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Fracture Analysis of Vessels – Oak Ridge
FAVOR v20.1.12
User's Guide

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EXECUTIVE SUMMARY

The **F**racture **A**nalysis of **V**essels – **O**ak **R**idge (**FAVOR**) computer program has been developed to perform deterministic and probabilistic risk-informed analyses of the structural integrity of a nuclear reactor pressure vessel (RPV) when subjected to a range of thermal-hydraulic events. The focus of this analysis is the beltline region of the RPV wall.

Overcooling events, where the temperature of the coolant in contact with the inner surface of the RPV wall rapidly decreases with time, produce time-dependent temperature gradients that induce biaxial stress states varying in magnitude through the vessel wall. Near the inner surface and through most of the wall thickness, the stresses are tensile, thus generating Mode I opening driving forces that can act on possible existing internal surface-breaking or embedded flaws near the wetted inner surface. If the internal pressure of the coolant is sufficiently high, then the combined thermal plus mechanical loading results in a transient condition known as a pressurized-thermal shock (PTS) event.

Normal planned reactor operational transients, such as start-up, cool-down, and leak-test can also present challenges to the structural integrity of the RPV. FAVOR, v16.1 is an evolution of the FAVOR code (version 06.1) used to develop the PTS risk estimates reported in NUREGs-1806 and 1874, which were published in 2006 and 2007, respectively.

In 1999 ORNL, working in cooperation with the NRC staff and with other NRC contractors, illustrated that the application of fracture-related technology developed since the derivation of the current pressurized-thermal-shock (PTS) regulations (established in the 1980s) had the potential for providing a technical basis for a re-evaluation of the then-current PTS regulations. Motivated by these findings, the U.S. Nuclear Regulatory Commission (NRC) began the PTS Re-evaluation Project to develop a technical basis to support a revision to the rule within the framework established by modern probabilistic risk assessment techniques and advances in the technologies associated with the physics of PTS events.

An updated computational methodology was developed through research and interactions among experts in the relevant disciplines of thermal-hydraulics, probabilistic risk assessment (PRA), materials embrittlement, probabilistic fracture mechanics (PFM), and inspection (flaw characterization). Major differences between this methodology and that used to establish the technical basis for the original version of the PTS rule include the following:

- **the ability to incorporate new detailed flaw-characterization distributions from NRC research obtained via work performed at the Pacific Northwest National Laboratory, PNNL,**
- **the ability to incorporate detailed neutron fluence maps,**
- **the ability to incorporate warm-prestressing effects into the analysis,**
- **the ability to include temperature-dependencies in the thermo-elastic properties of base and cladding,**
- **the ability to include crack-face pressure loading for surface-breaking flaws,**
- **the addition of a new ductile-fracture model simulating stable and unstable ductile tearing,**
- **the addition of a new embrittlement correlation,**
- **the ability to include multiple transients in one execution of FAVOR,**
- **the ability to include input from the Reactor Vessel Integrity Database, Revision 2, (RVID2) of relevant RPV material properties,**

- **the addition of new fracture-toughness models based on extended databases and improved statistical distributions,**
- **the addition of a variable failure criterion, i.e., how far must a flaw propagate into the RPV wall for the vessel simulation to be considered as "failed" ?**
- **the addition of semi-elliptic surface-breaking and embedded-flaw models,**
- **the addition of through-wall weld stresses,**
- **the addition of base material SIFIC(s) from the ASME code, Section XI, Appendix A, Article A-3000, *Method of K_I Determination*, for infinite and finite axial and 360° continuous and finite circumferential flaws into the FAVOR SIFIC database, and**
- **the implementation of improved PFM methodology that incorporates modern PRA procedures for the classification and propagation of input uncertainties and the characterization of output uncertainties as statistical distributions.**

These updated methodologies were implemented into the FAVOR computer code, which was then subjected to extensive verification studies. A specific version, FAVOR, v06.1, was used to develop the PTS TWCF estimates reported in NUREG-1806 and NUREG-1874, which were published in 2006 and 2007, respectively. The TWCF estimates in NUREG-1874 formed part of the technical basis for the alternate PTS rule (10 CFR 50.61a).

The FAVOR computer code has continued to evolve and to be extensively applied by analysts from the nuclear industry, both nationally and internationally, and by regulators at the NRC. FAVOR, V20.1 has added the capability to evaluate as-found flaws to v16.1, and retains backward compability with FAVOR 16.1 to do analyses of flaws as defined with VFLAW. This report documents the technical bases for the assumptions, algorithms, methods, and correlations employed in the development of the FAVOR code.

ACRONYMS

BNL	Brookhaven National Laboratory
EFPY	effective full-power years
EOL	end-of-licensing
IPTS	Integrated Pressurized Thermal Shock Program
LEFM	linear-elastic fracture mechanics
LOCA	loss-of-coolant accident
ORNL	Oak Ridge National Laboratory
NRC	United States Nuclear Regulatory Commission
PFM	probabilistic fracture mechanics
PNNL	Pacific Northwest National Laboratory
PRA	Probabilistic Risk Assessment
PTS	pressurized thermal shock
PWR	pressurized water reactor
RPV	reactor pressure vessel
T-E	thermo-elastic
T-H	thermal-hydraulic

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FAVOR 20.1.12 was developed in a collaborative manner by a team composed of:

- Terry Dickson, Andrew Dyszel, and Marvin Smith, of NUMARK Associates, Inc.
- Brad Richardson, Karla Morris, Kate Rasmussen, and Damian Rouson, of Sourcery Inc.
- Giovanni Facco, James Burke, and Patrick Raynaud, of the NRC's Office of Nuclear Regulatory Research.

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1. Introduction

1.1 Background

In 1999, Dickson et al. [1]illustrated that the application of fracture-related technology developed since the derivation of the original pressurized-thermal-shock (PTS) rules (established in the early-mid 1980s) had the potential to better inform the basis of the then-extant PTS regulations. An updated computational methodology was developed over several years through research and interactions among experts in the relevant disciplines of thermal-hydraulics, probabilistic risk assessment (PRA), materials embrittlement, probabilistic fracture mechanics (PFM), and inspection (flaw characterization).

This updated methodology has been implemented into the **F**racture **A**nalysis of **V**essels – **O**ak **R**idge computer code developed at Oak Ridge National Laboratory (ORNL) for the U.S. Nuclear Regulatory Commission (NRC). FAVOR was applied in the *PTS Re-evaluation Project* to successfully establish a technical basis supporting an alternative to the original *PTS Rule* (Title 10 of the *Code of Federal Regulations*, Chapter I, Part 50, Section 50.61, 10CFR50.61) within the framework established by modern probabilistic risk assessment techniques and advances in the technologies associated with the physics of PTS events. The alternative PTS rule has been codified in 10 CFR 50.61(a).

The FAVOR computer code continues to evolve. Extensively applied by analysts from the nuclear industry and regulators at the NRC, FAVOR incorporates fracture mechanics and risk-informed methodologies to assess and update regulations designed to insure that the structural integrity of aging nuclear reactor pressure vessels (RPVs) is maintained throughout the licensing period of the reactor.

The analysis of PTS was the primary motivation in the development of FAVOR; however, the problem class for which FAVOR is applicable encompasses a broad range of events that include normal operational transients (such as start-up, shut-down, and leak-test) as well as upset conditions beyond PTS. Essentially any event in which the RPV wall is exposed to time-varying thermal-hydraulic boundary conditions would be an appropriate candidate for a FAVOR analysis of the vessel's structural integrity.

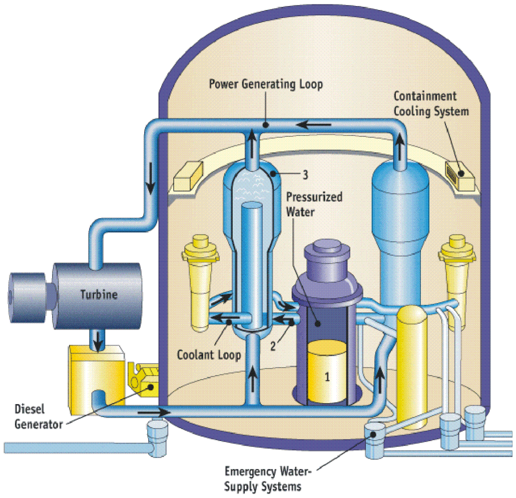
Earlier versions of FAVOR were developed to perform deterministic and risk-informed probabilistic analyses of the structural integrity of a nuclear RPV when subjected to overcooling events such as PTS accidental transients and normal cool-down transients such as those associated with reactor shutdown. *Overcooling events*, where the temperature of the coolant in contact with the inner surface of the RPV wall *decreases* with time, produce time-dependent temperature and stress gradients that are tensile on and near the RPV inner surface, thus generating Mode I opening driving forces that tend to open inner surface-breaking or embedded flaws located near the inner surface of the RPV wall.

The **F**racture **A**nalysis of **V**essels – **O**ak **R**idge **H**ea**t**-Up (FAVOR^{HT}) computer program was previously developed to perform deterministic and probabilistic fracture analyses of a nuclear RPV subjected to heat-up events, such as those transients associated with the start-up of reactors. *Heat-up events*, where the temperature of the coolant in contact with the inner surface of the RPV wall *increases* with time, produce time-dependent temperature and stress gradients that are tensile on and near the RPV external surface, thus generating Mode I opening driving forces that tend to open external surface-breaking or embedded flaws located near the external surface of the reactor vessel wall. The focus of these analyses of both *overcooling* and *heat-up* events is the *beltline* region of the RPV wall as shown in Fig. 1.

A limitation of the earlier versions of FAVOR is that they performed analyses of reactor vessels with an internal radius, R_i, to wall thickness, t, (R_i/t), ratio of approximately 10; this value for R_i/t being characteristic of pressurized water reactors (PWRs). Most boiling water reactors (BWRs) have R_i/t ratios of approximately 20, although a few BWRs in the United States have R_i/t ratios between 10 and 20. This limitation was removed in FAVOR, v09.1.

