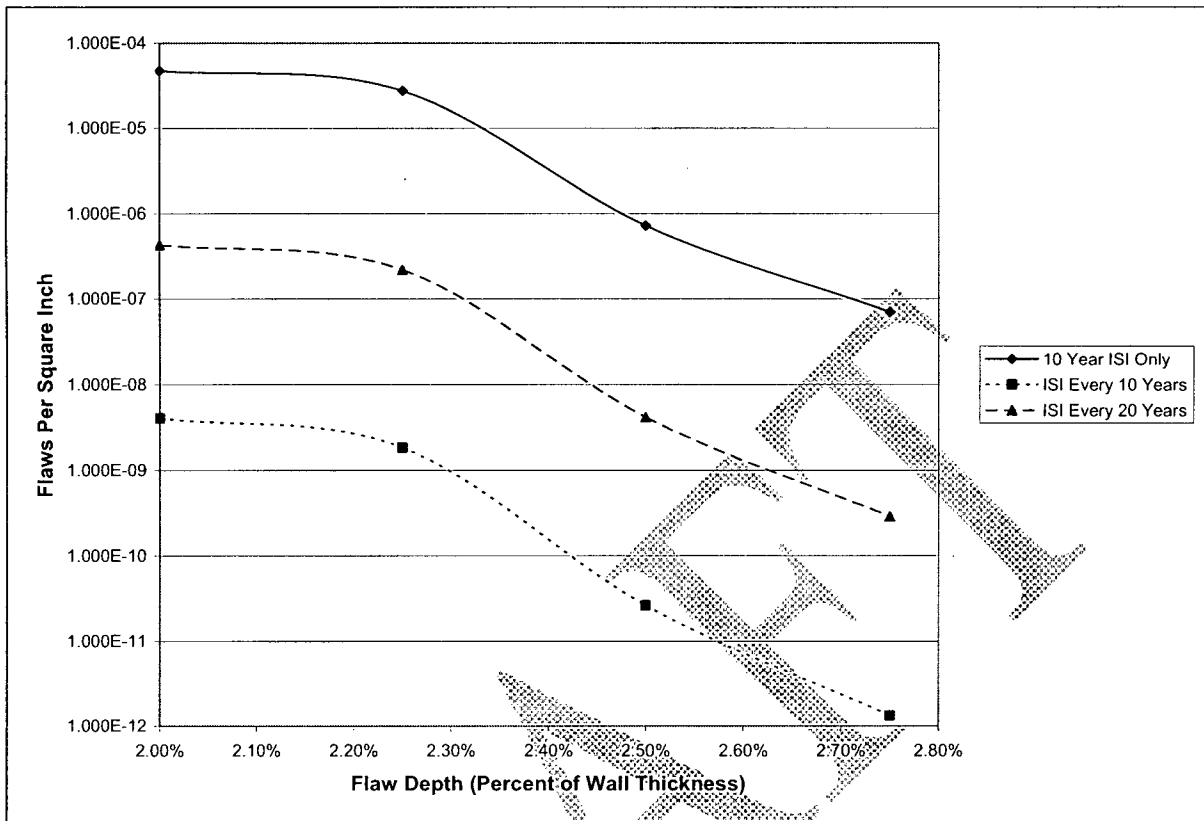


Figure 3-7 Growth of Flaws with an Infinite Aspect Ratio for BV1

### 3.4 RESULTS FOR THE COMBUSTION ENGINEERING PILOT PLANT: PALISADES

Reactor vessel failure frequencies were calculated for Palisades for two cases corresponding to the two surface flaw density files discussed in the section on “Initial Flaw Distribution”. These cases were referred to as “ISI Every 10 Years” and “10-year ISI Only”. As the names imply, the “ISI Every 10 Years” case simulates the current ASME Code required inspections while the “10-year ISI Only” case simulates a discontinuation of inspections after the first 10-year ISI. While the failure frequency for the “ISI Every 10 Years” case is higher than the “10-Year ISI Only” case, statistically, the difference between the mean failure frequencies for the “ISI Every 10 Years” case and the “10-year ISI Only” case is insignificant. This is due to the fact that the difference between the mean values is less than the standard error for each of the cases. However, to calculate a change in risk for comparison to regulatory guidelines, a bounding change in failure frequency was calculated based on the difference between an “Upper Bound” and a “Lower Bound.” The Lower Bound was determined by subtracting 2 times the standard error as reported by FAVPOST from the mean value of the “ISI Every 10 Years” case. The Upper Bound was determined by adding 2 times the standard error as reported by FAVPOST to the mean value of the “10-Year ISI Only” case.

Elimination of ISI after the first 10-year ISI for the Palisades RPV results in a bounding difference in failure (through-wall flow) frequency of less than  $5E-09$  to  $8E-08$ . A summary table of the results of the evaluation are included in Table 3-3. The results reflect the maximum statistically calculated value for the potential change in risk at a number of reactor vessel simulations at which the Monte Carlo statistical analysis has reached a stable solution. The difference between the Upper Bound and Lower Bound represents the bounding difference between the 10-year inspection interval currently applicable under ASME criteria and elimination of all future inspections following an inspection within the first 10 years of operation.

This change in failure frequency is acceptable per the regulatory guidance discussed in Section 4.1. Transient input was based on design basis transients and the transients used in the NRC PTS Risk Study [8, 9]. The input data included consideration of postulated life extension to 60 EFPY. The FAVPOST outputs for the cases presented in Table 3-3 are presented in Appendix I. As previously mentioned in Section 3.1, the Category B-1 welds were included in the Palisades RI ISI piping program, but were selected as defense in depth examinations and not credited in the delta risk evaluation. Therefore, extending the inspection interval for these welds would not impact the RI ISI program.

10-Year ISI Only (Mean Value / Standard Error)	$1.54E-08 / 1.62E-09$ $7.62E-08 / 4.08E-09$
Upper Bound Value	$1.86E-08$ $8.44E-08$
ISI Every 10 Years (Mean Value / Standard Error)	$1.67E-08 / 1.23E-09$ $7.39E-08 / 3.80E-09$
Lower Bound Value	$6.63E-08$ $4.42E-08$

Bounding Difference in Risk	1.81E-084.40E-09
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The mean effects of fatigue crack growth and ISI on the surface breaking flaw density for 1000 simulations are shown in Figures 3-8 and 3-9. These figures plot the flaw density as a function of the flaw depth for the cases of 1 initial 10-year ISI, a 10-year ISI interval, and a 20-year ISI interval. These plots display the results for the of 10-to-1 and infinite aspect ratio sizes. The PROBSBFD outputs used to generate these plots are included in Appendix G. The crack growth and density reduction due to ISI would both be reduced for the flaw length-to-depth aspect ratios of 2-to-1 and 6-to-1 also considered in the pilot plant study.

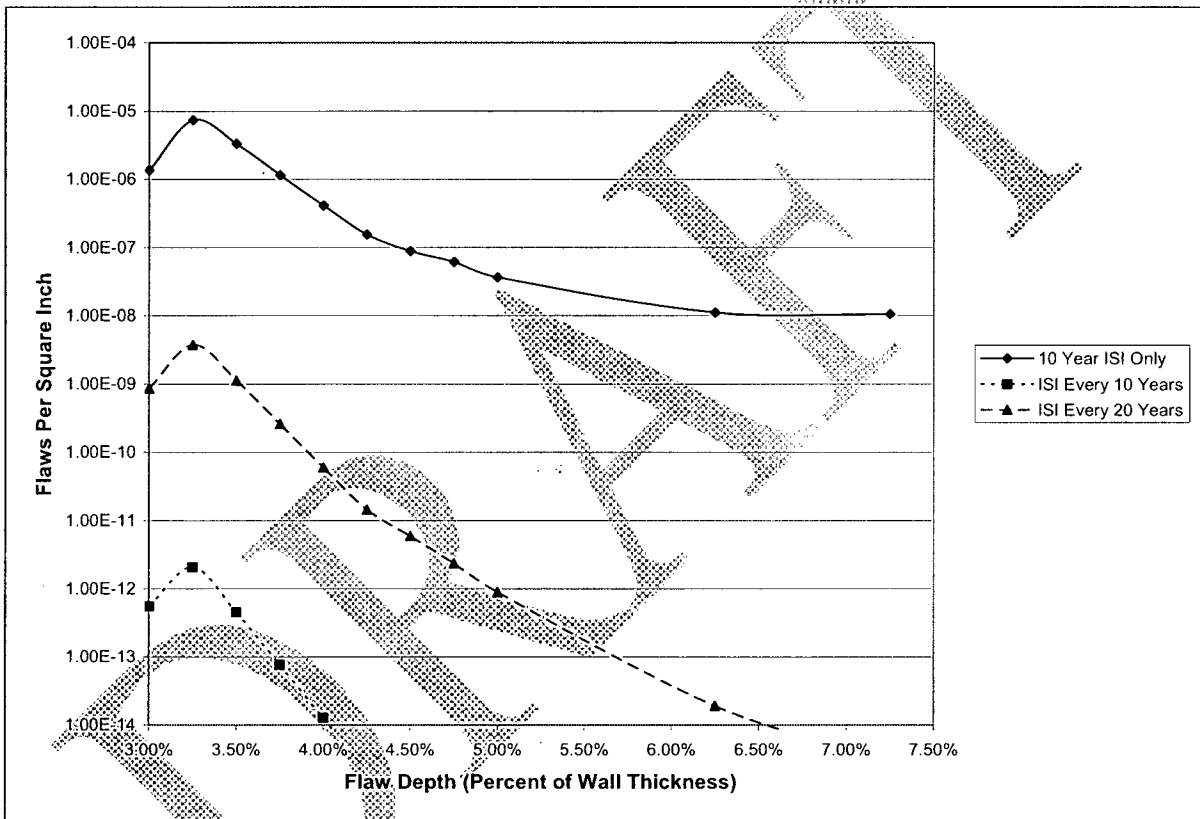


Figure 3-8 Growth of Flaws with an Aspect Ratio of 10 for Palisades

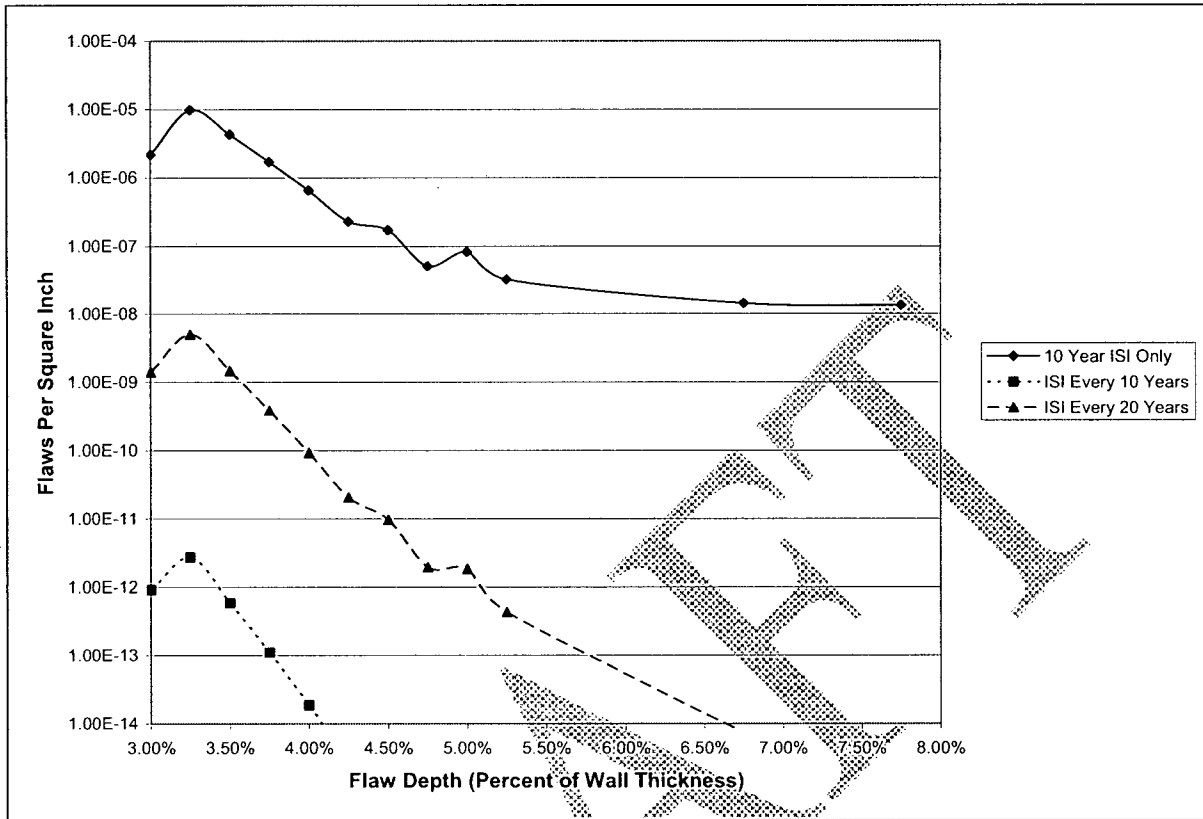


Figure 3-9: Growth of Flaws with an Infinite Aspect Ratio for Palisades

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### 3.5 RESULTS FOR THE BABCOCK AND WILCOX PILOT PLANT: OC1

Reactor vessel failure frequencies were calculated for OC1 for two cases corresponding to the two surface flaw density files discussed in the section on "Initial Flaw Distribution". These cases were referred to as "ISI Every 10 Years" and "10-year ISI Only". As the names imply, the "ISI Every 10 Years" case simulates the current ASME Code required inspections while the "10-year ISI Only" case simulates a discontinuation of inspections after the first 10-year ISI. While the failure frequency for the "ISI Every 10 Years" case is higher than the "10-Year ISI Only" case, statistically, the difference between the mean failure frequencies for the "ISI Every 10 Years" case and the "10-year ISI Only" case is insignificant. This is due to the fact that the difference between the mean values is less than the standard error for each of the cases. However, to calculate a change in risk for comparison to regulatory guidelines, a bounding change in failure frequency was calculated based on the difference between an "Upper Bound" and a "Lower Bound." The Lower Bound was determined by subtracting 2 times the standard error as reported by FAVPOST from the mean value of the "ISI Every 10 Years" case. The Upper Bound was determined by adding 2 times the standard error as reported by FAVPOST to the mean value of the "10-Year ISI Only" case.

Elimination of ISI after the first 10-year ISI for the OC1 RPV results in a difference in failure (through-wall flaw) frequency of  $8E-10$  to  $1.26E-08$ . A summary table of the results of the evaluation are included in Table 3-4. The results reflect the maximum statistically calculated value for the potential change in risk at a number of reactor vessel simulations at which the Monte Carlo statistical analysis has reached a stable solution. The difference between the Upper Bound and Lower Bound represents the bounding difference between the 10-year inspection interval currently applicable under ASME criteria and elimination of all future inspections following an inspection within the first 10 years of operation.

This change in failure frequency is acceptable per the regulatory guidance discussed in Section 4.1. Transient input was based on design basis transients and the transients used in the NRC PTS Risk Study [8, 9]. The input data included consideration of postulated life extension to 60 EFPY. The FAVPOST outputs for the cases presented in Table 3-4 are presented in Appendix M. As previously mentioned in Section 3.1, the Category B-J welds were not inspected as part of OC1's RI-ISI piping program and are therefore not impacted by the extended inspection interval.

10-Year ISI Only (Mean Value / Standard Error)	$2.06E-09 / 2.71E-10$ $3.11E-08 / 2.55E-09$
Upper Bound Value	$2.60E-09$ $3.62E-08$
ISI Every 10 Years (Mean Value / Standard Error)	$2.18E-09 / 1.87E-10$ $2.62E-08 / 1.28E-09$
Lower Bound Value	$1.81E-09$ $2.36E-08$
Bounding Difference in Risk	$1.26E-08$ $7.96E-10$

The mean effects of fatigue crack growth and ISI on the surface breaking flaw density for 1000 simulations are shown in Figures 3-10 and 3-11. These figures plot the flaw density as a function of the flaw depth for the cases of 1 initial 10-year ISI, a 10-year ISI interval, and a 20-year ISI interval. These plots display the results for the 10-to-1 and infinite aspect ratio sizes. The PROBSBFD outputs used to generate these plots are included in Appendix K. The crack growth and density reduction due to ISI would both be reduced for the flaw length-to-depth aspect ratios of 2-to-1 and 6-to-1 also considered in the pilot plant study.

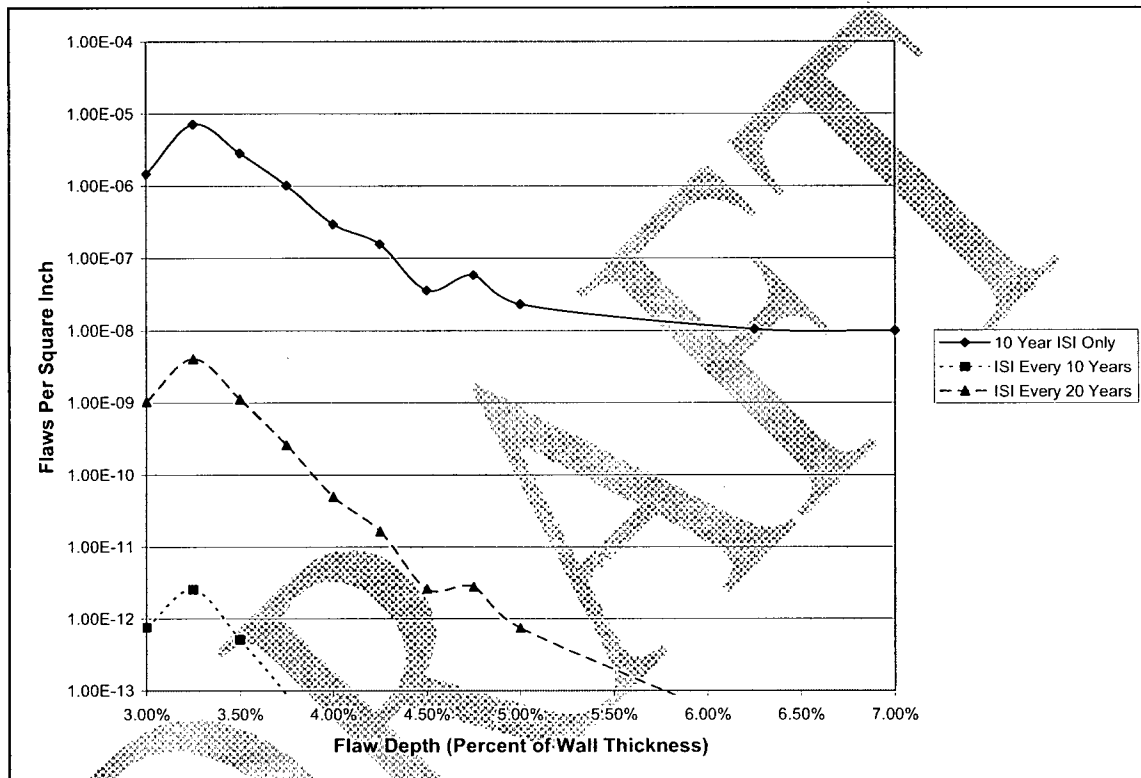


Figure 3-10: Growth of Flaws with an Aspect Ratio of 10 for OC1

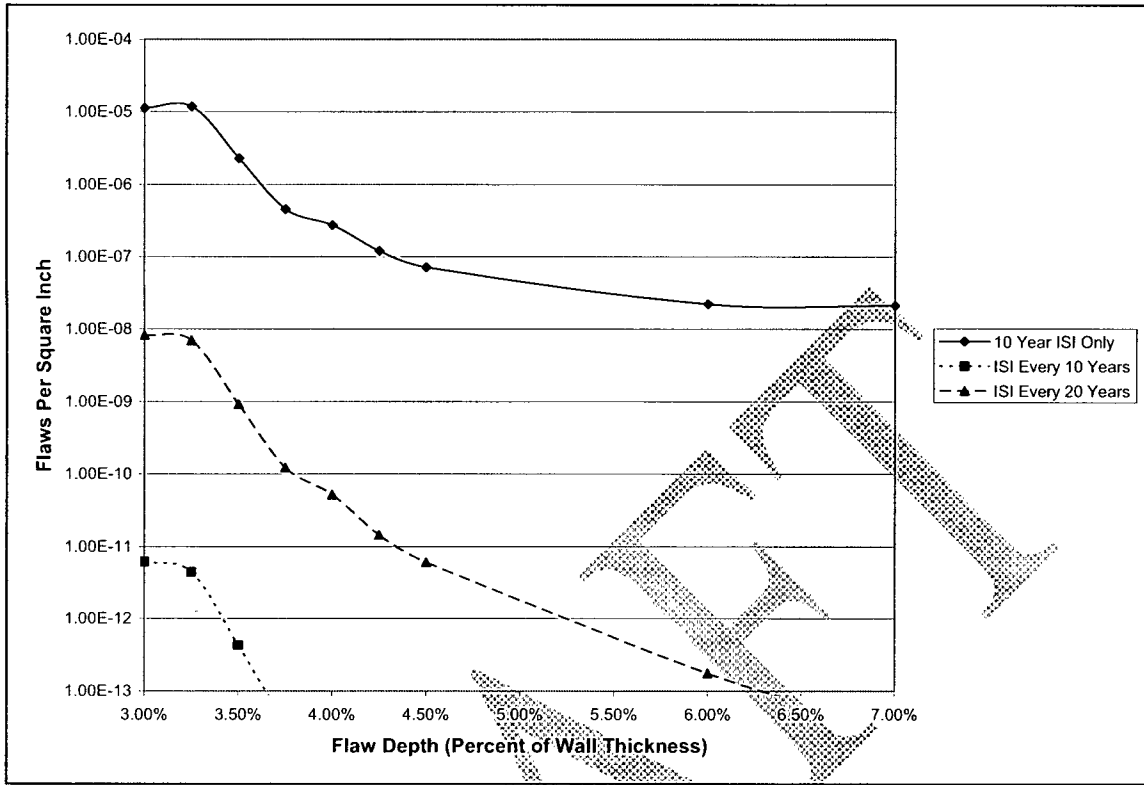


Figure 3-11 Growth of Flaws with an Infinite Aspect Ratio for OC1

## 4 RISK ASSESSMENT

The quantitative risk assessment discussed below shows that extending the inspection interval from 10 to a maximum of 20 years has an acceptably small impact on risk (core damage frequency [CDF] and large early release frequency [LERF]), i.e., that it is within the bounds of RG 1.174 [44]. A discussion on the requirements of RG 1.174 is included.

### 4.1 RISK-INFORMED REGULATORY GUIDE 1.174 METHODOLOGY

The NRC has developed a risk-informed regulatory framework. The NRC definition of risk-informed regulation is: “insights derived from probabilistic risk assessments are used in combination with deterministic system and engineering analysis to focus licensee and regulatory attention on issues commensurate with their importance to safety.”

The NRC issued RG 1.174, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Current Licensing Basis* [44]. In addition, the NRC issued application-specific RGs and Standard Review Plans (SRPs).

- RG-1.175 [3940] and SRP Chapter 3.9.7, related to in-service testing (IST) programs
- RG-1.176 [4140], related to Graded Quality Assurance (GQA) programs
- RG-1.177 [4244] and SRP Chapter 16.1, related to Technical Specifications
- RG-1.178 [4442] and SRP-3.9.8, related to ISI of piping programs

These RG and SRP chapters provide guidance in their respective application-specific subject areas to reactor licensees and the NRC staff regarding the submittal and review of risk-informed proposals that would change the licensing basis for a power reactor facility.

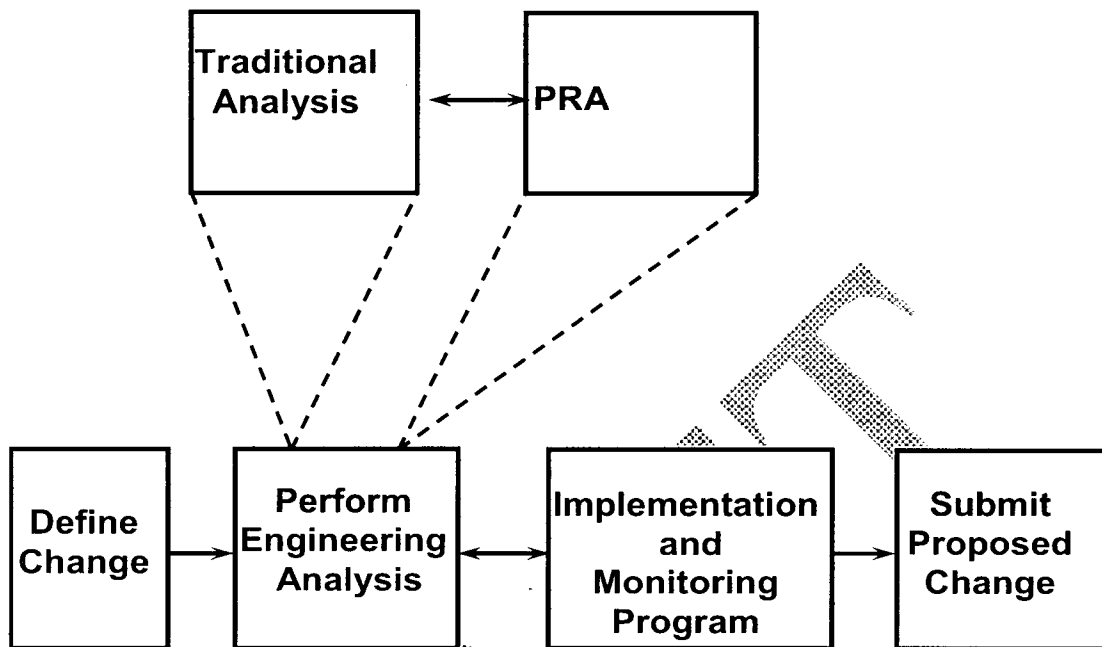
#### Regulatory Guide 1.174 Basic Steps

The approach described in RG 1.174 was used in each of the application-specific RGs/SRPs, and has 4 basic steps as shown in Figure 4-1. The four basic steps are discussed below.

##### Step 1: Define the Proposed Change

This element includes identifying:

1. Those aspects of the plant’s licensing bases that may be affected by the change.
2. All systems, structures, and components (SSCs), procedures, and activities that are covered by the change and consider the original reasons for inclusion of each program requirement.
3. Any engineering studies, methods, codes, applicable plant-specific and industry data and operational experience, PRA findings, and research and analysis results relevant to the proposed change.



**Figure 4-1 Basic Steps in (Principal Elements of) Risk-Informed, Plant-Specific Decision Making (from NRC RG 1.174)**

Step 2: Perform Engineering Analysis

This element includes performing the evaluation to show that the fundamental safety principles on which the plant design was based are not compromised (defense-in-depth attributes are maintained) and that sufficient safety margins are maintained. The engineering analysis includes both traditional deterministic analysis and probabilistic risk assessment (PRA). The evaluation of risk impact should also assess the expected change in CDF and LERF, including a treatment of uncertainties. The results from the traditional analysis and the PRA must be considered in an integrated manner when making a decision.

Step 3: Define Implementation and Monitoring Program

This element's goal is to assess SSC performance under the proposed change by establishing performance monitoring strategies to confirm assumptions and analyses that were conducted to justify the change. This is to ensure that no unexpected adverse safety degradation occurs because of the changes. Decisions concerning implementation of changes should be made in light of the uncertainty associated with the results of the evaluation. A monitoring program should have measurable parameters, objective criteria, and parameters that provide an early indication of problems before becoming a safety concern. In addition, the monitoring program should include a cause determination and corrective action plan.

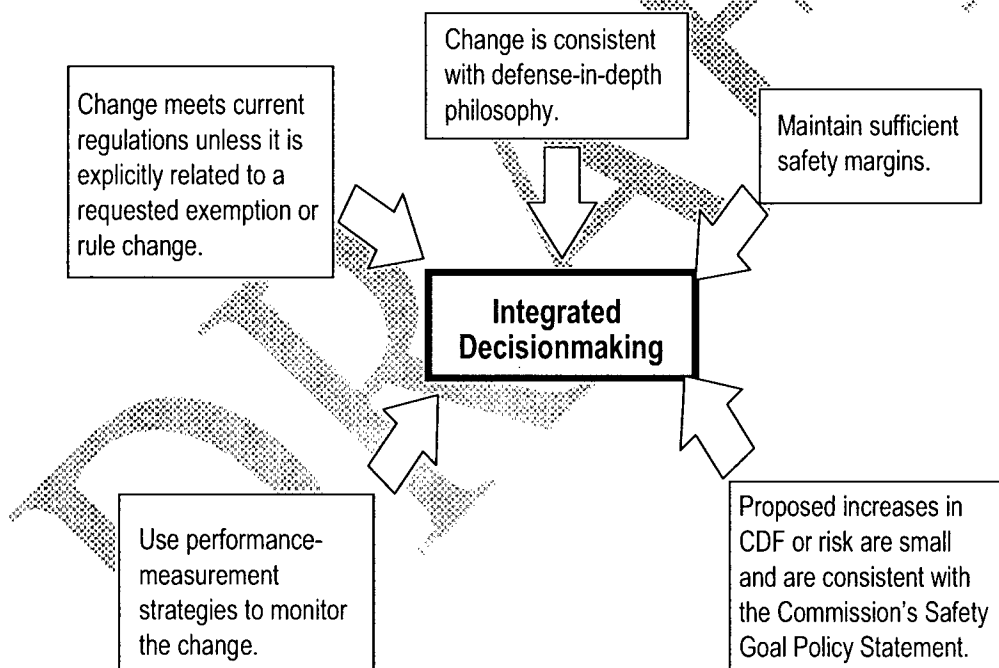
#### Step 4: Submit Proposed Change

This element includes:

1. Carefully reviewing the proposed change in order to determine the appropriate form of the change request.
2. Assuring that information required by the relevant regulation(s) in support of the request is developed.
3. Preparing and submitting the request in accordance with relevant procedural requirements.

#### Regulatory Guide 1.174 Fundamental Safety Principles

Five fundamental safety principles are described that each application for a change must meet. These are shown in Figure 4-2, and are discussed below.



**Figure 4-2 Principles of Risk-Informed Regulation (from NRC RG 1.174)**

*Principle 1: Change meets current regulations unless it is explicitly related to a requested exemption or rule change.*

The proposed change is evaluated against the current regulations (including the general design criteria) to either identify where changes are proposed to the current regulations (e.g., Technical Specification, license conditions, and FSAR), or where additional information may be required to meet the current regulations.

*Principle 2: Change is consistent with defense-in-depth philosophy.*

Defense-in-depth has traditionally been applied in reactor design and operation to provide a multiple means to accomplish safety functions and prevent the release of radioactive material. As defined in RG 1.174 [44], defense-in-depth is maintained by assuring that:

- A reasonable balance among prevention of core damage, prevention of containment failure, and consequence mitigation is preserved.
- Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided.
- System redundancy, independence, and diversity are preserved commensurate with the expected frequency and consequences to the system (e.g., no risk outliers).
- Defenses against potential common cause failures are preserved and the potential for introduction of new common cause failure mechanisms is assessed.
- Independence of barriers is not degraded (the barriers are identified as the fuel cladding, reactor coolant pressure boundary, and containment structure).
- Defenses against human errors are preserved.

Defense-in-depth philosophy is not expected to change unless:

- A significant increase in the existing challenges to the integrity of the barriers occurs.
- The probability of failure of each barrier changes significantly.
- New or additional failure dependencies are introduced that increase the likelihood of failure compared to the existing conditions.
- The overall redundancy and diversity in the barriers changes.

*Principle 3: Maintain sufficient safety margins.*

Safety margins must also be maintained. As described in RG 1.174, sufficient safety margins are maintained by assuring that:

- Codes and standards, or alternatives proposed for use by the NRC, are met.
- Safety analysis acceptance criteria in the licensing basis (e.g., FSARs, supporting analyses) are met, or proposed revisions provide sufficient margin to account for analysis and data uncertainty.

*Principle 4: Proposed increases in CDF or risk are small and are consistent with the Commission's Safety Goal Policy Statement.*

To evaluate the proposed change with regard to a possible increase in risk, the risk assessment should be of sufficient quality to evaluate the change. The expected change in CDF and LERF are evaluated to address this principle. An assessment of the uncertainties associated with the evaluation is conducted. Additional qualitative assessments are also performed.

There are two acceptance guidelines, one for CDF and one for LERF, both of which should be used.

The guidelines for CDF are:

- If the application can be clearly shown to result in a decrease in CDF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to CDF.
- When the calculated increase in CDF is very small, which is taken as being less than  $10^{-6}$  per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF.
- When the calculated increase in CDF is in the range of  $10^{-6}$  per reactor year to  $10^{-5}$  per reactor year, applications will be considered only if it can be reasonably shown that the total CDF is less than  $10^{-4}$  per reactor year.
- Applications that result in increases to CDF above  $10^{-5}$  per reactor year would not normally be considered.

The guidelines for LERF are:

- If the application can be clearly shown to result in a decrease in LERF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to LERF.
- When the calculated increase in LERF is very small, which is taken as being less than  $10^{-7}$  per reactor year, the change will be considered regardless of whether there is a calculation of the total LERF.
- When the calculated increase in LERF is in the range of  $10^{-7}$  per reactor year to  $10^{-6}$  per reactor year, applications will be considered only if it can be reasonably shown that the total LERF is less than  $10^{-5}$  per reactor year.
- Applications that result in increases to LERF above  $10^{-6}$  per reactor year would not normally be considered.

These guidelines are intended to provide assurance that proposed increases in CDF and LERF are small and are consistent with the intent of the Commission's Safety Goal Policy Statement.



*Principle 5: Use performance-measurement strategies to monitor the change.*

Performance-based implementation and monitoring strategies are also addressed as part of the key elements of the evaluation as described previously.

### **Risk-Acceptance Criteria for Analysis**

For the purposes of this bounding analysis of the risk impact of the proposed change in RV inspection frequency, the following criteria are applied with respect to Principle 4 (small change in risk):

- Change in CDF  $< 1 \times 10^{-6}$  per reactor year
- Change in LERF  $< 1 \times 10^{-7}$  per reactor year

These values are selected so that the proposed change may be later considered on a plant-specific basis regardless of the plant's baseline CDF and LERF.

To conservatively simplify these acceptance criteria, it will be assumed that through-wall crack growth is equivalent to reactor vessel failure, and that reactor vessel failure results in both core damage and a large early release. It is also conservatively assumed that the conditional probability of a large early release given core damage is 1.0 (See Section 4.3).

Therefore, the simplified conservative/bounding acceptance criterion becomes:

$$\text{Change in CDF} = \text{Change in LERF} = \text{Increase in frequency of through-wall crack growth due to increase in inspection interval} < 1 \times 10^{-7} \text{ per reactor year}$$

## **4.2 FAILURE MODES AND EFFECTS**

### **Failure Modes**

The failure mode of concern was thermal fatigue crack growth due typical plant operation. The growth of an existing undetected fabrication flaw in the RV base metal, cladding, or weld metal was assumed to reach a critical size that would lead to reactor vessel through-wall fracture if a PTS-type transient would occur.

### **Failure Effects**

A through-wall flaw failure of the RV was assumed to result in core damage and a large early release.

### 4.3 CORE DAMAGE RISK EVALUATION

The objective of the risk assessment was to evaluate the core damage risk from the extension of the examination of the RV relative to other plant risk contributors through a qualitative and quantitative evaluation.

NRC RG 1.174 [44] provided the basis for this evaluation as well as the acceptance guidelines to make a change to the current licensing basis.

Risk was defined as the combination of likelihood of an event and severity of consequences of an event. Therefore, the following two questions were addressed:

- What was the likelihood of the event?
- What would the consequences be?

The following sections describe the likelihood and postulated consequences. The likelihood and consequences were then combined in the risk calculation and the results of the evaluation are presented in this report.

#### **What is the Likelihood of the Event?**

The likelihood of the event was addressed by identifying the plant transients or operational events that might lead to failure of the RV, and estimating the frequency of these events.

#### **What are the Consequences?**

The consequences were defined in terms of the CDF and LERF risk metrics.

For this evaluation, the conditional core damage probability given the failure of the RV was assumed to be 1.0 (no credit for safety system actuation to mitigate the consequences of the failure). Since this was intended as a bounding assessment, it was also conservatively assumed that the conditional probability of a large early release given core damage for this scenario is 1.0 (i.e., no credit for consequence mitigation via the containment and related systems). Note that this was a simplifying assumption, and a specific mechanism for LERF was not implied or defined here.

## Risk Calculation

For this evaluation, the CDF and LERF were calculated by:

$$TWCF = LERF = CDF = \sum_{i=1}^N IE_i * CPF_i$$

$$CDF = LERF = IE * CPF$$

where:

- TWCF = Through wall cracking frequency  
 CDF = Core damage frequency from all vessel failures due to PTS events (events per year)  
 LERF = Large early release frequency from all vessel failures due to PTS events (events per year)  
 IE<sub>i</sub> = Initiating event frequency (events per year) for a given PTS transient, i  
 CPF<sub>i</sub> = Conditional probability of reactor vessel failure for a given PTS transient i, and  
 N = The total number of postulated PTS transients for a given plant.  
 CDF = Core damage frequency from a failure (events per year)  
 LERF = Large early release frequency from a failure (events per year)  
 IE = Initiating event frequency (in events per year)  
 CPF = Conditional probability of reactor vessel failure

The transient initiating frequency distributions were identified in the NRC PTS Risk Study [78, 9] and are included in Appendices D, H, and L for the pilot plants. The probability of failure was calculated by the FAVPFS module of FAVOR. The FAVPOST module of FAVOR combined the transient initiating frequency distribution with the reactor vessel conditional failure probability distribution to determine a reactor vessel failure frequency distribution for each transient. From these failure frequency distributions, FAVPOST determined a mean reactor vessel failure frequency. In addition to this mean failure frequency a standard error was reported. To account for uncertainties, Upper and Lower Bounds are determined. The Upper Bound was determined by adding 2 times the standard error from the "10-Year ISI-Only" case. The Lower Bound was determined by subtracting 2 times the standard error from the "ISI Every 10 Years" case. The change in reactor vessel failure frequency was determined by subtracting the Lower Bound from the Upper Bound. The mean reactor vessel failure frequencies, Upper and Lower Bounds, and change in failure frequency are given in Sections 3.2 and 3.3. As previously stated, reactor vessel failure results in core damage which results in large early release. Therefore, the large early release frequencies were equal to the reactor vessel failure frequencies. The large early release frequencies, Upper and Lower Bounds, and change in large early release frequency are summarized in Table 4-1, based on FAVOR 0506.1 evaluations.

<b>Table 4-1 Large Early Release Frequencies</b>			
	<b>BV1 (per year)</b>	<b>Palisades (per year)</b>	<b>OC1 (per year)</b>

10-Year ISI Only	5.04E-09	7.62E-08+54E-08	3.11E-08+2.06E-09
Upper Bound	6.015.55E-09	8.44E-08+86E-08	2.60E-09+3.62E-08
ISI Every 10 Years	5.234.10E-09	1.67E-08+7.39E-08	2.18E-09+2.62E-08
Lower Bound	4.613.52E-09	6.63E-08+423E-09	1.81E-09+2.36E-08
Bounding Change in Large Early Release Frequency	9.4372.49E-09+10	4.40E-09+1.81E-08	1.26E-08+7.96E-10

### Risk Results and Conclusions

The analysis described above demonstrates that changes in CDF and LERF do not exceed the NRC's RG-1.174 [44] acceptance guidelines for a small change in CDF and LERF ( $<10^{-6}$  per year for CDF,  $<10^{-7}$  per year for LERF).

As part of this evaluation, the key principles identified in RG-1.174 were reviewed and the responses based on the evaluation are provided in Table 4-2.

This evaluation concluded that extension of the RV in-service examination from 10 to 20 years would not be expected to result in an unacceptable increase in risk. Given this outcome, and the fact that other key principles listed in RG-1.174 continue to be met, the proposed change in inspection interval from 10 to 20 years is acceptable.

<b>Table 4-2 Evaluation with Respect to Regulatory Guide 1.174 [44] Key Principles</b>	
<b>Key Principles</b>	<b>Evaluation Response</b>
Change meets current regulations unless it is explicitly related to a requested exemption or rule change.	Change to current RG 1.150 [22] requirements is proposed.
Change is consistent with defense-in-depth philosophy.	Potential for failure of the RV is acceptably small during normal or accident conditions, and does not threaten plant barriers. See the discussion below for additional information on defense in depth.
Maintain sufficient safety margins.	No safety analysis margins are changed.
Proposed increases in CDF or risk are small and are consistent with the Commission's Safety Goal Policy Statement.	Proposed increase in risk is estimated to be acceptably small.
Use performance-measurement strategies to monitor the change.	NDE examinations still conducted, but on less frequent basis not to exceed 20 years.  Other indications of potential degradation of RV are available (e.g., foreign experience and periodic testing with visual examinations)

## Defense-in-Depth

While the results presented in this report demonstrate that the contribution of eliminating future inspections after the initial 10 year ISI meets prescribed regulatory criteria for assessing risk, the proposed course of action is to extend the inspection interval requirements from 10 to 20 years while not eliminating any portion of the current inspection requirements. This provides additional margin for defense-in-depth and contributes directly toward maintaining plant safety.

Extending the RV ISI interval does not imply that generic degradation mechanisms will be ignored for 20 years. (With the number of PWR nuclear power plants in operation in the U.S. and globally, a sampling of plants inevitably undergo examinations in a given year.) This provides for early detection of any potential emerging generic degradation mechanisms, and would permit the industry to react with more frequent examinations if needed.

In addition, it must be recognized that all reactor coolant pressure boundary failures occurring to date have been identified as a result of leakage, and were discovered by visual examination. The proposed RV ISI interval extension does not alter the visual examination interval. The reactor vessel would undergo, as a minimum, the Section XI Examination Category B-P pressure tests and visual examinations conducted at the end of each refueling before plant start-up, as well as leak tests with visual examinations that precede each start-up following maintenance or repair activities.

Page 4-4 identifies from Regulatory Guide 1.174 that:

“Defense-in-depth philosophy is not expected to change unless:

- A significant increase in the existing challenges to the integrity of the barriers occurs.
- The probability of failure of each barrier changes significantly.
- New or additional failure dependencies are introduced that increase the likelihood of failure compared to the existing conditions.
- The overall redundancy and diversity in the barriers changes.”

The extension in inspection interval will not result in any of the changes identified above. Also identified on page 4-4 are six elements for maintaining defense in depth. Due to the fact that the interval extension will not result in any of the changes identified above, it is expected that the defense in depth elements listed on page 4-4 will not be impacted. Additional assessment of the impact on each of the defense-in-depth elements from page 4-4 is provided below:

- A reasonable balance among prevention of core damage, prevention of containment failure, and consequence mitigation is preserved:

The proposed increase in inspection would not cause an increased reliance on any of the identified elements. Therefore, the interval increase would not change the existing balance among prevention of core damage, prevention of containment failure, and consequence mitigation.

- Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided:

The change in inspection interval does not change the robustness of the vessel design in any way. It is because of this robustness that the inspection interval can be doubled with no significant change in failure frequency.

- System redundancy, independence, and diversity are preserved commensurate with the expected frequency and consequences to the system (e.g., no risk outliers):

The proposed increase in inspection interval does not impact system redundancy, independence, or diversity in any way since it is not changing the plant design or how it is operated.

- Defenses against potential common cause failures are preserved and the potential for introduction of new common cause failure mechanisms is assessed:

The proposed increase in inspection interval does not impact any defenses against any common cause failures and there is no reason to expect the introduction of any new common cause failure mechanisms. This requirement applies to multiple active components. There is only one reactor vessel per plant and it is a passive component.

- Independence of barriers is not degraded (the barriers are identified as the fuel cladding, reactor coolant pressure boundary, and containment structure):

The increase in inspection interval does not change the relationship between the barriers in anyway and therefore does not degrade the independence of the barriers. The change in inspection interval does not change the robustness of the vessel design in any way. It is because of this robustness that the inspection interval can be doubled with no significant change in failure frequency.

- Defenses against human errors are preserved:

The increase in the RV inspection interval does not impact any defenses against human errors in any way. The increase in the inspection interval reduces the frequency for which the lower internals need to be removed. Reducing this frequency reduces the possibility for human error and damaging the core. (Add changes from responses here)

## 5 CONCLUSIONS

Based on the results of this analysis, it is concluded that:

1. The beltline is the most limiting region for the evaluation of risk.
2. RV inspections performed to date have not detected any significant flaws.
3. Crack extension due to fatigue crack growth during service is small.
4. The man-rem exposure can be reduced by extending the inspection interval.
5. The failure frequencies for PWR RVs due to the dominant PTS transients are well below  $10^{-7}$  per year.
6. The change in risk meets the RG 1.174 [44] acceptance guidelines for a small change in LERF.
7. The increase in the RV ISI interval from 10 to 20 years satisfies all the RG 1.174 criteria, including other considerations, such as defense-in-depth.

Based on the above conclusions, the ASME Section XI [11] 10-year inspection interval for examination categories B-A and B-D welds in PWR RVs and category B-1 welds to RV nozzles, can be extended to 20 years. In-service inspection intervals of 20 years for FENOC's Beaver Valley Unit 1, NMC's Palisades, and Duke Energy's Oconee Unit 1 are acceptable for implementation. The methodology in WCAP-16168-NP Revision 1 is applicable to plants other than the pilot plants by confirming the applicability of the parameters in Appendix A on a plant-specific basis. Since the 10 year inspection interval is required by Section XI, IWB-2412, as codified in 10 CFR 50.55a, an exemption request must be submitted and approved by the NRC to extend the inspection interval to 20 years, unless 10 CFR 50.55a is amended to incorporate ASME Code Case N-691.

