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North Anna 1 & 2
Surry 1 & 2
Duke Energy
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Entergy Nuclear Northeast
Indian Point 2 & 3
Entergy Nuclear South
ANO 2
Waterford 3
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Braidwood 1 & 2
Byron 1 & 2
FirstEnergy Nuclear Operating Co.
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Ringhals 2 – 4
Taiwan Power Co.
Maanshan 1 & 2

October 31, 2003
WOG-03-565

WCAP-16168, Rev. 0
Project Number 694

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Attention: Chief, Information Management Branch,
Division of Program Management

Subject: Westinghouse Owners Group
Transmittal of WCAP-16168 Rev. 0, (Non-Proprietary) "Risk-Informed Extension of Reactor Vessel In-Service Inspection Interval" (MUHP-5097/5098/5099, Tasks 2008/2059)

This letter transmits four (4) copies of WCAP-16168 Rev. 0, (Non-Proprietary), entitled "Risk-Informed Extension of Reactor Vessel In-Service Inspection Interval," dated October 2003. The Westinghouse Owners Group (WOG) is submitting WCAP-16168 Rev. 0 in accordance with the Nuclear Regulatory Commission (NRC) licensing topical report program for review and acceptance for referencing in licensing actions. WCAP-16168 Rev. 0, provides justification to reduce the frequency of application of the current requirements for inspection of ASME Section XI Table IWB-2500-1 Category B-A reactor vessel seam welds, Category B-D reactor vessel nozzle and nozzle inner radius welds, and Category B-J welds at the reactor vessel nozzle by extending the interval between inspections from 10 years to 20 years.

The current requirements for the inspection of reactor vessel pressure-containing welds were originally required by the 1989 Edition of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, as supplemented by NRC Regulatory Guide 1.150. The manner in which these inspections are conducted has been augmented by Appendix VIII of Section XI, 1996 Addenda, as implemented by the NRC in amendment to 10CFR50.55a effective November 22, 1999.

Specific pilot studies have been performed on the Westinghouse and Combustion Engineering NSSS vessel designs. A feasibility study on the Babcock and Wilcox NSSS vessel design has also been performed. The results show that the change in risk associated with eliminating all inspections after the initial 10 year inservice inspection satisfy the guidelines specified in Regulatory Guide 1.174 for an insignificant change in risk for core damage frequency and large early release frequency. This applies for both a 40 year operating license and a 20 year license extension to a 60 year operating license.

Attachment

The WOG requests that the NRC review of WCAP-16168 Rev. 0 be granted a fee waiver pursuant to the provisions of 10 CFR 170.11, specifically:

1. The request is to support NRC generic regulatory improvements (ASME Boiler and Pressure Vessel Code, Section XI/Regulatory Guide 1.150.), in accordance with 10 CFR 170.11(a)(1)(iii).

2. The primary beneficiary of the NRC's review and approval is not limited to the requesting organization (WOG) in accordance with 10 CFR 170.11(a)(1)(iii)(C). All pressurized water reactors licensees (Babcock and Wilcox, Combustion Engineering and Westinghouse) would benefit from the NRC's review and approval.

Consistent with the Office of Nuclear Reactor Regulation, Office Instruction LIC-500, "Processing Request for Reviews of Topical Reports," the WOG requests that the NRC provide target dates for any Request(s) for Additional Information and for issuance of the Safety Evaluation for WCAP-16168 Rev 0. The WOG requests that the NRC complete their review and issue a safety evaluation for WCAP-16168 Rev. 0 by September 30, 2004.

Correspondence related to this transmittal and invoices associated with the review of WCAP-16168 should be addressed to:

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Westinghouse Electric Company
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Please do not hesitate to contact me at 630-657-3897 or Mr. Gordon Bischoff of the Owners Group Program Management Office at 860-731-6200 if you have any questions.

If you require further information, please contact Mr. Jim Molkenthin in the Owners Group Program Management Office at 860-731-6727.

Sincerely,

Frederick P. "Ted" Schiffley, II
Chairman, Westinghouse Owners Group

Enclosure

cc: WOG Steering Committee
WOG Management Committee
WOG Licensing Subcommittee
WOG Materials Subcommittee
WOG Project Management Office
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Westinghouse Non-Proprietary Class 3

WCAP-16168-NP

October 2003

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

Westinghouse Owners Group

CEOG Task 2008, 2059
WOG MUHP-5097, 5098, 5099

Westinghouse

WCAP-16168-NP

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

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October, 2003

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Reviewer: Richard L. Haessler
Reliability and Risk Assessment

Reviewer: Chris L. Hoffmann
Reactor Coolant System Design and Analysis

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Work performed for the Westinghouse Owners Group under WOG Project MUHP-5097, MUHP-5098, MUHP-5099, and CEOG Task 2008, 2059.

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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
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
OD	Outer diameter
ORNL	Oak Ridge National Laboratory
PFM	Probabilistic fracture mechanics
PNNL	Pacific Northwest National Laboratory
POD	Probability of detection
PRA	Probabilistic risk assessment
PT	Liquid penetrant examination

LIST OF ACRONYMS AND ABBREVIATIONS (cont.)

PTS	Pressurized thermal shock
PVRUF	Pressurized Vessel Research User Facility
PWR	Pressurized water reactor
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_{NDT}	Reference nil-ductility transition temperature
RT_{NDT}*	Reference nil-ductility transition temperature (Proposed NRC Embrittlement Metric for PTS Risk)
RV	Reactor vessel
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
UT	Ultrasonic examination
VT	Visual examination
WOG	Westinghouse Owners Group

EXECUTIVE SUMMARY

The current requirements for 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, 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 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, 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, B-D, and B-J RV nozzle welds. Specific pilot studies have been performed on the Westinghouse and Combustion Engineering vessel designs. A feasibility study on the Babcock and Wilcox vessel design has also been performed. 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 insignificant change in risk for core damage frequency (CDF) and large early release frequency (LERF).

This conclusion is applicable to all Westinghouse and Combustion Engineering 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 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], supplemented by the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.150 [2]. The manner in which these examinations are conducted has been augmented by Appendix VIII of Section XI, 1996 Addenda, as implemented by NRC in amendment to 10CFR50.55a effective November 22, 1999 [3]. The industry has expended significant cost and man-rem exposure performing required examinations that have shown no service-induced flaws in the reactor vessel (RV) for ASME Section XI Category B-A, B-D, or B-J RV nozzle welds. The current code criteria for selection of examination areas and frequency of examinations may not be a technically meaningful 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 insignificant 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 2 pilot plant bounding cases based on the calculated difference in frequency of vessel failure. The difference in frequency of vessel failure was evaluated using RG 1.174 [4] 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) [5] that provides the requirements for code users to make use of the generic work to provide the risk-informed insights to increase the inspection interval for pressurized water reactor (PWR) vessels.

2 BACKGROUND

The original objective of the ASME B&PV Code, Section XI [1] ISI program was to assess general overall condition. 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 frequency of examination, i.e., increasing the time interval between inspections.

The original examination interval of 10 years was an arbitrary choice 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 seem to be decreasing in value with increasing industry experience to rely upon. The U.S. Nuclear Regulatory Commission (NRC) has granted a number of exemptions to inspections for other areas and components based on experience and man-rem exposure that could be saved. 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 vessel, which shows that flaws, if they did 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 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 [6] evaluations. An evaluation to identify limiting locations in a typical geometry for a reactor vessel (RV) identified the beltline region as the critical location with respect to the potential to grow 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), contributing to the 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 provide descriptions of the conditions that would contribute to cyclic fatigue. This information provided input for identifying and defining the frequency of occurrence for each of the events that needed to be considered when determining the potential for RV failure from fatigue crack growth.

A technical consideration critical to success was the application of risk-informed assessment techniques to substantiate the deterministic fracture mechanics evaluation. Risk assessment techniques provided a means to quantify and calculate cumulative results from contributing mechanisms and uncertainties associated with the critical parameters. A Monte Carlo approach to probabilistic fracture mechanics (PFM) methodology can be used that considers the distributions and uncertainties in flaw numbers, flaw sizes, fluence, material properties, crack growth rate, residual stresses, and the effectiveness of inspections. The calculated change in the frequency of a vessel failure due to a change in inspection interval 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 [4] and the NRC risk assessment developed in conjunction with the current pressurized thermal shock (PTS) evaluations.

Significant work is on-going in the nuclear industry to investigate impacts from PTS or "off-normal" plant transients that are outside the current design basis but could contribute to vessel failure. 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 plant as the critical industry 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 Oak Ridge National Laboratory (ORNL) for PTS conditions [7].

This report summarizes the results from an evaluation of the extension of the inspection of ASME Section XI [1] 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 more than 20 years. It demonstrates that for pilot plant vessel geometry and fabrication history, any potential change in risk for a flaw to grow to critical size when the inspection interval is extended meets the change in risk evaluation guidelines defined in RG 1.174 [4]. The evaluation documented in this calculation considers FENOC's BV1 as the Westinghouse pilot plant used for this evaluation. NMC's Palisades Plant is the Combustion Engineering (CE) pilot plant used for this evaluation.

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

1. 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 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 [1] has called for inspections of weld areas of vessels and other pressure-containing nuclear system components. Selection was based on areas known to have high-service factors and additional areas to provide a representative sampling for general overall condition. 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 base metal.

Examination Volumes

Initially, for longitudinal and circumferential welds in a vessel shell, Section XI called for 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 50 percent of

the length. The 1977 Edition increased examination of RV welds from 5 or 10 percent of 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 [1] 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 [2]), flaws identified with the original construction have been detected that were acceptable to Section XI requirements. These flaws have been monitored and no growth has been identified. There has been no evidence of in-service flaw initiation in these welds in-service.

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 welds to RV nozzles are also included in this evaluation.

The ultrasonic examinations (UTs) of these RV welds, as of the 1996 Addenda of Section XI (the most recent that has been accepted by NRC), were conducted in accordance with Appendix I, I-2110. This requires Appendix VIII 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 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 code cases applicable to the RV and its piping connections include:

N-481 [8] Deals with cast austenitic pump casings. This was the first example of substituting analysis plus visual examination (VT) for volumetric, for a Class 1 component.

N-560 [9] Permits reduction in examination of Class 1 Category B-J piping welds from 25 to 10 percent, provided a specified risk-importance ranking selection process is followed. Again, a landmark in substantive reduction of an established Class 1 examination.

N-577 [10]
N-578 [11] Provide requirements for risk-informed ISI of Class 1, 2, and 3 piping. The cases provide different methods to achieve the same ends. First use of the plant probabilistic risk assessment (PRA). Both methods have received extensive field trials in the U.S. and in several other countries in Europe and Asia.

N-613 [12] Reduces 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 [13] Permits computational modeling for qualification of nozzle inner radius examination techniques, in lieu of qualification on a multitude of configurations.

N-610 [14] Permits K1r curve in Appendix G, in lieu of K1a curve. Indirectly, this is beneficial to the plant startup curve.

Not all of the changes in Section XI, due to operating considerations, have led to a decrease or elimination in the number of inspections.

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 code cases are limited to those applicable to the RV and its piping connections.

N-409 [15] 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 [16] Provided requirements for assessment of RVs with low upper shelf Charpy impact energy levels.

N-557 [17] 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 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. 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.

Table 2-1 Summary of Survey Results on ISI Findings

No. of Plants	Total Years of Service	Weld Category	No. of Welds in Category	Welds with No Flaws	Welds with Flaws	Means of Detection	Cause of Flaw/Failure
14	301	B-A		All	None		
		Shell, B1.10	112	112	0		
		Head. B1.20	105	105	0		
		Shell-to-flange. B1.30	16	16	0		Ginna reported 3 indications that may be just scratches.
		Head-to-flange, B1.40	16	16	0		Ginna reported 3 indications that may be just scratches.
		Repair welds, beltline B1.50	0	0	0		
		B-D					
		Nozzle-to-shell, B3.90	102	102	0		
		Nozzle inside radius B3.100	102	102	0		
		B-F					
		Dissimilar metal, B.5.10	84	84	0		
		B5.130	32	32	0		
		B-J					
		Piping, B9.10	64	64	0		
		B-K					
		Welded attach, B10.10	4	4	0		
		B-N					

Table 2-1 (cont.) Summary of Survey Results on ISI Findings

No. of Plants	Total Years of Service	Weld Category	No. of Welds in Category	Welds with No Flaws	Welds with Flaws	Means of Detection	Cause of Flaw/Failure
		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		

2.3 EXPOSURE AND COST REDUCTION

Data was gathered on CE- and Westinghouse-design plants related to the cost of a typical RV ISI outage, as well as the cost of the exposure affecting the involved personnel. The objective of this effort was to investigate the financial and exposure aspects of the RV ISI. The results of the survey were tabulated based on the probability of a life extension program, 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.

Table 2-2 Savings on Proposed Extension of RV ISI Interval from 10-Year to Proposed 20-Year Period (Per Plant)

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

The saving values associated with the less conservative assumption of the guaranteed life extension program 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 $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.

2.4 GENERIC REACTOR VESSEL WELD EXPERIENCE AT VARIOUS PLANTS

Section XI ISI requirements developed in the early 1970s were based on 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 assessment of general overall conditions has not been effective; when leakage and other deterioration has been identified, it has been by examinations other than the Section XI ISI non-destructive examination (NDE).

Primary system failures/leakage have almost always been associated with dissimilar metal welds or control rod drive, instrumentation, or vent connections of the RV and its head. The connections are all partial penetration welds. They were not included in the survey since we are not planning to recommend

changes to their present ISI interval requirements. Their examinations are not contingent on removal of reactor internals and use of the RV inspection tool. Dissimilar metal welds were not included as a candidate for inspection interval extension.

In many plants, the most highly stressed 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 contribution to cumulative risk determined through typical PFM methods. Calculations showed 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 PFM analysis of the effect of different inspection intervals on the frequency of vessel failure. Vessel failure is postulated to be more likely with increasing time of operation due to the growth of pre-existing fabrication flaws by fatigue in combination with a decrease in vessel toughness due to irradiation. Credible, postulated accident loads that could potentially lead to vessel failure must be considered to occur at a given 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, residual stresses, and the effectiveness of inspections. The PFM approach leads to a conditional vessel failure frequency due to a given accident loading condition and a prescribed inspection interval. All locations of interest in the vessel can be addressed in a similar way unless a bounding approach can be used to minimize the areas receiving detailed evaluation.

A feasibility study was performed [18] that showed the change in the frequency of vessel failure due to a change in inspection interval can be used to evaluate the acceptability of such an inspection interval change. The impact on plant safety from the change in risk presented in this study was based on current practices and standards for assessment as defined by RG 1.174 [4]. The proposed change in inspection interval was determined to be feasible because no impact on currently defined failure consequences could be identified.

3 PILOT PLANT SUMMARY

The applications summarized in this report utilized the same pilot plants and PTS transient data as used in the NRC PTS effort [7]. 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 plant as the pilot industry plants. These pilot plant applications also used fleet-specific design transient data for the Combustion Engineering (CE) and Westinghouse designs. A generic approach for the Babcock & Wilcox (B&W) feasibility study was used based on a typical generic heatup/cooldown transient. A study was performed to determine the bounding location from among the applicable weld locations on a typical vessel. The results of all of these investigations are included in the following sections.

3.1 BASIS FOR RISK DETERMINATION

As indicated in the recent ASME Code Case N-691 [5], application of risk-informed insights from PFM and risk analyses were used to justify an increase from 10 to 20 years in the requirements of Section XI, IWB-2412 for inspection interval for examination of Category B-A and B-D welds in PWR vessels, and Category B-J welds to the RV nozzles. The regulatory guidelines provided 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

Code Case N-691 [5] 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. Plant PRA models were exercised to define these events. Historically, a small-break loss-of-coolant accident (SBLOCA) with low decay heat has been the major contributor to PTS risk. The sequence of concern was cool-down and depressurization due to the initiating event, followed by repressurization due to high-pressure safety injection, charging, and swell. 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 runaway feedwater, all with reactor coolant pump (RCP) shutdown and multiple failures of the operator to take remedial action.

The pilot plant applications in this report used the accident transients and frequencies from the NRC PTS Risk Study [7] and are considered to be bounding of all design basis transients. These transients are the dominant contributors to PTS risk in that these transients each contribute greater than 1 percent to the total PTS risk. Details of the transients are provided in Appendix D for BV1, and Appendix H for Palisades. As indicated in Appendix A, a comparison of key plant parameters that affect PTS transient severity can be made to demonstrate that the pilot plant analyses are applicable to other plants.

Operational Transients and Cycles

Code Case N-691 [5] 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 [1] 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 envelops 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 both pilot plants is heat-up and cool-down. Each transient represents the 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 respective PWR plant designs in each fleet.

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). 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 may be enveloped.

Initial Flaw Distribution

Code Case N-691 [5] requires a credible flaw distribution for a PWR vessel. Significant work at Pacific Northwest National Laboratory (PNNL) and NRC was performed to more completely specify the initial flaw size distributions and their densities for input into the NRC PTS Risk Study [7]. This same flaw input is used directly for the pilot plant studies in this report.

These densities are input into the PFM analyses as flaw density files, P.dat (plate-embedded flaws) and W.dat (weld-embedded flaws). For the NRC PTS Risk Study [7], the BV1 and Palisades evaluations used multi-pass cladding with no surface breaking flaws. Cladding details are identified in Appendices B and F. For the pilot plant evaluations to bound all the plants of the same design, single-pass cladding was used. These were conservative assumptions. The presence of surface breaking flaws with an initial flaw depth equal to the cladding thickness was postulated. These surface breaking flaws are 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 methodology.

Fluence Distribution

Code Case N-691 [5] 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 license or for license renewal.

For the pilot plant evaluations in this report, the input fluence distributions were taken directly from the NRC PTS Risk Study [7]. The fluence used in the evaluations was for 60 effective full-power years (EFPYs). Representative fluence maps for BV1 and Palisades at 32 EFPY, can be found in Appendices B and F, respectively. While the fluence values on these maps are not the values used in the pilot plant evaluations, the contour of the fluence applies.

Material Fracture Toughness

Code Case N-691 [5] states that the vessel material fracture toughness of the limiting beltline plates and weld materials need to be based on plant-specific data:

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

These vessel material properties for the BV1 and Palisades pilot plants evaluated in this report are identified in Appendices B and F, respectively. One of the vessel properties identified is the embrittlement metric, RT_{NDT}*. This metric is defined in Equation 6-1 of the NRC PTS Risk Study [7] and is a weighted average of the embrittlement in RV beltline regions. For application to other plant vessels, the value of RT_{NDT}* will have to be equal to or less than the values used for pilot plant studies in this report (see Appendix A).

The initial beltline RT_{NDT} data are used with neutron fluence to calculate the shift and irradiated reference temperature as a function of time. The same Eason correlation used in the NRC PTS Risk Study [7] is used to determine the shift for the pilot plants.

The results of the significant work at ORNL, NRC, and industry to more completely specify the distribution on fracture toughness and its uncertainty for the NRC PTS Risk Study [7] are used for the pilot plant studies. This includes the effects of the statistical bias for direct measurement of fracture toughness (Master Curve Method) used in Versions 02.4 [19] and 03.1 of FAVOR [20] and the latest information on irradiated upper shelf fracture toughness used in Version 03.1 of FAVOR [20].

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.

Crack Growth Rate Correlation

Code Case N-691 [5] 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 uncomplicated 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 [1]. These correlations represented the behavior of the ferritic vessel materials for all domestic PWRs. This probabilistic representation was consistent with that used by the NRC-supported pc-PRAISE code [21] and the NRC-approved SRRA tool for piping-risk informed ISI [22].

Cladding and Residual Stresses

Code Case N-691 [5] requires that the residual stress distribution in welds and the cladding stress and its temperature dependence due to differential thermal expansion be considered, including the effects of uncertainties. For the pilot plant studies, the residual stress distribution was taken from the NRC PTS Risk Study [7]. This distribution is shown in Figure 3-1. The cladding stress used in the evaluation was consistent with the NRC PTS Risk Study. The cladding temperature dependence due to differential thermal expansion was based on a stress free temperature of 468°F, consistent with that used in the NRC PTS Risk Study [7].

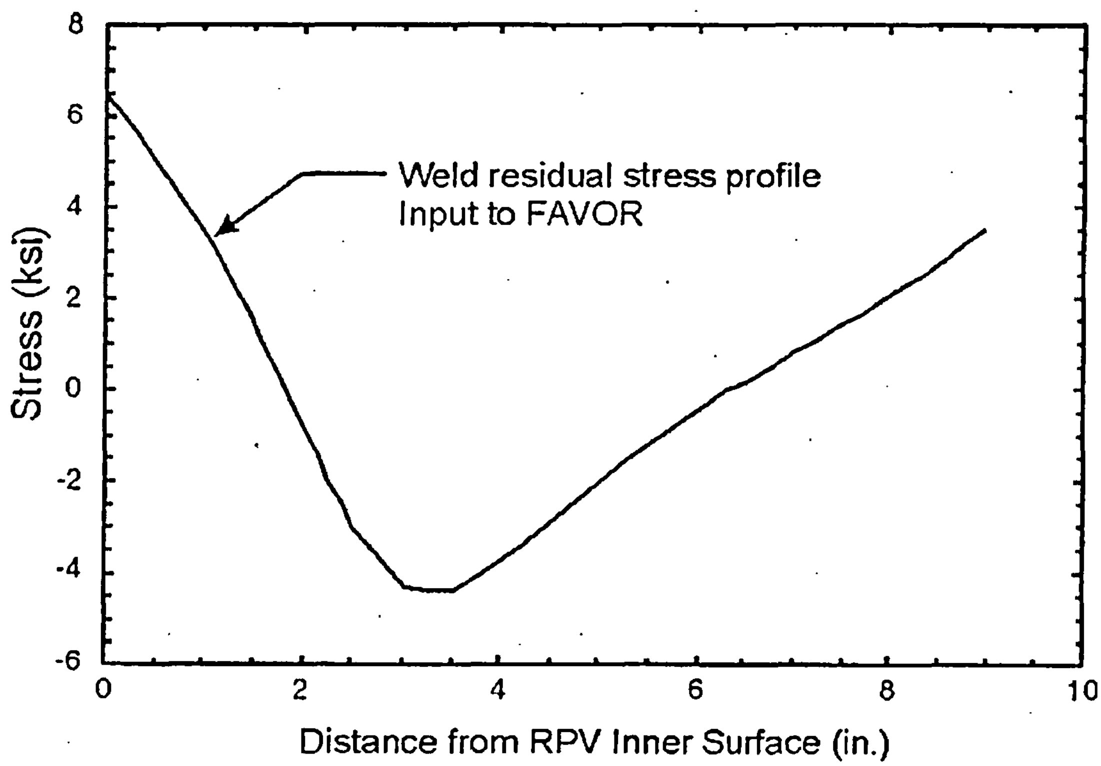

Figure 3-1 Weld Stress Profile

Effectiveness of ISI

The essential requirement for an effective volumetric examination in Code Case N-691 [5] is that it be conducted in accordance with Section XI Appendix VIII [1] or RG 1.150 [2].

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 was taken from studies performed at the EPRI NDE Center on the detection and sizing qualification of ISIs on the RV beltline welds [23]. Figure 3-2 shows the probability of detection with respect to flaw size used in the pilot studies in this report.

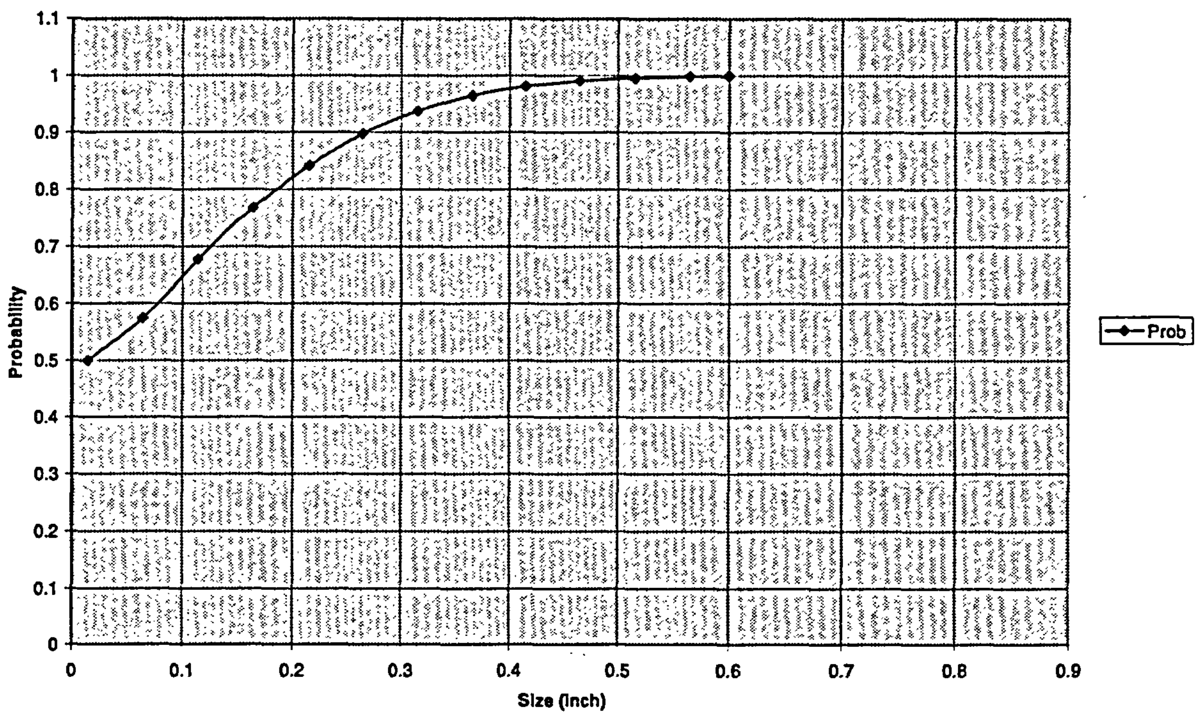

Figure 3-2 ISI Detection Probability

For the pilot plant evaluations, examinations were assumed to be conducted in accordance with Section XI Appendix VIII [1], so that Figure 3-2 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 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 Code Cases have been found that directly overlap the actions included in Code Case N-691 [5], there are related Code Cases and "problem areas" that may affect implementation of the Case. Code Cases that concern reactor vessel inspections but do not affect applicability of the Case are also listed

A Code Case currently in the ASME procedural approval process (BC03-716) 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 [5]. However, these welds are not inspected from inside the RPV and, therefore, there is no impact.

One of Section XI top priority items is to work with the Material Reliability Program Alloy 600 Issue Task Group to identify and incorporate changes needed in 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 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 [5] examinations.

A Code Case currently in the ASME technical approval process (BC02-3483) addresses Examination Category B-K, surface examination of welded attachments. It would permit examination of a single welded vessel attachment each inspection interval. Applicability of Case N-691 [5] to an internal attachment weld is likely but would have to be determined.

N-648-1 [24] permits a VT-1 visual examination of a reactor vessel nozzle inner radius in lieu of volumetric examination. Applicability of this Case would not be affected by the increased examination interval.

Case N-624 [25] provides for modification of the sequence of successive examinations. The increased examination interval would be applicable.

Case N-623 [26] 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 [5] would not be affected by application of this Case.

Case N-615 [27] permits ultrasonic examination as a surface examination method for Category B-F and B-J piping welds 4" Nominal Pipe Size and larger. It would be compatible with the increased examination interval.

Case N-613-1 [28] reduces the nozzle weld examination volume of Examination Category B-D. It would be compatible with the increased examination interval.

Case N-598 [29] provides alternatives to the required percentages of examinations each inspection period. Case N-691 [5] 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 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 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, BV1 does not have Category B-J welds 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 not impacted by the proposed extended inspection interval.

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 versions (02.4 and 03.1) of the FAVOR code [19, 20]. The Fracture Analysis of Vessels – Oak Ridge (FAVOR) computer program was developed as part of the NRC PTS Risk Study [7]. It is a program that performs a probabilistic analysis of a nuclear reactor pressure vessel when subjected to an event 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 3-3. In the NRC PTS Risk Study [7], 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 3-3.

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 inner surface-breaking flaw geometries (both infinite and finite-length).

The FAVPFS module in Figure 3-3 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. This FAVOR module uses the input flaw distributions (e.g., S.dat, W.dat, and P.dat), the loads for the dominant PTS events from the FAVLOAD module and fluence/chemistry input data at 60 EFPYs (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 vessel crack initiation and vessel failure. This module also generates statistical information on these distributions and the distributions for the conditional probabilities of vessel crack initiation and failure for each PTS transient included in the risk analysis.

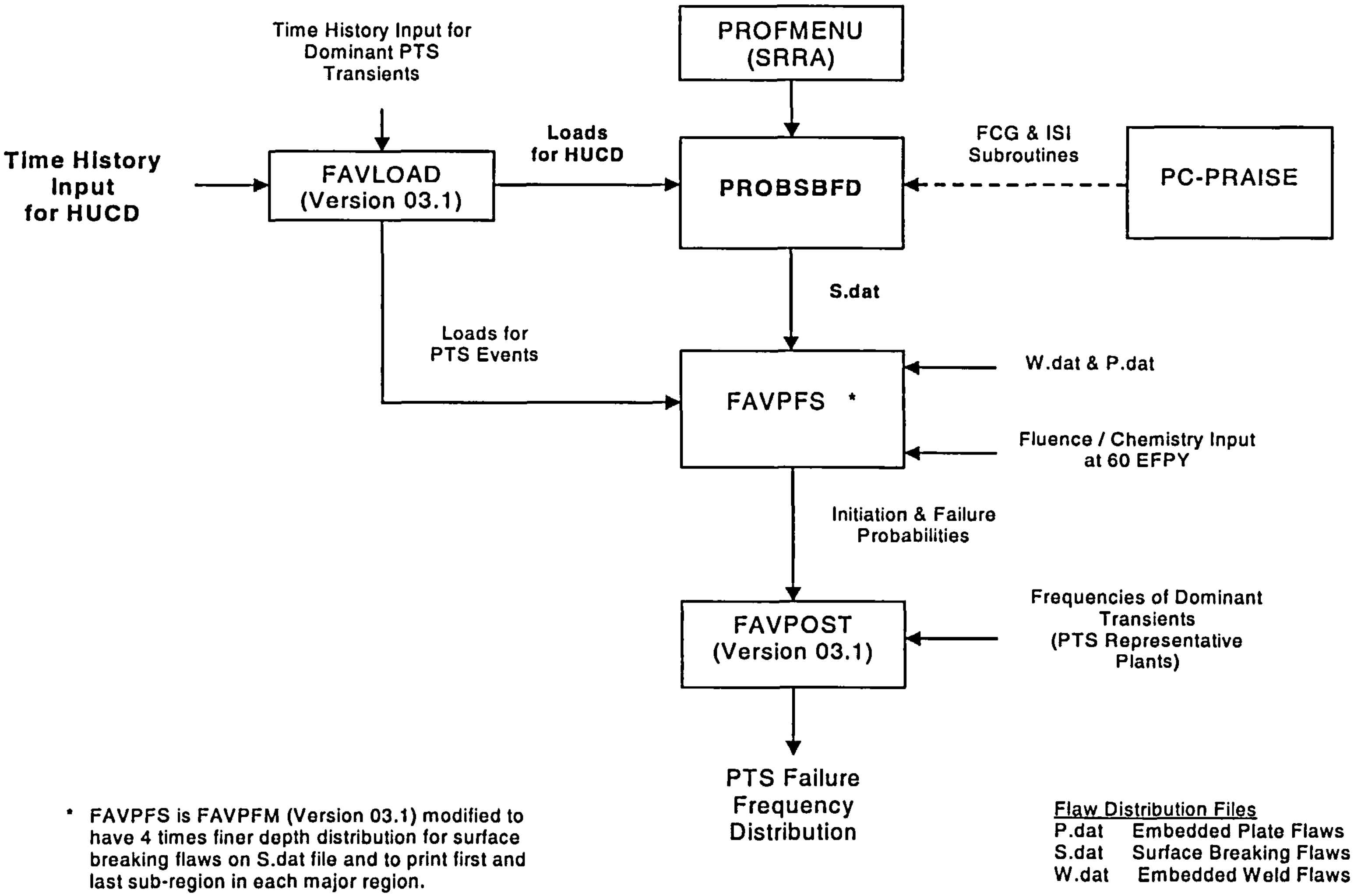

Figure 3-3 Software and Data Flow for Pilot Plant Analyses

It should be noted that the calculations for the pilot plant studies were originally performed using FAVOR Version 02.4 [19]. These calculations were repeated using FAVOR Version 03.1 [20]. The results from both versions are provided in this report.

The PROBSBFD code was specifically developed for the RV ISI interval extension project and verified in accordance with the Westinghouse Quality Assurance requirements. The source code for PROBSBFD is listed in Appendix J. This program calls the Westinghouse 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, but 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 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 [21] and the SRRA Code [22] 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 3-2), 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 3-3).

3.2 BOUNDING LOCATION

The focus of the evaluations for impact of vessel extension were assumed to be centered on the beltline of the RV. To confirm that the beltline location represented the bounding location for the vessel, all locations currently required for examination in the reactor pressure vessel (RPV) needed to be identified and considered. The beltline location was looked at as being the bounding location primarily due to irradiation induced change in the fracture toughness of the beltline materials. This was consistent with the location assumptions used to support the NRC PTS Risk Study [7]. Table 3-1 summarizes the current ASME B&PV Code, Section XI [1] ISI requirements for RPV inspection.

Table 3-1	Section XI ISI Requirements for RPVs		
	Item No.	**RPV Location**	**Examination Requirement**
		Pressure Retaining Welds in Reactor Vessel	
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	Volumetric
B-A	B1.50	Repair Welds	Volumetric
B-A	B1.51	Beltline Region	Volumetric
		Full Penetration Welded Nozzles in Vessels	
B-D	B3.90	RPV Nozzle-to-Vessel Welds	Volumetric
B-D	B3.100	RPV Nozzle Inside Radius Section	Volumetric
		Pressure Retaining Dissimilar Metal Welds in Vessel Nozzles	
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
		Pressure Retaining Welds in Piping	
B-J	B9.10	NPS 4 or Larger	Surface and Volumetric
B-J	B9.11	Circumferential Welds	Surface and Volumetric
		Welded Attachments for Vessels, Piping, Pumps and Valves	
B-K	B10.10	Welded Attachments	Surface
		Interior of Reactor Vessel	
B-N-1	B13.10	Vessel Interior	Visual, VT-3
		Welded Core Support Structures and Interior Attachments to Reactor Vessels	
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
		Removable Core Support Structures	
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 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

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

1. Select first inspection interval, I1, based on growth of assumed initial flaw to a fraction of the tolerable flaw size.
2. Perform inspection. If no defects larger than assumed flaw size are found, second inspection interval, I2, 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 3-4 and 3-5. Inspection intervals were based on 10-, 20-, 30-, or 40-year inspection intervals over a 40-year plant life. Each 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], 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 3-4 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 3-4 and 3-5 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.

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.

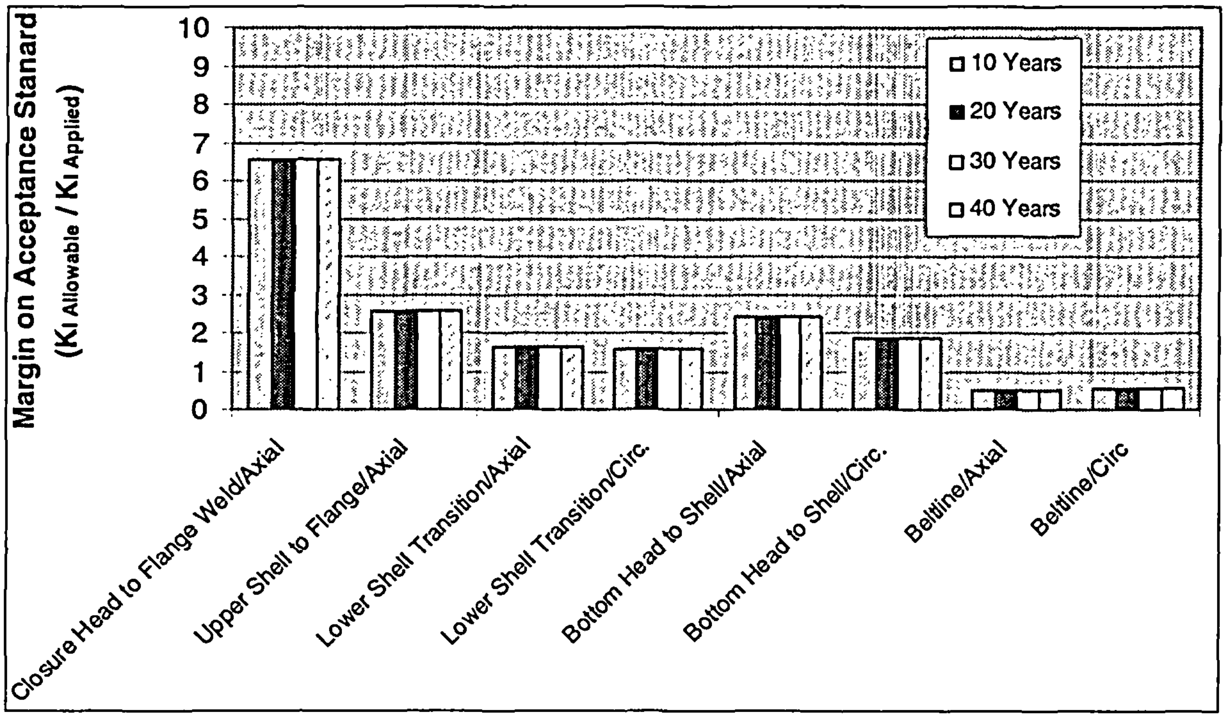

Figure 3-4 Comparison to Acceptance Criteria – Minimum Margins Code Allowable

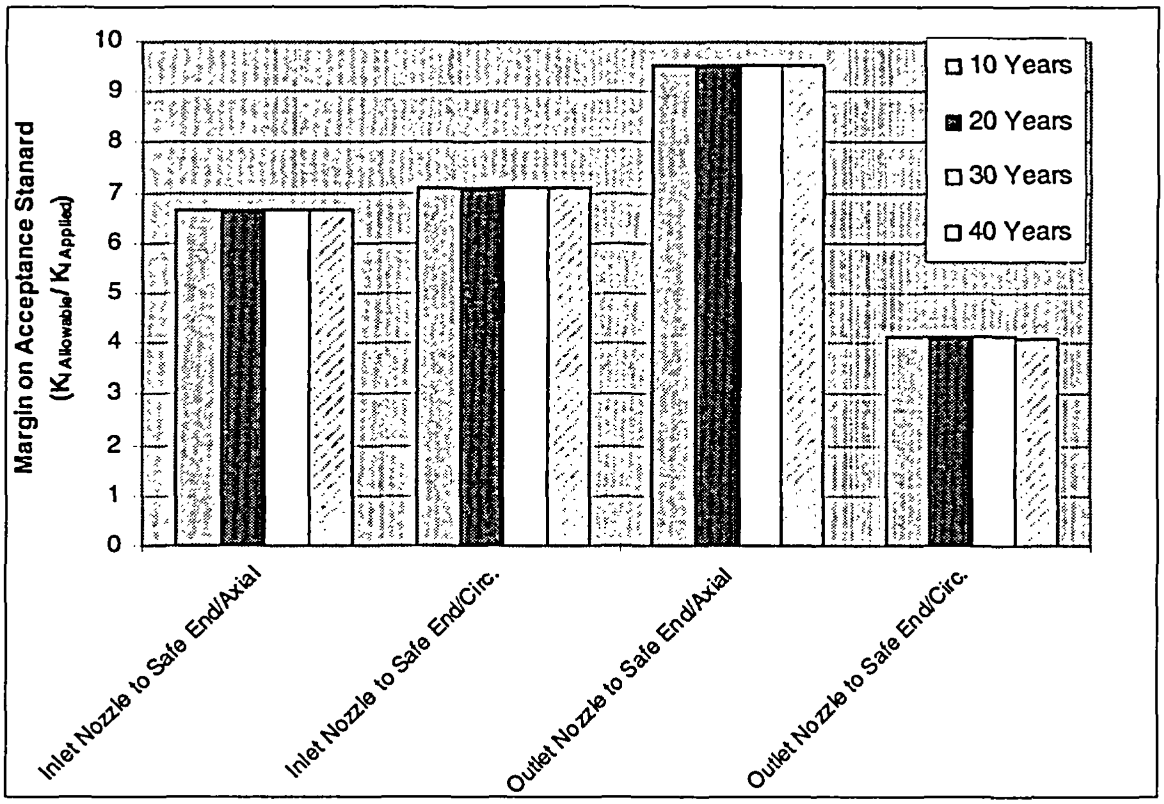

Figure 3-5 Comparison to Acceptance Criteria – Minimum Margins Code Allowable

3.3 RESULTS FOR WESTINGHOUSE DESIGN PILOT PLANT: BV1

Elimination of ISI after the first 10-year ISI for the BV1 RPV results in a difference in failure (through-wall flaw) frequency of 3.11E-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 potential change in risk at a number of vessel simulations at which a stable solution was reached. The change in failure frequency was calculated based on the difference between the "Upper Bound" and "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. The difference between the Upper Bound and Lower Bound represents the maximum 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. The Monte Carlo statistical analysis had reached a stable state at this number if iterations. 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 [7]. The input data included consideration of postulated life extension to 60 EFPYs. 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 and the RI-ISI piping program is not impacted by the extended inspection interval.