An objective of FAVOR is to continue to consolidate and expand the modeling and analysis capabilities of the previous versions of FAVOR and FAVOR^{HT} discussed above into a single computer program. FAVOR has, therefore, now been generalized to provide the capability to perform deterministic and probabilistic fracture analyses of PWRs and BWRs vessels subjected to cool-down and /or heat-up transients.

The FAVOR code represents the latest NRC applications tool for performing deterministic and risk-informed probabilistic fracture analyses of RPVs. This report is intended as a user's guide to the computer system requirements, installation, and execution of the FAVOR, v16.1, deterministic and probabilistic fracture mechanics code. Detailed instructions on input data deck preparation are presented along with a description of all output files. Example input and output cases are included. A detailed review of these advancements as implemented into the current release of FAVOR is presented in the companion report *FAVOR (v16.1): Theory and Implementation of Algorithms, Methods, and Correlations* [2].



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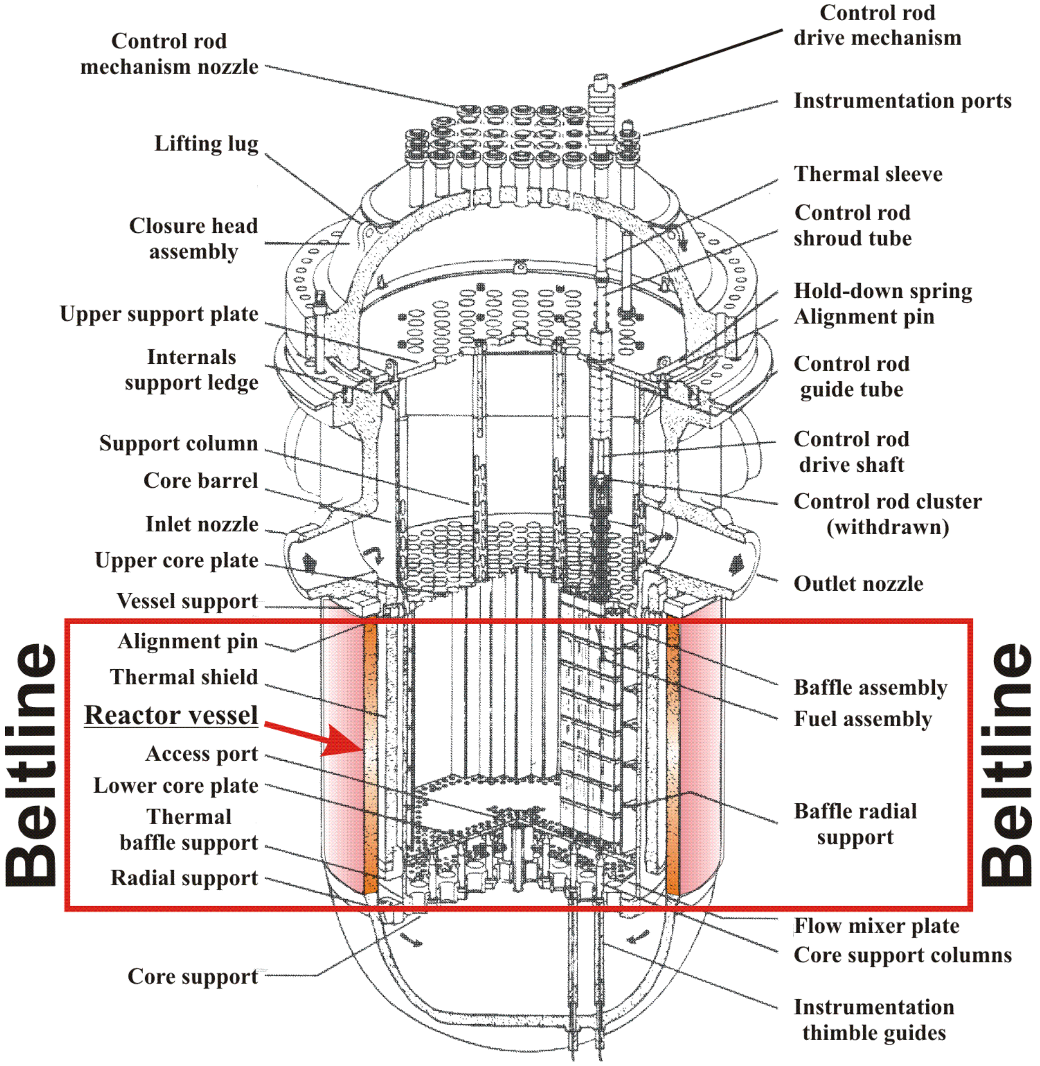


Fig. 1. The beltline region of the reactor pressure vessel wall extends from approximately one foot above the active reactor core to one foot below the core (adapted from [3]) for a pressurized water reactor (PWR).

Concern with PTS results from the combined effects of (1) simultaneous pressure and thermal-shock loadings, (2) embrittlement of the vessel due to cumulative irradiation exposure over the operating life of the vessel, and (3) the possible existence of crack-like defects at the inner surface of or embedded within the RPV heavy-section wall. The decrease in vessel temperature associated with a thermal shock also reduces the fracture toughness of the vessel and introduces the possibility of flaw propagation. Inner surface-breaking flaws and embedded flaws near the inner surface are particularly vulnerable, because at the inner surface the temperature is at its minimum and the stress and radiation-induced embrittlement are at their maximum.

The PTS issue has been under investigation for many years. Most of the early PTS analyses were of a deterministic nature. In an effort to establish more realistic limiting values of vessel embrittlement, the United States Nuclear Regulatory Commission (NRC) funded during the 1980s the Integrated Pressurized Thermal Shock (IPTS) Program [3-5] which developed a comprehensive probabilistic approach to risk assessment. Current regulatory requirements are based on the resulting *risk-informed* probabilistic methodology. In the early 1980s, extensive analyses were performed by the NRC and others to estimate the likelihood of vessel failure due to PTS events in PWRs. Though a large number of parameters governing vessel failure were identified, the single most significant parameter was a correlative index of the material that also serves as a measure of embrittlement. This material index is the reference nil-ductility transition temperature, RT_{NDT}. The NRC staff and others performed analyses of PTS risks on a conservative and generic basis to bound the risk of vessel failure for any PWR reactor. These analyses led to the establishment of the *PTS Rule* [6], promulgated in Title 10 of the *Code of Federal Regulations*, Chapter I, Part 50, Section 50.61 (10CFR50.61), and the issuance of the NRC Regulatory Guide 1.154 (RG1.154) [7].

The original *PTS Rule* specifies *screening criteria* in the form of limiting irradiated values of RT_{NDT} (designated by the rule as RT_{PTS}) of 270 °F for axially-oriented welds, plates, and forgings and 300 °F for circumferentially-oriented welds. The PTS Rule also prescribes a method to estimate RT_{PTS} for materials in an RPV in Regulatory Guide 1.99, Revision 2 [8]. For nuclear power plants to operate beyond the time that they exceed the screening criteria, the licensees must submit a plant-specific safety analysis to the NRC three years before the screening limit is anticipated to be reached..

In 2007, the NRC published a proposed amendment [9] (10CFR50.61a) to the *PTS Rule*. In 10CFR50.61a, the NRC is recommending to amend its regulations to provide updated fracture toughness requirements for protection against PTS events for PWRs. These new requirements would be voluntarily utilized by any PWR licensee as an alternative to complying with the existing requirements in 10CFR50.61. The technical bases for the amended *PTS Rule* are reported in ref. [10] in which the FAVOR code played a critical role. The recommended screening limits for PTS in 10CFR50.61a are discussed in ref. [11] which includes the following description:

> The NRC staff recommends using different reference temperature (*RT*) metrics to characterize the resistance of an RPV to fractures initiating from different flaws at different locations in the vessel. Specifically, the staff recommends an *RT* for flaws occurring along axial weld fusion lines ($RT_{MAX\text{-}AW}$), another for the embedded flaws occurring in plates ($RT_{MAX\text{-}PL}$), a third for flaws occurring along circumferential weld fusion lines ($RT_{MAX\text{-}CW}$), and a fourth for embedded and/or underclad cracks in forgings ($RT_{MAX\text{-}FO}$). These values can be estimated based mostly on the information in the NRC's Reactor Vessel Integrity Database (RVID). The staff also recommends using these different *RT* values together to characterize the fracture resistance of the vessel's beltline region, recognizing that the probability of a vessel fracture initiating from different flaw populations varies considerably in response to factors that are both understood and predictable. Correlations between these *RT* values and the through-wall cracking frequency attributable to different flaw populations show little plant-to-plant variability because of the general similarity of PTS challenges among plants.

An important element of the PTS plant-specific analysis is the calculation of the conditional probability of failure of the vessel by performing probabilistic fracture mechanics (PFM) analyses. The term *conditional* refers here to the assumption that the specific PTS event under study has in fact occurred. Combined with an estimate of the frequency of occurrence for the event, a predicted frequency of vessel failure can then be calculated. OCA-P [12] and VISA-II [13] are PTS PFM computer programs, independently developed with NRC funding at Oak Ridge National Laboratory (ORNL) and Pacific Northwest National Laboratory (PNNL), respectively, in the 1980s that are currently referenced in Regulatory Guide 1.154 as acceptable codes for performing plant-specific analyses. There have also been other proprietary PTS PFM codes independently developed in the US and internationally by reactor vendors and laboratories. These codes perform PFM analyses, using Monte Carlo techniques, to estimate the increase in failure probability as the vessel accumulates radiation damage over its operating service life. The results of such analyses, when compared with the limit of acceptable failure probability, provide an estimate of the residual life of a reactor pressure vessel. Also results of such analyses can be used to evaluate the potential benefits of plant-specific mitigating actions designed to reduce the probability of reactor vessel failure, thus potentially extending the service life of the vessel [14].