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- 34-35. *ASME Boiler and Pressure Vessel Code*, Code Case N-624, "Successive Inspections," Section XI, Division 1, 1998.
- 35-36. *ASME Boiler and Pressure Vessel Code*, Code Case N-623, "Deferral of Inspections of Shell-to-Flange and Head-to-Flange Welds of a Reactor Vessel," Section XI, Division 1, 1998.
- 36-37. *ASME Boiler and Pressure Vessel Code*, Code Case N-615, "Ultrasonic Examination as a Surface Examination Method for Category B-F and B-J Piping Welds," 2001.
- 37-38. *ASME Boiler and Pressure Vessel Code*, Code Case N-613, "Ultrasonic Examination of Full Penetration Nozzles, Examination Category B-D, Item Nos. B3.10 and B3.90, Reactor Vessel-to-Nozzle Welds," 2002.

- 38.39. *ASME Boiler and Pressure Vessel Code*, Code Case N-598, "Alternative Requirements to Required Percentages of Examinations," Section XI, Division 1, 1995.
- 39.40. NRC Regulatory Guide 1.175, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Inservice Testing*, August 1998 (ADAMS Accession #ML003740149).
- 40.41. NRC Regulatory Guide 1.176, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Graded Quality Assurance*, August 1998 (ADAMS Accession #ML003740172).
- 41.42. NRC Regulatory Guide 1.177, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Technical Specifications*, August 1998 (ADAMS Accession #ML003740176).
42. NRC Regulatory Guide 1.178, *An Approach for Plant-Specific, Risk-Informed Decisionmaking Inservice Inspection of Piping*, August 1998 (ADAMS Accession #ML032510128).
- 43.
44. NRC Memorandum. Thadani to Collins, Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Criteria in the PTS Rule (10CFR50.61), December 31, 2002 (ADAMS Accession #ML030090626). ~~(PTS)~~ (ADAMS Accession #ML070860156)

## APPENDIX A

### BOUNDING PARAMETER CHECKLIST PLANT SPECIFIC APPLICATION

WCAP-16168-NP Revision +2 describes the methodology used to demonstrate the feasibility of extending the reactor vessel inspection interval required by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section XI, as supplemented by Nuclear Regulatory Commission (NRC) Regulatory Guide 1.150. This methodology was used to perform risk analysis for pilot plants representing the Westinghouse and Combustion Engineering designs. It is an extension of work done as part of the NRC PTS Risk Study. Table A-1 identifies critical parameters to be used to determine if the pilot plant evaluations documented in this report bound a plant specific application. If the plant-specific parameter is not bounded by the pilot plant analysis, additional evaluations or sensitivity studies may be required to support the use of the pilot plant risk studies. Additional information relative to plant specific reactor vessel inspection is to be provided in Table A-2. Information required to calculate the plant specific through wall cracking frequency is to be provided in Table A-3. Additional information and requirements are provided following each table. Examples of plant specific use of these tables for Wolf Creek and Waterford 3 are contained in Appendices A-1 and A-2 respectively.

<b>Table A-1 Critical Parameters for the Application of the Bounding Analysis</b>			
<b>Parameter</b>	<b>Pilot Plant Basis</b>	<b>Plant Specific Basis</b>	<b>Additional Evaluation Required? (Y/N)</b>
Dominant PTS Transients in the NRC PTS Risk Study are applicable			
Through Wall Cracking Frequency (TWCF)			
Frequency and Severity of Design Basis Transients			
Cladding Layers (Single/Multiple)			

For each of the four parameters in Table A-1, the licensee must identify the pilot plant basis and the plant specific basis. If the plant specific basis is not bounded by the pilot plant basis, additional evaluation is required.

#### Dominant PTS Transients in the NRC PTS Risk Study are applicable

The transients evaluated in the WCAP pilot plant analyses were the PTS transients from the NRC PTS Risk Re-evaluation (NUREG-1806 or NUREG-1874). For this parameter, it is necessary to demonstrate that the PTS transients used in the pilot plant analyses are applicable for a specific plant. As stated in the last paragraph in Section 3.2.1 of NUREG-1874, the "PTS Generalization Study demonstrates that risk-significant PTS transients do not have any appreciable plant-specific differences within the population of PWRs currently operating in the United States." Based on this statement, plant specific analyses are not needed for this criterion. A licensee may enter the "PTS Generalization Study" in Table A-1 as the basis for the applicability of the pilot plant PTS transients to their specific plant.

### Through Wall Cracking Frequency (TWCF)

Each licensee shall calculate their plant specific  $TWCF_{95-TOTAL}$  value using the correlations in NUREG-1874. The calculated plant specific  $TWCF_{95-TOTAL}$  value must be lower than the applicable pilot plant  $TWCF_{95-TOTAL}$  value calculated using the correlations in NUREG-1874. The TWCF is essentially a measure of the embrittlement of the reactor vessel components weighted by their contribution to PTS failure. By demonstrating that the pilot plant has a higher  $TWCF_{95-TOTAL}$  value it follows that the pilot plant change in risk calculation is bounding of that for the specific plant.

The pilot plant  $TWCF_{95-TOTAL}$  values calculated using the NUREG-1874 correlations depend upon the applicable pilot plant design:

Westinghouse:	Beaver Valley Unit 1:	1.76E-08 Events per year
CE:	Palisades:	3.16E-07 Events per year
B&W:	Oconee Unit 1:	4.42E-07 Events per year

The applicable correlations from NUREG-1874 are as follows:

$$TWCF_{95-TOTAL} = \alpha_{AW}TWCF_{95-AW} + \alpha_{PL}TWCF_{95-PL} + \alpha_{CW}TWCF_{95-CW} + \alpha_{FO}TWCF_{95-FO}$$

Where,  $\alpha$  is determined as follows:

$$\text{If } RT_{MAX-XV} \leq 625^{\circ}R, \text{ then } \alpha = 2.5$$

$$\text{If } 625R < RT_{MAX-XV} < 875^{\circ}R \text{ then } \alpha = 2.5 - (1.5/250)(RT_{MAX-XV} - 625)$$

$$\text{If } RT_{MAX-XV} \geq 875^{\circ}R, \text{ then } \alpha = 1$$

and  $TWCF_{95-XV}$  values are calculated as follows:

$$TWCF_{95-AW} = \exp\{5.5198 \cdot \ln(RT_{MAX-AW} - 616) - 40.542\} \cdot \beta$$

$$TWCF_{95-PL} = \exp\{23.737 \cdot \ln(RT_{MAX-PL} - 300) - 162.38\} \cdot \beta$$

$$TWCF_{95-CW} = \exp\{9.1363 \cdot \ln(RT_{MAX-CW} - 616) - 65.066\} \cdot \beta$$

$$TWCF_{95-FO} = \exp\{23.737 \cdot \ln(RT_{MAX-FO} - 300) - 162.38\} \cdot \beta + \dots$$

$$+ \eta \cdot \{1.3 \times 10^{-137} \cdot 10^{0.185 \cdot RT_{MAX-FO}}\} \cdot \beta$$

$\eta$  is equal to "0" for ring forged vessels fabricated compliant with Regulatory Guide 1.43 and equal to "1" for ring forged vessels not fabricated compliant with Regulatory Guide 1.43.

$\beta$  is determined as follows irrespective of the set of TWCF formulas used.

$$\text{If } T_{WALL} \leq 9\frac{1}{2} \text{ -in, then } \beta = 1$$

$$\text{If } 9\frac{1}{2} < T_{WALL} < 11\frac{1}{2} \text{ -in, then } \beta = 1 + 8(T_{WALL} - 9\frac{1}{2})$$

$$\text{If } T_{WALL} \geq 11\frac{1}{2} \text{ -in, then } \beta = 17$$

Where  $T_{WALL}$  is the thickness of the RPV wall (inches), including the cladding.

$RT_{MAX-XX}$  values are calculated in degrees Rankin ( $^{\circ}R$ ) as follows:

$$RT_{MAX-AW} \equiv \text{MAX}_{i=1}^{n_{AWFL}} \left[ \text{MAX}_{AWFL(i)} \left\{ \begin{array}{l} \left( RT_{NDT(u)}^{adj-aw(i)} + \Delta T_{30}^{adj-aw(i)}(\phi_{FL}) \right)_b \\ \left( RT_{NDT(u)}^{adj-pl(i)} + \Delta T_{30}^{adj-pl(i)}(\phi_{FL}) \right)_b \end{array} \right\} \right]$$

Where:

$n_{AWFL}$  is the number of axial weld fusion lines in the beltline region of the vessel,

$i$  is a counter that ranges from 1 to  $n_{AWFL}$ ,

$\phi_{FL}$  is the maximum fluence occurring on the vessel ID along a particular axial weld fusion line,

$RT_{NDT(u)}^{adj-aw(i)}$  is the unirradiated  $RT_{NDT}$  of the weld adjacent to the  $i^{\text{th}}$  axial weld fusion line,

$RT_{NDT(u)}^{adj-pl(i)}$  is the unirradiated  $RT_{NDT}$  of the plate adjacent to the  $i^{\text{th}}$  axial weld fusion line

$\Delta T_{30}^{adj-aw(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation to  $\phi_{FL}$  of the weld adjacent to the  $i^{\text{th}}$  axial weld fusion line, and

$\Delta T_{30}^{adj-pl(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation due to  $\phi_{FL}$  of the plate adjacent to the  $i^{\text{th}}$  axial weld fusion line.

$$RT_{MAX-PL} \equiv \text{MAX}_{i=1}^{n_{PL}} \left[ RT_{NDT(u)}^{PL(i)} + \Delta T_{30}^{PL(i)}(\phi_{MAX}^{PL(i)}) \right]$$

Where:

$n_{PL}$  is the number of plates in the beltline region of the vessel,

$i$  is a counter that ranges from 1 to  $n_{PL}$ ,

$\phi_{MAX}^{PL(i)}$  is the maximum fluence occurring over the vessel ID occupied by a particular plate,

$RT_{NDT(u)}^{PL(i)}$  is the unirradiated  $RT_{NDT}$  of a particular plate, and

$\Delta T_{30}^{PL(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation to  $\phi_{MAX}^{PL(i)}$  of a particular plate.

$$RT_{MAX-FO} \equiv \text{MAX}_{i=1}^{n_{FO}} \left[ RT_{NDT(u)}^{FO(i)} + \Delta T_{30}^{FO(i)}(\phi_{MAX}^{FO(i)}) \right]$$

Where:

$n_{FO}$  is the number of forgings in the beltline region of the vessel,

$i$  is a counter that ranges from 1 to  $n_{FO}$

$\phi_{MAX}^{FO(i)}$  is the maximum fluence occurring over the vessel ID occupied by a particular forging,

$RT_{NDT(u)}^{FO(i)}$  is the unirradiated  $RT_{NDT}$  of a particular forging, and

$\Delta T_{30}^{FO(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation to  $\phi_{MAX}^{FO(i)}$  of a particular forging.

$$RT_{\text{MAX-CW}} \equiv \text{MAX}_{i=1}^{n_{\text{CWFL}}} \left[ \text{MAX}_{\text{CWFL}(i)} \left\{ \begin{array}{l} \left( RT_{\text{NDT}(u)}^{\text{adj-cw}(i)} + \Delta T_{30}^{\text{adj-cw}(i)}(\phi_{\text{FL}}) \right)_b \\ \left( RT_{\text{NDT}(u)}^{\text{adj-pl}(i)} + \Delta T_{30}^{\text{adj-pl}(i)}(\phi_{\text{FL}}) \right)_b \\ \left( RT_{\text{NDT}(u)}^{\text{adj-fo}(i)} + \Delta T_{30}^{\text{adj-fo}(i)}(\phi_{\text{FL}}) \right)_b \end{array} \right\} \right]$$

Where:

- $n_{\text{CWFL}}$  is the number of circumferential weld fusion lines in the beltline region of the vessel,
- $i$  is a counter that ranges from 1 to  $n_{\text{CWFL}}$ ,
- $\phi_{\text{FL}}$  is the maximum fluence occurring on the vessel ID along a particular circumferential weld fusion line,
- $RT_{\text{NDT}(u)}^{\text{adj-cw}(i)}$  is the unirradiated  $RT_{\text{NDT}}$  of the weld adjacent to the  $i^{\text{th}}$  circumferential weld fusion line,
- $RT_{\text{NDT}(u)}^{\text{adj-pl}(i)}$  is the unirradiated  $RT_{\text{NDT}}$  of the plate adjacent to the  $i^{\text{th}}$  circumferential weld fusion line (if there is no adjacent plate this term is ignored),
- $RT_{\text{NDT}(u)}^{\text{adj-fo}(i)}$  is the unirradiated  $RT_{\text{NDT}}$  of the forging adjacent to the  $i^{\text{th}}$  circumferential weld fusion line (if there is no adjacent forging this term is ignored),
- $\Delta T_{30}^{\text{adj-cw}(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation due to  $\phi_{\text{FL}}$  of the weld adjacent to the  $i^{\text{th}}$  circumferential weld fusion line,
- $\Delta T_{30}^{\text{adj-pl}(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation to  $\phi_{\text{FL}}$  of the plate adjacent to the  $i^{\text{th}}$  axial weld fusion line (if there is no adjacent plate this term is ignored), and
- $\Delta T_{30}^{\text{adj-fo}(i)}$  is the shift in the Charpy V-Notch 30-foot-pound (ft-lb) energy produced by irradiation to  $\phi_{\text{FL}}$  of the forging adjacent to the  $i^{\text{th}}$  axial weld fusion line (if there is no adjacent forging this term is ignored).

The  $\Delta T_{30}$  shift shall be determined using the latest approved methodology in Regulatory Guide 1.99 or other NRC-approved methodology (Equations in Section 3.5.2 of NUREG-1874 were used to calculate pilot plant values). All material properties used to determine the  $\text{TWCF}_{95\text{-TOTAL}}$  value shall be documented in Table A-3.

The plant specific  $\text{TWCF}_{95\text{-TOTAL}}$  value shall be re-evaluated any time fluence is re-projected to increase as a result of core reloading, core configuration, power uprating, or when a surveillance capsule is pulled from the reactor vessel. In the case that the calculated plant specific  $\text{TWCF}_{95\text{-TOTAL}}$  value exceeds the pilot plant value (at any time the evaluation is performed), additional evaluation shall be performed to demonstrate that the change-in-risk associated with the extension in the inservice inspection is acceptable.

#### Frequency and Severity of Design Basis Transients

It is necessary to demonstrate that the amount of fatigue crack growth considered in the pilot plant analyses is bounding for a specific plant. Since the amount of fatigue crack growth used in the pilot plant analyses was calculated based on the design basis transients, a comparison of design basis transients shall

be performed to ensure that the assumed number of heatup-cooldown transients per year is also applicable for the specific plant. The pilot plant basis depends on the applicable design:

Westinghouse:	7 Cooldowns per year
CE:	13 Cooldowns per year
B&W:	12 Cooldowns per year (assumed)

For CE and Westinghouse designs, if the specific plant has operated within its design basis, the amount of fatigue crack growth in the pilot plant will be bounding. If a plant has operated outside of its design basis, an additional evaluation is required to demonstrate that the pilot plant fatigue crack growth is still bounding. For B&W plants, an evaluation must be performed to show that the fatigue crack growth used in the pilot plant analysis is bounding of that which may occur at the specific plant. If the plant specific fatigue crack growth is projected to be greater than pilot plant fatigue crack growth considered, additional evaluation is required to demonstrate that the change-in-risk associated with the extension in the inservice inspection is acceptable.

Cladding Layers

The pilot plant analyses were performed assuming a single layer of cladding because the probability of having a surface breaking flaw in multi-layer cladding is much less than that of single-layer cladding. The licensee shall identify whether their reactor vessel was fabricated with single or multi-layer cladding. Since the pilot plant analyses were performed with single-layer, all plants are bounded by this parameter.

<b>Table A-2 Additional Information Pertaining to the Reactor Vessel Inspection</b>	
Inspection methodology:	
Number of past inspections:	
Number of indications found:	
Proposed inspection schedule for balance of plant life:	

Table A-2 is to be completed with plant specific reactor vessel inservice inspection data to meet the requirements stated below as follows.

Inspection Methodology

The licensee shall identify the methodology used for the most recent inservice inspection performed on the ASME Category B-A and B-D welds that are included in this evaluation. Typically the methodology used will be either Regulatory Guide 1.150 or ASME Section XI Appendix VIII.



Number of Past Inspections

The licensee shall identify the number of past inspections that have been performed on the ASME Category B-A and B-D welds that are included in this evaluation.

Number of Indications Found

The licensee shall identify the number of flaws of concern (as defined in part c of the requirements above) found during the most recent inservice inspection.

Proposed Inspection Schedule for Balance of Plant Life

The licensee shall identify the years in which future inservice inspections will be performed. The dates identified must be within plus or minus one refueling cycle of the dates identified in the implementation plan provided to the NRC in PWR Owners Group letter OG-06-356, "Plan for Plant Specific Implementation of Extended Inservice Inspection Interval per WCAP-16168-NP, Revision 1, "Risk-Informed Extension of the Reactor Vessel In-Service Inspection Interval." MUHP 5097-99, Task 2059," dated October 31, 2006. If the licensee identifies dates in Table A-2 that are not within plus or minus one refueling cycle of the dates in the plan, the licensee will be required to have additional discussion with the NRC Staff.

After implementation of the extended interval the following requirement must be met:

*All data on embedded flaws of concern with a through-wall extent (TWE) greater than 0.1 inch shall be provided to NRC within one year of completing the next vessel beltline inservice inspection per ASME Section XI, Appendix VIII, Supplement 4. For potential vessel failure due to PTS, embedded flaws of concern are axially oriented planar flaws in the vessel beltline within the inner 12.5% (1/8") of the vessel wall thickness.*

*An assessment of the inservice inspection results relative to the flaw distributions used in the pilot plant analyses shall also be provided. This assessment shall be performed in accordance with the requirements of Section (d) in the final published version of the voluntary PTS rule, 10 CFR 50.61(a).*

Table A-3 Details of TWCF Calculation								
Inputs								
Reactor Coolant System Temperature, $T_{RCS}$ [°F]:			T <sub>wall</sub> [inches]:					
#	Region/Component Description	Material	Cu [wt%]	Ni [wt%]	P [wt%]	Mn [wt%]	Un-Irradiated $R:T_{NDT(cu)}$ [°F]	Fluence [ $10^{19}$ Neutron/cm <sup>2</sup> , E>1 MeV]
Outputs								
Methodology Used to Calculate $\Delta T_{30}$ :								
	Region # (From Above)	RT <sub>MAX-XX</sub> [R]	Fluence [ $10^{19}$ Neutron/cm <sup>2</sup> , E>1 MeV]	$\phi$ (flux)	$\Delta T_{30}$ [°F]	TWCF <sub>95-XX</sub>		
	Limiting Axial Weld - AW							
	Limiting Plate - PL							
	Forging - FO							
	Circumferential Weld - CW							
TWCF <sub>95-TOTAL</sub> ( $\alpha_{AW}TWCF_{95-AW} + \alpha_{PL}TWCF_{95-PL} + \alpha_{CW}TWCF_{95-CW} + \alpha_{FO}TWCF_{95-FO}$ ):								

The information used to calculate the through wall cracking frequency (TWCF) shall be included in Table A-3. The fields are defined in the TWCF correlation definition for Table A-1. Additional rows should be added to the input section for each belline region/component where region/component is a particular weld, plate, or forging. Refer to Appendices A-1 and A-2 for examples of how Table A-3 are to be completed.

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## APPENDIX A-1 WOLF CREEK PLANT IMPLEMENTATION EXAMPLE

<b>Parameter</b>	<b>Pilot Plant Basis</b>	<b>Plant Specific Basis</b>	<b>Additional Evaluation Required? (Y/N)</b>
Dominant Pressurized Thermal Shock (PTS) Transients in the NRC PTS Risk Study are applicable	NRC PTS Risk Study (Reference 88)	PTS Generalization Study (Reference 25 26)	No
Through Wall Cracking Frequency	4.67E-1.76-098 Events per year	2.51E-132-15E-12 Events per year	No
Frequency and Severity of Design Basis Transients	WCAP-16168-NP Revision 4: Bounded by 7 heatup/cooldowns per year	Bounded by 7 heatup/cooldowns per year	No
Cladding Layers (Single/Multiple)	Single	Single (assumed)	No

Inspection methodology:	Past inspections have been performed to Regulatory Guide 1.150. Inspections performed during RF13 and RF 14 were also performed to ASME Section XI Appendix VIII.
Number of past inspections:	<ul style="list-style-type: none"> <li>- Category B-A welds (reactor vessel): 2 inspections, RF8 – Spring 1996 and RF14 – Spring 2005 with the exception of weld RV-101-121 which was also inspected in RF2 – Spring 1987 and RF10 – Spring 1999</li> <li>- Category B-A welds (closure head): 2 inspections, Interval 1 examinations in RF1 – Fall 1986, RF4 – Spring 1990, and RF6 – Spring 1993. Interval 2 examinations were performed in RF9 – Fall 1997, RF11 – Fall 2000, and RF13 – Fall 2003. 2 welds were examined each outage.</li> <li>- Category B-D welds (outlet nozzles): 3 inspections RF3 – Fall 1988, RF8 – Spring 1996, RF14 – Spring 2005</li> <li>- Category B-D welds (inlet nozzles): 2 inspections, RF8 – Spring 1996, RF14 – Spring 2005</li> </ul>
Number of indications found:	Zero reportable indications have been found to date. Any recordable indications have been acceptable per ASME Section XI IWB-3500. No flaws of concern were found detected.
Proposed inspection schedule for balance of plant life:	Third inservice inspection currently scheduled for 2015. The third inservice inspection is proposed to be performed in 2025. The fourth inservice inspection interval is proposed to be performed in 2045.

Table 3 Details of TWCF Calculation								
Inputs								
Reactor Coolant System Temperature, $T_{RCS}$ [°F]:			550		T <sub>wall</sub> [inches]:			8.62
#	Region/Component Description	Material	Cu [wt%]	Ni [wt%]	P [wt%]	Mn [wt%]	Un-Irradiated RT <sub>NDR(t<sub>0</sub>)</sub> [°F]	Fluence [ $10^{19}$ Neutron/cm <sup>2</sup> , E>1 MeV]
1	Lower Shell Plate	A 533B	0.070	0.620	0.008	1.35	40.0	3.90
2	Lower Shell Plate	A 533B	0.090	0.670	0.009	1.35	0.0	3.90
3	Lower Shell Plate	A 533B	0.060	0.640	0.008	1.35	10.0	3.90
4	Intermediate Shell Plate	A 533B	0.040	0.640	0.007	1.35	-20.0	3.90
5	Intermediate Shell Plate	A 533B	0.050	0.630	0.007	1.35	-20.0	3.90
6	Intermediate Shell Plate	A 533B	0.040	0.660	0.008	1.35	-20.0	3.90
7	Lower Shell Axial Weld	Linde 0091	0.040	0.080	0.005	1.35	-50.0	1.76
8	Lower Shell Axial Weld	Linde 0091	0.040	0.080	0.005	1.35	-50.0	3.42
9	Lower Shell Axial Weld	Linde 0091	0.040	0.080	0.005	1.35	-50.0	3.42
10	Inter. Shell Axial Weld	Linde 0091	0.040	0.080	0.005	1.35	-50.0	1.76
11	Inter. Shell Axial Weld	Linde 0091	0.040	0.080	0.005	1.35	-50.0	3.42
12	Inter. Shell Axial Weld	Linde 0091	0.040	0.080	0.005	1.35	-50.0	3.42
13	Inter. - Lower Circ Weld	Linde 124	0.040	0.080	0.007	1.35	-50.0	3.90
Outputs								
Methodology Used to Calculate $\Delta T_{30}$ :				NUREG-1874				
	Region # (From Above)	RT <sub>MAX-XX</sub> [R]	Fluence [ $10^{19}$ Neutron/cm <sup>2</sup> , E>1 MeV]	$\phi$ (flux)	$\Delta T_{30}$ [°F]	TWCF <sub>95-XX</sub>		
Limiting Axial Weld - AW		1	561.96	3.42	1.81E+10	62.27	2.47E-18	
Limiting Plate - PL		1	565.05	3.90	2.06E+10	65.36	1.00E-13	
Forging - FO		N/A	N/A	N/A	N/A	N/A	N/A	
Circumferential Weld - CW		1	565.05	3.90	2.06E+10	65.36	5.52E-29	
TWCF <sub>95-TOTAL</sub> ( $\alpha_{AW}TWCF_{95-AW} + \alpha_{PL}TWCF_{95-PL} + \alpha_{CW}TWCF_{95-CW} + \alpha_{FO}TWCF_{95-FO}$ ):							2.51E-13	

## APPENDIX A-2

### WATERFORD 3 PLANT IMPLEMENTATION EXAMPLE

<b>Parameter</b>	<b>Pilot Plant Basis</b>	<b>Plant Specific Basis</b>	<b>Additional Evaluation Required? (Y/N)</b>
Dominant Pressurized Thermal Shock (PTS) Transients in the NRC PTS Risk Study are applicable	NRC PTS Risk Re-Evaluation (Reference 88)	PTS Generalization Study (Reference 2526)	No
Through Wall Cracking Frequency	3.16E-076.42E-09 Events per year	5.19E-13-2.87E-14 Events per year	No
Frequency and Severity of Design Basis Transients	WCAP-16168-NP Revision 4; Bounded by 13 heatup/cooldowns/yr per year	Bounded by 13 heatup/cooldowns/yr per year	No
Cladding Layers (Single/Multiple)	Single	Single	No

Inspection methodology:	Past inspections have been performed to Regulatory Guide 1.150
Number of past inspections:	<ul style="list-style-type: none"> <li>- Category B-A welds (reactor vessel): 1 inspection – 1995, with the exception of weld 01-020 which was also inspected in 1988.</li> <li>- Category B-A welds (closure head): 4 inspections with 3 welds inspected 1986, 3 welds inspected 1989, 1 weld inspected 1994, 3 welds inspected 2000</li> <li>- Category B-D welds (outlet nozzles): 2 inspections – 1988 and 1995, with the exception of weld 01-021 which was also inspected in 1989.</li> <li>- Category B-D welds (inlet nozzles): 1 inspection – 1995</li> </ul>
Number of indications found:	Zero reportable indications have been found to date. Any recordable indications have been acceptable per ASME Section XI IWB-3500. No flaws of concern have been found detected.
Proposed inspection schedule for balance of plant life:	Second inservice inspection currently scheduled for Spring 2008. The second inservice inspection is proposed to be performed in 2018. The third inservice inspection is proposed to be performed in 2038.

Table 3 Details of TWCF Calculation									
Inputs									
Reactor Coolant System Temperature, $T_{RCS}$ [°F]:			553		T <sub>wall</sub> [inches]:			8.62	
#	Region/Component Description	Material	Cu [wt%]	Ni [wt%]	P [wt%]	Mn [wt%]	Un-Irradiated RT <sub>NDT(0)</sub> [°F]	Fluence [ $10^{19}$ Neutron/cm <sup>2</sup> , E>1 MeV]	
1	Lower Shell Plate	A 533B	0.030	0.580	0.005	1.35	22.0	4.49	
2	Lower Shell Plate	A 533B	0.030	0.620	0.006	1.35	-15.0	4.49	
3	Lower Shell Plate	A 533B	0.030	0.620	0.007	1.35	-10.0	4.49	
4	Intermediate Shell Plate	A 533B	0.020	0.700	0.007	1.35	-42.0	4.49	
5	Intermediate Shell Plate	A 533B	0.020	0.710	0.004	1.35	-30.0	4.49	
6	Intermediate Shell Plate	A 533B	0.020	0.670	0.006	1.35	-50.0	4.49	
7	Lower Shell Axial Weld	Linde 0091	0.030	0.200	0.007	1.35	-80.0	4.49	
8	Lower Shell Axial Weld	Linde 0091	0.030	0.200	0.007	1.35	-80.0	4.49	
9	Lower Shell Axial Weld	Linde 0091	0.030	0.200	0.007	1.35	-80.0	4.49	
10	Inter. Shell Axial Weld	E 8018	0.020	0.960	0.010	1.35	-60.0	4.50	
11	Inter. Shell Axial Weld	E 8018	0.020	0.960	0.010	1.35	-60.0	4.50	
12	Inter. Shell Axial Weld	E 8018	0.020	0.960	0.010	1.35	-60.0	4.50	
13	Inter. - Lower Circ. Weld	Linde 0091	0.050	0.160	0.008	1.35	-70.0	4.49	
Outputs									
Methodology Used to Calculate $\Delta T_{30}$ :				NUREG-1874					
	Region # (From Above)		RT <sub>MAX-XX</sub> [R]	Fluence [ $10^{19}$ Neutron/cm <sup>2</sup> , E>1 MeV]	$\phi$ (flux)	$\Delta T_{30}$ [°F]	TWCF <sub>95-XX</sub>		
Limiting Axial Weld - AW	1		541.91	4.49	2.37E10	57.93	2.47E-18		
Limiting Plate - PL	1		541.91	4.49	2.37E10	57.93	5.52E-29		
Forging - FO	N/A		N/A	N/A	N/A	N/A	N/A		
Circumferential Weld - CW	1		541.91	4.49	2.37E10	57.93	1.15E-14		
TWCF <sub>95-TOTAL</sub> ( $\alpha_{AW}TWCF_{95-AW} + \alpha_{PL}TWCF_{95-PL} + \alpha_{CW}TWCF_{95-CW} + \alpha_{FO}TWCF_{95-FO}$ ):								2.87E-14	

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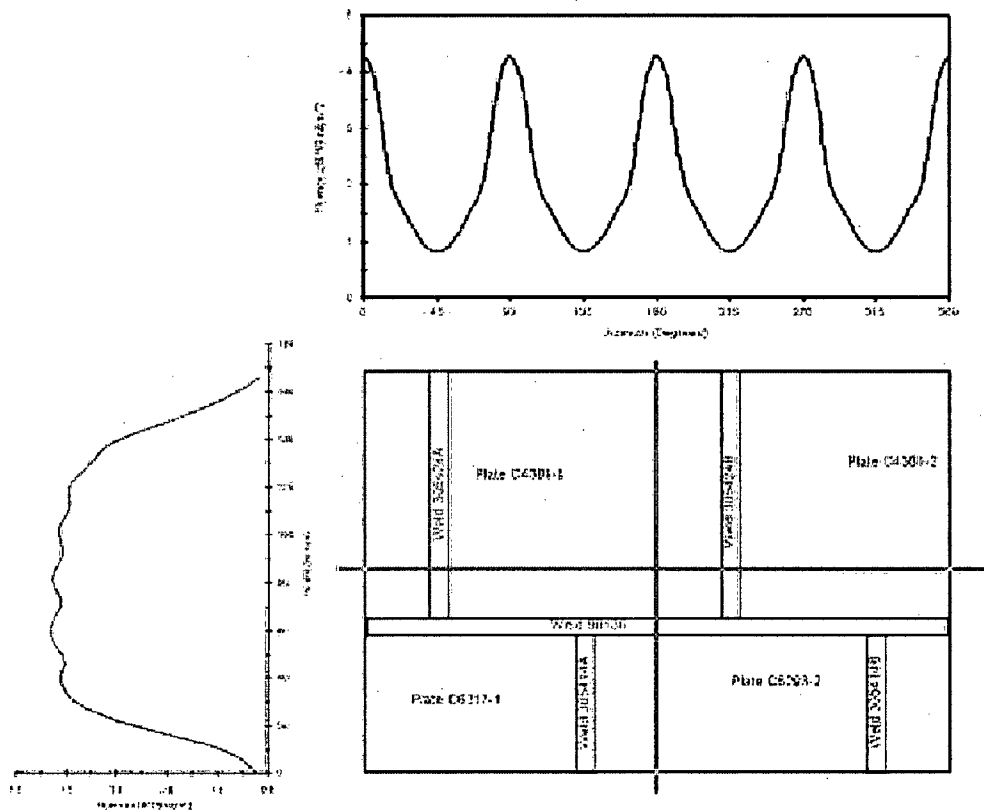
**APPENDIX B**  
**INPUTS FOR THE BEAVER VALLEY UNIT 1 PILOT PLANT EVALUATION**

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A summary of the NDE inspection history based on Regulatory Guide 1.150 and pertinent input data for BV1 is as follows:

1. Number of ISIs performed (relative to initial pre-service and 10-year interval inspections) for full penetration Category B-A and B-D reactor vessel welds assuming all of the candidate welds were inspected: 2 (covering all welds of the specified categories).
2. The inspections performed covered: A total of 34 items. 15 Category B-A items had coverage of <90%. 1 Category B-A item had coverage > 90% but <100%. 6 Category B-A items had coverage of 100%. 6 Category B-D items had coverage of 90% and 6 had coverage of 100%.
3. Number of indications found during the most recent inservice inspection: 42  
This number includes consideration of the following additional information:
  - a. Indications found that were reportable: 0
  - b. Indications found that were within acceptable limits: 42
  - c. Indications/anomalies currently being monitored: 0
4. Full penetration relief requests for the RV were submitted and accepted by the NRC for 15 items.
5. Fluence distribution at inside surface of RV beltline until end of life (EOL): see Figure B-1 taken from the NRC PTS Risk Study [7448], Figure 4.2.



**Figure B-1 Rollout Diagram of Beltline Materials and Representative Fluence Maps for BV1**

6. Reactor vessel cladding details:

- a. Thickness: 0.156 inches
- b. Material properties (assumed to be independent of temperature) are identified in Table B-1. This is consistent with the NRC PTS Risk Study [27, 438, 9]:

Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM-°F) "C"	Young's Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
0	-	-	-	-	489	.3
68	-	-	22045.7	-	489	.3
70	8.1	0.1158	-	-	489	.3
100	8.4	0.1185	-	8.55E-06	489	.3
150	8.6	0.1196	-	8.67E-06	489	.3
200	8.8	0.1208	-	8.79E-06	489	.3
250	9.1	0.1232	-	8.9E-06	489	.3
300	9.4	0.1256	-	9.0E-06	489	.3
302	-	-	20160.2	-	489	.3
350	9.6	0.1258	-	9.1E-06	489	.3
400	9.9	0.1281	-	9.19E-06	489	.3
450	10.1	0.1291	-	9.28E-06	489	.3
482	-	-	18419.8	-	489	.3
500	10.4	0.1305	-	9.37E-06	489	.3
550	10.6	0.1306	-	9.45E-06	489	.3
600	10.9	0.1327	-	9.53E-06	489	.3
650	11.1	0.1335	-	9.61E-06	489	.3
700	11.4	0.1348	-	9.69E-06	489	.3
750	11.6	0.1356	-	9.76E-06	489	.3
800	11.9	0.1367	-	9.82E-06	489	.3

2) Thermal conductivity (Btu/hr-ft-°F), K=10.0

3) Specific heat (Btu/LBM-F), C=0.120

4) Density (LBM/ft<sup>3</sup>), RHO=489.00

5) Young's Modulus of Elasticity (KSI), E=22800

6) Thermal expansion coefficient (°F<sup>-1</sup>), ALPHA=0.00000945

7) Poisson's Ratio, V=0.3

c. Material including copper and nickel content: Material properties assigned to clad flaws are that of the underlying material be it base metal or weld. These properties are identified in Table B-13. This is consistent with the NRC PTS Risk Study [78, 927, 43].

d. Material property uncertainties:

1) Bead width: 1 inch—bead widths vary for all plants. Based on the NRC PTS Risk Study [7], a nominal dimension of 1 inch is selected for all analyses because this parameter is not expected to influence significantly the predicted reactor vessel failure probabilities.

- 1) Bead width: 1 inch – bead widths vary for all plants. Based on the NRC PTS Risk Study [8, 98], a nominal dimension of 1 inch is selected for all analyses because this parameter is not expected to influence significantly the predicted reactor vessel failure probabilities.
  - 2) Truncation limit: Cladding thickness rounded to the next 1/100th of the total reactor vessel thickness to be consistent with the NRC PTS Risk Study [78, 98].
  - 3) Surface flaw depth: 0.161 inch
  - 4) All cladding flaws are surface-breaking. Only flaws in cladding that would influence brittle fracture of the reactor vessel are brittle. This is consistent with the NRC PTS Risk Study [78, 98].
- e. Additional cladding properties are identified in Table B-24.
7. Base metal:
- a. Wall thickness: 7.875 inches
  - b. Material properties (assumed to be independent of temperature) are identified in Table B-2 and B-3. This is consistent with the NRC PTS Risk Study [8, 927, 43]:

Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM- °F) "C"	Young's Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
0	-	-	-	-	489	.3
70	24.8	0.1052	29200	-	489	.3
100	25	0.1072	-	7.06E-06	489	.3
150	25.1	0.1101	-	7.16E-06	489	.3
200	25.2	0.1135	28500	7.25E-06	489	.3
250	25.2	0.1166	-	7.34E-06	489	.3
300	25.1	0.1194	28000	7.43E-06	489	.3
350	25	0.1223	-	7.5E-06	489	.3
400	25.1	0.1267	27400	7.58E-06	489	.3
450	24.6	0.1277	-	7.63E-06	489	.3
500	24.3	0.1304	27000	7.7E-06	489	.3
550	24	0.1326	-	7.77E-06	489	.3
600	23.7	0.135	26400	7.83E-06	489	.3
650	23.4	0.1375	-	7.9E-06	489	.3
700	23	0.1404	25300	7.94E-06	489	.3
750	22.6	0.1435	-	8.0E-06	489	.3
800	22.2	0.1474	23900	8.05E-06	489	.3

- 1) Thermal conductivity (Btu/hr ft °F),  $K=24.0$
  - 2) Specific heat (Btu/LBM °F),  $C=0.120$
  - 3) Density (LBM/ft<sup>3</sup>),  $RHO=489.00$
  - 4) Young's Modulus of Elasticity (KSI),  $E=28000$
  - 5) Thermal expansion coefficient (°F<sup>-1</sup>),  $ALPHA=0.00000777$
  - 6) Poisson's Ratio,  $\nu=0.3$
- Other material properties are identified in Table B-1

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7)

Major Material Region Description				Cu [wt%]	Ni [wt%]	P [wt%]	Mn [wt%]	Un-Irradiated RT <sub>NDR</sub> [°F]
#	Type	Heat	Location					
1	Axial Weld	305414A	Lower	0.337	0.609	0.012	1.440	- 56
2	Axial Weld	305414B	Lower	0.337	0.609	0.012	1.440	- 56
3	Axial Weld	305424A	Upper	0.273	0.629	0.013	1.440	- 56
4	Axial Weld	305424B	Upper	0.273	0.629	0.013	1.440	- 56
5	Circ Weld	90136	Intermediate	0.269	0.070	0.013	0.964	- 56
6	Plate	C6317-1	Lower	0.200	0.540	0.010	1.310	27
7	Plate	C6293-2	Lower	0.140	0.570	0.015	1.300	20
8	Plate	C4381-2	Upper	0.140	0.620	0.015	1.400	73
9	Plate	C4381-1	Upper	0.140	0.620	0.015	1.400	43

Major Material Region Description				Cu [wt%]	Ni [wt%]	P [wt%]	Un-Irradiated RT <sub>NDR</sub>		RIPTS @60 EFPPY
#	Type	Heat	Location				[°F]	Method	
1	Axial Weld	305414A	Lower	0.337	0.609	0.012	-56	Generic	230.4
2	Axial Weld	305414B	Lower	0.337	0.609	0.012	-56	Generic	230.4
3	Axial Weld	305424A	Upper	0.273	0.629	0.013	-56	Generic	217.8
4	Axial Weld	305424B	Upper	0.273	0.629	0.013	-56	Generic	217.8
5	Circ Weld	90136	Intermediate	0.269	0.070	0.013	-56	Generic	159.1
6	Plate	C6317-1	Lower	0.200	0.540	0.010	27	MTEB-5-2	296.6
7	Plate	C6293-2	Lower	0.140	0.570	0.015	20	MTEB-5-2	275.7
8	Plate	C4381-2	Upper	0.140	0.620	0.015	73	MTEB-5-2	332.9
9	Plate	C4381-1	Upper	0.140	0.620	0.015	43	MTEB-5-2	302.9

8. Weld metal details: Details of information used in addressing weld-specific information are taken directly from the NRC PTS Risk Study [744], Table 4.2. Summaries are reproduced as Table B-

24. Values for SAW Weld Volume fraction and Repair Weld Volume fraction in Table B-4 were changed to 96.7% and 2.3% respectively per NUREG-1874 [9].

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**Table B-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Inner Radius (to cladding)	[in]	85.5	78.5	86	86	Vessel specific info
Base Metal Thickness	[in]	8.438	7.875	8.5	8.675	Vessel specific info
Total Wall Thickness	[in]	8.626	8.031	8.75	8.988	Vessel specific info

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
SAW Weld	Volume fraction	97%				100% - SMAW% - REPAIR%
	Thru-Wall Bead Thickness	0.1875	0.1875	0.1875	0.1875	All plants report plant specific dimensions of 3/16-in.
	Truncation Limit	1				Judgment. Approx. 2X the size of the largest non-repair flaw observed in PVRUF & Shoreham.
	Buried or Surface	All flaws are buried				Observation
	Orientation	Circ flaws in circ welds, axial flaws in axial welds.				Observation: Virtually all of the weld flaws in PVRUF & Shoreham were aligned with the welding direction because they were lack of sidewall fusion defects.
	Density basis	Shoreham density				Highest of observations
	Aspect ratio basis	Shoreham & PVRUF observations				Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
Depth basis	Shoreham & PVRUF observations				Statistically similar distributions combined to provide more robust estimates	



**Table B-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes	
SMAW Weld	Volume fraction	[%]	1%			Upper bound to all plant specific info provided by Steve Byrne (Westinghouse – Windsor).	
	Thru-Wall Bead Thickness	[in]	0.21	0.20	0.22	0.25	Oconee is generic value based on average of all plants specific values (including Shoreham & PVRUF data). Other values are plant specific as reported by Steve Byrne.
	Truncation Limit	[in]	1			Judgment. Approx. 2X the size of the largest non-repair flaw observed in PVRUF & Shoreham.	
	Buried or Surface	--	All flaws are buried			Observation	
	Orientation	--	Circ flaws in circ welds, axial flaws in axial welds.			Observation: Virtually all of the weld flaws in PVRUF & Shoreham were aligned with the welding direction because they were lack of sidewall fusion defects.	
	Density basis	--	Shoreham density			Highest of observations	
	Aspect ratio basis	--	Shoreham & PVRUF observations			Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.	
Depth basis	--	Shoreham & PVRUF observations			Statistically similar distributions combined to provide more robust estimates		

Table B-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)

Variable		Oconee	Beaver Valley	Pallsades	Calvert Cliffs	Notes
Repair Weld	Volume fraction	[%]	2%			Judgment. A rounded integral percentage that exceeds the repaired volume observed for Shoreham and for PVRUF, which was 1.5%.
	Thru-Wall Bead Thickness	[in]	0.14			Generic value: As observed in PVRUF and Shoreham by PNNL.
	Truncation Limit	[in]	2			Judgment. Approx. 2X the largest repair flaw found in PVRUF & Shoreham. Also based on maximum expected width of repair cavity.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Circ flaws in circ welds, axial flaws in axial welds.			The repair flaws had complex shapes and orientations that were not aligned with either the axial or circumferential welds; for consistency with the available treatments of flaws by the FAVOR code, a common treatment of orientations was adopted for flaws in SAW/SMAW and repair welds.
	Density basis	--	Shoreham density			Highest of observations
	Aspect ratio basis	--	Shoreham & PVRUF observations			Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
	Depth basis	--	Shoreham & PVRUF observations			Statistically similar distributions combined to provide more robust estimates

**Table B-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes	
Cladding	Actual Thickness	[in]	0.188	0.156	0.25	0.313	Vessel specific info
	# of Layers	[#]	1	2	2	2	Vessel specific info
	Bead Width	[in]	1				Bead widths of 1 to 5-in. characteristic of machine deposited cladding. Bead widths down to ½-in. can occur over welds. Nominal dimension of 1-in. selected for all analyses because this parameter is not expected to influence significantly the predicted vessel failure probabilities. May need to refine this estimate later, particularly for Oconee who reported a 5-in bead width.
	Truncation Limit	[in]	Actual clad thickness rounded to the nearest 1/100 <sup>th</sup> of the total vessel wall thickness				Judgment & computational convenience
	Surface flaw depth in FAVOR	[in]	0.259	0.161	0.263	0.360	
	Buried or Surface	--	All flaws are surface breaking				Judgment. Only flaws in cladding that would influence brittle fracture of the vessel are brittle. Material properties assigned to clad flaws are that of the underlying material, be it base or weld.
Orientation	--	All circumferential.				Observation: All flaws observed in PVRUF & Shoreham were lack of inter-run fusion defects, and cladding is always deposited circumferentially	
Density basis	--	No surface flaws observed. Density is 1/1000 that of the observed buried flaws in cladding of vessels examined by PNNL. If there is more than one clad layer then there are no clad flaws.				Judgment	
Aspect ratio basis	--	Observations on buried flaws				Judgment	
Depth basis	--	Depth of all surface flaws is the actual clad thickness rounded up to the nearest 1/100 <sup>th</sup> of the total vessel wall thickness.				Judgment.	

Table B-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Plate	Truncation Limit	[in]	0.433			Judgment. Twice the depth of the largest flaw observed in all PNNL plate inspections.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Half of the simulated flaws are circumferential, half are axial.			Observation & Physics: No observed orientation preference, and no reason to suspect one (other than laminations which are benign.
	Density basis	--	1/10 of small weld flaw density, 1/40 of large weld flaw density of the PVRUF data			Judgment. Supported by limited data.
	Aspect ratio basis	--	Same as for PVRUF welds			Judgment
	Depth basis	--	Same as for PVRUF welds			Judgment. Supported by limited data.