Table 3-2 BV1 Vessel Frequency Results

	FAVOR 02.4 (25,000 Simulations)	FAVOR 03.1 (30,000 Simulations)
Upper Bound	9.40E-09	8.22E-09
10-Year ISI Only	7.85E-09	7.18E-09
10 Every 10 Years	7.11E-09	6.71E-09
Lower Bound	5.96E-09	5.11E-09
Difference in Risk	3.44E-09	3.11E-09

The effects of fatigue crack growth and ISI on the surface breaking flaw density 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 aspect ratio sizes of 10 and infinite. 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.

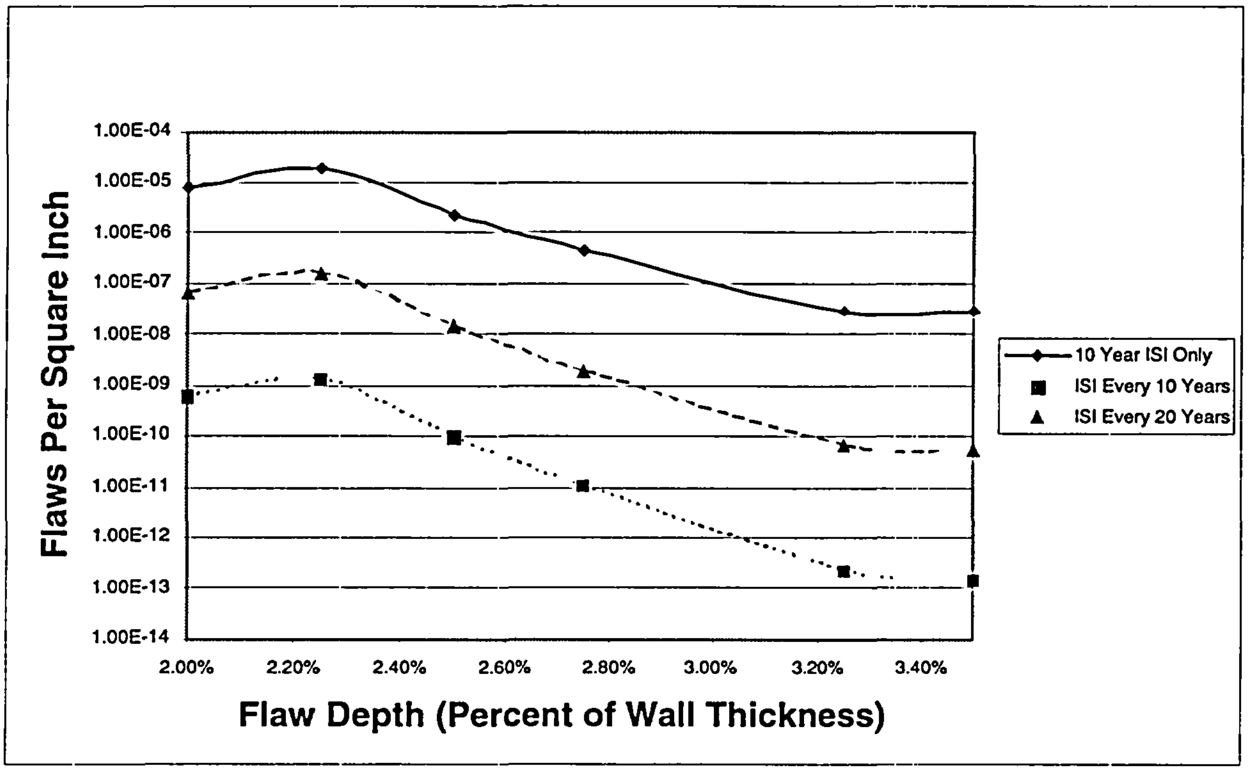

Figure 3-6 Flaw Growth of Flaws with an Aspect Ratio of 10

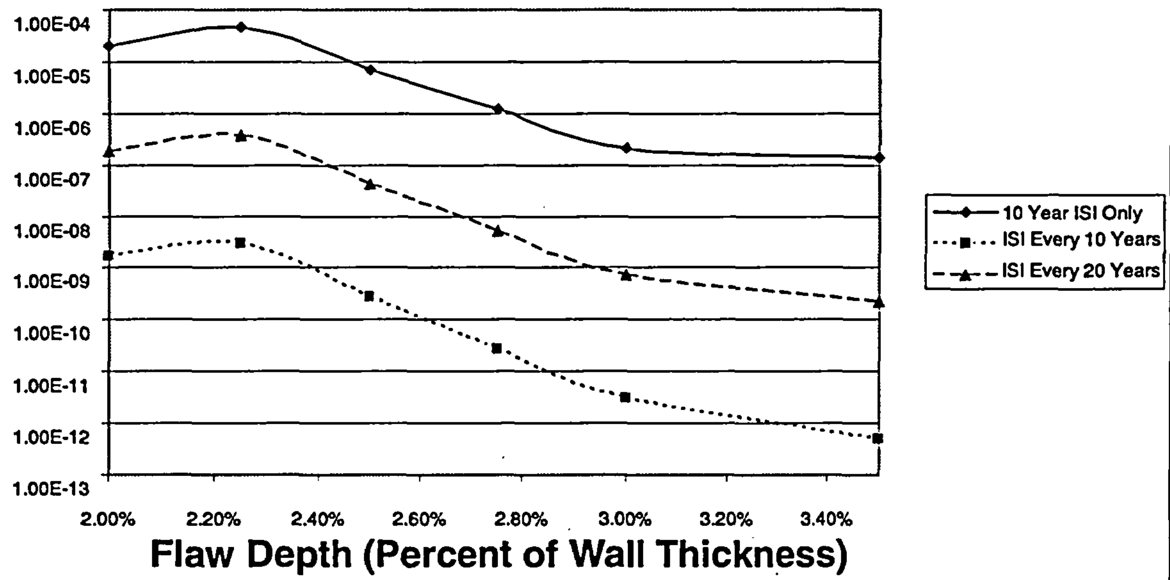

Figure 3-7 Flaw Growth of Flaws with an Infinite Aspect Ratio

3.4 RESULTS FOR COMBUSTION ENGINEERING PILOT PLANT: PALISADES

Elimination of ISI after the first 10-year ISI for the Palisades RPV results in a difference in failure (through-wall flaw) frequency of 2.62E-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 potential change in risk at a number of vessel simulations at which a stable solution was reached. The change in failure frequency was calculated based on the difference between the "Upper Bound" and "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. The difference between the Upper Bound and Lower Bound represents the maximum 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. The Monte Carlo statistical analysis had reached a stable state at this number of iterations. 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. The input data included consideration of postulated life extension to 60 EFPYs. 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-J welds were not inspected as part of Palisades RI-ISI piping program and are therefore not impacted by the extended inspection interval.

Table 3-3 Palisades Vessel Failure Frequency Results		
	FAVOR 02.4 (13,000 Simulations)	FAVOR 03.1 (30,000 Simulations)
Upper Bound	6.38E-08	4.95E-09
10-Year ISI Only	5.36E-08	3.93E-08
10 Every 10 Years	4.60E-.08	3.58E-08
Lower Bound	3.76E-08	2.81E-08
Difference in Risk	2.62E-08	2.14E-08

The effects of fatigue crack growth and ISI on the surface breaking flaw density 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 aspect ratio sizes of 10 and infinite. 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.

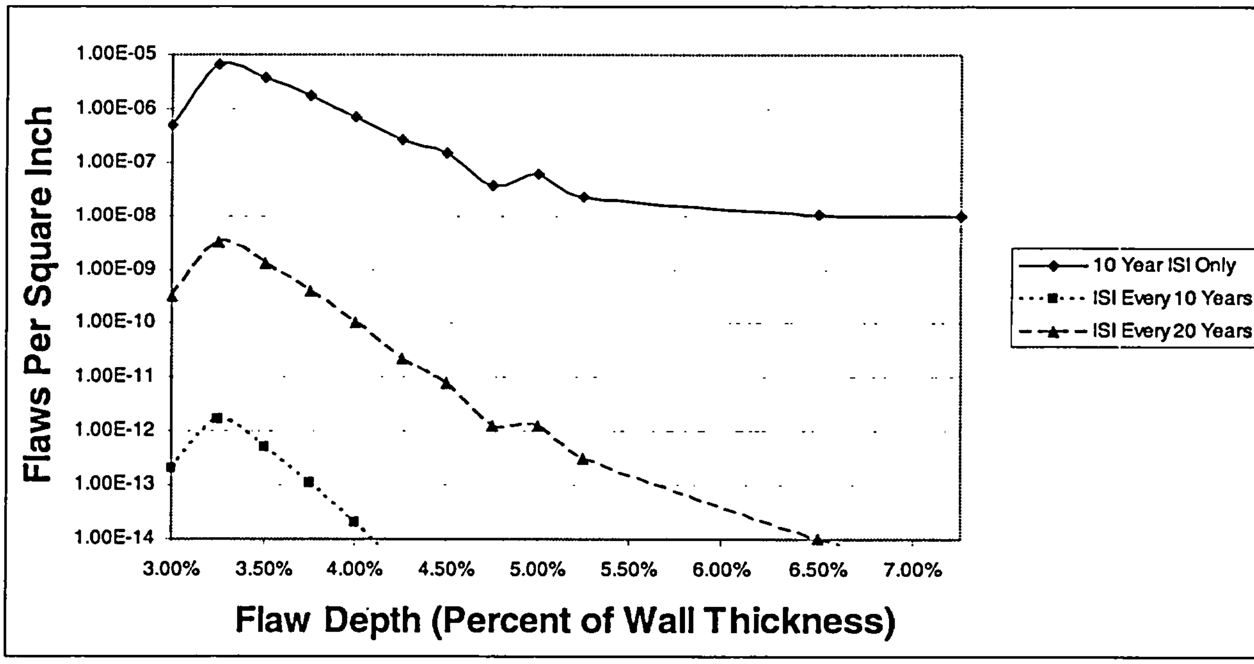

Figure 3-8 Flaw Growth of Flaws with an Aspect Ratio of 10

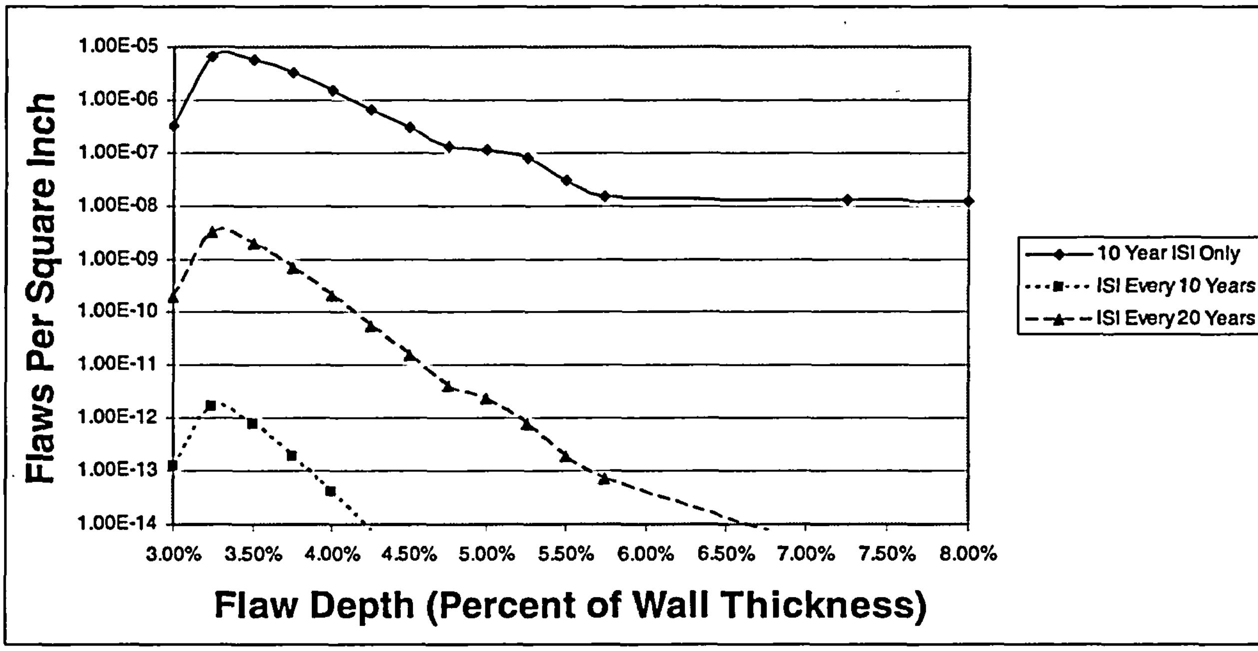

Figure 3-9 Flaw Growth of Flaws with an Infinite Aspect Ratio

3.5 FEASIBILITY FOR BABCOCK AND WILCOX DESIGN PILOT PLANT: OCONEE

The feasibility of eliminating an ISI after the first 10-year ISI for the Oconee plant relative to an insignificant change in risk was also investigated. PTS transient and material property input were based on the inputs used in the NRC PTS Risk Study [7] for 60 EFPY. A generic curve for heat-up/cool-down was used with an assumed number of cycles. The input data included consideration of postulated life extension to 60 EFPYs of embrittlement and 80 years of operation. Additional evaluation using B&W plant-specific duty-cycle inputs would likely confirm that the methodology proposed in this report would apply to the B&W vessel design.

4 RISK ASSESSMENT

The quantitative risk assessment discussed below shows that extending the inspection interval from 10 to a maximum of 20 years has negligible 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 [4]. 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* [4]. In addition, the NRC issued application-specific RGs and Standard Review Plans (SRPs):

- RG-1.175 [30] and SRP Chapter 3.9.7, related to in-service testing (IST) programs
- RG-1.176 [31], related to Graded Quality Assurance (GQA) programs
- RG-1.177 [32] and SRP Chapter 16.1, related to Technical Specifications
- RG-1.178 [33] 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.

<u>Step 1: Define the Proposed Change</u>

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.

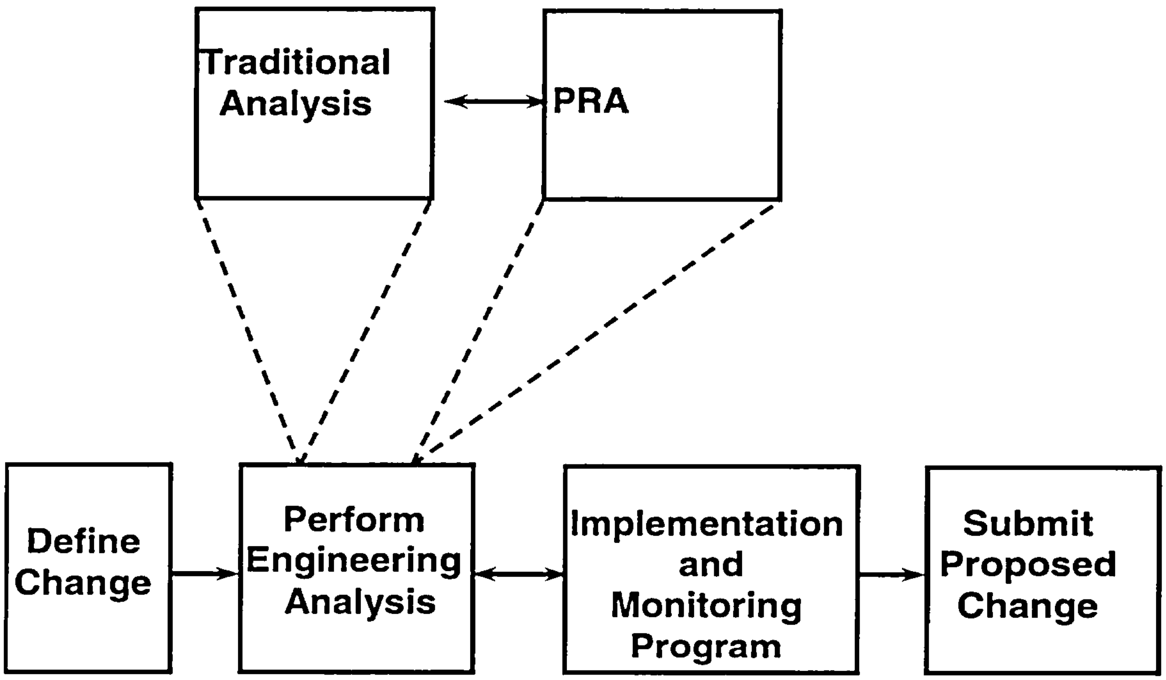

Figure 4-1 Basic Steps in (Principal Elements of) Risk-Informed, Plant-Specific Decision Making (from NRC RG 1.174)

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.

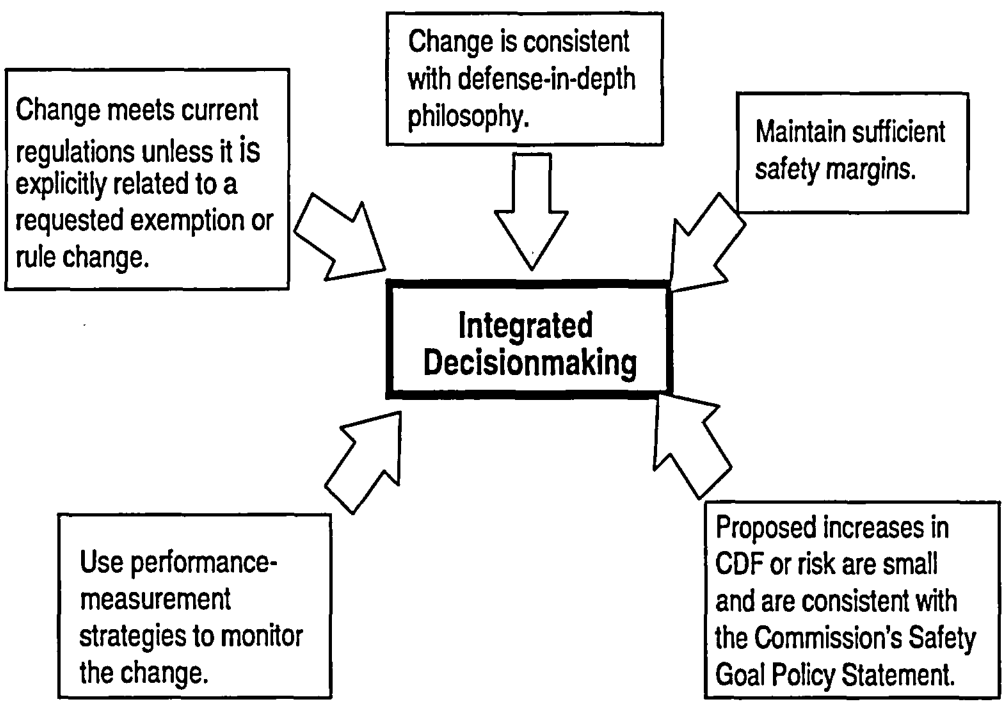

Figure 4-2 Principles of Risk-Informed Regulation (from NRC RG 1.174)

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 [4], 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 < 1×10^{-6} per reactor year
- Change in LERF < 1×10^{-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 vessel failure, and that 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:

Change in CDF	≡	Increase in frequency of through-wall crack growth due to increase in inspection interval	<	1×10^{-7} 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-induced flaw in the RV base metal, cladding, or weld metal was assumed to reach a critical size that would lead to 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 [4] 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:

$$CDF = LERF = IE * CPF$$

where:

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 vessel failure

The transient initiating frequency distributions were identified in the NRC PTS Risk Study [7]. The probability of failure was calculated by the FAVPFS module of FAVOR. The FAVPOST module of FAVOR multiplied the transient initiating frequency distribution by the vessel failure probability to determine a vessel failure frequency distribution for each transient. From these failure frequency

distributions, FAVPOST determined a mean 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 vessel failure frequency was determined by subtracting the Lower Bound from the Upper Bound. The mean vessel failure frequencies, Upper and Lower Bounds, and change in failure frequency are given in Sections 3.2 and 3.3. As previously stated, vessel failure results in core damage and, therefore, the core damage frequencies were equal to the vessel failure frequencies. The core damage frequencies, Upper and Lower Bounds, and change in core damage frequency are summarized in Table 4-1, based on FAVOR 03.1 evaluations.

Table 4-1 Core Damage Frequencies

	Palisades (per year)	BV1 (per year)
Upper Bound	4.95E-08	8.22E-09
10-Year ISI Only	3.93E-08	7.18E-09
ISI Every 10 Years	3.58E-08	6.71E-09
Lower Bound	2.81E-08	5.11E-09
Change in Core Damage Frequency	2.14E-8	3.11E-09

Risk Results and Conclusions

The analysis described above demonstrates that CDF, LERF, and changes in risk would not exceed the NRC's guidelines for insignificant change in RG-1.174 [4] ($<10^{-6}$ 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 a significant 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.

Table 4-2 Evaluation with Respect to Regulatory Guide 1.174 [4] Key Principles	
Key Principles	**Evaluation Response**
Change meets current regulations unless it is explicitly related to a requested exemption or rule change.	Change to current RG 1.150 [2] requirements is proposed.
Change is consistent with defense-in-depth philosophy.	Potential for failure of the RV is negligible during normal or accident conditions, and does not threaten plant barriers. See 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 negligible.
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

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 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.

Lastly, while the results presented in this report demonstrate that the contribution of eliminating future inspections 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.

5 CONCLUSIONS

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

1. The beltline is the most limiting region for evaluation of risk.
2. RV inspections performed to date have detected no service-induced flaws.
3. Crack extension due to FCG during service is small.
4. The man-rem exposure can be reduced through the extension of the inspection interval.
5. The failure frequencies for PWR RVs due to the dominant PTS transients are below 10^{-7} per year.
6. The change in risk is insignificant per the RG 1.174 [4] CDF and LERF acceptability guidelines.
7. The decrease in the RV ISI frequency 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 [1] 10-year inspection interval for Examination Categories B-A and B-D welds in PWR RVs and Category B-J welds to those RV nozzles, can be extended to 20 years. In-service inspection intervals of 20 years for FENOC's Beaver Valley Unit 1 and NMC's Palisades are acceptable for implementation. The methodology in WCAP-16168-NP 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 Code Case N-691.

6 REFERENCES

1. *ASME Boiler and Pressure Vessel Code,* Section XI, 1989 Edition with the 1989 Addenda up to and including the 2003 Addenda, American Society of Mechanical Engineers, New York.

2. NRC Regulatory Guide 1.150, *Ultrasonic Testing of Reactor Vessel Welds During Preservice and Inservice Examinations,* June 1981.

3. 10CFR50.55a, *Codes and Standards,* 36 FR 11424, June 12, 1971.

4. NRC Regulatory Guide 1.174, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis,* July 1998.

5. *ASME Boiler and Pressure Vessel Code,* Code Case N-691, "Application of Risk-Informed Insights to Increase the Inspection Interval for Pressurized Water Reactor Vessels," Section XI, Division 1, approval pending.

6. *ASME Boiler and Pressure Vessel Code,* Section III, Appendix G, 2001 Edition, American Society of Mechanical Engineers, New York.

7. 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.

8. *ASME Boiler and Pressure Vessel Code,* Code Case N-481, " Alternative Examination Requirements for Cast Austenitic Pump Casings," Section XI, Division 1, March 5, 1990

9. *ASME Boiler and Pressure Vessel Code,* Code Case N-560, "Alternative Examination Requirements for Class 1, Category B-J Piping Welds," Section XI, Division 1, August 9, 1996.

10. *ASME Boiler and Pressure Vessel Code,* Code Case N-577, "Risk-Informed Requirements for Class 1, 2, and 3 Piping, Method A," Section XI, Division 1, September 2, 1997.

11. *ASME Boiler and Pressure Vessel Code,* Code Case N-578, "Risk-Informed Requirements for Class 1, 2, and 3 Piping, Method B," Section XI, Division 1, September 2, 1997.

12. *ASME Boiler and Pressure Vessel Code,* Code Case N-613, "Ultrasonic Examination of Full Penetration Nozzles in Vessels, Examination Category B-D Item No's B3.10 and B3.90, Reactor Vessel-To-Nozzle Welds, Fig. IWB-2500-7 (a), (b), and (c)," Section XI, Division 1, July 30, 1998.

13. *ASME Boiler and Pressure Vessel Code,* Code Case N-552, "Alternative Methods – Qualification for Nozzle Inside Radius Section from Outside Surface," Section XI, Division 1, December 12, 1995.

14. *ASME Boiler and Pressure Vessel Code,* Code Case N-610, "Alternative Reference Stress Intensity Factor (KIR) Curve for Class Components," Section III, Division 1, July 30, 1998.

15. *ASME Boiler and Pressure Vessel Code*, Code Case N-409, "Procedure and Personnel Qualification for Ultrasonic Detection and Sizing of Intergranular Stress Corrosion Cracking in Austenitic Piping Welds," Section XI, Division 1, December 5, 1984.

16. *ASME Boiler and Pressure Vessel Code*, Code Case N-512, "Assessment of Reactor Vessels with Low Upper Shelf Charpy Impact Energy Levels," Section XI, Division 1, February 12, 1993.

17. *ASME Boiler and Pressure Vessel Code*, Code Case N-557, "In-Place Dry Annealing of a PWR Nuclear Reactor Vessel," Section XI, Division 1, March 19, 1996.

18. WCAP-15912, Extension of Inservice Inspection Interval for PWR Reactor Vessels, November 2002.

19. *Fracture Analysis of Vessels – Oak Ridge FAVOR, v02.4, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations*, issued by Oak Ridge National Laboratory, November 22, 2002.

20. *Fracture Analysis of Vessels – Oak Ridge FAVOR, v03.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations*, issued by Oak Ridge National Laboratory, August 29, 2003.

21. NUREG-CR/5864, Theoretical and User's Manual for pc-PRAISE, *A Probabilistic Fracture Mechanics Computer Code for Piping Reliability Analysis*, 1999.

22. WCAP-14572 Supplement 1, *Westinghouse Structural Reliability and Risk Assessment (SRRA) Model for Piping Risk-Informed In-Service Inspection*, Rev. 1-NP-A, February 1999.

23. BWRVIP-108: *BWR Vessel and Internals Project, Technical Basis for the Reduction of Inspection Requirements for the Boiling Water Reactor Nozzle-to-Vessel Shell Welds and Nozzle Blend Radii*, EPRI, Palo Alto, CA 1003557, 2002.

24. Code Case N-648, Alternative Requirements for Inner Radius Examination of Class 1 Reactor Vessel Nozzles, Section XI, Division 1, 2001.

25. Code Case N-624, Successive Inspections, Section XI, Division 1, 1998.

26. 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.

27. Code Case N-615, Ultrasonic Examination as a Surface Examination Method for Category B-F and B-J Piping Welds.

28. 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.

29. Code Case N-598, Alternative Requirements to Required Percentages of Examinations, Section XI, Division 1, 1995.

30. NRC Regulatory Guide 1.175, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Inservice Testing*, August 1998.

31. NRC Regulatory Guide 1.176, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Graded Quality Assurance*, August 1998.

32. NRC Regulatory Guide 1.177, *An Approach for Plant-Specific, Risk-Informed Decisionmaking: Technical Specifications*, August 1998.

33. NRC Regulatory Guide 1.178, *An Approach for Plant-Specific, Risk-Informed Decisionmaking Inservice Inspection of Piping*, August 1998.

APPENDIX A
BOUNDING PARAMETER CHECKLIST

WCAP-16168-NP 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, 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.

Table A-1 Critical Parameters for Application of Bounding Analysis

Parameter	Pilot Plant Basis	Plant Specific Basis	Additional Evaluation Required? (Y/N)
Dominant PTS Transients in the NRC PTS Risk Study are applicable			
Degree of Reactor Vessel Embrittlement (RT_{NDT}*)			
Frequency and Severity of Design Basis Transients			
Cladding Layers (Single/Multiple)			

Table A-2 Additional Information Pertaining to Reactor Vessel Inspection

Inspection methodology:	
Number of past inspections:	
Number of indications found:	
Proposed inspection schedule for balance of plant life:	

APPENDIX B
INPUTS FOR BEAVER VALLEY UNIT 1 PILOT PLANT EVALUATION

A summary of the NDE inspection history based on ASME Section XI Appendix VIII 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, B-D, and B-J vessel welds assuming all of the candidate welds were inspected: 2 (covering all welds of the specified categories).

2. The inspections performed covered 100 percent of all welds.

3. Number of indications found to date: 0
   This number includes consideration of the following additional information.

   a. Indications found that were reportable
   b. Indications found that were within acceptable limits
   c. Indications/anomalies currently being monitored

4. Full penetration relief requests for the RV submitted and accepted by the NRC: 0

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 [7], Figure 4.2.

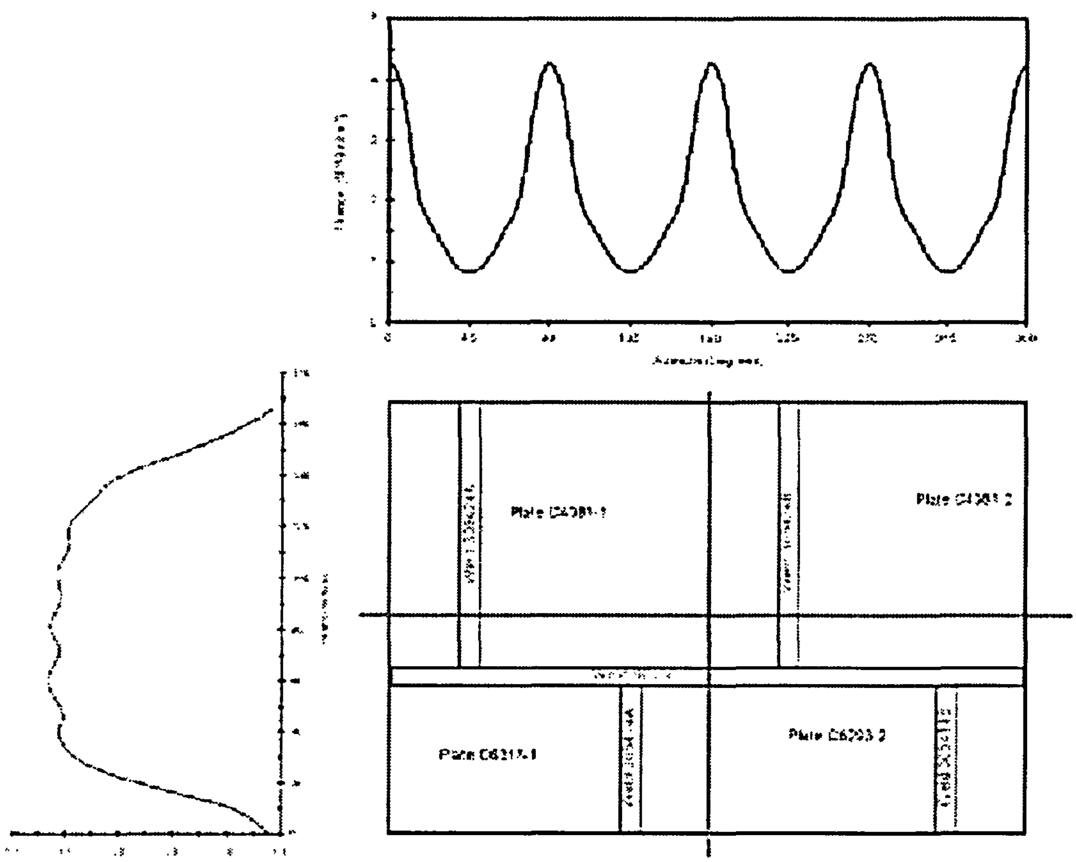

Figure B-1 Rollout Diagram of Beltline Materials and Representative Fluence Maps for BV1

6. Vessel cladding details:

   a. Thickness: 0.156 inches

   b. Material properties (assumed to be independent of temperature):

      1) Thermal conductivity (Btu/hr-ft-°F), K=10.0
      2) Specific heat (Btu/LBM-F),C=0.120
      3) Density (LBM/ft^3).RHO=489.00
      4) Young's Modulus of Elasticity (KSI), E=22800
      5) Thermal expansion coefficient (°F^{-1}), ALPHA=0.00000945
      6) 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-1. This is consistent with the NRC PTS Risk Study [7].

   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 vessel failure probabilities.

      2) Truncation limit: Cladding thickness rounded to the next 1/100th of the total vessel thickness to be consistent with the NRC PTS Risk Study [7].

      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 vessel are brittle. This is consistent with the NRC PTS Risk Study [7].

   e. Additional cladding properties are identified in Table B-2.

7. Base metal:

   a. Wall thickness: 7.875 inches

   b. Material properties (assumed to be independent of temperature):

      1) Thermal conductivity (Btu/hr-ft-°F), K=24.0
      2) Specific heat (Btu/LBM-°F),C=0.120
      3) Density (LBM/ft^3).RHO=489.00
      4) Young's Modulus of Elasticity (KSI), E=28000
      5) Thermal expansion coefficient (°F^{-1}), ALPHA=0.00000777

6) Poisson's Ratio, V=0.3
7) Other material properties are identified in Table B-1

Table B-1 BV1-Specific Material Values Drawn from the RVID (see Ref. 7, Table 4.1)

Major Material Region Description				Cu	Ni	P	Un-Irradiated RT_{NDT}		RTPTS
#	Type	Heat	Location	[wt%]	[wt%]	[wt%]	[°F]	Method	@60 EFPY
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. The RT_{NDT}* screening criteria determined in the NRC PTS Risk Study [7] for a plant life of 60 EFPY is: 181.5°F

9. Weld metal details: Details of information used in addressing weld-specific information are taken directly from the NRC PTS Risk Study [7], Table 4.2. Summaries are reproduced as Table B-2.

Table B-2 Summary of 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	[in]	0.1875	0.1875	0.1875	0.1875	All plants report plant specific dimensions of 3/16-in.
	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-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

	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-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

	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	[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-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

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 1/100th 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 1/100th of the total vessel wall thickness.				Judgment.

Table B-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

	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.