Previous efforts at obtaining the same probabilistic solutions to a specified PTS problem using different PFM codes have met with varying degrees of success [15-17]. Experience with the application of OCA-P and VISA-II as well as advancements in the science of probabilistic risk assessment (PRA) over the past 15 years have provided insights into areas where the PTS PFM methodology could be improved. The FAVOR (**F**racture **A**nalysis of **V**essels – **O**ak **R**idge) computer code was initially developed in the early 1990s [18] (see Fig. 2) in an effort to combine the best attributes of OCA-P and VISA-II. In the ensuing years, the NRC-funded FAVOR code has continued its advancement with the goal of providing a computational platform for incorporating additional capabilities and new developments in the fields of thermal hydraulics (as an input source to FAVOR), deterministic and probabilistic fracture mechanics, and probabilistic risk assessment (PRA).

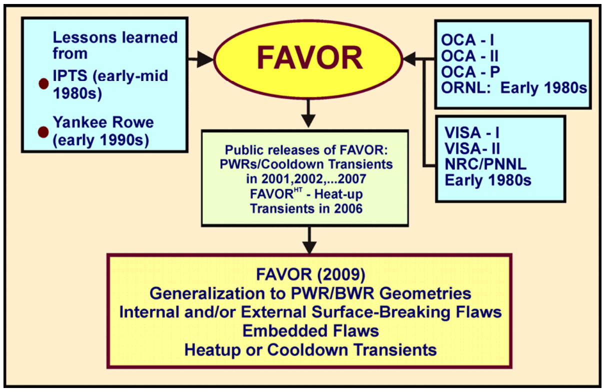


Fig. 2. Depiction of the development history of the FAVOR PFM code

1.2 PTS Re-Evaluation Project

The NRC began the *PTS Re-Evaluation Project* in 1999 to develop a technical basis for a revised PTS rule within the framework established by modern probabilistic risk assessment techniques and advances in the technologies associated with the physics of PTS events. An updated computational methodology evolved through interactions between experts in the relevant disciplines (see Fig. 3) of thermal hydraulics, PRA, materials embrittlement, PFM, and inspection (flaw characterization). This updated methodology was implemented into the FAVOR code and applied in the PTS Re-evaluation Project to establish a technical basis that better informs the basis developed for the original PTS rule. The PTS Re-evaluation was limited to performing analyses of Pressurized Water Reactors (PWRs) subjected to cool-down transients imposed on the inner (wetted) surface of the reactor pressure vessel.

As depicted in Fig. 3, FAVOR has continued to evolve with the objective of being applied to determine if a technical basis can also be established that better informs the basis of the then-existent PTS regulations (per ASME Code, Section XI, Appendix G) for normal operational transients such as those associated with reactor start-up (heat-up) and reactor shutdown (cool-down). Specifically, FAVOR has been generalized to meet this requirement, i.e., to be able perform risk-informed fracture analyses for heat-up and cool-down transients in Boiling Water Reactors (BWRs) as well as PWRs.

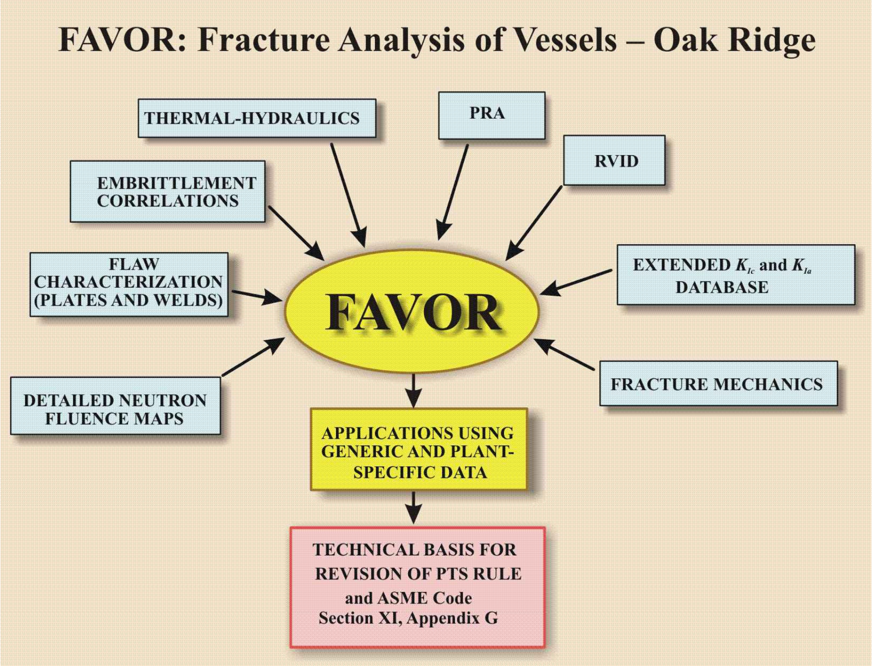


Fig. 3. The PTS Re-Evaluation Project incorporates advancements across a range of technical disciplines relevant to PTS assessment methodologies.

In support of the PTS Re-Evaluation Project, the following advanced technologies have been incorporated into FAVOR:

- **the ability to incorporate new detailed flaw-characterization distributions from NRC research (with Pacific Northwest National Laboratory, PNNL),**
- **the ability to incorporate detailed neutron fluence maps,**
- **the ability to incorporate warm-prestressing effects into the analysis,**
- **the ability to include temperature-dependencies in the thermo-elastic properties of base and cladding,**
- **the ability to include crack-face pressure loading for surface-breaking flaws,**
- **the addition of a new ductile-fracture model simulating stable and unstable ductile tearing,**
- **the addition of a new embrittlement correlation,**
- **the ability to include multiple transients in one execution of FAVOR,**
- **the ability to include input from the Reactor Vessel Integrity Database, Revision 2, (RVID2) of relevant RPV material properties,**
- **the addition of new fracture-toughness models based on extended databases and improved statistical distributions,**
- **the addition of a variable failure criterion, i.e., how far must a flaw propagate into the RPV wall for the vessel simulation to be considered as “failed” ?**
- **the addition of semi-elliptic surface-breaking and embedded-flaw models,**
- **the addition of through-wall weld stresses,**

- **the addition of base material SIFIC(s) from the proposed ASME code, Section XI, Appendix A, Article A-3000, *Method of K_I Determination*, for infinite and finite axial and 360° continuous and finite circumferential flaws into the FAVOR SIFIC database, and**
- **the implementation of improved PFM methodology that incorporates modern PRA procedures for the classification and propagation of input uncertainties and the characterization of output uncertainties as statistical distributions.**

1.3 Overview – Structure and Organization of the FAVOR Code

As shown in Fig. 4, FAVOR is composed of three computational modules: (1) a deterministic load generator (**FAVLoad**), (2) a Monte Carlo PFM module (**FAVPFM**), and (3) a post-processor (**FAVPost**). Figure 4 also indicates the nature of the data streams that flow through these modules.

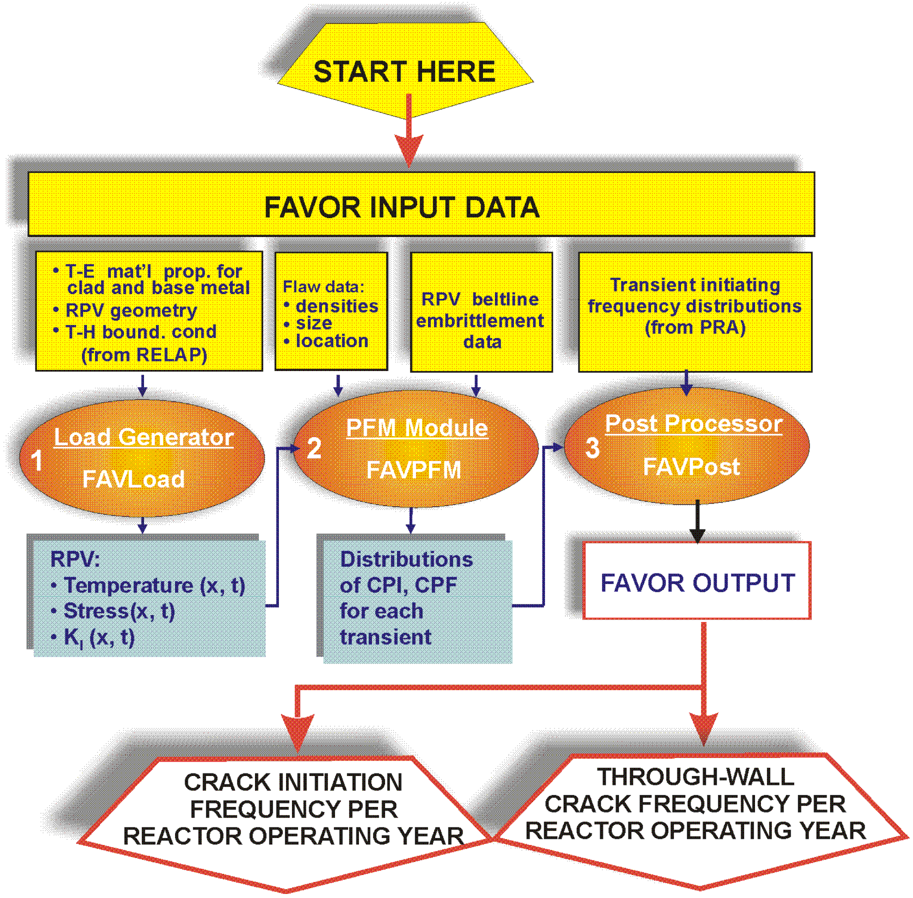


Fig. 4. FAVOR data streams flow through three modules: (1) FAVLoad, (2) FAVPFM, and (3) FAVPost.