9.  $TWCF_{95-TOTAL}$  value calculated at 60 EFPY using correlations from NUREG-1874 (Reference-27 9):  $4.67E-09$   $1.76E-08$  Events per year

**APPENDIX C  
BEAVER VALLEY UNIT 1 PROBSBFD OUTPUT**

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**C-1: 10 Year ISI Only**

WESTINGHOUSE STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)  
 1.0 MONTE-CARLO SIMULATION PROGRAM PROBSBFD VERSION

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INPUT VARIABLES FOR CASE 3: BV1 HUCD 10 YR ISI ONLY

NCYCLE = 80 NFAILS = 1001 NTRIAL = 1000  
 NOVARS = 19 NUMSET = 2 NUMISI = 5  
 NUMSSC = 4 NUMTRC = 4 NUMFMD = 4

VARIABLE NO.	NAME	DISTRIBUTION TYPE	LOG	MEDIAN VALUE	DEVIATION OR FACTOR	SHIFT MV/SD	USAGE NO. SUB
1	FIFDepth	- CONSTANT	-	2.0000D-02			1 SET
2	IFlawDen	- CONSTANT	-	3.6589D-03			2 SET
3	ICy-ISI	- CONSTANT	-	1.0000D+01			1 ISI
4	DCy-ISI	- CONSTANT	-	8.0000D+01			2 ISI
5	MV-Depth	- CONSTANT	-	1.5000D-02			3 ISI
6	SD-Depth	- CONSTANT	-	1.8500D-01			4 ISI
7	CEff-ISI	- CONSTANT	-	1.0000D+00			5 ISI
8	Aspect1	- CONSTANT	-	2.0000D+00			1 SSC
9	Aspect2	- CONSTANT	-	6.0000E+00			2 SSC
10	Aspect3	- CONSTANT	-	1.0000D+01			3 SSC
11	Aspect4	- CONSTANT	-	9.3000E+01			4 SSC
12	NoTr/Cy	- CONSTANT	-	7.0000D+00			1 TRC
13	FCGThld	- CONSTANT	-	1.5000D+00			2 TRC
14	FCGR-UC	NORMAL	NO	0.0000D+00	1.0000D+00	.00	3 TRC
15	DKINFile	- CONSTANT	-	1.0000D+00			4 TRC
16	Percent1	- CONSTANT	-	5.6175D+01			1 FMD
17	Percent2	- CONSTANT	-	3.0283E+01			2 FMD
18	Percent3	- CONSTANT	-	3.2086D+00			3 FMD
19	Percent4	- CONSTANT	-	9.6333D+00			4 FMD

INFORMATION GENERATED FROM FAVLOADS.DAT FILE AND SAVED IN DKINSAVE.DAT FILE:

WALL THICKNESS = 8.0360 INCH

FLAW DEPTH MINIMUM K AND MAXIMUM K FOR

TYPE 1 WITH AN ASPECT RATIO OF 2.

8.03600D-02	2.41927D+00	1.03655D+01
1.47862D-01	3.22858D+00	1.40170D+01
4.01800D-01	1.29279D+01	1.75751D+01
6.02700D-01	1.41327D+01	2.09080D+01
8.03600D-01	1.49423D+01	2.33544D+01
1.60720D+00	1.45812D+01	2.72710D+01
2.41080D+00	1.02448D+01	2.63600D+01
4.01800D+00	2.35823D+00	2.78623D+01

**C-1: 10 Year ISI Only (cont.)**

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.03600D-02	3.63673D+00	1.56338D+01
1.47862D-01	4.95557D+00	2.15454D+01
4.01800D-01	1.90999D+01	2.63794D+01
6.02700D-01	2.31650D+01	3.16223D+01
8.03600D-01	2.48064D+01	3.60464D+01
1.60720D+00	2.65025D+01	4.51155D+01
2.41080D+00	2.31198D+01	4.76172D+01
4.01800D+00	1.54934D+01	5.27667D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.03600D-02	3.98451D+00	1.71374D+01
1.47862D-01	5.29827D+00	2.30393D+01
4.01800D-01	2.02922D+01	2.81955D+01
6.02700D-01	2.51750D+01	3.36684D+01
8.03600D-01	2.69393D+01	3.84779D+01
1.60720D+00	2.92755D+01	4.91684D+01
2.41080D+00	2.74642D+01	5.45509D+01
4.01800D+00	2.02195D+01	6.28814D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.03600D-02	6.51796D+00	1.75511D+01
1.60720D-01	1.01756D+01	2.28059D+01
2.41080D-01	1.54398D+01	2.23553D+01
4.01800D-01	2.18696D+01	2.94323D+01
6.02700D-01	2.69582D+01	3.66108D+01
8.03600D-01	2.88204D+01	4.17713D+01
1.60720D+00	3.37365D+01	5.67413D+01
2.41080D+00	3.35927D+01	6.64759D+01

AVERAGE CALCULATED VALUES FOR: Surface Flaw Density with FCG and ISI

NUMBER FAILED = 0

NUMBER OF TRIALS = 1000

DEPTH (WALL/400) AND FLAW DENSITY FOR ASPECT RATIOS OF 2, 6, 10 AND 99

8	4.4254D-04	1.4320D-04	1.4728D-05	4.7035D-05
9	0.0000D+00	8.8686D-05	1.4703D-05	2.7347D-05
10	0.0000D+00	4.4175D-06	9.2631D-07	7.2598D-07
11	0.0000D+00	2.2821D-07	5.9150D-08	7.0131D-08
12	0.0000D+00	2.2665D-07	2.9099D-08	0.0000D+00
13	0.0000D+00	0.0000D+00	2.8861D-08	0.0000D+00

**C-2: ISI Every 10 Years**

WESTINGHOUSE STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA) VERSION  
 1.0 MONTE-CARLO SIMULATION PROGRAM PROBSBFD

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 ==  
 INPUT VARIABLES FOR CASE 2: BV1 HUCD 10 YR ISI INT

NCYCLE = 80 NFAILS = 1001 NTRIAL = 1000  
 NOVARS = 19 NUMSET = 2 NUMISI = 5  
 NUMSSC = 4 NUMTRC = 4 NUMFMD = 4

VARIABLE NO.	NAME	DISTRIBUTION TYPE	LOG	MEDIAN VALUE	DEVIATION OR FACTOR	SHIFT MV/SD	USAGE NO. SUB
1	FIFDepth	- CONSTANT	-	2.0000D-02			1 SET
2	IFlawDen	- CONSTANT	-	3.6589D-03			2 SET
3	ICy-ISI	- CONSTANT	-	1.0000D+01			1 ISI
4	DCy-ISI	- CONSTANT	-	1.0000D+01			2 ISI
5	MV-Depth	- CONSTANT	-	1.5000D-02			3 ISI
6	SD-Depth	- CONSTANT	-	1.8500D-01			4 ISI
7	CEff-ISI	- CONSTANT	-	1.0000D+00			5 ISI
8	Aspect1	- CONSTANT	-	2.0000D+00			1 SSC
9	Aspect2	- CONSTANT	-	6.0000E+00			2 SSC
10	Aspect3	- CONSTANT	-	1.0000D+01			3 SSC
11	Aspect4	- CONSTANT	-	9.5000E+01			4 SSC
12	NoTr/Cy	- CONSTANT	-	7.0000D+00			1 TRC
13	FCGThld	- CONSTANT	-	1.5000D+00			2 TRC
14	FCGR-UC	NORMAL	NO	0.0000D+00	1.0000D+00	.00	3 TRC
15	DKINFile	- CONSTANT	-	1.0000E+00			4 TRC
16	Percent1	- CONSTANT	-	5.6175E+01			1 FMD
17	Percent2	- CONSTANT	-	3.0283E+01			2 FMD
18	Percent3	- CONSTANT	-	3.2086D+00			3 FMD
19	Percent4	- CONSTANT	-	9.6333D+00			4 FMD

INFORMATION GENERATED FROM FAVLOADS.DAT FILE AND SAVED IN DKINSAVE.DAT FILE:

WALL THICKNESS = 8.0360 INCH

FLAW DEPTH MINIMUM K AND MAXIMUM K FOR

TYPE 1 WITH AN ASPECT RATIO OF 2.

8.03600D-02	2.41927D+00	1.03655D+01
1.47862D-01	3.22858D+00	1.40170D+01
4.01800D-01	1.29279D+01	1.75751D+01
6.02700D-01	1.41327D+01	2.09080D+01
8.03600D-01	1.49423D+01	2.33544D+01
1.60720D+00	1.45812D+01	2.72710D+01
2.41080D+00	1.02448D+01	2.63600D+01
4.01800D+00	2.35823D+00	2.78623D+01



## C-2: ISI Every 10 Years (cont.)

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.03600D-02	3.63673D+00	1.56338D+01
1.47862D-01	4.95557D+00	2.15454D+01
4.01800D-01	1.90999D+01	2.63794D+01
6.02700D-01	2.31650D+01	3.16223D+01
8.03600D-01	2.48064D+01	3.60464D+01
1.60720D+00	2.65025D+01	4.51155D+01
2.41080D+00	2.31198D+01	4.76172D+01
4.01800D+00	1.54934D+01	5.27667D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.03600D-02	3.98451D+00	1.71374D+01
1.47862D-01	5.29827D+00	2.30393D+01
4.01800D-01	2.02922D+01	2.81955D+01
6.02700D-01	2.51750D+01	3.36684D+01
8.03600D-01	2.69393D+01	3.84779D+01
1.60720D+00	2.92755D+01	4.91684D+01
2.41080D+00	2.74642D+01	5.45509D+01
4.01800D+00	2.02195D+01	6.28814D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.03600D-02	6.54796D+00	1.75511D+01
1.60720D-01	1.01756D+01	2.28059D+01
2.41080D-01	1.54398D+01	2.23553D+01
4.01800D-01	2.18696D+01	2.94323D+01
6.02700D-01	2.69582D+01	3.66108D+01
8.03600D-01	2.88204D+01	4.17713D+01
1.60720D+00	3.37365D+01	5.67413D+01
2.41080D+00	3.35927D+01	6.64759D+01

AVERAGE CALCULATED VALUES FOR: Surface Flaw Density with FCG and ISI

NUMBER FAILED = 0

NUMBER OF TRIALS = 1000

DEPTH (WALL/400) AND FLAW DENSITY FOR ASPECT RATIOS OF 2, 6, 10 AND 99

8	4.3486D-08	1.2355D-08	1.2447D-09	4.0471D-09
9	0.0000D+00	6.1902D-09	9.9626D-10	1.8380D-09
10	0.0000D+00	1.8825D-10	3.7663D-11	2.6218D-11
11	0.0000D+00	4.7355D-12	1.6752D-12	1.3302D-12
12	0.0000D+00	3.5199D-12	4.3837D-13	0.0000D+00
13	0.0000D+00	0.0000D+00	3.0423D-13	0.0000D+00

**APPENDIX D**  
**BEAVER VALLEY UNIT 1 PTS TRANSIENTS**

Table D-1 PTS Transient Descriptions for BV1						
Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Dominant*
1	002	3.59 cm [1.414 in] surge line break	None.	1.23E-04	No	No
2	003	5.08 cm [2 in] surge line break	None.	9.76E-05	No	No
3	007	2.54 cm [8 in] surge line break	None.	2.17E-05	No	Yes at $\beta$ 2, 60, 100, 200 EFPY
4	009	2.54 cm [16 in] hot leg break	None.	6.99E-06	No	Yes at $\beta$ 2, 60, 100, 200 EFPY
5	014	Reactor/turbine trip w/one stuck open pressurizer SRV	None.	2.22E-04	No	No
6	031	Reactor/turbine trip w/feed and bleed (Operator open all pressurizer PORVs and use all charging/HHSI pumps)	None.	3.10E-07	No	No
7	034	Reactor/turbine trip w/two stuck open pressurizer SRV's	None.	4.95E-07	No	No
8	056	10.16 cm [4.0 in] surge line break	None.	1.23E-04	Yes	Yes at $\beta$ 2, 60, 100, 200 EFPY
9	059	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 3,000 s.	None.	3.46E-04	No	No
10	060	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 6,000 s.	None.	2.15E-05	No	Yes at $\beta$ 2, 60, 100 EFPY
11	061	Reactor/turbine trip w/two stuck open pressurizer SRV which recloses at 3,000 s.	None.	1.79E-06	No	No
12	062	Reactor/turbine trip w/two stuck open pressurizer SRV which recloses at 6,000 s.	None.	1.08E-07	No	No
13	064	Reactor/turbine trip w/two stuck open pressurizer SRV's	None.	8.67E-08	Yes	No
14	065	Reactor/turbine trip w/two stuck open pressurizer SRV's and HHSI failure	Operator opens all ASDVs 5 minutes after HHSI would have come on.	1.04E-09	No	No

<b>Count</b>	<b>TH Case #</b>	<b>System Failure</b>	<b>Operator Action</b>	<b>Mean IE Frequency</b>	<b>HZP</b>	<b>Dominant*</b>
15	066	Reactor/turbine trip w/two stuck open pressurizer SRV's. One valve recloses at 3000 seconds while the other valve remains open.	None.	1.18E-06	No	No
16	067	Reactor/turbine trip w/two stuck open pressurizer SRV's. One valve recloses at 6000 seconds while the other valve remains open.	None.	1.18E-06	No	No
17	068	Reactor/turbine trip w/two stuck open pressurizer SRV's that reclose at 6000 s with HHSI failure.	Operator opens all ASDVs 5 minutes after HHSI would have come on.	1.33E-08	No	No
18	069	Reactor/turbine trip w/two stuck open pressurizer SRVs which reclose at 3,000 s.	None.	2.09E-08	Yes	No
19	070	Reactor/turbine trip w/two stuck open pressurizer SRVs which reclose at 6,000 s.	None.	2.09E-08	Yes	No
20	071	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 6,000 s.	None.	3.74E-06	Yes	Yes at 32 EFPY
21	072	Reactor/turbine trip w/one stuck open pressurizer SRV with HHSI failure.	Operator opens all ASDVs 5 minutes after HHSI would have come on.	5.14E-07	No	No
22	073	Reactor/turbine trip w/one stuck open pressurizer SRV with HHSI failure.	Operator open all ASDVs 5 minutes after HHSI would have come on.	6.56E-08	Yes	No
23	074	Main steam line break with AFW continuing to feed affected generator.	None.	1.46E-06	No	No
24	076	Reactor/turbine trip w/full MFW to all 3 SGs (MFW maintains SG level near top).	Operator trips reactor coolant pumps.	1.06E-04	Yes	No
25	078	Reactor/turbine trip with failure of MFW and AFW.	Operator opens all ASDVs to let condensate fill SGs.	3.25E-08	No	No
26	081	Main Steam Line Break with AFW continuing to feed affected generator and with HHSI failure initially.	Operator opens ADVs (on intact generators). HHSI is restored after CFTs discharge 50%.	2.65E-06	No	No
27	082	Reactor/turbine trip w/one stuck open pressurizer SRV (recloses at 6000 s) and with HHSI failure.	Operator opens all ASDVs 5 minutes after HHSI would have started.	1.51E-06	No	No

Table D-1 PTS Transient Descriptions for BV1						
Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Dominant*
28	083	2.54 cm [1.0 in] surge line break with HHSI failure and motor driven AFW failure. MFW is tripped. Level control failure causes all steam generators to be overfed with turbine AFW, with the level maintained at top of SGs.	Operator trips RCPs. Operator opens all ASDVs 5 minutes after HHSI would have come on.	3.51E-06	No	No
29	092	Reactor/turbine trip w/two stuck open pressurizer SRV's, one recloses at 3000 s.	None.	2.13E-07	Yes	No
30	093	Reactor/turbine trip w/two stuck open pressurizer SRV's. One valve recloses at 6000 seconds while the other valve remains open.	None.	2.13E-07	Yes	No
31	094	Reactor/turbine trip w/one stuck open pressurizer SRV.	None.	4.10E-05	Yes	No
32	097	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 3,000 s.	None.	3.74E-06	Yes	Yes at 2, 60 EFPY
33	102	Main steam line break with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	1.02E-04	No	Yes at 100, 200 EFPY
34	103	Main steam line break with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	1.07E-05	Yes	Yes at 60, 100, 200 EFPY
35	104	Main steam line break with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 60 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	1.09E-04	No	Yes at 100, 200 EFPY

Table D-1 PTS Transient Descriptions for BV1						
Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Dominant*
36	105	Main steam line break with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 60 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	1.07E-05	Yes	No
37	106	Main steam line break with AFW continuing to feed affected generator.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	2.21E-05	No	No
38	107	Main steam line break with AFW continuing to feed affected generator.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	4.31E-07	Yes	No
39	108	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 30 minutes after allowed.	6.46E-04	Yes	No
40	109	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	6.81E-05	Yes	No
41	110	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 60 minutes after allowed.	6.91E-04	No	Yes at 200 EFPY
42	111	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator for 30 minutes.	Operator controls HHSI 60 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	6.82E-05	Yes	No

Table D-1 PTS Transient Descriptions for BV1						
Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Dominant*
43	112	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	1.41E-05	No	No
44	113	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator.	Operator controls HHSI 30 minutes after allowed. Break is assumed to occur inside containment so that the operator trips the RCPs due to adverse containment conditions.	2.74E-06	Yes	No
45	114	7.18 cm [2.828 in] surge line break, summer conditions (HHSI, LHSI temp = 55°F, Accumulator Temp = 105°F), heat transfer coefficient increased 30% (modeled by increasing heat transfer surface area by 30% in passive heat structures)	None.	9.76E-05	No	No
46	115	7.18 cm [2.828 in] cold leg break	None.	9.76E-05	No	No
47	116	14.366 cm [5.657 in] cold leg break with break area increased 30%	None.	1.81E-05	No	No
48	117	14.366 cm [5.657 in] cold leg break, summer conditions (HHSI, LHSI temp = 55°F, Accumulator Temp = 105°F)	None.	2.11E-05	No	No
49	118	Small steam line break (simulated by sticking open all SG-A SRVs) with AFW continuing to feed affected generator	None.	9.30E-06	No	No
50	119	Reactor/turbine trip w/two stuck open pressurizer SRV which recloses at 6,000 s	Operator controls HHSI (1 minute delay). Updated control logic.	6.84E-07	No	No
51	120	Reactor/turbine trip w/two stuck open pressurizer SRV which recloses at 6,000 s	Operator controls HHSI (10 minute delay). Updated control logic.	9.98E-07	No	No
52	121	Reactor/turbine trip w/two stuck open pressurizer SRV which recloses at 3,000 s	Operator controls HHSI (1 minute delay). Updated control logic.	1.33E-07	Yes	No

Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Dominant*
53	122	Reactor/turbine trip w/two stuck open pressurizer SRVs which reclose at 6,000 s	Operator controls HHSI (1 minute delay). Updated control logic.	1.33E-07	Yes	No
54	123	Reactor/turbine trip w/two stuck open pressurizer SRVs which reclose at 3,000 s	Operator controls HHSI (10 minute delay). Updated control logic.	1.65E-07	Yes	Yes at 32 EFPY
55	124	Reactor/turbine trip w/two stuck open pressurizer SRVs which reclose at 6,000 s	Operator controls HHSI (10 minute delay). Updated control logic.	1.65E-07	Yes	No
56	125	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 6,000 s	Operator controls HHSI (1 minute delay). Updated control logic.	1.34E-04	No	No
57	126	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 6,000 s	Operator controls HHSI (10 minute delay). Updated control logic.	1.87E-04	No	Yes at 32, 60, 100 EFPY
58	127	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 6,000 s	Operator controls HHSI (1 minute delay). Updated control logic.	2.59E-05	Yes	No
59	128	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 3,000 s	Operator controls HHSI (1 minute delay). Updated control logic.	2.59E-05	Yes	No
60	129	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 6,000 s	Operator controls HHSI (10 minute delay). Updated control logic.	3.09E-05	Yes	Yes at 32, 60 EFPY
61	130	Reactor/turbine trip w/one stuck open pressurizer SRV which recloses at 3,000 s	Operator controls HHSI (10 minute delay). Updated control logic.	3.09E-05	Yes	Yes at 32, 60, 100 EFPY

## Notes:

1. TH – Thermal hydraulics
2. LOCA – Loss-of-coolant accident
3. SBLOCA – Small-break loss-of-coolant accident
4. MBLOCA – Medium-break loss-of-coolant accident
5. LBLOCA – Large-break loss-of-coolant accident
6. HZP – Hot-zero power
7. SRV – Safety and relief valve
8. MSLB – Main steam line break
9. AFW – Auxiliary feedwater
10. HPI – High-pressure injection
11. RCPs – Reactor coolant pumps

\* The arbitrary definition of a dominant transient is a transient that contributes 1% or more of the total Through-Wall Cracking Failure (TWCF).

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**APPENDIX E**  
**BEAVER VALLEY UNIT 1 FAVPOST OUTPUT**

DRAFT



E-1: 10 Year ISI Only

```

*****
*
*           WELCOME TO FAVOR
*
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
*           VERSION 06.1
*
*   FAVPOST MODULE: POSTPROCESSOR MODULE
*   COMBINES TRANSIENT INITIATING FREQUENCIES
*   WITH RESULTS OF PFM ANALYSIS
*
*   PROBLEMS OR QUESTIONS REGARDING FAVOR
*   SHOULD BE DIRECTED TO
*
*           TERRY DICKSON
*   OAK RIDGE NATIONAL LABORATORY
*
*           e-mail: dickson1@ornl.gov
*
*****

```

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*****
* This computer program was prepared as an account of
* work sponsored by the United States Government
* Neither the United States, nor the United States
* Department of Energy, nor the United States Nuclear
* Regulatory Commission, nor any of their employees,
* nor any of their contractors, subcontractors, or their
* employees, makes any warranty, expressed or implied, or
* assumes any legal liability or responsibility for the
* accuracy, completeness, or usefulness of any
* information, apparatus, product, or process disclosed,
* or represents that its use would not infringe
* privately-owned rights.
*****

```

DATE: 03-May-2007 TIME: 16:02:21

```

Begin echo of FAVPost input data deck      16:02:21  03-May-2007
End echo of FAVPost input data deck        16:02:21  03-May-2007

```

```

FAVPOST INPUT FILE NAME           = postbv.in
FAVPEM OUTPUT FILE CONTAINING PFM1 ARRAY = INITIATE.DAT
FAVPEM OUTPUT FILE CONTAINING PFM2 ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME           = 70000.out (Change

```

~~this to 74000.out and include other associated changes)~~

```

*****
*
* WELCOME TO FAVOR
*
* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
* VERSION 05.1
*
* FAVORPOST MODULE: POSTPROCESSOR MODULE
* COMBINES TRANSIENT INITIATING FREQUENCIES
* WITH RESULTS OF FEM ANALYSIS
*
* PROBLEMS OR QUESTIONS REGARDING FAVOR
* SHOULD BE DIRECTED TO
*
* TERRY DICKSON
* OAK RIDGE NATIONAL LABORATORY
*
* e-mail: dickson@ornl.gov
*
*****

```

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*****
* This computer program was prepared as an account of
* work sponsored by the United States Government
* Neither the United States, nor the United States
* Department of Energy, nor the United States Nuclear
* Regulatory Commission, nor any of their employees,
* nor any of their contractors, subcontractors, or their
* employees, makes any warranty, expressed or implied, or
* assumes any legal liability or responsibility for the
* accuracy, completeness, or usefulness of any
* information, apparatus, product, or process disclosed,
* or represents that its use would not infringe
* privately owned rights.
*****

```

DATE: 04-Nov-2005 TIME: 10:28:56

```

FAVPOST INPUT FILE NAME = postbv.in
FAVFEM OUTPUT FILE CONTAINING FEM1 ARRAY = INITIATE.DAT
FAVFEM OUTPUT FILE CONTAINING FEM2 ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME = 76000.out

```

```

*****
* NUMBER OF SIMULATIONS = 70000 *
*****

```

## E-1: 10 Year ISI Only (cont.)

\*\*\*\*\*  
 \* NUMBER OF SIMULATIONS = 70000 \*  
 \*\*\*\*\*

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=F(F E)			RATIO CPFmn/CPImm
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
3	3.4447E-07	0.0000E+00	0.0000E+00	1.0487E-08	0.0000E+00	0.0000E+00	0.0304
7	2.4538E-03	5.7840E-03	2.9648E-02	8.9261E-06	1.7129E-04	1.6542E-04	0.0036
9	3.5917E-03	8.8320E-03	4.7025E-02	9.1001E-06	1.5080E-04	1.8094E-04	0.0025
14	2.8062E-09	0.0000E+00	0.0000E+00	3.9534E-11	0.0000E+00	0.0000E+00	0.0141
31	3.1040E-06	0.0000E+00	9.1224E-07	6.5429E-09	0.0000E+00	0.0000E+00	0.0021
34	3.6725E-06	0.0000E+00	8.8530E-06	1.3780E-08	0.0000E+00	0.0000E+00	0.0038
56	3.6233E-03	8.4587E-03	4.0163E-02	1.5372E-05	2.1788E-04	2.9507E-04	0.0042
59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
60	1.8872E-05	2.1105E-04	1.4508E-04	1.9606E-05	2.1105E-04	1.4063E-04	0.9859
61	2.7682E-05	3.6093E-04	3.3554E-04	5.9360E-06	9.8116E-05	6.4286E-05	0.2162
62	8.8381E-06	0.0000E+00	3.9900E-05	5.3279E-06	0.0000E+00	5.4892E-06	0.6028
64	3.0356E-04	2.4273E-03	4.1264E-03	3.3421E-07	0.0000E+00	8.1349E-08	0.0011
65	1.2194E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
66	2.6208E-05	3.6093E-04	2.9981E-04	1.4196E-07	0.0000E+00	7.0609E-08	0.0054
67	4.2327E-06	0.0000E+00	4.7032E-05	2.0694E-07	0.0000E+00	1.1577E-06	0.0489
68	4.0785E-07	0.0000E+00	0.0000E+00	3.6585E-07	0.0000E+00	0.0000E+00	0.8970
69	6.2806E-04	1.6800E-03	9.3269E-03	4.6732E-04	1.6799E-03	6.5428E-03	0.7441
70	3.3801E-04	2.4275E-03	4.9362E-03	4.7246E-05	6.4369E-04	6.3369E-04	0.1398
71	1.7881E-05	3.7377E-04	1.5558E-04	1.6288E-05	3.7377E-04	1.0611E-04	0.9109
72	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
73	4.1554E-06	6.8843E-05	4.5561E-05	8.3562E-08	0.0000E+00	3.6136E-07	0.0201
74	1.1710E-07	0.0000E+00	0.0000E+00	4.4526E-09	0.0000E+00	0.0000E+00	0.0380
76	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
78	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
81	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
82	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000

E-1: 10 Year ISI Only (cont.)

83	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
92	2.7070E-04	1.1915E-03	3.0316E-03	1.0747E-06	6.0187E-05	8.1838E-06	0.0047
93	2.3070E-04	1.1915E-03	3.0316E-03	1.0747E-06	6.0187E-05	8.1838E-06	0.0047
94	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
97	7.7573E-05	6.7177E-04	1.2231E-03	7.4960E-05	6.7177E-04	1.1540E-03	0.9663
102	1.6387E-06	0.0000E+00	0.0000E+00	2.8950E-08	0.0000E+00	0.0000E+00	0.0177
103	2.5650E-05	3.9193E-04	2.2038E-04	2.0631E-06	0.0000E+00	2.3905E-06	0.0804
104	1.6387E-06	0.0000E+00	0.0000E+00	2.8950E-08	0.0000E+00	0.0000E+00	0.0177
105	1.8207E-07	0.0000E+00	0.0000E+00	9.2460E-09	0.0000E+00	0.0000E+00	0.0508
106	1.5553E-06	0.0000E+00	0.0000E+00	3.0059E-08	0.0000E+00	0.0000E+00	0.0193
107	2.5612E-05	3.5810E-04	1.8762E-04	2.6496E-06	0.0000E+00	3.9040E-06	0.1035
108	5.8945E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
109	5.1071E-08	0.0000E+00	0.0000E+00	2.9873E-09	0.0000E+00	0.0000E+00	0.0585
110	5.8945E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
111	5.1071E-08	0.0000E+00	0.0000E+00	2.9873E-09	0.0000E+00	0.0000E+00	0.0585
112	4.9435E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
113	3.8359E-07	0.0000E+00	0.0000E+00	1.1730E-09	0.0000E+00	0.0000E+00	0.0031
114	3.2501E-05	2.9625E-04	5.5873E-04	1.8948E-07	0.0000E+00	1.0536E-06	0.0058
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	3.2756E-05	1.4620E-04	7.1227E-04	2.0959E-07	0.0000E+00	1.8495E-06	0.0064
117	1.3498E-04	8.6111E-04	1.6687E-03	6.1235E-07	1.7625E-05	5.7374E-06	0.0045
118	1.0922E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
119	5.2979E-06	0.0000E+00	2.6217E-05	1.2116E-07	0.0000E+00	5.0497E-08	0.0229
120	2.2859E-05	6.2652E-04	1.8086E-04	1.8474E-05	6.2025E-04	9.6291E-05	0.8082
121	1.9161E-04	1.0949E-03	2.4748E-03	1.6094E-06	5.2227E-05	5.0140E-06	0.0084
122	1.9161E-04	1.0949E-03	2.4748E-03	5.0299E-07	0.0000E+00	1.0741E-07	0.0026
123	4.9718E-04	1.5265E-03	7.3133E-03	3.7011E-04	1.5265E-03	4.8876E-03	0.7444
124	2.1942E-04	1.0951E-03	2.8781E-03	3.2633E-05	1.0262E-03	2.0102E-04	0.1487
125	2.2644E-08	0.0000E+00	0.0000E+00	1.4703E-12	0.0000E+00	0.0000E+00	0.0001
126	3.2134E-06	0.0000E+00	1.0696E-05	3.0296E-06	0.0000E+00	9.4015E-06	0.9428
127	3.3065E-05	4.2287E-04	4.9126E-04	7.0810E-08	0.0000E+00	2.4099E-08	0.0021
128	3.3065E-05	4.2287E-04	4.9126E-04	7.0810E-08	0.0000E+00	2.4099E-08	0.0021
129	3.5962E-05	4.2289E-04	5.6359E-04	4.2114E-06	1.0047E-04	2.8955E-05	0.1171
130	6.4214E-05	4.8542E-04	9.0405E-04	3.7700E-05	4.8057E-04	4.3728E-04	0.5871

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI-P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF-P(F E)			RATIO CPF <sub>mn</sub> /CPI <sub>mn</sub>
	MEAN	95th %	99th %	MEAN	95th %	99th %	
	CPI	CPI	CPI	CPF	CPF	CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
3	7.6374E-07	0.0000E+00	0.0000E+00	5.5035E-10	0.0000E+00	0.0000E+00	0.0007
7	2.7571E-03	5.6821E-03	3.3310E-02	2.2374E-05	1.3975E-04	2.1081E-04	0.0081
9	3.2069E-03	6.4951E-03	2.2593E-02	1.5386E-05	1.3201E-04	2.5868E-04	0.0048
14	3.8125E-08	0.0000E+00	0.0000E+00	1.8254E-12	0.0000E+00	0.0000E+00	0.0000
31	3.7578E-06	0.0000E+00	5.2939E-06	9.7546E-09	0.0000E+00	0.0000E+00	0.0026
34	3.2068E-06	0.0000E+00	3.1590E-06	5.4857E-09	0.0000E+00	0.0000E+00	0.0017
50	3.0133E-03	5.9261E-03	2.5996E-02	1.1795E-05	1.8407E-04	1.9278E-04	0.0039
59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
60	1.6254E-05	3.3482E-04	4.7535E-05	1.6188E-05	3.3482E-04	4.6936E-05	0.9960
61	3.2188E-05	1.0222E-03	4.2646E-04	9.7772E-06	1.6071E-04	1.2352E-04	0.3038

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<del>62</del>	<del>6.7799E-06</del>	<del>0.0000E+00</del>	<del>1.1850E-05</del>	<del>3.7461E-06</del>	<del>0.0000E+00</del>	<del>2.5715E-07</del>	<del>0.5525</del>
<del>64</del>	<del>5.9938E-05</del>	<del>6.6389E-04</del>	<del>8.3149E-04</del>	<del>1.4250E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0024</del>
<del>65</del>	<del>1.6724E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>66</del>	<del>3.0302E-05</del>	<del>1.0222E-03</del>	<del>4.0011E-04</del>	<del>2.8466E-07</del>	<del>0.0000E+00</del>	<del>7.6395E-08</del>	<del>0.0094</del>
<del>67</del>	<del>2.5244E-06</del>	<del>0.0000E+00</del>	<del>1.2032E-06</del>	<del>1.8558E-09</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0007</del>
<del>68</del>	<del>7.3375E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>3.3318E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.5290</del>
<del>69</del>	<del>4.6965E-04</del>	<del>2.6882E-03</del>	<del>5.9400E-03</del>	<del>3.4299E-04</del>	<del>2.3854E-03</del>	<del>3.4546E-03</del>	<del>0.7303</del>
<del>70</del>	<del>1.2588E-04</del>	<del>1.4959E-03</del>	<del>2.5843E-03</del>	<del>2.4716E-05</del>	<del>1.4959E-03</del>	<del>1.6818E-04</del>	<del>0.1963</del>
<del>71</del>	<del>1.1163E-05</del>	<del>0.0000E+00</del>	<del>4.2542E-05</del>	<del>1.0078E-05</del>	<del>0.0000E+00</del>	<del>3.4650E-05</del>	<del>0.9028</del>
<del>72</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>73</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>74</del>	<del>9.4097E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>1.4446E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.1535</del>
<del>76</del>	<del>1.5000E-12</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>78</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>81</del>	<del>3.0845E-10</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>82</del>	<del>2.0239E-09</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>1.9682E-09</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.9725</del>
<del>83</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>

<del>92</del>	<del>2.5221E-04</del>	<del>2.6882E-03</del>	<del>4.3698E-03</del>	<del>2.4069E-06</del>	<del>1.3492E-04</del>	<del>1.7547E-05</del>	<del>0.0095</del>
<del>93</del>	<del>2.5221E-04</del>	<del>2.6882E-03</del>	<del>4.3698E-03</del>	<del>2.4069E-06</del>	<del>1.3492E-04</del>	<del>1.7547E-05</del>	<del>0.0095</del>
<del>94</del>	<del>9.3226E-10</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>97</del>	<del>4.2917E-05</del>	<del>1.3064E-03</del>	<del>3.8919E-04</del>	<del>4.1429E-05</del>	<del>1.3064E-03</del>	<del>3.5267E-04</del>	<del>0.9653</del>
<del>102</del>	<del>7.6743E-06</del>	<del>0.0000E+00</del>	<del>1.8991E-05</del>	<del>3.8212E-07</del>	<del>0.0000E+00</del>	<del>5.7475E-08</del>	<del>0.0498</del>

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E-1: 10 Year ISI Only (cont.)

103	7.4101E-05	1.7535E-03	1.2240E-03	1.0560E-05	3.3704E-04	1.0577E-04	0.1425
104	7.6743E-06	0.0000E+00	1.8991E-05	3.3212E-07	0.0000E+00	5.7475E-08	0.0498
105	9.7900E-07	0.0000E+00	0.0000E+00	2.3627E-07	0.0000E+00	0.0000E+00	0.2413
106	7.3240E-05	0.0000E+00	1.9911E-05	3.0346E-07	0.0000E+00	6.1572E-08	0.0403
107	6.2004E-05	1.6508E-03	6.8517E-04	1.2311E-05	3.3756E-04	1.3610E-04	0.1986
108	4.6067E-08	0.0000E+00	0.0000E+00	5.4710E-11	0.0000E+00	0.0000E+00	0.0012
109	3.6621E-07	0.0000E+00	0.0000E+00	1.2338E-08	0.0000E+00	0.0000E+00	0.0337
110	4.6067E-08	0.0000E+00	0.0000E+00	5.4710E-11	0.0000E+00	0.0000E+00	0.0012
111	3.6621E-07	0.0000E+00	0.0000E+00	1.2338E-08	0.0000E+00	0.0000E+00	0.0337
112	4.1576E-08	0.0000E+00	0.0000E+00	5.2737E-11	0.0000E+00	0.0000E+00	0.0013
113	2.5716E-07	0.0000E+00	0.0000E+00	1.8363E-08	0.0000E+00	0.0000E+00	0.0714
114	2.1511E-05	8.1510E-04	2.8659E-04	5.8566E-08	0.0000E+00	0.0000E+00	0.0027
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	1.0473E-05	5.9788E-04	7.0627E-05	1.4761E-08	0.0000E+00	0.0000E+00	0.0014
117	5.1424E-05	5.0747E-04	8.3700E-04	2.1688E-08	0.0000E+00	0.0000E+00	0.0004
118	9.3071E-08	0.0000E+00	0.0000E+00	4.5498E-10	0.0000E+00	0.0000E+00	0.0049
119	5.4721E-06	0.0000E+00	1.2451E-05	1.7745E-08	0.0000E+00	0.0000E+00	0.0032
120	1.6463E-05	7.3530E-04	9.9671E-05	1.0717E-05	7.3525E-04	3.0519E-05	0.6510
121	6.0575E-05	2.4970E-03	6.5834E-04	9.1184E-08	0.0000E+00	3.4630E-09	0.0015
122	6.0575E-05	2.4970E-03	6.5834E-04	9.1115E-09	0.0000E+00	0.0000E+00	0.0002
123	2.1671E-04	2.4970E-03	2.9800E-03	1.8248E-04	2.1693E-03	2.4295E-03	0.8420
124	7.2595E-05	2.4970E-03	8.1638E-04	1.3063E-05	1.1486E-03	3.5391E-05	0.1799
125	1.0684E-07	0.0000E+00	0.0000E+00	2.5450E-11	0.0000E+00	0.0000E+00	0.0003
126	4.0844E-06	0.0000E+00	1.3341E-06	3.9031E-06	0.0000E+00	1.1204E-06	0.9556
127	2.3342E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
128	2.3342E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
129	2.8388E-06	0.0000E+00	1.4336E-07	1.7696E-06	0.0000E+00	9.2881E-09	0.6234
130	1.2370E-05	0.0000E+00	1.8447E-05	1.1955E-05	0.0000E+00	1.6861E-05	0.9665

NOTES: CFI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)

CFE IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)



## E-1: 10 Year ISI Only (cont.)

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 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
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FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	16.2600	16.2600
1.3009E-06	78.7386	94.9986
3.9026E-06	2.5114	97.5100
6.5043E-06	1.0343	98.5443
9.1060E-06	0.5171	99.0614
1.1708E-05	0.2743	99.3357
1.4309E-05	0.1857	99.5214
1.6911E-05	0.1057	99.6271
1.9513E-05	0.0586	99.6857
2.2115E-05	0.3529	99.7586
2.4716E-05	0.0357	99.7943
2.7318E-05	0.0286	99.8229
2.9920E-05	0.0171	99.8400
3.2521E-05	0.0243	99.8643
3.5123E-05	0.0171	99.8814
3.7725E-05	0.0123	99.8937
4.0327E-05	0.0114	99.9051
4.2928E-05	0.0086	99.9137
4.5530E-05	0.0100	99.9237
4.8132E-05	0.0057	99.9314
5.0733E-05	0.0043	99.9357
5.3335E-05	0.0043	99.9400
5.5937E-05	0.0029	99.9429
5.8539E-05	0.0014	99.9443
6.1140E-05	0.0014	99.9457
6.3742E-05	0.0086	99.9543
6.6344E-05	0.0014	99.9557
6.8946E-05	0.0071	99.9629
7.1547E-05	0.0029	99.9657
7.4149E-05	0.0014	99.9671
7.6751E-05	0.0014	99.9686
7.9352E-05	0.0029	99.9714
8.1954E-05	0.0029	99.9743
8.4556E-05	0.0014	99.9757
8.7158E-05	0.0014	99.9771
8.9760E-05	0.0014	99.9786
9.2361E-05	0.0014	99.9800
9.4963E-05	0.0014	99.9829
9.7564E-05	0.0014	99.9857
1.0797E-04	0.0029	99.9871
1.1057E-04	0.0029	99.9900
1.1838E-04	0.0014	99.9914
1.2098E-04	0.0029	99.9943
1.2879E-04	0.0014	99.9957
1.3919E-04	0.0029	99.9971
1.5480E-04	0.0029	99.9986

E-1: 10 Year ISI Only (cont.)