APPENDIX C
BEAVER VALLEY UNIT 1 PROBSBFD OUTPUT

C-1: 10 Year ISI Only

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

============================================================================
      INPUT VARIABLES FOR CASE  2: BV1 RPV 7HUCD/YR 10YR ISI AND NONE

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

    VARIABLE        DISTRIBUTION      MEDIAN      DEVIATION    SHIFT   USAGE
   NO.   NAME       TYPE     LOG       VALUE      OR FACTOR    MV/SD   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 -    7.0000D+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 -    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 -    3.0283D+01                          2  FMD
   18  Percent3     - CONSTANT -    3.9086D+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    2.75388D+00    1.26149D+01
    1.47862D-01    3.68549D+00    1.70791D+01
    4.01800D-01    1.17003D+01    1.60380D+01
    6.02700D-01    1.42758D+01    1.89171D+01
    8.03600D-01    1.62658D+01    2.10395D+01
    1.60720D+00    1.68800D+01    2.39186D+01
    2.41080D+00    1.21106D+01    2.22465D+01
    4.01800D+00    2.48084D+00    2.19076D+01
```

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

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.03600D-02	4.13997D+00	1.90363D+01
1.47862D-01	5.65483D+00	2.62610D+01
4.01800D-01	1.71854D+01	2.52432D+01
6.02700D-01	2.12058D+01	2.89109D+01
8.03600D-01	2.46603D+01	3.26997D+01
1.60720D+00	3.00165D+01	4.00498D+01
2.41080D+00	2.64833D+01	4.09880D+01
4.01800D+00	1.74031D+01	4.32676D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.03600D-02	4.53592D+00	2.08688D+01
1.47862D-01	6.04563D+00	2.80832D+01
4.01800D-01	1.82882D+01	2.73290D+01
6.02700D-01	2.24850D+01	3.09015D+01
8.03600D-01	2.62390D+01	3.49861D+01
1.60720D+00	3.30161D+01	4.37237D+01
2.41080D+00	3.12498D+01	4.71146D+01
4.01800D+00	2.27134D+01	5.17890D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.03600D-02	5.88909D+00	2.12716D+01
1.60720D-01	9.12149D+00	2.75411D+01
2.41080D-01	1.36474D+01	2.62813D+01
4.01800D-01	1.92266D+01	2.86458D+01
6.02700D-01	2.47758D+01	3.32825D+01
8.03600D-01	2.87788D+01	3.77081D+01
1.60720D+00	3.81454D+01	5.03759D+01
2.41080D+00	3.87355D+01	5.75556D+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	4.4164D-04	7.7531D-05	7.5875D-06	2.0216D-05
9	4.3869D-07	1.4384D-04	1.9887D-05	4.5952D-05
10	0.0000D+00	1.2013D-05	2.3550D-06	6.9747D-06
11	0.0000D+00	1.5939D-06	4.3982D-07	1.2244D-06
12	0.0000D+00	2.2290D-07	0.0000D+00	2.1327D-07
13	0.0000D+00	2.2085D-07	2.8487D-08	0.0000D+00
14	0.0000D+00	0.0000D+00	2.8185D-08	1.3687D-07

C-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: BV1 RPV WITH 7 HUCD/YR & 10/10 YR ISI

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

    VARIABLE        DISTRIBUTION       MEDIAN      DEVIATION    SHIFT    USAGE
   NO.   NAME       TYPE      LOG      VALUE       OR FACTOR    MV/SD   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 -     6.0000D+00                           2  SSC
   10  Aspect3      - CONSTANT -     1.0000D+01                           3  SSC
   11  Aspect4      - CONSTANT -     9.9000D+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 -     3.0283D+01                           2  FMD
   18  Percent3     - CONSTANT -     3.9086D+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    2.75388D+00    1.26149D+01
    1.47862D-01    3.68549D+00    1.70791D+01
    4.01800D-01    1.17003D+01    1.60380D+01
    6.02700D-01    1.42758D+01    1.89171D+01
    8.03600D-01    1.62658D+01    2.10395D+01
    1.60720D+00    1.68800D+01    2.39186D+01
    2.41080D+00    1.21106D+01    2.22465D+01
    4.01800D+00    2.48084D+00    2.19076D+01
```

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

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.03600D-02	4.13997D+00	1.90363D+01
1.47862D-01	5.65483D+00	2.62610D+01
4.01800D-01	1.71854D+01	2.52432D+01
6.02700D-01	2.12058D+01	2.89109D+01
8.03600D-01	2.46603D+01	3.26997D+01
1.60720D+00	3.00165D+01	4.00498D+01
2.41080D+00	2.64833D+01	4.09880D+01
4.01800D+00	1.74031D+01	4.32676D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.03600D-02	4.53592D+00	2.08688D+01
1.47862D-01	6.04563D+00	2.80832D+01
4.01800D-01	1.82882D+01	2.73290D+01
6.02700D-01	2.24850D+01	3.09015D+01
8.03600D-01	2.62390D+01	3.49861D+01
1.60720D+00	3.30161D+01	4.37237D+01
2.41080D+00	3.12498D+01	4.71146D+01
4.01800D+00	2.27134D+01	5.17890D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.03600D-02	5.88909D+00	2.12716D+01
1.60720D-01	9.12149D+00	2.75411D+01
2.41080D-01	1.36474D+01	2.62813D+01
4.01800D-01	1.92266D+01	2.86458D+01
6.02700D-01	2.47758D+01	3.32825D+01
8.03600D-01	2.87788D+01	3.77081D+01
1.60720D+00	3.81454D+01	5.03759D+01
2.41080D+00	3.87355D+01	5.75556D+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	4.2236D-08	6.4639D-09	6.2854D-10	1.6900D-09
9	3.4217D-11	9.5283D-09	1.2947D-09	2.9799D-09
10	0.0000D+00	4.8474D-10	9.4658D-11	2.7336D-10
11	0.0000D+00	4.0466D-11	1.0486D-11	2.6677D-11
12	0.0000D+00	2.6098D-12	0.0000D+00	3.0110D-12
13	0.0000D+00	1.7805D-12	2.2927D-13	0.0000D+00
14	0.0000D+00	0.0000D+00	1.4391D-13	5.1334D-13

APPENDIX D
BEAVER VALLEY UNIT 1 DOMINANT PTS TRANSIENTS

Table D-1 BV1 Major Transients Contributing to PTS Risk [7]			
		BV1-Specific Notes	
Break Description	PRA BIN Description	Description	Mean Frequency
Primary System: LOCAs	SBLOCA (1.4 – 4.0 inch)	TH 56: 4-inch surge line break at HZP	1.2E-4
	MBLOCA (4.0 – 8.0 inch)	TH 7: 8- inch surge line break	2.1E-5
	LBLOCA (greater than 8.0 inch)	TH 9: 16-inch hot-leg break	7.0E-6
Primary System: Stuck-Open Valves	SRV stuck open/recloses	TH 60: Reactor/turbine trip with 1 stuck-open pressurizer SRV, SRV recloses at 6,000 seconds.	2.2E-05
		TH 96: Reactor/turbine trip with 1 stuck-open pressurizer SRV, SRV recloses at 6,000 seconds. HPI throttling after 10 minutes allowed	1.3E-04
		TH 97: Reactor/turbine trip with 1 stuck-open pressurizer SRV that recloses at 3000 sec. At HZP, no HPI throttling	1.9E-4
		TH 101: Reactor/turbine trip with 1 stuck-open pressurizer SRV, SRV recloses at 3,000 seconds. HPI throttling after 10 minutes allowed.	3.1E-5
Secondary System: MSLBs	Large MSLBs	TH 102: MSLB with AFW continuing to feed bad generator for 30 min and operator throttles HPI 30 min after allowed, break is assumed to occur inside containment so RCPs are tripped due to adverse containment conditions.	3.1E-5
		TH 103: MSLB with AFW continuing to feed bad generator for 30 min and operator throttles HPI 30 min after allowed, at HZP, break is assumed to occur inside containment so RCPs are tripped due to adverse containment conditions	1.0E-4
		TH 104: MSLB with AFW continuing to feed bad generator for 30 min and operator throttles HPI 60 min after allowed, break is assumed to occur inside containment so RCPs are tripped due to adverse containment conditions	1.1E-5
		TH 105: MSLB with AFW continuing to feed bad generator for 30 min and operator throttles HPI 60 min after allowed, at HZP, break is assumed to occur inside containment so RCPs are tripped due to adverse containment conditions.	1.1E-4

Table D-1 (cont.) BV1 Major Transients Contributing to PTS Risk [7]			
		BV1-Specific Notes	
Break Description	PRA BIN Description	Description	Mean Frequency
	SRVs stuck open	TH 108: All Main Steam SRVs on SG A stuck open with AFW continuing to feed bad generator for 30 min and operator throttles HPI 30 min after allowed.	4.3E-7

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. 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

Case Category	LOCA
Primary Failures	20.32 cm (8.0 in) surge line break
Secondary Failures	None
Operator Actions	None
Min DC Temp	291.2 K (64.5°F) at 1050 s
Comments	None

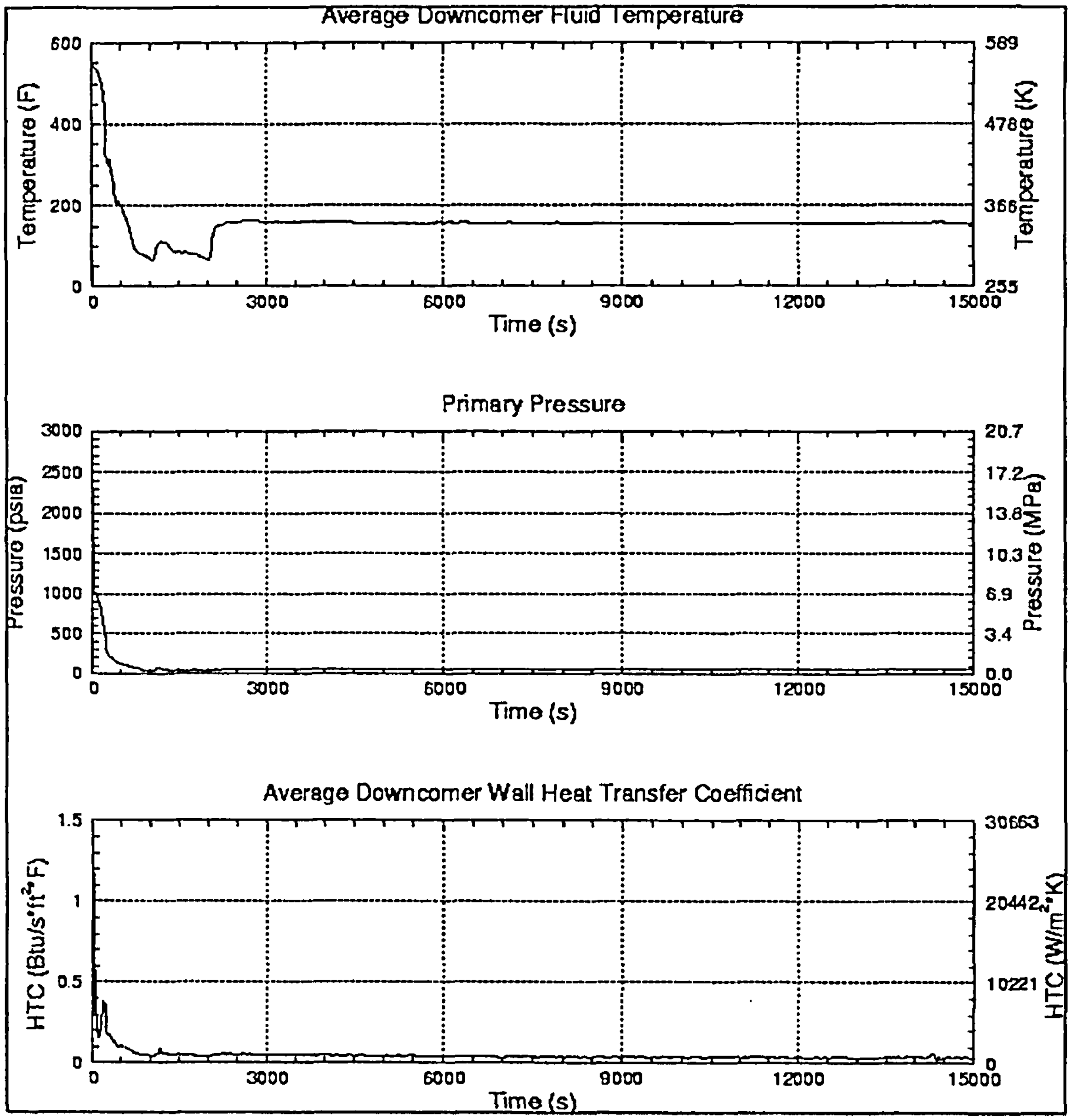

Figure D-1 BV1 PTS Transient 007

Case Category	LOCA
Primary Failures	40.64 cm (16.0 in) hot leg break
Secondary Failures	None
Operator Actions	None
Min DC Temp	291.2 K (64.6°F) at 960 s
Comments	None

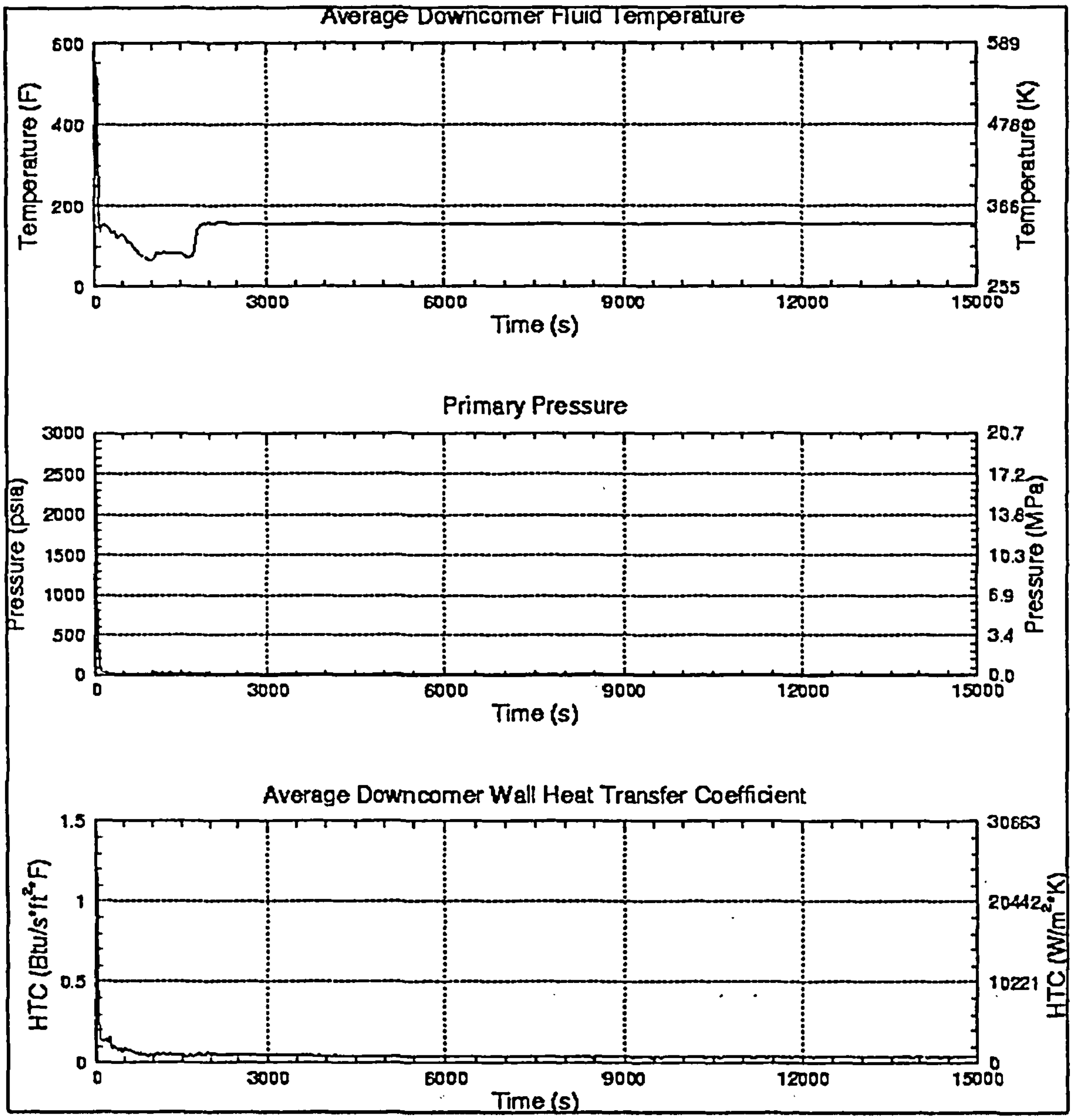

Figure D-2 BV1 PTS Transient 009

Case Category	LOCA, HZP
Primary Failures	10.16 cm (4.0 in) surge line break
Secondary Failures	None
Operator Actions	None
Min DC Temp	288.4 K (59.5°F) at 2970 s
Comments	Case 005 @ HZP

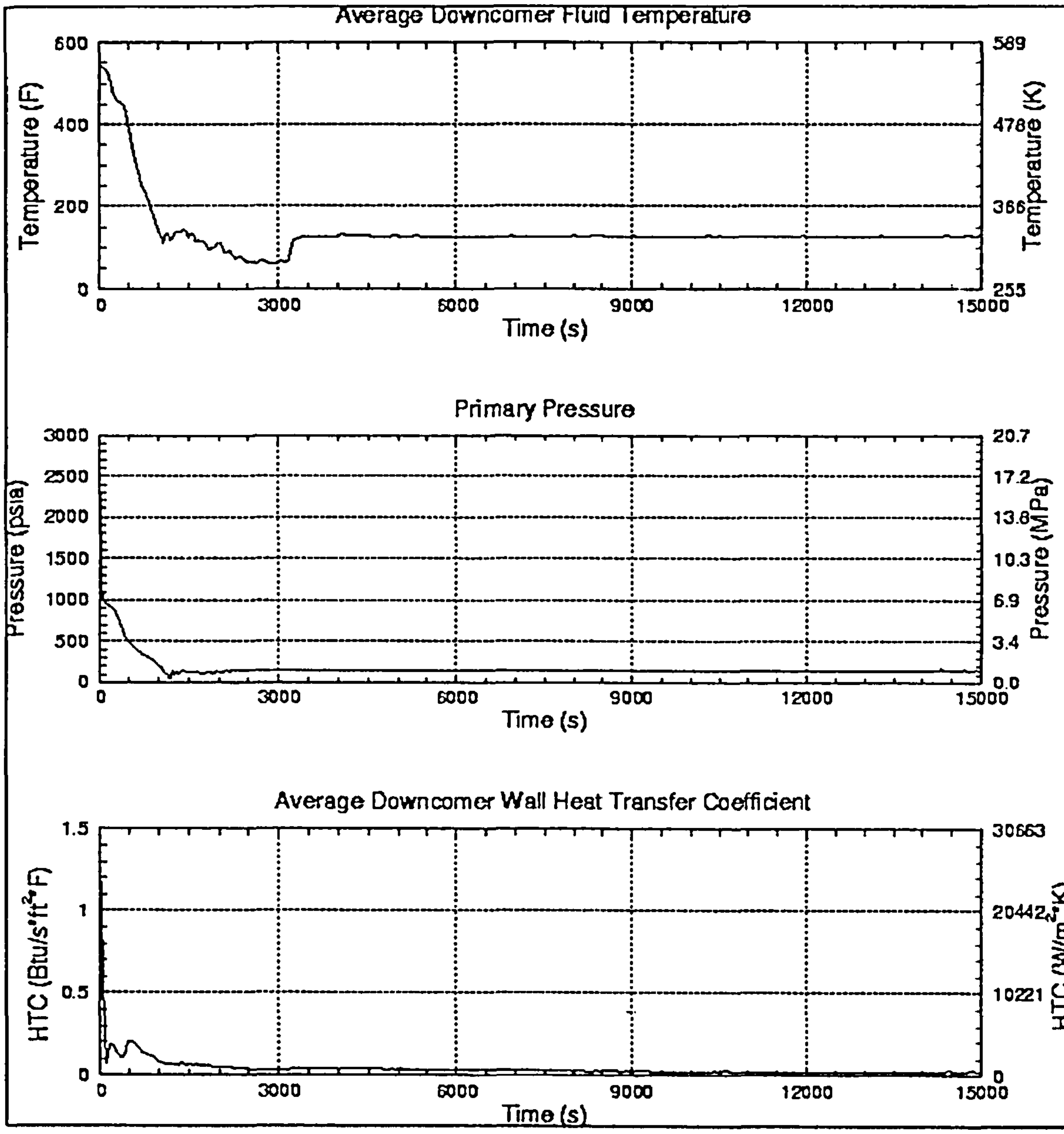

Figure D-3 BV1 PTS Transient 056

Case Category	RT/TT
Primary Failures	One stuck open pressurizer SRV
Secondary Failures	None
Operator Actions	None
Min DC Temp	329.8 K (133.9°F) at 6000 s
Comments	SRV recloses at 6,000 seconds

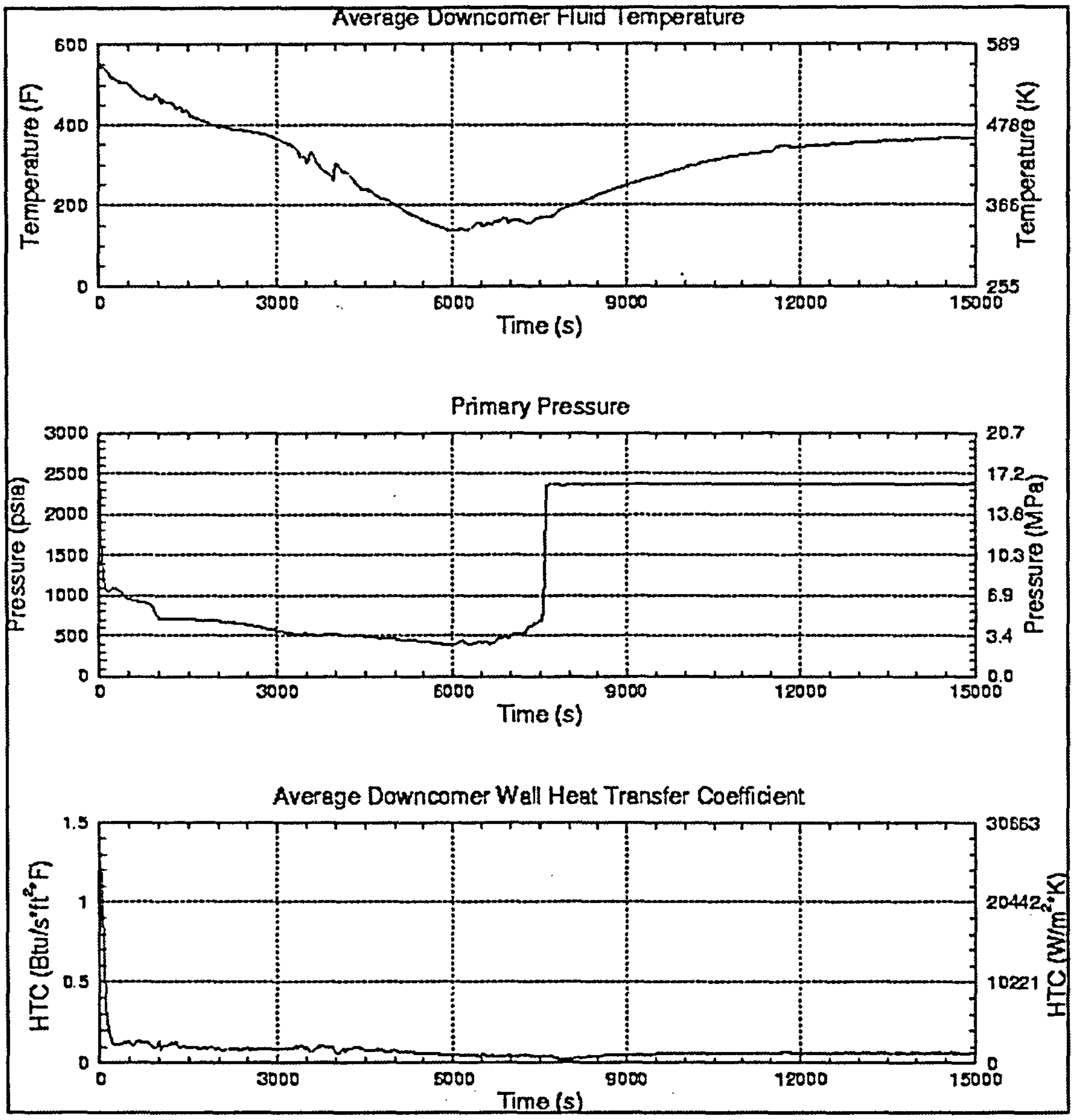

Figure D-4 BV1 PTS Transient 060

Case Category	RT/TT
Primary Failures	One stuck open pressurizer SRV
Secondary Failures	None
Operator Actions	Controls HPI 10 minutes after allowed
Min DC Temp	331.6 K (137.2°F) at 6030 s
Comments	SRV recloses at 6,000 seconds.

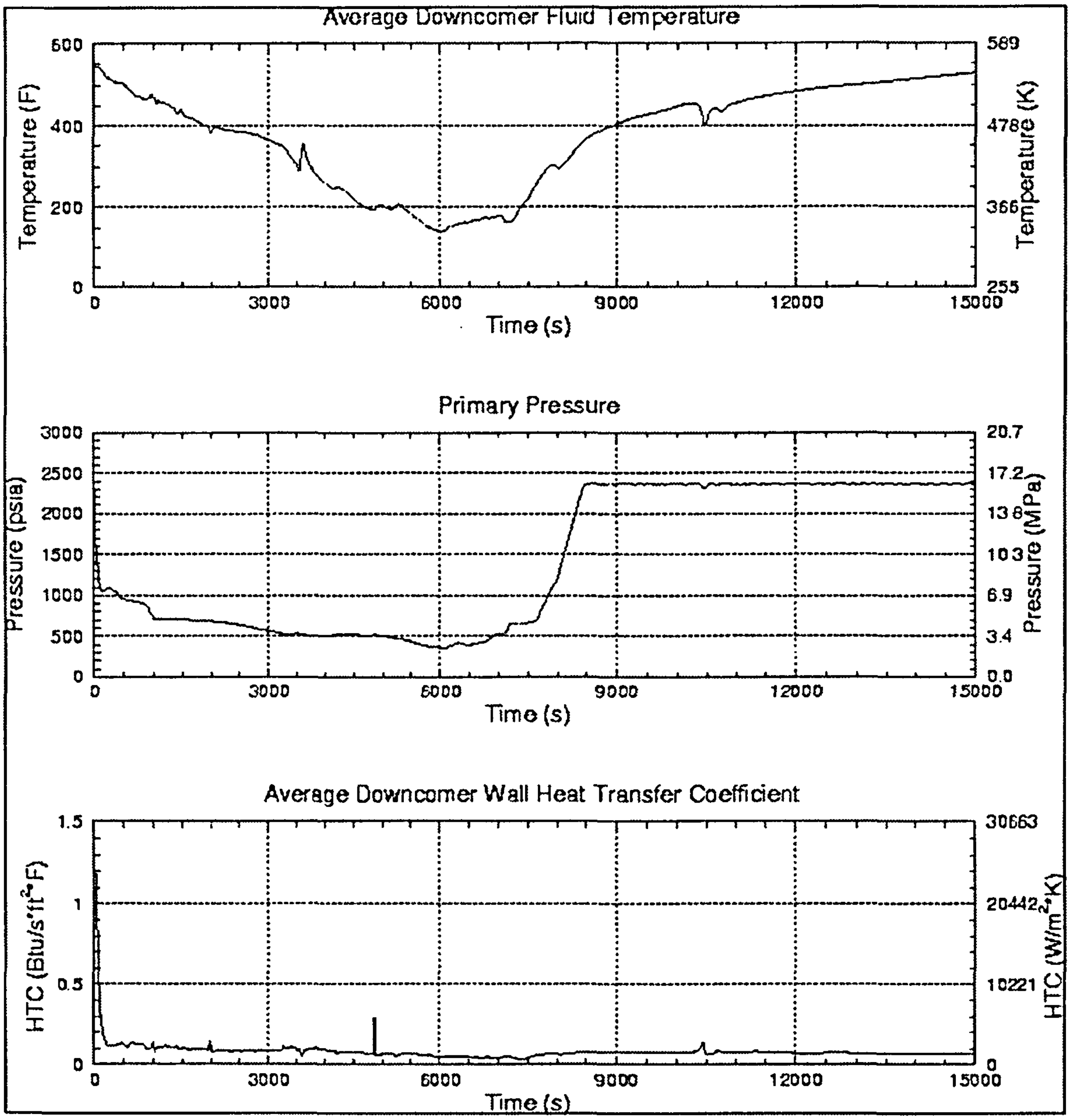

Figure D-5 BV1 PTS Transient 096

Case Category	RT/TT, HZP
Primary Failures	One stuck open pressurizer SRV
Secondary Failures	None
Operator Actions	None
Min DC Temp	296.8 K (74.6°F) at 15000 s
Comments	SRV recloses at 3,000 seconds.

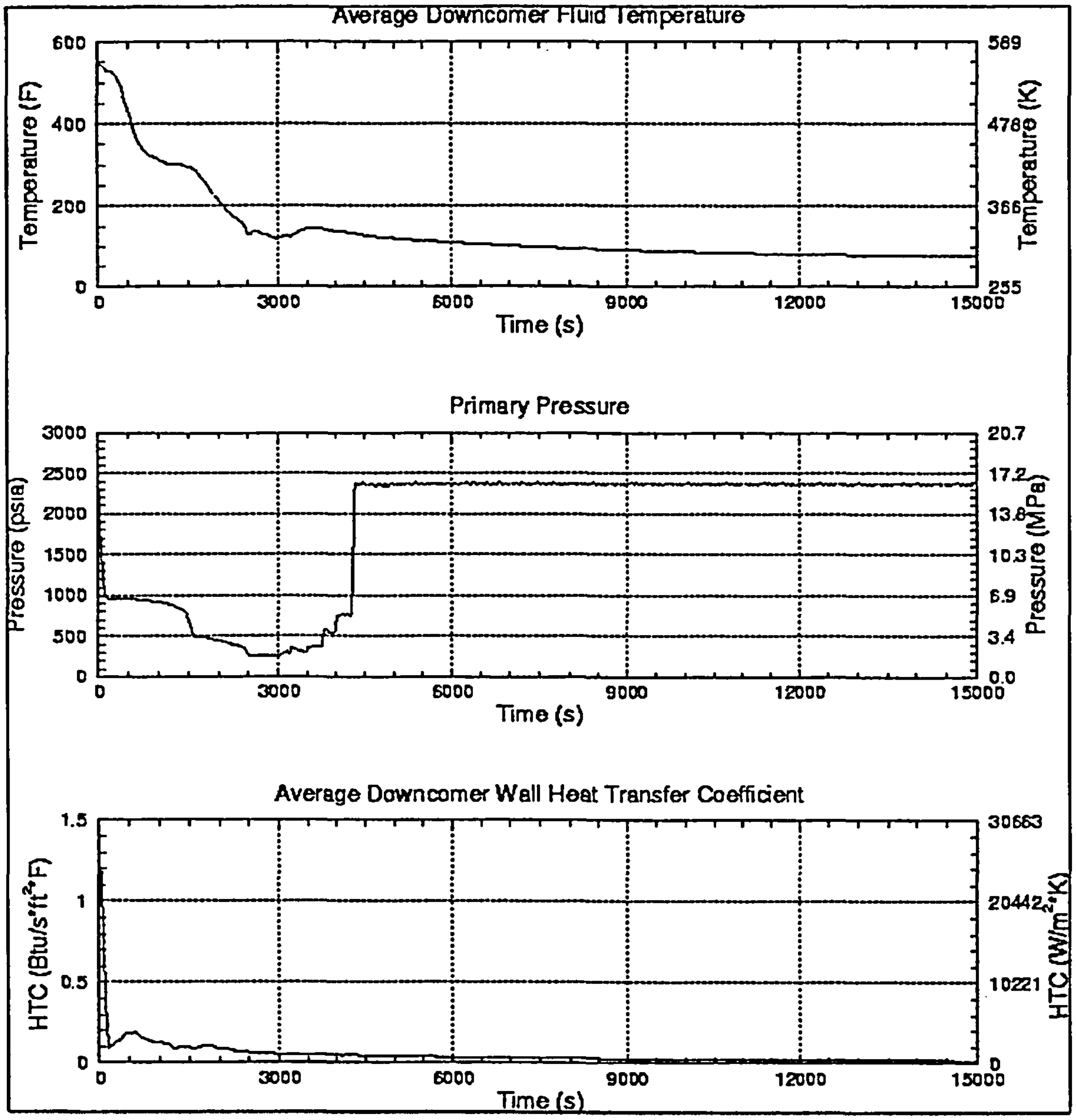

Figure D-6 BV1 PTS Transient 097

Case Category	RT/TT, HZP
Primary Failures	One stuck open pressurizer SRV
Secondary Failures	None
Operator Actions	Controls HPI 10 minutes after allowed
Min DC Temp	320.4 K (117.1°F) at 3030 s
Comments	SRV recloses at 3,000 seconds.

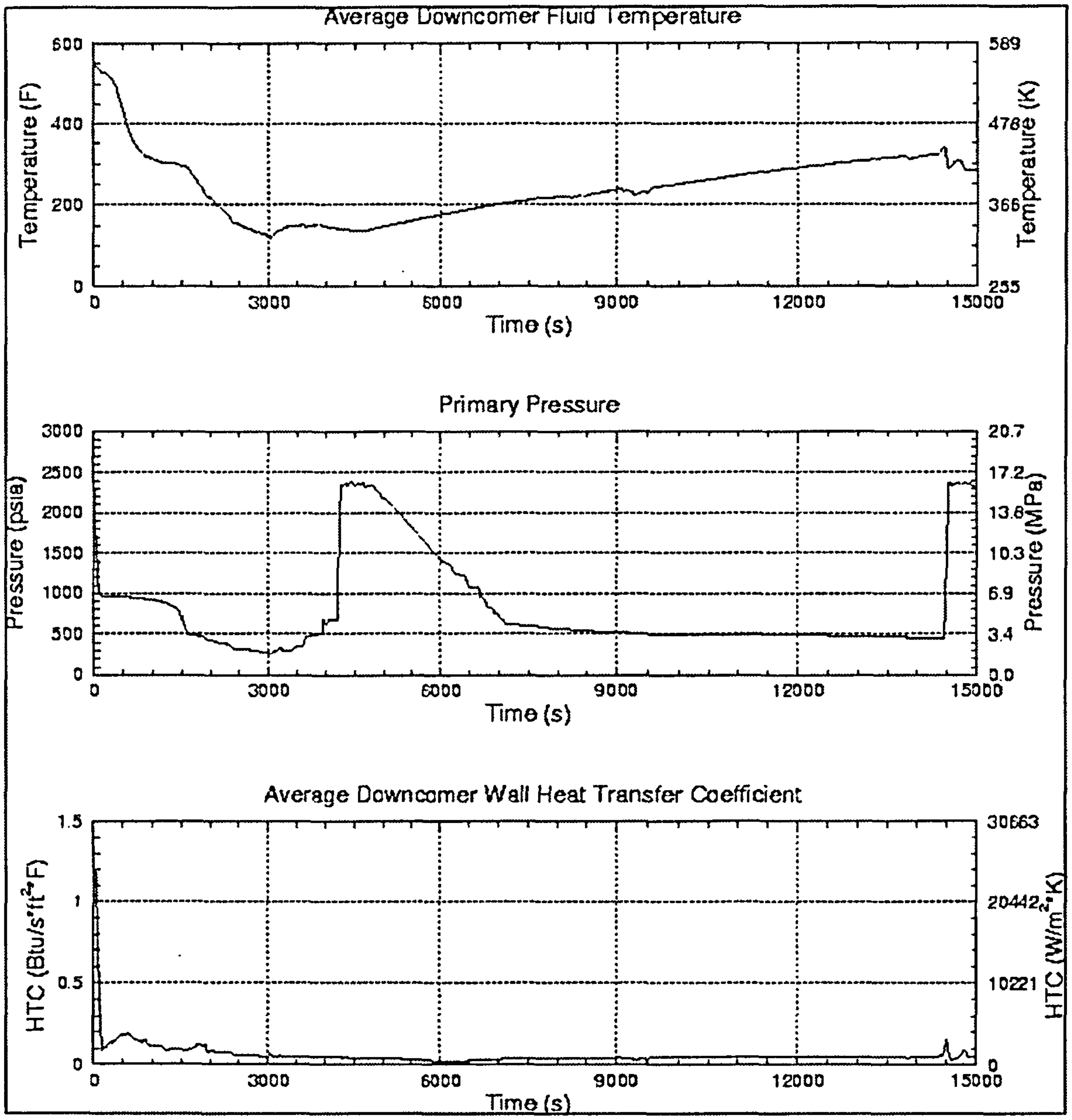

Figure D-7 BV1 PTS Transient 101

Case Category	MSLB
Primary Failures	None
Secondary Failures	Double ended guillotine break of steam line A
Operator Actions	RCP's are tripped. Controls HPI 30 minutes after allowed
Min DC Temp	373.3 K (212.2°F) at 3990 s
Comments	AFW continues to feed SG A for 30 minutes.

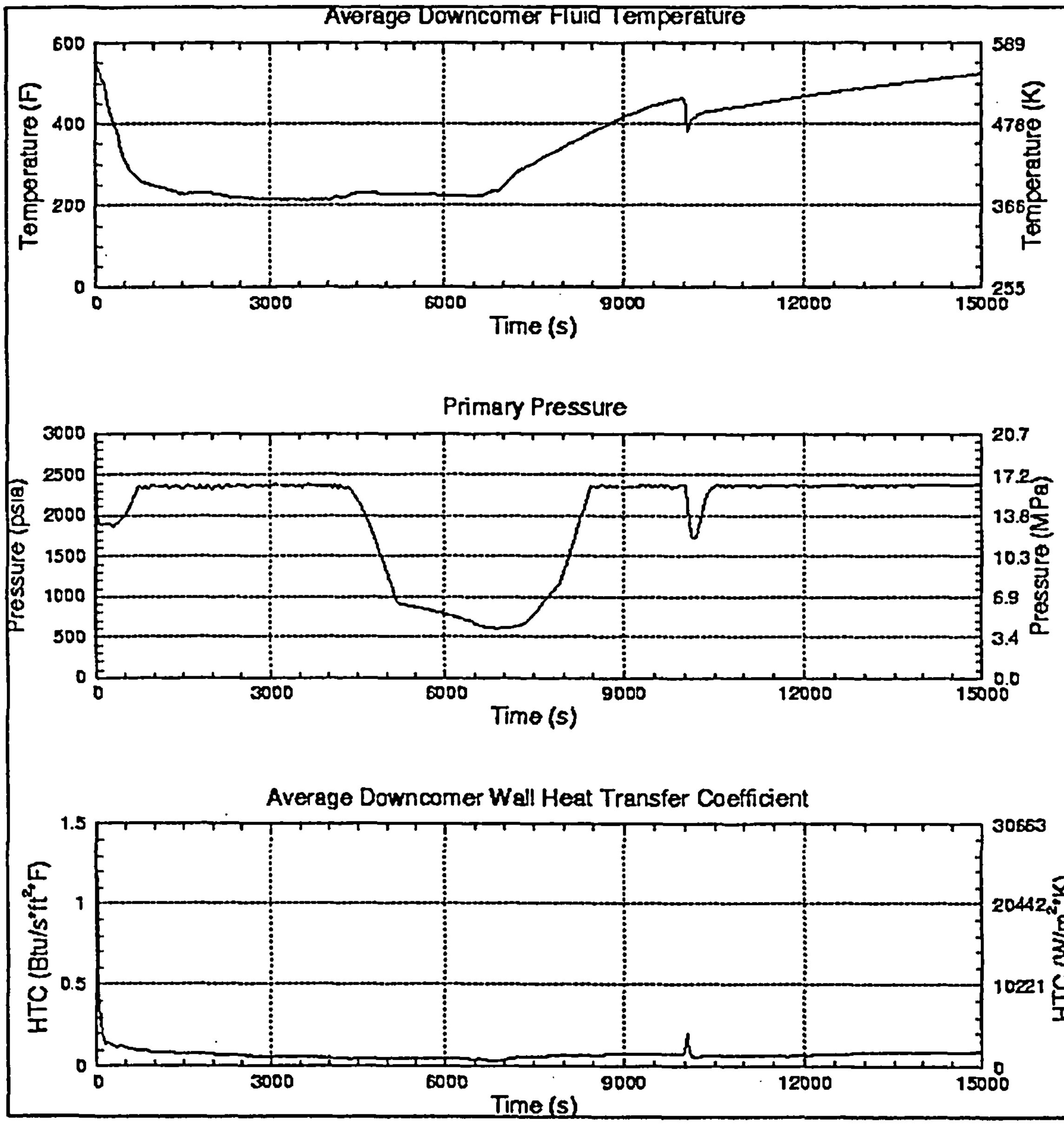

Figure D-8 BV1 PTS Transient 102

Case Category	MSLB, HZP
Primary Failures	None
Secondary Failures	Double ended guillotine break of steam line A
Operator Actions	RCP's are tripped. Controls HPI 30 minutes after allowed
Min DC Temp	361.7 K (191.5°F) at 3420 s
Comments	AFW continues to feed SG A for 30 minutes. Case 102 @ HZP.