The PFM model in FAVOR is based on the application of Monte Carlo techniques in which deterministic fracture analyses are performed on a large number of stochastically-generated RPV *trials* or *realizations*. Each vessel realization, containing a specified number of flaws, is analyzed to determine the conditional probability of initiation (*CPI*) and the conditional probability of failure

(*CPF*) for an RPV challenged by a postulated thermal-hydraulic transient at a selected time in the vessel's operating history. The fracture-initiation mechanism is stress-controlled cleavage (in the lower transition-temperature region of the vessel material) modeled under the assumptions of linear-elastic fracture mechanics (LEFM), and the associated failure modes are sufficient flaw growth either to produce a net-section plastic collapse of the remaining ligament or to advance the crack tip to a user-specified fractional distance of the wall thickness. The potential for plane-strain crack arrest is also simulated. The time-dependent load path is assumed to be quasi-static.

A ductile-fracture capability has been implemented into the *Initiation-Growth-Arrest* (IGA) submodel to allow the simulation of flaw growth by stable ductile tearing in combination with cleavage propagation. When this user-selected option is turned on, an additional failure mode of *unstable ductile tearing* is included in the determination of *CPF*.

The Monte Carlo method involves sampling from appropriate probability distributions to simulate many possible combinations of flaw geometry and RPV material embrittlement, all exposed to the same transient loading conditions. The PFM analysis is performed for the *beltline* of the RPV, usually assumed to extend from one foot below the active length of the reactor core to one foot above the core. As shown in Fig. 5, the RPV beltline can be divided into major regions such as axial welds, circumferential welds, and plates or forgings that may have their own embrittlement-sensitive chemistries. These major regions may be further divided into subregions to accommodate detailed mappings of azimuthal and axial variations in fast-neutron fluence.

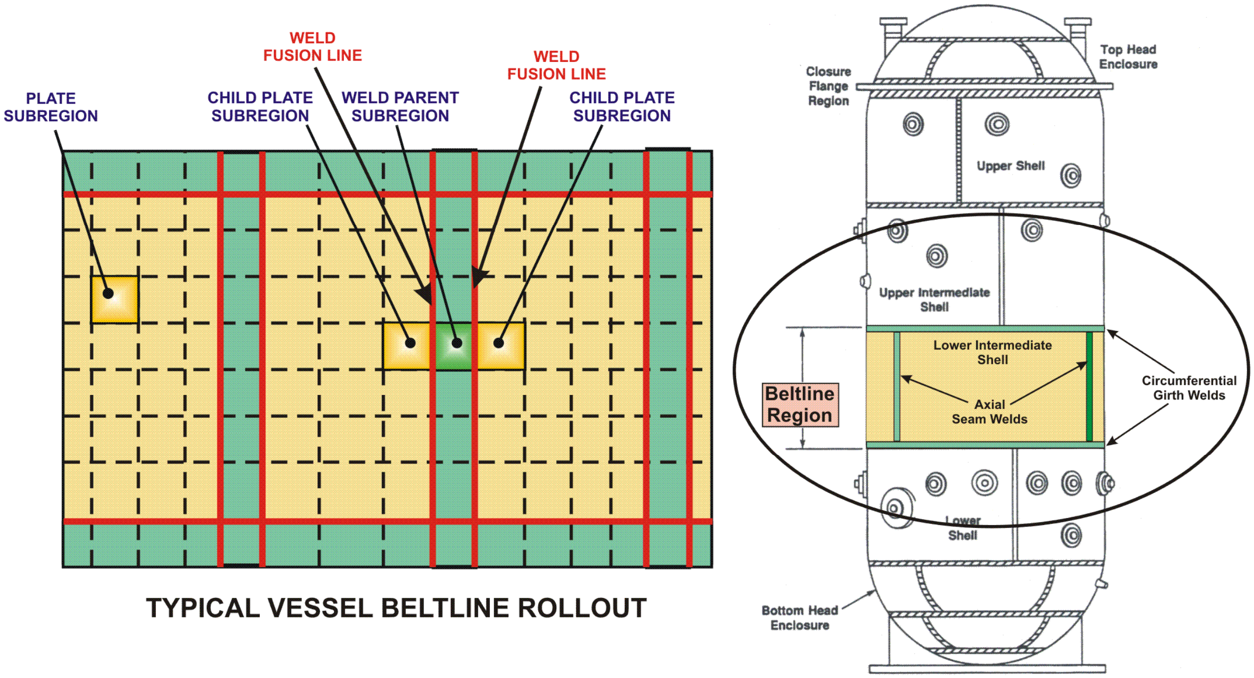


Fig. 5. The global modeling approach in FAVOR allows the entire beltline to be simulated in one model definition. (The above schematic is for a BWR.)

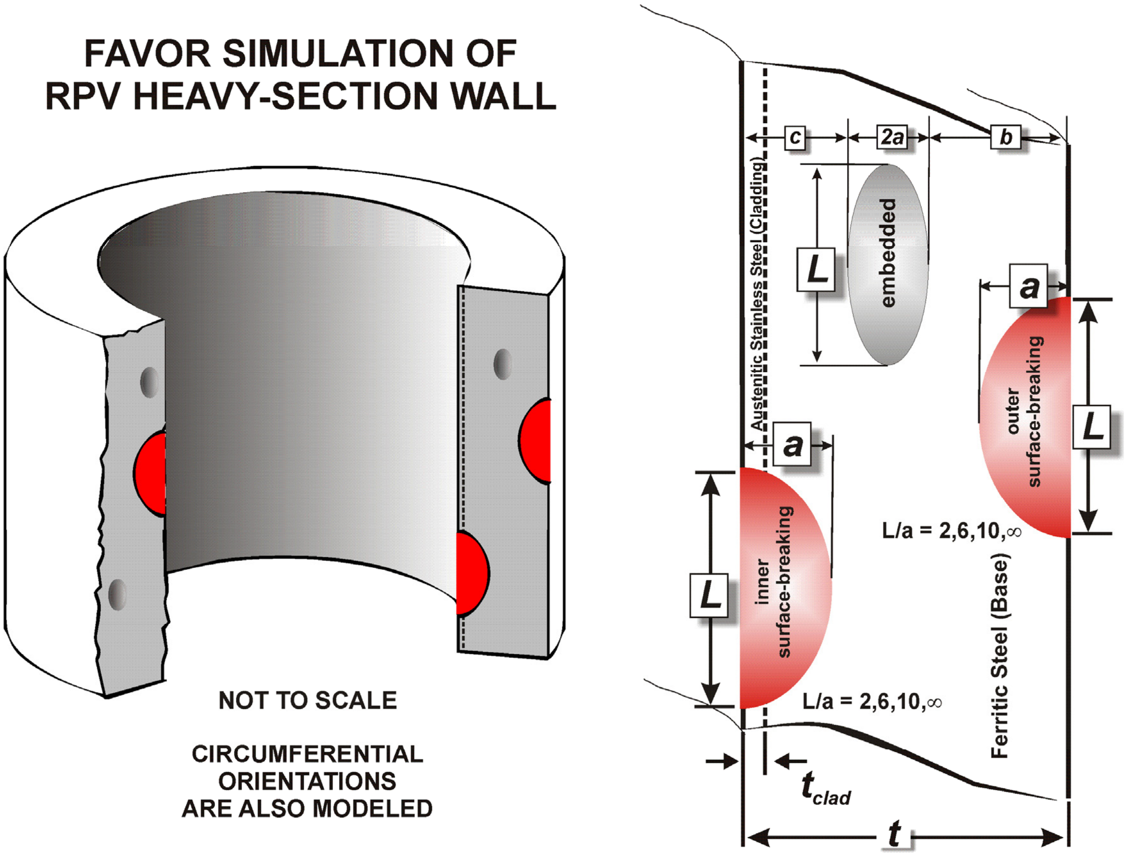


Fig. 6. Flaw models available in FAVOR.

Figure 6 shows the flaw models that are available in FAVOR:

A significant part of the generalization included in FAVOR is (1) the capability to model different flaw populations depending on the problem and (2) the capability to model BWR vessel geometries as well as PWR geometries.

FAVOR was originally developed to perform deterministic and probabilistic fracture mechanics (PFM) analyses of reactor pressure vessels subjected to cool-down thermal hydraulic transients imposed on the inner (wetted) surface of the reactor such as those associated with accidental PTS conditions and normal transients associated with reactor shutdown.

For such cool-down transients, the flaw populations of interest are those flaws on and/or near the inner surface of the reactor vessel wall, because at the inner surface, the temperature is at its minimum and the tensile stress and radiation-induced embrittlement are at their maximum. These tensile stresses tend to open existing cracks located on or near the internal surface of the RPV wall.

Therefore, earlier versions of FAVOR were limited to modeling internal surface-breaking flaws and/or embedded flaws that reside near the inner surface of the vessel wall. The embedded flaws (quantified in the embedded flaw characterization files) are assumed to be distributed uniformly throughout the entire vessel wall; however, for computational efficiency, only those postulated to reside in the first 3/8 of the base metal (wall thickness exclusive of clad thickness) were included in the analysis. For cool-down transients, the applied-K_I driving force for embedded flaws postulated to reside in the vessel wall beyond the inner 3/8 of the wall thickness is too small to have a conditional probability of initiating an embedded flaw in cleavage fracture.

For heat-up transients, such as normal transients associated with reactor start-up, flaws on or near the external surface of the reactor vessel are the most vulnerable because the tensile stresses are at their maximum there. The FAVOR^{HT} code was designed to perform analyses of these heat-up transients; i.e., however, it was limited to the modeling of embedded flaws in the outer 3/8 of the RPV wall thickness. FAVOR^{HT} did not have the capability of modeling external surface-breaking flaws.

FAVOR, v9.1, consolidated the capabilities of the previous versions of FAVOR and FAVOR^{HT} as discussed above as well as added additional capabilities. FAVOR now has the user-specified optional ability to model three different flaw populations as follows:

Flaw Population Option 1 – (Identical to previous versions of FAVOR.) All surface-breaking flaws (quantified in the surface flaw characterization input file) are internal surface breaking flaws and only those embedded flaws in the first 3/8 of the RPV wall thickness are included in the model. The primary application of this option is for modeling cool-down transients. Through-wall flaw propagation is included in this option

Flaw Population Option 2 – (Similar to previous versions of FAVOR^{HT}, however, it includes the capability to model external surface breaking flaws.) All surface-breaking flaws (quantified in the surface flaw characterization input file) are external surface-breaking flaws and those embedded flaws in the outer 3/8 of the RPV wall thickness are included in the model. The primary application of this option is for modeling heat-up transients. Through-wall flaw propagation is not included in this option, i.e., an initiated flaw is assumed to propagate thru-the-wall (thru the wetted inner surface) such that failure occurs. Therefore, the conditional probability of vessel failure is equal to the conditional probability crack initiation.