1.8082E-04            0.0014            99.9986  
 2.3546E-04            0.0014            100.0000

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 ==            Summary Descriptive Statistics            ==  
 =====

Minimum                            = 0.0000E+00  
 Maximum                            = 2.3451E-04  
 Range                                = 2.3451E-04  
  
 Number of Simulations            = 70000  
  
 5th Percentile                    = 0.0000E+00  
 Median                              = 1.0979E-08  
 95.0th Percentile                = 1.3009E-06  
 99.0th Percentile                = 8.7970E-06  
 99.9th Percentile                = 3.8701E-05  
  
 Mean                                 = 5.9461E-07  
 Standard Deviation                = 3.3139E-06  
 Standard Error                    = 1.2525E-08  
 Variance (unbiased)              = 1.0982E-11  
 Variance (biased)                 = 1.0982E-11  
 Moment Coeff. of Skewness        = 2.4476E+01  
 Pearson's 2nd Coeff. of Skewness = 5.3829E-01  
 Kurtosis                            = 1.0028E+03

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 \*            PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)            \*  
 \*            FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE)            \*  
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FREQUENCY OF THROUGH-WALL FAILURES (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	31.5414	31.5414
4.5123E-08	67.4686	99.0100
1.3537E-07	0.5000	99.5100
2.2561E-07	0.1786	99.6886
3.1586E-07	0.0843	99.7729
4.0611E-07	0.0543	99.8271
4.9635E-07	0.0400	99.8671
5.8660E-07	0.0257	99.8929
6.7684E-07	0.0186	99.9114
7.6709E-07	0.0157	99.9271
8.5733E-07	0.0100	99.9371
9.4758E-07	0.0100	99.9471

## E-1: 10 Year ISI Only (cont.)

1.0378E-06	0.0100	99.9571
1.1281E-06	0.0029	99.9600
1.2183E-06	0.0029	99.9629
1.3086E-06	0.0014	99.9643
1.4891E-06	0.0014	99.9657
1.5793E-06	0.0043	99.9700
1.6695E-06	0.0014	99.9714
1.7598E-06	0.0043	99.9757
1.8500E-06	0.0014	99.9771
1.9403E-06	0.0014	99.9786
2.0305E-06	0.0043	99.9829
2.2110E-06	0.0014	99.9843
2.3013E-06	0.0029	99.9871
2.7525E-06	0.0014	99.9886
2.8427E-06	0.0043	99.9929
3.2940E-06	0.0014	99.9943
3.4745E-06	0.0014	99.9957
4.1964E-06	0.0014	99.9971
5.3696E-06	0.0014	99.9986
8.8892E-06	0.0014	100.0000

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== Summary Descriptive Statistics ==
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Minimum = 0.0000E+00
Maximum = 8.9343E-06
Range = 8.9343E-06

Number of Simulations = 70000

5th Percentile = 0.0000E+00
Median = 3.2629E-13
95.0th Percentile = 4.5123E-08
99.0th Percentile = 8.9609E-08
99.9th Percentile = 6.2131E-07

Mean = 5.0396E-09
Standard Deviation = 6.7097E-08
Standard Error = 2.5360E-10
Variance (unbiased) = 4.5020E-15
Variance (biased) = 4.5019E-15
Moment Coeff. of Skewness = 5.9654E+01
Pearson's 2nd Coeff. of Skewness = -2.6549E-01
Kurtosis = 5.8120E+03

```

```

*****
* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION *
* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - *
* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES *
*****

```

## E-1: 10 Year ISI Only (cont.)

	% of total frequency of crack initiation	% of total frequency of of TWC failure
2	0.00	0.00
3	0.01	0.03
7	2.62	1.25
9	1.18	0.37
14	0.00	0.00
31	0.00	0.00
34	0.00	0.00
56	93.99	43.32
59	0.00	0.00
60	0.08	3.80
61	0.01	0.23
62	0.00	0.00
64	0.00	0.00
65	0.00	0.00
66	0.01	0.00
67	0.00	0.01
68	0.00	0.00
69	0.00	0.23
70	0.00	0.03
71	0.01	1.29
72	0.00	0.00
73	0.00	0.00
74	0.00	0.00
76	0.00	0.00
77	0.00	0.00
81	0.00	0.00
82	0.00	0.00
83	0.00	0.00
82	0.01	0.00
94	0.00	0.00
97	0.05	6.07
102	0.03	0.08
103	0.05	0.44
104	0.03	0.04
105	0.00	0.00
106	0.00	0.00
107	0.00	0.02
108	0.00	0.00
109	0.00	0.00
110	0.00	0.00
111	0.00	0.00
112	0.00	0.00
113	0.00	0.00
114	0.72	0.46
115	0.00	0.00
116	0.03	0.03
117	0.14	0.08
118	0.00	0.00
119	0.00	0.00
120	0.00	0.42

## E-1: 10 Year ISI Only (cont.)

121	0.00	0.01
122	0.00	0.00
123	0.02	1.34
124	0.01	0.14
125	0.00	0.00
126	0.10	10.65
127	0.18	0.04
128	0.15	0.04
129	0.21	2.56
130	0.32	22.00

TOTALS 100.00 100.00

DATE: 03-May-2007 TIME: 16:03:48

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	0.2186	0.2186
2.3948E-06	0.0957	98.2143
7.1845E-06	0.0371	99.2514
1.1974E-05	0.3443	99.5957
1.8764E-05	0.1600	99.7557
2.1553E-05	0.0643	99.8200
2.6343E-05	0.0514	99.8714
3.1133E-05	0.0343	99.9057
3.5922E-05	0.0214	99.9271
4.0712E-05	0.0086	99.9357
4.5502E-05	0.0086	99.9443
5.0291E-05	0.0057	99.9500
5.5081E-05	0.0043	99.9543
5.9871E-05	0.0043	99.9586
6.4660E-05	0.0043	99.9629
6.9450E-05	0.0100	99.9729
7.4240E-05	0.0057	99.9786
7.9029E-05	0.0014	99.9800
8.3819E-05	0.0014	99.9814
1.0298E-04	0.0014	99.9829
1.0777E-04	0.0029	99.9857
1.1256E-04	0.0014	99.9871
1.1608E-04	0.0029	99.9900
1.1556E-04	0.0014	99.9914
1.1524E-04	0.0014	99.9929
1.1903E-04	0.0014	99.9943
1.1482E-04	0.0014	99.9957
1.9877E-04	0.0014	99.9971
2.6104E-04	0.0014	99.9986
4.7657E-04	0.0014	100.0000

=====  
Summary Descriptive Statistics  
=====

Minimum	= 0.0000E+00
Maximum	= 4.7418E-04
Range	= 4.7418E-04
Number of Simulations	= 70000
5th Percentile	= 2.72105E-10
Median	= 5.8229E-08
95.0th Percentile	= 2.3948E-06
99.0th Percentile	= 6.0234E-06

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## E-1: 10 Year ISI Only (cont.)

99.9th Percentile	= 3.0334E-05
Mean	= 5.4171E-07
Standard Deviation	= 3.5373E-06
Standard Error	= 1.3370E-08
Variance (unbiased)	= 1.2512E-11
Variance (biased)	= 1.2512E-11
Moment Coeff. of Skewness	= 5.6550E+01
Pearson's 2nd Coeff. of Skewness	= 4.5943E-01
Kurtosis	= 5.6636E+03

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	0.3643	99.3643
9.0896E-08	0.00371	99.6014
2.7269E-07	0.00129	99.8143
4.5448E-07	0.0529	99.8671
6.3327E-07	0.0257	99.8929
8.1803E-07	0.0200	99.9129
9.9987E-07	0.0157	99.9286
1.1816E-06	0.0043	99.9329
1.3634E-06	0.0071	99.9400
1.5452E-06	0.0100	99.9500
1.7270E-06	0.0143	99.9643
1.9088E-06	0.0057	99.9700
2.0906E-06	0.0057	99.9757
2.2724E-06	0.0043	99.9800
2.4542E-06	0.0014	99.9814
2.6360E-06	0.0014	99.9829
2.8178E-06	0.0014	99.9843
3.0000E-06	0.0014	99.9857
3.1822E-06	0.0029	99.9886
3.3644E-06	0.0014	99.9900
3.5466E-06	0.0014	99.9914
3.7288E-06	0.0014	99.9929
3.9110E-06	0.0014	99.9943
4.0932E-06	0.0014	99.9957
4.2754E-06	0.0014	99.9971
4.4576E-06	0.0014	99.9986
4.6398E-06	0.0014	100.0000

=====  
 Summary Descriptive Statistics  
 =====

E-1: 10 Year ISI Only (cont.)

Minimum	= 0.0000E+00
Maximum	= 1.7997E-05
Range	= 1.7997E-05
Number of Simulations	= 70000
5th Percentile	= 0.0000E+00
Median	= 2.2644E-12
95.0th Percentile	= 2.0896E-08
99.0th Percentile	= 5.9436E-08
99.9th Percentile	= 7.0119E-07
Mean	= 5.0405E-09
Standard Deviation	= 1.2772E-07
Standard Error	= 4.3927E-10
Variance (unbiased)	= 1.6311E-14
Variance (biased)	= 1.6311E-14
Moment Coeff. of Skewness	= 8.8158E+01
Pearson's 2nd Coeff. of Skewness	= 1.2494E+00
Kurtosis	= 9.8765E+03

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
2	0.00	0.00
3	0.02	0.00
4	15.92	14.79
6	5.97	2.61
14	0.00	0.00
31	0.00	0.00
34	0.00	0.00
58	76.28	31.09
59	0.00	0.00
60	0.09	10.11
61	0.01	0.37
62	0.00	0.01
64	0.00	0.00
65	0.00	0.00
66	0.01	0.01
67	0.00	0.00
68	0.00	0.00
69	0.00	0.18
70	0.00	0.01
71	0.01	1.13
72	0.00	0.00
73	0.00	0.00
74	0.00	0.00
76	0.00	0.00



E-1: 10 Year ISI Only (cont.)

78	0.00	0.00
81	0.00	0.00
82	0.00	0.00
83	0.00	0.00
92	0.01	0.01
93	0.01	0.01
94	0.00	0.00
97	0.04	3.88
102	0.10	0.74
103	0.16	2.23
104	0.17	0.93
105	0.00	0.07
106	0.01	0.01
107	0.01	0.10
108	0.01	0.00
109	0.01	0.01
110	0.01	0.00
111	0.00	0.01
112	0.00	0.00
113	0.00	0.00
114	0.47	0.14
115	0.00	0.00
116	0.05	0.00
117	0.25	0.01
118	0.00	0.00
119	0.00	0.00
120	0.00	0.29
121	0.00	0.00
122	0.00	0.00
123	0.01	0.69
124	0.00	0.04
125	0.00	0.00
126	0.19	19.41
127	0.00	0.00
128	0.00	0.00
129	0.01	0.86
130	0.08	8.23
TOTALS	100.00	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \* BY \*  
 \* RPV BELTLINE MAJOR REGION \*  
 \* BY PARENT SUBREGION \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

E-1: 10 Year ISI Only (cont.)

		<del>% of</del>	<del>% of total</del>	<del>% of total</del>	<del>through wall crack</del>
<del>MAJOR</del>	<del>RTndt</del>	<del>total</del>	<del>frequency of</del>	<del>frequency</del>	
<del>REGION</del>	<del>(MLX)</del>	<del>flaws</del>	<del>crack initiation</del>	<del>cleavage ductile</del>	<del>total</del>
DATE: 04-Nov-2005 TIME: 10:30:14					

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E-2: ISI Every 10 Years

```
*****  
*  
* WELCOME TO FAVOR *  
*  
* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE *  
* VERSION 06.1 *  
*  
* FAVPOST MODULE: POSTPROCESSOR MODULE *  
* COMBINES TRANSIENT INITIATING FREQUENCIES *  
* WITH RESULTS OF PFM ANALYSIS *  
*  
* PROBLEMS OR QUESTIONS REGARDING FAVOR *  
* SHOULD BE DIRECTED TO *  
*  
* TERRY DICKSON *  
* OAK RIDGE NATIONAL LABORATORY *  
*  
* e-mail: dickson1@ornl.gov *  
*  
*****
```

```
*****  
* This computer program was prepared as an account of *  
* work sponsored by the United States Government *  
* Neither the United States, nor the United States *  
* Department of Energy, nor the United States Nuclear *  
* Regulatory Commission, nor any of their employees, *  
* nor any of their contractors, subcontractors, or their *  
* employees, makes any warranty, expressed or implied, or *  
* assumes any legal liability or responsibility for the *  
* accuracy, completeness, or usefulness of any *  
* information, apparatus, product, or process disclosed, *  
* or represents that its use would not infringe *  
* privately owned rights. *  
*****
```

DATE: 03-May-2007 TIME: 15:03:08

Begin echo of FAVPost input data deck 15:03:08 03-May-2007  
End echo of FAVPost input data deck 15:03:08 03-May-2007

FAVPOST INPUT FILE NAME = postbv.in  
FAVPFM OUTPUT FILE CONTAINING PFM1 ARRAY = INITIATE.DAT  
FAVPFM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT  
FAVPOST OUTPUT FILE NAME = 70000.out (Change  
~~this to 74000.out and include other associated changes)~~

```
*****  
*  
* WELCOME TO FAVOR *  
*  
* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE *  
* VERSION 05.1 *  
*  
* FAVORPOST MODULE: POSTPROCESSOR MODULE *  
* COMBINES TRANSIENT INITIATING FREQUENCIES *  
* WITH RESULTS OF FEM ANALYSIS *  
*  
* PROBLEMS OR QUESTIONS REGARDING FAVOR *  
* SHOULD BE DIRECTED TO *  
*  
* TERRY DICKSON *  
* OAK RIDGE NATIONAL LABORATORY *  
*  
* e-mail: dicksentl@ornl.gov *  
*  
*****
```

```
*****  
* This computer program was prepared as an account of *  
* work sponsored by the United States Government *  
* Neither the United States, nor the United States *  
* Department of Energy, nor the United States Nuclear *  
* Regulatory Commission, nor any of their employees, *  
* nor any of their contractors, subcontractors, or their *  
* employees, makes any warranty, expressed or implied, or *  
* assumes any legal liability or responsibility for the *  
* accuracy, completeness, or usefulness of any *  
* information, apparatus, product, or process disclosed, *  
* or represents that its use would not infringe *  
* privately owned rights. *  
*****
```

DATE: 04 Nov 2005 TIME: 10:56:03

```
FAVPOST INPUT FILE NAME = postbv.in  
FAVPEM OUTPUT FILE CONTAINING FEM1 ARRAY = INITIATE.DAT  
FAVPEM OUTPUT FILE CONTAINING FEM2 ARRAY = FAILURE.DAT  
FAVPOST OUTPUT FILE NAME = 70000.out
```

```
*****  
* NUMBER OF SIMULATIONS = 70000 *  
*****
```

## E-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* NUMBER OF SIMULATIONS = 70000 \*  
 \*\*\*\*\*

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPFmn/CFImn
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
3	2.9800E-07	0.0000E+00	0.0000E+00	1.0009E-11	0.0000E+00	0.0000E+00	0.0000
7	2.3214E-03	5.3036E-03	3.1228E-02	9.5073E-06	1.6615E-04	1.5375E-04	0.0041
9	3.4412E-03	8.2533E-03	4.6458E-02	9.7557E-06	1.2533E-04	1.6701E-04	0.0028
14	9.1393E-09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
31	2.9830E-06	0.0000E+00	5.6087E-07	6.0712E-09	0.0000E+00	0.0000E+00	0.0020
34	3.5119E-06	0.0000E+00	1.7572E-06	8.9484E-10	0.0000E+00	0.0000E+00	0.0003
56	3.4601E-03	7.9216E-03	3.9985E-02	1.6170E-05	2.0726E-04	2.7235E-04	0.0047
59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
60	2.0168E-05	3.2408E-04	1.3509E-04	1.0908E-05	3.0787E-04	1.3395E-04	0.9871
61	2.7685E-05	8.4773E-04	3.2463E-04	6.6560E-06	1.7053E-04	6.1162E-05	0.2404
62	7.5949E-06	0.0000E+00	1.9721E-05	4.0857E-06	0.0000E+00	8.8105E-07	0.5380
64	2.2973E-04	2.4655E-03	3.8380E-03	1.4364E-07	0.0000E+00	1.7605E-09	0.0006
65	2.2001E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
66	2.6002E-05	8.4773E-04	2.9721E-04	2.3979E-07	0.0000E+00	1.4232E-08	0.0092
67	2.0237E-06	0.0000E+00	1.0314E-08	4.1104E-10	0.0000E+00	0.0000E+00	0.0002
68	3.1241E-07	0.0000E+00	0.0000E+00	2.5031E-07	0.0000E+00	0.0000E+00	0.8012
69	6.2793E-04	2.3821E-03	0.8419E-03	4.7965E-04	2.3081E-03	6.1921E-03	0.7639
70	2.6032E-04	2.4655E-03	1.5217E-03	3.5399E-05	4.5620E-04	3.0528E-04	0.1360
71	1.1361E-05	0.0000E+00	1.1871E-05	1.1359E-05	0.0000E+00	2.1795E-05	0.9998
72	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
73	2.6310E-06	0.0000E+00	6.8862E-06	1.1986E-08	0.0000E+00	0.0000E+00	0.0046
74	1.9735E-07	0.0000E+00	0.0000E+00	4.1257E-09	0.0000E+00	0.0000E+00	0.0209
76	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
78	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
81	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
82	2.3896E-12	0.0000E+00	0.0000E+00	1.4423E-12	0.0000E+00	0.0000E+00	0.6036

## E-2: ISI Every 10 Years (cont.)

83	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
92	2.2151E-04	2.3171E-03	3.9602E-03	1.4445E-06	6.6444E-05	6.9896E-06	0.0065
93	2.2151E-04	2.3171E-03	3.9602E-03	1.4435E-06	6.6444E-05	6.9896E-06	0.0065
94	5.0580E-13	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
97	5.6862E-05	1.1055E-03	5.9676E-04	5.6592E-05	1.1055E-03	5.9102E-04	0.9953
102	2.3159E-06	0.0000E+00	0.0000E+00	1.7235E-08	0.0000E+00	0.0000E+00	0.0074
103	2.7193E-05	1.3062E-03	2.3097E-04	2.2622E-06	0.0000E+00	2.7032E-06	0.0832
104	2.3159E-06	0.0000E+00	0.0000E+00	1.7235E-08	0.0000E+00	0.0000E+00	0.0074
105	3.0512E-07	0.0000E+00	0.0000E+00	6.1501E-09	0.0000E+00	0.0000E+00	0.0202
106	2.2119E-06	0.0000E+00	0.0000E+00	2.0044E-08	0.0000E+00	0.0000E+00	0.0091
107	2.6872E-05	1.4079E-03	1.8487E-04	2.9860E-06	0.0000E+00	4.3421E-06	0.1111
108	6.2467E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
109	1.1837E-07	0.0000E+00	0.0000E+00	3.2204E-11	0.0000E+00	0.0000E+00	0.0003
110	6.2467E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
111	1.1837E-07	0.0000E+00	0.0000E+00	3.2204E-11	0.0000E+00	0.0000E+00	0.0003
112	6.2651E-10	0.0000E+00	0.0000E+00	2.9991E-18	0.0000E+00	0.0000E+00	0.0000
113	6.1401E-07	0.0000E+00	0.0000E+00	2.1350E-09	0.0000E+00	0.0000E+00	0.0035
114	2.4706E-05	7.7763E-04	3.1629E-04	5.7738E-08	0.0000E+00	0.0000E+00	0.0023
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	5.5954E-06	0.0000E+00	1.1859E-05	2.5625E-09	0.0000E+00	0.0000E+00	0.0005
117	1.2355E-04	1.5759E-03	2.1069E-03	8.5564E-07	3.3720E-05	3.4261E-06	0.0069
118	2.7278E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
119	4.5739E-06	0.0000E+00	3.4377E-06	1.5422E-08	0.0000E+00	0.0000E+00	0.0034
120	2.0558E-05	4.1262E-04	1.0483E-04	1.6115E-05	3.6562E-04	5.0320E-05	0.7839
121	1.8168E-04	2.1666E-03	3.0167E-03	1.5012E-06	7.2990E-05	2.5174E-06	0.0093
122	1.8168E-04	2.1666E-03	3.1073E-03	4.0757E-07	0.0000E+00	7.5126E-08	0.0022
123	5.0111E-04	2.1906E-03	6.5400E-03	3.8406E-04	2.0773E-03	4.9104E-03	0.7664
124	2.0576E-04	2.1666E-03	8.6134E-03	2.8451E-05	6.1944E-04	1.8793E-04	0.1383
125	5.2120E-08	0.0000E+00	0.0000E+00	2.5396E-13	0.0000E+00	0.0000E+00	0.0000
126	3.4102E-06	0.0000E+00	7.9349E-07	3.2667E-06	0.0000E+00	6.8717E-07	0.9579
127	2.6738E-05	2.5191E-04	3.1581E-04	2.6252E-12	0.0000E+00	0.0000E+00	0.0000
128	2.6738E-05	2.5191E-04	3.1581E-04	2.6252E-12	0.0000E+00	0.0000E+00	0.0000
129	2.9639E-05	2.5191E-04	2.7032E-04	2.9210E-06	0.0000E+00	7.9206E-07	0.0986
130	5.5626E-05	9.5051E-04	7.2434E-04	3.2049E-05	9.4101E-04	2.4706E-04	0.5762

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPF <sub>mn</sub> /CPI <sub>mn</sub>
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
3	7.3099E-07	0.0000E+00	0.0000E+00	4.5869E-10	0.0000E+00	0.0000E+00	0.0006
7	2.6095E-03	5.3460E-03	3.1509E-02	2.3240E-05	1.6898E-07	2.2607E-04	0.0039
9	3.0658E-03	6.2771E-03	4.0860E-02	1.7123E-05	1.3425E-04	2.5602E-04	0.0056
14	2.2735E-08	0.0000E+00	0.0000E+00	1.0830E-13	0.0000E+00	0.0000E+00	0.0000
31	3.6059E-06	0.0000E+00	3.3987E-06	4.3053E-09	0.0000E+00	0.0000E+00	0.0013
34	2.8045E-06	0.0000E+00	6.7039E-07	2.5594E-09	0.0000E+00	0.0000E+00	0.0009
56	2.8825E-03	5.6301E-03	3.4746E-02	1.2533E-05	1.5293E-04	1.6910E-04	0.0043
59	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
60	1.1138E-05	0.0000E+00	1.0644E-05	1.1125E-05	0.0000E+00	1.0497E-05	0.9968
61	2.9915E-05	6.2439E-04	3.4900E-04	0.3081E-06	1.5377E-04	9.9742E-05	0.3144
62	4.7339E-06	0.0000E+00	6.2706E-06	1.8666E-06	0.0000E+00	2.1643E-06	0.4154
64	5.4989E-05	1.9871E-03	5.5502E-04	6.0010E-08	0.0000E+00	0.0000E+00	0.0011
65	1.5967E-07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
66	2.8258E-05	6.2439E-04	3.1813E-04	3.0198E-07	0.0000E+00	2.5370E-06	0.0107
67	2.3731E-06	0.0000E+00	6.2562E-07	9.1027E-10	0.0000E+00	0.0000E+00	0.0003
68	4.8167E-07	0.0000E+00	0.0000E+00	1.5477E-07	0.0000E+00	0.0000E+00	0.3213
69	4.4360E-04	1.8769E-03	5.9474E-03	3.2319E-04	1.4112E-03	3.9874E-03	0.7286
70	6.7323E-05	1.9871E-03	7.3304E-04	1.3026E-05	2.8848E-04	4.8209E-05	0.1935
71	2.9876E-06	0.0000E+00	2.9199E-07	2.9737E-06	0.0000E+00	2.5586E-07	0.9979
72	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
73	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
74	6.1491E-07	0.0000E+00	0.0000E+00	4.4065E-08	0.0000E+00	0.0000E+00	0.0541
76	6.3064E-11	0.0000E+00	0.0000E+00	2.4171E-13	0.0000E+00	0.0000E+00	0.0029
78	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
81	1.9977E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
82	2.0484E-12	0.0000E+00	0.0000E+00	1.3286E-12	0.0000E+00	0.0000E+00	0.6486
83	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
92	2.3879E-04	1.8768E-03	2.1861E-03	2.3813E-06	4.7982E-05	1.3929E-05	0.0100
93	2.3879E-04	1.8768E-03	2.1861E-03	2.3813E-06	4.7982E-05	1.3929E-05	0.0100
94	1.1629E-03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
97	1.9455E-05	7.4525E-04	5.5437E-05	1.9451E-05	7.4525E-04	5.5437E-05	0.9998

## E-2: ISI Every 10 Years (cont.)

102	7.6059E-06	0.0000E+00	1.7988E-05	3.4031E-07	0.0000E+00	3.2659E-08	0.0447
103	7.2086E-05	1.2014E-03	1.0838E-03	9.3180E-06	2.5629E-04	9.0875E-05	0.1293
104	7.6059E-06	0.0000E+00	1.7988E-05	3.4031E-07	0.0000E+00	3.2659E-08	0.0447
105	7.8222E-07	0.0000E+00	0.0000E+00	3.9488E-08	0.0000E+00	0.0000E+00	0.0505
106	7.7355E-06	0.0000E+00	1.9001E-05	3.1620E-07	0.0000E+00	3.6654E-08	0.0409
107	6.0651E-05	1.1241E-03	7.4550E-04	1.1002E-05	2.8868E-04	1.1158E-04	0.1814
108	3.4049E-08	0.0000E+00	0.0000E+00	1.5682E-10	0.0000E+00	0.0000E+00	0.0046
109	3.6270E-07	0.0000E+00	0.0000E+00	3.1459E-09	0.0000E+00	0.0000E+00	0.0087
110	3.4049E-08	0.0000E+00	0.0000E+00	1.5682E-10	0.0000E+00	0.0000E+00	0.0046
111	3.6270E-07	0.0000E+00	0.0000E+00	3.1459E-09	0.0000E+00	0.0000E+00	0.0087
112	2.9426E-08	0.0000E+00	0.0000E+00	1.5351E-10	0.0000E+00	0.0000E+00	0.0052
113	2.9348E-07	0.0000E+00	0.0000E+00	3.7048E-09	0.0000E+00	0.0000E+00	0.0297
114	1.5853E-05	4.8071E-04	1.1595E-04	1.6236E-08	0.0000E+00	0.0000E+00	0.0010
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	9.9888E-06	3.4660E-04	6.2966E-05	3.0747E-09	0.0000E+00	0.0000E+00	0.0009
117	4.1320E-05	5.8616E-04	6.6857E-04	1.0703E-08	0.0000E+00	0.0000E+00	0.0005
118	9.1276E-08	0.0000E+00	0.0000E+00	4.3537E-10	0.0000E+00	0.0000E+00	0.0048
119	5.1182E-06	0.0000E+00	9.4538E-06	3.1800E-09	0.0000E+00	0.0000E+00	0.0016
120	1.1915E-05	3.3334E-04	5.4145E-05	6.9078E-06	0.0000E+00	6.5630E-06	0.5797
121	5.0631E-05	1.7120E-03	4.3095E-04	2.3141E-08	0.0000E+00	1.0207E-11	0.0006
122	5.0631E-05	1.7120E-03	4.5095E-04	6.3711E-09	0.0000E+00	0.0000E+00	0.0001
123	1.8872E-04	1.7120E-03	2.8004E-03	1.5743E-04	1.2600E-03	2.2751E-03	0.8342
124	5.8284E-05	1.7120E-03	6.4134E-04	8.0551E-06	1.9826E-04	2.3633E-05	0.1382
125	7.4039E-08	0.0000E+00	0.0000E+00	5.9480E-11	0.0000E+00	0.0000E+00	0.0008
126	2.3632E-06	0.0000E+00	1.2657E-07	2.2871E-06	0.0000E+00	9.7627E-08	0.9678
127	1.5164E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
128	1.5164E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
129	8.7384E-07	0.0000E+00	0.0000E+00	8.5868E-07	0.0000E+00	0.0000E+00	0.9826
130	6.3755E-06	0.0000E+00	7.5345E-06	8.3596E-06	0.0000E+00	7.1473E-06	0.9981

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)



## E-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	16.2857	16.2857
1.2622E-06	78.7129	94.9986
3.7866E-06	2.5743	97.5729
6.3111E-06	0.9743	98.5471
8.8355E-06	0.4671	99.0142
1.1360E-05	0.2614	99.2756
1.3884E-05	0.1829	99.4585
1.6409E-05	0.1029	99.5614
1.8933E-05	0.0900	99.6514
2.1458E-05	0.0643	99.7157
2.3982E-05	0.0490	99.7647
2.6506E-05	0.0314	99.7961
2.9031E-05	0.0329	99.8290
3.1555E-05	0.0171	99.8461
3.4080E-05	0.0200	99.8661
3.6604E-05	0.0143	99.8804
3.9129E-05	0.0086	99.8890
4.1653E-05	0.0114	99.8994
4.4177E-05	0.0086	99.9080
4.6702E-05	0.0129	99.9209
4.9226E-05	0.0014	99.9343
5.1751E-05	0.0071	99.9414
5.4275E-05	0.0043	99.9457
5.6800E-05	0.0043	99.9500
5.9324E-05	0.0043	99.9543
6.1848E-05	0.0043	99.9586
6.4373E-05	0.0029	99.9614
6.6897E-05	0.0014	99.9629
6.9422E-05	0.0029	99.9657
7.1946E-05	0.0014	99.9671
7.4471E-05	0.0029	99.9700
7.7093E-05	0.0014	99.9714
7.9617E-05	0.0029	99.9743
8.2141E-05	0.0029	99.9771
8.4666E-05	0.0014	99.9786
8.7190E-05	0.0029	99.9814
8.9714E-05	0.0014	99.9829
9.2238E-05	0.0014	99.9843
9.4763E-05	0.0014	99.9857
9.7287E-05	0.0014	99.9871
9.9811E-05	0.0014	99.9886
1.0224E-04	0.0014	99.9900
1.0729E-04	0.0014	99.9914
1.1098E-04	0.0014	99.9929
1.1739E-04	0.0014	99.9943
1.2243E-04	0.0014	99.9957
1.3506E-04	0.0014	99.9971
1.5020E-04	0.0014	99.9986
1.5525E-04	0.0014	99.9990

E-2: ISI Every 10 Years (cont.)

1.5778E-04	0.0014	99.9943
1.7797E-04	0.0014	99.9957
2.2089E-04	0.0014	99.9971
2.2846E-04	0.0014	99.9986
2.3098E-04	0.0014	100.0000

=====  
 == Summary Descriptive Statistics ==  
 =====

Minimum	= 0.0000E+00
Maximum	= 2.3200E-04
Range	= 2.3200E-04
Number of Simulations	= 70000
5th Percentile	= 0.0000E+00
Median	= 9.7197E-09
95.0th Percentile	= 1.2622E-06
99.0th Percentile	= 8.6578E-06
99.9th Percentile	= 3.9129E-05
Mean	= 5.9049E-07
Standard Deviation	= 3.4364E-06
Standard Error	= 1.2989E-08
Variance (unbiased)	= 1.1809E-11
Variance (biased)	= 1.1809E-11
Moment Coeff. of Skewness	= 2.8192E+01
Pearson's 2nd Coeff. of Skewness	= 5.0677E-01
Kurtosis	= 1.3237E+03

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	32.3229	32.3229
3.7808E-08	66.6543	98.9771
1.1342E-07	0.4457	99.4229
1.8904E-07	0.2186	99.6414
2.6466E-07	0.0914	99.7329
3.4027E-07	0.0514	99.7843
4.1589E-07	0.0343	99.8186
4.9151E-07	0.0271	99.8457
5.6712E-07	0.0171	99.8629

## E-2: ISI Every 10 Years (cont.)

6.4274E-07	0.0186	99.8814
7.1836E-07	0.0171	99.8986
7.9397E-07	0.0143	99.9129
8.6959E-07	0.0043	99.9171
9.4521E-07	0.0086	99.9257
1.0208E-06	0.0043	99.9300
1.0964E-06	0.0043	99.9343
1.1721E-06	0.0071	99.9414
1.2477E-06	0.0043	99.9457
1.3989E-06	0.0029	99.9486
1.4745E-06	0.0057	99.9543
1.5501E-06	0.0014	99.9557
1.6258E-06	0.0057	99.9614
1.7014E-06	0.0029	99.9643
1.7770E-06	0.0043	99.9686
2.0038E-06	0.0029	99.9714
2.1551E-06	0.0014	99.9729
2.3063E-06	0.0014	99.9743
2.6844E-06	0.0014	99.9757
2.9869E-06	0.0014	99.9771
3.0625E-06	0.0014	99.9786
3.1381E-06	0.0014	99.9800
3.2893E-06	0.0029	99.9829
3.5162E-06	0.0014	99.9843
3.6674E-06	0.0014	99.9857
3.8186E-06	0.0014	99.9871
3.9699E-06	0.0029	99.9900
4.0205E-06	0.0014	99.9914
4.2722E-06	0.0014	99.9929
5.2554E-06	0.0014	99.9943
5.5578E-06	0.0029	99.9971
7.0115E-06	0.0014	99.9986
7.4482E-06	0.0014	100.0000

=====
  
Summary Descriptive Statistics
  
=====

Minimum	= 0.0000E+00
Maximum	= 7.4860E-06
Range	= 7.4860E-06
Number of Simulations	= 70000
5th Percentile	= 0.0000E+00
Median	= 2.5574E-13
95.0th Percentile	= 3.7808E-08
99.0th Percentile	= 4.1686E-08
99.9th Percentile	= 7.2592E-07
Mean	= 5.2336E-09
Standard Deviation	= 8.2534E-08

## E-2: ISI Every 10 Years (cont.)

Standard Error = 3.1195E-10  
 Variance (unbiased) = 6.8118E-15  
 Variance (biased) = 6.8117E-15  
 Moment Coeff. of Skewness = 4.7286E+01  
 Pearson's 2nd Coeff. of Skewness = -1.6306E-01  
 Kurtosis = 2.9147E+03

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
2	0.00	0.00
3	0.00	0.00
7	2.58	1.01
9	1.13	0.39
14	0.00	0.00
31	0.00	0.00
34	0.00	0.00
56	94.32	43.78
59	0.00	0.00
60	0.00	11.13
61	0.01	0.28
62	0.00	0.01
64	0.00	0.00
65	0.00	0.00
66	0.00	0.01
67	0.00	0.00
68	0.00	0.00
69	0.00	0.22
70	0.00	0.02
71	0.01	0.78
72	0.00	0.00
75	0.00	0.00
74	0.00	0.00
76	0.00	0.00
78	0.00	0.00
81	0.00	0.00
82	0.00	0.00
83	0.00	0.00
92	0.01	0.01
93	0.01	0.01
94	0.00	0.00
97	0.05	5.07
102	0.07	0.12
103	0.06	0.51
104	0.05	0.04
105	0.00	0.00

E-2: ISI Every 10 Years (cont.)

106	0.00	0.00
107	0.00	0.03
108	0.00	0.00
109	0.00	0.00
110	0.00	0.00
111	0.00	0.00
112	0.00	0.00
113	0.01	0.00
114	0.47	0.13
115	0.00	0.00
116	0.01	0.00
117	0.13	0.09
118	0.00	0.00
119	0.00	0.00
120	0.00	0.00
121	0.00	0.00
122	0.00	0.00
123	0.02	1.33
124	0.01	0.10
125	0.00	0.00
126	0.09	10.04
127	0.13	0.00
128	0.15	0.00
129	0.20	1.27
130	0.36	23.28
TOTALS	100.00	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* BY \*  
 \* RPV BELTLINE MAJOR REGION \*  
 \* BY PARENT SUBREGION \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency	cleavage	ductile	total
1	174.15	2.29	0.11	2.82	0.02	2.84	
2	174.15	2.29	0.10	2.15	0.03	2.18	
3	164.48	3.69	4.16	25.64	4.45	30.09	
4	164.48	3.69	3.65	20.74	4.15	24.90	
5	89.30	19.28	89.66	2.88	0.05	2.93	

E-2: ISI Every 10 Years (cont.)

6	220.82	13.16	0.08	0.82	0.07	0.89
7	192.65	13.16	0.00	0.00	0.00	0.00
8	253.03	21.22	2.06	32.01	2.57	34.58
9	223.03	21.22	0.18	1.36	0.24	1.60
TOTALS		100.00	100.00	88.43	11.57	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* BY \*  
 \* RPV BELTLINE MAJOR REGION \*  
 \* BY CHILD SUBREGION \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	of total through-wall crack cleavage ductile frequency	total
1	174.15	2.29	0.00	0.00	0.00
2	174.15	2.29	0.00	0.00	0.00
3	164.48	3.69	0.00	0.00	0.00
4	164.48	3.69	0.00	0.00	0.00
5	89.30	10.28	0.00	0.00	0.00
6	220.82	13.16	2.29	5.80	5.92
7	192.65	13.16	0.00	0.00	0.00
8	253.03	21.22	86.26	81.11	92.32
9	223.03	21.22	10.85	1.51	1.76
TOTALS		100.00	100.00	88.43	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* MATERIAL, FLAW CATEGORY, AND FLAW DEPTH \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

## E-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* WELD MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.080	0.00	1.68	0.00	0.00	0.06	0.00
0.161	0.00	38.20	0.00	0.00	2.93	0.00
0.241	0.00	18.39	0.00	0.00	2.38	0.00
0.321	0.00	9.55	0.00	0.00	0.39	0.01
0.402	0.00	7.76	0.00	0.00	2.20	0.03
0.482	0.00	6.12	0.00	0.00	2.57	0.08
0.563	0.00	4.14	0.00	0.00	3.19	0.08
0.643	0.00	2.73	0.00	0.00	2.74	0.13
0.723	0.00	2.03	0.00	0.00	2.78	0.12
0.804	0.00	1.35	0.00	0.00	3.51	0.30
0.884	0.00	1.02	0.00	0.00	3.28	0.26
0.964	0.00	0.67	0.00	0.00	2.93	0.19
1.045	0.00	1.08	0.00	0.00	2.91	0.07
1.125	0.00	0.40	0.00	0.00	2.84	0.07
1.205	0.00	0.30	0.00	0.00	2.57	0.06
1.286	0.00	0.21	0.00	0.00	4.21	0.44
1.366	0.00	0.34	0.01	0.00	1.35	0.80
1.446	0.00	0.16	0.00	0.00	4.13	0.16
1.527	0.00	0.42	0.00	0.00	2.18	0.05
1.607	0.00	0.21	0.00	0.00	4.06	0.29
1.688	0.00	0.29	0.00	0.00	1.86	0.14
1.768	0.00	0.02	0.00	0.00	0.61	0.39
1.848	0.00	0.01	0.01	0.00	1.15	0.66
1.929	0.00	0.53	0.00	0.00	0.69	0.10
TOTALS	0.00	97.63	0.05	0.00	58.51	4.42

\*\*\*\*\*  
 \* PLATE MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.080	0.00	0.01	0.00	0.00	0.13	0.00
0.161	0.00	0.48	0.00	0.00	7.33	0.00
0.241	0.00	0.69	0.00	0.00	10.42	0.00
0.321	0.00	0.61	0.00	0.00	9.99	0.00

E-2: ISI Every 10 Years (cont.)

0.402	0.00	0.54	0.00	0.00	9.20	0.00
0.482	0.00	0.00	0.00	0.00	0.00	0.00
0.563	0.00	0.00	0.00	0.00	0.00	0.00
0.643	0.00	0.00	0.00	0.00	0.00	0.00
0.723	0.00	0.00	0.00	0.00	0.00	0.00
0.804	0.00	0.00	0.00	0.00	0.00	0.00
0.884	0.00	0.00	0.00	0.00	0.00	0.00
0.964	0.00	0.00	0.00	0.00	0.00	0.00
1.045	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	0.00	2.33	0.00	0.00	37.06	0.00

DATE: 03-May-2007 TIME: 15:04:07

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION  
 (PER REACTOR OPERATING YEAR)      RELATIVE DENSITY (%)      CUMULATIVE DISTRIBUTION (%)

0.0000E+00	0.1957	0.1957
1.5531E-06	0.8100	97.0057
4.6594E-06	1.7143	98.7200
7.7657E-06	0.5614	99.2814
1.0872E-05	0.2714	99.5529
1.3978E-05	0.1286	99.6814
1.7084E-05	0.0814	99.7629
2.0191E-05	0.0500	99.8129
2.3298E-05	0.0314	99.8443
2.6403E-05	0.0257	99.8700
2.9510E-05	0.0271	99.8971
3.2618E-05	0.0157	99.9129
3.5722E-05	0.0114	99.9243
3.8828E-05	0.0100	99.9343
4.1935E-05	0.0057	99.9400
4.5041E-05	0.0043	99.9443
4.8147E-05	0.0029	99.9471
5.1253E-05	0.0100	99.9571
5.4360E-05	0.0029	99.9600
5.7466E-05	0.0043	99.9643
6.0572E-05	0.0071	99.9714
6.3678E-05	0.0014	99.9729
6.6785E-05	0.0014	99.9743
6.9891E-05	0.0029	99.9771
7.2997E-05	0.0014	99.9786
8.2316E-05	0.0014	99.9800
8.5422E-05	0.0029	99.9829
8.8529E-05	0.0043	99.9871
9.1635E-05	0.0014	99.9886
9.4741E-05	0.0014	99.9900
1.0095E-04	0.0014	99.9914



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1.1338E-04	0.0014	99.9929
1.4755E-04	0.0014	99.9943
1.5997E-04	0.0014	99.9957
2.3142E-04	0.0014	99.9971
2.5316E-04	0.0014	99.9986
3.0597E-04	0.0014	100.0000

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=====  
Summary Descriptive Statistics  
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E-2: ISI Every 10 Years (cont.)

Minimum	=	0.0000E+00
Maximum	=	3.0752E-04
Range	=	3.0752E-04
Number of Simulations	=	70000
5th Percentile	=	1.9684E-10
Median	=	9.3514E-08
95.0th Percentile	=	1.5531E-06
99.0th Percentile	=	6.2086E-06
99.9th Percentile	=	3.0074E-05
Mean	=	5.9694E-07
Standard Deviation	=	2.4934E-06
Standard Error	=	1.1344E-08
Variance (unbiased)	=	8.9603E-12
Variance (biased)	=	8.9601E-12
Moment Coeff. of Skewness	=	4.3241E+01
Pearson's 2nd Coeff. of Skewness	=	5.0806E-01
Kurtosis	=	3.2246E+03

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	9.6271	9.6271
1.7659E-09	89.6043	99.2314
1.1298E-07	0.3486	99.5800
1.8829E-07	0.1214	99.7014
2.6361E-07	0.6714	99.7729
3.3893E-07	0.0486	99.8214
4.1424E-07	0.0329	99.8543
4.8956E-07	0.0200	99.8743
5.6488E-07	0.0171	99.8914
6.4020E-07	0.0100	99.9014
7.1551E-07	0.0114	99.9129
7.9083E-07	0.0057	99.9186
8.6615E-07	0.0057	99.9243
9.4147E-07	0.0086	99.9329
1.0168E-06	0.0071	99.9400
1.0921E-06	0.0043	99.9443
1.1674E-06	0.0043	99.9486
1.2427E-06	0.0029	99.9514
1.3181E-06	0.0057	99.9571
1.3934E-06	0.0014	99.9586

## E-2: ISI Every 10 Years (cont.)

1.4687E-06	0.0029	99.9614
1.5440E-06	0.0014	99.9629
1.6193E-06	0.0029	99.9657
1.6946E-06	0.0014	99.9671
1.8453E-06	0.0029	99.9700
1.9959E-06	0.0029	99.9729
2.0712E-06	0.0014	99.9743
2.2972E-06	0.0014	99.9757
2.3725E-06	0.0014	99.9771
2.4478E-06	0.0029	99.9800
2.6738E-06	0.0014	99.9814
2.9750E-06	0.0014	99.9829
3.2010E-06	0.0014	99.9843
3.2763E-06	0.0014	99.9857
3.5023E-06	0.0014	99.9871
3.6529E-06	0.0014	99.9886
3.8035E-06	0.0014	99.9900
4.1048E-06	0.0014	99.9914
4.3307E-06	0.0014	99.9929
4.4814E-06	0.0014	99.9943
4.7073E-06	0.0014	99.9957
5.2346E-06	0.0014	99.9971
6.8915E-06	0.0014	99.9986
7.4941E-06	0.0014	100.0000

=====  
 Summary Descriptive Statistics  
 =====

Minimum	= 0.0000E+00
Maximum	= 7.4564E-06
Range	= 7.4564E-06
Number of Simulations	= 70000
5th Percentile	= 0.0000E+00
Median	= 1.8724E-12
95.0th Percentile	= 3.7659E-08
99.0th Percentile	= 5.2893E-08
99.9th Percentile	= 6.2944E-07
Mean	= 4.0995E-09
Standard Deviation	= 7.6551E-08
Standard Error	= 2.8934E-10
Variance (unbiased)	= 5.8600E-15
Variance (biased)	= 5.8600E-15
Moment Coeff. of Skewness	= 5.2718E+01
Pearson's 2nd Coeff. of Skewness	= 1.9366E+00
Kurtosis	= 3.6577E+03

## E-2: ISI Every 10 Years (cont.)

*****		
* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION *		
* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) *		
* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES *		
*****		
	% of total frequency of crack initiation	% of total frequency of failure
2	0.00	0.00
3	0.02	0.00
7	14.70	17.42
9	5.52	4.14
14	0.00	0.00
31	0.00	0.00
34	0.00	0.00
56	78.20	41.56
59	0.00	0.00
60	0.07	9.01
61	0.01	0.49
62	0.00	0.01
64	0.00	0.00
65	0.00	0.00
66	0.01	0.02
67	0.00	0.00
68	0.00	0.00
69	0.00	0.25
70	0.00	0.01
71	0.00	0.31
72	0.00	0.00
73	0.00	0.00
74	0.00	0.00
75	0.00	0.00
76	0.00	0.00
81	0.00	0.00
82	0.00	0.00
83	0.00	0.00
92	0.01	0.01
93	0.01	0.02
94	0.00	0.00
97	0.02	1.92
102	0.19	0.78
103	0.16	2.43
104	0.21	0.71
105	0.00	0.01
106	0.00	0.01
107	0.01	0.14
108	0.00	0.00
109	0.00	0.00
110	0.00	0.00
111	0.00	0.00
112	0.00	0.00
113	0.00	0.00
114	0.36	0.04

E-2: ISI Every 10 Years (cont.)

115	0.00	0.00
116	0.00	0.00
117	0.20	0.01
118	0.00	0.00
119	0.00	0.00
120	0.00	0.18
121	0.00	0.00
122	0.00	0.00
123	0.01	0.72
124	0.00	0.03
125	0.00	0.00
126	0.10	1.83
127	0.00	0.00
128	0.00	0.00
129	0.01	0.63
130	0.00	7.28
TOTALS	100.00	100.00

DATE: 04 Nov 2005 TIME: 10:57:18

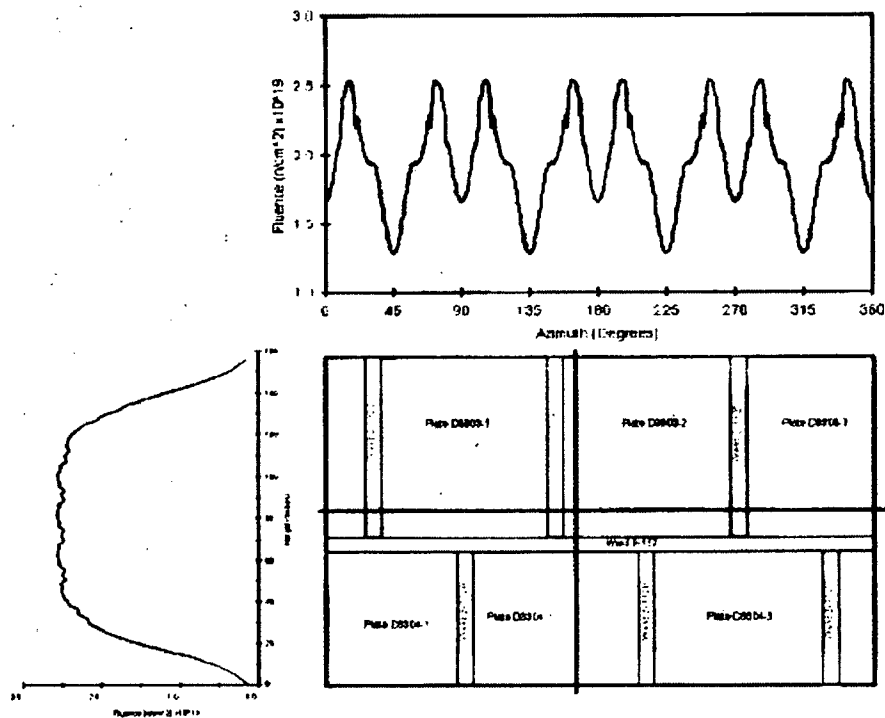
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**APPENDIX F**  
**INPUTS FOR THE PALISADES PILOT PLANT EVALUATION**

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A summary of the NDE inspection history based on Regulatory Guide 1.150 and pertinent input data for Palisades is as follows:

1. Number of ISIs performed (relative to initial pre-service and 10-year interval inspections) for full penetration Category B-A, and B-D, and B-J reactor vessel welds assuming all of the candidate welds were inspected: 2 (covering all welds of the specified categories).
2. The inspections performed covered: 100% for 13 Category B-A welds, >90% but <100% for 6 Category B-A welds, <90% for 8 Category B-A welds, and 100% of all Category B-D and B-J welds.
3. Number of indications found during most recent inservice inspection: 11  
This number includes consideration of the following additional information:
  - a. Indications found that were reportable: 0
  - b. Indications found that were within acceptable limits: 11
  - c. Indications/anomalies currently being monitored: 0
4. Full penetration relief requests for the RV submitted and accepted by the NRC: 2 relief requests for limited coverage for 12 welds
5. Fluence distribution at inside surface of RV beltline until end of life (EOL): see Figure F-1 taken from the NRC PTS Risk Study [798], Figure 4.3



**Figure F-1 Rollout Diagram of Beltline Materials and Representative Fluence Maps for Palisades**

- 6. Reactor vessel cladding details:
  - a. Thickness: 0.25 inches
  - b. Material properties (assumed to be independent of temperature) are identified in Table F-1:

Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM- °F) "C"	Young's Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
0	-	-	-	-	489	.3
68	-	-	22045.7	-	489	.3
70	8.1	0.1158	-	-	489	.3
100	8.4	0.1185	-	8.55E-06	489	.3
150	8.6	0.1196	-	8.67E-06	489	.3
200	8.8	0.1208	-	8.79E-06	489	.3
250	9.1	0.1232	-	8.9E-06	489	.3
300	9.4	0.1256	-	9.0E-06	489	.3
302	-	-	20160.2	-	489	.3
350	9.6	0.1258	-	9.1E-06	489	.3
400	9.9	0.1281	-	9.19E-06	489	.3
450	10.1	0.1291	-	9.28E-06	489	.3
482	-	-	18419.8	-	489	.3



Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM-°F) "C"	Young's Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
500	10.4	0.1305	-	9.37E-06	489	.3
550	10.6	0.1306	-	9.45E-06	489	.3
600	10.9	0.1327	-	9.53E-06	489	.3
650	11.1	0.1335	-	9.61E-06	489	.3
700	11.4	0.1348	-	9.69E-06	489	.3
750	11.6	0.1356	-	9.76E-06	489	.3
800	11.9	0.1367	-	9.82E-06	489	.3

3) Thermal conductivity (Btu/hr-ft-°F), K=10.0

4) Specific heat (Btu/LBM-°F), C=0.120

5) Density (LBM/ft<sup>3</sup>), RHO=489.00

6) Young's Modulus of Elasticity (KSI), E=22800

7) Thermal expansion coefficient (°F<sup>-1</sup>), ALPHA=0.00000945

8) Poisson's Ratio, ν=0.3

c. Material including copper and nickel content: Material properties assigned to clad flaws are that of the underlying material be it base metal or weld. These properties are identified in Table F-13. This is consistent with the NRC PTS Risk Study [78, 927, 43].

d. Material property uncertainties:

1) Bead width: 1 inch – bead widths vary for all plants. Based on the NRC PTS Risk Study [78, 98], a nominal dimension of 1 inch is selected for all analyses because this parameter is not expected to influence significantly the predicted vessel failure probabilities.

2) Truncation limit: Cladding thickness rounded to the next 1/100th of the total reactor vessel thickness to be consistent with the NRC PTS Risk Study [78, 98].

3) Surface flaw depth: 0.263 inch

4) All flaws are surface-breaking. Only flaws in cladding that would influence brittle fracture of the reactor vessel are brittle. This is consistent with the NRC PTS Risk Study [8, 987].

e. Additional cladding properties are identified in Table F-24. This is consistent with the NRC PTS Risk Study [8, 927, 43].

7. Base metal:

a. Wall thickness: 8.5 inches

- b. Material properties are identified in Tables F-2 and F-3 (assumed to be independent of temperature):

Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM- °F) "C"	Young's Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
0	-	-	-	-	489	.3
70	24.8	0.1052	29200	-	489	.3
100	25	0.1072	-	7.06E-06	489	.3
150	25.1	0.1101	-	7.16E-06	489	.3
200	25.2	0.1135	28500	7.25E-06	489	.3
250	25.2	0.1166	-	7.34E-06	489	.3
300	25.1	0.1194	28000	7.43E-06	489	.3
350	25	0.1223	-	7.5E-06	489	.3
400	25.1	0.1267	27400	7.58E-06	489	.3
450	24.6	0.1277	-	7.63E-06	489	.3
500	24.3	0.1304	27000	7.7E-06	489	.3
550	24	0.1326	-	7.77E-06	489	.3
600	23.7	0.135	26400	7.83E-06	489	.3
650	23.4	0.1375	-	7.9E-06	489	.3
700	23	0.1404	25800	7.94E-06	489	.3
750	22.6	0.1435	-	8.0E-06	489	.3
800	22.2	0.1474	23900	8.05E-06	489	.3

- 5) Thermal conductivity (Btu/hr ft °F), K=24.0
- 6) Specific heat (Btu/LBM °F), C=0.120
- 7) Density (LBM/ft<sup>3</sup>), RHO=489.00
- 8) Young's Modulus of Elasticity (KSI), E=28000
- 9) Thermal expansion coefficient (°F<sup>-1</sup>), ALPHA=0.00000777
- 10) Poisson's Ratio, V=0.3
- 11) Other material properties are identified in Table F-1

**Table F-13 Palisades-Specific Material Values Drawn from the RVID (see Ref. 7-448 Table 4.1)**

Major Material Region Description				Cu [wt%]	Ni [wt%]	P [wt%]	Mn [wt%]	Un-Irradiated RT <sub>NDT</sub> [°F]	Un-Irradiated RT <sub>NDT</sub> [°F] RT <sub>ERS</sub> @60 EFPY
#	Type	Heat	Location				Un-Irradiated RT <sub>NDT</sub> [°F]		
1	Axial Weld	3-112A	lower	0.213	1.010	0.019	1.315-56	-56276.4	Generic
2	Axial Weld	3-112B	lower	0.213	1.010	0.019	1.315-56	-56285.3	Generic
3	Axial Weld	3-112C	lower	0.213	1.010	0.019	1.315-56	-56285.3	Generic
4	Axial Weld	2-112A	upper	0.213	1.010	0.019	1.315-56	-56285.8	Generic

5	Axial Weld	2-112B	upper	0.213	1.010	0.019	1.315- 56 Generi e	- 56276.7
6	Axial Weld	2-112C	upper	0.213	1.010	0.019	1.315- 56 Generi e	- 56285.8
7	Circ Weld	9-112	intermediate	0.203	1.018	0.013	1.147- 56 Generi e	- 56270.3
8	Plate	D3804-1	lower	0.190	0.480	0.016	1.235- 30 ASME NB- 2334	-0264.9
9	Plate	D3804-2	lower	0.190	0.500	0.015	1.235- 30 MTEB 5-2	-30230.5
10	Plate	D3804-3	lower	0.120	0.550	0.010	1.270- 25 MTEB 5-2	-25470.0
11	Plate	D3803-1	upper	0.240	0.510	0.009	1.293- 5 ASME NB- 2334	-5264.5
12	Plate	D3803-2	upper	0.240	0.520	0.010	1.350- 30 MTEB 5-2	-30242.4
13	Plate	D3803-3	upper	0.240	0.500	0.011	1.293- 5 ASME NB- 2334	-5268.4

8. Weld metal details: Details of information used in addressing weld-specific information are taken directly from the NRC PTS Risk Study [447], Table 4.2. Summaries are reproduced as Table F-24. Values for SAW Weld Volume fraction and Repair Weld Volume fraction in Table F-4 were changed to 96.7% and 2.3% respectively per NUREG-1874 [9].

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**Table F-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Inner Radius (to cladding)	[in]	85.5	78.5	86	86	Vessel specific info
Base Metal Thickness	[in]	8.438	7.875	8.5	8.675	Vessel specific info
Total Wall Thickness	[in]	8.626	8.031	8.75	8.988	Vessel specific info

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
SAW Weld	Volume fraction	97%				100% - SMAW% - REPAIR%
	Thru-Wall Bead Thickness	0.1875	0.1875	0.1875	0.1875	All plants report plant specific dimensions of 3/16-in.
	Truncation Limit	1				Judgment. Approx. 2X the size of the largest non-repair flaw observed in PVRUF & Shoreham.
	Buried or Surface	All flaws are buried				Observation
	Orientation	Circ flaws in circ welds. axial flaws in axial welds.				Observation: Virtually all of the weld flaws in PVRUF & Shoreham were aligned with the welding direction because they were lack of sidewall fusion defects.
	Density basis	Shoreham density				Highest of observations
	Aspect ratio basis	Shoreham & PVRUF observations				Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
	Depth basis	Shoreham & PVRUF observations				Statistically similar distributions combined to provide more robust estimates

**Table F-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes	
SMAW Weld	Volume fraction	[%]	1%			Upper bound to all plant specific info provided by Steve Byrne (Westinghouse – Windsor).	
	Thru-Wall Bead Thickness	[in]	0.21	0.20	0.22	0.25	Oconee is generic value based on average of all plants specific values (including Shoreham & PVRUF data). Other values are plant specific as reported by Steve Byrne.
	Truncation Limit	[in]	1			Judgment. Approx. 2X the size of the largest non-repair flaw observed in PVRUF & Shoreham.	
	Buried or Surface	--	All flaws are buried			Observation	
	Orientation	--	Circ flaws in circ welds, axial flaws in axial welds.			Observation: Virtually all of the weld flaws in PVRUF & Shoreham were aligned with the welding direction because they were lack of sidewall fusion defects.	
	Density basis	--	Shoreham density			Highest of observations	
	Aspect ratio basis	--	Shoreham & PVRUF observations			Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.	
	Depth basis	--	Shoreham & PVRUF observations			Statistically similar distributions combined to provide more robust estimates	

Table F-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Repair Weld	Volume fraction			2%		Judgment. A rounded integral percentage that exceeds the repaired volume observed for Shoreham and for PVRUF, which was 1.5%.
	Thru-Wall Bead Thickness			0.14		Generic value: As observed in PVRUF and Shoreham by PNNL.
	Truncation Limit			2		Judgment. Approx. 2X the largest repair flaw found in PVRUF & Shoreham. Also based on maximum expected width of repair cavity.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Circ flaws in circ welds, axial flaws in axial welds.			The repair flaws had complex shapes and orientations that were not aligned with either the axial or circumferential welds; for consistency with the available treatments of flaws by the FAVOR code, a common treatment of orientations was adopted for flaws in SAW/SAW and repair welds.
	Density basis	--	Shoreham density			Highest of observations
	Aspect ratio basis	--	Shoreham & PVRUF observations			Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
	Depth basis	--	Shoreham & PVRUF observations			Statistically similar distributions combined to provide more robust estimates



**Table F-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes	
Cladding	Actual Thickness	[in]	0.188	0.156	0.25	0.313	Vessel specific info
	# of Layers	[#]	1	2	2	2	Vessel specific info
	Bead Width	[in]	1				Bead widths of 1 to 5-in. characteristic of machine deposited cladding. Bead widths down to ½-in. can occur over welds. Nominal dimension of 1-in. selected for all analyses because this parameter is not expected to influence significantly the predicted vessel failure probabilities. May need to refine this estimate later, particularly for Oconee who reported a 5-in bead width.
	Truncation Limit	[in]	Actual clad thickness rounded to the nearest 1/100 <sup>th</sup> of the total vessel wall thickness				Judgment & computational convenience
	Surface flaw depth in FAVOR	[in]	0.259	0.161	0.263	0.360	
	Buried or Surface	--	All flaws are surface breaking				Judgment. Only flaws in cladding that would influence brittle fracture of the vessel are brittle. Material properties assigned to clad flaws are that of the underlying material, be it base or weld.
Orientation	--	All circumferential.				Observation: All flaws observed in PVRUF & Shoreham were lack of inter-run fusion defects, and cladding is always deposited circumferentially	
Density basis	--	No surface flaws observed. Density is 1/1000 that of the observed buried flaws in cladding of vessels examined by PNNL. If there is more than one clad layer then there are no clad flaws.				Judgment	
Aspect ratio basis	--	Observations on buried flaws				Judgment	
Depth basis	--	Depth of all surface flaws is the actual clad thickness rounded up to the nearest 1/100 <sup>th</sup> of the total vessel wall thickness.				Judgment.	

Table F-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Plate	Truncation Limit	[in]	0.433			Judgment. Twice the depth of the largest flaw observed in all PNNL plate inspections.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Half of the simulated flaws are circumferential, half are axial.			Observation & Physics: No observed orientation preference, and no reason to suspect one (other than laminations which are benign.
	Density basis	--	1/10 of small weld flaw density, 1/40 of large weld flaw density of the PVRUF data			Judgment. Supported by limited data.
	Aspect ratio basis	--	Same as for PVRUF welds			Judgment
	Depth basis	--	Same as for PVRUF welds			Judgment. Supported by limited data.

9.  $TWCF_{95-TOTAL}$  value calculated at 60 EFPY using correlations from NUREG-1874 (Reference 927):  $6.42E-093.16E-7$  Events per year

**APPENDIX G  
PALISADES PROBSBFD OUTPUT**

DRAFT

## G-1: 10 Year ISI Only

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)  
 WESTINGHOUSE MONTE-CARLO SIMULATION PROGRAM PROBSBFD VERSION 1.0

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INPUT VARIABLES FOR CASE 2: PAL 10 YEAR ISI ONLY

NCYCLE = 80                      NFAILS = 1001                      NTRIAL = 1000  
 NOVARS = 19                      NUMSET = 2                      NUMISI = 5  
 NUMSSC = 4                      NUMTRC = 4                      NUMFMD = 4

VARIABLE NO.	NAME	DISTRIBUTION TYPE	LOG	MEDIAN VALUE	DEVIATION OR FACTOR	SHIFT MV/SD	USAGE NO. SUB
1	FIFDepth	- CONSTANT	-	3.0000D-02			1 SET
2	IflawDen	- CONSTANT	-	3.6589D-03			2 SET
3	ICy-ISI	- CONSTANT	-	1.0000D+01			1 ISI
4	DCy-ISI	- CONSTANT	-	8.0000D+01			2 ISI
5	MV-Depth	- CONSTANT	-	1.5000D-02			3 ISI
6	SD-Depth	- CONSTANT	-	1.8500D-01			4 ISI
7	CEff-ISI	- CONSTANT	-	1.0000D+00			5 ISI
8	Aspect1	- CONSTANT	-	2.0000D+00			1 SSC
9	Aspect2	- CONSTANT	-	6.0000D+00			2 SSC
10	Aspect3	- CONSTANT	-	1.0000D+01			3 SSC
11	Aspect4	- CONSTANT	-	9.9000D+01			4 SSC
12	NoTr/Cy	- CONSTANT	-	1.3000D+01			1 TRC
13	FCGThld	- CONSTANT	-	1.5000D+00			2 TRC
14	FCCR-UC	NORMAL	NO	0.0000D+00	1.0000D+00	.00	3 TRC
15	DKINFile	- CONSTANT	-	1.0000D+00			4 TRC
16	Percent1	- CONSTANT	-	7.8870D+01			1 FMD
17	Percent2	- CONSTANT	-	1.0720D+01			2 FMD
18	Percent3	- CONSTANT	-	4.3807E+00			3 FMD
19	Percent4	- CONSTANT	-	6.0298D+00			4 FMD

INFORMATION GENERATED FROM FAVLOADS.DAT FILE  
 AND SAVED IN DKINSAVE.DAT FILE:

WALL THICKNESS = 8.7500 INCH

FLAW DEPTH: MINIMUM K AND MAXIMUM K FOR

TYPE 1 WITH AN ASPECT RATIO OF 2.

8.75000D-02	2.69285D+00	1.08492D+01
1.61000D-01	3.60064D+00	1.46562D+01
4.37500D-01	1.26609D+01	2.00367D+01
6.56250D-01	1.49279D+01	2.39231D+01
8.75000D-01	1.53491D+01	2.67406D+01
1.75000D+00	1.37876D+01	3.14212D+01
2.62500D+00	8.13906D+00	3.01520D+01
4.37500D+00	-2.32655D+00	2.91175D+01

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.75000D-02	4.04516D+00	1.64003D+01
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**G-1: 10 Year ISI Only (cont.)**

1.61000D-01	5.52109D+00	2.25832D+01
4.37500D-01	1.80126D+01	3.03772D+01
6.56250D-01	2.31235D+01	3.61026D+01
8.75000D-01	2.65795D+01	4.11957D+01
1.75000D+00	2.62424D+01	5.18633D+01
2.62500D+00	2.10650D+01	5.45640D+01
4.37500D+00	9.61580D+00	5.85179D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.75000D-02	4.43154D+00	1.79837D+01
1.61000D-01	5.90218D+00	2.41564D+01
4.37500D-01	1.90406D+01	3.24750D+01
6.56250D-01	2.45354D+01	3.85918D+01
8.75000D-01	2.87821D+01	4.40958D+01
1.75000D+00	2.91774D+01	5.64674D+01
2.62500D+00	2.54877D+01	6.25646D+01
4.37500D+00	1.38132D+01	7.03917D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.75000D-02	7.10780D+00	1.85180D+01
1.75000D-01	1.00487D+01	2.59141D+01
2.62500D-01	1.38195D+01	2.86661D+01
4.37500D-01	2.16458D+01	3.45538D+01
6.56250D-01	2.85157D+01	4.23747D+01
8.75000D-01	3.03914D+01	4.83133D+01
1.75000D+00	3.36289D+01	6.57043D+01
2.62500D+00	3.16032D+01	7.68320D+01

AVERAGE CALCULATED VALUES FOR: Surface Flaw Density with FCG and ISI

NUMBER FAILED = 0

NUMBER OF TRIALS = 1000

DEPTH (WALL/400) AND FLAW DENSITY FOR ASPECT RATIOS OF 2, 6, 10 AND 99

12	2.5402D-04	4.5317D-06	1.3489D-06	2.1739D-06
13	5.8986D-06	1.9521D-05	7.3792D-06	9.7312D-06
14	0.0000D+00	7.0234D-06	3.2977D-06	4.3086D-06
15	0.0000D+00	1.9775D-06	1.1450D-06	1.7029D-06
16	0.0000D+00	5.8037D-07	4.0809D-07	6.4975D-07
17	0.0000D+00	3.4736D-07	1.5441D-07	2.2919D-07
18	0.0000D+00	1.5414D-07	8.8627D-08	1.7208D-07
19	0.0000D+00	9.1024D-08	6.1738D-08	5.0696D-08
20	0.0000D+00	0.0000D+00	3.6375D-08	8.2449D-08
21	0.0000D+00	0.0000D+00	0.0000D+00	3.2256D-08
23	0.0000D+00	2.7971D-08	0.0000D+00	0.0000D+00
25	0.0000D+00	0.0000D+00	1.1041D-08	0.0000D+00
26	0.0000D+00	2.6821D-08	0.0000D+00	0.0000D+00
27	0.0000D+00	0.0000D+00	0.0000D+00	1.4338D-08
29	0.0000D+00	0.0000D+00	1.0518D-08	0.0000D+00
31	0.0000D+00	0.0000D+00	0.0000D+00	1.3440D-08

## G-2: ISI Every 10 Years

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)  
 WESTINGHOUSE MONTE-CARLO SIMULATION PROGRAM PROBSBFD VERSION 1.0

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INPUT VARIABLES FOR CASE 2: PAL 10 YEAR INT

NCYCLE = 80                      NFAILS = 1001                      NTRIAL = 1000  
 NOVARS = 19                      NUMSET = 2                      NUMISI = 5  
 NUMSSC = 4                      NUMTRC = 4                      NUMFMD = 4

VARIABLE NO.	NAME	DISTRIBUTION TYPE	LOG	MEDIAN VALUE	DEVIATION OR FACTOR	SHIFT MV/SD	USAGE NO. SUB
1	FIFDepth	- CONSTANT	-	3.0000D-02			1 SET
2	IFlawDen	- CONSTANT	-	3.6589D-03			2 SET
3	ICy-ISI	- CONSTANT	-	1.0000D+01			1 ISI
4	DCy-ISI	- CONSTANT	-	1.0000D+01			2 ISI
5	MV-Depth	- CONSTANT	-	1.5000D-02			3 ISI
6	SD-Depth	- CONSTANT	-	1.8500D-01			4 ISI
7	Ceff-ISI	- CONSTANT	-	1.0000D+00			5 ISI
8	Aspect1	- CONSTANT	-	2.0000D+00			1 SSC
9	Aspect2	- CONSTANT	-	6.0000D+00			2 SSC
10	Aspect3	- CONSTANT	-	1.0000D+01			3 SSC
11	Aspect4	- CONSTANT	-	9.0000D+01			4 SSC
12	NoTr/Cy	- CONSTANT	-	1.3000D+01			1 TRC
13	FCGThld	- CONSTANT	-	1.5000D+00			2 TRC
14	FCGR-UC	NORMAL	NO	0.0000D+00	1.0000D+00	.00	3 TRC
15	DKINFile	- CONSTANT	-	1.0000D+00			4 TRC
16	Percent1	- CONSTANT	-	7.8870D+01			1 FMD
17	Percent2	- CONSTANT	-	1.0720E+01			2 FMD
18	Percent3	- CONSTANT	-	4.3807E+00			3 FMD
19	Percent4	- CONSTANT	-	6.0298E+00			4 FMD

INFORMATION GENERATED FROM FAVLOADS.DAT FILE  
 AND SAVED IN DKINSAVE.DAT FILE:

WALL THICKNESS = 8.7500 INCH

FLAW DEPTH MINIMUM K AND MAXIMUM K FOR

TYPE 1 WITH AN ASPECT RATIO OF 2.

8.75000D-02	2.69285D+00	1.08492D+01
1.61000D-01	3.60064D+00	1.46562D+01
4.37500D-01	1.26609D+01	2.00367D+01
6.56250D-01	1.49279D+01	2.39231D+01
8.75000D-01	1.53491D+01	2.67406D+01
1.75000D+00	1.37876D+01	3.14212D+01
2.62500D+00	8.13906D+00	3.01520D+01
4.37500D+00	-2.32655D+00	2.91175D+01

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.75000D-02	4.04516D+00	1.64003D+01
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**G-2: ISI Every 10 Years (cont.)**

1.61000D-01	5.52109D+00	2.25832D+01
4.37500D-01	1.80126D+01	3.03772D+01
6.56250D-01	2.31235D+01	3.61026D+01
8.75000D-01	2.65795D+01	4.11957D+01
1.75000D+00	2.62424D+01	5.18633D+01
2.62500D+00	2.10650D+01	5.45640D+01
4.37500D+00	9.61580D+00	5.85179D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.75000D-02	4.43154D+00	1.79837D+01
1.61000D-01	5.90218D+00	2.41564D+01
4.37500D-01	1.90406D+01	3.24750D+01
6.56250D-01	2.45354D+01	3.85918D+01
8.75000D-01	2.87821D+01	4.40958D+01
1.75000D+00	2.91774D+01	5.64674D+01
2.62500D+00	2.54877D+01	6.25646D+01
4.37500D+00	1.38132D+01	7.03917D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.75000D-02	7.10780D+00	1.85180D+01
1.75000D-01	1.00487D+01	2.59141D+01
2.62500D-01	1.38195D+01	2.86661D+01
4.37500D-01	2.16458D+01	3.45538D+01
6.56250D-01	2.85157D+01	4.23747D+01
8.75000D-01	3.03911D+01	4.83133D+01
1.75000D+00	3.36289D+01	6.57043D+01
2.62500D+00	3.16032D+01	7.68320D+01

AVERAGE CALCULATED VALUES FOR: Surface Flaw Density with FCG and ISI

NUMBER FAILED = 0

NUMBER OF TRIALS = 1000

DEPTH (WALL/400) AND FLAW DENSITY FOR ASPECT RATIOS OF 2, 6, 10 AND 99

12	1.2465D-10	1.8940D-12	5.5678D-13	9.1111D-13
13	1.9983D-12	5.5048D-12	2.0459D-12	2.7226D-12
14	0.0000D+00	9.6570D-13	4.5289D-13	5.8811D-13
15	0.0000D+00	1.2835D-13	7.5032D-14	1.0930D-13
16	0.0000D+00	1.8170D-14	1.2594D-14	1.8759D-14
17	0.0000D+00	5.2179D-15	2.1701D-15	2.9926D-15
18	0.0000D+00	9.4118D-16	6.6938D-16	9.6145D-16
19	0.0000D+00	2.9809D-16	1.7580D-16	1.4879D-16
20	0.0000D+00	0.0000D+00	4.8987D-17	9.2976D-17
21	0.0000D+00	0.0000D+00	0.0000D+00	1.4658D-17
23	0.0000D+00	2.2110D-18	0.0000D+00	0.0000D+00
25	0.0000D+00	0.0000D+00	1.5152D-19	0.0000D+00
26	0.0000D+00	2.1470D-19	0.0000D+00	0.0000D+00
27	0.0000D+00	0.0000D+00	0.0000D+00	2.4461D-20
29	0.0000D+00	0.0000D+00	7.9308D-21	0.0000D+00
31	0.0000D+00	0.0000D+00	0.0000D+00	5.2922D-22

## APPENDIX H PALISADES PTS TRANSIENTS

Table H-1 PTS Transient Descriptions for Palisades							
Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	HiK	Dominant*
1	2	3.59 cm (1.414 in) surge line break. Containment sump recirculation included in the analysis.	None	2.66E-04	No	Yes	No
2	16	Turbine/reactor trip with 2 stuck-open ADVs on SG-A combined with controller failure resulting in the flow from two AFW pumps into affected steam generator.	Operator starts second AFW pump. Operator isolates AFW to affected SG at 30 minutes after initiation. Operator assumed to throttle HPI if auxiliary feedwater is running with SG wide range level > 84% and RCS subcooling > 25 F. HPI is throttled to maintain pressurizer level between 40 and 60%.	1.23E-04	No	No	No
3	18	Turbine/reactor trip with 1 stuck-open ADV on SG-A. Failure of both MSIVs (SG-A and SG-B) to close.	Operator does not isolate AFW on affected SG. Normal AFW flow assumed (200 gpm). Operator assumed to throttle HPI if auxiliary feedwater is running with SG wide range level > 84% and RCS subcooling > 25 F. HPI is throttled to maintain pressurizer level between 40 and 60%.	4.71E-03	No	No	No
4	19	Reactor trip with 1 stuck-open ADV on SG-A.	None Operator does not throttle HPI.	2.29E-03	Yes	No	Yes at 60, 200, 500 EFPY
5	22	Turbine/reactor trip with loss of MFW and AFW.	Operator depressurizes through ADVs and feeds SG's using condensate booster pumps. Operators maintain a cooldown rate within technical specification limits and throttle condensate flow at 84 % level in the steam generator.	6.67E-05	No	No	No
6	24	Main steam line break with the break assumed to be inside containment causing containment spray actuation.	None	2.43E-06	No	No	No



Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	HiK	Dominant*
7	26	Main steam line break with the break assumed to be inside containment causing containment spray actuation.	Operator isolates AFW to affected SG at 30 minutes after initiation.	5.69E-04	No	No	No
8	27	Main steam line break with controller failure resulting in the flow from two AFW pumps into affected steam generator. Break assumed to be inside containment causing containment spray actuation.	Operator starts second AFW pump.	3.65E-05	No	No	No
9	29	Main steam line break with break assumed to be inside containment causing containment spray actuation.	None. Operator does not throttle HPI.	4.20E-08	Yes	No	No
10	31	Turbine/reactor trip with failure of MFW and AFW. Containment spray actuation assumed due to PORV discharge.	Operator maintains core cooling by "feed and bleed" using HPI to feed and two PORVs to bleed.	1.29E-05	No	No	No
11	32	Turbine/reactor trip with failure of MFW and AFW. Containment spray actuation assumed due to PORV discharge.	Operator maintains core cooling by "feed and bleed" using HPI to feed and two PORV to bleed. AFW is recovered 15 minutes after initiation of "feed and bleed" cooling. Operator closes PORVs when SG level reaches 60 percent.	1.08E-06	No	No	No
12	34	Main steam line break concurrent with a single tube failure in SG-A due to MSLB vibration.	Operator isolates AFW to affected SG at 15 minutes after initiation. Operator trips RCPs assuming that they do not trip as a result of the event. Operator assumed to throttle HPI if auxiliary feedwater is running with SG wide range level > -84% and RCS subcooling > 25 F. HPI is throttled to maintain pressurizer level between 40 and 60 %.	1.48E-05	No	No	No
13	40	40.64 cm (16 in) hot leg break. Containment sump recirculation included in the analysis.	None. Operator does not throttle HPI.	3.22E-05	No	Yes	Yes at 32, 60, 200, 500 EFPY

Table H-1 PTS Transient Descriptions for Palisades							
Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	HiK	Dominant*
14	42	Turbine/reactor trip with two stuck open pressurizer SRVs. Containment spray is assumed not to actuate.	Operator assumed to throttle HPI if auxiliary feedwater is running with SG wide range level > -84% and RCS subcooling > 25 F. HPI is throttled to maintain pressurizer level between 40 and 60 %.	7.67E-07	No	No	No
15	48	Two stuck-open pressurizer SRVs that reclose at 6000 sec after initiation. Containment spray is assumed not to actuate.	None. Operator does not throttle HPI.	7.67E-07	Yes	No	Yes at 32 EFPY
16	49	Main steam line break with the break assumed to be inside containment causing containment spray actuation.	Operator isolates AFW to affected SG at 30 minutes after initiation. Operator does not throttle HPI.	1.00e-05	Yes	No	No
17	50	Main steam line break with controller failure resulting in the flow from two AFW pumps into affected steam generator. Break assumed to be inside containment causing containment spray actuation.	Operator starts second AFW pump. Operator does not throttle HPI.	5.81E-07	Yes	No	No
18	51	Main steam line break with failure of both MSIVs to close. Break assumed to be inside containment causing containment spray actuation.	Operator does not isolate AFW on affected SG. Operator does not throttle HPI.	7.51E-08	Yes	No	No
19	52	Reactor trip with 1 stuck-open ADV on SG-A. Failure of both MSIVs (SG-A and SG-B) to close.	Operator does not isolate AFW on affected SG. Normal AFW flow assumed (200 gpm). Operator does not throttle HPI.	6.37E-04	Yes	No	Yes at 500 EFPY
20	53	Turbine/reactor trip with two stuck-open pressurizer SRVs that reclose at 6000 sec after initiation. Containment spray is assumed not to actuate.	None. Operator does not throttle HPI.	1.09E-03	No	No	Yes at 500 EFPY
21	54	Main steam line break with failure of both MSIVs to close. Break assumed to be inside containment causing containment spray actuation.	Operator does not isolate AFW on affected SG. Operator does not throttle HPI.	4.26E-06	No	No	Yes at 32, 60, 200, 500 EFPY

<b>Table H-1 PTS Transient Descriptions for Palisades</b>							
<b>Count</b>	<b>TH Case #</b>	<b>System Failure</b>	<b>Operator Action</b>	<b>Mean IE Frequency</b>	<b>HZP</b>	<b>HiK</b>	<b>Dominant*</b>
22	55	Turbine/reactor trip with 2 stuck-open ADVs on SG-A combined with controller failure resulting in the flow from two AFW pumps into affected steam generator.	Operator starts second AFW pump.	2.74E-03	No	No	Yes at 32, 60, 200, 500 EFPY
23	58	10.16 cm (4 in) cold leg break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)	None. Operator does not throttle HPI.	2.66E-04	No	Yes	Yes at 32, 60, 200, 500 EFPY
24	59	10.16 cm (4 in) cold leg break. Summer conditions assumed (HPI and LPI injection temp = 100 F, Accumulator temp = 90 F)	None. Operator does not throttle HPI.	2.09E-04	No	Yes	Yes at 500 EFPY
25	60	5.08 cm (2 in) surge line break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)	None. Operator does not throttle HPI.	2.09E-04	No	Yes	Yes at 60, 200, 500 EFPY
26	61	7.18 cm (2.8 in) cold leg break. Summer conditions assumed (HPI and LPI injection temp = 100 F, Accumulator temp = 90 F)	None. Operator does not throttle HPI.	2.09E-04	No	Yes	No
27	62	20.32 cm (8 in) cold leg break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)	None. Operator does not throttle HPI.	7.07E-06	No	Yes	Yes at 32, 60, 200, 500 EFPY
28	63	14.37 cm (5.656 in) cold leg break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)	None. Operator does not throttle HPI.	6.06E-06	No	Yes	Yes at 60, 200, 500 EFPY
29	64	10.16 cm (4 in) surge line break. Summer conditions assumed (HPI and LPI injection temp = 100 F, Accumulator temp = 90 F)	None. Operator does not throttle HPI.	7.07E-06	No	Yes	Yes at 32, 60, 200, 500 EFPY
30	65	One stuck-open pressurizer SRV that recloses at 6000 sec after initiation. Containment spray is assumed not to actuate.	None. Operator does not throttle HPI.	1.24E-04	Yes	No	Yes at 32, 60, 200, 500 EFPY

## Notes:

1. TH ### – Thermal hydraulics run number ###
2. LOCA – Loss-of-coolant accident
3. SBLOCA – Small-break loss-of-coolant accident
4. MBLOCA – Medium-break loss-of-coolant accident
5. LBLOCA – Large-break loss-of-coolant accident
6. HZP – Hot-zero power
7. ADV – Atmospheric dump valve
8. SRV – Safety and relief valve
9. MSLB – Main steam line break
10. AFW – Auxiliary feedwater
11. HPI – High-pressure injection
12. RCP – Reactor coolant pump
13. SG – Steam generator

\* The arbitrary definition of a dominant transient is a transient that contributes 1% or more of the total Through-Wall Cracking Failure (TWCF).

DRAFT

**APPENDIX I  
PALISADES FAVPOST OUTPUT**

DRAFT

## I-1: 10 Year ISI only