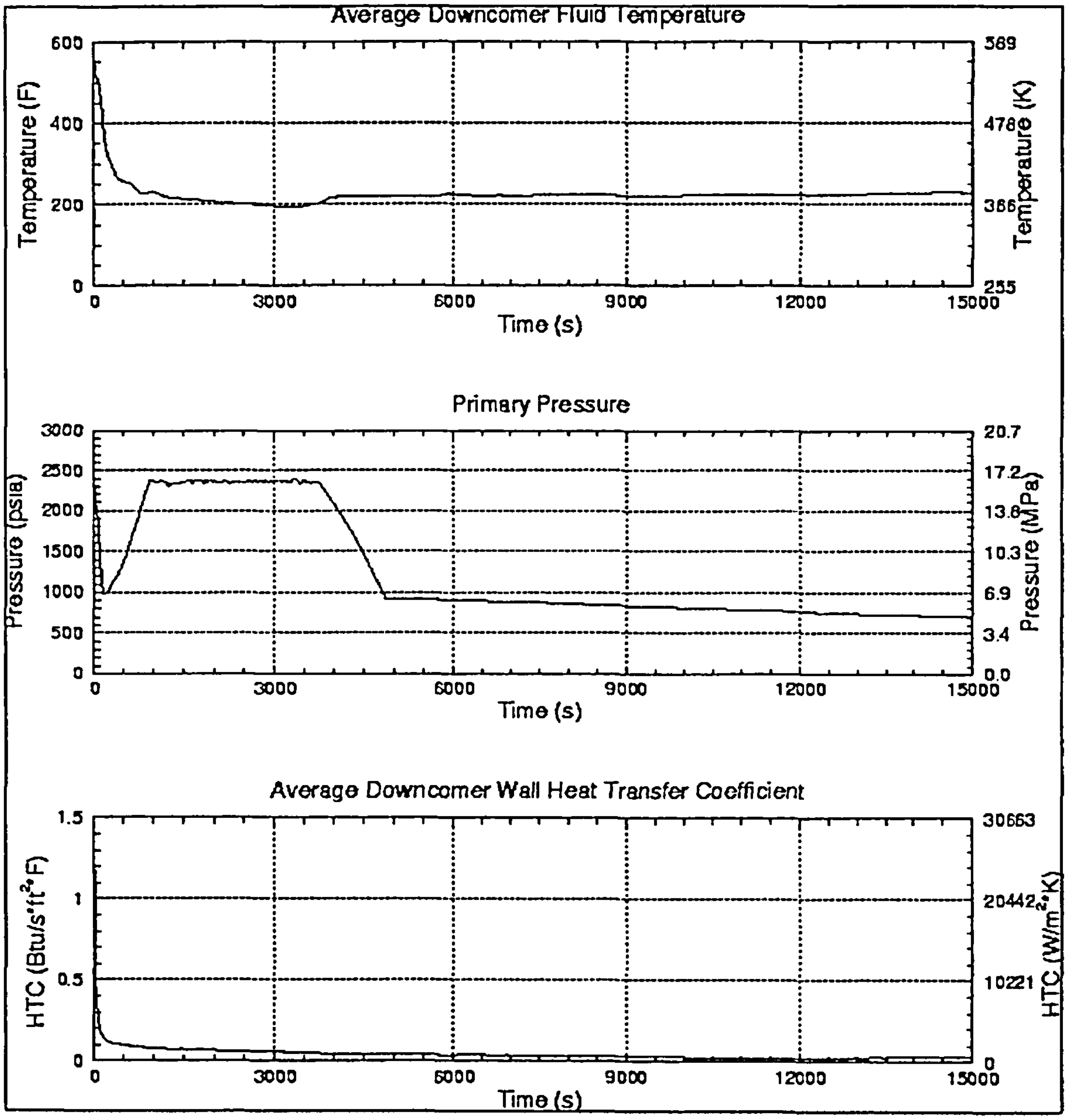

Figure D-9 BV1 PTS Transient 103

Case Category	MSLB
Primary Failures	None
Secondary Failures	Double ended guillotine break of steam line A
Operator Actions	RCP's are tripped. Controls HPI 60 minutes after allowed
Min DC Temp	369.6 K (205.6°F) at 5820 s
Comments	AFW continues to feed SG A for 30 minutes.

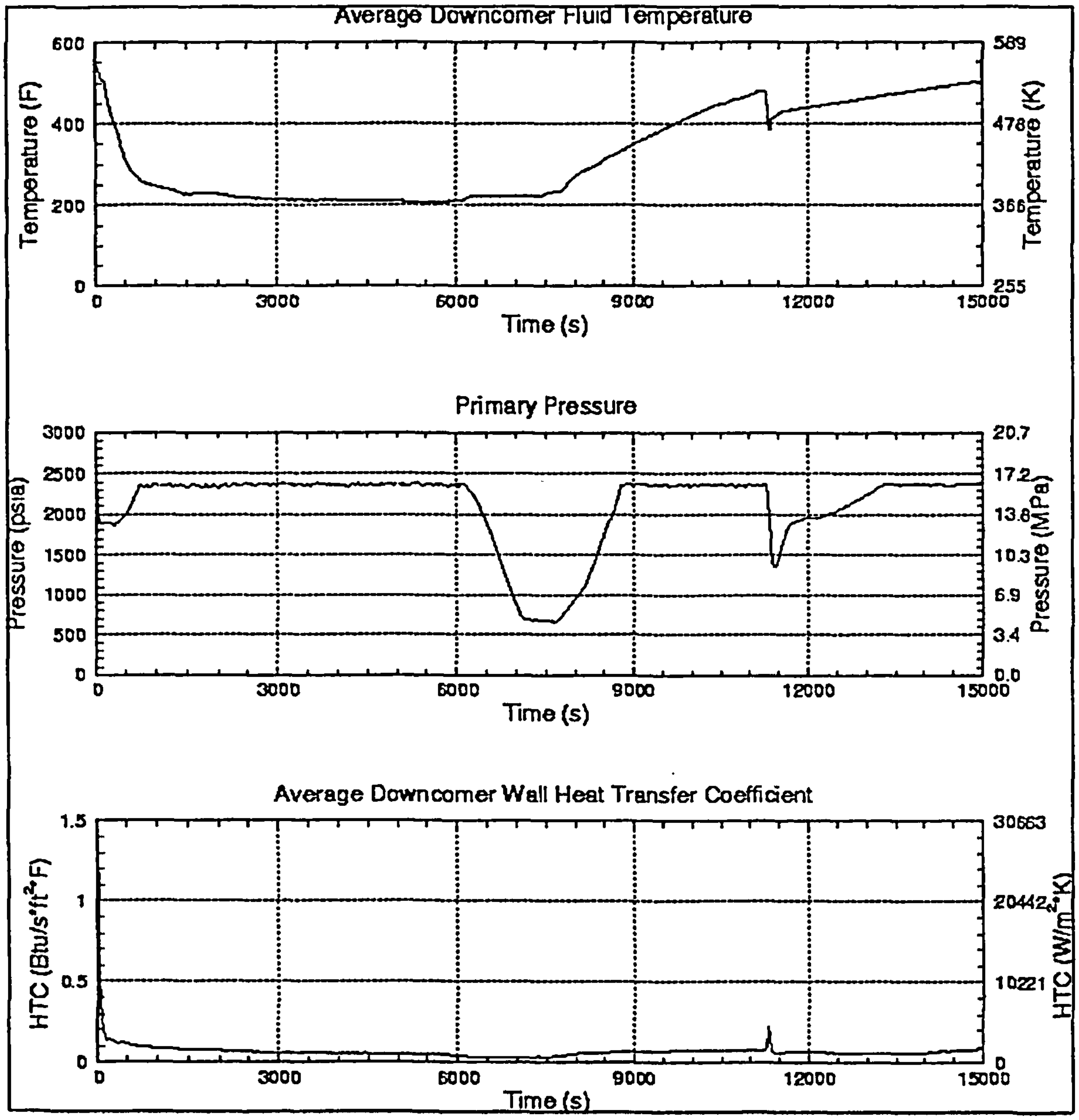

Figure D-10 BV1 PTS Transient 104

Case Category	MSLB, HZP
Primary Failures	None
Secondary Failures	Double ended guillotine break of steam line A
Operator Actions	RCP's are tripped. Controls HPI 60 minutes after allowed
Min DC Temp	355.0 K (179.4°F) at 5220 s
Comments	AFW continues to feed SG A for 30 minutes. Case 104 @ HZP.

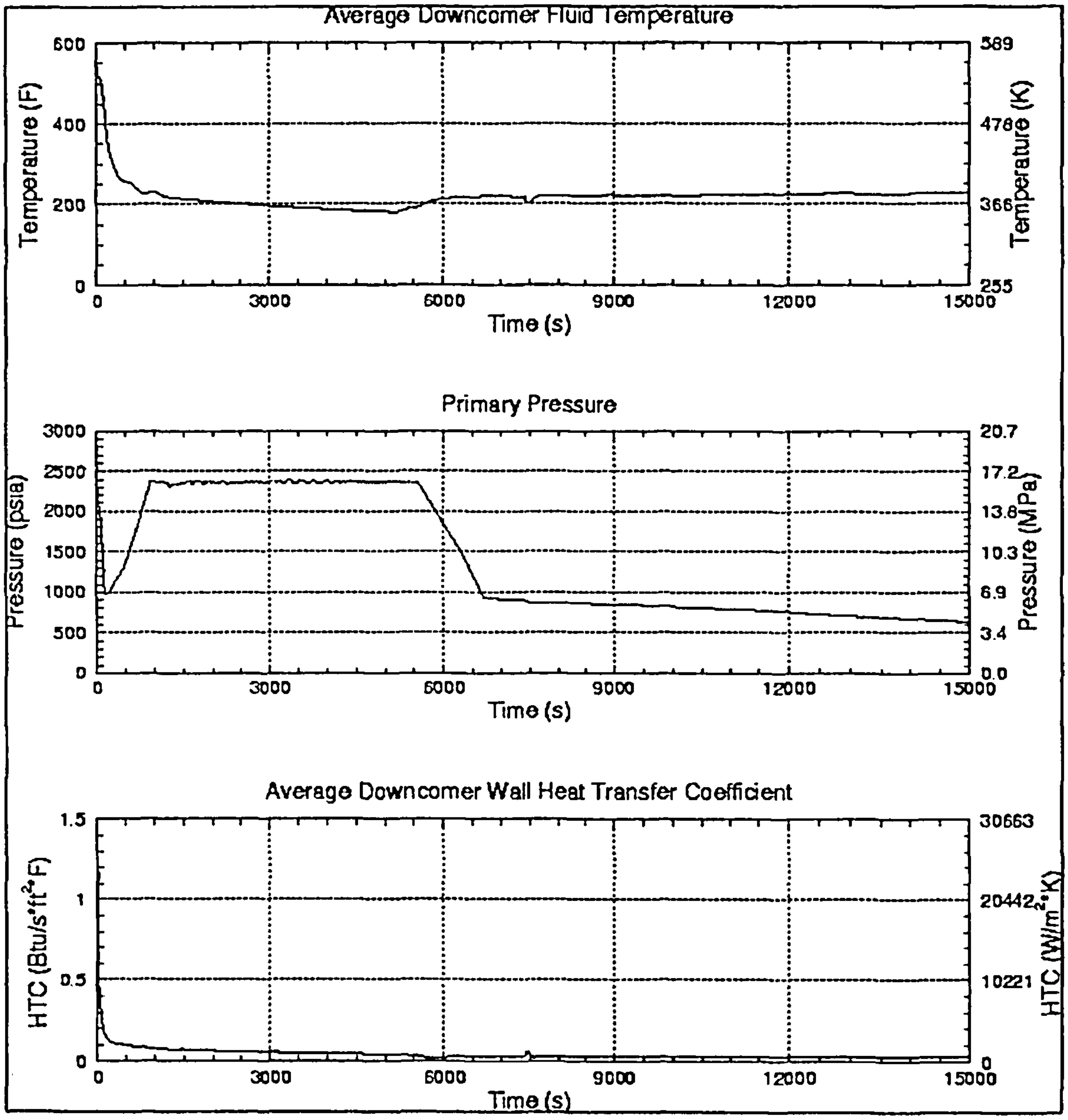

Figure D-11 BV1 PTS Transient 105

Case Category	MSLB
Primary Failures	None
Secondary Failures	All MS-SRVs on SG A stuck open
Operator Actions	Controls HPI 30 minutes after allowed
Min DC Temp	395.3 K (251.8°F) at 3600 s
Comments	AFW continues to feed SG A for 30 minutes.

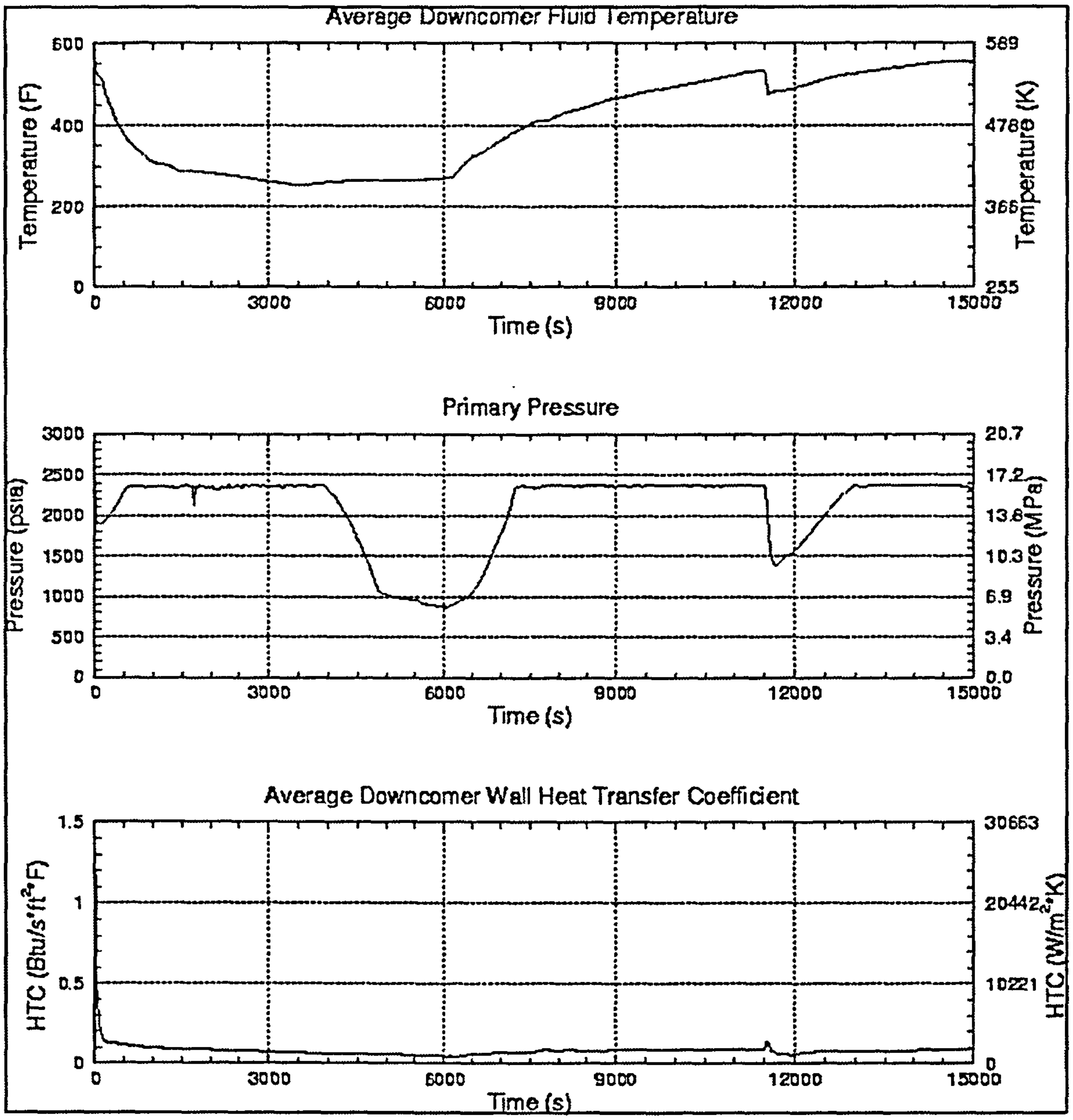

Figure D-12 BV1 PTS Transient 108

APPENDIX E
BEAVER VALLEY UNIT 1 FAVPOST OUTPUT

E-1: 10 Year ISI Only, FAVOR 03.1

```
**************************************************
*                                                *
*              WELCOME TO FAVOR                  *
*                                                *
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE      *
*              VERSION 03.1                      *
*                                                *
*     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: dicksontl@ornl.gov             *
*                                                *
**************************************************

************************************************************
* This computer program was prepared as an account of     *
* 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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* 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.                                 *
*                                                         *
*          All rights reserved.                           *
************************************************************


DATE: 16-Sep-2003  TIME: 10:21:46


FAVPOST INPUT  FILE NAME                        = bvfavpost.in
FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME                        = 30000.out

   **********************************
   * NUMBER OF SIMULATIONS =  30000 *
   **********************************
```

E-1: 10 Year ISI Only, FAVOR 03.1 (cont.)

	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E)			
TRANSIENT NUMBER	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
7	2.9269E-03	5.9997E-03	3.7284E-02	8.6108E-06	9.8373E-06	1.4630E-04	0.0029
9	4.2381E-03	8.8758E-03	5.1206E-02	1.5420E-06	1.2258E-06	2.7949E-05	0.0004
56	3.4781E-03	7.1417E-03	4.1483E-02	1.6837E-05	2.2308E-05	2.9000E-04	0.0048
60	2.1131E-05	2.1920E-06	2.5866E-04	1.9787E-05	1.8743E-06	2.4428E-04	0.9364
96	1.4750E-05	9.5950E-07	2.2452E-04	1.4061E-06	0.0000E+00	6.3296E-06	0.0953
97	2.9846E-04	4.2856E-04	5.6427E-03	1.9984E-04	2.0642E-04	3.6389E-03	0.6696
101	7.8027E-05	9.6192E-06	1.0998E-03	6.9119E-05	7.1182E-06	8.8367E-04	0.8858
102	4.8672E-06	0.0000E+00	1.0853E-05	1.5905E-07	0.0000E+00	0.0000E+00	0.0327
103	5.2025E-05	2.9717E-05	8.2335E-04	5.7275E-06	1.3427E-07	5.0889E-05	0.1101
104	4.8672E-06	0.0000E+00	1.0853E-05	1.5905E-07	0.0000E+00	0.0000E+00	0.0327
105	5.2025E-05	2.9717E-05	8.2335E-04	5.7275E-06	1.3427E-07	5.0889E-05	0.1101
108	2.2935E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000

E-1: 10 Year ISI Only, FAVOR 03.1 (cont.)

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

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	0.1367	0.1367
1.2373E-06	94.8633	95.0000
3.7118E-06	2.8600	97.8600
6.1863E-06	0.8233	98.6833
8.6608E-06	0.3733	99.0567
1.1135E-05	0.2733	99.3300
1.3610E-05	0.1900	99.5200
1.6084E-05	0.0967	99.6167
1.8559E-05	0.0667	99.6833
2.1033E-05	0.0633	99.7467
2.3508E-05	0.0467	99.7933
2.5982E-05	0.0367	99.8300
2.8457E-05	0.0367	99.8667
3.0932E-05	0.0300	99.8967
3.3406E-05	0.0167	99.9133
3.5881E-05	0.0133	99.9267
3.8355E-05	0.0067	99.9333
4.0830E-05	0.0033	99.9367
4.5779E-05	0.0033	99.9400
4.8253E-05	0.0167	99.9567
5.0728E-05	0.0067	99.9633
5.3202E-05	0.0033	99.9667
5.8151E-05	0.0033	99.9700
6.3100E-05	0.0067	99.9767
6.5575E-05	0.0067	99.9833
9.2795E-05	0.0033	99.9867
9.5269E-05	0.0033	99.9900
1.0517E-04	0.0033	99.9933
1.2991E-04	0.0033	99.9967
2.2889E-04	0.0033	100.0000

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

Minimum                          = 0.0000E+00
Maximum                          = 2.2895E-04
Range                            = 2.2895E-04

Number of Simulations            =   30000
```

E-1: 10 Year ISI Only, FAVOR 03.1 (cont.)

5th Percentile	= 6.5245E-10
Median	= 8.5655E-08
95.0th Percentile	= 1.2373E-06
99.0th Percentile	= 8.2852E-06
99.9th Percentile	= 3.1426E-05
Mean	= 6.2573E-07
Standard Deviation	= 2.9125E-06
Standard Error	= 1.6816E-08
Variance (unbiased)	= 8.4829E-12
Variance (biased)	= 8.4826E-12
Moment Coeff. of Skewness	= 2.8626E+01
Pearson's 2nd Coeff. of Skewness	= 6.4452E-01
Kurtosis	= 1.5994E+03

```
*************************************************************
*     PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)         *
*        FOR THE FREQUENCY OF VESSEL FAILURE                *
*************************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	13.2633	13.2633
7.1370E-09	81.7667	95.0300
2.1411E-08	1.7700	96.8000
3.5685E-08	0.8567	97.6567
4.9959E-08	0.5467	98.2033
6.4233E-08	0.3433	98.5467
7.8507E-08	0.1700	98.7167
9.2781E-08	0.1733	98.8900
1.0705E-07	0.1333	99.0233
1.2133E-07	0.0900	99.1133
1.3560E-07	0.0800	99.1933
1.4988E-07	0.0733	99.2667
1.6415E-07	0.0400	99.3067
1.7842E-07	0.0633	99.3700
1.9270E-07	0.0467	99.4167
2.0697E-07	0.0200	99.4367
2.2125E-07	0.0467	99.4833
2.3552E-07	0.0200	99.5033
2.4979E-07	0.0233	99.5267
2.6407E-07	0.0133	99.5400
2.7834E-07	0.0267	99.5667
2.9262E-07	0.0133	99.5800
3.0689E-07	0.0267	99.6067
3.2116E-07	0.0100	99.6167
3.3544E-07	0.0033	99.6200
3.4971E-07	0.0267	99.6467
3.6399E-07	0.0133	99.6600
3.7826E-07	0.0100	99.6700

E-1: 10 Year ISI Only, FAVOR 03.1 (cont.)

3.9253E-07	0.0100	99.6800
4.0681E-07	0.0200	99.7000
4.2108E-07	0.0200	99.7200
4.3536E-07	0.0033	99.7233
4.6390E-07	0.0100	99.7333
4.7818E-07	0.0133	99.7467
4.9245E-07	0.0067	99.7533
5.0673E-07	0.0100	99.7633
5.2100E-07	0.0100	99.7733
5.3527E-07	0.0067	99.7800
5.4955E-07	0.0067	99.7867
5.6382E-07	0.0100	99.7967
5.9237E-07	0.0067	99.8033
6.0664E-07	0.0100	99.8133
6.2092E-07	0.0067	99.8200
6.3519E-07	0.0033	99.8233
6.6374E-07	0.0033	99.8267
6.7801E-07	0.0067	99.8333
6.9229E-07	0.0033	99.8367
7.0656E-07	0.0033	99.8400
7.3511E-07	0.0033	99.8433
7.6366E-07	0.0033	99.8467
7.7793E-07	0.0067	99.8533
7.9221E-07	0.0100	99.8633
8.0648E-07	0.0033	99.8667
8.2075E-07	0.0033	99.8700
8.4930E-07	0.0033	99.8733
8.6358E-07	0.0067	99.8800
8.9212E-07	0.0033	99.8833
9.0640E-07	0.0067	99.8900
9.2067E-07	0.0033	99.8933
9.9204E-07	0.0067	99.9000
1.0349E-06	0.0033	99.9033
1.0491E-06	0.0033	99.9067
1.0634E-06	0.0033	99.9100
1.1633E-06	0.0033	99.9133
1.1919E-06	0.0067	99.9200
1.2204E-06	0.0033	99.9233
1.2632E-06	0.0033	99.9267
1.3346E-06	0.0033	99.9300
1.3489E-06	0.0033	99.9333
1.4345E-06	0.0033	99.9367
1.4631E-06	0.0033	99.9400
1.5345E-06	0.0033	99.9433
1.5487E-06	0.0033	99.9467
1.5773E-06	0.0033	99.9500
1.6058E-06	0.0033	99.9533
1.6486E-06	0.0033	99.9567
1.7343E-06	0.0033	99.9600
1.8628E-06	0.0033	99.9633
1.9912E-06	0.0033	99.9667
2.0198E-06	0.0033	99.9700
2.5907E-06	0.0033	99.9733
2.7049E-06	0.0033	99.9767

E-1: 10 Year ISI Only, FAVOR 03.1 (cont.)

2.8905E-06	0.0033	99.9800
3.4043E-06	0.0033	99.9833
4.2608E-06	0.0033	99.9867
4.5463E-06	0.0033	99.9900
5.0316E-06	0.0033	99.9933
5.2457E-06	0.0033	99.9967
6.0022E-06	0.0033	100.0000

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

Minimum                               = 0.0000E+00
Maximum                               = 5.9959E-06
Range                                 = 5.9959E-06

Number of Simulations                 =  30000

5th Percentile                        = 0.0000E+00
Median                                = 2.1415E-11
95.0th Percentile                     = 7.1370E-09
99.0th Percentile                     = 1.0456E-07
99.9th Percentile                     = 9.9204E-07

Mean                                  = 7.1809E-09
Standard Deviation                    = 9.0161E-08
Standard Error                        = 5.2055E-10
Variance (unbiased)                   = 8.1290E-15
Variance (biased)                     = 8.1287E-15
Moment Coeff. of Skewness             = 3.8496E+01
Pearson's 2nd Coeff. of Skewness      =-2.6111E+00
Kurtosis                              = 1.9452E+03

**********************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON  *
*             AND FREQUENCY OF RPV FAILURE BY            *
*                        TRANSIENT                       *
*      WEIGHTED BY TRANSIENT INITIATING FREQUENCIES      *
**********************************************************
```

	% of total frequency of crack initiation	% of total frequency of of RPV failure
7	13.01	2.82
9	7.13	0.25
56	78.21	33.91
60	0.09	7.02
96	0.47	4.09
97	0.20	10.90
101	0.49	38.54
102	0.13	0.25
103	0.10	0.84
104	0.06	0.06

E-1: 10 Year ISI Only, FAVOR 03.1 (cont.)

105	0.10	1.33
108	0.00	0.00
TOTALS	100.00	100.00

DATE: 16-Sep-2003 TIME: 10:23:19

E-2: ISI Every 10 Years, FAVOR 03.1

```
************************************************
*                                              *
*              WELCOME TO FAVOR                *
*                                              *
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
*                VERSION 03.1                  *
*                                              *
*     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: dicksontl@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.                                 *
*                                                         *
*         All rights reserved.                            *
************************************************************


     DATE: 16-Sep-2003  TIME: 11:25:52


     FAVPOST INPUT  FILE NAME                    = bvfavpost.in
     FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
     FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
     FAVPOST OUTPUT FILE NAME                    = 30000.out

        **********************************
        * NUMBER OF SIMULATIONS =  30000 *
        **********************************
```

E-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E) MEAN CPI	95th % CPI	99th % CPI	CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E) MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
7	2.5850E-03	4.9641E-03	2.9325E-02	9.1988E-06	9.0609E-06	1.4239E-04	0.0036
9	3.8778E-03	8.1915E-03	4.2538E-02	1.9687E-06	1.0612E-06	2.7167E-05	0.0005
56	3.1275E-03	6.0897E-03	3.3294E-02	1.7652E-05	2.1231E-05	2.7273E-04	0.0056
60	2.9954E-05	2.8844E-07	1.4066E-04	2.9067E-05	2.5695E-07	1.2668E-04	0.9704
96	1.3070E-05	9.4735E-08	7.6262E-05	8.2438E-07	0.0000E+00	2.0143E-08	0.0631
97	2.7455E-04	2.6668E-04	3.7891E-03	1.8521E-04	1.2935E-04	2.2075E-03	0.6746
101	7.0277E-05	1.7392E-06	3.2940E-04	7.0265E-05	1.7276E-06	3.2998E-04	0.9998
102	6.7913E-06	0.0000E+00	1.1115E-05	3.0300E-07	0.0000E+00	0.0000E+00	0.0446
103	6.4252E-05	2.5547E-05	8.1239E-04	9.7267E-06	7.9836E-08	3.8880E-05	0.1514
104	6.7913E-06	0.0000E+00	1.1115E-05	3.0300E-07	0.0000E+00	0.0000E+00	0.0446
105	6.4252E-05	2.5547E-05	8.1239E-04	9.7267E-06	7.9836E-08	3.8880E-05	0.1514
108	2.6980E-08	0.0000E+00	0.0000E+00	4.6787E-11	0.0000E+00	0.0000E+00	0.0017

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

E-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	0.1867	0.1867
1.0303E-06	94.8133	95.0000
3.0908E-06	2.8067	97.8067
5.1514E-06	0.9000	98.7067
7.2119E-06	0.4667	99.1733
9.2724E-06	0.2400	99.4133
1.1333E-05	0.1100	99.5233
1.3394E-05	0.0767	99.6000
1.5454E-05	0.0667	99.6667
1.7515E-05	0.0433	99.7100
1.9575E-05	0.0200	99.7300
2.1636E-05	0.0467	99.7767
2.3696E-05	0.0100	99.7867
2.5757E-05	0.0400	99.8267
2.7817E-05	0.0133	99.8400
2.9878E-05	0.0133	99.8533
3.1938E-05	0.0200	99.8733
3.3999E-05	0.0133	99.8867
3.6059E-05	0.0133	99.9000
3.8120E-05	0.0133	99.9133
4.2241E-05	0.0033	99.9167
4.6362E-05	0.0033	99.9200
4.8423E-05	0.0033	99.9233
5.0483E-05	0.0100	99.9333
5.2544E-05	0.0033	99.9367
5.4604E-05	0.0033	99.9400
5.6665E-05	0.0067	99.9467
5.8725E-05	0.0033	99.9500
6.4907E-05	0.0033	99.9533
6.9028E-05	0.0033	99.9567
7.5210E-05	0.0067	99.9633
7.7270E-05	0.0033	99.9667
8.3452E-05	0.0033	99.9700
8.5512E-05	0.0033	99.9733
8.9634E-05	0.0033	99.9767
9.1694E-05	0.0033	99.9800
9.5815E-05	0.0033	99.9833
9.7876E-05	0.0033	99.9867
9.9936E-05	0.0033	99.9900
1.1024E-04	0.0033	99.9933
1.2672E-04	0.0067	100.0000

E-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

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

Minimum                                  = 0.0000E+00
Maximum                                  = 1.2618E-04
Range                                    = 1.2618E-04

Number of Simulations                    =  30000

5th Percentile                           = 5.4848E-10
Median                                   = 7.7473E-08
95.0th Percentile                        = 1.0303E-06
99.0th Percentile                        = 6.4466E-06
99.9th Percentile                        = 3.6059E-05

Mean                                     = 5.5722E-07
Standard Deviation                       = 2.8640E-06
Standard Error                           = 1.6535E-08
Variance (unbiased)                      = 8.2022E-12
Variance (biased)                        = 8.2020E-12
Moment Coeff. of Skewness                = 2.2370E+01
Pearson's 2nd Coeff. of Skewness         = 5.8369E-01
Kurtosis                                 = 6.9807E+02
```

```
************************************************************
*      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)       *
*         FOR THE FREQUENCY OF VESSEL FAILURE              *
************************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	13.8900	13.8900
5.5286E-09	81.1267	95.0167
1.6586E-08	2.0033	97.0200
2.7643E-08	0.7900	97.8100
3.8700E-08	0.4767	98.2867
4.9758E-08	0.3133	98.6000
6.0815E-08	0.1667	98.7667
7.1872E-08	0.1300	98.8967
8.2930E-08	0.1067	99.0033
9.3987E-08	0.0700	99.0733
1.0504E-07	0.0833	99.1567
1.1610E-07	0.0600	99.2167
1.2716E-07	0.0600	99.2767
1.3822E-07	0.0367	99.3133
1.4927E-07	0.0767	99.3900
1.6033E-07	0.0200	99.4100
1.7139E-07	0.0367	99.4467
1.8245E-07	0.0467	99.4933

E-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

1.9350E-07	0.0267	99.5200
2.0456E-07	0.0367	99.5567
2.1562E-07	0.0300	99.5867
2.2667E-07	0.0133	99.6000
2.3773E-07	0.0200	99.6200
2.4879E-07	0.0067	99.6267
2.5985E-07	0.0233	99.6500
2.7090E-07	0.0133	99.6633
2.8196E-07	0.0167	99.6800
2.9302E-07	0.0233	99.7033
3.0408E-07	0.0033	99.7067
3.2619E-07	0.0133	99.7200
3.3725E-07	0.0133	99.7333
3.4830E-07	0.0100	99.7433
3.7042E-07	0.0033	99.7467
3.8148E-07	0.0067	99.7533
3.9253E-07	0.0133	99.7667
4.1465E-07	0.0067	99.7733
4.2571E-07	0.0067	99.7800
4.4782E-07	0.0067	99.7867
4.5888E-07	0.0067	99.7933
4.6993E-07	0.0033	99.7967
4.8099E-07	0.0033	99.8000
4.9205E-07	0.0067	99.8067
5.0311E-07	0.0033	99.8100
5.1416E-07	0.0067	99.8167
5.2522E-07	0.0067	99.8233
5.3628E-07	0.0067	99.8300
5.8051E-07	0.0033	99.8333
6.0262E-07	0.0033	99.8367
6.1368E-07	0.0033	99.8400
6.2474E-07	0.0100	99.8500
6.5791E-07	0.0033	99.8533
6.6897E-07	0.0100	99.8633
7.0214E-07	0.0033	99.8667
7.1319E-07	0.0067	99.8733
7.3531E-07	0.0033	99.8767
7.6848E-07	0.0033	99.8800
8.0165E-07	0.0033	99.8833
8.1271E-07	0.0033	99.8867
8.6800E-07	0.0100	99.8967
8.7905E-07	0.0033	99.9000
8.9011E-07	0.0033	99.9033
9.0117E-07	0.0033	99.9067
9.3434E-07	0.0033	99.9100
9.6751E-07	0.0033	99.9133
9.8963E-07	0.0033	99.9167
1.0670E-06	0.0033	99.9200
1.1223E-06	0.0033	99.9233
1.1444E-06	0.0033	99.9267
1.1555E-06	0.0067	99.9333
1.2550E-06	0.0067	99.9400
1.4872E-06	0.0033	99.9433
1.5204E-06	0.0033	99.9467

E-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

1.5425E-06	0.0033	99.9500
1.6088E-06	0.0033	99.9533
1.6199E-06	0.0033	99.9567
1.8300E-06	0.0033	99.9600
1.9074E-06	0.0033	99.9633
2.4934E-06	0.0033	99.9667
2.6814E-06	0.0033	99.9700
2.7256E-06	0.0033	99.9733
2.8583E-06	0.0033	99.9767
3.6434E-06	0.0033	99.9800
3.8645E-06	0.0033	99.9833
3.9419E-06	0.0033	99.9867
5.0476E-06	0.0033	99.9900
7.4913E-06	0.0033	99.9933
1.1583E-05	0.0033	99.9967
1.5132E-05	0.0033	100.0000

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

Minimum                               = 0.0000E+00
Maximum                               = 1.5134E-05
Range                                 = 1.5134E-05

Number of Simulations                 =  30000

5th Percentile                        = 0.0000E+00
Median                                = 1.7324E-11
95.0th Percentile                     = 5.5286E-09
99.0th Percentile                     = 8.2584E-08
99.9th Percentile                     = 8.7905E-07

Mean                                  = 6.7052E-09
Standard Deviation                    = 1.3840E-07
Standard Error                        = 7.9904E-10
Variance (unbiased)                   = 1.9154E-14
Variance (biased)                     = 1.9153E-14
Moment Coeff. of Skewness             = 7.3714E+01
Pearson's 2nd Coeff. of Skewness      =-1.5340E+00
Kurtosis                              = 6.8160E+03

**********************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON  *
*             AND FREQUENCY OF RPV FAILURE BY            *
*                       TRANSIENT                        *
*     WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
**********************************************************
```

	% of total frequency of crack initiation	% of total frequency of of RPV failure
7	14.45	3.68
9	6.51	0.37
56	77.19	35.46