Flaw Population Option 3 – This additional population includes internal and external surface-breaking flaws; all of the embedded flaws are uniformly distributed through the RPV wall (approximately 8/3 times the number of embedded flaws postulated in Options 1 and 2). The number of postulated surface breaking flaws is double that of Options 1 or 2; and they are evenly divided between internal and external surface breaking flaws. The application of Option 3 is for modeling transients in which the pressure-induced loading is dominant (e.g., hydro-testing, etc.), since the applied-K_I for all flaws has a smaller dependence on their respective locations. Also, it is anticipated that this option may be more appropriate for modeling BWRs since the pressure-induced applied-K_I is larger for BWRs than for PWRs. Through-wall flaw propagation is not yet included in this option.

For flaw population option 3, internal surface breaking flaws and embedded flaws in the inner half of the RPV (category 2) will be incrementally propagated thru the wall to determine if the vessel fails. External surface breaking flaws and embedded flaws in the outer half of the RPV (category 3) will not be propagated thru the wall, but rather, its is just assumed that they fail the vessel.

Flaw Population Options 1 and 2 are available for computational efficiency. If the dominant loading is thermally induced, only those populations of flaws on or near the relevant RPV surface would likely ever initiate (and subsequently fail), so the other flaws are excluded from the analysis because their presence would not change the PFM solution(s), but could dramatically increase the computational resources (memory and time) to complete a PFM analysis. When in doubt, Option 3 is suggested; however, this option will require considerably more computational resources in terms of memory and computational time to reach a converged solution.

Another limitation of earlier versions of FAVOR is that the analysis of internal surface-breaking flaws was restricted to reactor vessels with an internal radius to wall thickness (R_i/t) ratio of approximately 10, characteristic of PWRs. This limitation was because the stress intensity factor-influence coefficients (SIFICs), applied by FAVOR to calculate values of applied-K_I for surface-breaking flaws, were applicable only to this specific geometry. Most BWRs have an R_i/t ratio of approximately 20, although a few BWRs in the United States have an R_i/t ratio of approximately 15.

The SIFIC datasets for BWR vessel geometry ($R_i/t \approx 20$) are distinctly different from those generated for the PWR geometry ($R_i/t \approx 10$); therefore, there are two SIFIC datasets for each of the 16 surface breaking flaw types in FAVOR; one each for PWR geometry $R_i/t \approx 10$ and BWR geometry $R_i/t \approx 20$. The generalization of FAVOR to include the capability to calculate applied-K_I 's for the 16 axially- and circumferentially-oriented internal and external surface breaking flaw types for both BWR and PWR required the creation, implementation, and verification of a total 32 SIFIC databases, compared to eight SIFIC datasets in previous versions of FAVOR. Also, algorithms have been developed and verified such that the SIFIC datasets for $R_i/t \approx 10$ and BWR geometry $R_i/t \approx 20$ for internal and external surface-breaking flaws are appropriately interpolated for application to RPVs for which $10 < R_i/t < 20$; therefore, FAVOR can be also be applied to those BWRs in the United States that have an R_i/t ratio of approximately 15.

Regarding flaw orientation, consistent with previous versions of FAVOR, all inner-surface breaking flaws are assumed to be circumferentially oriented. External surface-breaking flaws in axial welds are axially oriented; external surface-breaking flaws in circumferential welds are circumferentially oriented; and external surface-breaking flaws in plates are evenly divided between axial and circumferential orientations. As in previous versions of FAVOR, embedded flaws in welds assume the orientation of the weld, i.e., embedded flaws in axial welds are axially oriented, and embedded flaws in circumferential welds are circumferentially oriented. Embedded flaws in plates are evenly divided between axial and circumferential orientations.

For the finite-length semielliptical flaw geometries, the SIFIC datasets contain values corresponding to multiple angular positions around the semielliptical crack front; however, currently FAVOR only applies those values that correspond to the deepest point of the flaw. The code could be further generalized to have the capability to calculate the applied-K_I at multiple locations around the crack front.

It is anticipated that this generalized version of FAVOR will be instrumental in addressing the wide range of vessel geometries and transient types required in the current on-going NRC/industry study to determine if a risk-informed technical basis can be established to improve the current regulations for normal transients associated with reactor start-up and shutdown

The flaw models shown in Fig. 6 are included in the three categories of flaws identified by FAVOR:

Category 1:

Includes Flaw Population Option 1 – internal surface-breaking flaws only (flaw types 1-8)

Includes Flaw Population Option 2 – external surface-breaking flaws only (flaw types 9-16)

Includes Flaw Population Option 3 – internal and external surface-breaking flaws only (flaw types 1-16)

Category 2:

Includes Flaw Population Option 1 with embedded flaws having fully elliptic geometry with the crack tip nearest the wetted inner surface located between the clad / base interface and the inner $1/8^{th}$ of the base metal thickness

Includes Flaw Population Option 2 with embedded flaws having fully elliptic geometry with crack tip nearest the external surface located in the outer $1/8^{th}$ of the base metal thickness

Includes Flaw Population Option 3 with embedded flaws having fully elliptic geometry with crack tip nearest the external surface located between the clad base interface and the outer half of the total wall thickness.

Note: base metal thickness = total vessel wall thickness – clad thickness

Category 3:

Includes Flaw Population Option 1 with embedded flaws having fully elliptic geometry with the crack tip nearest the wetted inner surface located between $1/8^{th}$ and $3/8^{th}$ of the base metal thickness ;

Includes Flaw Population Option 2 with embedded flaws having fully elliptic geometry with crack tip nearest the external surface located between $1/8^{th}$ and $3/8^{th}$ of the outer base metal thickness ;

Includes Flaw Population Option 3 with embedded flaws having fully elliptic geometry with crack tip nearest the external surface located in the outer half of the total wall thickness.

Away from nozzles and other geometric discontinuities in the vessel, the RPV wall experiences a biaxial stress state during an overcooling event in which the principal stresses are oriented in both the longitudinal (axial stresses) and azimuthal (hoop stresses) directions. FAVOR, therefore, provides the capability for the crack face to be oriented normal to either of the two opening-mode principal directions, i.e., axial stresses opening circumferential flaws and hoop stresses opening axial flaws. In addition to the combined states of mechanical loading due to internal pressure, thermal loading due to differential expansion between the cladding and base, crack-face pressure loading on surface-breaking flaws, and through-wall thermal stress loading due to temperature gradients in the cladding and base, FAVOR also provides the option to include the effects of residual stresses in axial and circumferential welds for all of the flaw models.

The format of the required user-input data files will be discussed in detail in the following sections. In summary, the input files along with the resulting output files for the three modules are:

- **FAVLoad Data Streams (see Fig. 7)**

  1) Input file that includes: vessel geometry, thermo-mechanical material properties for the cladding and base (either constant or temperature dependent), user-selected loading options, and thermal-hydraulic definitions of all transients to be analyzed
  2) Output file that provides an echo of the user input
  3) Output file that is used as a load-definition input file for FAVPFM

- **FAVPFM Data Streams (see Fig. 8)**

  4) Input file that provides user-selected case options, major region and subregion definitions with weld/plate embrittlement data, and the number of RPV realizations/trials to be simulated
  5) Input file from the FAVLoad module [data stream file 3)] that contains load-definition data for each thermal-hydraulic transient
  6) Input file that provides characterization data for surface-breaking flaws in plates, forgings, and welds
  7) Input file that provides characterization data for flaws embedded in welds
  8) Input file that provides characterization data for flaws embedded in plates and forgings
  9) Input file for restart cases (required only if the current execution is a restart from a previous run)
  10) Output file that provides an echo of the user input
  11) Output/Input binary restart file, created at user-selected checkpoints during the FAVPFM run
  12) Output file that contains summary reports of the PFM analysis
  13) Output files that can be used for Quality Assurance checks of PFM calculations
  14) Output file with the conditional probability of crack initiation matrix for input to FAVPost
  15) Output file with the conditional probability of through-wall cracking matrix for input to FAVPost

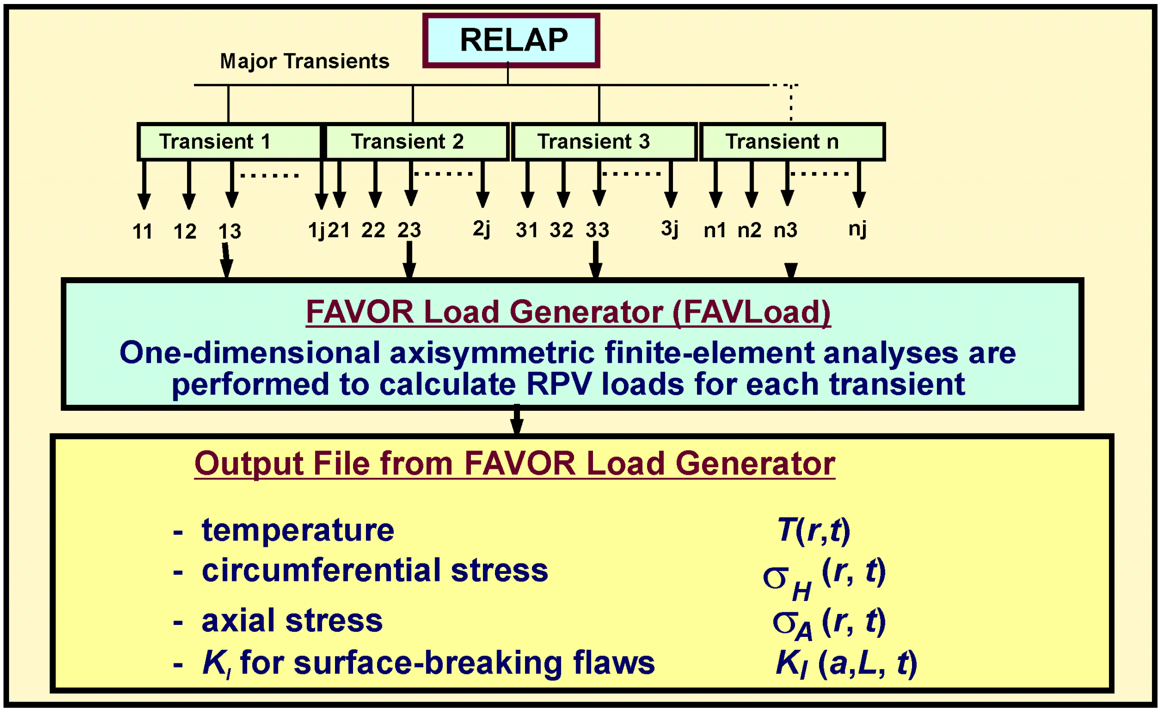


Fig. 7. The FAVOR load generator module FAVLoad performs deterministic analyses for a range of thermal-hydraulic transients.