```

*****
*
*                               *
*                   WELCOME TO FAVOR                   *
*                               *
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE           *
*                   VERSION 06.1                       *
*                               *
*   FAVPOST MODULE: POSTPROCESSOR MODULE             *
*   COMBINES TRANSIENT INITIATING FREQUENCIES        *
*   WITH RESULTS OF PFM ANALYSIS                      *
*                               *
*   PROBLEMS OR QUESTIONS REGARDING FAVOR             *
*   SHOULD BE DIRECTED TO                            *
*                               *
*                   TERRY DICKSON                     *
*   OAK RIDGE NATIONAL LABORATORY                   *
*                               *
*   e-mail: dickson1@ornl.gov                       *
*                               *
*****

```

```

*****
* This computer program was prepared as an account of *
* work sponsored by the United States Government      *
* Neither the United States, nor the United States   *
* Department of Energy, nor the United States Nuclear *
* Regulatory Commission, nor any of their employees, *
* nor any of their contractors, subcontractors, or their *
* employees, makes any warranty, expressed or implied, or *
* assumes any legal liability or responsibility for the *
* accuracy, completeness, or usefulness of any *
* information, apparatus, product, or process disclosed, *
* or represents that its use would not infringe *
* privately-owned rights. *
*****

```

DATE: 27-Jun-2007 TIME: 10:25:13

```

Begin echo of FAVPost input data deck          10:25:13   27-Jun-2007
End echo of FAVPost input data deck          10:25:13   27-Jun-2007

```

```

FAVPOST INPUT FILE NAME           = postpl.in
FAVPFM OUTPUT FILE CONTAINING PFM1 ARRAY = INITIATE.DAT
FAVPFM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME          = plpost10yronly.out

```

## I-1: 10 Year ISI only (cont.)

\*\*\*\*\*  
 \* NUMBER OF SIMULATIONS = 70000 \*  
 \*\*\*\*\*

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPFmn/CPImn
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
16	2.0991E-09	0.0000E+00	0.0000E+00	2.6647E-10	0.0000E+00	0.0000E+00	0.1269
18	4.1893E-11	0.0000E+00	0.0000E+00	2.0525E-11	0.0000E+00	0.0000E+00	0.4899
19	5.1457E-07	0.0000E+00	0.0000E+00	3.4107E-07	0.0000E+00	0.0000E+00	0.6628
22	6.0538E-09	0.0000E+00	0.0000E+00	1.7933E-09	0.0000E+00	0.0000E+00	0.2962
24	7.2366E-07	0.0000E+00	0.0000E+00	8.5291E-08	0.0000E+00	0.0000E+00	0.1181
26	7.2366E-07	0.0000E+00	0.0000E+00	9.3863E-08	0.0000E+00	0.0000E+00	0.1294
27	2.0421E-05	4.3132E-04	2.0173E-04	5.9362E-06	1.6195E-04	6.0880E-05	0.2907
29	6.8282E-07	0.0000E+00	0.0000E+00	1.6244E-07	0.0000E+00	0.0000E+00	0.6772
31	2.3780E-05	2.9665E-04	2.6221E-04	5.4087E-06	9.2535E-05	5.7966E-05	0.2274
32	4.3551E-07	0.0000E+00	0.0000E+00	3.6097E-07	0.0000E+00	0.0000E+00	0.6911
34	3.4459E-06	0.0000E+00	1.1896E-06	6.4255E-07	0.0000E+00	1.6486E-07	0.1868
40	6.0211E-03	1.2838E-02	6.9324E-02	3.8794E-04	8.0216E-04	5.1013E-03	0.0644
42	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
48	5.4079E-04	2.4464E-03	7.8391E-03	5.4190E-04	2.4464E-03	7.2226E-03	0.9835
49	2.8452E-07	0.0000E+00	0.0000E+00	4.9008E-08	0.0000E+00	0.0000E+00	0.1722
50	4.4689E-05	6.9298E-04	6.6733E-04	1.4807E-05	2.7591E-04	2.2267E-04	0.3313
51	2.3653E-04	1.5112E-03	3.3702E-03	1.1828E-04	8.5384E-04	1.6646E-03	0.5001
52	6.0157E-07	0.0000E+00	0.0000E+00	3.9569E-07	0.0000E+00	0.0000E+00	0.6578
53	2.6708E-07	0.0000E+00	0.0000E+00	1.8524E-07	0.0000E+00	0.0000E+00	0.6936
54	4.7146E-04	2.0579E-03	6.9604E-03	2.1455E-04	1.1565E-03	3.1205E-03	0.4551
55	1.3039E-06	0.0000E+00	0.0000E+00	9.5266E-07	0.0000E+00	0.0000E+00	0.7306
58	3.9842E-04	1.9057E-03	5.2952E-03	7.5527E-05	5.0201E-04	8.2070E-04	0.1896
59	1.6591E-05	2.2922E-04	1.5697E-04	1.1995E-06	3.1036E-05	9.8600E-06	0.0723
60	4.2014E-05	7.4348E-04	5.9014E-04	5.3889E-06	8.0611E-05	7.5170E-05	0.1283
61	9.0696E-07	0.0000E+00	2.2070E-10	3.9814E-08	0.0000E+00	1.5568E-12	0.0439
62	4.8426E-03	1.0080E-02	5.6235E-02	5.1473E-04	1.0533E-03	6.6194E-03	0.1063
63	1.7066E-03	3.3225E-03	2.3408E-02	2.4011E-04	8.3884E-04	3.0140E-03	0.1407
64	1.9466E-03	4.0456E-03	2.5502E-02	2.8279E-04	5.7833E-04	3.9028E-03	0.1453

## I-1: 10 Year ISI only (cont.)

65    1.7674E-04    1.5370E-03    2.8655E-03    1.7065E-04    1.5297E-03    2.7897E-03    0.9655

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

\*\*\*\*\*  
 \*            PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)            \*  
 \*            FOR THE FREQUENCY OF CRACK INITIATION                \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	1.7957	1.7957
1.8255E-06	95.9914	97.7871
5.4764E-06	1.1900	98.9771
9.1273E-06	0.3786	99.3557
1.2778E-05	0.1929	99.5486
1.6429E-05	0.1129	99.6614
2.0080E-05	0.0829	99.7443
2.3731E-05	0.0514	99.7957
2.7382E-05	0.0357	99.8314
3.1033E-05	0.0343	99.8657
3.4684E-05	0.0143	99.8800
3.8335E-05	0.0171	99.8971
4.1986E-05	0.0171	99.9143
4.5636E-05	0.0129	99.9271
4.9287E-05	0.0071	99.9343
5.2938E-05	0.0086	99.9429
5.6589E-05	0.0086	99.9514
6.0240E-05	0.0043	99.9557
6.3891E-05	0.0014	99.9571
6.7542E-05	0.0043	99.9614



## I-1: 10 Year ISI only (cont.)

7.1193E-05	0.0029	99.9643
7.4844E-05	0.0014	99.9657
7.8495E-05	0.0043	99.9700
8.2146E-05	0.0029	99.9729
8.9447E-05	0.0029	99.9757
9.3098E-05	0.0014	99.9771
9.6749E-05	0.0014	99.9786
1.0040E-04	0.0014	99.9800
1.0405E-04	0.0029	99.9829
1.0770E-04	0.0014	99.9843
1.1500E-04	0.0014	99.9857
1.1865E-04	0.0029	99.9886
1.3326E-04	0.0014	99.9900
1.3691E-04	0.0014	99.9914
1.4056E-04	0.0014	99.9929
1.4786E-04	0.0014	99.9943
1.5516E-04	0.0014	99.9957
2.0263E-04	0.0014	99.9971
3.0120E-04	0.0014	99.9986
3.5962E-04	0.0014	100.0000

```

=====
==      Summary Descriptive Statistics      ==
=====

```

```

Minimum                = 0.0000E+00
Maximum                = 3.6144E-04
Range                  = 3.6144E-04

Number of Simulations  = 70000

5th Percentile         = 1.0576E-11
Median                 = 3.1534E-08
95.0th Percentile     = 1.8255E-06
99.0th Percentile     = 5.6968E-06
99.9th Percentile     = 3.8943E-05

Mean                   = 4.7962E-07
Standard Deviation     = 3.4846E-06
Standard Error         = 1.3171E-08
Variance (unbiased)   = 1.2142E-11
Variance (biased)     = 1.2142E-11
Moment Coeff. of Skewness = 4.1589E+01
Pearson's 2nd Coeff. of Skewness = 4.1292E-01
Kurtosis               = 3.0077E+03

```

```

*****
*      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)      *
*      FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE)     *
*****

```

\*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	2.7414	2.7414
9.9132E-07	96.6714	99.4129
2.9740E-06	0.3271	99.7400
4.9566E-06	0.0971	99.8371
6.9392E-06	0.0557	99.8929
8.9219E-06	0.0286	99.9214
1.0904E-05	0.0186	99.9400
1.2887E-05	0.0100	99.9500
1.4870E-05	0.0100	99.9600
1.6852E-05	0.0071	99.9671
1.8835E-05	0.0071	99.9743
2.0818E-05	0.0029	99.9771
2.2800E-05	0.0057	99.9829
2.4783E-05	0.0029	99.9857
2.6748E-05	0.0014	99.9871
3.2713E-05	0.0014	99.9886
3.4696E-05	0.0014	99.9900
3.6679E-05	0.0014	99.9914
4.2627E-05	0.0014	99.9929
4.4609E-05	0.0014	99.9943
4.6592E-05	0.0029	99.9971
1.0409E-04	0.0014	99.9986
1.9727E-04	0.0014	100.0000

```

=====
==          Summary Descriptive Statistics          ==
=====

```

```

Minimum          = 0.0000E+00
Maximum          = 1.9628E-04
Range            = 1.9628E-04

Number of Simulations      = 70000

5th Percentile   = 1.2334E-13
Median           = 2.0809E-09
95.0th Percentile = 9.9132E-07
99.0th Percentile = 1.1299E-06
99.9th Percentile = 7.4349E-06

Mean             = 7.6237E-08
Standard Deviation = 1.0800E-06
Standard Error   = 4.0821E-09
Variance (unbiased) = 1.1664E-12
Variance (biased)  = 1.1664E-12
Moment Coeff. of Skewness = 1.0725E+02
Pearson's 2nd Coeff. of Skewness = 1.2417E-01
Kurtosis         = 1.7688E+04

```

I-1: 10 Year ISI only (cont.)

```

*****
*   FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION   *
*   AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -     *
*   WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
*****

```

	% of total frequency of crack initiation	% of total frequency of of TWC failure
2	0.00	0.00
16	0.00	0.00
18	0.00	0.00
19	0.28	1.10
22	0.00	0.00
24	0.00	0.00
26	0.10	0.08
27	0.16	0.30
29	0.00	0.00
31	0.07	0.10
32	0.00	0.00
34	0.01	0.01
40	50.98	20.66
42	0.00	0.00
48	0.09	0.58
49	0.00	0.00
50	0.01	0.01
51	0.01	0.02
52	0.05	0.21
53	0.06	0.26
54	0.57	1.62
55	1.02	4.91
58	24.02	27.50
59	0.79	0.36
60	1.91	1.55
61	0.05	0.01
62	8.97	5.93
63	2.59	2.33
64	3.42	3.01
65	4.84	29.44
TOTALS	100.00	100.00

I-1: 10 Year ISI only (cont.)