E-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

60	0.07	5.07
96	0.50	2.00
97	0.22	11.16
101	0.47	39.07
102	0.12	0.13
103	0.12	1.28
104	0.21	0.16
105	0.13	1.62
108	0.01	0.00
TOTALS	100.00	100.00

DATE: 16-Sep-2003 TIME: 11:27:51

E-3: 10 Year ISI Only, FAVOR 02.4

```
************************************************
*                                              *
*               WELCOME TO FAVOR               *
*                                              *
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
*                 VERSION 02.4                 *
*                                              *
*     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         *
*                                              *
*           phone : (865) 574-0650             *
*           fax   : (865) 574-0651             *
*         e-mail: dicksontl@ornl.gov           *
*                                              *
************************************************

***********************************************************
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*                                                         *
*           All rights reserved.                          *
***********************************************************


DATE: 11-Jul-2003  TIME: 10:59:06


FAVPOST INPUT  FILE NAME                        = bvdom8_post_input.in
FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME                        = Bv1Zero_post_25000.out
```

E-3: 10 Year ISI Only, FAVOR 02.4 (cont.)

```
**********************************
* NUMBER OF SIMULATIONS =  25000 *
**********************************
```

	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E)			
TRANSIENT NUMBER	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
7	1.4437E-03	2.5467E-03	2.3690E-02	3.4046E-05	2.9928E-05	6.0155E-04	0.0236
9	1.9235E-03	3.6023E-03	3.0119E-02	2.8493E-05	2.1207E-05	4.5205E-04	0.0148
56	1.6441E-03	3.0184E-03	2.5635E-02	4.4468E-05	4.0856E-05	7.2995E-04	0.0270
97	1.4127E-04	8.3028E-05	2.9255E-03	8.6936E-05	2.7579E-05	1.8065E-03	0.6154
102	4.5507E-06	0.0000E+00	2.2201E-08	2.9745E-07	0.0000E+00	0.0000E+00	0.0654
103	3.3463E-05	2.0133E-06	2.7180E-04	4.8487E-06	1.4507E-08	2.4763E-05	0.1449
104	4.5507E-06	0.0000E+00	2.2201E-08	2.9745E-07	0.0000E+00	0.0000E+00	0.0654
105	3.3463E-05	2.0133E-06	2.7180E-04	4.8412E-06	1.4306E-08	2.4134E-05	0.1447

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

E-3: 10 Year ISI Only, FAVOR 02.4 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	5.2640	5.2640
4.8543E-07	89.7440	95.0080
1.4563E-06	2.1320	97.1400
2.4271E-06	0.8880	98.0280
3.3980E-06	0.5520	98.5800
4.3688E-06	0.3120	98.8920
5.3397E-06	0.2160	99.1080
6.3105E-06	0.1440	99.2520
7.2814E-06	0.1560	99.4080
8.2522E-06	0.0800	99.4880
9.2231E-06	0.0720	99.5600
1.0194E-05	0.0440	99.6040
1.1165E-05	0.0360	99.6400
1.2136E-05	0.0280	99.6680
1.3107E-05	0.0240	99.6920
1.4077E-05	0.0440	99.7360
1.5048E-05	0.0320	99.7680
1.6019E-05	0.0240	99.7920
1.6990E-05	0.0120	99.8040
1.7961E-05	0.0200	99.8240
1.8932E-05	0.0200	99.8440
1.9902E-05	0.0280	99.8720
2.0873E-05	0.0040	99.8760
2.1844E-05	0.0120	99.8880
2.2815E-05	0.0040	99.8920
2.3786E-05	0.0040	99.8960
2.4757E-05	0.0080	99.9040
2.6698E-05	0.0120	99.9160
2.7669E-05	0.0080	99.9240
2.9611E-05	0.0040	99.9280
3.0582E-05	0.0120	99.9400
3.2524E-05	0.0040	99.9440
3.3494E-05	0.0080	99.9520
4.0290E-05	0.0040	99.9560
4.2232E-05	0.0040	99.9600
4.5145E-05	0.0040	99.9640
4.6115E-05	0.0040	99.9680
4.7086E-05	0.0040	99.9720
5.4853E-05	0.0040	99.9760
5.5824E-05	0.0040	99.9800
6.7474E-05	0.0040	99.9840
7.6212E-05	0.0040	99.9880
7.7183E-05	0.0040	99.9920
8.9804E-05	0.0040	99.9960
1.7912E-04	0.0040	100.0000

E-3: 10 Year ISI Only, FAVOR 02.4 (cont.)

```
*********** Descriptive Statistics ***********

Minimum                               = 0.0000E+00
Maximum                               = 1.7954E-04
Range                                 = 1.7954E-04

Number of Simulations                 =  25000

5th Percentile                        = 0.0000E+00
Median                                = 7.4237E-09
95.0th Percentile                     = 4.8543E-07
99.0th Percentile                     = 4.8543E-06
99.9th Percentile                     = 2.4271E-05

Mean                                  = 2.9031E-07
Standard Deviation                    = 2.1510E-06
Standard Error                        = 1.3604E-08
Variance (unbiased)                   = 4.6268E-12
Variance (biased)                     = 4.6266E-12
Moment Coeff. of Skewness             = 3.6708E+01
Pearson's 2nd Coeff. of Skewness      = 4.0489E-01
Kurtosis                              = 2.3118E+03
```

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************************************************************
*      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)       *
*         FOR THE FREQUENCY OF VESSEL FAILURE              *
************************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	37.3400	37.3400
7.3027E-09	57.6640	95.0040
2.1908E-08	1.7280	96.7320
3.6514E-08	0.7960	97.5280
5.1119E-08	0.5080	98.0360
6.5725E-08	0.3120	98.3480
8.0330E-08	0.1720	98.5200
9.4936E-08	0.1720	98.6920
1.0954E-07	0.1200	98.8120
1.2415E-07	0.1560	98.9680
1.3875E-07	0.0840	99.0520
1.5336E-07	0.0560	99.1080
1.6796E-07	0.0520	99.1600
1.8257E-07	0.0840	99.2440
1.9717E-07	0.0800	99.3240
2.1178E-07	0.0560	99.3800
2.2639E-07	0.0560	99.4360
2.4099E-07	0.0480	99.4840
2.5560E-07	0.0200	99.5040

E-3: 10 Year ISI Only, FAVOR 02.4 (cont.)

2.7020E-07	0.0160	99.5200
2.8481E-07	0.0280	99.5480
2.9941E-07	0.0200	99.5680
3.1402E-07	0.0320	99.6000
3.2862E-07	0.0440	99.6440
3.4323E-07	0.0120	99.6560
3.5783E-07	0.0080	99.6640
3.7244E-07	0.0120	99.6760
4.0165E-07	0.0240	99.7000
4.1626E-07	0.0040	99.7040
4.3086E-07	0.0160	99.7200
4.4547E-07	0.0040	99.7240
4.6007E-07	0.0120	99.7360
4.7468E-07	0.0120	99.7480
5.0389E-07	0.0120	99.7600
5.1850E-07	0.0080	99.7680
5.3310E-07	0.0200	99.7880
5.6231E-07	0.0040	99.7920
5.9152E-07	0.0120	99.8040
6.2073E-07	0.0040	99.8080
6.3534E-07	0.0080	99.8160
6.4994E-07	0.0080	99.8240
6.7916E-07	0.0040	99.8280
6.9376E-07	0.0080	99.8360
7.0837E-07	0.0080	99.8440
7.2297E-07	0.0040	99.8480
7.3758E-07	0.0040	99.8520
7.6679E-07	0.0120	99.8640
7.8139E-07	0.0080	99.8720
7.9600E-07	0.0040	99.8760
8.2521E-07	0.0040	99.8800
8.8363E-07	0.0080	99.8880
9.1284E-07	0.0080	99.8960
9.2745E-07	0.0080	99.9040
9.5666E-07	0.0040	99.9080
1.0005E-06	0.0040	99.9120
1.0151E-06	0.0040	99.9160
1.1319E-06	0.0040	99.9200
1.2196E-06	0.0040	99.9240
1.3510E-06	0.0040	99.9280
1.4386E-06	0.0040	99.9320
1.4825E-06	0.0080	99.9400
1.5117E-06	0.0040	99.9440
1.5993E-06	0.0040	99.9480
1.7600E-06	0.0040	99.9520
1.8330E-06	0.0040	99.9560
1.8476E-06	0.0040	99.9600
1.9060E-06	0.0040	99.9640
2.3880E-06	0.0040	99.9680
2.5048E-06	0.0040	99.9720
2.7970E-06	0.0040	99.9760
3.3520E-06	0.0040	99.9800
3.6733E-06	0.0040	99.9840
4.2429E-06	0.0040	99.9880

E-3: 10 Year ISI Only, FAVOR 02.4 (cont.)

```
6.1270E-06          0.0040       99.9920
7.4123E-06          0.0040       99.9960
1.2553E-05          0.0040      100.0000


*********** Descriptive Statistics ***********

Minimum                               = 0.0000E+00
Maximum                               = 1.2551E-05
Range                                 = 1.2551E-05

Number of Simulations                 =  25000

5th Percentile                        = 0.0000E+00
Median                                = 1.2100E-13
95.0th Percentile                     = 7.3027E-09
99.0th Percentile                     = 1.2971E-07
99.9th Percentile                     = 9.2015E-07

Mean                                  = 7.8474E-09
Standard Deviation                    = 1.2294E-07
Standard Error                        = 7.7754E-10
Variance (unbiased)                   = 1.5114E-14
Variance (biased)                     = 1.5113E-14
Moment Coeff. of Skewness             = 6.2224E+01
Pearson's 2nd Coeff. of Skewness      = 1.0339E-02
Kurtosis                              = 5.2580E+03

***********************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON   *
*             AND FREQUENCY OF RPV FAILURE BY             *
*                        TRANSIENT                        *
*      WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
***********************************************************
```

	% of total frequency of crack initiation	% of total frequency of of RPV failure
7	11.96	12.47
9	6.75	3.34
56	80.47	77.23
97	0.21	4.75
102	0.19	0.57
103	0.13	0.70
104	0.17	0.29
105	0.12	0.66
TOTALS	100.00	100.00

DATE: 11-Jul-2003 TIME: 10:59:36

E-4: ISI Every 10 Years, FAVOR 02.4

```
      ***********************************************
      *                                             *
      *             WELCOME TO FAVOR                *
      *                                             *
      *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE   *
      *               VERSION 02.4                  *
      *                                             *
      *    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        *
      *                                             *
      *          phone : (865) 574-0650             *
      *          fax   : (865) 574-0651             *
      *        e-mail: dicksontl@ornl.gov           *
      *                                             *
      ***********************************************

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 * privately-owned rights.                                *
 *                                                        *
 *          All rights reserved.                          *
 **********************************************************


      DATE: 11-Jul-2003  TIME: 11:05:16


      FAVPOST INPUT  FILE NAME                         =
bvdom8_post_input.in
      FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
      FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
      FAVPOST OUTPUT FILE NAME                         =
Bv110_post_25000.out
```

E-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

```
***********************************
* NUMBER OF SIMULATIONS =  25000 *
***********************************
```

TRANSIENT NUMBER	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E)			
7	9.2441E-04	1.6611E-03	1.3052E-02	3.0049E-05	2.8060E-05	5.3548E-04	0.0325
9	1.3952E-03	2.7780E-03	1.9446E-02	2.4848E-05	2.0620E-05	4.3608E-04	0.0178
56	1.1244E-03	2.1172E-03	1.5299E-02	3.9441E-05	4.0333E-05	6.8567E-04	0.0351
97	5.9755E-05	2.0435E-05	6.7435E-04	2.0851E-05	7.2339E-06	2.6042E-04	0.3489
102	1.4913E-06	0.0000E+00	7.2551E-09	3.1117E-08	0.0000E+00	0.0000E+00	0.0209
103	1.8897E-05	1.1989E-06	1.9062E-04	2.3934E-06	4.2677E-09	1.4455E-05	0.1267
104	1.4913E-06	0.0000E+00	7.2551E-09	3.1117E-08	0.0000E+00	0.0000E+00	0.0209
105	1.8897E-05	1.1989E-06	1.9062E-04	2.3934E-06	4.2388E-09	1.4459E-05	0.1267

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

E-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	5.7720	5.7720
3.5535E-07	89.2280	95.0000
1.0660E-06	2.4320	97.4320
1.7767E-06	0.9040	98.3360
2.4874E-06	0.4880	98.8240
3.1981E-06	0.2840	99.1080
3.9088E-06	0.2040	99.3120
4.6195E-06	0.1200	99.4320
5.3302E-06	0.0840	99.5160
6.0409E-06	0.0680	99.5840
6.7516E-06	0.0280	99.6120
7.4623E-06	0.0320	99.6440
8.1730E-06	0.0520	99.6960
8.8837E-06	0.0240	99.7200
9.5944E-06	0.0160	99.7360
1.0305E-05	0.0160	99.7520
1.1016E-05	0.0160	99.7680
1.1726E-05	0.0240	99.7920
1.2437E-05	0.0240	99.8160
1.3148E-05	0.0120	99.8280
1.3859E-05	0.0200	99.8480
1.4569E-05	0.0080	99.8560
1.5280E-05	0.0080	99.8640
1.5991E-05	0.0120	99.8760
1.6701E-05	0.0120	99.8880
1.7412E-05	0.0080	99.8960
1.8123E-05	0.0080	99.9040
1.8833E-05	0.0120	99.9160
1.9544E-05	0.0040	99.9200
2.0255E-05	0.0040	99.9240
2.0966E-05	0.0040	99.9280
2.1676E-05	0.0040	99.9320
2.2387E-05	0.0040	99.9360
2.3808E-05	0.0040	99.9400
2.5230E-05	0.0040	99.9440
2.6651E-05	0.0040	99.9480
2.7362E-05	0.0040	99.9520
2.8783E-05	0.0040	99.9560
3.1626E-05	0.0040	99.9600
3.5890E-05	0.0040	99.9640
3.6601E-05	0.0040	99.9680
3.8733E-05	0.0040	99.9720
4.2286E-05	0.0040	99.9760
4.3708E-05	0.0040	99.9800
4.5840E-05	0.0040	99.9840

E-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

5.0104E-05	0.0040	99.9880
5.6500E-05	0.0040	99.9920
7.4268E-05	0.0040	99.9960
8.4217E-05	0.0040	100.0000

*********** Descriptive Statistics ***********

Minimum	= 0.0000E+00
Maximum	= 8.4182E-05
Range	= 8.4182E-05
Number of Simulations	= 25000
5th Percentile	= 0.0000E+00
Median	= 5.6790E-09
95.0th Percentile	= 3.5535E-07
99.0th Percentile	= 2.9279E-06
99.9th Percentile	= 1.7767E-05
Mean	= 1.9914E-07
Standard Deviation	= 1.4286E-06
Standard Error	= 9.0355E-09
Variance (unbiased)	= 2.0410E-12
Variance (biased)	= 2.0409E-12
Moment Coeff. of Skewness	= 2.7818E+01
Pearson's 2nd Coeff. of Skewness	= 4.1818E-01
Kurtosis	= 1.1393E+03

****
* PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM) *
* FOR THE FREQUENCY OF VESSEL FAILURE *
****

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	38.9920	38.9920
5.7332E-09	56.0080	95.0000
1.7200E-08	1.5960	96.5960
2.8666E-08	0.8240	97.4200
4.0132E-08	0.5360	97.9560
5.1599E-08	0.3600	98.3160
6.3065E-08	0.2080	98.5240
7.4532E-08	0.1480	98.6720
8.5998E-08	0.1440	98.8160
9.7464E-08	0.1360	98.9520
1.0893E-07	0.0880	99.0400
1.2040E-07	0.0480	99.0880
1.3186E-07	0.0920	99.1800
1.4333E-07	0.0240	99.2040

E-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

1.5480E-07	0.0680	99.2720
1.6626E-07	0.0280	99.3000
1.7773E-07	0.0440	99.3440
1.8920E-07	0.0280	99.3720
2.0066E-07	0.0400	99.4120
2.1213E-07	0.0320	99.4440
2.2359E-07	0.0040	99.4480
2.3506E-07	0.0280	99.4760
2.4653E-07	0.0160	99.4920
2.5799E-07	0.0160	99.5080
2.6946E-07	0.0240	99.5320
2.8093E-07	0.0200	99.5520
2.9239E-07	0.0160	99.5680
3.0386E-07	0.0040	99.5720
3.1533E-07	0.0120	99.5840
3.2679E-07	0.0080	99.5920
3.3826E-07	0.0080	99.6000
3.4973E-07	0.0080	99.6080
3.6119E-07	0.0120	99.6200
3.7266E-07	0.0080	99.6280
3.8412E-07	0.0040	99.6320
3.9559E-07	0.0120	99.6440
4.0706E-07	0.0120	99.6560
4.1852E-07	0.0040	99.6600
4.2999E-07	0.0040	99.6640
4.4146E-07	0.0040	99.6680
4.5292E-07	0.0120	99.6800
4.6439E-07	0.0080	99.6880
4.7586E-07	0.0080	99.6960
4.8732E-07	0.0160	99.7120
4.9879E-07	0.0080	99.7200
5.1025E-07	0.0040	99.7240
5.3319E-07	0.0160	99.7400
5.4465E-07	0.0080	99.7480
5.7905E-07	0.0040	99.7520
6.0199E-07	0.0080	99.7600
6.1345E-07	0.0040	99.7640
6.2492E-07	0.0120	99.7760
6.3639E-07	0.0040	99.7800
6.4785E-07	0.0040	99.7840
6.5932E-07	0.0080	99.7920
6.7078E-07	0.0120	99.8040
6.8225E-07	0.0080	99.8120
6.9372E-07	0.0040	99.8160
7.2812E-07	0.0120	99.8280
7.5105E-07	0.0080	99.8360
7.6252E-07	0.0040	99.8400
7.7398E-07	0.0120	99.8520
7.8545E-07	0.0040	99.8560
8.3131E-07	0.0040	99.8600
8.4278E-07	0.0040	99.8640
8.7718E-07	0.0080	99.8720
9.0011E-07	0.0080	99.8800
9.1158E-07	0.0040	99.8840

E-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

9.6891E-07	0.0080	99.8920
1.0033E-06	0.0080	99.9000
1.1065E-06	0.0040	99.9040
1.1409E-06	0.0040	99.9080
1.1638E-06	0.0120	99.9200
1.3129E-06	0.0080	99.9280
1.3244E-06	0.0040	99.9320
1.5193E-06	0.0040	99.9360
1.7372E-06	0.0040	99.9400
2.0009E-06	0.0040	99.9440
2.0124E-06	0.0040	99.9480
2.1729E-06	0.0040	99.9520
2.2073E-06	0.0040	99.9560
2.3449E-06	0.0040	99.9600
2.4939E-06	0.0040	99.9640
2.6201E-06	0.0080	99.9720
2.7003E-06	0.0040	99.9760
2.7921E-06	0.0040	99.9800
3.6979E-06	0.0040	99.9840
3.9846E-06	0.0040	99.9880
4.2712E-06	0.0040	99.9920
4.6382E-06	0.0040	99.9960
5.1656E-06	0.0040	100.0000

```
*********** Descriptive Statistics ***********

Minimum                                   = 0.0000E+00
Maximum                                   = 5.1710E-06
Range                                     = 5.1710E-06

Number of Simulations                     =  25000

5th Percentile                            = 0.0000E+00
Median                                    = 4.7634E-14
95.0th Percentile                         = 5.7332E-09
99.0th Percentile                         = 1.0372E-07
99.9th Percentile                         = 1.0033E-06

Mean                                      = 7.1099E-09
Standard Deviation                        = 9.1079E-08
Standard Error                            = 5.7604E-10
Variance (unbiased)                       = 8.2955E-15
Variance (biased)                         = 8.2951E-15
Moment Coeff. of Skewness                 = 3.2522E+01
Pearson's 2nd Coeff. of Skewness          = 4.7131E-02
Kurtosis                                  = 1.3589E+03

************************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON    *
*             AND FREQUENCY OF RPV FAILURE BY              *
*                        TRANSIENT                         *
*      WEIGHTED BY TRANSIENT INITIATING FREQUENCIES        *
************************************************************
```

E-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

	% of total frequency of crack initiation	% of total frequency of of RPV failure
7	10.78	11.48
9	6.33	4.17
56	82.41	82.22
97	0.10	1.09
102	0.08	0.08
103	0.13	0.41
104	0.09	0.08
105	0.09	0.46
TOTALS	100.00	100.00

DATE: 11-Jul-2003 TIME: 11:05:43

APPENDIX F
INPUTS FOR PALISADES PILOT PLANT EVALUATION

A summary of the NDE inspection history based on ASME Section XI Appendix VIII 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, B-D, and B-J vessel welds assuming all of the candidate welds were inspected: 2 (covering all welds of the specified categories).

2. The inspections performed covered 100 percent of all welds.

3. Number of indications found to date: 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 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 [7], Figure 4.3.

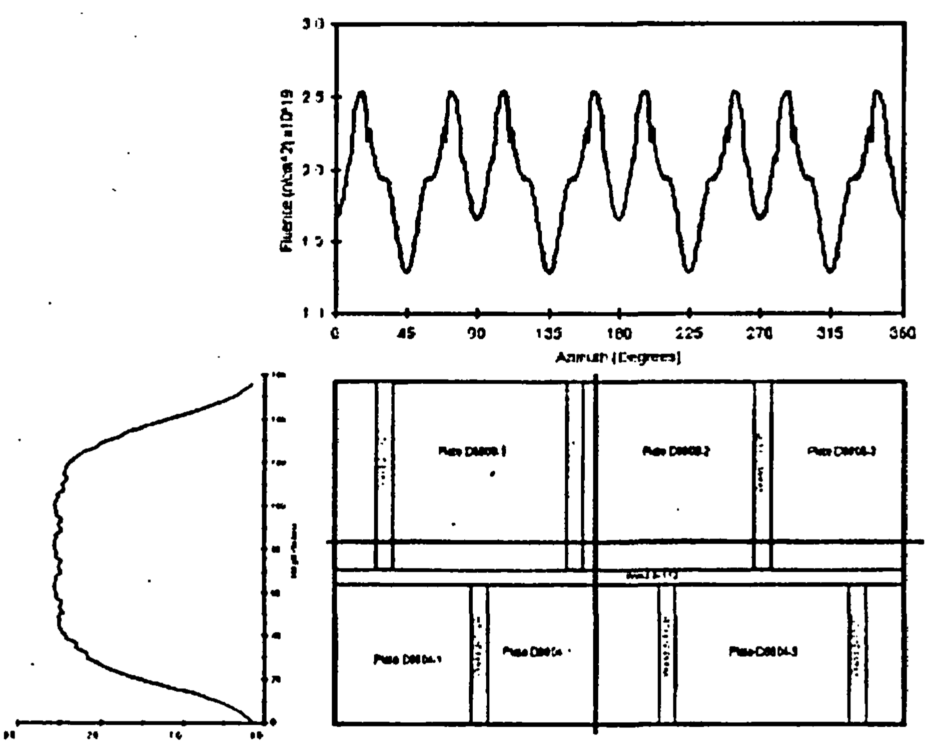

Figure F-1 Rollout Diagram of Beltline Materials and Representative Fluence Maps for Palisades

6. Vessel cladding details:

   a. Thickness: 0.25 inches

   b. Material properties (assumed to be independent of temperature):

      1) Thermal conductivity (Btu/hr-ft-°F), K=10.0
      2) Specific heat (Btu/LBM-°F),C=0.120
      3) Density (LBM/ft^3).RHO=489.00
      4) Young's Modulus of Elasticity (KSI), E=22800
      5) Thermal expansion coefficient (°F^{-1}), ALPHA=0.00000945
      6) 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 F-1. This is consistent with the NRC PTS Risk Study [7].

   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 vessel failure probabilities.

      2) Truncation limit: Cladding thickness rounded to the next 1/100th of the total vessel thickness to be consistent with the NRC PTS Risk Study [7].

      3) Surface flaw depth: 0.263 inch

      4) All flaws are surface-breaking. Only flaws in cladding that would influence brittle fracture of the vessel are brittle. This is consistent with the NRC PTS Risk Study [7].

   e. Additional cladding properties are identified in Table F-2.

7. Base metal:

   a. Wall thickness: 8.5 inches

   b. Material properties (assumed to be independent of temperature):

      1) Thermal conductivity (Btu/hr-ft-°F), K=24.0
      2) Specific heat (Btu/LBM-°F),C=0.120
      3) Density (LBM/ft^3).RHO=489.00
      4) Young's Modulus of Elasticity (KSI), E=28000
      5) Thermal expansion coefficient (°F^{-1}), ALPHA=0.00000777

6) Poisson's Ratio, V=0.3
7) Other material properties are identified in Table F-1

Table F-1 Palisades-Specific Material Values Drawn from the RVID (see Ref. 7 Table 4.1)

Major Material Region Description				Cu [wt%]	Ni [wt%]	P [wt%]	Un-Irradiated RT_{NDT}		RT_{PTS} @60 EFPY
#	Type	Heat	Location				[°F]	Method	
1	Axial Weld	3-112A	lower	0.213	1.010	0.019	- 56	Generic	276.4
2	Axial Weld	3-112B	lower	0.213	1.010	0.019	- 56	Generic	285.3
3	Axial Weld	3-112C	lower	0.213	1.010	0.019	- 56	Generic	285.3
4	Axial Weld	2-112A	lower	0.213	1.010	0.019	- 56	Generic	285.8
5	Axial Weld	2-112B	lower	0.213	1.010	0.019	- 56	Generic	276.7
6	Axial Weld	2-112C	lower	0.213	1.010	0.019	- 56	Generic	285.8
7	Circ Weld	9-112	intermediate	0.203	1.018	0.013	- 56	Generic	270.3
8	Plate	D3804-1	lower	0.190	0.480	0.016	0	ASME NB-2331	261.9
9	Plate	D3804-2	lower	0.190	0.500	0.015	-30	MTEB 5-2	230.5
10	Plate	D3804-3	lower	0.120	0.550	0.010	-25	MTEB 5-2	170.0
11	Plate	D3803-1	upper	0.240	0.510	0.009	-5	ASME NB-2331	261.5
12	Plate	D3803-2	upper	0.240	0.520	0.010	-30	MTEB 5-2	242.4
13	Plate	D3803-3	upper	0.240	0.500	0.011	-5	ASME NB-2331	268.1

8. The RT_{NDT}* screening criteria determined in the NRC PTS Risk Study [7] for a plant life of 60 EFPY is: 224.5°F

9. Weld metal details: Details of information used in addressing weld-specific information are taken directly from the NRC PTS Risk Study [7], Table 4.2. Summaries are reproduced as Table F-2.

Table F-2 Summary of 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	[in]	0.1875	0.1875	0.1875	0.1875	All plants report plant specific dimensions of 3/16-in.
	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-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

	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-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

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	[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 F-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

	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 1/100th 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 1/100th of the total vessel wall thickness.				Judgment.

Table F-2 (cont.) Summary of Vessel-Specific Inputs for Flaw Distribution

	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.

APPENDIX G
PALISADES PROBSBFD OUTPUT

G-1: 10 Year ISI Only

```
                    STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

 WESTINGHOUSE       MONTE-CARLO SIMULATION PROGRAM PROBSBFD      VERSION 1.0

============================================================================
      INPUT VARIABLES FOR CASE  4: PAL RPV with 13 HUCD/Yr & 10/80 Year ISI

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

    VARIABLE        DISTRIBUTION      MEDIAN      DEVIATION    SHIFT    USAGE
   NO.   NAME       TYPE     LOG       VALUE      OR FACTOR    MV/SD   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  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 -    1.0720D+01                          2  FMD
   18  Percent3     - CONSTANT -    4.3807D+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    3.05502D+00    1.33249D+01
    1.61000D-01    4.09518D+00    1.80304D+01
    4.37500D-01    1.14807D+01    1.90708D+01
    6.56250D-01    1.44441D+01    2.21925D+01
    8.75000D-01    1.66458D+01    2.45743D+01
    1.75000D+00    1.77348D+01    2.79095D+01
    2.62500D+00    1.14581D+01    2.57436D+01
    4.37500D+00   -1.01868D+00    2.29661D+01
```

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

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.75000D-02	4.59002D+00	2.01522D+01
1.61000D-01	6.27818D+00	2.77886D+01
4.37500D-01	1.66092D+01	2.98611D+01
6.56250D-01	2.08977D+01	3.43867D+01
8.75000D-01	2.47181D+01	3.85427D+01
1.75000D+00	3.32686D+01	4.67825D+01
2.62500D+00	2.77732D+01	4.78251D+01
4.37500D+00	1.47438D+01	4.88449D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.75000D-02	5.02858D+00	2.20994D+01
1.61000D-01	6.71137D+00	2.97252D+01
4.37500D-01	1.76117D+01	3.21960D+01
6.56250D-01	2.22171D+01	3.68605D+01
8.75000D-01	2.63585D+01	4.13491D+01
1.75000D+00	3.63813D+01	5.11052D+01
2.62500D+00	3.33241D+01	5.50487D+01
4.37500D+00	2.04164D+01	5.90727D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.75000D-02	6.47196D+00	2.26626D+01
1.75000D-01	9.14245D+00	3.17318D+01
2.62500D-01	1.24235D+01	3.44137D+01
4.37500D-01	1.91260D+01	3.36597D+01
6.56250D-01	2.50715D+01	3.97536D+01
8.75000D-01	2.94707D+01	4.47170D+01
1.75000D+00	4.20958D+01	5.90486D+01
2.62500D+00	4.05940D+01	6.75348D+01

AVERAGE CALCULATED VALUES FOR: Surface Flaw Density & FCG & 10 yr ISI

NUMBER FAILED = 0 NUMBER OF TRIALS = 1000

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

12	2.0557D-04	1.8607D-06	4.8763D-07	3.1569D-07
13	5.1983D-05	1.7561D-05	6.4059D-06	6.6519D-06
14	7.4643D-07	9.2736D-06	3.8699D-06	5.7725D-06
15	2.4340D-07	3.2547D-06	1.7732D-06	3.1509D-06
16	0.0000D+00	1.1545D-06	7.2028D-07	1.5060D-06
17	0.0000D+00	4.0649D-07	2.5533D-07	6.6300D-07
18	0.0000D+00	2.1495D-07	1.4917D-07	3.0567D-07
19	0.0000D+00	1.4966D-07	3.6579D-08	1.3222D-07
20	0.0000D+00	5.8851D-08	5.9633D-08	1.1358D-07
21	0.0000D+00	0.0000D+00	2.3388D-08	7.8196D-08
22	0.0000D+00	0.0000D+00	0.0000D+00	3.0568D-08
23	0.0000D+00	0.0000D+00	0.0000D+00	1.5116D-08
24	0.0000D+00	2.6973D-08	0.0000D+00	0.0000D+00
26	0.0000D+00	2.5766D-08	1.0574D-08	0.0000D+00

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

29	0.0000D+00	0.0000D+00	1.0026D-08	1.3292D-08
32	0.0000D+00	0.0000D+00	0.0000D+00	1.2394D-08

G-2: ISI Every 10 Years

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

=============================================================================
     INPUT VARIABLES FOR CASE  5: PAL RPV with 13 HUCD/Yr & 10/10 Year ISI

     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 -		9.9000D+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 -		1.0720D+01			2	FMD
18	Percent3	- CONSTANT -		4.3807D+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	3.05502D+00	1.33249D+01
1.61000D-01	4.09518D+00	1.80304D+01
4.37500D-01	1.14807D+01	1.90708D+01
6.56250D-01	1.44441D+01	2.21925D+01
8.75000D-01	1.66458D+01	2.45743D+01
1.75000D+00	1.77348D+01	2.79095D+01
2.62500D+00	1.14581D+01	2.57436D+01
4.37500D+00	-1.01868D+00	2.29661D+01

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

TYPE 2 WITH AN ASPECT RATIO OF 6.

8.75000D-02	4.59002D+00	2.01522D+01
1.61000D-01	6.27818D+00	2.77886D+01
4.37500D-01	1.66092D+01	2.98611D+01
6.56250D-01	2.08977D+01	3.43867D+01
8.75000D-01	2.47181D+01	3.85427D+01
1.75000D+00	3.32686D+01	4.67825D+01
2.62500D+00	2.77732D+01	4.78251D+01
4.37500D+00	1.47438D+01	4.88449D+01

TYPE 3 WITH AN ASPECT RATIO OF 10.

8.75000D-02	5.02858D+00	2.20994D+01
1.61000D-01	6.71137D+00	2.97252D+01
4.37500D-01	1.76117D+01	3.21960D+01
6.56250D-01	2.22171D+01	3.68605D+01
8.75000D-01	2.63585D+01	4.13491D+01
1.75000D+00	3.63813D+01	5.11052D+01
2.62500D+00	3.33241D+01	5.50487D+01
4.37500D+00	2.04164D+01	5.90727D+01

TYPE 4 WITH AN ASPECT RATIO OF 99.

8.75000D-02	6.47196D+00	2.26626D+01
1.75000D-01	9.14245D+00	3.17318D+01
2.62500D-01	1.24235D+01	3.44137D+01
4.37500D-01	1.91260D+01	3.36597D+01
6.56250D-01	2.50715D+01	3.97536D+01
8.75000D-01	2.94707D+01	4.47170D+01
1.75000D+00	4.20958D+01	5.90486D+01
2.62500D+00	4.05940D+01	6.75348D+01

AVERAGE CALCULATED VALUES FOR: Surface Flaw Density & FCG & 10/10 ISI

NUMBER FAILED = 0 NUMBER OF TRIALS = 1000

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

12	9.3317D-11	7.6505D-13	1.9848D-13	1.2667D-13
13	1.7061D-11	4.8045D-12	1.6957D-12	1.6999D-12
14	1.1274D-13	1.2526D-12	5.1299D-13	7.4932D-13
15	1.9307D-14	2.0515D-13	1.1187D-13	1.8879D-13
16	0.0000D+00	3.3386D-14	2.0526D-14	3.9590D-14
17	0.0000D+00	5.0963D-15	3.1179D-15	7.4676D-15
18	0.0000D+00	1.4210D-15	7.2042D-16	1.4380D-15
19	0.0000D+00	3.8262D-16	8.6445D-17	2.5247D-16
20	0.0000D+00	7.7539D-17	5.9401D-17	1.1097D-16
21	0.0000D+00	0.0000D+00	1.0444D-17	2.0478D-17
22	0.0000D+00	0.0000D+00	0.0000D+00	3.3859D-18
23	0.0000D+00	0.0000D+00	0.0000D+00	1.0727D-18
24	0.0000D+00	8.4691D-19	0.0000D+00	0.0000D+00
26	0.0000D+00	8.1900D-20	4.6299D-20	0.0000D+00

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

29	0.0000D+00	0.0000D+00	2.3727D-21	3.3134D-21
32	0.0000D+00	0.0000D+00	0.0000D+00	7.1841D-23

APPENDIX H
PALISADES DOMINANT PTS TRANSIENTS

Table H-1 Palisades Major Transients Contributing to PTS Risk [7]

Break Description	PRA BIN Description	Palisades Specific Notes	
		Description	Mean Frequency
Primary System: LOCAs	SBLOCA (1.4 – 4.0 inch)	TH 58: 4-inch cold leg break, winter conditions	2.7E-04
		TH 59: 4-inch cold leg break, winter conditions	2.1E-04
		TH 60: 2-inch surge line break, winter conditions	2.1E-04
	MBLOCA (4.0 – 8.0 inch)	TH 62: 8-inch cold leg break, winter conditions	7.1E-06
		TH 63: 5.656 inch cold leg break, winter conditions	6.1E-06
		TH 64: 4-inch surge line break, summer conditions	7.1E-06
	LBLOCA (greater than 8.0 inch)	TH 40: 16-inch hot leg break	3.2E-05
Primary System: Stuck-Open Valves	SRV stuck open/recloses	TH 65: Reactor/turbine trip with 1 stuck-open pressurizer SRV that recloses at 6000 sec, at HZP, no HPI throttling or charging control	1.3E-04
Secondary System: MSLBs	Large MSLBs	TH 54: MSLB with failure of both MSIVs to close, break is assumed to be inside containment causing containment spray actuation and RCP trip, operator does not isolate AFW on affected SG, operator does not throttle HPI or control charging.	4.3E-06
Secondary System: Stuck-Open Valves	Secondary Side Stuck-Open Valve	TH 19: Reactor/turbine trip with 1 stuck-open ADV, at HZP operator does not throttle HPI or control charging, AFW continues to feed bad generator	2.3E-03
		TH 52: Reactor/turbine trip with 1 stuck-open ADV, at HZP, operator does not throttle HPI or control charging, failure of both MSIVs to close, AFW continues to feed bad generator	6.4E-04
Secondary System: Stuck-Open Valves	Secondary Side Stuck-Open Valve	TH 55: Reactor/turbine trip with 2 stuck-open ADVs, controller failure resulting in the flow from 2 AFWS pumps into affected SG, operator starts second AFW pump, operator does not throttle HPI or control charging.	2.7E-03

Table H-1 Palisades Major Transients Contributing to PTS Risk [7] (cont.)

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

Case Category	TT/RT, HZP
Primary Failures	None.
Secondary Failures	1 stuck-open ADV on SG-A
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	423.0 K (301.7°F) at 15000 s
Comments	None.