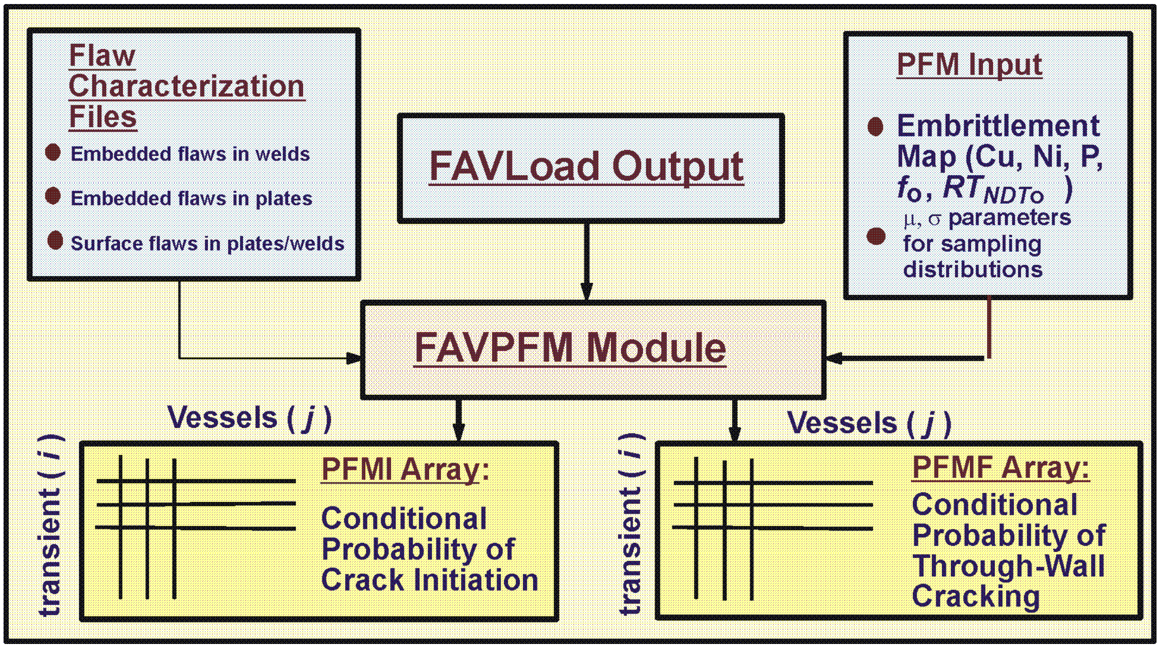


Fig. 8. The FAVPFM module takes output from FAVLoad and user-supplied data on flaw distributions and embrittlement of the RPV beltline and generates PFMI (INITIATE.DAT) and PFMF (FAILURE.DAT) arrays.

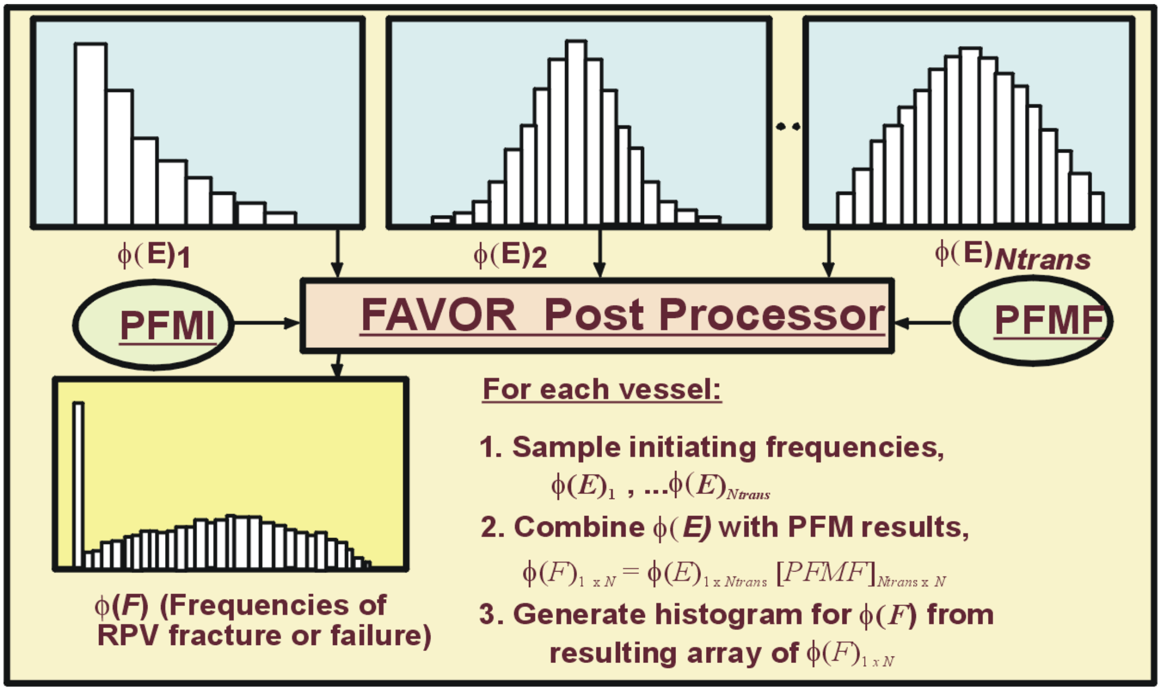


Fig. 9. The FAVOR post-processor FAVPost combines the distributions of conditional probability of initiation and failure calculated by FAVPFM with initiating frequency distributions for all of the transients under study to create distributions of frequencies of RPV fracture and failure.

- **FAVPost Data Streams (see Fig. 9)**

  16) Input file that provides initiating frequency distributions for each transient defined in 1) above.

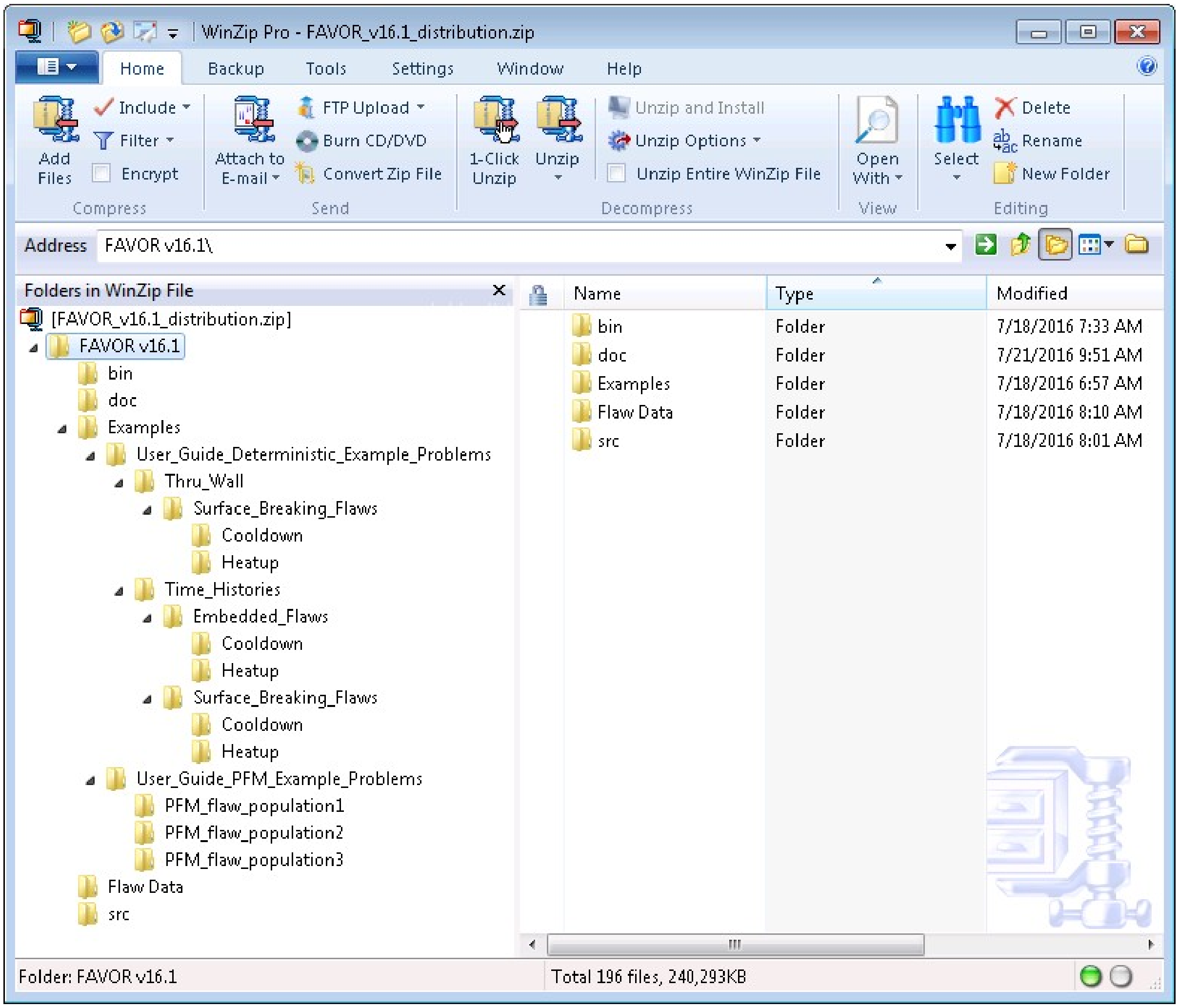
  17) Input file from FAVPFM containing the conditional probability of initiation matrix

  18) Input file from FAVPFM containing the conditional probability of failure matrix

  19) Output file that, in addition to an echo of the user input, contains histograms describing the distributions for the frequency of crack initiation and frequency of failure (also known as the through-wall crack frequency) with the units of cracked vessels per reactor operating year and failed vessels per reactor operating year, respectively.