```

*****
*   FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION   *
*   AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -     *
*   BY                                                     *
*   RPV BELTLINE MAJOR REGION                             *
*   BY PARENT SUBREGION                                   *
*   *                                                     *
*   WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT        *
*   TO FREQUENCY OF CRACK INITIATION AND                *
*   THROUGH-WALL CRACKING FREQUENCY (FAILURE)          *
*****
    
```

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency		
				cleavage	ductile	total
1	237.44	2.04	7.75	3.95	2.55	6.51
2	246.96	2.04	10.50	6.85	4.40	11.24
3	246.96	2.04	11.34	7.15	4.89	12.04
4	247.43	3.16	23.77	19.46	10.46	29.92
5	237.77	3.16	16.33	10.62	5.75	16.36
6	247.43	3.16	22.11	14.52	9.40	23.92
7	231.49	19.12	7.68	0.01	0.00	0.01
8	195.14	8.55	0.04	0.00	0.00	0.00
9	166.15	8.55	0.00	0.00	0.00	0.00
10	130.00	8.55	0.00	0.00	0.00	0.00
11	206.88	13.21	0.18	0.00	0.00	0.00
12	186.36	13.21	0.03	0.00	0.00	0.00
13	208.62	13.21	0.26	0.00	0.00	0.00
TOTALS		100.00	100.00	62.56	37.44	100.00

```

*****
*   FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION   *
*   AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -     *
*   BY                                                     *
*   RPV BELTLINE MAJOR REGION                             *
*   BY CHILD SUBREGION                                   *
*   *                                                     *
*   WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT        *
*   TO FREQUENCY OF CRACK INITIATION AND                *
*   THROUGH-WALL CRACKING FREQUENCY (FAILURE)          *
*****
    
```

I-1: 10 Year ISI only (cont.)

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency		
				cleavage	ductile	total
1	237.44	2.04	7.75	3.95	2.55	6.51
2	246.96	2.04	10.50	6.84	4.40	11.24
3	246.96	2.04	11.34	7.15	4.88	12.04
4	247.43	3.16	23.77	19.46	10.46	29.92
5	237.77	3.16	16.33	10.62	5.75	16.36
6	247.43	3.16	22.11	14.52	9.40	23.92
7	231.49	19.12	7.32	0.01	0.00	0.01
8	195.14	8.55	0.04	0.00	0.00	0.00
9	166.15	8.55	0.00	0.00	0.00	0.00
10	130.00	8.55	0.00	0.00	0.00	0.00
11	206.88	13.21	0.18	0.00	0.00	0.00
12	186.36	13.21	0.03	0.00	0.00	0.00
13	208.62	13.21	0.61	0.00	0.00	0.00
TOTALS		100.00	100.00	62.56	37.44	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* MATERIAL, FLAW CATEGORY, AND FLAW DEPTH \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

\*\*\*\*\*  
 \* WELD MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.088	0.00	3.48	0.00	0.00	1.59	0.00
0.175	0.00	36.00	0.00	0.00	19.98	0.00
0.263	0.00	13.27	0.00	0.00	10.08	0.00
0.350	0.00	8.79	0.00	0.00	9.08	0.01
0.438	0.00	7.99	0.01	0.00	9.15	0.03
0.525	0.00	6.37	0.01	0.00	9.36	0.06

I-1: 10 Year ISI only (cont.)

0.613	0.00	4.47	0.01	0.00	5.81	0.05
0.700	0.00	3.48	0.01	0.00	5.76	0.08
0.787	0.00	2.88	0.02	0.00	4.99	0.10
0.875	0.00	2.33	0.01	0.00	3.81	0.05
0.963	0.00	1.55	0.03	0.00	2.79	0.18
1.050	0.06	2.27	0.04	0.00	6.36	0.20
1.137	1.00	1.78	0.02	0.03	3.20	0.13
1.225	0.02	1.27	0.01	0.00	2.32	0.09
1.313	0.09	0.76	0.00	0.00	1.53	0.02
1.400	0.00	0.35	0.01	0.00	0.63	0.03
1.488	0.00	0.19	0.00	0.00	0.37	0.02
1.575	0.00	0.29	0.00	0.00	0.49	0.00
1.663	0.00	0.03	0.00	0.00	0.10	0.01
1.750	0.00	0.26	0.01	0.00	0.72	0.05
1.837	0.03	0.00	0.00	0.00	0.03	0.00
1.925	0.00	0.28	0.00	0.00	0.68	0.02
2.013	0.00	0.00	0.00	0.00	0.00	0.00
2.100	0.00	0.00	0.00	0.00	0.00	0.00
2.188	0.00	0.00	0.00	0.00	0.00	0.00
2.275	0.00	0.00	0.00	0.00	0.00	0.00
2.363	0.00	0.00	0.00	0.00	0.00	0.00
2.450	0.00	0.00	0.00	0.00	0.00	0.00
2.537	0.00	0.00	0.00	0.00	0.00	0.00
2.625	0.00	0.00	0.00	0.00	0.00	0.00
2.712	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	1.20	98.08	0.19	0.03	98.83	1.13

\*\*\*\*\*  
 \* PLATE MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.088	0.00	0.00	0.00	0.00	0.00	0.00
0.175	0.00	0.00	0.00	0.00	0.00	0.00
0.263	0.00	0.00	0.00	0.00	0.00	0.00
0.350	0.00	0.00	0.00	0.00	0.00	0.00
0.438	0.00	0.00	0.00	0.00	0.00	0.00
0.525	0.00	0.00	0.00	0.00	0.00	0.00
0.613	0.00	0.00	0.00	0.00	0.00	0.00
0.700	0.00	0.00	0.00	0.00	0.00	0.00
0.787	0.00	0.00	0.00	0.00	0.00	0.00
0.875	0.00	0.00	0.00	0.00	0.00	0.00
0.963	0.00	0.00	0.00	0.00	0.00	0.00
1.050	0.07	0.00	0.00	0.00	0.00	0.00
1.137	0.28	0.00	0.00	0.00	0.00	0.00

## I-1: 10 Year ISI only (cont.)

1.225	0.10	0.00	0.00	0.00	0.00	0.00
1.313	0.02	0.00	0.00	0.00	0.00	0.00
1.400	0.04	0.00	0.00	0.00	0.00	0.00
1.488	0.00	0.00	0.00	0.00	0.00	0.00
1.575	0.00	0.00	0.00	0.00	0.00	0.00
1.663	0.00	0.00	0.00	0.00	0.00	0.00
1.750	0.01	0.00	0.00	0.00	0.00	0.00
1.837	0.00	0.00	0.00	0.00	0.00	0.00
1.925	0.00	0.00	0.00	0.00	0.00	0.00
2.013	0.00	0.00	0.00	0.00	0.00	0.00
2.100	0.00	0.00	0.00	0.00	0.00	0.00
2.188	0.00	0.00	0.00	0.00	0.00	0.00
2.275	0.00	0.00	0.00	0.00	0.00	0.00
2.363	0.00	0.00	0.00	0.00	0.00	0.00
2.450	0.00	0.00	0.00	0.00	0.00	0.00
2.537	0.00	0.00	0.00	0.00	0.00	0.00
2.625	0.00	0.00	0.00	0.00	0.00	0.00
2.712	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	0.52	0.00	0.00	0.00	0.00	0.00

DATE: 27-Jun-2007 TIME: 10:25:45

```

*****
*
* WELCOME TO FAVOR
*
* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
* VERSION 05.1
*
* FAVORPOST MODULE: POSTPROCESSOR MODULE
* COMBINES TRANSIENT INITIATING FREQUENCIES
* WITH RESULTS OF FEM ANALYSIS
*
* PROBLEMS OR QUESTIONS REGARDING FAVOR
* SHOULD BE DIRECTED TO
*
* TERRY DICKSON
* OAK RIDGE NATIONAL LABORATORY
*
* e-mail: dicksentl@ornl.gov
*
*****

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*****
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* work sponsored by the United States Government
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* Department of Energy, nor the United States Nuclear
* Regulatory Commission, nor any of their employees,
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* assumes any legal liability or responsibility for the
* accuracy, completeness, or usefulness of any

```

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~~\* or represents that its use would not infringe \*~~  
~~\* privately owned rights. \*~~  
~~\*\*\*\*\*~~

~~DATE: 17-Aug-2005 TIME: 13:36:46~~

~~FAVPOST INPUT FILE NAME = postpl.in~~  
~~FAVPEM OUTPUT FILE CONTAINING PEMI ARRAY = INITIATE.DAT~~  
~~FAVPEM OUTPUT FILE CONTAINING PEMF ARRAY = FAILURE.DAT~~  
~~FAVPOST OUTPUT FILE NAME = 80000.out~~

~~\*\*\*\*\*~~  
~~\* NUMBER OF SIMULATIONS = 80000 \*~~  
~~\*\*\*\*\*~~



**4-1: 10-Year ISI only (cont.)**

PROBABILITY	CONDITIONAL PROBABILITY OF INITIATION $CPI=P(I E)$				CONDITIONAL PROBABILITY OF FAILURE	
	MEAN	95th %	99th %	MEAN	95th %	
$CPI=P(F E)$	CPI	CPI	CPI	CPI	CPI	
TRANSIENT	RATIO					
NUMBER	CPI	CPI	CPI	CPI	CPI	
$CPI$	$CPI_{min}/CPI_{max}$					
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
16	8.5514E-11	0.0000E+00	0.0000E+00	6.4577E-12	0.0000E+00	
18	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
19	2.0472E-07	0.0000E+00	0.0000E+00	1.4761E-07	0.0000E+00	
22	1.9263E-10	0.0000E+00	0.0000E+00	3.5754E-11	0.0000E+00	
24	2.1733E-07	0.0000E+00	0.0000E+00	2.0921E-08	0.0000E+00	
26	2.1733E-07	0.0000E+00	0.0000E+00	2.1544E-08	0.0000E+00	
27	6.1144E-06	0.0000E+00	7.3401E-06	1.7443E-06	0.0000E+00	
29	1.2217E-07	0.0000E+00	0.0000E+00	6.6567E-08	0.0000E+00	
31	6.0427E-06	0.0000E+00	7.2749E-06	1.3184E-06	0.0000E+00	
32	1.7253E-07	0.0000E+00	0.0000E+00	1.2111E-07	0.0000E+00	
34	1.0526E-06	0.0000E+00	0.0000E+00	1.6479E-07	0.0000E+00	
40	1.7124E-03	4.0206E-03	2.4764E-02	9.2478E-05	3.1386E-04	
42	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
48	1.4380E-04	2.7147E-03	2.1555E-03	1.4279E-04	2.7091E-03	
49	6.4972E-08	0.0000E+00	0.0000E+00	7.8356E-09	0.0000E+00	
50	1.3736E-05	3.1047E-04	7.6335E-05	3.6895E-06	0.0000E+00	
51	6.8134E-05	8.5399E-04	9.3788E-04	3.4744E-05	4.4063E-04	
52	2.4938E-07	0.0000E+00	0.0000E+00	1.7929E-07	0.0000E+00	
53	1.0285E-07	0.0000E+00	0.0000E+00	7.8464E-08	0.0000E+00	
54	1.2929E-04	1.2053E-03	7.0543E-03	6.4735E-05	6.6773E-04	

<del>55</del>	<del>5.2116E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>4.1702E-07</del>	<del>0.0000E+00</del>
<del>0.0000E+00</del>	<del>0.8002</del>				
<del>58</del>	<del>5.3040E-05</del>	<del>1.9353E-03</del>	<del>6.0871E-04</del>	<del>5.6862E-06</del>	<del>2.3038E-04</del>
<del>4.9345E-05</del>	<del>0.1072</del>				
<del>59</del>	<del>4.6920E-06</del>	<del>0.0000E+00</del>	<del>3.9194E-06</del>	<del>2.4849E-07</del>	<del>0.0000E+00</del>
<del>1.1407E-07</del>	<del>0.0530</del>				
<del>60</del>	<del>1.2442E-05</del>	<del>8.3152E-04</del>	<del>5.6793E-05</del>	<del>1.4351E-06</del>	<del>4.7793E-05</del>
<del>5.6811E-06</del>	<del>0.1153</del>				
<del>61</del>	<del>3.2870E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>8.0845E-09</del>	<del>0.0000E+00</del>
<del>0.0000E+00</del>	<del>0.0239</del>				
<del>62</del>	<del>8.9226E-04</del>	<del>4.2246E-03</del>	<del>1.1498E-02</del>	<del>7.0150E-05</del>	<del>5.1237E-04</del>
<del>7.1432E-04</del>	<del>0.0786</del>				
<del>63</del>	<del>3.4598E-04</del>	<del>3.6819E-03</del>	<del>5.8713E-03</del>	<del>3.2526E-05</del>	<del>3.3214E-04</del>
<del>5.0588E-04</del>	<del>0.0940</del>				
<del>64</del>	<del>5.1177E-04</del>	<del>2.7766E-03</del>	<del>6.7856E-03</del>	<del>6.4962E-05</del>	<del>4.3520E-04</del>
<del>8.0933E-04</del>	<del>0.1269</del>				
<del>65</del>	<del>4.8006E-05</del>	<del>1.6992E-03</del>	<del>4.8467E-04</del>	<del>4.7426E-05</del>	<del>1.6732E-03</del>
<del>4.7726E-04</del>	<del>0.9879</del>				

I-1: 10 Year ISI only (cont.)

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	9.5813	9.5813
9.4162E-07	89.5063	99.0925
2.8249E-06	0.5238	99.6163
4.7081E-06	0.1488	99.7651
6.5913E-06	0.0675	99.8326
8.4746E-06	0.0363	99.8689
1.0358E-05	0.0313	99.8950
1.2241E-05	0.0225	99.9175
1.4124E-05	0.0125	99.9300
1.6008E-05	0.0075	99.9375
1.7891E-05	0.0075	99.9450
1.9774E-05	0.0038	99.9487
2.1657E-05	0.0063	99.9550
2.3540E-05	0.0038	99.9587
2.5424E-05	0.0038	99.9625
2.7307E-05	0.0025	99.9650
2.9190E-05	0.0038	99.9687
3.1074E-05	0.0025	99.9712
3.2957E-05	0.0013	99.9725
3.4840E-05	0.0038	99.9762
3.6724E-05	0.0025	99.9787
3.8607E-05	0.0025	99.9812
4.0490E-05	0.0013	99.9825
4.2374E-05	0.0025	99.9850
4.4257E-05	0.0013	99.9862
4.6140E-05	0.0013	99.9875
4.8024E-05	0.0013	99.9887
4.9907E-05	0.0013	99.9900
5.1790E-05	0.0013	99.9912
5.3674E-05	0.0013	99.9925
5.5557E-05	0.0013	99.9937
5.7440E-05	0.0013	99.9950
5.9324E-05	0.0025	99.9975
6.1207E-05	0.0013	99.9987
6.3090E-05	0.0013	99.9990
6.4974E-05	0.0013	99.9992
6.6857E-05	0.0013	99.9995
6.8740E-05	0.0013	99.9997
7.0624E-05	0.0013	99.9999
7.2507E-05	0.0013	100.0000

I-1: 10 Year ISI only (cont.)

Summary Descriptive Statistics		
Minimum	=	0.0000E+00
Maximum	=	1.8644E-04
Range	=	1.8644E-04
Number of Simulations	=	80000
5th Percentile	=	0.0000E+00
Median	=	4.422E-09
95.0th Percentile	=	9.4162E-07
99.0th Percentile	=	1.7191E-06
99.9th Percentile	=	1.0770E-05
Mean	=	1.1076E-07
Standard Deviation	=	1.5009E-06
Standard Error	=	5.3064E-09
Variance (unbiased)	=	2.2526E-12
Variance (biased)	=	2.2526E-12
Moment Coeff. of Skewness	=	6.3441E+01
Pearson's 2nd Coeff. of Skewness	=	2.2139E-01
Kurtosis	=	5.5931E+03
*****		
* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) *		
* FOR THROUGH WALL CRACKING FREQUENCY (FAILURE) *		
*****		
FREQUENCY OF TWO FAILURES (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	17.3700	17.3700
1.9226E-07	82.4238	99.7938
1.1768E-06	0.1012	99.8950
2.2613E-06	0.0375	99.9325
3.7458E-06	0.0187	99.9513
4.4303E-06	0.0113	99.9625
5.4148E-06	0.0100	99.9725
6.3993E-06	0.0050	99.9775
7.3839E-06	0.0025	99.9800
8.3684E-06	0.0025	99.9825
9.3529E-06	0.0025	99.9850
1.0337E-05	0.0013	99.9862
1.1322E-05	0.0013	99.9875
1.2306E-05	0.0025	99.9900
1.4275E-05	0.0025	99.9925
1.7229E-05	0.0013	99.9937
1.8214E-05	0.0013	99.9950
2.4121E-05	0.0013	99.9962
3.3966E-05	0.0013	99.9975

I-1: 10 Year ISI only (cont.)

4.8733E-05	0.0013	99.9987
9.7959E-05	0.0013	100.0000

Summary Descriptive Statistics

Minimum	= 0.0000E+00
Maximum	= 9.7467E-05
Range	= 9.7467E-05
Number of Simulations	= 80000
5th Percentile	= 0.0000E+00
Median	= 2.0039E-11
95.0th Percentile	= 4.9227E-07
99.0th Percentile	= 1.9186E-07
99.9th Percentile	= 1.6080E-06
Mean	= 1.5364E-08
Standard Deviation	= 4.5949E-07
Standard Error	= 1.6246E-09
Variance (unbiased)	= 2.1113E-13
Variance (biased)	= 2.1113E-13
Moment Coeff. of Skewness	= 1.4562E+02
Pearson's 2nd Coeff. of Skewness	= 9.0898E-02
Kurtosis	= 2.7526E+04

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
2	0.00	0.00
4	0.00	0.00
6	0.00	0.00
8	0.00	0.00
10	0.16	0.93
12	0.00	0.00
14	0.00	0.00
16	0.00	0.00
18	0.11	0.08
20	0.21	0.45
22	0.00	0.00
24	0.00	0.00
26	0.00	0.00
28	0.09	0.16
30	0.00	0.00
32	0.00	0.00
34	0.02	0.02
36	0.00	0.00
38	61.35	23.84
40	0.00	0.00
42	0.00	0.00
44	0.10	0.74
46	0.00	0.00
48	0.00	0.00
50	0.00	0.00

I-1: 10 Year ISI only (cont.)

50	0.01	0.02
51	0.01	0.03
52	0.05	0.32
53	0.09	0.44
54	0.81	2.82
55	0.96	5.53
56	13.03	10.90
59	1.10	0.42
60	2.48	2.04
61	0.06	0.01
62	7.31	4.49
63	2.36	1.74
64	3.86	3.40
65	5.84	11.57
TOTALS	100.00	100.00
DATE: 17 Aug 2005 TIME: 13:37:51		

DRAFT

I-2: ISI Every 10 Years

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*****
*
*           WELCOME TO FAVOR
*
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
*           VERSION 06.1
*
*   FAVPOST MODULE: POSTPROCESSOR MODULE
*   COMBINES TRANSIENT INITIATING FREQUENCIES
*   WITH RESULTS OF PFM ANALYSIS
*
*   PROBLEMS OR QUESTIONS REGARDING FAVOR
*   SHOULD BE DIRECTED TO
*
*           TERRY DICKSON
*   OAK RIDGE NATIONAL LABORATORY
*
*           e-mail: dickson1@ornl.gov
*
*****

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*****
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*****

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DATE: 27-Jun-2007 TIME: 10:23:32

```

Begin echo of FAVPost input data deck          10:23:32      27-Jun-2007

```

```

*****
*
*           WELCOME TO FAVOR
*
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
*           VERSION 06.1
*
*   FAVPOST MODULE: POSTPROCESSOR MODULE
*   COMBINES TRANSIENT INITIATING FREQUENCIES
*   WITH RESULTS OF PFM ANALYSIS
*

```

```

*
* PROBLEMS OR QUESTIONS REGARDING FAVOR *
* SHOULD BE DIRECTED TO *
*
* TERRY DICKSON *
* OAK RIDGE NATIONAL LABORATORY *
*
* e-mail: dicksent1@ornl.gov *
*
*****

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*****
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* Regulatory Commission, nor any of their employees, *
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* or represents that its use would not infringe *
* privately owned rights. *
*****

```

DATE: 17 Aug 2005 TIME: 13:48:45

```

FAVPOST INPUT FILE NAME = postpl.in
FAVPFM OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME = 80000.out

```

\*\*\*\*\*  
\* NUMBER OF SIMULATIONS = 80000 \*

End echo of FAVPost input data deck 10:23:32 27-Jun-2007