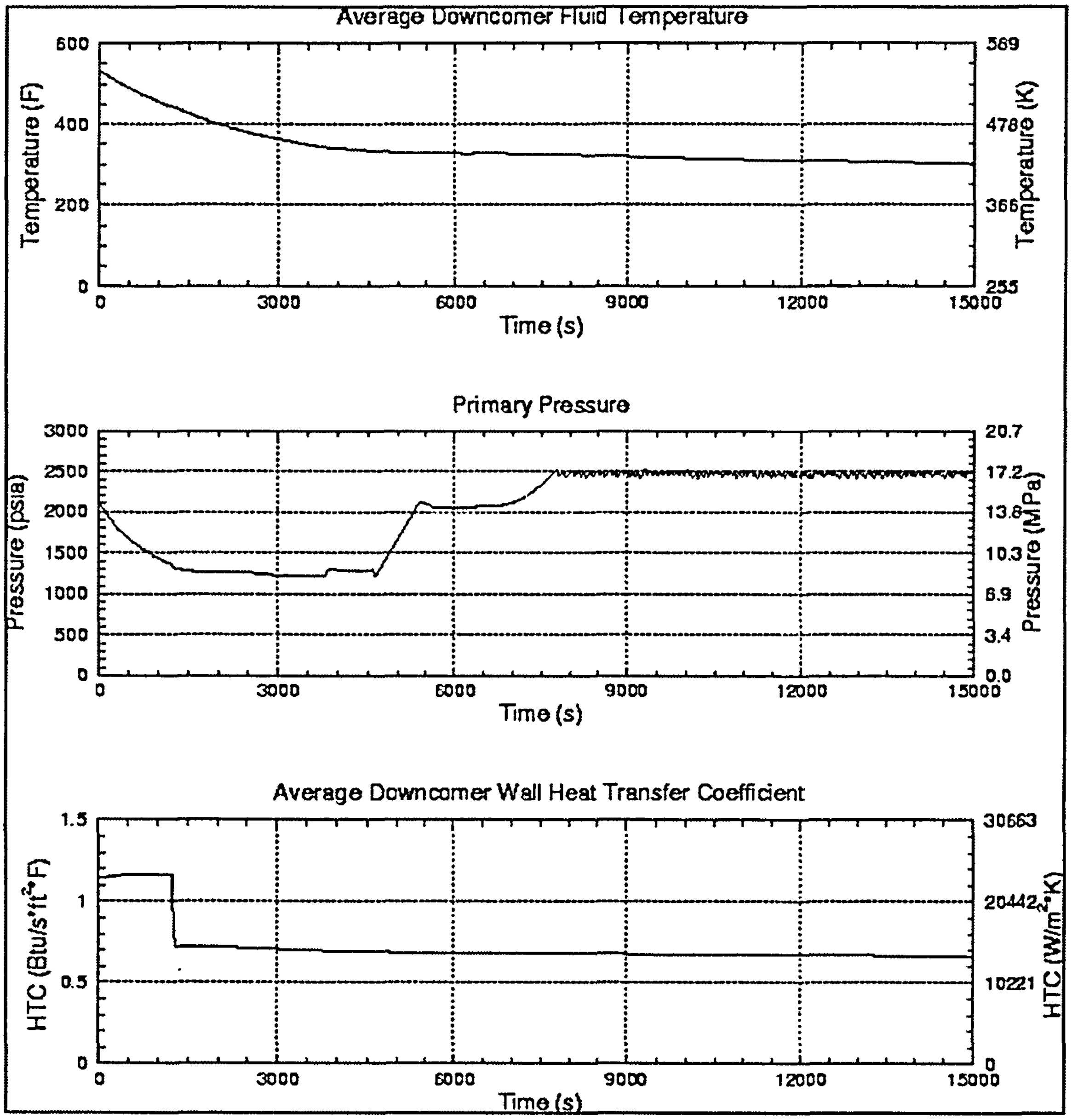

Figure H-1 Palisades PTS Transient 019

Case Category	LOCA
Primary Failures	40.64 cm (16 in) hot leg break. Containment sump recirculation included in the analysis.
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	307.8 K (94.4°F) at 1260 s
Comments	Momentum Flux Disabled in DC

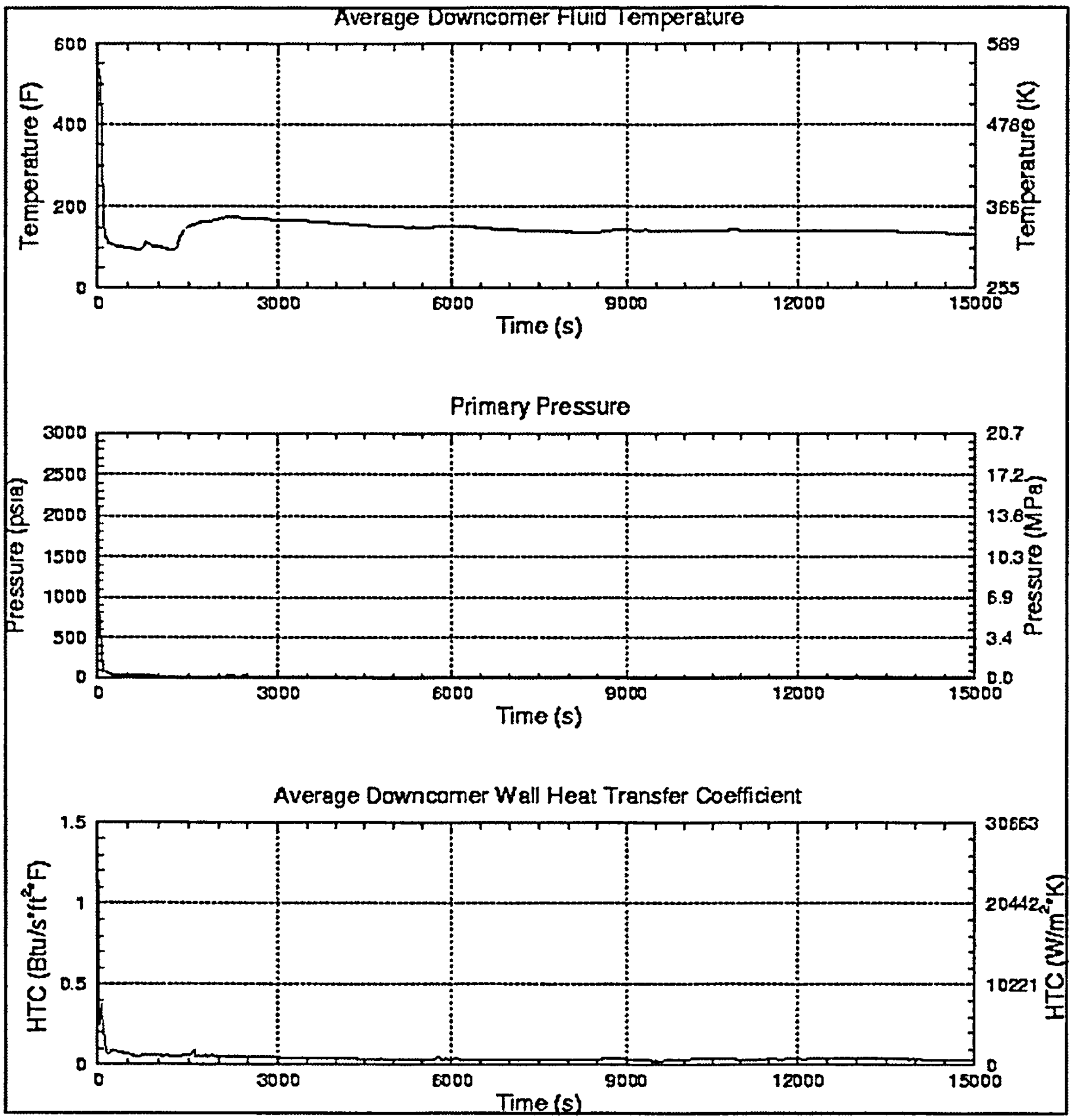

Figure H-2 Palisades PTS Transient 040

Case Category	TT/RT, HZP
Primary Failures	None.
Secondary Failures	1 stuck-open ADV on SG-A. Failure of both MSIVs (SG-A and SG-B) to close.
Operator Actions	Operator does not isolate AFW on affected SG. Normal AFW flow assumed (200 gpm). Operator does not throttle HPI.
Min DC Temp	424.6 K (304.7°F) at 14850 s
Comments	None.

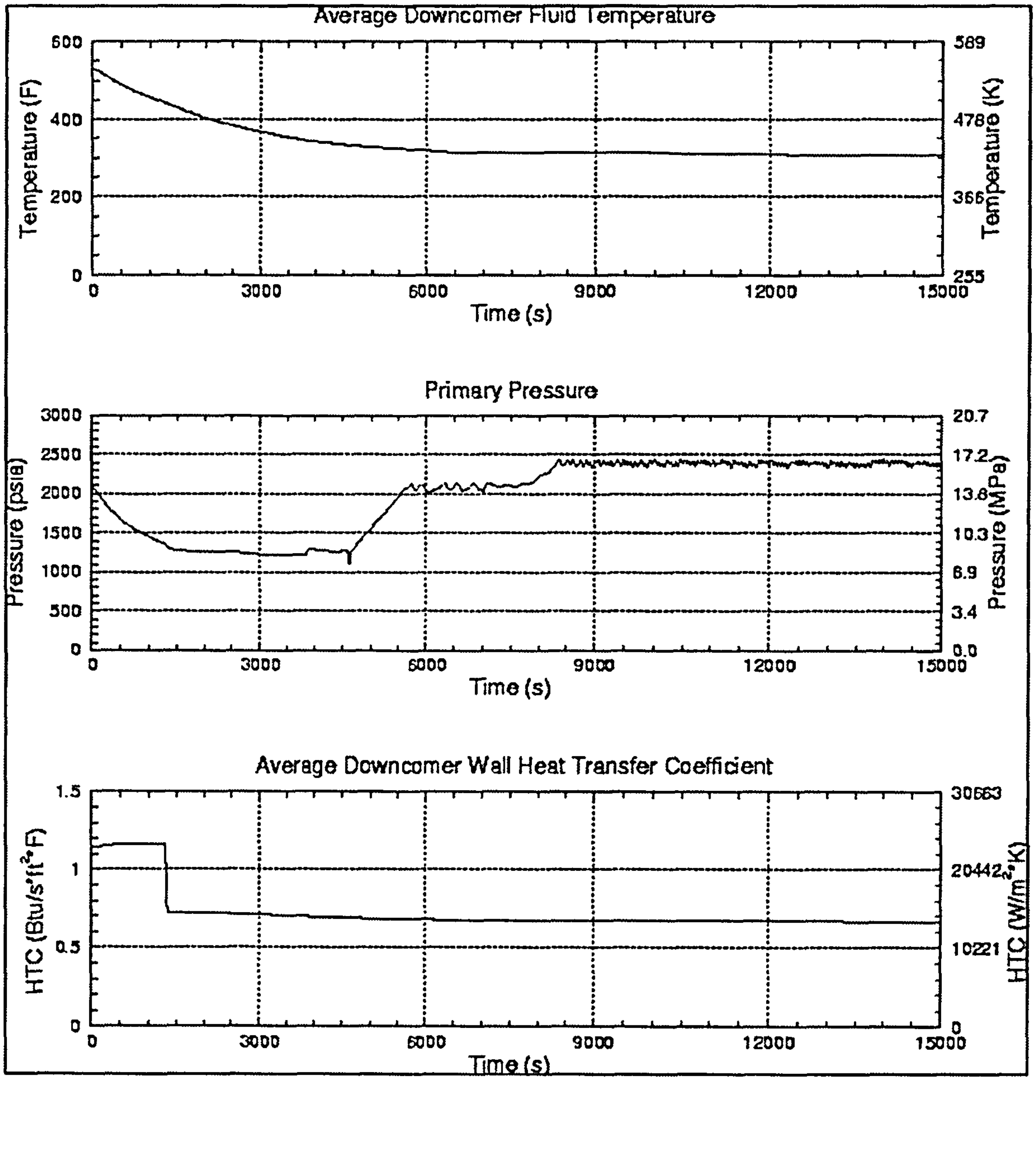

Figure H-3 Palisades PTS Transient 052

Case Category	MSLB
Primary Failures	None.
Secondary Failures	Failure of both MSIVs to close. Break assumed to be inside containment causing containment spray actuation.
Operator Actions	Operator does not isolate AFW on affected SG. Operator does not throttle HPI.
Min DC Temp	377.1 K (219.1°F) at 4110 s
Comments	None.

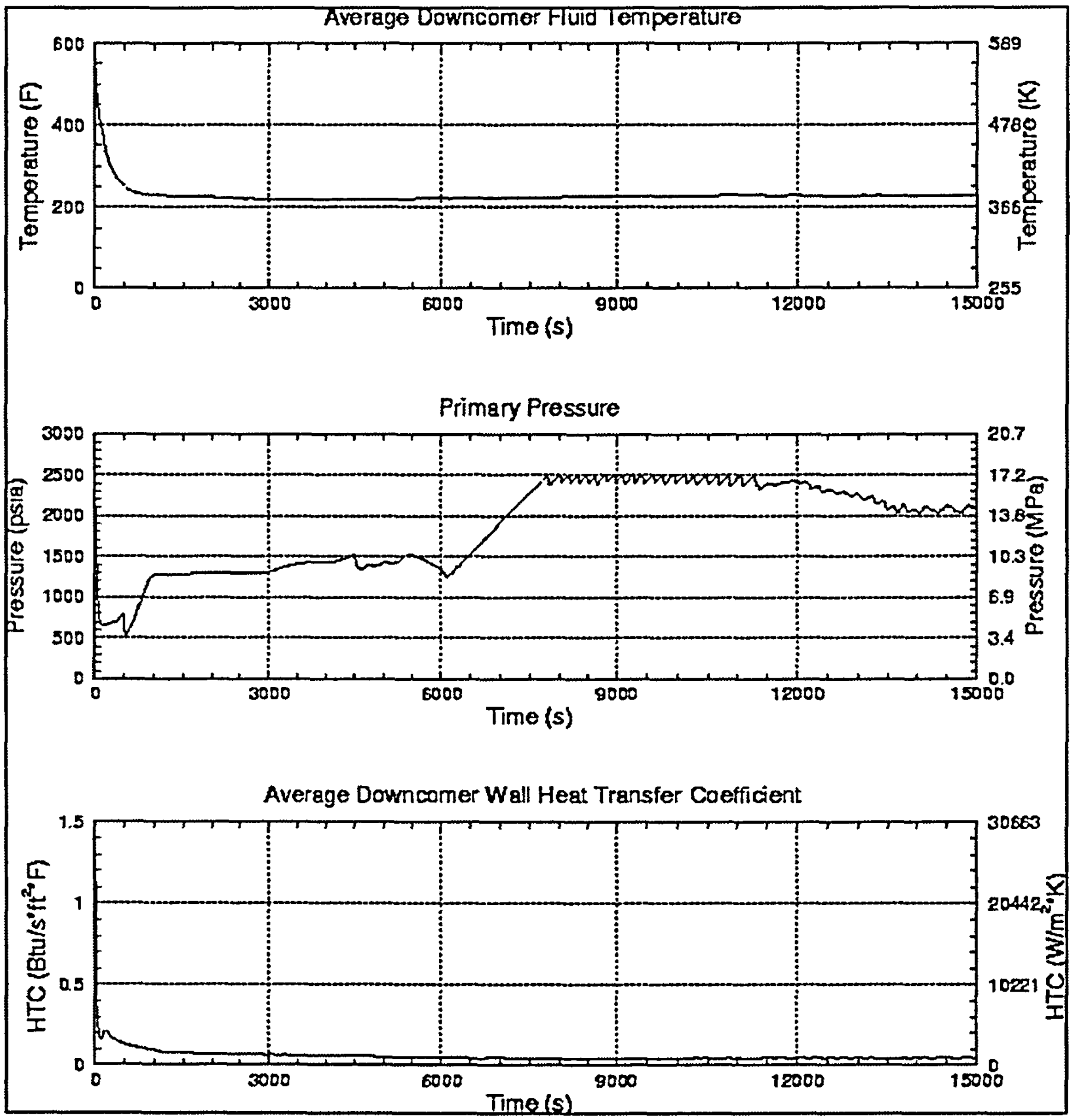

Figure H-4 Palisades PTS Transient 054

Case Category	TT/RT
Primary Failures	None.
Secondary Failures	2 stuck-open ADVs on SG-A combined with controller failure resulting in the flow from two AFW pumps into affected steam generator.
Operator Actions	Operator starts second AFW pump.
Min DC Temp	437.4 K (327.7°F) at 4320 s
Comments	None.

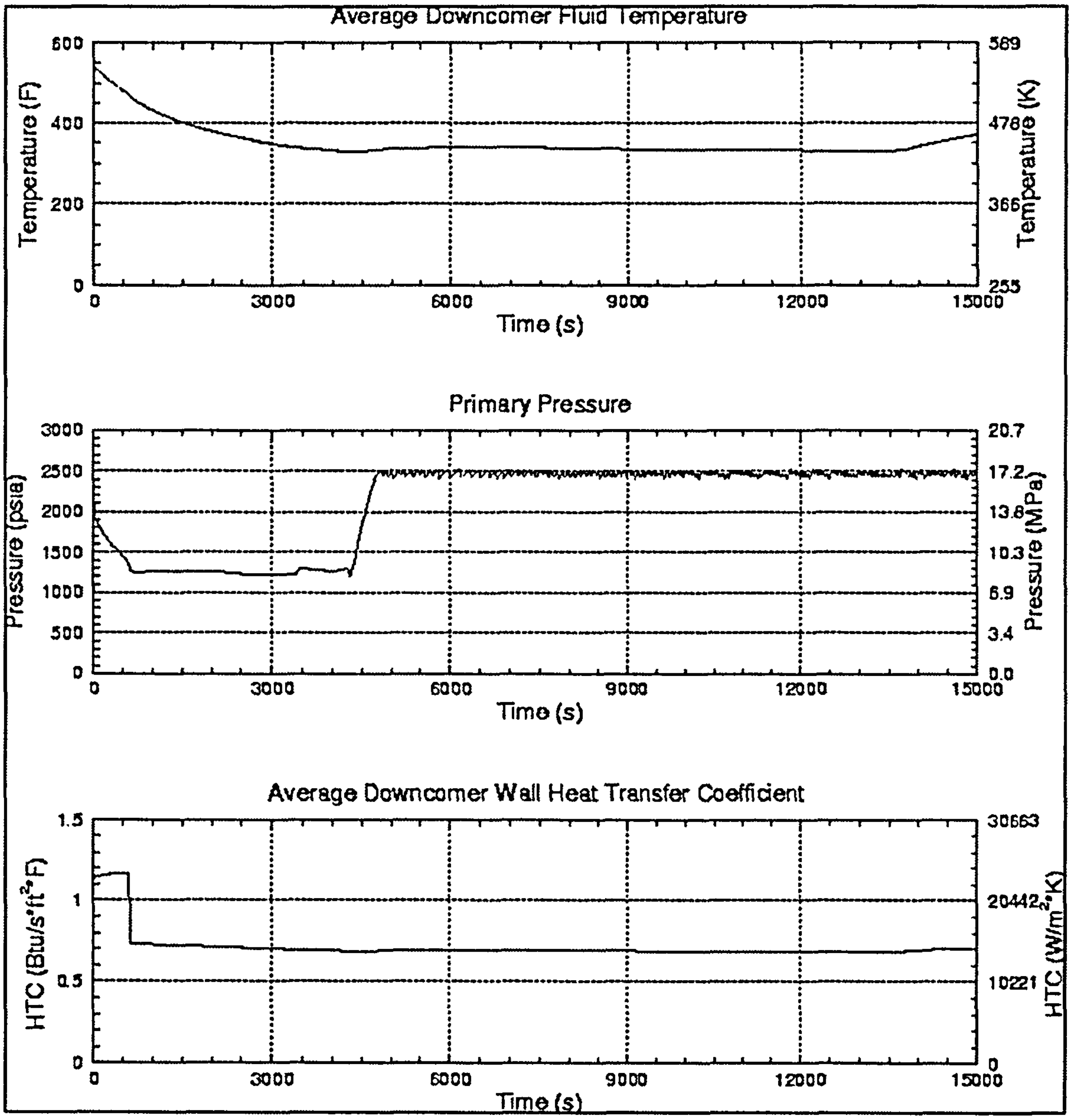

Figure H-5 Palisades PTS Transient 055

Case Category	LOCA
Primary Failures	10.16 cm (4 in) cold leg break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	331.0 K (136.2°F) at 2700 s
Comments	Momentum Flux Disabled in the DC

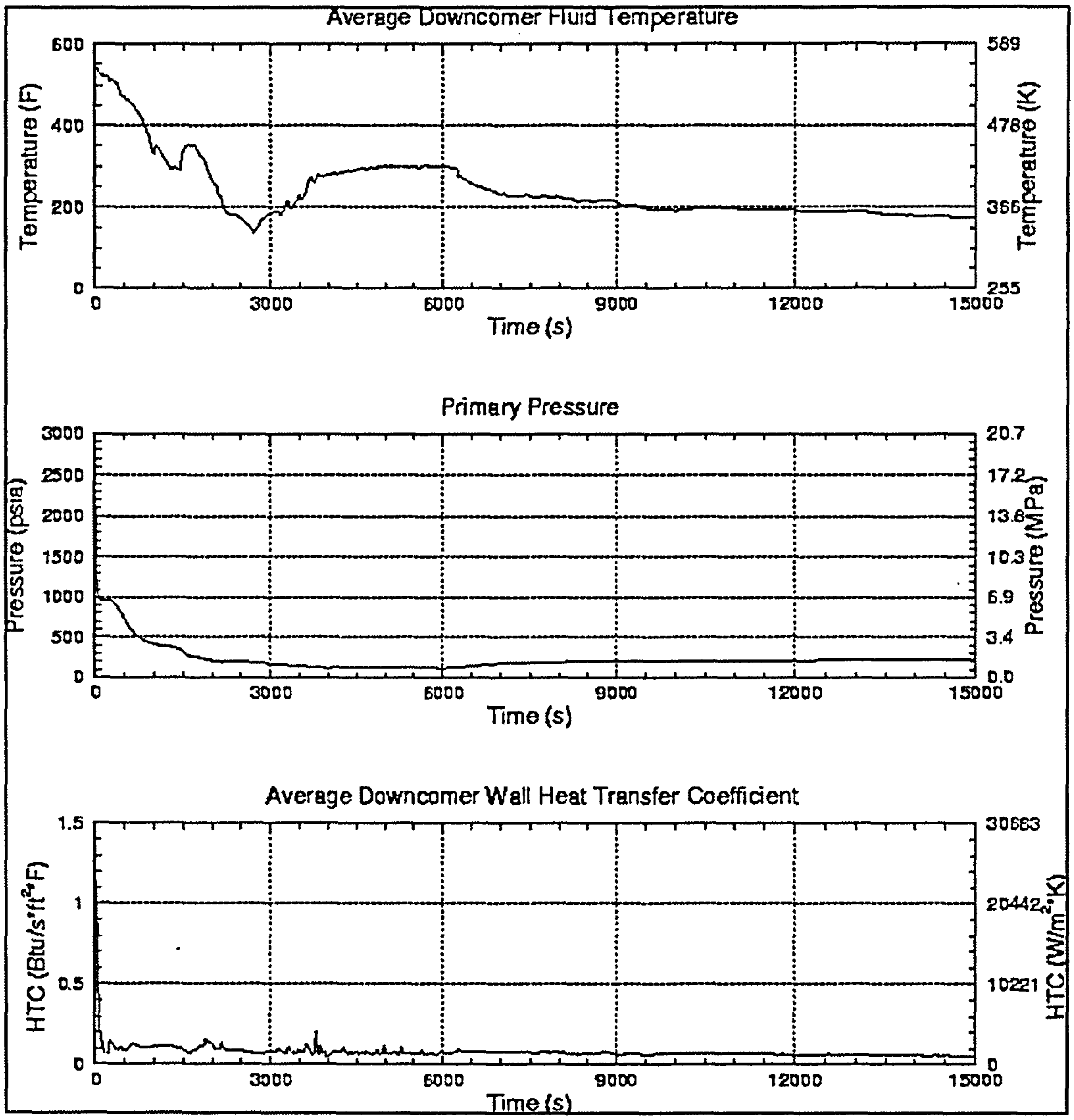

Figure H-6 Palisades PTS Transient 058

Case Category	LOCA
Primary Failures	10.16 cm (4 in) cold leg break. Summer conditions assumed (HPI and LPI injection temp = 100 F, Accumulator temp = 90 F)
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	350.7 K (171.6°F) at 14940 s
Comments	Momentum Flux Disabled in the DC

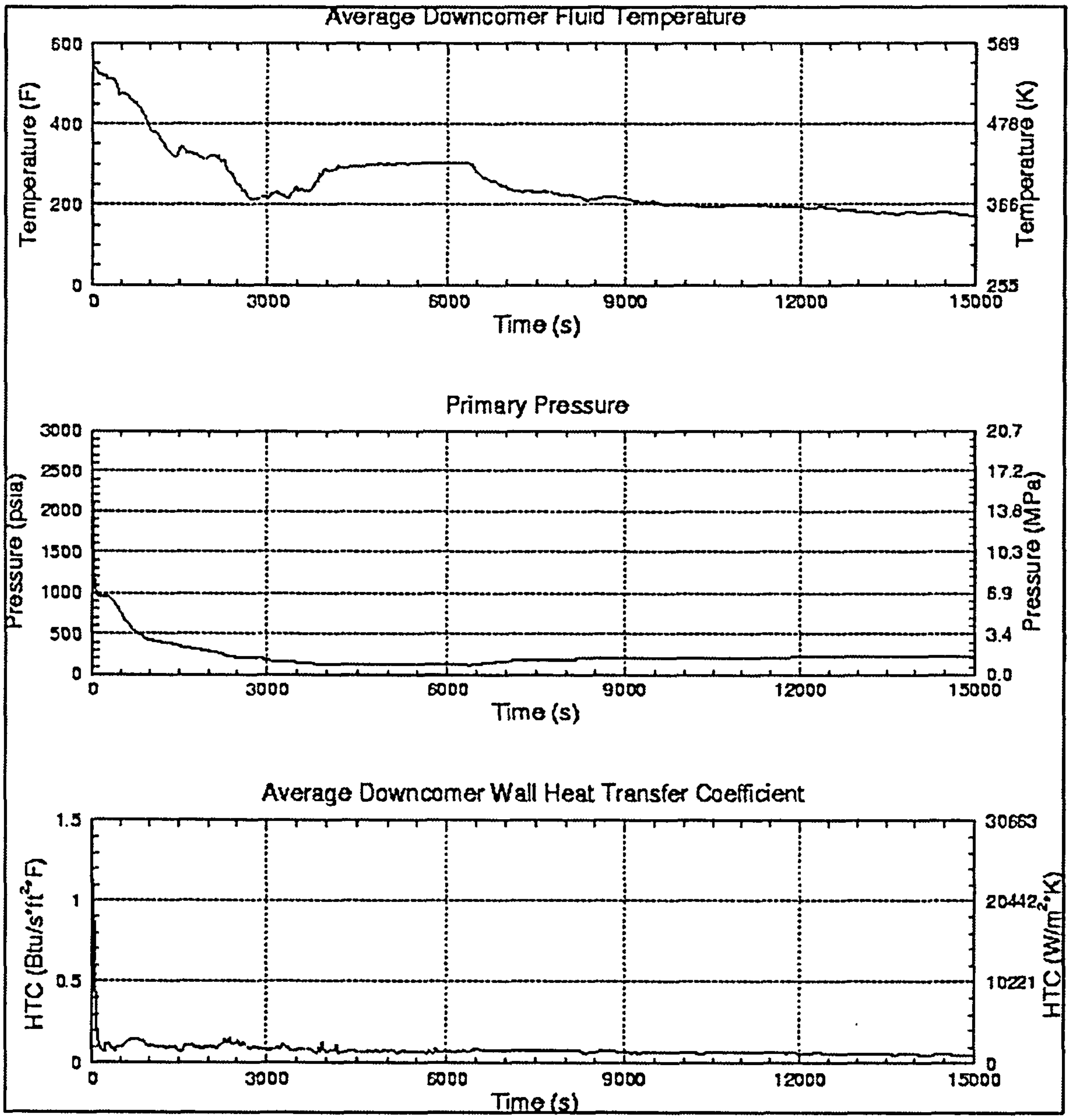

Figure H-7 Palisades PTS Transient 059

Case Category	LOCA
Primary Failures	5.08 cm (2 in) surge line break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	351.3 K (172.7°F) at 3540 s
Comments	None.

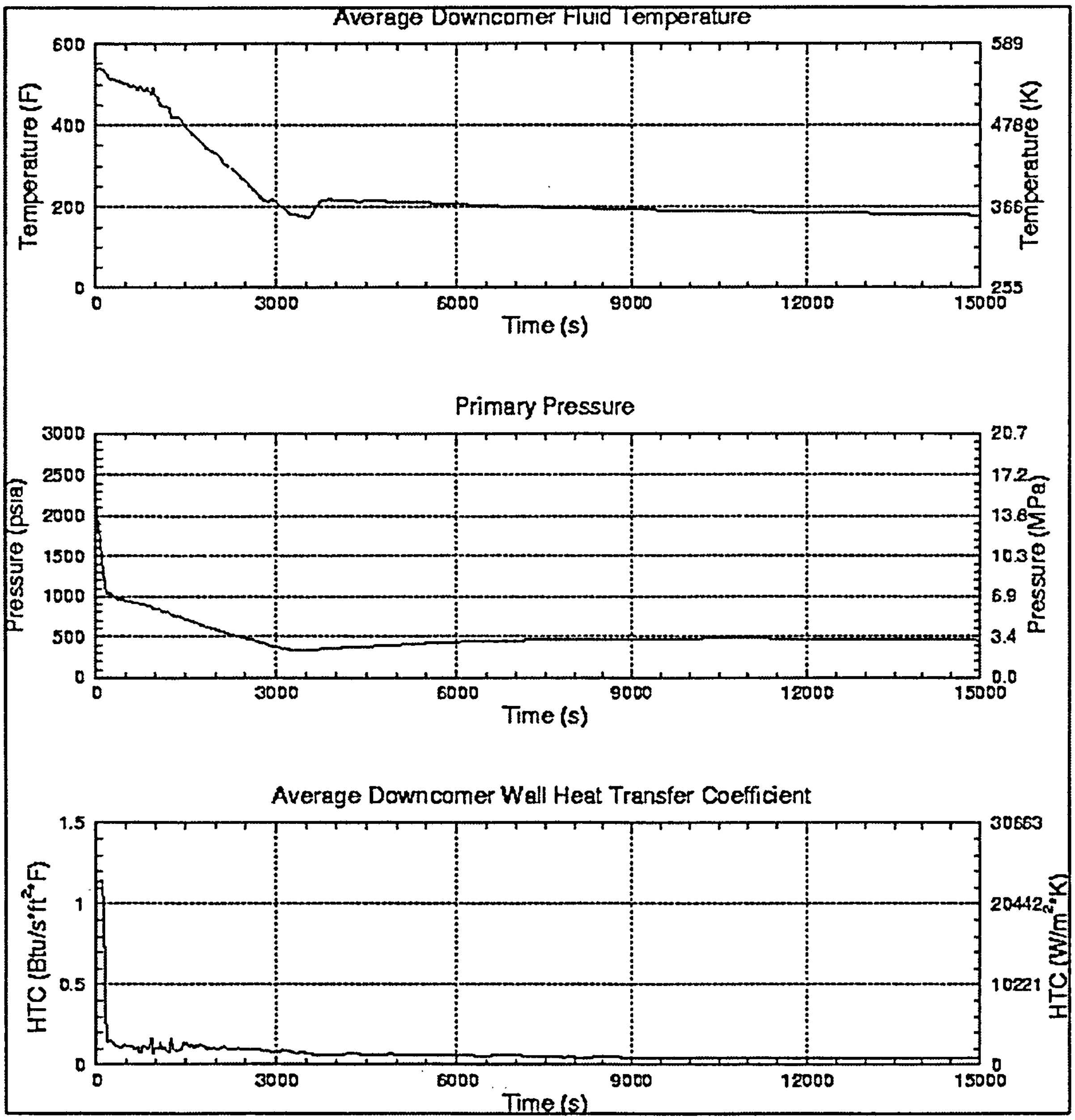

Figure H-8 Palisades PTS Transient 060

Case Category	LOCA
Primary Failures	20.32 cm (8 in) cold leg break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	308.0 K (94.7°F) at 1470 s
Comments	Momentum Flux Disabled in the DC

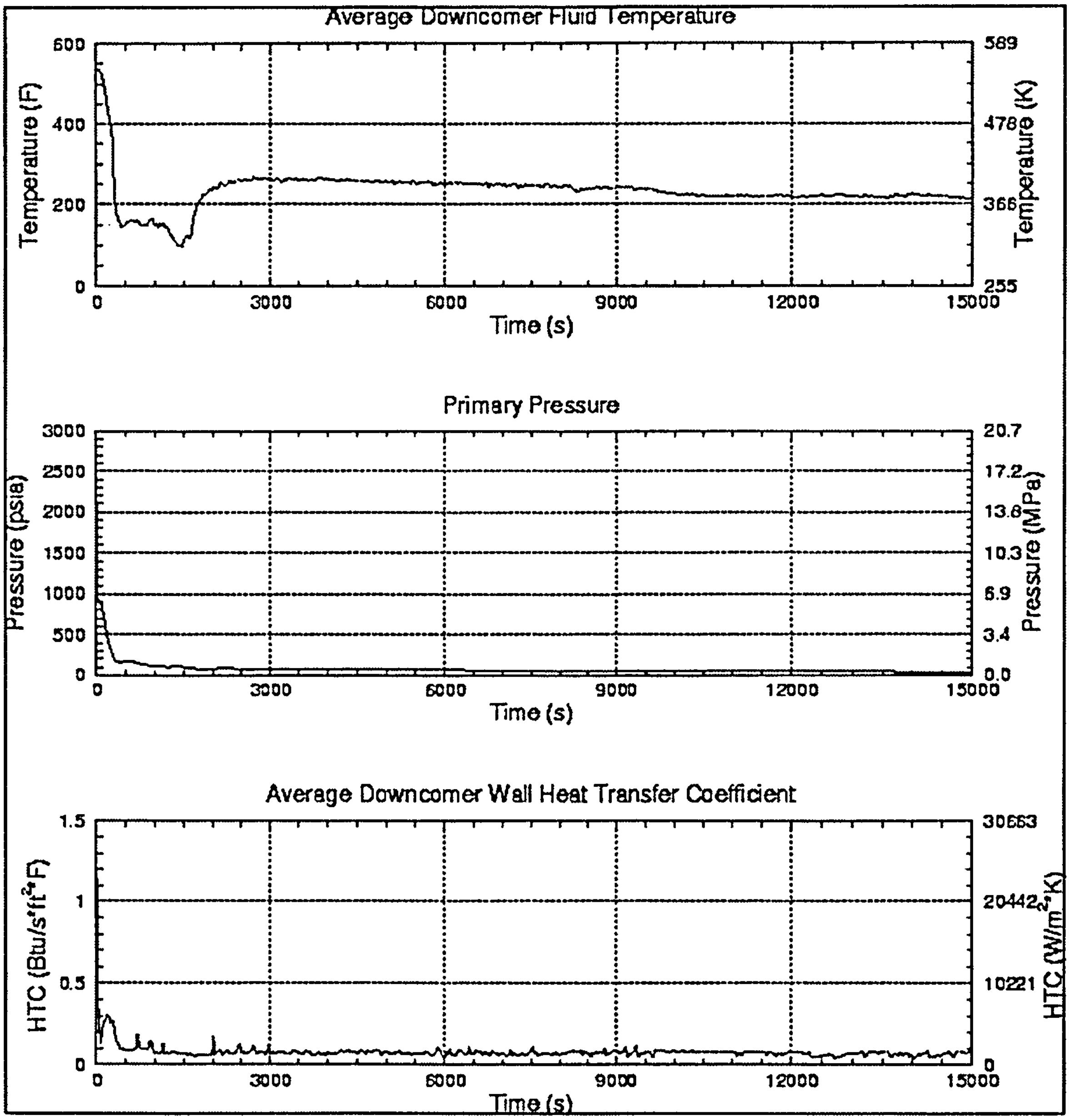

Figure H-9 Palisades PTS Transient 062

Case Category	LOCA
Primary Failures	14.37 cm (5.656 in) cold leg break. Winter conditions assumed (HPI and LPI injection temp = 40 F, Accumulator temp = 60 F)
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	306.4 K (91.8°F) at 2070 s
Comments	Momentum Flux Disabled in the DC

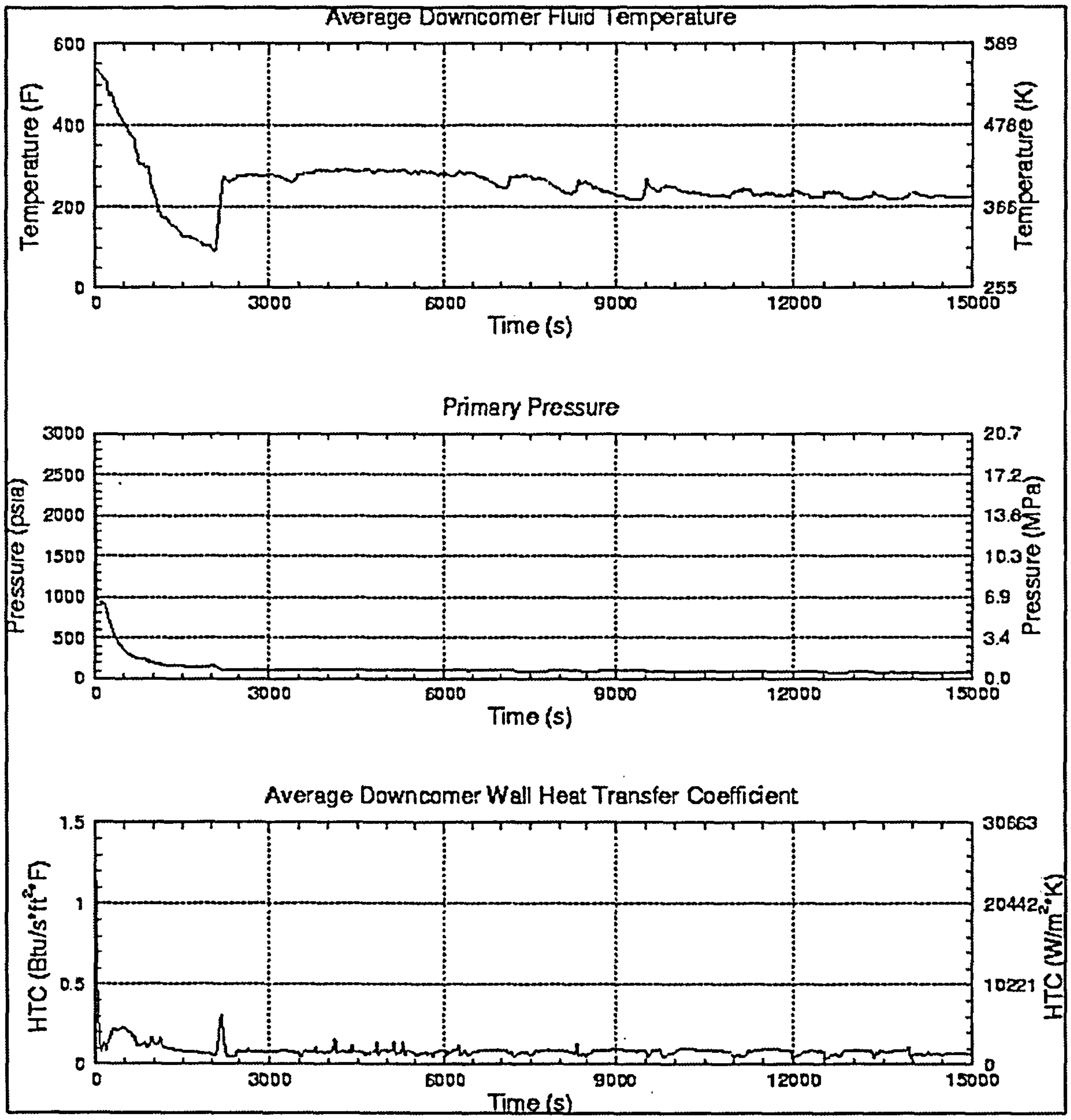

Figure H-10 Palisades PTS Transient 063

Case Category	LOCA
Primary Failures	10.16 cm (4 in) surge line break. Summer conditions assumed (HPI and LPI injection temp = 100 F, Accumulator temp = 90 F)
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	322.8 K (121.4°F) at 2730 s
Comments	None.