1.4 Installation

All of the files required to run FAVOR including executables, example input and output files, documentation, and source code, are distributed in a WINZIP file. Using the WINZIP utility application, these files can be unzipped to the user's local directory. The contents of this WINZIP file are shown in Fig. 10.



Address: FAVOR v16.1\

- [FAVOR_v16.1_distribution.zip]
  - FAVOR v16.1
    - bin
    - doc
    - Examples
      - User_Guide_Deterministic_Example_Problems
        - Thru_Wall
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
        - Time_Histories
          - Embedded_Flaws
            - Cooldown
            - Heatup
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
      - User_Guide_PFM_Example_Problems
        - PFM_flaw_population1
        - PFM_flaw_population2
        - PFM_flaw_population3
    - Flaw Data
    - src

Name	Type	Modified
bin	Folder	7/18/2016 7:33 AM
doc	Folder	7/21/2016 9:51 AM
Examples	Folder	7/18/2016 6:57 AM
Flaw Data	Folder	7/18/2016 8:10 AM
src	Folder	7/18/2016 8:01 AM

Folder: FAVOR v16.1

Total 196 files, 240,293KB

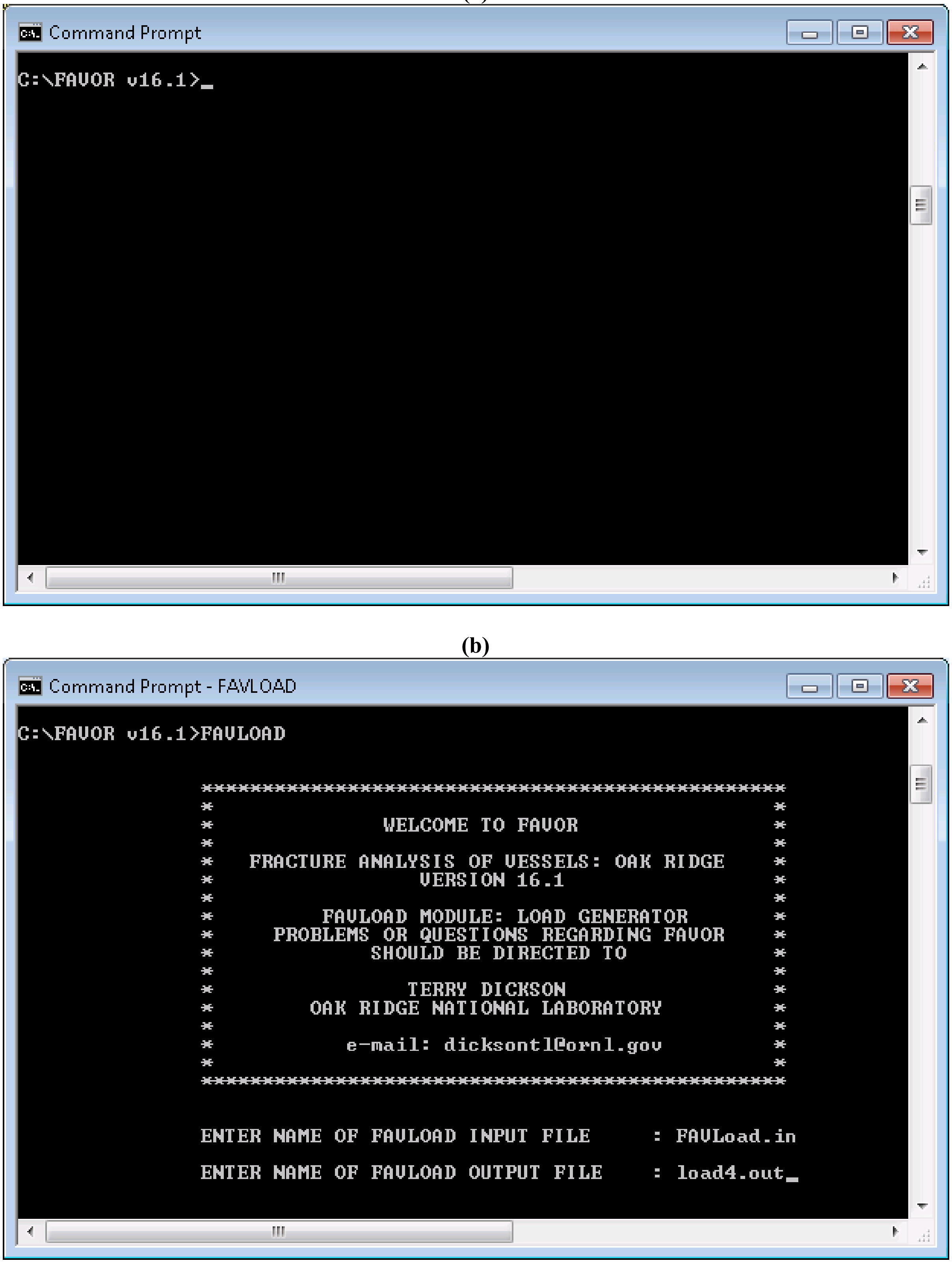
Fig. 10. Contents of the FAVOR WINZIP package file.

1.5 Execution

On Microsoft Windows operating systems (Windows XP/VISTA/7/10), the three FAVOR modules can be started either by double clicking on the executables' icon (named FAVLoad.exe, FAVPFM.exe, and FAVPost.exe) in Windows Explorer or by opening a Command Prompt window and typing in the name of the executable at the line prompt as shown in Fig. 11a for FAVLoad execution. All input files and executables must reside in the same current working directory. For details on the creation of FAVOR input files see Chapter 2. In Fig. 11b, the code prompts for the names of the FAVLoad input and FAVLoad output files. The FAVLoad output file will be used as the load-definition input file for the FAVPFM module. Figure 12 shows the messages written to the screen as FAVLoad performs its calculations.

Upon creation of the load-definition file by FAVLoad, FAVPFM execution can be started by typing "FAVPFM" at the line prompt (see Fig. 13). FAVPFM will then prompt the user for the names of six files (see Fig. 14a): (1) the FAVPFM input file, (2) load-definition file output from FAVLoad, (3) a name for the output file to be created by FAVPFM, (4) the name of the input flaw-characterization file for surface-breaking flaws in weld and plate regions (DEFAULT=S.DAT), (5) the name of the flaw-characterization file for embedded flaws in weld regions (DEFAULT=W.DAT), and (6) the name of the flaw-characterization file for embedded flaws in plate regions (DEFAULT=P.DAT). The user can accept the default file names for input files (4)-(6) by hitting the ENTER key at the prompt. If FAVPFM cannot find the named input files in the current execution directory, it will prompt the user for new file names. If the FAVPFM output file to be created already exists in the current directory, the code will query the user if it should overwrite the file. For RESTART cases, the user will be prompted for the name of a binary restart file created during a previous execution (see Fig. 14b). See Sect. 2.2, Record 1 – CNT1, for detailed information on the execution of restart cases.

The user may abort the execution at any time by typing a <ctrl>c. FAVPFM provides monitoring information during execution by writing the running averages of conditional probabilities of initiation and vessel failure for all of the transients defined in the load file for each RPV trial as shown in Fig. 15.



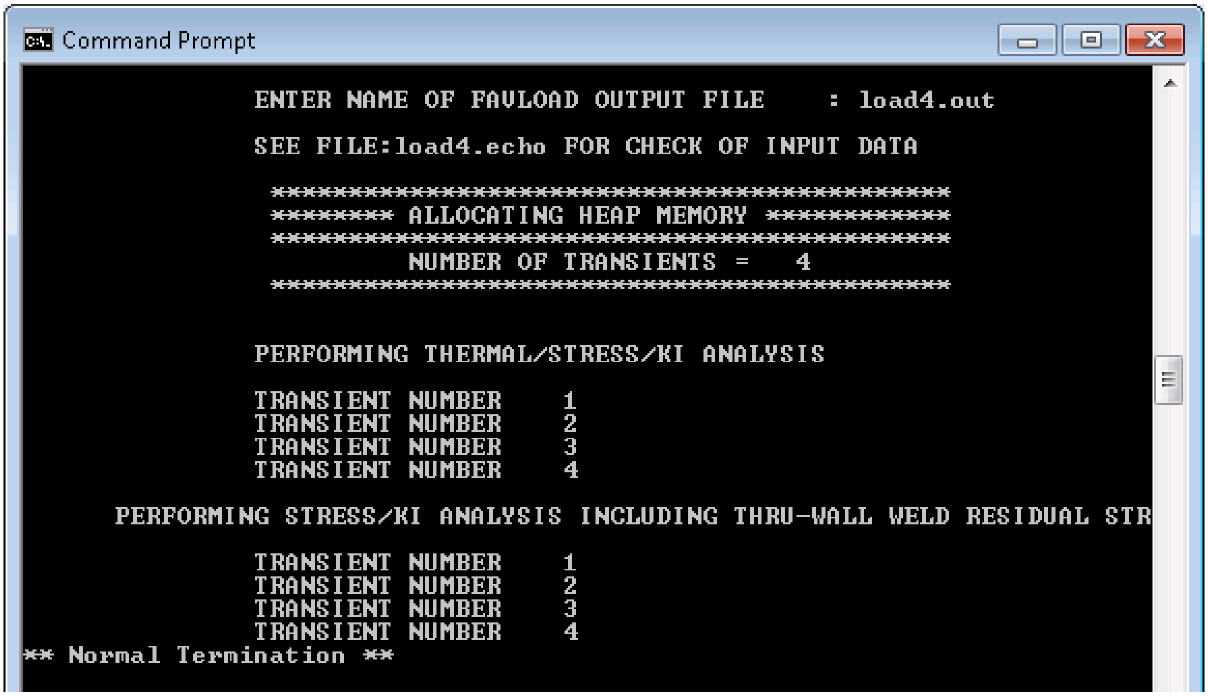
(a)

```
C:\FAVOR v16.1>_
```

(b)