```

FAVPOST INPUT FILE NAME = postpl.in
FAVPFM OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME = plpost10yrprint.out
*****

```



## I-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* NUMBER OF SIMULATIONS = 70000 \*  
 \*\*\*\*\*

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPFmn/CPImm
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
16	1.2905E-10	0.0000E+00	0.0000E+00	1.9672E-11	0.0000E+00	0.0000E+00	0.1524
18	1.9999E-08	0.0000E+00	0.0000E+00	1.3349E-08	0.0000E+00	0.0000E+00	0.6675
19	4.3542E-07	0.0000E+00	0.0000E+00	2.4996E-07	0.0000E+00	0.0000E+00	0.6730
22	4.7785E-10	0.0000E+00	0.0000E+00	1.6163E-10	0.0000E+00	0.0000E+00	0.3382
24	4.2145E-07	0.0000E+00	0.0000E+00	5.5149E-08	0.0000E+00	0.0000E+00	0.1309
26	4.2145E-07	0.0000E+00	0.0000E+00	5.6127E-08	0.0000E+00	0.0000E+00	0.1332
27	1.6669E-05	4.0851E-04	1.0224E-04	5.0727E-06	1.3999E-04	5.5346E-05	0.3040
29	3.2222E-07	0.0000E+00	0.0000E+00	2.2848E-07	0.0000E+00	0.0000E+00	0.7091
31	1.9968E-05	3.1503E-04	2.2641E-04	5.2229E-06	8.4354E-05	5.6231E-05	0.2616
32	4.1319E-07	0.0000E+00	0.0000E+00	2.7632E-07	0.0000E+00	0.0000E+00	0.6688
34	2.0638E-06	0.0000E+00	2.6818E-07	3.9138E-07	0.0000E+00	1.4814E-07	0.1896
40	5.8654E-03	1.3025E-02	6.3577E-02	3.8441E-04	8.2240E-04	4.9153E-03	0.0655
42	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
48	5.1460E-04	2.9847E-03	7.2004E-03	5.0771E-04	2.9613E-03	7.1338E-03	0.9866
49	1.2025E-07	0.0000E+00	0.0000E+00	2.3074E-08	0.0000E+00	0.0000E+00	0.1919
50	3.8097E-05	6.1000E-04	6.0949E-04	1.3058E-05	2.3488E-04	2.0982E-04	0.3428
51	2.1960E-04	1.5122E-03	3.0705E-03	1.1283E-04	6.4702E-04	1.6553E-03	0.5138
52	5.4043E-07	0.0000E+00	0.0000E+00	3.6486E-07	0.0000E+00	0.0000E+00	0.6751
53	2.6394E-07	0.0000E+00	0.0000E+00	1.9008E-07	0.0000E+00	0.0000E+00	0.7202
54	4.4223E-04	2.0292E-03	6.0638E-03	2.0682E-04	9.2843E-04	2.9785E-03	0.4677
55	1.1909E-06	0.0000E+00	0.0000E+00	8.8283E-07	0.0000E+00	0.0000E+00	0.7413
58	3.4658E-04	1.0963E-03	5.2758E-03	7.1215E-05	3.8156E-04	9.2302E-04	0.2055
59	1.3685E-05	2.8125E-04	1.3312E-04	1.1435E-06	2.6929E-05	8.8218E-06	0.0836

I-2: ISI Every 10 Years (cont.)

60	3.4196E-05	5.1697E-04	4.9575E-04	5.1734E-06	1.0186E-04	6.8749E-05	0.1513
61	6.3437E-07	0.0000E+00	2.4648E-11	3.7831E-08	0.0000E+00	2.4484E-14	0.0596
62	4.6580E-03	1.0090E-02	5.1261E-02	5.0659E-04	1.0724E-03	6.4912E-03	0.1088
63	1.5523E-03	3.1172E-03	2.1441E-02	2.2840E-04	8.1778E-04	3.0185E-03	0.1471
64	1.8747E-03	4.0838E-03	2.2910E-02	2.8006E-04	6.6854E-04	3.7212E-03	0.1494
65	1.6533E-04	1.9541E-03	2.8139E-03	1.6078E-04	1.9452E-03	2.7094E-03	0.9725

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE,

P(F|E):

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI-P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF-P(F E)			RATIO CPF <sub>mn</sub> /CPI <sub>mn</sub>
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
16	7.7445E-13	0.0000E+00	0.0000E+00	4.0453E-14	0.0000E+00	0.0000E+00	0.0522
18	1.5330E-12	0.0000E+00	0.0000E+00	1.3049E-12	0.0000E+00	0.0000E+00	0.9099
19	9.5976E-08	0.0000E+00	0.0000E+00	7.0366E-08	0.0000E+00	0.0000E+00	0.7332
22	1.6973E-12	0.0000E+00	0.0000E+00	3.0494E-13	0.0000E+00	0.0000E+00	0.1797
24	1.8918E-07	0.0000E+00	0.0000E+00	1.9286E-08	0.0000E+00	0.0000E+00	0.1019
26	1.8918E-07	0.0000E+00	0.0000E+00	2.1409E-08	0.0000E+00	0.0000E+00	0.1132
27	6.0143E-06	0.0000E+00	1.2200E-05	1.9166E-06	0.0000E+00	3.8500E-06	0.3187
29	1.4942E-07	0.0000E+00	0.0000E+00	1.1331E-07	0.0000E+00	0.0000E+00	0.7584
31	5.6325E-06	0.0000E+00	9.8974E-06	1.5013E-06	0.0000E+00	1.8825E-06	0.2665
32	6.3302E-08	0.0000E+00	0.0000E+00	4.5718E-08	0.0000E+00	0.0000E+00	0.7222
34	6.9279E-07	0.0000E+00	0.0000E+00	1.1530E-07	0.0000E+00	0.0000E+00	0.1664
40	1.7563E-03	2.5046E-03	2.6632E-02	1.0662E-04	5.3379E-04	1.4595E-03	0.0607
42	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
48	1.6777E-04	1.0595E-03	2.4975E-03	1.6654E-04	1.9556E-03	2.4899E-03	0.9927
49	4.2963E-08	0.0000E+00	0.0000E+00	5.9375E-09	0.0000E+00	0.0000E+00	0.1382
50	1.4198E-05	2.3376E-04	9.8468E-05	5.3103E-06	1.0187E-04	3.5054E-05	0.3740
51	7.3994E-05	6.9359E-04	1.0986E-03	3.9840E-05	4.5202E-04	6.2532E-04	0.5384
52	1.2878E-07	0.0000E+00	0.0000E+00	9.6447E-08	0.0000E+00	0.0000E+00	0.7489
53	3.0031E-08	0.0000E+00	0.0000E+00	2.1896E-08	0.0000E+00	0.0000E+00	0.7291
54	1.4119E-04	9.8601E-04	1.6965E-03	7.2979E-05	6.2722E-04	6.3054E-04	0.5169
55	2.7149E-07	0.0000E+00	0.0000E+00	2.2231E-07	0.0000E+00	0.0000E+00	0.8188

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58	4.6551E-05	4.7271E-04	6.0087E-04	6.1176E-06	1.6444E-04	5.9645E-05	0.1314
59	4.0810E-06	0.0000E+00	6.0089E-06	3.2603E-07	0.0000E+00	1.9652E-07	0.0823
60	1.0945E-05	1.8544E-04	6.6125E-05	1.6980E-06	6.5520E-05	7.6249E-06	0.1551
61	2.2645E-07	0.0000E+00	0.0000E+00	1.0152E-08	0.0000E+00	0.0000E+00	0.0448
62	9.1091E-04	2.8994E-03	1.3298E-02	8.3097E-05	7.3500E-04	7.1829E-04	0.0912
63	3.2398E-04	1.5885E-03	4.5267E-03	3.5907E-05	5.1264E-04	5.9140E-04	0.1075
64	5.3039E-04	1.6958E-03	7.6957E-03	7.4704E-05	6.1773E-04	9.3671E-04	0.1408
65	5.4910E-05	1.0905E-03	5.8651E-04	5.4180E-05	1.0833E-03	5.8057E-04	0.9867

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## I-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	1.8657	1.8657
1.3669E-06	95.1129	96.9786
4.1008E-06	1.6643	98.6429
6.8346E-06	0.5400	99.1829
9.5685E-06	0.2614	99.4443
1.2302E-05	0.1471	99.5914
1.5036E-05	0.0986	99.6900
1.7770E-05	0.0771	99.7671
2.0504E-05	0.0329	99.8000
2.3238E-05	0.0300	99.8300
2.5972E-05	0.0186	99.8486
2.8705E-05	0.0229	99.8714
3.1439E-05	0.0157	99.8871
3.4173E-05	0.0186	99.9057
3.6907E-05	0.0071	99.9129
3.9641E-05	0.0043	99.9171
4.2375E-05	0.0029	99.9200
4.5109E-05	0.0057	99.9257
4.7842E-05	0.0157	99.9414
5.0576E-05	0.0086	99.9500
5.3310E-05	0.0029	99.9529
5.6044E-05	0.0029	99.9557
5.8778E-05	0.0029	99.9586
6.1512E-05	0.0071	99.9657
6.4246E-05	0.0043	99.9700
6.6979E-05	0.0043	99.9743
6.9713E-05	0.0029	99.9771
7.2447E-05	0.0014	99.9786
7.5181E-05	0.0014	99.9800
7.7915E-05	0.0014	99.9814
8.0649E-05	0.0014	99.9857
8.3383E-05	0.0043	99.9886
8.6117E-05	0.0029	99.9914
8.8850E-05	0.0014	99.9929
9.1584E-05	0.0014	99.9943
9.4318E-05	0.0014	99.9957
9.7052E-05	0.0014	99.9971
9.9786E-05	0.0014	99.9986
1.1072E-04	0.0014	100.0000
1.2166E-04		
1.7907E-04		
2.4195E-04		
2.6928E-04		

## I-2: ISI Every 10 Years (cont.)

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=====
==          Summary Descriptive Statistics          ==
=====

Minimum                = 0.0000E+00
Maximum                = 2.7065E-04
Range                  = 2.7065E-04

Number of Simulations  = 70000

5th Percentile        = 9.2117E-12
Median                = 3.0552E-08
95.0th Percentile    = 3.669E-06
99.0th Percentile    = 5.9089E-06
99.9th Percentile    = 3.3335E-05

Mean                  = 4.4736E-07
Standard Deviation    = 2.9010E-06
Standard Error        = 1.0965E-08
Variance (unbiased)  = 8.4156E-12
Variance (biased)    = 8.4155E-12
Moment Coeff. of Skewness = 3.6027E+01
Pearson's 2nd Coeff. of Skewness = 4.6263E-01
Kurtosis              = 2.3099E+03

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*****
*          PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)          *
*          FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE)        *
*****

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FREQUENCY OF TWC FAILURES (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	2.7414	2.7414
7.0253E-07	96.4900	99.2314
2.1076E-06	0.3986	99.6300
3.5126E-06	0.1529	99.7829
4.9177E-06	0.0600	99.8429
6.3228E-06	0.0414	99.8843
7.7278E-06	0.0286	99.9129
9.1329E-06	0.0257	99.9386
1.0538E-05	0.0043	99.9429
1.1943E-05	0.0086	99.9514
1.3348E-05	0.0114	99.9629
1.4753E-05	0.0014	99.9643
1.6158E-05	0.0043	99.9686
1.7563E-05	0.0071	99.9757
2.4589E-05	0.0029	99.9786

I-2: ISI Every 10 Years (cont.)

2.7399E-05	0.0029	99.9814
3.0209E-05	0.0014	99.9829
3.1614E-05	0.0029	99.9857
3.4424E-05	0.0014	99.9871
3.5829E-05	0.0029	99.9900
3.7234E-05	0.0014	99.9914
3.8639E-05	0.0014	99.9929
4.0044E-05	0.0014	99.9943
4.4259E-05	0.0014	99.9957
6.9550E-05	0.0014	99.9971
1.3278E-04	0.0014	99.9986
1.3980E-04	0.0014	100.0000

=====  
 == Summary Descriptive Statistics ==  
 =====

Minimum	=	0.0000E+00
Maximum	=	1.3910E-04
Range	=	1.3910E-04
Number of Simulations	=	70000
5th Percentile	=	1.2899E-13
Median	=	2.0727E-09
95.0th Percentile	=	7.0253E-07
99.0th Percentile	=	1.0895E-06
99.9th Percentile	=	7.0955E-06
Mean	=	7.3880E-08
Standard Deviation	=	1.0054E-06
Standard Error	=	3.8001E-09
Variance (unbiased)	=	1.0108E-12
Variance (biased)	=	1.0108E-12
Moment Coeff. of Skewness	=	8.5112E+01
Pearson's 2nd Coeff. of Skewness	=	1.2928E-01
Kurtosis	=	1.0251E+04

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
2	0.00	0.00
16	0.00	0.00
18	0.00	0.01
19	0.16	0.66

I-2: ISI Every 10 Years (cont.)

22	0.00	0.00
24	0.00	0.00
26	0.05	0.04
27	0.18	0.34
29	0.00	0.00
31	0.06	0.10
32	0.00	0.00
34	0.01	0.01
40	52.00	24.41
42	0.00	0.00
48	0.10	0.57
49	0.00	0.00
50	0.01	0.01
51	0.01	0.02
52	0.09	0.46
53	0.08	0.37
54	0.37	1.63
55	0.66	3.11
58	22.68	28.39
59	0.69	0.33
60	1.80	1.68
61	0.03	0.01
62	9.31	6.13
63	2.8	2.66
64	3.76	3.33
65	4.90	28.85
TOTALS	100.00	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* BY \*  
 \* RPV BESTLINE MAJOR REGION \*  
 \* BY PARENT SUBREGION \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency	cleavage	ductile	total
1	237.44	2.04	8.49	6.27	3.00		9.27
2	246.96	2.04	11.97	8.50	5.03		13.53
3	246.96	2.04	11.45	7.14	4.59		11.73
4	247.43	3.16	21.86	12.94	10.00		22.94

I-2: ISI Every 10 Years (cont.)

5	237.77	3.16	15.63	8.90	5.70	14.60
6	247.43	3.16	23.36	17.70	10.23	27.93
7	231.49	19.12	7.26	0.00	0.00	0.00
8	195.14	8.55	0.00	0.00	0.00	0.00
9	166.15	8.55	0.00	0.00	0.00	0.00
10	130.00	8.55	0.00	0.00	0.00	0.00
11	206.88	13.21	0.00	0.00	0.00	0.00
12	186.36	13.21	0.00	0.00	0.00	0.00
13	208.62	13.21	0.00	0.00	0.00	0.00
TOTALS	100.00		100.00	61.45	38.55	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -  
 \* BY  
 \* RPV BELTLINE MAJOR REGION  
 \* BY CHILD SUBREGION  
 \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT  
 \* TO FREQUENCY OF CRACK INITIATION AND  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE)  
 \*  
 \*\*\*\*\*

MAJOR REGION	RtIndc (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency		
				cleavage	ductile	total
1	237.44	2.04	8.49	6.27	3.00	9.27
2	246.96	2.04	11.97	8.50	5.03	13.53
3	246.96	2.04	11.45	7.14	4.59	11.73
4	247.43	3.16	21.86	12.94	10.00	22.94
5	237.77	3.16	15.63	8.90	5.70	14.60
6	247.43	3.16	23.36	17.70	10.23	27.93
7	231.49	19.12	6.96	0.00	0.00	0.00
8	195.14	8.55	0.00	0.00	0.00	0.00
9	166.15	8.55	0.00	0.00	0.00	0.00
10	130.00	8.55	0.00	0.00	0.00	0.00
11	206.88	13.21	0.00	0.00	0.00	0.00
12	186.36	13.21	0.00	0.00	0.00	0.00
13	208.62	13.21	0.29	0.00	0.00	0.00
TOTALS		100.00	100.00	61.45	38.55	100.00



I-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* MATERIAL, FLAW CATEGORY, AND FLAW DEPTH \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

\*\*\*\*\*  
 \* WELD MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.088	0.00	37.20	0.00	0.00	1.68	0.00
0.175	0.00	37.45	0.00	0.00	20.91	0.00
0.263	0.00	13.39	0.00	0.00	10.25	0.00
0.350	0.00	10.03	0.00	0.00	9.61	0.01
0.438	0.00	7.97	0.01	0.00	9.27	0.05
0.525	0.00	6.65	0.01	0.00	10.34	0.06
0.613	0.00	5.13	0.01	0.00	7.94	0.06
0.700	0.00	3.58	0.03	0.00	5.22	0.14
0.787	0.00	2.47	0.02	0.00	3.86	0.13
0.875	0.00	3.59	0.00	0.00	1.90	0.02
0.963	0.00	2.29	0.01	0.00	4.94	0.05
1.050	0.00	0.96	0.02	0.00	1.60	0.10
1.137	0.00	1.31	0.01	0.00	2.78	0.03
1.225	0.00	0.78	0.00	0.00	1.67	0.01
1.313	0.00	0.34	0.01	0.00	0.43	0.04
1.400	0.00	0.54	0.00	0.00	1.31	0.03
1.488	0.00	0.40	0.00	0.00	1.14	0.01
1.575	0.00	0.05	0.00	0.00	0.13	0.01
1.663	0.00	0.84	0.01	0.00	3.14	0.04
1.750	0.00	0.13	0.00	0.00	0.42	0.00
1.837	0.00	0.17	0.00	0.00	0.60	0.00
1.925	0.00	0.06	0.00	0.00	0.04	0.02
TOTALS	0.00	99.86	0.14	0.00	99.17	0.83

I-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* PLATE MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.088	0.00	0.00	0.00	0.00	0.00	0.00
0.175	0.00	0.00	0.00	0.00	0.00	0.00
0.263	0.00	0.00	0.00	0.00	0.00	0.00
0.350	0.00	0.00	0.00	0.00	0.00	0.00
0.438	0.00	0.00	0.00	0.00	0.00	0.00
0.525	0.00	0.00	0.00	0.00	0.00	0.00
0.613	0.00	0.00	0.00	0.00	0.00	0.00
0.700	0.00	0.00	0.00	0.00	0.00	0.00
0.787	0.00	0.00	0.00	0.00	0.00	0.00
0.875	0.00	0.00	0.00	0.00	0.00	0.00
0.963	0.00	0.00	0.00	0.00	0.00	0.00
1.050	0.00	0.00	0.00	0.00	0.00	0.00
1.137	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	0.00	0.00	0.00	0.00	0.00	0.00

DATE: 27-Jun-2007 TIME: 10:24:06

NOTES: CPE IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CFE IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	9.4225	9.4225
1.0787E-06	89.7512	99.1737
3.2360E-06	0.4283	99.6025
5.3934E-06	0.1513	99.7537
7.5507E-06	0.0838	99.8375
9.7081E-06	0.0425	99.8800
1.1869E-05	0.0187	99.8987
1.4023E-05	0.0225	99.9212
1.6180E-05	0.0150	99.9362
1.8338E-05	0.0075	99.9437
2.0495E-05	0.0125	99.9562
2.2652E-05	0.0087	99.9650

2.4810E-05	0.0038	99.9687
2.6967E-05	0.0038	99.9725
2.9124E-05	0.0013	99.9737
3.1282E-05	0.0025	99.9762
3.3439E-05	0.0013	99.9775
3.5596E-05	0.0025	99.9800
4.2068E-05	0.0013	99.9812
4.4226E-05	0.0025	99.9837
4.6383E-05	0.0025	99.9862
4.8541E-05	0.0013	99.9875
5.0698E-05	0.0013	99.9887
5.2855E-05	0.0013	99.9900
5.7170E-05	0.0025	99.9925
6.3642E-05	0.0013	99.9937
6.5799E-05	0.0013	99.9950
8.3058E-05	0.0013	99.9962
1.0247E-04	0.0013	99.9975
1.4346E-04	0.0013	99.9987
2.1466E-04	0.0013	100.0000

==== Summary Descriptive Statistics =====

Minimum	= 0.0000E+00
Maximum	= 2.1358E-04
Range	= 2.1358E-04

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I-2: ISI Every 10 Years (cont.)

Number of Simulations	= 80000
5th Percentile	= 0.0000E+00
Median	= 1.4375E-09
95.0th Percentile	= 1.0787E-06
99.0th Percentile	= 1.8108E-06
99.9th Percentile	= 1.1985E-05
Mean	= 1.1279E-07
Standard Deviation	= 1.4163E-06
Standard Error	= 5.0072E-09
Variance (unbiased)	= 2.0058E-12
Variance (biased)	= 2.0057E-12
Moment Coeff. of Skewness	= 3.3721E+01
Pearson's 2nd Coeff. of Skewness	= 2.0092E-01
Kurtosis	= 8.5746E+03

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF THW FAILURES (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	14.5263	14.5263
3.0689E-07	85.0700	99.5963
3.2049E-07	0.2087	99.8050
1.5342E-06	0.0675	99.8725
2.1479E-06	0.0263	99.8988
2.7615E-06	0.0250	99.9238
3.3751E-06	0.0128	99.9375
3.9888E-06	0.0087	99.9463
4.6025E-06	0.0087	99.9550
5.2161E-06	0.0075	99.9625
5.8298E-06	0.0075	99.9700
6.4434E-06	0.0038	99.9738
7.0571E-06	0.0038	99.9775
7.6708E-06	0.0013	99.9788
8.2845E-06	0.0025	99.9813
8.8981E-06	0.0025	99.9838
9.5117E-06	0.0025	99.9862
1.0739E-05	0.0013	99.9875
1.3307E-05	0.0013	99.9887
1.5648E-05	0.0013	99.9900
1.7489E-05	0.0038	99.9937
1.9330E-05	0.0013	99.9950
2.1785E-05	0.0013	99.9962
2.3626E-05	0.0013	99.9975
2.9763E-05	0.0013	99.9987

I-2: ISI Every 10 Years (cont.)

6.0446E-05 0.0013 100.0000

=====  
 --- Summary Descriptive Statistics ---  
 =====

Minimum = 0.0000E+00  
 Maximum = 6.0752E-05  
 Range = 6.0752E-05  
 Number of Simulations = 80000  
 5th Percentile = 0.0000E+00  
 Median = 3.9800E-11  
 95.0th Percentile = 3.0683E-07  
 99.0th Percentile = 2.1221E-07  
 99.9th Percentile = 2.1785E-06  
 Mean = 1.6655E-08  
 Standard Deviation = 3.4892E-07  
 Standard Error = 1.2336E-09  
 Variance (unbiased) = 1.2175E-13  
 Variance (biased) = 1.2174E-13  
 Moment Coeff. of Skewness = 9.3708E+01  
 Pearson's 2nd Coeff. of Skewness = 1.3084E-01  
 Kurtosis = 1.3132E+04

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
22	0.00	0.00
16	0.00	0.00
18	0.00	0.00
19	0.17	0.90
22	0.00	0.00
24	0.00	0.00
26	0.11	0.00
27	0.24	0.50
29	0.00	0.00
31	0.03	0.13
32	0.00	0.00
34	0.01	0.01
40	63.92	27.54
42	0.00	0.00
48	0.12	0.77

I-2: ISI Every 10 Years (cont.)

49	0.00	0.00
50	0.01	0.02
51	0.01	0.03
52	0.16	0.91
53	0.04	0.18
54	0.68	2.28
55	0.82	4.53
58	11.29	9.77
59	0.75	0.41
60	2.05	2.01
61	0.04	0.01
62	7.00	3.98
63	2.29	1.63
64	4.15	3.76
65	6.07	40.54
TOTALS	100.00	100.00

DATE: 17-Aug-2005 TIME: 13:49:41

DRAFT

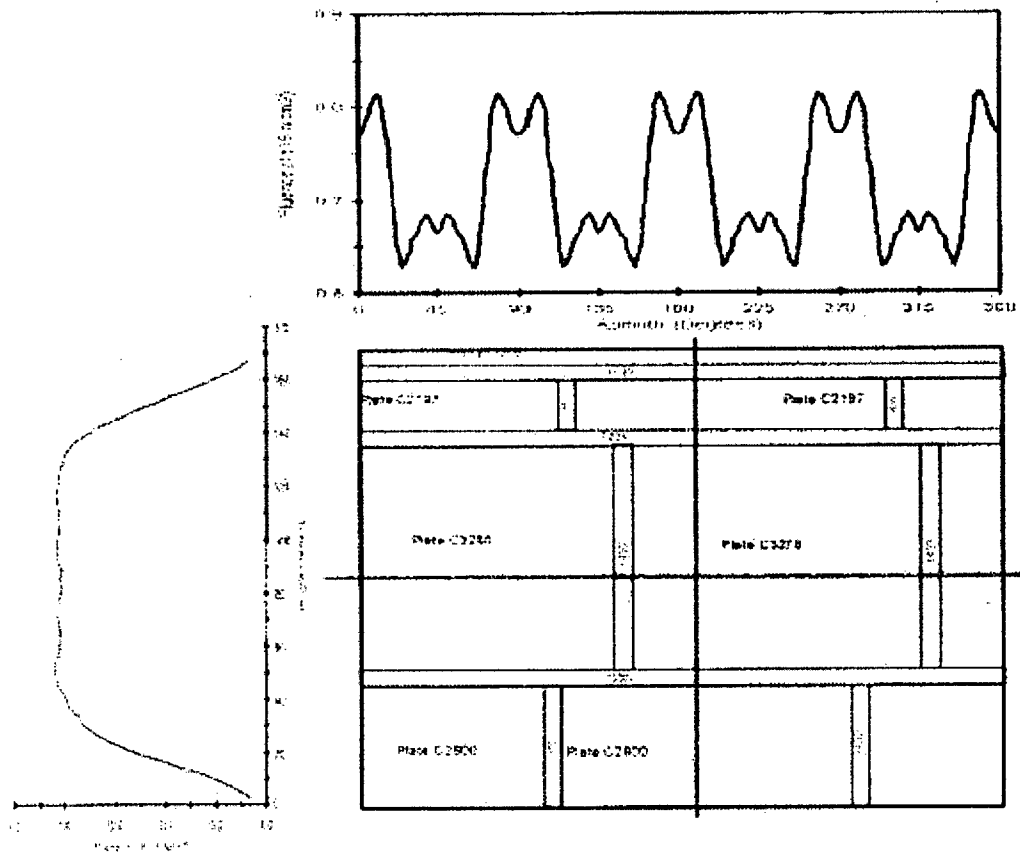
**APPENDIX J**  
**INPUTS FOR THE OCONEE UNIT 1 PILOT PLANT EVALUATION**

DRAFT

A summary of the NDE inspection history based on Regulatory Guide 1.150 and pertinent input data for OC1 is as follows:

1. Number of inservice inspections performed (relative to initial pre-service and 10 year interval inspections) for full penetration category B-A and ~~B-D, and B-1~~ vessel welds assuming all of the candidate welds were inspected: 3 (covering all welds of the specified categories).
2. The inspections performed covered: 62 total examinations, 23 items with 100% coverage, 22 items with < 90% coverage and 17 items with coverage >90% but less than 100%.
3. Number of indications found during most recent inservice inspection: 44  
This number includes consideration of the following additional information.
  - a. Indications found that were reportable: 0
  - b. Indications found that were within acceptable limits: 44
  - c. Indications/anomalies currently being monitored: 0
4. Full Penetration Relief requests for the reactor vessel submitted and accepted by the NRC: 2 relief requests for limited coverage for 22 items, as noted in item 2
5. Fluence distribution at inside surface of RV Beltline until end of life is shown in: see Figure J-1 taken from the NRC PTS Risk Study [7448], Figure 4.1.





**Figure J-1 Rollout Diagram of Beltline Materials and Representative Fluence Maps for OC1**

6. Reactor Vessel cladding details (Table 4.2 of Reference 78):
  - a. Number of layers: 1
  - b. Thickness: 0.188
  - c. Material properties (assumed to be independent of temperature) are identified in Table J-1. This is consistent with the NRC PTS Risk Study [27, 43];

e.

Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM-°F) "C"	Young's Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
0	-	-	-	-	489	.3
68	-	-	22045.7	-	489	.3
70	8.1	0.1158	-	-	489	.3
100	8.4	0.1185	-	8.55E-06	489	.3
150	8.6	0.1196	-	8.67E-06	489	.3
200	8.8	0.1208	-	8.79E-06	489	.3
250	9.1	0.1232	-	8.9E-06	489	.3
300	9.4	0.1256	-	9.0E-06	489	.3
302	-	-	20160.2	-	489	.3
350	9.6	0.1258	-	9.1E-06	489	.3
400	9.9	0.1281	-	9.19E-06	489	.3
450	10.1	0.1291	-	9.28E-06	489	.3
482	-	-	18419.8	-	489	.3
500	10.4	0.1305	-	9.37E-06	489	.3
550	10.6	0.1306	-	9.45E-06	489	.3
600	10.9	0.1325	-	9.53E-06	489	.3
650	11.1	0.1335	-	9.61E-06	489	.3
700	11.4	0.1348	-	9.69E-06	489	.3
750	11.6	0.1356	-	9.76E-06	489	.3
800	11.9	0.1367	-	9.82E-06	489	.3

- i. Thermal conductivity (BTU/HR-FT-F), K = 10.0
- ii. Specific Heat (BTU/LBM-F), C = 0.120
- iii. Density (LBM-FT<sup>3</sup>), ρ = 489.00
- iv. Young's Modulus of Elasticity (KSI), E = 22800
- v. Thermal Expansion Coefficient (F<sup>-1</sup>), α = 0.00000945
- vi. Poisson's Ratio, ν = 0.3

d. Material including copper and nickel content: Material properties assigned to clad flaws are that of the underlying material be it base metal or weld. These properties are identified in Table J-3. This is consistent with the PTS evaluation (Reference 7s-[8, 927 and 43]).

e. Material property uncertainties:

- ±1) Bead width: 1 inch – bead widths vary for all plants. Based on Reference the NRC PTS Risk Study [8, 9], a nominal dimension of 1 inch is selected for all analyses because this parameter is not expected to significantly influence the predicted vessel failure probabilities.
- 2) Truncation Limit: Cladding thickness rounded up to the next 1/100<sup>th</sup> of the total vessel thickness to be consistent with the NRC PTS Risk Study [8, 9].
- 3) Surface flaw depth: 0.03 x 8.626 = 0.259 in

4) All flaws are surface-breaking. Only flaws in cladding that would influence brittle fracture of the reactor vessel are brittle. This is consistent with the NRC PTS Risk Study [8, 9].

f. Additional cladding properties are identified in Table J-4. Truncation Limit: Cladding thickness rounded up to the next 1/100<sup>th</sup> of the total vessel thickness to be consistent with PTS evaluation.

ii. Surface flaw depth:  $0.03 \times 8.626 = 0.259$  in

7. Base metal (Reference 78):

- a. Wall thickness: 8.438 inches
- b. Material properties are identified in Tables J-2 and J-3 (assumed to be independent of temperature). This is consistent with the NRC PTS Risk Study [27, 43].
- b.

Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F) "K"	Specific Heat (Btu/LBM-°F) "C"	Young Modulus of Elasticity (KSI) "E"	Thermal Expansion Coefficient (°F <sup>-1</sup> ) "α"	Density (LBM/ft <sup>3</sup> ) "ρ"	Poisson's Ratio "ν"
0	-	-	-	-	489	.3
70	24.8	0.1052	29200	-	489	.3
100	25	0.1072	-	7.06E-06	489	.3
150	25.1	0.1101	-	7.16E-06	489	.3
200	25.2	0.1135	28500	7.25E-06	489	.3
250	25.2	0.1166	-	7.34E-06	489	.3
300	25.1	0.1194	28000	7.43E-06	489	.3
350	25	0.1223	-	7.5E-06	489	.3
400	25.1	0.1267	27400	7.58E-06	489	.3
450	24.6	0.1277	-	7.63E-06	489	.3
500	24.3	0.1304	27000	7.7E-06	489	.3
550	24.3	0.1326	-	7.77E-06	489	.3
600	23.7	0.135	26400	7.83E-06	489	.3
650	23.4	0.1375	-	7.9E-06	489	.3
700	23	0.1404	25300	7.94E-06	489	.3
750	22.6	0.1435	-	8.0E-06	489	.3
800	22.2	0.1474	23900	8.05E-06	489	.3

- i. Thermal conductivity (BTU/HR-FT-F),  $K = 24.0$
- ii. Specific Heat (BTU/LBM-F),  $C = 0.120$
- iii. Density (LBM/FT<sup>3</sup>),  $\rho = 489.00$
- iv. Young's Modulus of Elasticity (KSI),  $E = 28000$
- v. Thermal Expansion Coefficient (F<sup>-1</sup>),  $\alpha = 0.00000777$
- vi. Poisson's Ratio,  $\nu = 0.3$
- i. Other material properties are identified in Table J-1.

**Table J-13 OC1-Specific Material Values Drawn from the RVID (see Ref. 7-448 Table 4.1)**

Major Material Region Description				Cu [wt%]	Ni [wt%]	P [wt%]	Mn [wt%] Un- Irradia- ted RT <sub>NDT</sub> [°F] Method	Un- Irradiated RT <sub>NDT</sub> [°F] RT <sub>RES</sub> @60 FFPY
#	Type	Heat	Location					
1	Axial Weld	SA-1430	Lower	0.190	0.570	0.017	1.480-5 B&W Generic	-5
2	Axial Weld	SA-1493	Intermediate	0.190	0.570	0.017	1.480-5 B&W Generic	-5
3	Axial Weld	SA-1073	Upper	0.210	0.640	0.025	1.380-5 B&W Generic	-5
4	Circ Weld	SA-1585	Lower	0.220	0.540	0.016	1.436-5 B&W Generic	-5
5	Circ Weld	SA-1229	Intermediate	0.230	0.590	0.021	1.48840 ASME NB- 2334	10
6	Circ Weld	SA-1135	Upper	0.230	0.520	0.011	1.404-5 B&W Generic	-5
7	Plate	C-2800	Lower	0.110	0.630	0.012	1.4004 B&W Generic	1

8	Plate	C3265-1	Intermediate	0.100	0.500	0.015	1.4204 B&W Generic	1
9	Plate	C3278-1	Intermediate	0.120	0.600	0.010	1.2604 B&W Generic	1
10	Plate	C2197-2	Upper	0.150	0.500	0.008	1.2804 B&W Generic	1
11	Forging	ZV2861	Upper	0.160	0.650	0.006	0.8003 B&W Generic	3

8. Weld metal details: Details of information used in addressing weld-specific information are taken directly from the NRC PTS Risk Study [447], Table 4.2. Summaries are reproduced as Table J-24. Values for SAW Weld Volume fraction and Repair Weld Volume fraction in Table J-4 were changed to 96.7% and 2.3% respectively per NUREG-1874 [9].

**Table JJ-42 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Inner Radius (to cladding)	[in]	85.5	78.5	86	86	Vessel specific info
Base Metal Thickness	[in]	8.438	7.875	8.5	8.675	Vessel specific info
Total Wall Thickness	[in]	8.626	8.031	8.75	8.988	Vessel specific info

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
SAW Weld	Volume fraction	97%				100% - SMAW% - REPAIR%
	Thru-Wall Bead Thickness	0.1875	0.1875	0.1875	0.1875	All plants report plant specific dimensions of 3/16-in.
	Truncation Limit	1				Judgment. Approx. 2X the size of the largest non-repair flaw observed in PVRUF & Shoreham.
	Buried or Surface	All flaws are buried				Observation
	Orientation	Circ flaws in circ welds, axial flaws in axial welds.				Observation: Virtually all of the weld flaws in PVRUF & Shoreham were aligned with the welding direction because they were lack of sidewall fusion defects.
	Density basis	Shoreham density				Highest of observations
	Aspect ratio basis	Shoreham & PVRUF observations				Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
Depth basis	Shoreham & PVRUF observations				Statistically similar distributions combined to provide more robust estimates	

**Table J-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
SMAW Weld	Volume fraction	1%				Upper bound to all plant specific info provided by Steve Byrne (Westinghouse – Windsor).
	Thru-Wall Bead Thickness	0.21	0.20	0.22	0.25	Oconee is generic value based on average of all plants specific values (including Shoreham & PVRUF data). Other values are plant specific as reported by Steve Byrne.
	Truncation Limit	1				Judgment. Approx. 2X the size of the largest non-repair flaw observed in PVRUF & Shoreham.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Circ flaws in circ welds, axial flaws in axial welds.			Observation: Virtually all of the weld flaws in PVRUF & Shoreham were aligned with the welding direction because they were lack of sidewall fusion defects.
	Density basis	--	Shoreham density			Highest of observations
	Aspect ratio basis	--	Shoreham & PVRUF observations			Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
Depth basis	--	Shoreham & PVRUF observations			Statistically similar distributions combined to provide more robust estimates	

**Table J-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Pallades	Calvert Cliffs	Notes
Repair Weld	Volume fraction	[%]		2%		Judgment. A rounded integral percentage that exceeds the repaired volume observed for Shoreham and for PVRUF, which was 1.5%.
	Thru-Wall Bead Thickness	[in]		0.14		Generic value: As observed in PVRUF and Shoreham by PNNL.
	Truncation Limit	[in]		2		Judgment. Approx. 2X the largest repair flaw found in PVRUF & Shoreham. Also based on maximum expected width of repair cavity.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Circ flaws in circ welds, axial flaws in axial welds.			The repair flaws had complex shapes and orientations that were not aligned with either the axial or circumferential welds; for consistency with the available treatments of flaws by the FAVOR code, a common treatment of orientations was adopted for flaws in SAW/SAW and repair welds.
	Density basis	--	Shoreham density			Highest of observations
	Aspect ratio basis	--	Shoreham & PVRUF observations			Statistically similar distributions from Shoreham and PVRUF were combined to provide more robust estimates, when based on judgment the amount data were limited and/or insufficient to identify different trends for aspect ratios for flaws in the two vessels.
	Depth basis	--	Shoreham & PVRUF observations			Statistically similar distributions combined to provide more robust estimates



Table J-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes	
Cladding	Actual Thickness	[in]	0.188	0.156	0.25	0.313	Vessel specific info
	# of Layers	[#]	1	2	2	2	Vessel specific info
	Bead Width	[in]	1				Bead widths of 1 to 5-in. characteristic of machine deposited cladding. Bead widths down to ½-in. can occur over welds. Nominal dimension of 1-in. selected for all analyses because this parameter is not expected to influence significantly the predicted vessel failure probabilities. May need to refine this estimate later, particularly for Oconee who reported a 5-in bead width.
	Truncation Limit	[in]	Actual clad thickness rounded to the nearest 1/100 <sup>th</sup> of the total vessel wall thickness				Judgment & computational convenience
	Surface flaw depth in FAVOR	[in]	0.259	0.161	0.263	0.360	
	Buried or Surface	--	All flaws are surface breaking				Judgment. Only flaws in cladding that would influence brittle fracture of the vessel are brittle. Material properties assigned to clad flaws are that of the underlying material, be it base or weld.
Orientation	--	All circumferential.				Observation: All flaws observed in PVRUF & Shoreham were lack of inter-run fusion defects, and cladding is always deposited circumferentially	
Density basis	--	No surface flaws observed. Density is 1/1000 that of the observed buried flaws in cladding of vessels examined by PNNL. If there is more than one clad layer then there are no clad flaws.				Judgment	
Aspect ratio basis	--	Observations on buried flaws				Judgment	
Depth basis	--	Depth of all surface flaws is the actual clad thickness rounded up to the nearest 1/100 <sup>th</sup> of the total vessel wall thickness.				Judgment.	

**Table J-24 Summary of Reactor Vessel-Specific Inputs for Flaw Distribution (cont.)**

Variable		Oconee	Beaver Valley	Palisades	Calvert Cliffs	Notes
Plate	Truncation Limit	[in]	0.433			Judgment. Twice the depth of the largest flaw observed in all PNNL plate inspections.
	Buried or Surface	--	All flaws are buried			Observation
	Orientation	--	Half of the simulated flaws are circumferential, half are axial.			Observation & Physics: No observed orientation preference, and no reason to suspect one (other than laminations which are benign).
	Density basis	--	1/10 of small weld flaw density, 1/40 of large weld flaw density of the PVRUF data			Judgment. Supported by limited data.
	Aspect ratio basis	--	Same as for PVRUF welds			Judgment
	Depth basis	--	Same as for PVRUF welds			Judgment. Supported by limited data.

9. TWCF<sub>95-TOTAL</sub> value calculated at 500 EFPY using correlations from NUREG-1874 (Reference 279): 7.18E-093.16E-07 Events per year

**APPENDIX K  
OCONEE UNIT 1 PROBSBFD OUTPUT**

**DRAFT**

## K-1: 10 Year ISI only

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)  
 WESTINGHOUSE MONTE-CARLO SIMULATION PROGRAM PROBSBFD VERSION 1.0

 =====  
 INPUT VARIABLES FOR CASE 3: OC1 10 YEAR ISI ONLY

NCYCLE = 80                      NFAILS = 1001                      NTRIAL = 1000  
 NOVARS = 19                      NUMSET = 2                      NUMISI = 5  
 NUMSSC = 4                      NUMTRC = 4                      NUMFMD = 4

VARIABLE NO.	NAME	DISTRIBUTION TYPE	LOG	MEDIAN VALUE	DEVIATION OR FACTOR	SHIFT MV/SD	USAGE NO. SUB
1	FIFDepth	- CONSTANT	-	3.0000D-02			1 SET
2	IFlawDen	- CONSTANT	-	3.6589D-03			2 SET
3	ICy-ISI	- CONSTANT	-	1.0000D+01			1 ISI
4	DCy-ISI	- CONSTANT	-	8.0000E+01			2 ISI
5	MV-Depth	- CONSTANT	-	1.5000D-02			3 ISI
6	SD-Depth	- CONSTANT	-	1.8500D-01			4 ISI
7	CEff-ISI	- CONSTANT	-	1.0000D+00			5 ISI
8	Aspect1	- CONSTANT	-	2.0000D+00			1 SSC
9	Aspect2	- CONSTANT	-	6.0000D+00			2 SSC
10	Aspect3	- CONSTANT	-	1.0000D+01			3 SSC
11	Aspect4	- CONSTANT	-	1.9000D+01			4 SSC
12	NoTr/Cy	- CONSTANT	-	1.2000D+01			1 TRC
13	FCGThld	- CONSTANT	-	1.5000E+00			2 TRC
14	FCGR-UC	NORMAL	NO	0.0000D+00	1.0000D+00	.00	3 TRC
15	DKINFile	- CONSTANT	-	1.0000D+00			4 TRC
16	Percent1	- CONSTANT	-	6.7450D+01			1 FMD
17	Percent2	- CONSTANT	-	2.0769E+01			2 FMD
18	Percent3	- CONSTANT	-	3.9642E+00			3 FMD
19	Percent4	- CONSTANT	-	7.8166E+00			4 FMD

INFORMATION GENERATED FROM FAVLOADS.DAT FILE  
 AND SAVED IN DKINSAVE.DAT FILE:

WALL THICKNESS = 8.6260 INCH

FLAW DEPTH MINIMUM K AND MAXIMUM K FOR

TYPE 1 WITH AN ASPECT RATIO OF 2.

8.62600D-02	2.26895D+00	1.06757D+01
1.58718D-01	3.02106D+00	1.44232D+01
4.31300D-01	1.30893D+01	2.08943D+01
6.46950D-01	1.39096D+01	2.49826D+01
8.62600D-01	1.44263D+01	2.80058D+01
1.72520D+00	1.30110D+01	3.31903D+01
2.58780D+00	7.51977D+00	3.23837D+01
4.31300D+00	-2.67288D+00	3.20852D+01

TYPE 2 WITH AN ASPECT RATIO OF 6.

**K-1: 10 Year ISI only (cont.)**

8.62600D-02	3.40901D+00	1.61172D+01
1.58718D-01	4.63620D+00	2.21942D+01
4.31300D-01	1.99455D+01	3.13897D+01
6.46950D-01	2.33230D+01	3.76625D+01
8.62600D-01	2.45197D+01	4.30412D+01
1.72520D+00	2.46021D+01	5.46183D+01
2.58780D+00	1.95704D+01	5.81373D+01
4.31300D+00	8.31986D+00	6.38027D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.62600D-02	3.73472D+00	1.76698D+01
1.58718D-01	4.95671D+00	2.37364D+01
4.31300D-01	2.11257D+01	3.35265D+01
6.46950D-01	2.53490D+01	4.01563D+01
8.62600D-01	2.66367D+01	4.59818D+01
1.72520D+00	2.73025D+01	5.94651D+01
2.58780D+00	2.36720D+01	6.65485D+01
4.31300D+00	1.21426D+01	7.64376D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.62600D-02	6.74437D+00	1.82354D+01
1.72520D-01	9.55233D+00	2.55450D+01
2.58780D-01	1.62039D+01	2.74271D+01
4.31300D-01	2.37153D+01	3.58624D+01
6.46950D-01	2.70360D+01	4.44287D+01
8.62600D-01	2.84566D+01	5.07281D+01
1.72520D+00	3.19293D+01	6.96665D+01
2.58780D+00	2.97815D+01	8.22041D+01

AVERAGE CALCULATED VALUES FOR Surface Flaw Density with FCG and ISI

NUMBER FAILED = 0

NUMBER OF TRIALS = 1000

DEPTH (WALL/400) AND FLAW DENSITY FOR ASPECT RATIOS OF 2, 6, 10 AND 99

12	2.2380D-04	1.0377D-05	1.4547D-06	1.1205D-05
13	6.5980D-06	4.0083D-05	7.1947D-06	1.1813D-05
14	0.0000D+00	1.2906D-05	2.8652D-06	2.3081D-06
15	0.0000D+00	3.4523D-06	1.0131D-06	4.5211D-07
16	0.0000D+00	1.1683D-06	2.9704D-07	2.7150D-07
17	0.0000D+00	5.0981D-07	1.5720D-07	1.2084D-07
18	0.0000D+00	3.1177D-07	3.5675D-08	7.1479D-08
19	0.0000D+00	1.2295D-07	5.8386D-08	0.0000D+00
20	0.0000D+00	0.0000D+00	2.2976D-08	0.0000D+00
22	0.0000D+00	5.7099D-08	0.0000D+00	0.0000D+00
24	0.0000D+00	0.0000D+00	0.0000D+00	2.2058D-08
25	0.0000D+00	5.4884D-08	1.0551D-08	0.0000D+00
28	0.0000D+00	0.0000D+00	1.0078D-08	2.1150D-08

## K-2: ISI Every 10 Years

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)  
WESTINGHOUSE MONTE-CARLO SIMULATION PROGRAM PROBSBFD VERSION 1.0

=====

INPUT VARIABLES FOR CASE 2: OC1 10 YEAR INTERVAL

NCYCLE = 80                      NFAILS = 1001                      NTRIAL = 1000  
NOVARS = 19                      NUMSET = 2                      NUMISI = 5  
NUMSSC = 4                      NUMTRC = 4                      NUMFMD = 4

VARIABLE NO.	NAME	DISTRIBUTION TYPE	LOG	MEDIAN VALUE	DEVIATION OR FACTOR	SHIFT MV/SD	USAGE NO. SUB
1	FIFDepth	- CONSTANT	-	3.0000D-02			1 SET
2	IFlawDen	- CONSTANT	-	3.6589D-03			2 SET
3	ICy-ISI	- CONSTANT	-	1.0000D+01			1 ISI
4	DCy-ISI	- CONSTANT	-	1.0000D+01			2 ISI
5	MV-Depth	- CONSTANT	-	1.5000D-02			3 ISI
6	SD-Depth	- CONSTANT	-	1.8500D-01			4 ISI
7	CEff-ISI	- CONSTANT	-	1.0000D+00			5 ISI
8	Aspect1	- CONSTANT	-	2.0000D+00			1 SSC
9	Aspect2	- CONSTANT	-	6.0000D+00			2 SSC
10	Aspect3	- CONSTANT	-	1.0000E+01			3 SSC
11	Aspect4	- CONSTANT	-	9.9000D+01			4 SSC
12	NoTr/Cy	- CONSTANT	-	1.2000E+01			1 TRC
13	FCGThld	- CONSTANT	-	1.5000D+00			2 TRC
14	FCGR-UC	NORMAL	NO	0.0000D+00	1.0000D+00	.00	3 TRC
15	DKINFile	- CONSTANT	-	1.0000D+00			4 TRC
16	Percent1	- CONSTANT	-	6.7456D+01			1 FMD
17	Percent2	- CONSTANT	-	2.0769D+01			2 FMD
18	Percent3	- CONSTANT	-	3.9642D+00			3 FMD
19	Percent4	- CONSTANT	-	7.6166D+00			4 FMD

INFORMATION GENERATED FROM FAVLOADS.DAT FILE  
AND SAVED IN DKINSAVE.DAT FILE:

WALL THICKNESS = 8.6260 INCH

FLAW DEPTH MINIMUM K AND MAXIMUM K FOR

TYPE 1 WITH AN ASPECT RATIO OF 2.

8.62600D-02	2.26895D+00	1.06757D+01
1.58718D-01	3.02106D+00	1.44232D+01
4.31300D-01	1.30893D+01	2.08943D+01
6.46950D-01	1.39096D+01	2.49826D+01
8.62600D-01	1.44263D+01	2.80058D+01
1.72520D+00	1.30110D+01	3.31903D+01
2.58780D+00	7.51977D+00	3.23837D+01
4.31300D+00	-2.67288D+00	3.20852D+01

TYPE 2 WITH AN ASPECT RATIO OF 6.

**K-2: ISI Every 10 Years (cont.)**

8.62600D-02	3.40901D+00	1.61172D+01
1.58718D-01	4.63620D+00	2.21942D+01
4.31300D-01	1.99455D+01	3.13897D+01
6.46950D-01	2.33230D+01	3.76625D+01
8.62600D-01	2.45197D+01	4.30412D+01
1.72520D+00	2.46021D+01	5.46183D+01
2.58780D+00	1.95704D+01	5.81373D+01
4.31300D+00	8.31986D+00	6.38027D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.62600D-02	3.73472D+00	1.76698D+01
1.58718D-01	4.95671D+00	2.37364D+01
4.31300D-01	2.11257D+01	3.35265D+01
6.46950D-01	2.53490D+01	4.01563D+01
8.62600D-01	2.66367D+01	4.59818D+01
1.72520D+00	2.73025D+01	5.94651D+01
2.58780D+00	2.36720D+01	6.65485D+01
4.31300D+00	1.21426D+01	7.64376D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.62600D-02	6.74437D+00	1.82354D+01
1.72520D-01	9.55233D+00	2.55450D+01
2.58780D-01	1.62039D+01	2.74271D+01
4.31300D-01	2.37153D+01	3.58624D+01
6.46950D-01	2.70360D+01	4.44287D+01
8.62600D-01	2.84566D+01	5.07281D+01
1.72520D+00	3.19293D+01	6.96665D+01
2.58780D+00	2.97815D+01	8.22041D+01

AVERAGE CALCULATED VALUES FOR Surface Flaw Density with FCG and ISI

NUMBER FAILED = 0

NUMBER OF TRIALS = 1000

DEPTH (WALL/400) AND FLAW DENSITY FOR ASPECT RATIOS OF 2, 6, 10 AND 99

12	1.3580D-10	5.4482D-12	7.5613D-13	6.1767D-12
13	2.8117D-12	1.4377D-11	2.5387D-12	4.4630D-12
14	0.0000D+00	2.2869D-12	5.0820D-13	4.3208D-13
15	0.0000D+00	2.9908D-13	8.6948D-14	4.2493D-14
16	0.0000D+00	4.7816D-14	1.1866D-14	1.3716D-14
17	0.0000D+00	1.0793D-14	2.7598D-15	2.7273D-15
18	0.0000D+00	2.8658D-15	3.3064D-16	8.9749D-16
19	0.0000D+00	6.3484D-16	2.5927D-16	0.0000D+00
20	0.0000D+00	0.0000D+00	5.0956D-17	0.0000D+00
22	0.0000D+00	1.1431D-17	0.0000D+00	0.0000D+00
24	0.0000D+00	0.0000D+00	0.0000D+00	5.0464D-18
25	0.0000D+00	1.4911D-18	3.6983D-19	0.0000D+00
28	0.0000D+00	0.0000D+00	2.2911D-20	2.7483D-19

## APPENDIX L OCONEE UNIT 1 PTS TRANSIENTS

Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Hi K	Dominant*
1	8	2.54 cm [1 in] surge line break with 1 stuck open safety valve in SG-A.	None	9.68E-08	No	No	No
2	12	2.54 cm [1 in] surge line break with 1 stuck open safety valve in SG-A.	HPI throttled to maintain 27.8 K [50° F] subcooling margin	9.24E-07	No	No	No
3	15	2.54 cm [1 in] surge line break with HPI Failure	At 15 minutes after transient initiation, operator opens all TBVs to lower primary system pressure and allow CFT and LPI injection.	3.39E-08	No	No	No
4	27	MSLB without trip of turbine driven emergency feedwater.	Operator throttles HPI to maintain 27.8 K [50° F] subcooling margin.	2.13E-06	No	No	No
5	28	Reactor/turbine trip with 1 stuck open safety valve in SG-A	None	7.53E-08	No	No	No
6	29	Reactor/turbine trip with 1 stuck open safety valve in SG-A and a second stuck open safety valve in SG-B	None	3.09E-07	No	No	No
7	30	Reactor/turbine trip with 1 stuck open safety valve in SG-A	None	1.46E-07	Yes	No	No
8	31	Reactor/turbine trip with 1 stuck open safety valve in SG-A and a second stuck open safety valve in SG-B	None	8.36E-09	Yes	No	No
9	36	Reactor/turbine trip with 1 stuck open safety valve in SG-A and a second stuck open safety valve in SG-B	Operator throttles HPI to maintain 27.8 K [50° F] subcooling and 304.8 cm [120 in] pressurizer level.	1.40E-05	No	No	No
10	37	Reactor/turbine trip with 1 stuck open safety valve in SG-A	Operator throttles HPI to maintain 27.8 K [50° F] subcooling and 304.8 cm [120 in] pressurizer level.	1.41E-06	Yes	No	No
11	38	Reactor/turbine trip with 1 stuck open safety valve in SG-A and a second stuck open safety valve in SG-B	Operator throttles HPI to maintain 27.8 K [50° F] subcooling and 304.8 cm [120 in] pressurizer level.	2.65E-06	Yes	No	No



Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Hi K	Dominant*
12	44	2.54 cm [1 in] surge line break with HPI Failure	At 15 minutes after initiation, operators open all TBVs to depressurize the system to the CFT setpoint. When the CFTs are 50 percent discharged, HPI is assumed to be recovered. The TBVs are assumed remain open for the duration of the transient.	2.69E-07	No	No	No
13	89	Reactor/turbine trip with Loss of MFW and EFW.	Operator opens all TBVs to depressurize the secondary side to below the condensate booster pump shutoff head so that these pumps feed the steam generators. Booster pumps are assumed to be initially uncontrolled so that the steam generators are overfilled (609 cm [240 in] startup level). Operator controls booster pump flow to maintain SG level at 76 cm [30 in] due to continued RCP operation. Operator also throttles HPI to maintain 55 K [100°F] subcooling and a pressurizer level of 254 cm [100 in]. The TBVs are kept fully opened due to operator error.	5.38E-07	No	No	No
14	90	Reactor/turbine trip with 2 stuck open safety valves in SG-A	Operator throttles HPI 20 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached [throttling criteria is 27.8 K [50°F] subcooling].	6.29E-07	No	No	No

Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Hi K	Dominant*
15	98	Reactor/turbine trip with loss of MFW and EFW	Operator opens all TBVs to depressurize the secondary side to below the condensate booster pump shutoff head so that these pumps feed the steam generators. Booster pumps are assumed to be initially uncontrolled so that the steam generators are overfilled (610 cm [240 in] startup level). Operator controls booster pump flow to maintain SG level at 76 cm [30 in] due to continued RCP operation. Operator also throttles HPI to maintain 55-K [100°F] subcooling and a pressurizer level of 254 cm [100 in]. The TBVs are kept fully opened due to operator error.	9.96E-08	Yes	No	No
16	99	MSLB with trip of turbine driven EFW by MSLB Circuitry	HPI is throttled 20 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	2.44E-07	No	No	No
17	100	MSLB with trip of turbine driven EFW by MSLB Circuitry	Operator throttles HPI 20 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	5.11E-08	Yes	No	No
18	101	MSLB without trip of turbine driven EFW by MSLB Circuitry	Operator throttles HPI to maintain 27.8 K [50° F] subcooling margin (throttling criteria is 27.8 K [50°F] subcooling).	3.86E-07	Yes	No	No
19	102	Reactor/turbine trip with 2 stuck open safety valves in SG-A	Operator throttles HPI 20 minutes after 2.77 K [5°F] subcooling and 254 cm [100 in] pressurizer level is reached (throttling criteria is 27 K [50°F] subcooling).	2.03E-07	Yes	No	No

Table L-1 PTS Transient Descriptions for OC1

Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Hi K	Dominant*
20	109	Stuck open pressurizer safety valve. Valve recloses at 6000 secs [RCS low pressure point].	None	9.58E-06	No	Yes	No
21	110	5.08 cm [2 inch] surge line break with HPI failure	At 15 minutes after transient initiation, operator opens both TBV to lower primary system pressure and allow CFT and LPI injection.	3.42E-06	No	Yes	Yes at 1000 EFPY
22	111	2.54 cm [1 in] surge line break with HPI failure	At 15 minutes after initiation, operator opens all TBVs to lower primary pressure and allow CFT and LPI injection. When the CFTs are 50% discharged, HPI is recovered. At 3000 seconds after initiation, operator starts throttling HPI to 55 K [100°F] subcooling and 254 cm [100"] pressurizer level.	4.16E-07	No	Yes	No
23	112	Stuck open pressurizer safety valve. Valve recloses at 6000 secs.	After valve recloses, operator throttles HPI 1 minute after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27 K [50°F] subcooling)	1.25E-04	No	Yes	No
24	113	Stuck open pressurizer safety valve. Valve recloses at 6000 secs.	After valve recloses, operator throttles HPI 10 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling)	5.07E-05	No	Yes	No
25	114	Stuck open pressurizer safety valve. Valve recloses at 3000 secs.	After valve recloses, operator throttles HPI 1 minute after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 50°F subcooling)	1.25E-04	No	Yes	No
26	115	Stuck open pressurizer Safety Valve. Valve recloses at 3000 secs.	After valve recloses, operator throttles HPI 10 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 50°F subcooling)	5.07E-05	No	Yes	No

<b>Count</b>	<b>TH Case #</b>	<b>System Failure</b>	<b>Operator Action</b>	<b>Mean IE Frequency</b>	<b>HZP</b>	<b>Hi K</b>	<b>Dominant*</b>
27	116	Stuck open pressurizer safety valve and HPI failure	At 15 minutes after initiation, operator opens all TBVs to lower primary pressure and allow CFT and LPI injection. When the CFTs are 50% discharged, HPI is recovered. The HPI is throttled 20 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 50°F subcooling).	2.60E-07	No	Yes	No
28	117	Stuck open pressurizer safety valve and HPI failure	At 15 minutes after initiation, operator opens all TBV to lower primary pressure and allow CFT and LPI injection. When the CFTs are 50% discharged, HPI is recovered. The SRV is closed 5 minutes after HPI recovered. HPI is throttled at 1 minute after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	5.38E-07	No	Yes	No
29	119	2.54 cm [1 in] surge line break with HPI Failure	At 15 minutes after transient initiation, the operator opens all turbine bypass valves to lower primary system pressure and allow core flood tank and LPI injection.	4.41E-07	Yes	Yes	No
30	120	2.54 cm [1 in] surge line break with HPI Failure	At 15 minutes after sequence initiation, operators open all TBVs to depressurize the system to the CFT setpoint. When the CFTs are 50 percent discharged, HPI is assumed to be recovered. The TBVs are assumed remain opened for the duration of the transient.	4.22E-08	Yes	Yes	No
31	121	Stuck open pressurizer safety valve. Valve recloses at 6000 secs .	Operator throttles HPI at 1 minute after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached [throttling criteria is 27.8 K [50°F] subcooling].	2.28E-05	Yes	Yes	No

Count	TH Case #	System Failure	Operator Action	Mean IE Frequency	HZP	Hi K	Dominant*
32	122	Stuck open pressurizer safety valve. Valve recloses at 6000 secs.	Operator throttles HPI at 10 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	7.57E-06	Yes	Yes	Yes at 32, 60, 500, 1000 EFPY
33	123	Stuck open pressurizer safety valve. Valve recloses at 3000 secs.	Operator throttles HPI at 1 minute after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	2.28E-05	Yes	Yes	No
34	124	Stuck open pressurizer safety valve. Valve recloses at 3000 secs.	Operator throttles HPI at 10 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	7.57E-06	Yes	Yes	Yes at 60, 500, 1000 EFPY
35	125	Stuck open pressurizer safety valve and HPI Failure	At 15 minutes after initiation, operator opens all TBVs to lower primary pressure and allow CFT and LPI injection. When the CFTs are 50% discharged, HPI is recovered. HPI is throttled 20 minutes after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	4.61E-08	Yes	Yes	No
36	126	Stuck open pressurizer safety valve and HPI Failure	At 15 minutes after initiation, operator opens all TBVs to lower primary pressure and allow CFT and LPI injection. When the CFTs are 50% discharged, HPI is recovered. SRV is closed at 5 minutes after HPI is recovered. HPI is throttled at 1 minute after 2.7 K [5°F] subcooling and 254 cm [100"] pressurizer level is reached (throttling criteria is 27.8 K [50°F] subcooling).	8.41E-08	Yes	Yes	No

<b>Count</b>	<b>TH Case #</b>	<b>System Failure</b>	<b>Operator Action</b>	<b>Mean IE Frequency</b>	<b>HZP</b>	<b>Hi K</b>	<b>Dominant*</b>
37	127	SGTR with a stuck open SRV in SG-B. A reactor trip is assumed to occur at the time of the tube rupture. Stuck safety relief valve is assumed to reclose 10 minutes after initiation.	Operator trips RCP's 1 minute after initiation. Operator also throttles HPI 10 minutes after 2.77 K [5° F] subcooling and 254 cm [100 in] pressurizer level is reached (assumed throttling criteria is 27 K [50° F] subcooling).	1.25E-07	Yes	Yes	No
38	141	8.19 cm [3.22 in] surge line break [Break flow area increased by 30% from 7.18 cm [2.828 in] break].	None	1.06E-04	No	Yes	Yes at 500, 1000 EFPY
39	142	6.01 cm [2.37 in] surge line break [Break flow area decreased by 30% from 7.18 cm [2.828 in] break].	None	1.06E-04	No	Yes	No
40	145	4.34 cm [1.71 in] surge line break [Break flow area increased by 30% from 3.81 cm [1.5 in] break]. Winter conditions assumed [HPI, LPI temp = 277 K [40° F] and CFT temp = 294 K [70° F]].	None	1.34E-04	No	Yes	No
41	146	TT/RT with stuck open pzz SRV [valve flow area reduced by 30 percent]. Summer conditions assumed [HPI, LPI temp = 302 K [85° F] and CFT temp = 310 K [100° F]]. Vent valves do not function.	None	4.23E-05	No	Yes	No
42	147	TT/RT with stuck open pzz SRV. Summer conditions assumed [HPI, LPI temp = 302 K [85° F] and CFT temp = 310 K [100° F]].	None	3.63E-05	No	Yes	No
43	148	TT/RT with partially stuck open pzz SRV [flow area equivalent to 1.5 in diameter opening]. HTC coefficients increased by 1.3.	None	4.23E-05	No	Yes	No
44	149	TT/RT with stuck open pzz SRV. SRV assumed to reclose at 3000 secs. Operator does not throttle HPI.	None	9.58E-06	No	Yes	No

<b>Count</b>	<b>TH Case #</b>	<b>System Failure</b>	<b>Operator Action</b>	<b>Mean IE Frequency</b>	<b>HZP</b>	<b>Hi K</b>	<b>Dominant*</b>
45	154	8.53 cm [3.36 in] surge line break [Break flow area reduced by 30% from 10.16 cm [4 in] break]. Vent valves do not function. ECC suction switch to the containment sump included in the analysis.	None	1.34E-04	No	Yes	No
46	156	40.64 cm [16 in] hot leg break. ECC suction switch to the containment sump included in the analysis.	None	7.03E-06	No	Yes	Yes at 500, 1000 EFPY
47	160	14.37 cm [5.656 in] surge line break. ECC suction switch to the containment sump included in the analysis.	None	1.82E-05	No	Yes	Yes at 500, 1000 EFPY
48	164	20.32 cm [8 inch] surge line break. ECC suction switch to the containment sump included in the analysis.	None	2.12E-05	No	Yes	Yes at 60, 500, 1000 EFPY
49	165	Stuck open pressurizer safety valve. Valve recloses at 6000 secs [RCS low pressure point].	None	4.76E-06	Yes	Yes	Yes at 32, 60, 500, 1000 EFPY
50	168	TT/RT with stuck open pZR SRV. SRV assumed to reclose at 3000 secs. Operator does not throttle HPI.	None	1.76E-06	Yes	Yes	Yes at 500, 1000 EFPY
51	169	TT/RT with stuck open pZR SRV [valve flow area reduced by 30 percent]. Summer conditions assumed [HPI, LPI temp = 302 K [85° F] and CFT temp = 310 K [100° F]]. Vent valves do not function.	None	7.33E-06	Yes	Yes	No
52	170	TT/RT with stuck open pZR SRV. Summer conditions assumed [HPI, LPI temp = 302 K [85° F] and CFT temp = 310 K [100° F]].	None	6.28E-06	Yes	Yes	No
53	171	TT/RT with partially stuck open pZR SRV [flow area equivalent to 1.5 in diameter opening]. HTC coefficients increased by 1.3.	None	7.33E-06	Yes	Yes	No

<b>Count</b>	<b>TH Case #</b>	<b>System Failure</b>	<b>Operator Action</b>	<b>Mean IE Frequency</b>	<b>HZP</b>	<b>Hi K</b>	<b>Dominant*</b>
54	172	10.16 cm [4 in] cold leg break. ECC suction switch to the containment sump included in the analysis.	None	1.06E-04	No	Yes	Yes at 1000 EFPY
55	178	8.53 cm [3.36 in] surge line break [Break flow area reduced by 30% from 10.16 cm [4 in] break]. Vent valves do not function. ECC suction switch to the containment sump included in the analysis.	None	2.12E-05	No	Yes	No

## Notes:

1. TH – Thermal hydraulics
2. LOCA – Loss-of-coolant accident
3. SBLOCA – Small-break loss-of-coolant accident
4. MBLOCA – Medium-break loss-of-coolant accident
5. LBLOCA – Large-break loss-of-coolant accident
6. HZP – Hot-zero power
7. SRV – Safety and relief valve
8. MSLB – Main steam line break
9. AFW – Auxiliary feedwater
10. HPI – High-pressure injection
11. RCPs – Reactor coolant pumps

\* The arbitrary definition of a dominant transient is a transient that contributes 1% or more of the total Through-Wall Cracking Failure (TWCF).



**APPENDIX M**  
**OCONEE UNIT 1 FAVPOST OUTPUT**

DRAFT

M-1: 10 Year ISI only

```

*****
*
*           WELCOME TO FAVOR
*
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
*           VERSION 06.1
*
*   FAVPOST MODULE: POSTPROCESSOR MODULE
*   COMBINES TRANSIENT INITIATING FREQUENCIES
*   WITH RESULTS OF PFM ANALYSIS
*
*   PROBLEMS OR QUESTIONS REGARDING FAVOR
*   SHOULD BE DIRECTED TO
*
*           TERRY DICKSON
*   OAK RIDGE NATIONAL LABORATORY
*
*           e-mail: dickson1@ornl.gov
*
*****

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*****
* This computer program was prepared as an account of
* work sponsored by the United States Government
* Neither the United States, nor the United States
* Department of Energy, nor the United States Nuclear
* Regulatory Commission, nor any of their employees,
* nor any of their contractors, subcontractors, or their
* employees, makes any warranty, expressed or implied, or
* assumes any legal liability or responsibility for the
* accuracy, completeness, or usefulness of any
* information, apparatus, product, or process disclosed,
* or represents that its use would not infringe
* privately owned rights.
*****

```

DATE: 27-Jun-2007 TIME: 10:37:21

```

Begin echo of FAVPost input data deck      10:37:21  27-Jun-2007
End echo of FAVPost input data deck        10:37:21  27-Jun-2007

```

```

FAVPOST INPUT FILE NAME           = postoc55.in
FAVPFM OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME           = ocpost10yronly.out

```

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*
*           WELCOME TO FAVOR
*
-----

```

```

* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE *
* VERSION 05.1 *
*
* FAVPOST MODULE: POSTPROCESSOR MODULE *
* COMBINES TRANSIENT INITIAITING FREQUENCIES *
* WITH RESULTS OF PFM ANALYSIS *
*
* PROBLEMS OR QUESTIONS REGARDING FAVOR *
* SHOULD BE DIRECTED TO *
*
* TERRY DICKSON *
* OAK RIDGE NATIONAL LABORATORY *
*
* e-mail: dickson1@ornl.gov *
*
*****

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*****
* This computer program was prepared as an account of *
* work sponsored by the United States Government *
* Neither the United States, nor the United States *
* Department of Energy, nor the United States Nuclear *
* Regulatory Commission, nor any of their employees, *
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*****

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DATE: 08-Sep-2005 TIME: 17:17:09

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FAVPOST INPUT FILE NAME = postec.in
FAVPEM OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPEM OUTPUT FILE CONTAINING PFME ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME = 90000.out

```

```

*****
% NUMBER OF SIMULATIONS = 90000 *
*****

```

M-1: 10 Year ISI only (cont.)

\*\*\*\*\*  
 \* NUMBER OF SIMULATIONS = 42000 \*  
 \*\*\*\*\*

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPFmn/CPImn
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
12	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
15	1.3573E-07	0.0000E+00	0.0000E+00	1.8219E-12	0.0000E+00	0.0000E+00	0.0000
27	3.5321E-06	0.0000E+00	9.7209E-06	1.0415E-08	0.0000E+00	0.0000E+00	0.0029
28	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
31	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
37	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
38	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
44	4.1737E-06	0.0000E+00	4.4260E-06	2.8303E-06	0.0000E+00	1.7178E-06	0.6782
89	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
90	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
98	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
99	5.9408E-07	0.0000E+00	0.0000E+00	1.4020E-08	0.0000E+00	0.0000E+00	0.0236
100	1.7278E-06	0.0000E+00	3.6037E-07	4.0017E-07	0.0000E+00	0.0000E+00	0.2316
101	1.4057E-05	0.0000E+00	5.7634E-05	1.4131E-08	0.0000E+00	0.0000E+00	0.0010
102	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
109	1.2484E-07	0.0000E+00	0.0000E+00	4.0517E-08	0.0000E+00	0.0000E+00	0.3251
110	2.5705E-02	5.9843E-03	3.2961E-02	1.7099E-05	1.1551E-04	2.3858E-04	0.0067
111	4.5456E-08	0.0000E+00	0.0000E+00	1.4016E-11	0.0000E+00	0.0000E+00	0.0003
112	8.3691E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
113	3.1674E-08	0.0000E+00	0.0000E+00	2.9159E-08	0.0000E+00	0.0000E+00	0.9206
114	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000

M-1: 10 Year ISI only (cont.)

115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	2.6284E-06	0.0000E+00	3.2436E-07	1.1695E-09	0.0000E+00	0.0000E+00	0.0004
117	5.3511E-09	5.7899E-04	1.0032E-03	6.4161E-08	0.0000E+00	1.1859E-13	0.0012
119	9.2288E-05	5.7141E-04	1.4015E-03	6.2724E-07	1.2359E-05	3.9221E-06	0.0068
120	3.3053E-05	4.2682E-04	4.6996E-04	2.4359E-05	4.0226E-04	3.5238E-04	0.7368
121	7.5802E-08	0.0000E+00	0.0000E+00	2.9336E-12	0.0000E+00	0.0000E+00	0.0000
122	4.2849E-04	2.6185E-03	4.5275E-03	4.2818E-04	2.6185E-03	4.5275E-03	0.9995
123	7.5802E-08	0.0000E+00	0.0000E+00	2.9336E-12	0.0000E+00	0.0000E+00	0.0000
124	1.0762E-04	1.1252E-03	2.2503E-03	1.6517E-04	1.1140E-03	2.2106E-03	0.9860
125	7.0273E-05	5.4000E-04	3.7650E-04	2.7388E-07	0.0000E+00	7.8181E-07	0.0039
126	1.1462E-06	0.0000E+00	6.9098E-08	8.8915E-10	0.0000E+00	0.0000E+00	0.0008
127	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
141	1.3088E-04	6.5253E-04	2.1093E-03	2.4722E-06	5.4576E-05	2.1956E-05	0.0189
142	4.5999E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
145	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
146	2.7129E-06	0.0000E+00	6.0255E-07	9.5223E-08	0.0000E+00	0.0000E+00	0.0351
147	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
149	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
149	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
154	1.4610E-04	9.2152E-04	2.2196E-03	5.0292E-07	0.0000E+00	0.0000E+00	0.0034
156	3.2010E-02	5.2143E-02	1.7530E-01	8.9468E-05	3.2180E-04	1.4740E-03	0.0041
160	1.3270E-02	2.8340E-02	1.0630E-01	1.7457E-04	4.0235E-04	2.9084E-03	0.0132
164	1.3995E-02	3.2240E-02	1.2584E-01	8.8292E-05	2.5946E-04	1.5275E-03	0.0063
165	3.9220E-04	2.6738E-03	3.0921E-03	3.9180E-04	2.6738E-03	3.0921E-03	0.9990
168	2.0391E-04	1.3992E-03	2.8916E-03	2.0139E-04	1.2392E-03	2.8344E-03	0.9876
169	2.1163E-04	1.0072E-03	3.3572E-03	6.7665E-06	1.0975E-04	8.2906E-05	0.0320
170	4.6761E-08	0.0000E+00	0.0000E+00	4.6483E-13	0.0000E+00	0.0000E+00	0.0000
171	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
172	8.0788E-05	5.5702E-04	1.1954E-03	3.2570E-07	0.0000E+00	1.2316E-06	0.0040
178	1.4610E-04	9.2152E-04	2.2196E-03	5.0292E-07	0.0000E+00	0.0000E+00	0.0034

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

TRANSIENT	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO
	MEAN	95th %	99th %	MEAN	95th %	99th %	

NUMBER	CPI	CPI	CPI	CPF	CPF	CPF	CPFImm/CFImm
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
12	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
15	7.2398E-09	0.0000E+00	0.0000E+00	2.3438E-19	0.0000E+00	0.0000E+00	0.0000
27	2.9388E-07	0.0000E+00	0.0000E+00	5.2252E-10	0.0000E+00	0.0000E+00	0.0018
28	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
31	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
37	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
38	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
44	7.3186E-07	0.0000E+00	0.0000E+00	6.3417E-07	0.0000E+00	0.0000E+00	0.8669
89	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
96	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
98	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
99	5.8411E-08	0.0000E+00	0.0000E+00	1.0865E-09	0.0000E+00	0.0000E+00	0.0183
100	1.3730E-07	0.0000E+00	0.0000E+00	5.9149E-08	0.0000E+00	0.0000E+00	0.4306
101	4.3136E-07	0.0000E+00	0.0000E+00	1.0206E-09	0.0000E+00	0.0000E+00	0.0024
102	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
109	3.3299E-08	0.0000E+00	0.0000E+00	3.3366E-08	0.0000E+00	0.0000E+00	0.9820
110	2.6322E-04	1.6630E-03	3.3311E-03	2.5634E-06	4.7298E-05	1.3155E-05	0.0097
111	1.5338E-09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
112	4.6889E-11	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
113	7.7127E-08	0.0000E+00	0.0000E+00	2.6545E-08	0.0000E+00	0.0000E+00	0.3786
114	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	1.5678E-07	0.0000E+00	0.0000E+00	1.3680E-11	0.0000E+00	0.0000E+00	0.0001
117	4.6853E-06	0.0000E+00	0.6372E-06	7.2052E-09	0.0000E+00	0.0000E+00	0.0015
119	0.1160E-06	2.3484E-04	4.9562E-05	7.1294E-08	0.0000E+00	0.0000E+00	0.0088
120	3.8499E-06	0.0000E+00	1.8546E-06	3.3791E-06	0.0000E+00	1.3591E-06	0.8777
121	1.1616E-09	0.0000E+00	0.0000E+00	2.4623E-15	0.0000E+00	0.0000E+00	0.0000
122	6.7438E-05	2.8018E-03	6.6407E-04	6.7433E-05	2.8618E-03	6.6407E-04	1.0000

**M-1: 10 Year ISI only (cont.)**

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THE FREQUENCY OF CRACK INITIATION \*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	2.9119	2.9119
2.1448E-06	92.0857	94.9976
6.4345E-06	2.9429	97.9405
1.0724E-05	0.8714	98.8119
1.5014E-05	0.4571	99.2690
1.9304E-05	0.2405	99.5095
2.3593E-05	0.1524	99.6619
2.7883E-05	0.0905	99.7524
3.2173E-05	0.0619	99.8143
3.6462E-05	0.0357	99.8500
4.0752E-05	0.0214	99.8714
4.5042E-05	0.0214	99.8929
4.9331E-05	0.0214	99.9143
5.3621E-05	0.0167	99.9310
5.7911E-05	0.0095	99.9405
6.2200E-05	0.0048	99.9452
6.6490E-05	0.0071	99.9524
7.0780E-05	0.0095	99.9619
7.5069E-05	0.0071	99.9690
7.9359E-05	0.0048	99.9738
8.3648E-05	0.0024	99.9762
8.7938E-05	0.0048	99.9810
9.2227E-05	0.0024	99.9833
9.6517E-05	0.0048	99.9881
1.0081E-04	0.0024	99.9905
1.0510E-04	0.0024	99.9929
1.0940E-04	0.0024	99.9952
1.1368E-04	0.0024	99.9976
1.1797E-04	0.0024	99.9997
1.2226E-04	0.0024	100.0000

=====  
 == Summary Descriptive Statistics ==  
 =====

Minimum	= 0.0000E+00
Maximum	= 2.0449E-04
Range	= 2.0449E-04
Number of Simulations	= 42000
5th Percentile	= 3.8158E-12
Median	= 1.1260E-07
95.0th Percentile	= 2.1448E-06

M-1: 10 Year ISI only (cont.)