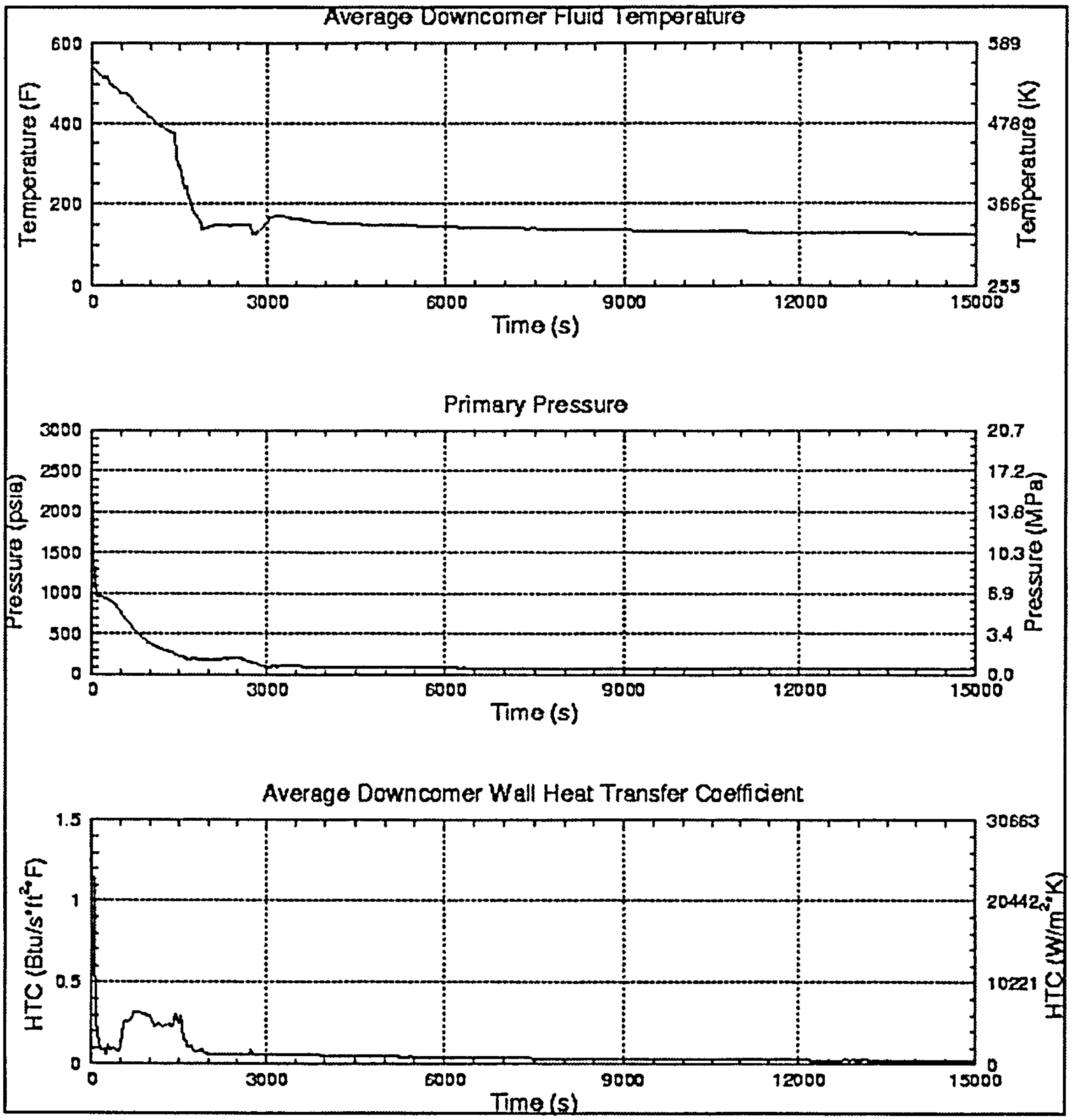

Figure H-11 Palisades PTS Transient 064

Case Category	RT
Primary Failures	One stuck-open pressurizer SRV that recloses at 6000 sec after initiation. Containment spray is assumed not to actuate.
Secondary Failures	None.
Operator Actions	None. Operator does not throttle HPI.
Min DC Temp	366.1 K (199.3°F) at 6570 s
Comments	None

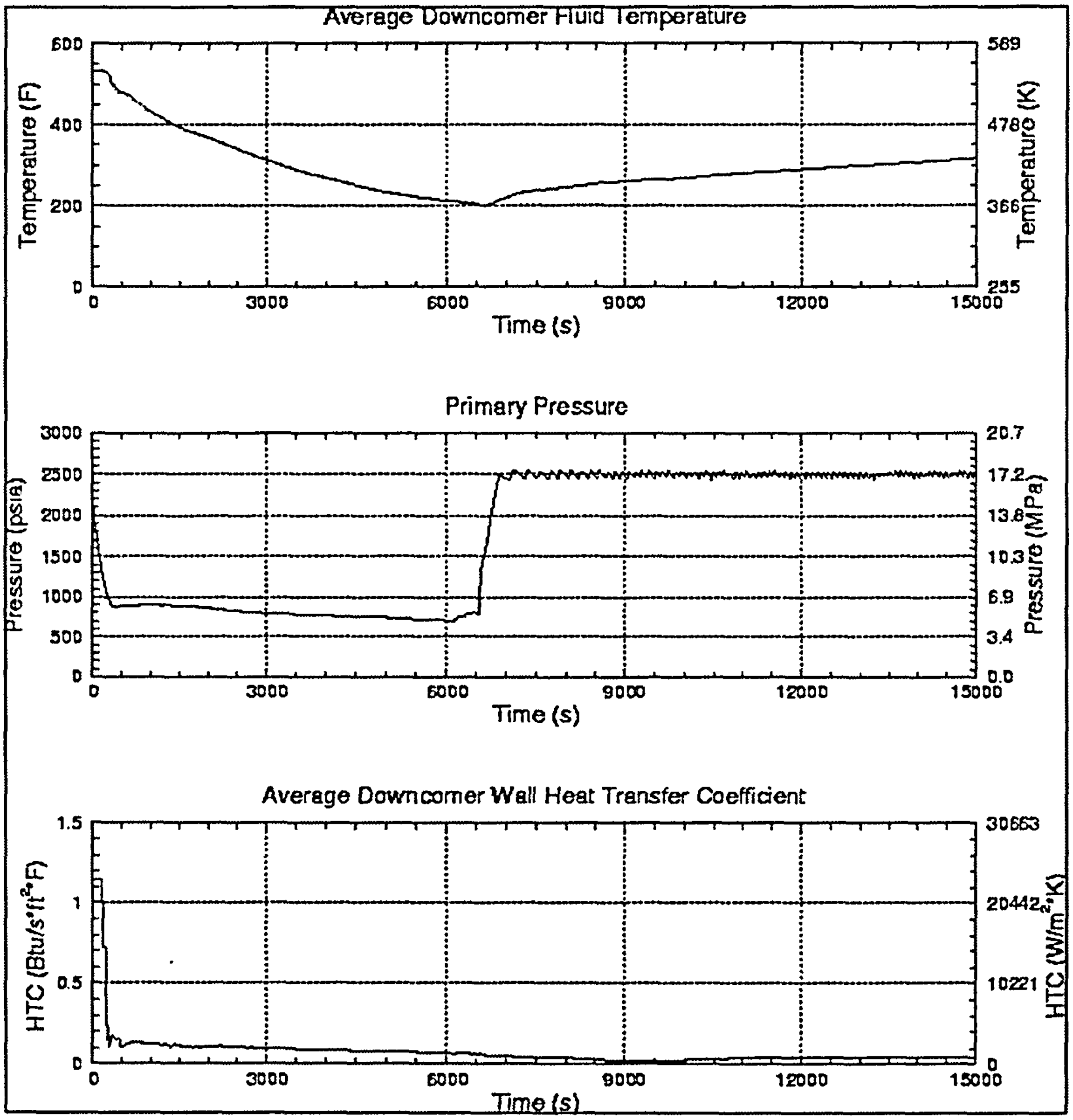

Figure H-12 Palisades PTS Transient 065

APPENDIX I
PALISADES FAVPOST OUTPUT

I-1: 10 Year ISI only, FAVOR 03.1

```
*************************************************
*                                               *
*               WELCOME TO FAVOR                *
*                                               *
*    FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
*                VERSION 03.1                   *
*                                               *
*     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: dicksontl@ornl.gov           *
*                                               *
*************************************************

***********************************************************
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***********************************************************


     DATE: 29-Sep-2003  TIME: 16:06:17


     FAVPOST INPUT  FILE NAME                        = ppost12.in
     FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
     FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
     FAVPOST OUTPUT FILE NAME                        = 30000.out

        **********************************
        * NUMBER OF SIMULATIONS =  30000 *
        **********************************
```

I-1: 10 Year ISI only, FAVOR 03.1 (cont.)

TRANSIENT NUMBER	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E)			
19	4.7575E-07	0.0000E+00	0.0000E+00	3.7253E-07	0.0000E+00	0.0000E+00	0.7830
40	2.4780E-03	4.9091E-03	3.4002E-02	4.7751E-05	7.2507E-05	7.2266E-04	0.0193
52	4.2145E-07	0.0000E+00	0.0000E+00	3.0941E-07	0.0000E+00	0.0000E+00	0.7342
54	1.6198E-04	1.1566E-04	2.2922E-03	6.5053E-05	5.2778E-05	9.9187E-04	0.4016
55	9.9680E-07	0.0000E+00	0.0000E+00	8.0342E-07	0.0000E+00	0.0000E+00	0.8060
58	2.4799E-04	2.5039E-04	3.9474E-03	6.2072E-05	6.3551E-05	9.2961E-04	0.2503
59	7.5549E-06	0.0000E+00	6.8297E-06	3.6454E-07	0.0000E+00	1.4638E-07	0.0483
60	2.0501E-05	2.4046E-07	1.0556E-04	1.3571E-06	2.6220E-10	4.1083E-06	0.0662
62	2.2572E-03	4.3403E-03	3.0266E-02	1.5540E-04	2.7839E-04	2.3391E-03	0.0688
63	8.8946E-04	1.2981E-03	1.3697E-02	9.7045E-05	1.3350E-04	1.4018E-03	0.1091
64	6.2090E-04	9.9416E-04	9.1884E-03	5.0009E-05	6.9672E-05	8.2161E-04	0.0805
65	8.6055E-05	1.6819E-05	9.4184E-04	8.4983E-05	1.6635E-05	9.3392E-04	0.9875

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

I-1: 10 Year ISI only, FAVOR 03.1 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	2.1333	2.1333
3.2067E-07	92.8700	95.0033
9.6201E-07	2.2300	97.2333
1.6034E-06	0.8900	98.1233
2.2447E-06	0.4733	98.5967
2.8860E-06	0.2800	98.8767
3.5274E-06	0.2167	99.0933
4.1687E-06	0.1033	99.1967
4.8101E-06	0.0967	99.2933
5.4514E-06	0.1167	99.4100
6.0928E-06	0.0933	99.5033
6.7341E-06	0.0533	99.5567
7.3754E-06	0.0500	99.6067
8.0168E-06	0.0333	99.6400
8.6581E-06	0.0233	99.6633
9.2995E-06	0.0233	99.6867
9.9408E-06	0.0367	99.7233
1.0582E-05	0.0233	99.7467
1.1223E-05	0.0167	99.7633
1.2506E-05	0.0167	99.7800
1.3148E-05	0.0267	99.8067
1.3789E-05	0.0033	99.8100
1.4430E-05	0.0200	99.8300
1.5072E-05	0.0033	99.8333
1.6354E-05	0.0100	99.8433
1.6996E-05	0.0067	99.8500
1.7637E-05	0.0033	99.8533
1.8920E-05	0.0100	99.8633
1.9561E-05	0.0100	99.8733
2.0202E-05	0.0067	99.8800
2.0844E-05	0.0067	99.8867
2.1485E-05	0.0100	99.8967
2.2126E-05	0.0033	99.9000
2.4050E-05	0.0033	99.9033
2.7257E-05	0.0067	99.9100
2.7898E-05	0.0033	99.9133
2.8540E-05	0.0033	99.9167
2.9181E-05	0.0033	99.9200
3.1105E-05	0.0033	99.9233
3.1746E-05	0.0067	99.9300
3.2388E-05	0.0033	99.9333
3.3029E-05	0.0033	99.9367
3.5594E-05	0.0033	99.9400
3.6877E-05	0.0033	99.9433
4.0725E-05	0.0033	99.9467

I-1: 10 Year ISI only, FAVOR 03.1 (cont.)

4.1367E-05	0.0033	99.9500
4.2008E-05	0.0033	99.9533
4.5215E-05	0.0033	99.9567
4.5856E-05	0.0033	99.9600
4.7780E-05	0.0033	99.9633
4.9704E-05	0.0033	99.9667
5.2269E-05	0.0033	99.9700
6.2531E-05	0.0033	99.9733
9.0750E-05	0.0033	99.9767
9.4598E-05	0.0033	99.9800
1.0037E-04	0.0033	99.9833
1.0165E-04	0.0033	99.9867
1.0871E-04	0.0033	99.9900
1.1256E-04	0.0033	99.9933
2.2415E-04	0.0033	99.9967
2.5557E-04	0.0033	100.0000

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

Minimum                               = 0.0000E+00
Maximum                               = 2.5531E-04
Range                                 = 2.5531E-04

Number of Simulations                 =  30000

5th Percentile                        = 7.4427E-13
Median                                = 6.0879E-09
95.0th Percentile                     = 3.2067E-07
99.0th Percentile                     = 3.2511E-06
99.9th Percentile                     = 2.2126E-05

Mean                                  = 2.3217E-07
Standard Deviation                    = 2.7871E-06
Standard Error                        = 1.6091E-08
Variance (unbiased)                   = 7.7679E-12
Variance (biased)                     = 7.7677E-12
Moment Coeff. of Skewness             = 5.5096E+01
Pearson's 2nd Coeff. of Skewness      = 2.4990E-01
Kurtosis                              = 4.1213E+03
```

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***********************************************************
*     PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)       *
*        FOR THE FREQUENCY OF VESSEL FAILURE              *
***********************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)

I-1: 10 Year ISI only, FAVOR 03.1 (cont.)

0.0000E+00	7.4267	7.4267
3.2764E-08	87.6333	95.0600
9.8291E-08	1.9500	97.0100
1.6382E-07	0.7900	97.8000
2.2935E-07	0.5033	98.3033
2.9487E-07	0.2633	98.5667
3.6040E-07	0.1867	98.7533
4.2593E-07	0.1500	98.9033
4.9145E-07	0.1233	99.0267
5.5698E-07	0.0967	99.1233
6.2251E-07	0.0633	99.1867
6.8804E-07	0.0633	99.2500
7.5356E-07	0.0667	99.3167
8.1909E-07	0.0400	99.3567
8.8462E-07	0.0333	99.3900
9.5014E-07	0.0300	99.4200
1.0157E-06	0.0500	99.4700
1.0812E-06	0.0400	99.5100
1.1467E-06	0.0367	99.5467
1.2123E-06	0.0433	99.5900
1.2778E-06	0.0267	99.6167
1.3433E-06	0.0167	99.6333
1.4088E-06	0.0167	99.6500
1.4744E-06	0.0133	99.6633
1.5399E-06	0.0100	99.6733
1.6054E-06	0.0067	99.6800
1.6709E-06	0.0133	99.6933
1.7365E-06	0.0133	99.7067
1.8020E-06	0.0133	99.7200
1.8675E-06	0.0200	99.7400
1.9986E-06	0.0167	99.7567
2.0641E-06	0.0100	99.7667
2.1296E-06	0.0067	99.7733
2.1952E-06	0.0033	99.7767
2.2607E-06	0.0033	99.7800
2.3262E-06	0.0067	99.7867
2.3917E-06	0.0033	99.7900
2.4573E-06	0.0033	99.7933
2.5228E-06	0.0033	99.7967
2.5883E-06	0.0067	99.8033
2.7194E-06	0.0033	99.8067
2.7849E-06	0.0067	99.8133
2.9160E-06	0.0033	99.8167
2.9815E-06	0.0067	99.8233
3.1781E-06	0.0167	99.8400
3.3091E-06	0.0067	99.8467
3.3746E-06	0.0033	99.8500
3.5057E-06	0.0033	99.8533
3.6368E-06	0.0100	99.8633
3.7023E-06	0.0033	99.8667
3.8333E-06	0.0067	99.8733
3.9644E-06	0.0033	99.8767
4.2265E-06	0.0067	99.8833
4.3576E-06	0.0067	99.8900

I-1: 10 Year ISI only, FAVOR 03.1 (cont.)

4.6197E-06	0.0033	99.8933
4.8162E-06	0.0033	99.8967
4.9473E-06	0.0033	99.9000
5.0128E-06	0.0100	99.9100
5.4060E-06	0.0033	99.9133
5.6026E-06	0.0033	99.9167
6.3234E-06	0.0033	99.9200
6.5855E-06	0.0033	99.9233
6.6510E-06	0.0033	99.9267
7.1097E-06	0.0033	99.9300
7.6339E-06	0.0033	99.9333
8.4858E-06	0.0033	99.9367
8.7479E-06	0.0033	99.9400
9.4687E-06	0.0033	99.9433
1.0321E-05	0.0033	99.9467
1.0714E-05	0.0033	99.9500
1.1631E-05	0.0033	99.9533
1.1893E-05	0.0033	99.9567
1.2155E-05	0.0033	99.9600
1.4121E-05	0.0033	99.9633
1.4449E-05	0.0033	99.9667
1.4514E-05	0.0033	99.9700
1.6742E-05	0.0033	99.9733
1.6808E-05	0.0033	99.9767
1.8839E-05	0.0033	99.9800
2.0215E-05	0.0033	99.9833
2.0805E-05	0.0033	99.9867
2.5916E-05	0.0033	99.9900
3.2010E-05	0.0033	99.9933
8.0631E-05	0.0033	99.9967
1.0501E-04	0.0033	100.0000

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

Minimum                             = 0.0000E+00
Maximum                             = 1.0498E-04
Range                               = 1.0498E-04

Number of Simulations               =  30000

5th Percentile                      = 0.0000E+00
Median                              = 9.4143E-11
95.0th Percentile                   = 3.2764E-08
99.0th Percentile                   = 4.7729E-07
99.9th Percentile                   = 4.9473E-06

Mean                                = 3.9285E-08
Standard Deviation                  = 8.8640E-07
Standard Error                      = 5.1176E-09
Variance (unbiased)                 = 7.8570E-13
Variance (biased)                   = 7.8568E-13
```

I-1: 10 Year ISI only, FAVOR 03.1 (cont.)

```
Moment Coeff. of Skewness              = 8.5408E+01
Pearson's 2nd Coeff. of Skewness       = 1.1236E-01
Kurtosis                               = 8.9532E+03

************************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON    *
*              AND FREQUENCY OF RPV FAILURE BY             *
*                        TRANSIENT                         *
*       WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
************************************************************
                       % of total          % of total
                      frequency of        frequency of
                    crack initiation     of RPV failure
          19              0.19                0.76
          40             43.81                5.24
          52              0.39                1.84
          54              0.48                1.01
          55              2.12                9.84
          58             29.56               43.33
          59              0.74                0.19
          60              1.32                0.59
          62              9.69                4.11
          63              2.67                1.62
          64              4.08                2.67
          65              4.95               28.81

              TOTALS    100.00              100.00

               DATE: 29-Sep-2003   TIME: 16:06:48
```

I-2: ISI Every 10 Years, FAVOR 03.1

```
************************************************
*                                              *
*              WELCOME TO FAVOR                *
*                                              *
*   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
*               VERSION 03.1                   *
*                                              *
*     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: dicksontl@ornl.gov           *
*                                              *
************************************************

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**********************************************************


     DATE: 07-Oct-2003  TIME: 09:30:52


     FAVPOST INPUT  FILE NAME                    = ppost12.in
     FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
     FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
     FAVPOST OUTPUT FILE NAME                    = 30000.out

        **********************************
        * NUMBER OF SIMULATIONS =  30000 *
        **********************************
```

I-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E) MEAN CPI	95th % CPI	99th % CPI	CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E) MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
19	3.3377E-07	0.0000E+00	0.0000E+00	1.4760E-07	0.0000E+00	0.0000E+00	0.4422
40	2.3860E-03	4.8482E-03	3.2081E-02	4.6934E-05	7.5411E-05	7.5882E-04	0.0197
52	4.0722E-07	0.0000E+00	0.0000E+00	1.9231E-07	0.0000E+00	0.0000E+00	0.4723
54	1.4965E-04	1.2282E-04	2.3882E-03	6.3502E-05	5.5104E-05	1.0280E-03	0.4243
55	8.3525E-07	0.0000E+00	0.0000E+00	5.1828E-07	0.0000E+00	0.0000E+00	0.6205
58	2.1827E-04	2.3733E-04	3.3409E-03	6.5956E-05	6.4336E-05	9.9935E-04	0.3022
59	5.3760E-06	0.0000E+00	5.4791E-06	3.1575E-07	0.0000E+00	1.9976E-07	0.0587
60	1.4233E-05	1.4598E-07	8.2189E-05	1.2803E-06	7.8274E-10	4.8350E-06	0.0899
62	2.1646E-03	4.2546E-03	2.8081E-02	1.5718E-04	2.8928E-04	2.3914E-03	0.0726
63	7.6690E-04	1.1693E-03	1.1139E-02	9.4564E-05	1.3362E-04	1.2429E-03	0.1233
64	5.8182E-04	9.8298E-04	8.5122E-03	5.2815E-05	7.6888E-05	8.6583E-04	0.0908
65	7.9828E-05	1.7801E-05	9.4344E-04	7.8660E-05	1.7566E-05	9.2219E-04	0.9854

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

I-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	2.4200	2.4200
3.1067E-07	92.5800	95.0000
9.3202E-07	2.3433	97.3433
1.5534E-06	0.8167	98.1600
2.1747E-06	0.4833	98.6433
2.7960E-06	0.2767	98.9200
3.4174E-06	0.2000	99.1200
4.0387E-06	0.1467	99.2667
4.6601E-06	0.1100	99.3767
5.2814E-06	0.0667	99.4433
5.9028E-06	0.0567	99.5000
6.5241E-06	0.0667	99.5667
7.1455E-06	0.0433	99.6100
7.7668E-06	0.0567	99.6667
8.3881E-06	0.0333	99.7000
9.0095E-06	0.0233	99.7233
9.6308E-06	0.0167	99.7400
1.0252E-05	0.0167	99.7567
1.0874E-05	0.0133	99.7700
1.1495E-05	0.0100	99.7800
1.2116E-05	0.0033	99.7833
1.2738E-05	0.0100	99.7933
1.3359E-05	0.0200	99.8133
1.3980E-05	0.0167	99.8300
1.5223E-05	0.0067	99.8367
1.6466E-05	0.0033	99.8400
1.7087E-05	0.0067	99.8467
1.7708E-05	0.0067	99.8533
1.8330E-05	0.0033	99.8567
1.8951E-05	0.0100	99.8667
1.9572E-05	0.0033	99.8700
2.0194E-05	0.0033	99.8733
2.0815E-05	0.0100	99.8833
2.2058E-05	0.0033	99.8867
2.2679E-05	0.0033	99.8900
2.3300E-05	0.0033	99.8933
2.3922E-05	0.0033	99.8967
2.4543E-05	0.0067	99.9033
2.5786E-05	0.0033	99.9067
2.6407E-05	0.0100	99.9167
2.7028E-05	0.0067	99.9233
2.7650E-05	0.0067	99.9300
2.8271E-05	0.0067	99.9367
2.8892E-05	0.0067	99.9433
3.0135E-05	0.0067	99.9500

I-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

3.1378E-05	0.0067	99.9567
3.1999E-05	0.0033	99.9600
3.4485E-05	0.0033	99.9633
3.8213E-05	0.0033	99.9667
3.8834E-05	0.0033	99.9700
4.3805E-05	0.0033	99.9733
4.7533E-05	0.0033	99.9767
4.9397E-05	0.0033	99.9800
5.6232E-05	0.0033	99.9833
8.6056E-05	0.0033	99.9867
1.0718E-04	0.0033	99.9900
1.1837E-04	0.0033	99.9933
1.5068E-04	0.0033	99.9967
1.5503E-04	0.0033	100.0000

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

Minimum                               = 0.0000E+00
Maximum                               = 1.5529E-04
Range                                 = 1.5529E-04

Number of Simulations                 =  30000

5th Percentile                        = 4.4053E-13
Median                                = 6.0795E-09
95.0th Percentile                     = 3.1067E-07
99.0th Percentile                     = 3.0446E-06
99.9th Percentile                     = 2.4232E-05

Mean                                  = 2.0855E-07
Standard Deviation                    = 2.0764E-06
Standard Error                        = 1.1988E-08
Variance (unbiased)                   = 4.3113E-12
Variance (biased)                     = 4.3112E-12
Moment Coeff. of Skewness             = 4.4440E+01
Pearson's 2nd Coeff. of Skewness      = 3.0131E-01
Kurtosis                              = 2.7191E+03


*********************************************************
*     PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)     *
*          FOR THE FREQUENCY OF VESSEL FAILURE          *
*********************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	6.7133	6.7133
3.2417E-08	88.3333	95.0467

I-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

9.7251E-08	1.9700	97.0167
1.6208E-07	0.7900	97.8067
2.2692E-07	0.4267	98.2333
2.9175E-07	0.2833	98.5167
3.5659E-07	0.2067	98.7233
4.2142E-07	0.1133	98.8367
4.8625E-07	0.1467	98.9833
5.5109E-07	0.0833	99.0667
6.1592E-07	0.0900	99.1567
6.8075E-07	0.0767	99.2333
7.4559E-07	0.0733	99.3067
8.1042E-07	0.0333	99.3400
8.7526E-07	0.0267	99.3667
9.4009E-07	0.0433	99.4100
1.0049E-06	0.0433	99.4533
1.0698E-06	0.0500	99.5033
1.1346E-06	0.0200	99.5233
1.1994E-06	0.0367	99.5600
1.2643E-06	0.0133	99.5733
1.3291E-06	0.0167	99.5900
1.3939E-06	0.0267	99.6167
1.4588E-06	0.0200	99.6367
1.5236E-06	0.0133	99.6500
1.5884E-06	0.0233	99.6733
1.6533E-06	0.0167	99.6900
1.7181E-06	0.0067	99.6967
1.7829E-06	0.0067	99.7033
1.8478E-06	0.0067	99.7100
1.9126E-06	0.0133	99.7233
1.9774E-06	0.0200	99.7433
2.0423E-06	0.0100	99.7533
2.1071E-06	0.0033	99.7567
2.1719E-06	0.0100	99.7667
2.2368E-06	0.0033	99.7700
2.3016E-06	0.0033	99.7733
2.3664E-06	0.0033	99.7767
2.4313E-06	0.0100	99.7867
2.5609E-06	0.0033	99.7900
2.6258E-06	0.0133	99.8033
2.6906E-06	0.0067	99.8100
2.7554E-06	0.0100	99.8200
2.8203E-06	0.0133	99.8333
2.8851E-06	0.0067	99.8400
3.0148E-06	0.0100	99.8500
3.0796E-06	0.0067	99.8567
3.1444E-06	0.0033	99.8600
3.2093E-06	0.0033	99.8633
3.2741E-06	0.0033	99.8667
3.3389E-06	0.0033	99.8700
3.4038E-06	0.0033	99.8733
3.4686E-06	0.0033	99.8767
3.5334E-06	0.0033	99.8800
3.5983E-06	0.0033	99.8833
3.6631E-06	0.0033	99.8867

I-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

3.8576E-06	0.0100	99.8967
3.9224E-06	0.0033	99.9000
4.3763E-06	0.0033	99.9033
4.7004E-06	0.0033	99.9067
4.8949E-06	0.0033	99.9100
5.0246E-06	0.0067	99.9167
5.1543E-06	0.0033	99.9200
5.3488E-06	0.0033	99.9233
5.5433E-06	0.0033	99.9267
5.8026E-06	0.0033	99.9300
5.8675E-06	0.0033	99.9333
6.1916E-06	0.0033	99.9367
6.4510E-06	0.0033	99.9400
7.5531E-06	0.0033	99.9433
7.6180E-06	0.0033	99.9467
8.7850E-06	0.0033	99.9500
8.8498E-06	0.0033	99.9533
9.3036E-06	0.0033	99.9567
1.0471E-05	0.0033	99.9600
1.1249E-05	0.0033	99.9633
1.1767E-05	0.0033	99.9667
1.1962E-05	0.0033	99.9700
1.2480E-05	0.0033	99.9733
1.2934E-05	0.0033	99.9767
1.3842E-05	0.0033	99.9800
1.5917E-05	0.0033	99.9833
1.9936E-05	0.0033	99.9867
2.0779E-05	0.0033	99.9900
3.9386E-05	0.0033	99.9933
5.9031E-05	0.0033	99.9967
6.7784E-05	0.0033	100.0000

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

Minimum                          = 0.0000E+00
Maximum                          = 6.7796E-05
Range                            = 6.7796E-05

Number of Simulations            =  30000

5th Percentile                   = 0.0000E+00
Median                           = 1.1574E-10
95.0th Percentile                = 3.2417E-08
99.0th Percentile                = 4.9922E-07
99.9th Percentile                = 3.9224E-06

Mean                             = 3.5769E-08
Standard Deviation               = 6.6120E-07
Standard Error                   = 3.8174E-09
Variance (unbiased)              = 4.3718E-13
Variance (biased)                = 4.3717E-13
```

I-2: ISI Every 10 Years, FAVOR 03.1 (cont.)

```
Moment Coeff. of Skewness              = 7.1125E+01
Pearson's 2nd Coeff. of Skewness       = 1.3471E-01
Kurtosis                               = 6.3082E+03

*************************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON     *
*            AND FREQUENCY OF RPV FAILURE BY                *
*                      TRANSIENT                            *
*      WEIGHTED BY TRANSIENT INITIATING FREQUENCIES         *
*************************************************************
```

	% of total frequency of crack initiation	% of total frequency of of RPV failure
19	0.26	0.74
40	46.05	5.23
52	0.20	0.51
54	0.36	0.94
55	1.58	5.39
58	31.00	52.07
59	0.47	0.15
60	1.31	0.72
62	9.05	4.08
63	2.62	2.04
64	2.42	1.24
65	4.68	26.89
TOTALS	100.00	100.00

DATE: 07-Oct-2003   TIME: 09:31:56

I-3: 10 Year ISI only, FAVOR 02.4

```
************************************************
*                                              *
*              WELCOME TO FAVOR                *
*                                              *
*    FRACTURE ANALYSIS OF VESSELS: OAK RIDGE   *
*                VERSION 02.4                  *
*                                              *
*     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         *
*                                              *
*           phone : (865) 574-0650             *
*           fax   : (865) 574-0651             *
*         e-mail: dicksontl@ornl.gov           *
*                                              *
************************************************

************************************************************
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************************************************************


DATE: 18-Jul-2003   TIME: 09:01:08


FAVPOST INPUT  FILE NAME                        = ppost12.in
FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME                        = 13000.out
```

I-3: 10 Year ISI only, FAVOR 02.4 (cont.)

```
**********************************
* NUMBER OF SIMULATIONS =  13000 *
**********************************
```

	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E)			CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E)			
TRANSIENT NUMBER	MEAN CPI	95th % CPI	99th % CPI	MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
19	5.5438E-08	0.0000E+00	0.0000E+00	3.7501E-08	0.0000E+00	0.0000E+00	0.6764
40	2.5975E-03	5.1677E-03	3.2453E-02	9.4692E-05	1.2146E-04	1.3174E-03	0.0365
52	8.1778E-08	0.0000E+00	0.0000E+00	5.3850E-08	0.0000E+00	0.0000E+00	0.6585
54	1.4571E-04	1.3639E-04	2.2536E-03	9.5544E-05	1.0317E-04	1.5635E-03	0.6557
55	2.4935E-07	0.0000E+00	0.0000E+00	1.9463E-07	0.0000E+00	0.0000E+00	0.7805
58	2.4016E-04	2.6229E-04	3.3546E-03	9.7791E-05	1.1693E-04	1.5033E-03	0.4072
59	4.9495E-06	0.0000E+00	3.6274E-06	3.8909E-07	0.0000E+00	3.8868E-07	0.0786
60	2.3459E-05	6.3340E-07	1.1085E-04	2.5755E-06	6.1796E-09	1.5084E-05	0.1098
62	2.3730E-03	4.7445E-03	2.8926E-02	5.4928E-04	1.1958E-03	8.0998E-03	0.2315
63	8.9382E-04	1.3960E-03	1.2099E-02	2.7731E-04	4.3398E-04	3.9059E-03	0.3103
64	6.2193E-04	1.0713E-03	8.9827E-03	1.7004E-04	3.2055E-04	2.6285E-03	0.2734
65	7.8688E-05	1.9294E-05	9.1968E-04	7.5861E-05	1.8012E-05	8.8260E-04	0.9641

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

I-3: 10 Year ISI only, FAVOR 02.4 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	1.5154	1.5154
3.4381E-07	93.5077	95.0231
1.0314E-06	2.2077	97.2308
1.7191E-06	1.0000	98.2308
2.4067E-06	0.5077	98.7385
3.0943E-06	0.2308	98.9692
3.7820E-06	0.1923	99.1615
4.4696E-06	0.1154	99.2769
5.1572E-06	0.1077	99.3846
5.8448E-06	0.0769	99.4615
6.5325E-06	0.0385	99.5000
7.2201E-06	0.0846	99.5846
7.9077E-06	0.0385	99.6231
8.5954E-06	0.0308	99.6538
9.2830E-06	0.0077	99.6615
9.9706E-06	0.0154	99.6769
1.0658E-05	0.0462	99.7231
1.1346E-05	0.0462	99.7692
1.2033E-05	0.0308	99.8000
1.2721E-05	0.0231	99.8231
1.3409E-05	0.0077	99.8308
1.4096E-05	0.0077	99.8385
1.4784E-05	0.0077	99.8462
1.5472E-05	0.0077	99.8538
1.6159E-05	0.0077	99.8615
1.6847E-05	0.0077	99.8692
1.7535E-05	0.0077	99.8769
1.8222E-05	0.0154	99.8923
1.8910E-05	0.0077	99.9000
2.0285E-05	0.0154	99.9154
2.2348E-05	0.0077	99.9231
2.3036E-05	0.0077	99.9308
2.3723E-05	0.0077	99.9385
2.8537E-05	0.0077	99.9462
3.3350E-05	0.0077	99.9538
3.5413E-05	0.0077	99.9615
4.1602E-05	0.0077	99.9692
6.5669E-05	0.0077	99.9769
7.5295E-05	0.0154	99.9923
3.4897E-04	0.0077	100.0000

*********** Descriptive Statistics ***********

Minimum = 0.0000E+00

I-3: 10 Year ISI only, FAVOR 02.4 (cont.)

Maximum	= 3.4888E-04
Range	= 3.4888E-04
Number of Simulations	= 13000
5th Percentile	= 3.9267E-12
Median	= 9.1862E-09
95.0th Percentile	= 3.4381E-07
99.0th Percentile	= 3.2043E-06
99.9th Percentile	= 1.8910E-05
Mean	= 2.3935E-07
Standard Deviation	= 3.4388E-06
Standard Error	= 3.0160E-08
Variance (unbiased)	= 1.1825E-11
Variance (biased)	= 1.1824E-11
Moment Coeff. of Skewness	= 8.2903E+01
Pearson's 2nd Coeff. of Skewness	= 2.0881E-01
Kurtosis	= 8.1786E+03

```
*************************************************************
*     PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)         *
*        FOR THE FREQUENCY OF VESSEL FAILURE                *
*************************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	5.4538	5.4538
6.4155E-08	89.5462	95.0000
1.9247E-07	2.2077	97.2077
3.2078E-07	0.7846	97.9923
4.4909E-07	0.4769	98.4692
5.7740E-07	0.2769	98.7462
7.0571E-07	0.1923	98.9385
8.3402E-07	0.1077	99.0462
9.6233E-07	0.0923	99.1385
1.0906E-06	0.0846	99.2231
1.2190E-06	0.0923	99.3154
1.3473E-06	0.0692	99.3846
1.4756E-06	0.0538	99.4385
1.6039E-06	0.0615	99.5000
1.7322E-06	0.0462	99.5462
1.8605E-06	0.0308	99.5769
1.9888E-06	0.0231	99.6000
2.1171E-06	0.0308	99.6308
2.2454E-06	0.0538	99.6846
2.3738E-06	0.0077	99.6923
2.5021E-06	0.0154	99.7077
2.6304E-06	0.0154	99.7231
2.7587E-06	0.0077	99.7308

I-3: 10 Year ISI only, FAVOR 02.4 (cont.)