99.0th Percentile = 1.2489E-05  
 99.9th Percentile = 4.6472E-05  
  
 Mean = 9.9210E-07  
 Standard Deviation = 3.7931E-06  
 Standard Error = 1.8508E-08  
 Variance (unbiased) = 1.4387E-11  
 Variance (biased) = 1.4387E-11  
 Moment Coeff. of Skewness = 1.6997E+01  
 Pearson's 2nd Coeff. of Skewness = 7.8467E-01  
 Kurtosis = 5.3092E+02

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	23.0000	23.0000
3.5468E-07	76.3452	99.3452
1.0641E-06	0.3333	99.6786
1.7734E-06	0.1357	99.8143
2.4828E-06	0.0429	99.8571
3.1922E-06	0.0405	99.8976
3.9015E-06	0.0119	99.9095
4.6109E-06	0.0143	99.9238
5.3203E-06	0.0119	99.9357
6.0296E-06	0.0095	99.9452
6.7390E-06	0.0143	99.9595
7.4484E-06	0.0071	99.9667
8.1577E-06	0.0048	99.9714
8.8671E-06	0.0048	99.9762
1.0286E-05	0.0048	99.9810
1.0995E-05	0.0024	99.9833
1.1705E-05	0.0048	99.9881
1.3833E-05	0.0024	99.9905
1.4542E-05	0.0024	99.9929
2.6601E-05	0.0024	99.9952
5.4267E-05	0.0024	99.9976
7.0582E-05	0.0024	100.0000

=====  
 == Summary Descriptive Statistics ==  
 =====

Minimum = 0.0000E+00



M-1: 10 Year ISI only (cont.)

```

Maximum                = 7.0227E-05
Range                  = 7.0227E-05

Number of Simulations  = 42000

5th Percentile         = 0.0000E+00
Median                 = 9.3729E-11
95.0th Percentile     = 3.5468E-07
99.0th Percentile     = 4.7205E-07
99.9th Percentile     = 3.3340E-06

Mean                   = 3.1118E-08
Standard Deviation     = 5.2306E-07
Standard Error         = 2.5523E-09
Variance (unbiased)   = 2.7359E-13
Variance (biased)     = 2.7358E-13
Moment Coeff. of Skewness = 9.0777E+01
Pearson's 2nd Coeff. of Skewness = -4.6734E-01
Kurtosis               = 1.0697E+04
  
```

```

*****
*   FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION   *
*   AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -     *
*   WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
*****
  
```

	% of total frequency of crack initiation	% of total frequency of of TWC failure
8	0.00	0.00
12	0.00	0.00
15	0.00	0.00
27	0.00	0.00
28	0.00	0.00
29	0.00	0.00
30	0.00	0.00
31	0.00	0.00
36	0.00	0.00
37	0.00	0.00
38	0.00	0.00
44	0.00	0.00
89	0.00	0.00
90	0.00	0.00
98	0.00	0.00
99	0.00	0.00
100	0.00	0.00
101	0.00	0.00
102	0.00	0.00
103	0.00	0.00
110	1.11	0.22
111	0.00	0.00
112	0.00	0.00

M-1: 10 Year ISI only (cont.)

113	0.00	0.02
114	0.00	0.00
115	0.00	0.00
116	0.00	0.00
117	0.00	0.00
119	0.00	0.00
120	0.00	0.00
121	0.00	0.00
122	1.38	44.11
123	0.00	0.00
124	0.52	16.27
125	0.00	0.00
126	0.00	0.00
127	0.00	0.00
141	1.58	0.91
142	0.00	0.00
145	0.00	0.00
146	0.04	0.04
147	0.00	0.00
148	0.00	0.00
149	0.00	0.00
154	2.36	0.34
156	21.78	2.62
160	31.29	12.37
164	37.57	7.32
165	0.30	9.70
168	0.17	5.29
169	0.58	0.60
170	0.00	0.00
171	0.00	0.00
172	0.93	0.12
178	0.37	0.05
TOTALS 100.00		100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* BY \*  
 \* SPV BELTLINE MAJOR REGION \*  
 \* BY PARENT SUBREGION \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

M-1: 10 Year ISI only (cont.)

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency		
				cleavage	ductile	total
1	223.80	3.03	2.10	18.32	2.77	21.09
2	220.74	3.54	4.01	36.95	5.25	42.21
3	253.04	1.43	3.54	26.25	10.23	36.48
4	236.56	13.81	14.70	0.06	0.00	0.06
5	277.07	13.81	75.50	0.14	0.00	0.14
6	168.76	13.81	0.09	0.00	0.00	0.00
7	158.07	18.93	0.02	0.01	0.00	0.01
8	152.82	11.05	0.01	0.00	0.00	0.00
9	154.58	11.05	0.02	0.01	0.00	0.02
10	155.89	8.92	0.01	0.00	0.00	0.00
11	101.31	0.62	0.00	0.00	0.00	0.00
TOTALS		100.00	100.00	81.74	18.26	100.00

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* BY \*  
 \* RPV BELTLINE MAJOR REGION \*  
 \* BY CHILD SUBREGION \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

MAJOR REGION	RTndt (MAX)	% of total flaws	% of total frequency of crack initiation	% of total through-wall crack frequency		
				cleavage	ductile	total
1	223.80	3.03	2.10	18.32	2.77	21.09
2	220.74	3.54	4.01	36.95	5.25	42.21
3	253.04	1.43	3.54	26.25	10.23	36.48
4	236.56	13.81	14.70	0.06	0.00	0.06
5	277.07	13.81	75.50	0.14	0.00	0.14
6	168.76	13.81	0.09	0.00	0.00	0.00
7	158.07	18.93	0.02	0.01	0.00	0.01
8	152.82	11.05	0.01	0.00	0.00	0.00
9	154.58	11.05	0.02	0.01	0.00	0.02
10	155.89	8.92	0.01	0.00	0.00	0.00
11	101.31	0.62	0.00	0.00	0.00	0.00
TOTALS		100.00	100.00	81.74	18.26	100.00

M-1: 10 Year ISI only (cont.)

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* MATERIAL, FLAW CATEGORY, AND FLAW DEPTH \*  
 \* \*  
 \* WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT \*  
 \* TO FREQUENCY OF CRACK INITIATION AND \*  
 \* THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

\*\*\*\*\*  
 \* WELD MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.086	0.00	3.46	0.00	0.00	0.89	0.00
0.173	0.00	43.13	0.00	0.00	12.86	0.00
0.259	0.00	15.98	0.00	0.00	6.44	0.00
0.345	0.00	9.47	0.00	0.00	5.39	0.05
0.431	0.00	7.02	0.01	0.00	6.88	0.17
0.518	0.00	4.91	0.01	0.00	7.10	0.31
0.604	0.00	3.69	0.02	0.00	4.99	0.50
0.690	0.00	2.24	0.02	0.00	5.04	0.48
0.776	0.00	1.85	0.01	0.00	4.00	0.45
0.863	0.00	1.97	0.02	0.00	5.08	0.52
0.949	0.00	0.88	0.02	0.00	4.28	0.65
1.035	0.03	1.03	0.01	0.00	4.67	0.20
1.121	0.04	0.70	0.00	0.00	2.85	0.10
1.208	0.01	0.61	0.01	0.00	2.08	0.21
1.294	0.00	0.66	0.01	0.00	3.93	0.23
1.380	0.00	0.86	0.01	0.00	3.34	0.30
1.466	0.00	0.20	0.01	0.00	3.29	0.19
1.553	0.00	0.25	0.00	0.00	2.25	0.13
1.639	0.00	0.24	0.01	0.00	0.81	0.20
1.725	0.00	0.12	0.00	0.00	1.45	0.03
1.811	0.00	0.38	0.00	0.00	5.61	0.06
1.898	0.00	0.05	0.00	0.00	1.62	0.02
1.984	0.00	0.04	0.00	0.00	0.25	0.02
2.070	0.00	0.00	0.00	0.00	0.00	0.00
2.157	0.00	0.00	0.00	0.00	0.00	0.00
2.243	0.00	0.00	0.00	0.00	0.00	0.00
2.329	0.00	0.00	0.00	0.00	0.00	0.00
2.415	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	0.08	99.72	0.15	0.00	95.13	4.85

M-1: 10 Year ISI only (cont.)

\*\*\*\*\*  
 \* PLATE MATERIAL \*  
 \*\*\*\*\*

FLAW DEPTH (in)	% of total frequency of crack initiation			% of total through-wall crack frequency		
	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws	CAT 1 flaws	CAT 2 flaws	CAT 3 flaws
0.086	0.00	0.00	0.00	0.00	0.00	0.00
0.173	0.00	0.00	0.00	0.00	0.01	0.00
0.259	0.00	0.00	0.00	0.00	0.01	0.00
0.345	0.00	0.00	0.00	0.00	0.00	0.00
0.431	0.00	0.00	0.00	0.00	0.01	0.00
0.518	0.00	0.00	0.00	0.00	0.00	0.00
0.604	0.00	0.00	0.00	0.00	0.00	0.00
0.690	0.00	0.00	0.00	0.00	0.00	0.00
0.776	0.00	0.00	0.00	0.00	0.00	0.00
0.863	0.00	0.00	0.00	0.00	0.00	0.00
0.949	0.00	0.00	0.00	0.00	0.00	0.00
1.035	0.02	0.00	0.00	0.00	0.00	0.00
1.121	0.02	0.00	0.00	0.00	0.00	0.00
1.208	0.00	0.00	0.00	0.00	0.00	0.00
1.294	0.00	0.00	0.00	0.00	0.00	0.00
1.380	0.00	0.00	0.00	0.00	0.00	0.00
1.466	0.00	0.00	0.00	0.00	0.00	0.00
1.553	0.00	0.00	0.00	0.00	0.00	0.00
1.639	0.00	0.00	0.00	0.00	0.00	0.00
1.725	0.00	0.00	0.00	0.00	0.00	0.00
1.811	0.00	0.00	0.00	0.00	0.00	0.00
1.898	0.00	0.00	0.00	0.00	0.00	0.00
1.984	0.00	0.00	0.00	0.00	0.00	0.00
2.070	0.00	0.00	0.00	0.00	0.00	0.00
2.157	0.00	0.00	0.00	0.00	0.00	0.00
2.243	0.00	0.00	0.00	0.00	0.00	0.00
2.329	0.00	0.00	0.00	0.00	0.00	0.00
2.415	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	0.05	0.00	0.00	0.00	0.03	0.00

DATE: 27-Jun-2007 TIME: 10:38:00

~~123 1.1616E-09 0.0000E+00 0.0000E+00 2.4623E-15 0.0000E+00 0.0000E+00 0.0000~~  
~~124 2.0309E-05 1.3429E-03 1.3420E-04 2.0269E-05 1.3429E-03 1.3407E-04 0.9980~~  
~~125 6.2610E-06 2.5158E-04 2.5355E-05 1.9360E-08 0.0000E+00 0.0000E+00 0.0031~~  
~~126 8.7233E-08 0.0000E+00 0.0000E+00 8.2837E-12 0.0000E+00 0.0000E+00 0.0001~~

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<del>127</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>141</del>	<del>1.0863E-05</del>	<del>2.5369E-04</del>	<del>7.5651E-05</del>	<del>2.2179E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0204</del>
<del>142</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>145</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>146</del>	<del>1.1757E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>1.2582E-08</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.1070</del>
<del>147</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>148</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>149</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>154</del>	<del>6.8954E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>3.7947E-09</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0055</del>
<del>156</del>	<del>2.8339E-03</del>	<del>6.1751E-03</del>	<del>3.1558E-02</del>	<del>1.2301E-05</del>	<del>9.7288E-05</del>	<del>1.7165E-04</del>	<del>0.0043</del>
<del>160</del>	<del>1.2999E-03</del>	<del>2.9990E-03</del>	<del>1.5041E-02</del>	<del>1.7600E-05</del>	<del>1.9275E-04</del>	<del>2.6694E-04</del>	<del>0.0135</del>
<del>164</del>	<del>1.2683E-03</del>	<del>3.4267E-03</del>	<del>1.5518E-02</del>	<del>8.9460E-06</del>	<del>1.1956E-04</del>	<del>1.1128E-04</del>	<del>0.0071</del>
<del>165</del>	<del>5.2553E-05</del>	<del>7.1010E-04</del>	<del>5.4086E-04</del>	<del>5.2549E-05</del>	<del>7.1010E-04</del>	<del>5.4086E-04</del>	<del>0.9999</del>
<del>168</del>	<del>2.4637E-05</del>	<del>1.4671E-03</del>	<del>1.9041E-04</del>	<del>2.4591E-05</del>	<del>1.4671E-03</del>	<del>1.8976E-04</del>	<del>0.9981</del>
<del>169</del>	<del>1.3342E-05</del>	<del>3.7174E-04</del>	<del>9.1620E-05</del>	<del>6.1163E-07</del>	<del>0.0000E+00</del>	<del>9.3081E-12</del>	<del>0.0458</del>
<del>170</del>	<del>4.6746E-10</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>171</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0000</del>
<del>172</del>	<del>7.1525E-06</del>	<del>2.6205E-04</del>	<del>3.9921E-05</del>	<del>4.7288E-08</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0066</del>
<del>178</del>	<del>6.8954E-07</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>3.7947E-09</del>	<del>0.0000E+00</del>	<del>0.0000E+00</del>	<del>0.0055</del>

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NOTES: CPE IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)

CPE IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)



## M-1: 10 Year ISI only (cont.)

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*****
*          PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)          *
*          FOR THE FREQUENCY OF CRACK INITIATION                  *
*****

```

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	0.8300	0.8300
2.9933E-07	96.4467	97.2767
8.9800E-07	1.4756	98.7522
1.4967E-06	0.4778	99.2300
2.0953E-06	0.2444	99.4744
2.6940E-06	0.1344	99.6089
3.2927E-06	0.0867	99.6956
3.8913E-06	0.0533	99.7489
4.4900E-06	0.0378	99.7867
5.0887E-06	0.0311	99.8178
5.6874E-06	0.0256	99.8433
6.2860E-06	0.0167	99.8600
6.8847E-06	0.0222	99.8822
7.4834E-06	0.0122	99.8944
8.0820E-06	0.0133	99.9078
8.6807E-06	0.0111	99.9189
9.2794E-06	0.0044	99.9233
9.8780E-06	0.0078	99.9311
1.0477E-05	0.0033	99.9344
1.1075E-05	0.0056	99.9400
1.1674E-05	0.0056	99.9456
1.2273E-05	0.0033	99.9489
1.2871E-05	0.0011	99.9500
1.3470E-05	0.0033	99.9533
1.4069E-05	0.0033	99.9567
1.5265E-05	0.0022	99.9589
1.6463E-05	0.0022	99.9611
1.7662E-05	0.0022	99.9633
1.7661E-05	0.0011	99.9644
1.8259E-05	0.0011	99.9656
1.8858E-05	0.0022	99.9678
2.0755E-05	0.0022	99.9700
2.0654E-05	0.0011	99.9711
2.1253E-05	0.0022	99.9733
2.1851E-05	0.0033	99.9767
2.2450E-05	0.0011	99.9778
2.4246E-05	0.0011	99.9789
2.4845E-05	0.0022	99.9811
2.5042E-05	0.0011	99.9822
2.7239E-05	0.0011	99.9833
2.7838E-05	0.0011	99.9844
2.8437E-05	0.0011	99.9856
3.9634E-05	0.0011	99.9867
1.1430E-05	0.0011	99.9878



M-1: 10-Year ISI only (cont.)

3.2029E-05	0.0011	99.9889
3.3226E-05	0.0022	99.9911
3.4423E-05	0.0011	99.9922
3.7417E-05	0.0011	99.9933
3.8015E-05	0.0011	99.9944
3.8614E-05	0.0011	99.9956
4.0410E-05	0.0011	99.9967
4.2206E-05	0.0011	99.9978
4.7594E-05	0.0011	99.9989
5.8969E-05	0.0011	100.0000

==== Summary Descriptive Statistics ====

Minimum	=	0.0000E+00
Maximum	=	5.9268E-05
Range	=	5.9268E-05
Number of Simulations	=	90000
5th Percentile	=	1.0021E-11
Median	=	6.3992E-09
95.0th Percentile	=	2.9933E-07
99.0th Percentile	=	1.2085E-06
99.9th Percentile	=	7.7328E-06
Mean	=	9.6315E-08
Standard Deviation	=	7.2357E-07
Standard Error	=	2.4119E-09
Variance (Unbiased)	=	5.2356E-13
Variance (Biased)	=	5.2355E-13
Moment Coeff. of Skewness	=	3.4633E+01
Pearson's 2nd Coeff. of Skewness	=	3.9933E-01
Kurtosis	=	1.7340E+03

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	58.0878	58.0878
1.0195E-07	41.7589	99.8467
3.0584E-07	0.0911	99.9378
5.0973E-07	0.0200	99.9578
7.1362E-07	0.0100	99.9678

M 1: 10 Year ISI only (cont.)

9.1751E-07	0.0078	99.9756
1.1214E-06	0.0078	99.9833
1.5292E-06	0.0022	99.9856
1.7331E-06	0.0022	99.9878
1.9370E-06	0.0011	99.9889
2.1408E-06	0.0011	99.9900
2.3447E-06	0.0011	99.9911
2.5486E-06	0.0011	99.9922
3.3542E-06	0.0022	99.9944
3.7720E-06	0.0022	99.9967
3.9759E-06	0.0011	99.9978
7.4420E-06	0.0011	99.9989
2.0083E-05	0.0011	100.0000

==== Summary Descriptive Statistics =====

Minimum	=	0.0000E+00
Maximum	=	2.0185E-05
Range	=	2.0185E-05
Number of Simulations	=	90000
5th Percentile	=	0.0000E+00
Median	=	0.0000E+00
95.0th Percentile	=	1.0195E-07
99.0th Percentile	=	2.2874E-08
99.9th Percentile	=	2.2130E-07
Mean	=	2.0641E-09
Standard Deviation	=	8.1215E-08
Standard Error	=	2.7072E-10
Variance (unbiased)	=	6.5958E-15
Variance (biased)	=	6.5958E-15
Moment Coeff. of Skewness	=	1.8585E+02
Pearson's 2nd Coeff. of Skewness	=	-1.6013E-01
Kurtosis	=	4.3419E+04

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
8	0.00	0.00
12	0.00	0.00
15	0.00	0.00
27	0.00	0.00

AI-1: 10 Year ISI only (cont.)

28	0.00	0.00
29	0.00	0.00
30	0.00	0.00
31	0.00	0.00
36	0.00	0.00
37	0.00	0.00
38	0.00	0.00
44	0.00	0.00
89	0.00	0.00
90	0.00	0.00
98	0.00	0.00
99	0.00	0.00
100	0.00	0.00
101	0.00	0.00
102	0.00	0.00
109	0.00	0.01
110	1.16	0.49
111	0.00	0.00
112	0.00	0.00
113	0.00	0.02
114	0.00	0.00
115	0.00	0.00
116	0.00	0.00
117	0.00	0.00
119	0.00	0.00
120	0.00	0.01
121	0.00	0.00
122	0.61	28.54
123	0.00	0.00
124	0.21	9.75
125	0.00	0.00
126	0.00	0.00
127	0.00	0.00
141	1.25	1.27
142	0.00	0.00
145	0.00	0.00
146	0.01	0.02
147	0.00	0.00
148	0.00	0.00
149	0.00	0.00
154	0.09	0.03
156	27.80	6.96
160	30.94	29.68
164	36.76	13.00
165	0.14	6.31
168	0.07	3.44
169	0.12	0.23
170	0.00	0.00
171	0.00	0.00
172	0.83	0.25
178	0.01	0.00
TOTALS	100.00	100.00

M-2: ISI Every 10 Years

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*****
*
* WELCOME TO FAVOR
*
* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
* VERSION 06.1
*
* FAVPOST MODULE: POSTPROCESSOR MODULE
* COMBINES TRANSIENT INITIAITING FREQUENCIES
* WITH RESULTS OF PFM ANALYSIS
*
* PROBLEMS OR QUESTIONS REGARDING FAVOR
* SHOULD BE DIRECTED TO
*
* TERRY DICKSON
* OAK RIDGE NATIONAL LABORATORY
*
* e-mail: dickson1@ornl.gov
*
*****
```

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*****
* This computer program was prepared as an account of
* work sponsored by the United States Government
* Neither the United States, nor the United States
* Department of Energy, nor the United States Nuclear
* Regulatory Commission, nor any of their employees,
* nor any of their contractors, subcontractors, or their
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DATE: 27-Jun-2007 TIME: 10:36:09

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End echo of FAVPost input data deck 10:36:09 27-Jun-2007

FAVPOST INPUT FILE NAME = postoc55.in  
FAVPEM OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT  
FAVPEM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT  
FAVPOST OUTPUT FILE NAME = ocpst10yrint.out

```
*****
*
* WELCOME TO FAVOR
*
* FRACTURE ANALYSIS OF VESSELS: OAK RIDGE
*
```

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*-----*
*          VERSION 05.1          *
*-----*
*          FAVPOST MODULE: POSTPROCESSOR MODULE          *
*-----*
*    COMBINES TRANSIENT INITIATING FREQUENCIES          *
*    WITH RESULTS OF PFM ANALYSIS                      *
*-----*
*          PROBLEMS OR QUESTIONS REGARDING FAVOR          *
*          SHOULD BE DIRECTED TO                        *
*-----*
*          TERRY DICKSON                                  *
*          OAK RIDGE NATIONAL LABORATORY                *
*-----*
*          e-mail: dickson1@ornl.gov                    *
*-----*
*****

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*****
* This computer program was prepared as an account of *
* work sponsored by the United States Government      *
* Neither the United States, nor the United States   *
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*****

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DATE: 02 Sep 2005 TIME: 16:13:04

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FAVPOST INPUT FILE NAME          = postoc.in
FAVPEM OUTPUT FILE CONTAINING PEMI ARRAY = INITIATE.DAT
FAVPEM OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME         = 90000.out

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*****
* NUMBER OF SIMULATIONS = 90000 *
*****

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M-2: ISI Every 10 Years (cont.)

\*\*\*\*\*  
 \* NUMBER OF SIMULATIONS = 42000 \*  
 \*\*\*\*\*

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPFmn/CPImn
	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
12	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
15	6.9014E-08	0.0000E+00	0.0000E+00	3.6598E-12	0.0000E+00	0.0000E+00	0.0001
27	3.0898E-06	0.0000E+00	9.3807E-06	2.6045E-08	0.0000E+00	0.0000E+00	0.0084
28	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
31	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
37	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
38	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
44	4.4385E-06	0.0000E+00	3.1287E-06	3.3673E-06	0.0000E+00	1.6329E-06	0.7586
53	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
90	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
98	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
99	4.3209E-07	0.0000E+00	0.0000E+00	4.2164E-08	0.0000E+00	0.0000E+00	0.0976
100	1.6582E-06	0.0000E+00	1.6005E-07	6.5525E-07	0.0000E+00	0.0000E+00	0.3952

## M-2: ISI Every 10 Years (cont.)

101	9.7363E-06	0.0000E+00	5.0383E-05	1.9741E-08	0.0000E+00	0.0000E+00	0.0020
102	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
109	1.1900E-07	0.0000E+00	0.0000E+00	7.7323E-08	0.0000E+00	0.0000E+00	0.6498
110	2.6087E-03	6.2367E-03	3.2743E-02	1.7303E-05	2.1472E-04	3.0001E-04	0.0066
111	1.4966E-08	0.0000E+00	0.0000E+00	5.2442E-11	0.0000E+00	0.0000E+00	0.0035
112	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
113	6.2055E-08	0.0000E+00	0.0000E+00	5.9294E-08	0.0000E+00	0.0000E+00	0.9555
114	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	2.2291E-06	0.0000E+00	7.0608E-07	5.1327E-09	0.0000E+00	0.0000E+00	0.0023
117	5.5617E-05	3.4579E-04	7.7732E-04	9.5098E-08	0.0000E+00	0.0000E+00	0.0017
119	9.1956E-05	3.0210E-04	1.5073E-03	7.8504E-07	2.9569E-05	3.7212E-06	0.0085
120	3.1952E-05	2.8404E-04	4.5357E-04	2.5547E-05	2.6061E-04	3.1323E-04	0.7995
121	2.7485E-08	0.0000E+00	0.0000E+00	7.2283E-10	0.0000E+00	0.0000E+00	0.0263
122	3.8697E-04	2.6683E-03	3.8068E-03	3.8690E-04	2.6683E-03	3.8068E-03	0.9998
123	2.7485E-08	0.0000E+00	0.0000E+00	7.2283E-10	0.0000E+00	0.0000E+00	0.0263
124	1.7117E-04	8.5298E-04	2.3535E-03	1.6870E-04	8.5298E-04	2.3226E-03	0.9856
125	7.0998E-05	3.0103E-04	1.1539E-03	3.7122E-07	0.0000E+00	7.3397E-07	0.0052
126	8.9419E-07	0.0000E+00	1.4998E-07	3.0547E-09	0.0000E+00	0.0000E+00	0.0034
127	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
141	1.2407E-04	3.1186E-04	2.2591E-03	2.6331E-06	4.3366E-05	2.3103E-05	0.0212
142	4.5517E-11	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
145	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
146	2.2255E-06	0.0000E+00	7.2719E-07	1.8547E-07	0.0000E+00	0.0000E+00	0.0833
147	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
148	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
149	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
154	1.4390E-04	4.9507E-04	2.3339E-03	3.8809E-07	0.0000E+00	0.0000E+00	0.0027
156	2.2374E-02	5.3757E-02	1.8079E-01	8.5646E-05	4.1552E-04	1.2331E-03	0.0038
160	1.3434E-02	2.9083E-02	1.0573E-01	1.7218E-04	5.9581E-04	2.6851E-03	0.0128
164	1.4231E-02	3.3616E-02	1.2566E-01	8.7527E-05	5.4722E-04	1.2941E-03	0.0062
165	3.5089E-04	2.6865E-03	2.7402E-03	3.5077E-04	2.6865E-03	2.7402E-03	0.9997
168	2.0794E-04	9.4460E-04	2.8225E-03	2.0523E-04	9.4460E-04	2.8108E-03	0.9870
169	2.0891E-04	5.2788E-04	3.5882E-03	7.6133E-06	1.4604E-04	8.9295E-05	0.0364
170	1.7072E-08	0.0000E+00	0.0000E+00	3.3194E-10	0.0000E+00	0.0000E+00	0.0194
171	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
172	8.2142E-05	3.0025E-04	1.3571E-03	4.2000E-07	0.0000E+00	9.8847E-07	0.0051

M-2: ISI Every 10 Years (cont.)

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178	1.4390E-04	4.9507E-04	2.3339E-03	3.8804E-07	0.0000E+00	0.0000E+00	0.0027
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NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

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DRAFT



TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F E)			RATIO CPFmn/CPIInn
	MEAN	95th %	99th %	MEAN	95th %	99th %	
	CPI	CPI	CPI	CPF	CPF	CPF	
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
12	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
15	1.7815E-09	0.0000E+00	0.0000E+00	9.3921E-13	0.0000E+00	0.0000E+00	0.0005
27	1.4039E-07	0.0000E+00	0.0000E+00	6.6856E-09	0.0000E+00	0.0000E+00	0.0476
28	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
29	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
30	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
31	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
36	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
37	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
38	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
44	5.3390E-07	0.0000E+00	0.0000E+00	4.9845E-07	0.0000E+00	0.0000E+00	0.9336
89	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
90	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
98	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
99	2.5350E-08	0.0000E+00	0.0000E+00	1.1771E-08	0.0000E+00	0.0000E+00	0.4643
100	1.7558E-07	0.0000E+00	0.0000E+00	1.4948E-07	0.0000E+00	0.0000E+00	0.8514
101	1.7367E-07	0.0000E+00	0.0000E+00	2.3133E-09	0.0000E+00	0.0000E+00	0.0133
102	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
109	7.3421E-09	0.0000E+00	0.0000E+00	7.7631E-09	0.0000E+00	0.0000E+00	0.9903
110	2.4559E-04	3.2031E-04	3.3823E-03	3.4652E-06	1.6053E-04	1.4147E-05	0.0141
111	1.9195E-10	0.0000E+00	0.0000E+00	2.4773E-14	0.0000E+00	0.0000E+00	0.0001
112	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
113	5.7623E-09	0.0000E+00	0.0000E+00	5.7071E-09	0.0000E+00	0.0000E+00	0.9904
114	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
115	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
116	4.2378E-08	0.0000E+00	0.0000E+00	1.7003E-10	0.0000E+00	0.0000E+00	0.0040
117	3.4748E-06	0.0000E+00	7.9204E-06	1.9228E-08	0.0000E+00	0.0000E+00	0.0055
119	6.3411E-06	8.7828E-05	4.5421E-05	2.0663E-07	0.0000E+00	0.0000E+00	0.0326
120	3.7181E-06	0.0000E+00	2.6462E-06	3.3372E-06	0.0000E+00	2.1160E-06	0.8976
121	9.5832E-11	0.0000E+00	0.0000E+00	1.1044E-11	0.0000E+00	0.0000E+00	0.1152
122	8.2527E-05	1.1594E-03	8.5743E-04	8.2526E-05	1.1594E-03	8.5743E-04	1.0000

## M-2: ISI Every 10 Years (cont.)

123	9.5832E-11	0.0000E+00	0.0000E+00	1.1044E-11	0.0000E+00	0.0000E+00	0.1152
124	2.2553E-05	5.8212E-04	1.8636E-04	2.2501E-05	5.8212E-04	1.8553E-04	0.9977
125	4.8152E-06	8.5566E-05	2.6193E-05	8.0652E-08	0.0000E+00	0.0000E+00	0.0167
126	2.9183E-08	0.0000E+00	0.0000E+00	2.8699E-10	0.0000E+00	0.0000E+00	0.0098
127	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
141	7.9520E-06	1.1655E-04	6.6654E-05	3.9694E-07	0.0000E+00	0.0000E+00	0.0438
142	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
145	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
146	7.9326E-08	0.0000E+00	0.0000E+00	3.8870E-08	0.0000E+00	0.0000E+00	0.4900
147	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
148	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
149	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
154	3.1638E-07	0.0000E+00	0.0000E+00	2.4759E-08	0.0000E+00	0.0000E+00	0.0783
156	2.7343E-03	6.0920E-03	2.9727E-02	1.3731E-05	3.8866E-04	1.8007E-04	0.0959
160	1.2415E-03	2.2956E-03	1.5514E-02	2.2394E-05	6.6379E-04	3.0192E-04	0.0180
164	1.2169E-03	2.3202E-03	1.5756E-02	1.4117E-05	3.4727E-04	1.1747E-04	0.0091
165	7.5936E-05	1.1789E-03	7.1367E-04	7.5936E-05	1.1789E-03	7.1367E-04	1.0000
168	2.7524E-05	6.4298E-04	2.5502E-04	2.7467E-05	6.4298E-04	2.5487E-04	0.9986
169	1.0686E-05	1.9109E-04	8.9740E-05	9.4985E-07	0.0000E+00	3.4677E-10	0.0889
170	5.5133E-11	0.0000E+00	0.0000E+00	1.5098E-12	0.0000E+00	0.0000E+00	0.0274
171	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000
172	5.4843E-06	7.9106E-05	3.7104E-05	1.1567E-07	0.0000E+00	0.0000E+00	0.0211
178	3.1638E-07	0.0000E+00	0.0000E+00	2.4759E-08	0.0000E+00	0.0000E+00	0.0783

NOTES: CPI IS CONDITIONAL PROBABILITY OF CRACK INITIATION, P(I|E)  
 CPF IS CONDITIONAL PROBABILITY OF TWC FAILURE, P(F|E)

## -M-2: ISI Every 10 Years (cont.)

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*****
*          PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)          *
*          FOR THE FREQUENCY OF CRACK INITIATION                  *
*****

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FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	2.8976	2.8976
2.1486E-06	92.1000	94.9976
6.4459E-06	2.9714	97.9690
1.0743E-05	0.8738	98.8429
1.5040E-05	0.3714	99.2143
1.9338E-05	0.2548	99.4690
2.3635E-05	0.1476	99.6167
2.7932E-05	0.1000	99.7167
3.2230E-05	0.0643	99.7810
3.6527E-05	0.0381	99.8190
4.0824E-05	0.0262	99.8452
4.5121E-05	0.0262	99.8714
4.9419E-05	0.0143	99.8857
5.3716E-05	0.0262	99.9119
5.8013E-05	0.0190	99.9310
6.2311E-05	0.0119	99.9429
6.6608E-05	0.0095	99.9524
7.0905E-05	0.0071	99.9595
7.5202E-05	0.0048	99.9643
7.9500E-05	0.0024	99.9667
8.3797E-05	0.0048	99.9714
8.8094E-05	0.0048	99.9762
9.2392E-05	0.0024	99.9786
9.6689E-05	0.0048	99.9833
1.0099E-04	0.0071	99.9905
1.0528E-04	0.0024	99.9929
1.0958E-04	0.0048	99.9976
1.1387E-04	0.0024	100.0000

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-- Summary Descriptive Statistics --
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Minimum	= 0.0000E+00
Maximum	= 1.6165E-04
Range	= 1.6165E-04
Number of Simulations	= 42000
5th Percentile	= 3.8070E-12
Median	= 1.0893E-07
95.0th Percentile	= 2.1486E-06

## M-2: ISI Every 10 Years (cont.)

99.0th Percentile	= 1.2561E-05
99.9th Percentile	= 5.1763E-05
Mean	= 1.0085E-06
Standard Deviation	= 3.8747E-06
Standard Error	= 1.8907E-08
Variance (unbiased)	= 1.5013E-11
Variance (biased)	= 1.5013E-11
Moment Coeff. of Skewness	= 1.4853E+01
Pearson's 2nd Coeff. of Skewness	= 7.8082E-01
Kurtosis	= 3.6493E+02

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	22.6333	22.6333
9.0774E-08	74.9690	97.6024
2.7232E-07	1.1857	98.7881
4.5387E-07	0.4024	99.1905
6.3542E-07	0.1905	99.3810
8.1696E-07	0.1286	99.5095
9.9851E-07	0.0810	99.5905
1.1801E-06	0.0952	99.6857
1.3616E-06	0.0405	99.7262
1.5432E-06	0.0143	99.7405
1.7247E-06	0.0167	99.7571
1.9062E-06	0.0167	99.7738
2.0878E-06	0.0238	99.7976
2.2693E-06	0.0167	99.8143
2.4509E-06	0.0143	99.8286
2.6324E-06	0.0310	99.8595
2.8140E-06	0.0071	99.8667
2.9955E-06	0.0048	99.8714
3.1771E-06	0.0071	99.8786
3.3586E-06	0.0214	99.9000
3.5402E-06	0.0167	99.9167
3.7217E-06	0.0095	99.9262
4.0848E-06	0.0119	99.9381
4.2664E-06	0.0048	99.9429
4.4479E-06	0.0024	99.9452
4.6295E-06	0.0095	99.9548
4.8110E-06	0.0095	99.9643
6.2634E-06	0.0024	99.9667
6.4449E-06	0.0024	99.9690

M-2: ISI Every 10 Years (cont.)

6.8080E-06	0.0048	99.9738
6.9896E-06	0.0024	99.9762
7.1711E-06	0.0024	99.9786
7.3527E-06	0.0024	99.9810
7.8973E-06	0.0024	99.9833
8.4419E-06	0.0024	99.9857
1.0076E-05	0.0024	99.9881
1.0802E-05	0.0048	99.9929
1.7156E-05	0.0024	99.9952
1.7882E-05	0.0024	99.9976
1.8064E-05	0.0024	100.0000

=====  
 == Summary Descriptive Statistics ==  
 =====

Minimum	= 0.0000E+00
Maximum	= 1.7973E-05
Range	= 1.7973E-05
Number of Simulations	= 42000
5th Percentile	= 0.0000E+00
Median	= 8.9093E-11
95.0th Percentile	= 9.0774E-08
99.0th Percentile	= 3.6793E-07
99.9th Percentile	= 3.3586E-06
Mean	= 2.6200E-08
Standard Deviation	= 2.6170E-07
Standard Error	= 1.2770E-09
Variance (unbiased)	= 6.8486E-14
Variance (biased)	= 6.8485E-14
Moment Coeff. of Skewness	= 3.5238E+01
Pearson's 2nd Coeff. of Skewness	= -9.4834E-01
Kurtosis	= 1.8441E+03

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) - \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of of TWC failure
8	0.00	0.00
12	0.00	0.00
15	0.00	0.00
27	0.00	0.00
28	0.00	0.00

## M-2: ISI Every 10 Years (cont.)

29	0.00	0.00
30	0.00	0.00
31	0.00	0.00
36	0.00	0.00
37	0.00	0.00
38	0.00	0.00
44	0.00	0.01
89	0.00	0.00
90	0.00	0.00
98	0.00	0.00
99	0.00	0.00
100	0.00	0.00
101	0.00	0.00
102	0.00	0.00
109	0.00	0.02
110	1.06	0.30
111	0.00	0.00
112	0.00	0.00
113	0.00	0.01
114	0.00	0.00
115	0.00	0.00
116	0.00	0.00
117	0.01	0.00
119	0.01	0.00
120	0.00	0.01
121	0.00	0.00
122	0.96	36.96
123	0.00	0.00
124	0.44	16.78
125	0.00	0.00
126	0.00	0.00
127	0.00	0.00
141	1.43	1.04
142	0.00	0.00
145	0.00	0.00
146	0.03	0.12
147	0.00	0.00
148	0.00	0.00
149	0.00	0.00
154	2.13	0.22
156	21.66	3.30
160	30.94	14.65
164	38.99	9.54
165	0.24	9.06
168	0.17	6.32
169	0.60	1.45
170	0.00	0.00
171	0.00	0.00
172	0.99	0.20
178	0.36	0.02
TOTALS	100.00	100.00

DATE: 27-Jun-2007 TIME: 10:36:45

\*\*\*\*\*  
 \*----- PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) -----\*  
 \*----- FOR THE FREQUENCY OF CRACK INITIATION -----\*  
 \*\*\*\*\*

FREQUENCY OF CRACK INITIATION (PER REACTOR-OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	0.8700	0.8700
1.0899E-06	98.5233	99.3933
3.2698E-06	0.3711	99.7644
5.4496E-06	0.0944	99.8589
7.6295E-06	0.0533	99.9122
9.8093E-06	0.0267	99.9389
1.1969E-05	0.0122	99.9511
1.4169E-05	0.0044	99.9556
1.6349E-05	0.0089	99.9644
1.8529E-05	0.0111	99.9756
2.0709E-05	0.0044	99.9800
2.2889E-05	0.0044	99.9844
2.5068E-05	0.0033	99.9878
2.7248E-05	0.0022	99.9900
2.9428E-05	0.0033	99.9933
3.1607E-05	0.0011	99.9944
3.3787E-05	0.0011	99.9956
3.5967E-05	0.0022	99.9978
3.8146E-05	0.0011	99.9989
4.0326E-05	0.0011	99.9999
4.2506E-05	0.0011	100.0000

=====  
 Summary Descriptive Statistics  
 =====

Minimum	= 0.0000E+00
Maximum	= 2.1580E-04
Range	= 2.1580E-04
Number of Simulations	= 90000
5th Percentile	= 1.1016E-11
Median	= 6.2400E-09
95.0th Percentile	= 1.0899E-06
99.0th Percentile	= 1.4158E-06
99.9th Percentile	= 7.1299E-06
Mean	= 9.6929E-08
Standard Deviation	= 9.9040E-07
Standard Error	= 3.3013E-09
Variance (unbiased)	= 9.8090E-13
Variance (biased)	= 9.8088E-13
Moment Coeff. of Skewness	= 1.2603E+02
Pearson's 2nd Coeff. of Skewness	= 2.9361E-01

M-2: ISI Every 10 Years (cont.)

Kurtosis = 2.5418E+04

\*\*\*\*\*  
 \* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) \*  
 \* FOR THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \*\*\*\*\*

FREQUENCY OF TWC FAILURES (PER REACTOR OPERATING YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	55.2600	55.2600
4.6338E-08	44.3778	99.6378
1.3901E-07	0.1667	99.8044
2.3169E-07	0.0700	99.8744
3.2437E-07	0.0256	99.9000
4.1704E-07	0.0289	99.9289
5.0972E-07	0.0133	99.9422
6.0239E-07	0.0122	99.9544
6.9507E-07	0.0044	99.9589
7.8774E-07	0.0078	99.9667
8.8042E-07	0.0022	99.9689
9.7310E-07	0.0056	99.9744
1.0658E-06	0.0022	99.9767
1.1584E-06	0.0011	99.9778
1.2511E-06	0.0044	99.9822
1.3438E-06	0.0033	99.9856
1.4365E-06	0.0011	99.9867
1.5292E-06	0.0022	99.9889
1.7145E-06	0.0011	99.9900
1.8999E-06	0.0011	99.9911
2.1779E-06	0.0011	99.9922
3.3827E-06	0.0011	99.9933
3.7534E-06	0.0011	99.9944
4.0314E-06	0.0011	99.9956
4.7728E-06	0.0011	99.9967
5.6996E-06	0.0011	99.9978
5.9776E-06	0.0011	99.9989
9.1286E-06	0.0011	100.0000

=====  
 Summary Descriptive Statistics  
 =====

Minimum	= 0.0000E+00
Maximum	= 9.1749E-06
Range	= 9.1749E-06
Number of Simulations	= 90000
5th Percentile	= 0.0000E+00
Median	= 0.0000E+00
95.0th Percentile	= 4.6338E-08



M-2: ISI Every 10 Years (cont.)

99.0th Percentile	= 2.6796E-08
99.9th Percentile	= 3.2437E-07
Mean	= 2.1755E-09
Standard Deviation	= 5.6060E-08
Standard Error	= 1.8687E-10
Variance (unbiased)	= 3.1427E-15
Variance (biased)	= 3.1427E-15
Moment Coeff. of Skewness	= 9.4559E+01
Pearson's 2nd Coeff. of Skewness	= 2.1751E-01
Kurtosis	= 1.4887E+04

\*\*\*\*\*  
 \* FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION \*  
 \* AND THROUGH WALL CRACKING FREQUENCY (FAILURE) \*  
 \* WEIGHTED BY TRANSIENT INITIATING FREQUENCIES \*  
 \*\*\*\*\*

	% of total frequency of crack initiation	% of total frequency of TWC failure
8	0.00	0.00
12	0.00	0.00
15	0.00	0.00
27	0.00	0.00
28	0.00	0.00
29	0.00	0.00
30	0.00	0.00
31	0.00	0.00
36	0.00	0.00
37	0.00	0.00
38	0.00	0.00
40	0.00	0.01
50	0.00	0.00
90	0.00	0.00
98	0.00	0.00
99	0.00	0.00
100	0.00	0.00
101	0.00	0.00
102	0.00	0.00
109	0.00	0.00
110	1.22	0.63
111	0.00	0.00
112	0.00	0.00
113	0.00	0.01
114	0.00	0.00
115	0.00	0.00
116	0.00	0.00
117	0.00	0.00
118	0.00	0.01
120	0.00	0.01
121	0.00	0.00
122	0.70	31.40

M-2: ISI Every 10 Years (cont.)

123	0.00	0.00
124	0.18	8.09
125	0.00	0.00
126	0.00	0.00
127	0.00	0.00
128	0.01	1.69
129	0.00	0.00
130	0.00	0.00
131	0.00	0.00
132	0.00	0.00
133	0.00	0.00
134	0.00	0.00
135	0.07	0.34
136	26.68	7.15
137	30.45	24.43
138	38.82	14.53
139	0.17	2.23
140	0.06	2.68
141	0.09	0.54
142	0.00	0.00
143	0.00	0.00
144	0.64	0.63
145	0.01	0.01

TOTALS 100.00 100.00

DATE: 05 Sep 2005 TIME: 16:14:05