2.8870E-06	0.0154	99.7462
3.1436E-06	0.0077	99.7538
3.2719E-06	0.0077	99.7615
3.4002E-06	0.0154	99.7769
3.5285E-06	0.0231	99.8000
3.6569E-06	0.0077	99.8077
4.1701E-06	0.0077	99.8154
4.2984E-06	0.0154	99.8308
4.4267E-06	0.0077	99.8385
4.6833E-06	0.0077	99.8462
4.8117E-06	0.0077	99.8538
4.9400E-06	0.0077	99.8615
5.0683E-06	0.0077	99.8692
5.3249E-06	0.0077	99.8769
5.7098E-06	0.0077	99.8846
6.2231E-06	0.0077	99.8923
7.2496E-06	0.0077	99.9000
8.1477E-06	0.0077	99.9077
8.2761E-06	0.0077	99.9154
9.0459E-06	0.0077	99.9231
9.5592E-06	0.0077	99.9308
1.1227E-05	0.0077	99.9385
1.2767E-05	0.0077	99.9462
1.3024E-05	0.0077	99.9538
1.3922E-05	0.0077	99.9615
1.6103E-05	0.0077	99.9692
1.6616E-05	0.0077	99.9769
1.7258E-05	0.0077	99.9846
3.2655E-05	0.0077	99.9923
4.5615E-05	0.0077	100.0000

```
*********** Descriptive Statistics ***********

Minimum                              = 0.0000E+00
Maximum                              = 4.5569E-05
Range                                = 4.5569E-05

Number of Simulations                =  13000

5th Percentile                       = 0.0000E+00
Median                               = 4.0626E-10
95.0th Percentile                    = 6.4155E-08
99.0th Percentile                    = 7.7903E-07
99.9th Percentile                    = 7.2496E-06

Mean                                 = 5.3576E-08
Standard Deviation                   = 6.5836E-07
Standard Error                       = 5.7742E-09
Variance (unbiased)                  = 4.3344E-13
Variance (biased)                    = 4.3340E-13
Moment Coeff. of Skewness            = 4.2104E+01
Pearson's 2nd Coeff. of Skewness     = 2.0227E-01
Kurtosis                             = 2.3729E+03
```

I-3: 10 Year ISI only, FAVOR 02.4 (cont.)

```
***********************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON   *
*             AND FREQUENCY OF RPV FAILURE BY             *
*                        TRANSIENT                        *
*      WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
***********************************************************
```

	% of total frequency of crack initiation	% of total frequency of of RPV failure
19	0.12	0.30
40	43.44	6.19
52	0.01	0.03
54	0.93	2.64
55	1.23	3.64
58	33.59	49.15
59	0.38	0.14
60	1.96	1.30
62	8.71	9.21
63	2.59	3.61
64	2.20	2.94
65	4.85	20.86
TOTALS	100.00	100.00

DATE: 18-Jul-2003   TIME: 09:01:18

I-4: ISI Every 10 Years, FAVOR 02.4

```
**************************************************
*                                                *
*               WELCOME TO FAVOR                 *
*                                                *
*    FRACTURE ANALYSIS OF VESSELS: OAK RIDGE     *
*                VERSION 02.4                    *
*                                                *
*     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           *
*                                                *
*          phone : (865) 574-0650                *
*          fax   : (865) 574-0651                *
*        e-mail: dicksontl@ornl.gov              *
*                                                *
**************************************************

************************************************************
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************************************************************


DATE: 14-Jul-2003  TIME: 12:48:54


FAVPOST INPUT  FILE NAME                       = ppost12.in
FAVPFM  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE.DAT
FAVPFM  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE.DAT
FAVPOST OUTPUT FILE NAME                       = 13000.out


   **********************************
   * NUMBER OF SIMULATIONS =  13000 *
   **********************************
```

I-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

TRANSIENT NUMBER	CONDITIONAL PROBABILITY OF INITIATION CPI=P(I|E) MEAN CPI	95th % CPI	99th % CPI	CONDITIONAL PROBABILITY OF FAILURE CPF=P(F|E) MEAN CPF	95th % CPF	99th % CPF	RATIO CPFmn/CPImn
19	1.7739E-07	0.0000E+00	0.0000E+00	1.4712E-07	0.0000E+00	0.0000E+00	0.8294
40	2.5004E-03	5.3196E-03	3.2910E-02	6.9340E-05	1.1258E-04	1.1680E-03	0.0277
52	1.4740E-07	0.0000E+00	0.0000E+00	1.1386E-07	0.0000E+00	0.0000E+00	0.7725
54	1.2874E-04	1.1940E-04	2.3604E-03	8.7219E-05	8.6598E-05	1.6330E-03	0.6775
55	4.4750E-07	0.0000E+00	0.0000E+00	3.8799E-07	0.0000E+00	0.0000E+00	0.8670
58	1.9499E-04	2.6320E-04	3.2385E-03	8.8316E-05	1.2096E-04	1.5120E-03	0.4529
59	2.8949E-06	0.0000E+00	4.6176E-06	2.9601E-07	0.0000E+00	2.4198E-07	0.1022
60	1.2719E-05	5.0623E-07	9.7196E-05	2.0664E-06	3.1552E-09	1.2731E-05	0.1625
62	2.2713E-03	4.6475E-03	2.7804E-02	5.2128E-04	1.1558E-03	7.3840E-03	0.2295
63	7.8733E-04	1.3722E-03	1.2209E-02	2.4395E-04	4.4170E-04	3.8726E-03	0.3098
64	5.7768E-04	1.0801E-03	8.8567E-03	1.5117E-04	2.8781E-04	2.5492E-03	0.2617
65	6.0039E-05	2.1371E-05	9.9588E-04	5.8075E-05	2.0714E-05	9.6664E-04	0.9673

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

I-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

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

FREQUENCY OF CRACK INITIATION (CRACKED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	1.3308	1.3308
3.3818E-07	93.6692	95.0000
1.0145E-06	2.3846	97.3846
1.6909E-06	0.8769	98.2615
2.3673E-06	0.4385	98.7000
3.0436E-06	0.2462	98.9462
3.7200E-06	0.1923	99.1385
4.3964E-06	0.1385	99.2769
5.0727E-06	0.1077	99.3846
5.7491E-06	0.1000	99.4846
6.4254E-06	0.0615	99.5462
7.1018E-06	0.0615	99.6077
7.7782E-06	0.0308	99.6385
8.4545E-06	0.0308	99.6692
9.1309E-06	0.0538	99.7231
9.8073E-06	0.0308	99.7538
1.0484E-05	0.0154	99.7692
1.1160E-05	0.0385	99.8077
1.1836E-05	0.0231	99.8308
1.2513E-05	0.0077	99.8385
1.3189E-05	0.0154	99.8538
1.4542E-05	0.0077	99.8615
1.5895E-05	0.0077	99.8692
1.7247E-05	0.0077	99.8769
1.7924E-05	0.0154	99.8923
1.8600E-05	0.0077	99.9000
1.9276E-05	0.0077	99.9077
1.9953E-05	0.0077	99.9154
2.0629E-05	0.0077	99.9231
2.1982E-05	0.0154	99.9385
2.4011E-05	0.0077	99.9462
2.8745E-05	0.0077	99.9538
3.6862E-05	0.0077	99.9615
4.4978E-05	0.0077	99.9692
5.0389E-05	0.0077	99.9769
5.2418E-05	0.0077	99.9846
7.6091E-05	0.0077	99.9923
1.3223E-04	0.0077	100.0000

*********** Descriptive Statistics ***********

Minimum	= 0.0000E+00
Maximum	= 1.3226E-04
Range	= 1.3226E-04

I-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

Number of Simulations	= 13000
5th Percentile	= 4.0219E-12
Median	= 8.4205E-09
95.0th Percentile	= 3.3818E-07
99.0th Percentile	= 3.2330E-06
99.9th Percentile	= 1.8600E-05
Mean	= 2.1217E-07
Standard Deviation	= 1.8302E-06
Standard Error	= 1.6052E-08
Variance (unbiased)	= 3.3495E-12
Variance (biased)	= 3.3493E-12
Moment Coeff. of Skewness	= 4.1372E+01
Pearson's 2nd Coeff. of Skewness	= 3.4778E-01
Kurtosis	= 2.4628E+03

```
************************************************************
*     PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)        *
*        FOR THE FREQUENCY OF VESSEL FAILURE               *
************************************************************
```

FREQUENCY OF VESSEL FAILURES (FAILED VESSELS PER YEAR)	RELATIVE DENSITY (%)	CUMULATIVE DISTRIBUTION (%)
0.0000E+00	5.6231	5.6231
6.4978E-08	89.3769	95.0000
1.9494E-07	2.0538	97.0538
3.2489E-07	0.9769	98.0308
4.5485E-07	0.4846	98.5154
5.8481E-07	0.2692	98.7846
7.1476E-07	0.2308	99.0154
8.4472E-07	0.1462	99.1615
9.7468E-07	0.1154	99.2769
1.1046E-06	0.0538	99.3308
1.2346E-06	0.0462	99.3769
1.3645E-06	0.0538	99.4308
1.4945E-06	0.0692	99.5000
1.6245E-06	0.0462	99.5462
1.7544E-06	0.0308	99.5769
1.8844E-06	0.0692	99.6462
2.1443E-06	0.0231	99.6692
2.2742E-06	0.0077	99.6769
2.4042E-06	0.0154	99.6923
2.5342E-06	0.0615	99.7538
2.6641E-06	0.0077	99.7615
2.9240E-06	0.0308	99.7923
3.1839E-06	0.0154	99.8077
3.3139E-06	0.0385	99.8462
3.4439E-06	0.0231	99.8692
3.7038E-06	0.0077	99.8769

I-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

3.9637E-06	0.0077	99.8846
4.0936E-06	0.0077	99.8923
4.2236E-06	0.0154	99.9077
4.3536E-06	0.0077	99.9154
4.8734E-06	0.0077	99.9231
5.6531E-06	0.0077	99.9308
7.7324E-06	0.0077	99.9385
7.9924E-06	0.0077	99.9462
8.1223E-06	0.0154	99.9615
9.1620E-06	0.0077	99.9692
1.6440E-05	0.0077	99.9769
1.6829E-05	0.0077	99.9846
1.9169E-05	0.0077	99.9923
3.2424E-05	0.0077	100.0000

```
*********** Descriptive Statistics ***********

Minimum                              = 0.0000E+00
Maximum                              = 3.2421E-05
Range                                = 3.2421E-05

Number of Simulations                =  13000

5th Percentile                       = 0.0000E+00
Median                               = 3.8415E-10
95.0th Percentile                    = 6.4978E-08
99.0th Percentile                    = 7.0610E-07
99.9th Percentile                    = 4.1586E-06

Mean                                 = 4.6015E-08
Standard Deviation                   = 4.7112E-07
Standard Error                       = 4.1320E-09
Variance (unbiased)                  = 2.2196E-13
Variance (biased)                    = 2.2194E-13
Moment Coeff. of Skewness            = 4.0046E+01
Pearson's 2nd Coeff. of Skewness     = 2.3939E-01
Kurtosis                             = 2.2075E+03

**********************************************************
*  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATIONON   *
*             AND FREQUENCY OF RPV FAILURE BY            *
*                       TRANSIENT                        *
*      WEIGHTED BY TRANSIENT INITIATING FREQUENCIES      *
**********************************************************
```

	% of total frequency of crack initiation	% of total frequency of of RPV failure
19	0.05	0.17
40	51.42	6.22
52	0.10	0.36
54	0.34	1.06
55	0.33	1.19
58	26.57	56.05
59	0.26	0.13

I-4: ISI Every 10 Years, FAVOR 02.4 (cont.)

60	1.52	1.05
62	9.62	10.73
63	3.36	3.78
64	2.95	3.82
65	3.47	15.44
TOTALS	100.00	100.00

DATE: 14-Jul-2003 TIME: 12:49:05

APPENDIX J
PROBSBFD COMPUTER TOOL SOURCE CODE

```
      PROGRAM PROBSBFD
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                  *
*     FATIGUE CRACK GROWTH AND ISI BY THE MONTE-CARLO METHOD       *
*                                                                  *
*     FOR SURFACE BREAKING FLAWS IN FAVOR 02.4 S.DAT INPUT FILE    *
*                                                                  *
*     WRITTEN BY BRUCE A. BISHOP FOR WOG/CEOG RI-RVI PROGRAM       *
*                                                                  *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*    COPYRIGHT - WESTINGHOUSE ELECTRIC COMPANY - APRIL 2003        *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
       COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
C
      PRGNAM='PROBSBFD 1.0'
C
C     DO ALL CALCULATIONS IN SUBROUTINE PROFONPC
C
C     KEY VARIABLES EACH CYCLE PASSED AMONG SUBROUTINES:
C
C     ANOW(I) = CURRENT CRACK DEPTH (FOR 4 TYPES OF FLAWS)
C     PRND(I) = NON-DETECTION PROBABILITY AFTER EACH ISI
C
      CALL PROFONPC
C
      STOP
      END
      BLOCK DATA CONPROF
C
C     SETS CONSTANTS FOR INCLUSION IN COMMON BLOCK PROF
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
       COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
      DATA ZERO,CENT,HALF,ONE,TWO,PI,TEN
     1     / 0.0, 0.01, 0.5, 1.0, 2.0, 3.141592654, 10.0 /
C
      END
```

```
      SUBROUTINE ISI
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                   *
*    CALCULATES PROBABILITY OF NONDETECTION DURING ISI              *
*                                                                   *
*    FOR PROBSBFD - WRITTEN BY BRUCE A. BISHOP OF WESTINGHOUSE      *
*                                                                   *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*    COPYRIGHT - WESTINGHOUSE ELECTRIC COMPANY - APRIL 2003         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
       COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
C
      DIMENSION IV(8)
      EQUIVALENCE (IV(1),INDX(1,2))
C
C *** INPUTS TO ISI WHERE IV(1) = 3
C
C     PRND(I)     = PROBABILITY OF NONDETECTION BEFORE ISI
C     ANOW(I)     = CURRENT CRACK DEPTH (FOR EACH TYPE FLAW)
C     VAL(IV(1)) = Cycle for 1st In-Service Inspection
C     VAL(IV(2)) = Cycles Between In-Service Inspections
C     VAL(IV(3)) = Mean Value of Detectable Depth (in.)
C     VAL(IV(4)) = Std. Dev. of Detectable Depth (inch)
C     VAL(IV(5)) = Cumulative ISI Effect (0=No 1=Yes)
C
C *** ISI RETURNS
C
C     PRND(I) = PROBABILITY OF NONDETECTION AFTER CURRENT ISI
C
C     BASED UPON PC-PRAISE SUBROUTINE INSPCT(PROB) MODIFIED TO
C     INCORPORATE THE LATEST POD CURVE FOR RPV BELTLINE ISI
C     FROM THE EPRI NDE CENTER (ERWIN BECKER)
C
      DATA P,A1,A2,A3,A4,A5,A6,ZMAX / 0.3275911, 0.254829592,
     1 -0.284496736, 1.421413541, -1.453152027, 1.061405429,
     2  1.414213562, 2.575 /
C
      IF(ICYCLE.GT.0) GOTO 100
      ISIC=IDINT(VAL(IV(1)))
      ISID=IDINT(VAL(IV(2)))
      VMN=VAL(IV(3))
      SDV=VAL(IV(4))
      CISI=VAL(IV(5))
C
 100  IF(ICYCLE.LT.ISIC) RETURN
      ISIC=ISIC+ISID
```

```
      DO 200, ITYP=1,4
      PND=PRND(ITYP)
      PNDI=PND
      X=(ANOW(ITYP)-VMN)/SDV/A6
      XX=DABS(X)
      IF(XX.GT.ZMAX) THEN
 XX=ZMAX
 X=DSIGN(XX,X)
      ENDIF
      T = ONE / (ONE + P * XX)
      CON = T*(A1+T*(A2+T*(A3+T*(A4+A5*T))))
      PNDE = HALF*DEXP(-X*X)*CON
      IF(CISI.GT.HALF) THEN
   PND=PNDE*PNDI
      ELSE
   PND=PNDE
      ENDIF
C
 200  PRND(ITYP)=PND
      IF(IDBUG.EQ.ITRIAL) WRITE(9,3000) ICYCLE,(PRND(J),J=1,4)
3000  FORMAT(I6,1P,5E14.5)
      RETURN
      END
      SUBROUTINE SET
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                               *
*    SETS INITIAL VALUES OF TIME-INVARIANT VARIABLES            *
*                                                               *
*    FOR PROBSBFD - WRITTEN BY BRUCE A. BISHOP OF WESTINGHOUSE  *
*                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
       COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
C
      DIMENSION IV(8)
      EQUIVALENCE (IV(1),INDX(1,1))
C
C *** INPUT TO SET WHERE IV(1) = 1
C
C     VAL(IV(1)) = Fractional Initial Flaw Depth
C     VAL(IV(2)) = Initial Flaw Density
C
C *** SET RETURNS
C
```

```
C     ANOW(I) = INITIAL CRACK DEPTH A (FOR EACH TYPE FLAW)
C     ILOW(I) = INITIAL INDEX FOR INTERPOLATION OF SIFS
C     PRND(I) = INITIAL PROBABILITY OF NONDETECTION
C
      IPRF=31
      VAL(31)=ONE
      DO 100 ITYP=1,4
      ANOW(ITYP)= WALL * VAL(1)
      AMIN=XK(1,ITYP)
      IF(ANOW(ITYP).LT.AMIN) ANOW(ITYP)=AMIN
      ILOW(ITYP)=1
 100  PRND(ITYP)=ONE
C
      ITYP=0
      IF(IDBUG.EQ.ITRIAL) WRITE(9,3001) ITYP,(ANOW(J),J=1,4),
     1 VAL(1), VAL(2), VAL (13), VAL(14)
3001  FORMAT(I6,1P, 4E14.5/6X, 4E14.5)
      RETURN
      END
      SUBROUTINE SSC
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                 *
*    CALCULATES STRESS INTENSITY FACTOR AKA IN DEPTH DIRECTION    *
*                                                                 *
*    FOR PROBSBFD - WRITTEN BY BRUCE A. BISHOP OF WESTINGHOUSE    *
*                                                                 *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
       COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
C
      DIMENSION IV(8)
      EQUIVALENCE (IV(1),INDX(1,3))
C
C *** INPUT TO SSC WHERE IV(1) = 8
C
C     VAL(IV(1)) = Aspect Ratio for 1st Flaw Type
C     VAL(IV(2)) = Aspect Ratio for 2nd Flaw Type
C     VAL(IV(3)) = Aspect Ratio for 3rd Flaw Type
C     VAL(IV(4)) = Aspect Ratio for 4th Flaw Type
C
C *** SCC RETURNS
C
C     AKMN(ITYP) = MINIMUM SIF FOR ANOW(ITYP)
C     AKMX(ITYP) = MAXIMUM SIF FOR ANOW(ITYP)
```

```
C
C     THESE ARE CALCULATED BY LINEAR INTERPOLATION OF THE
C     VALUES EXTRACTED FROM THE FAVLOAD FILE FOR THE FCG
C     TRANSIENT, TYPICALLY COOLDOWN AND HEATUP, IN /DKIN/
C
      DO 100, ITYP=1,4
10    I=ILOW(ITYP)
      J=ILOW(ITYP)+1
      IF(ANOW(ITYP).LT.XK(J,ITYP)) THEN
 XF=(ANOW(ITYP)-XK(I,ITYP))/(XK(J,ITYP)-XK(I,ITYP))
      ELSE
 ILOW(ITYP)=J
 GOTO 10
      ENDIF
      AKMN(ITYP)=(ONE-XF)*AKXMN(I,ITYP)+XF*AKXMN(J,ITYP)
      IF(AKMN(ITYP).LT.ZERO) AKMN(ITYP)=ZERO
      AKMX(ITYP)=(ONE-XF)*AKXMX(I,ITYP)+XF*AKXMX(J,ITYP)
 100  CONTINUE
      IF(IDBUG.EQ.ITRIAL) WRITE(9,3001) ICYCLE, (AKMN(J),J=1,4),
     1 (AKMX(J),J=1,4)
3001  FORMAT(I6, 1P, 4E14.5/6X, 4E14.5)
      RETURN
C
      END
      SUBROUTINE TRC
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                               *
*    CALCULATES FATIGUE CRACK GROWTH DUE TO TRANSIENT LOADS     *
*                                                               *
*    FOR PROBSBFD - WRITTEN BY BRUCE A. BISHOP OF WESTINGHOUSE  *
*                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
        COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
C
      DIMENSION IV(8)
      EQUIVALENCE (IV(1),INDX(1,4))
C
C *** INPUT FOR TRC WHERE IV(1) = 12
C
C     VAL(IV(1)) = Number Transients per Operating Cycle
C     VAL(IV(2)) = Fatigue Crack Growth Threshold (ksi)
C     VAL(IV(3)) = Fatigue Crack Growth Rate Uncertainty
C     VAL(IV(4)) = DKIN *.DAT File (1=FAVLOADS 2=DKINSAVE)
```

```
C
C *** TRC RETURNS
C
C     ANOW(I)  = CRACK DEPTH AFTER FATIGUE CRACK GROWTH
C
      IF(ICYCLE.GT.1) GOTO 100
      CYCCON=VAL(12)
      THRHLD=VAL(13)
      STDNUM=VAL(14)
      AMAX=HALF*WALL/TWO
C
 100  DO 300, ITYP=1,4
      DA=ZERO
      AKMIN=AKMN(ITYP)
      AKMAX=AKMX(ITYP)
C *** START SUBROUTINE FERGRO IN PC-PRAISE VERSION 2
C   THIS ROUTINE CALCULATES ( FOR FERRITE ) THE GROWTH OF A SURFACE
C   DEFECT WITH INITIAL DIMENSIONS  A  AND  B
      DATA C1 , C2 / 1.02E-12 , 1.01E-07 /
C   DA / DN = CONST * ( DKEFFA ** EMEXP )
C   DOUG STILLMAN'S VERSION HAS BEEN UNKNOWND BY C. Y. LIAW'S VERSION
C   WITH MODIFICATIONS BY STAN BUMPUS
C   START OF GROWTH CALCULATIONS FOR  A  DIRECTION
      DKA = AKMAX - AKMIN
      IF ( DKA .LT. THRHLD ) GO TO 201
      RA = AKMIN / AKMAX
      IF ( RA .GT. 0.25 ) GO TO 110
      Q = EXP ( -0.408 + 0.542 * STDNUM )
      IF ( DKA .GE. 19.0 ) GO TO 105
      DADN = C1 * DKA ** 5.95
      GO TO 199
  105 DADN = C2 * DKA ** 1.95
      GO TO 199
  110 IF ( RA .GE. 0.65 ) GO TO 120
      Q = EXP (0.1025*RA-0.433625+(0.6875*RA+0.370125)*STDNUM)
      C1Q1 = C1 * ( 26.9 * RA - 5.725 )
      C2Q2 = C2 * ( 3.75 * RA + 0.06 )
      X = SQRT ( SQRT ( C2Q2 / C1Q1 ) )
      IF ( DKA .GE. X ) GO TO 115
      DADN = C1Q1*DKA ** 5.95
      GO TO 199
  115 DADN = C2Q2*DKA ** 1.95
      GO TO 199
  120 CONTINUE
      Q = EXP ( -0.367 + 0.817 * STDNUM )
      IF ( DKA .GE. 12.0 ) GO TO 125
      DADN = 1.20E-11*DKA ** 5.95
      GO TO 199
  125 DADN = 2.52E-07*DKA ** 1.95
C 199 A = A + Q*CYCCON*DADN FOR PC-PRAISE SUBROUTINE
  199 DA = Q*CYCCON*DADN
  201 CONTINUE
C *** END SUBROUTINE FERGRO IN PC-PRAISE VERSION 2
      ANOW(ITYP)=ANOW(ITYP)+DA
      IF(ANOW(ITYP).GT.AMAX) ANOW(ITYP)=AMAX
  300 CONTINUE
C
```

```
      IF(IDBUG.EQ.ITRIAL) WRITE(9,3000) ICYCLE,(ANOW(J),J=1,4)
3000  FORMAT(I6,1P,5E14.5)
      RETURN
      END
      SUBROUTINE FMD(IFAIL)
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                 *
*    WRITES S.DAT FILE FOR FAVOR AFTER ALL TIME STEPS (IFAIL=1)    *
*                                                                 *
*    FOR PROBSBFD - WRITTEN BY BRUCE A. BISHOP OF WESTINGHOUSE    *
*                                                                 *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
      COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
     1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
     2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
     3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
     4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
       COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
      CHARACTER*12 PRGNAM
C
      DIMENSION IV(8),S(5)
      EQUIVALENCE (IV(1),INDX(1,5))
C
C *** INPUT FOR FMD WHERE IV(1) = 16
C
C     VAL(IV(1)) = Percent of Initial Type 1 Flaws
C     VAL(IV(2)) = Percent of Initial Type 2 Flaws
C     VAL(IV(3)) = Percent of Initial Type 3 Flaws
C     VAL(IV(4)) = Percent of Initial Type 4 Flaws
C
C *** FMD RETURNS
C
C     IFAIL  = 1 WHEN SPECIFIED LIMIT IS EXCEEDED OR 0 OTHERWISE
C
      IF(ICYCLE.GT.1) GOTO 100
      IFAIL=0
      DWALL=HALF*CENT*WALL/TWO
      P100=TEN*TEN
      SMIN=CENT*VAL(2)/P100
C
 100  IF(ICYCLE.EQ.NCYCLE) THEN
C
C     CALCULATE END OF LIFE PARAMETERS
C
       IFAIL=1
 DO 150 ITYP=1,4
 JTYP=ITYP+15
 PRND(ITYP)=CENT*PRND(ITYP)*VAL(2)*VAL(JTYP)
       S(ITYP)=ANOW(ITYP)/DWALL
```

```
 150    ILOW(ITYP)=INT(S(ITYP)+HALF)
        IF(IDBUG.EQ.ITRIAL) WRITE(9,3001) NCYCLE,(PRND(J),J=1,4),
      1 (S(J),J=1,4)
 3001   FORMAT (I6, 1P, 4E14.5/6X, 4E14.5)
C
C      WRITE 100 LINES OF S.DAT FILE 8
C
 DO 300 I=1,100
 II=0
 S(5)=ZERO
 DO 200 J=1,4
    S(J)=ZERO
    IF(ILOW(J).EQ.I) THEN
       II=II+1
       S(J)=PRND(J)
       S(5)=S(5)+S(J)
       SD(I,J)=SD(I,J)+S(J)
    ENDIF
 200     CONTINUE
 IF(II.GT.0) THEN
 IF(S(5).EQ.ZERO) S(5)=SMIN
     DO 250 J=1,4
 250         S(J)=S(J)/S(5)/CENT
 IF(IDBUG.EQ.ITRIAL) WRITE(9,3000) I, (S(J),J=1,5)
 3000    FORMAT(I6, 1P, 5E14.5)
 ELSE
    S(1)=P100
 ENDIF
 300     WRITE(8,3452) I,S(5),(S(J),J=1,4)
       ENDIF
C
       RETURN
C *** FORMAT FROM PNNL PROGRAM VFLAW02.FOR FOR GENERATING S.DAT
C 452 FORMAT(I6, E16.5, 11F12.3 )
 3452 FORMAT(I6, 1PE16.5, 0P, SP, 5F12.3 )
       END
       SUBROUTINE DKCALC
C
C      READS FAVLOADS.DAT FILE, CALCULATES MAXIMUM AND MINIMUM K
c      VALUES FOR 4 TYPES OF CIRC. FLAWS (AR = 2, 6, 10 AND 99),
C      PRINTS RESULTS AND WRITES DATA TO FILE DKINSAVE.DAT
C
       IMPLICIT REAL*8 (A-H,O-Z)
C
C      ALL KEY VARIABLES IN LABELLED COMMON BLOCKS /PROF/ AND /DKIN/
C
       COMMON /PROF/ ICASE,NCYCLE,NFAILS,NTRIAL,NOVAR,NSET,NISI,NSSC,
      1  NTRC,NFMD,NFWT,VMEAN(40),IVTYPE(40),VSTDEV(40),VSHIFT(40),
      2  NRND,IRND(40),ICYCLE,IPRF,ITRIAL,NFAIL,VAL(81),ILOW(4),
      3  INDX(8,5),IDBUG,PRGNAM,ANOW(4),PRND(4),AKMN(4),AKMX(4),
      4  SD(100,4),ZERO,CENT,HALF,ONE,TWO,PI,TEN
        COMMON /DKIN/ WALL,XK(8,4),AKXMN(8,4),AKXMX(8,4)
C
       CHARACTER*12 PRGNAM,ATITLE
C
C*********** FROM KINFO.FOR BY JOHN KITZMILLER 04/04/03 ***************
C      USE FAVLOAD1.DAT AS INPUT I.E., READ IN COMPLETE LIST OF K      *
```

```
C     VALUES                                                              *
C*************************************************************************
      DIMENSION X(16)
C*************************************************************************
C FILE HEADER INFORMATION                                                 *
C*************************************************************************
      READ (4,1000) ATITLE
      READ (4,*) I1, I2
      READ (4,*) RI, RO, CLTH
      WALL=RO-RI
      READ (4,*) NT, NXI
C*************************************************************************
C READ OVER NT DTIMES                                                     *
C*************************************************************************
      DO 10 J=1,NT
 10   READ (4,*) I1,XIN
C*************************************************************************
C*************************************************************************
C FOLLOWING IS INFORMATION WITHOUT RESIDUAL STRESS USED FOR PLATES       *
C*************************************************************************
C*************************************************************************
C READ 16 HCDs                                                            *
C*************************************************************************
      READ (4,1001) (X(J), J=1,NXI)
C*************************************************************************
C DEFINE 8 LOCATIONS FOR INFINITE FLAWS)                                  *
C*************************************************************************
      DO 20 I=1,8
20    XK(I,4)=X(I+1)
C*************************************************************************
C READ OVER NT PRESSURES (PRESS)                                          *
C*************************************************************************
      DO 25 J=1,NT
 25   READ (4,1001) XIN
C*************************************************************************
C READ OVER TEMP (ZSURFT - NT GROUPS OF 16), HOOP STRESS W/O RESIDUAL *
C STRESS (STRHCD - NT GROUPS OF 16), AXIAL STRESS W/O RESIDUAL STRESS *
C (STAXCD - NT GROUPS OF 16), INF LENGTH AXIAL FLAWS KIs (ZKAX99 - NT *
C GROUPS OF 16)                                                           *
C*************************************************************************
      DO 30 I=1,4
      DO 30 J=1,NT
30    READ (4,1001) (X(K), K=1,NXI)
C*************************************************************************
C READ KIs FOR 360 DEGREE CIRCUM FLAWS W/O RESIDUAL STRESS (ZKCR99) AT*
C FIRST TIME                                                              *
C*************************************************************************
      READ (4,1001) (X(I), I=1,NXI)
C*************************************************************************
C READ 8 KIs FOR 360 DEGREE CIRCUM (8:4) ARRAYS - 2, 6, 10, INF          *
C*************************************************************************
      DO 40 I=1,8
      AKXMN(I,4)=X(I+1)
40    AKXMX(I,4)=X(I+1)
      DO 50 I=2, NT
      READ (4,1001) (X(J), J=1,NXI)
C*************************************************************************
```

```
C DETERMINE AKMN,AKMX READ VALUES FOR REMAINING TIMES ON 360 DEGREE     *
C CIRCUM FLAWS W/O RESIDUAL STRESS (ZKCR99)                            *
C***********************************************************************
      DO 50 K=1,8
      XIN=X(K+1)
      IF(XIN.LT.AKXMN(K,4)) AKXMN(K,4)=XIN
      IF(XIN.GT.AKXMX(K,4)) AKXMX(K,4)=XIN
50    CONTINUE
C***********************************************************************
C READ DEPTHS OF FINITE LENGTH FLAWS (CD3D - 1 GROUP OF 9)             *
C***********************************************************************
      NX=9
      READ (4,1001) (X(J), J=1,NX)
      DO 60 I=1,3
      DO 60 J=1,8
60    XK(J,I)=X(J+1)
C***********************************************************************
C READ OVER AXIAL FLAWS KIs WITH AR OF 2 (AXK2TOT - NT GROUPS OF 9),   *
C AXIAL FLAWS KIs WITH AR OF 6 (AXK6TOT - NT GROUPS OF 9), AXIAL       *
C FLAWS KIs WITH AR OF 10 (AXK10TOT - NT GROUPS OF 9)                  *
C***********************************************************************
      DO 70 I=1,3
      DO 70 J=1,NT
70    READ (4,1001) (X(K), K=1,NX)
C***********************************************************************
C READ KIs FOR FINITE CIRCUM FLAWS W/O RESIDUAL STRESS AT              *
C ASPECT RATIO OF 2, 6, 10 (CIRK2TOT, CIRK6TOT, CIRK10TOT)             *
C***********************************************************************
      DO 100 I=1,3
C***********************************************************************
C READ FINITE CIRCUM FLAWS FOR FIRST TIME                              *
C***********************************************************************
      READ (4,1001) (X(K), K=1,NX)
C***********************************************************************
C READ 8 KIs FOR FINITE CIRCUM (8:3) ARRAYS - 2, 6, 10                 *
C***********************************************************************
      DO 80 J=1,8
      AKXMN(J,I)=X(J+1)
80    AKXMX(J,I)=X(J+1)
C***********************************************************************
C DETERMINE AKMN,AKMX READ VALUES FOR REMAINING TIMES FOR FINITE       *
C CIRCUM FLAWS W/O RESIDUAL STRESS                                     *
C***********************************************************************
      DO 90 J=2,NT
      READ (4,1001) (X(K), K=1,NX)
      DO 90 K=1,8
      XIN=X(K+1)
      IF(XIN.LT.AKXMN(K,I)) AKXMN(K,I)=XIN
      IF(XIN.GT.AKXMX(K,I)) AKXMX(K,I)=XIN
90    CONTINUE
100   CONTINUE
C***********************************************************************
C***********************************************************************
C FOLLOWING IS INFORMATION WITH RESIDUAL STRESS USED FOR WELDS         *
C***********************************************************************
C***********************************************************************
C READ OVER HOOP STRESS WITH RESIDUAL STRESS (STRHCD - NT GROUPS OF    *
```

```
C 16), AXIAL STRESS W RESIDUAL STRESS (STAXCD - NT GROUPS OF 16),     *
C INF LENGTH AXIAL FLAWS KIs W RESIDUAL STRESS (ZKAX99 - NT GROUPS OF *
C 16)                                                                 *
C**********************************************************************
      DO 130 I=1,3
      DO 130 J=1,NT
130   READ (4,1001) (X(K), K=1,NXI)
C**********************************************************************
C READ KIs FOR 360 DEGREE CIRCUM FLAWS W RESIDUAL STRESS (ZKCR99) AT  *
C FIRST TIME                                                           *
C**********************************************************************
      READ (4,1001) (X(I), I=1,NXI)
      DO 140 I=1,8
      AKXMN(I,4)=X(I+1)
140   AKXMX(I,4)=X(I+1)
      DO 150 I=2, NT
      READ (4,1001) (X(J), J=1,NXI)
C**********************************************************************
C DETERMINE AKMN,AKMX READ VALUES FOR REMAINING TIMES ON 360 DEGREE   *
C CIRCUM FLAWS W RESIDUAL STRESS (ZKCR99)                              *
C**********************************************************************
      DO 150 K=1,8
      XIN=X(K+1)
      IF(XIN.LT.AKXMN(K,4)) AKXMN(K,4)=XIN
      IF(XIN.GT.AKXMX(K,4)) AKXMX(K,4)=XIN
150   CONTINUE
C**********************************************************************
C READ OVER AXIAL FLAWS KIs WITH AR OF 2 W RESIDUAL STRESS (AXK2TOT - *
C NT GROUPS OF 9), AXIAL FLAWS KIs WITH AR OF 6 WITH RESIDUAL STRESS  *
C (AXK6TOT - NT GROUPS OF 9), AXIAL FLAWS KIs WITH AR OF 10 W         *
C RESIDUAL STRESS (AXK10TOT - NT GROUPS OF 9)                          *
C**********************************************************************
      DO 170 I=1,3
      DO 170 J=1,NT
170   READ (4,1001) (X(K), K=1,NX)
C**********************************************************************
C READ KIs FOR FINITE CIRCUM FLAWS W RESIDUAL STRESS AT                *
C ASPECT RATIO OF 2, 6, 10 (CIRK2TOT, CIRK6TOT, CIRK10TOT)             *
C**********************************************************************
      DO 200 I=1,3
C**********************************************************************
C READ FINITE CIRCUM FLAWS FOR FIRST TIME                              *
C**********************************************************************
      READ (4,1001) (X(K), K=1,NX)
      DO 180 J=1,8
      AKXMN(J,I)=X(J+1)
180   AKXMX(J,I)=X(J+1)
C**********************************************************************
C DETERMINE RKMN,RKMX READ VALUES FOR REMAINING TIMES FOR FINITE      *
C CIRCUM FLAWS W RESIDUAL STRESS                                       *
C**********************************************************************
      DO 190 J=2,NT
      READ (4,1001) (X(K), K=1,NX)
      DO 190 K=1,8
      XIN=X(K+1)
      IF(XIN.LT.AKXMN(K,I)) AKXMN(K,I)=XIN
      IF(XIN.GT.AKXMX(K,I)) AKXMX(K,I)=XIN
```

```
190   CONTINUE
200   CONTINUE
      CLOSE (4)
C
C     WRITE CALCULATED INFORMATION TO DKINSAVE & OUTPUT FILES
C
      OPEN(4,FILE='DKINSAVE.DAT',STATUS='UNKNOWN')
      WRITE (7,2300) WALL
      WRITE (4,2301) WALL
      DO 300 I=1,4
      WRITE(7,2302) I,VAL(I+7)
      DO 300 J=1,8
      WRITE(7,2301) XK(J,I),AKXMN(J,I),AKXMX(J,I)
 300  WRITE(4,2301) XK(J,I),AKXMN(J,I),AKXMX(J,I)
C*********************************************************************
C FORMAT STATEMENTS                                                  *
C*********************************************************************
 1000 FORMAT (A12)
 1001 FORMAT (E14.6)
 2300 FORMAT(/'  INFORMATION GENERATED FROM FAVLOADS.DAT FILE '/
    1        '  AND SAVED IN DKINSAVE.DAT FILE:'//
    2        '  WALL THICKNESS =',F8.4,' INCH'//
    3        '  FLAW DEPTH  MINIMUM K AND MAXIMUM K FOR')
 2301 FORMAT(1PD15.5,2D15.5)
 2302 FORMAT(/'    TYPE',I2,' WITH AN ASPECT RATIO OF',F5.0/)
      END
```