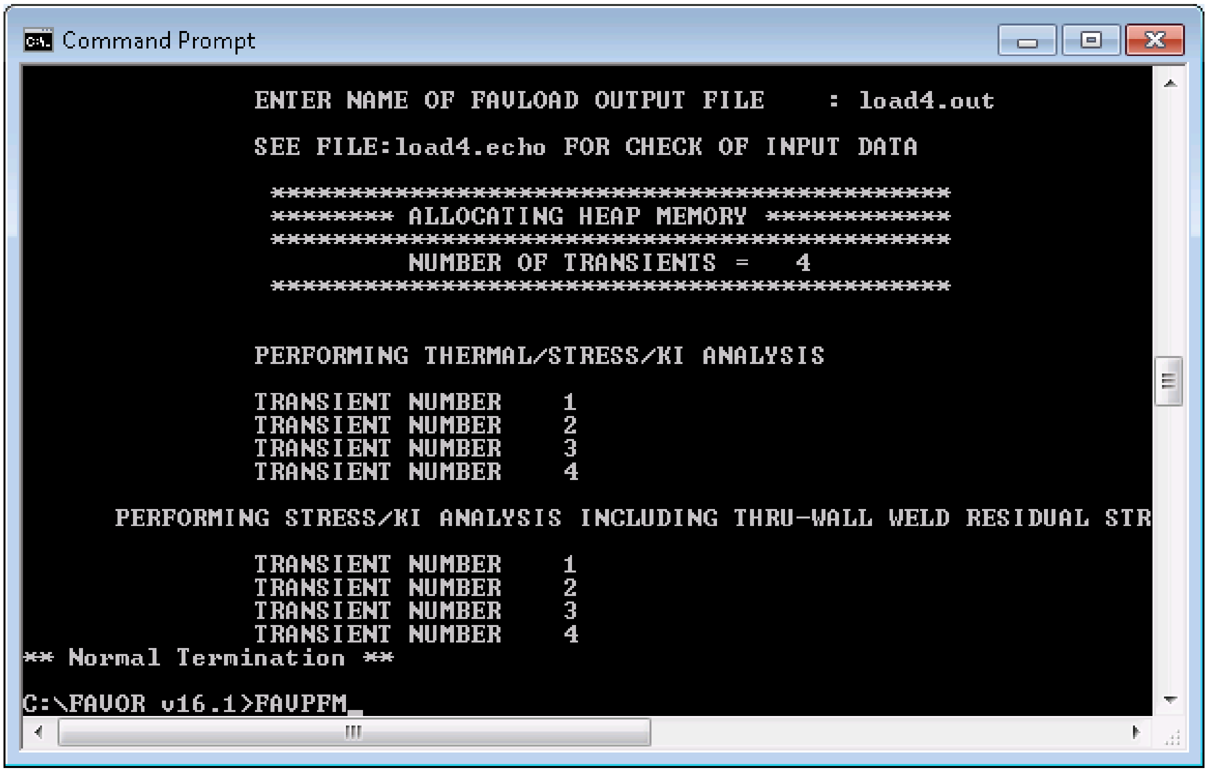
```
C:\FAVOR v16.1>FAVLOAD

               ************************************************
               *                                              *
               *              WELCOME TO FAVOR                *
               *                                              *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
               *                VERSION 16.1                  *
               *                                              *
               *        FAVLOAD MODULE: LOAD GENERATOR        *
               *     PROBLEMS OR QUESTIONS REGARDING FAVOR    *
               *             SHOULD BE DIRECTED TO            *
               *                                              *
               *                TERRY DICKSON                 *
               *         OAK RIDGE NATIONAL LABORATORY        *
               *                                              *
               *          e-mail: dicksontl@ornl.gov          *
               *                                              *
               ************************************************


               ENTER NAME OF FAVLOAD INPUT FILE      : FAVLoad.in

               ENTER NAME OF FAVLOAD OUTPUT FILE     : load4.out_
```

Fig. 11. Execution of the FAVLoad module: (a) type in FAVLoad at the line prompt and (b) respond to prompts for the input and output file names.



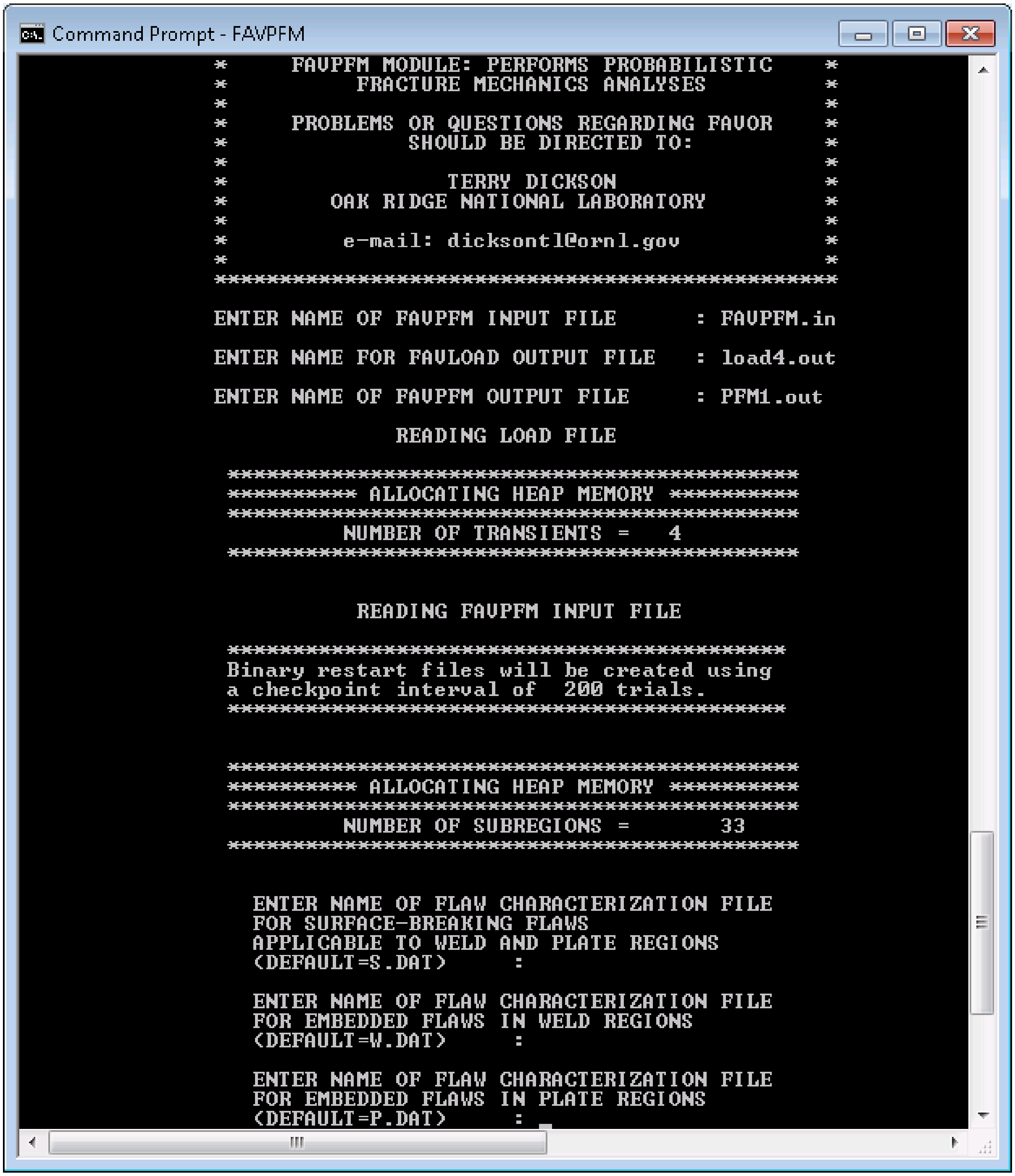
```
               ENTER NAME OF FAVLOAD OUTPUT FILE     : load4.out

               SEE FILE:load4.echo FOR CHECK OF INPUT DATA

                ********************************************
                ******** ALLOCATING HEAP MEMORY ************
                ********************************************
                         NUMBER OF TRANSIENTS =    4
                ********************************************


               PERFORMING THERMAL/STRESS/KI ANALYSIS

               TRANSIENT NUMBER     1
               TRANSIENT NUMBER     2
               TRANSIENT NUMBER     3
               TRANSIENT NUMBER     4

      PERFORMING STRESS/KI ANALYSIS INCLUDING THRU-WALL WELD RESIDUAL STR

               TRANSIENT NUMBER     1
               TRANSIENT NUMBER     2
               TRANSIENT NUMBER     3
               TRANSIENT NUMBER     4
** Normal Termination **
```

Fig. 12. FAVLoad calculates thermal, stress, and applied K_I loading for all of the transients defined in the input file.



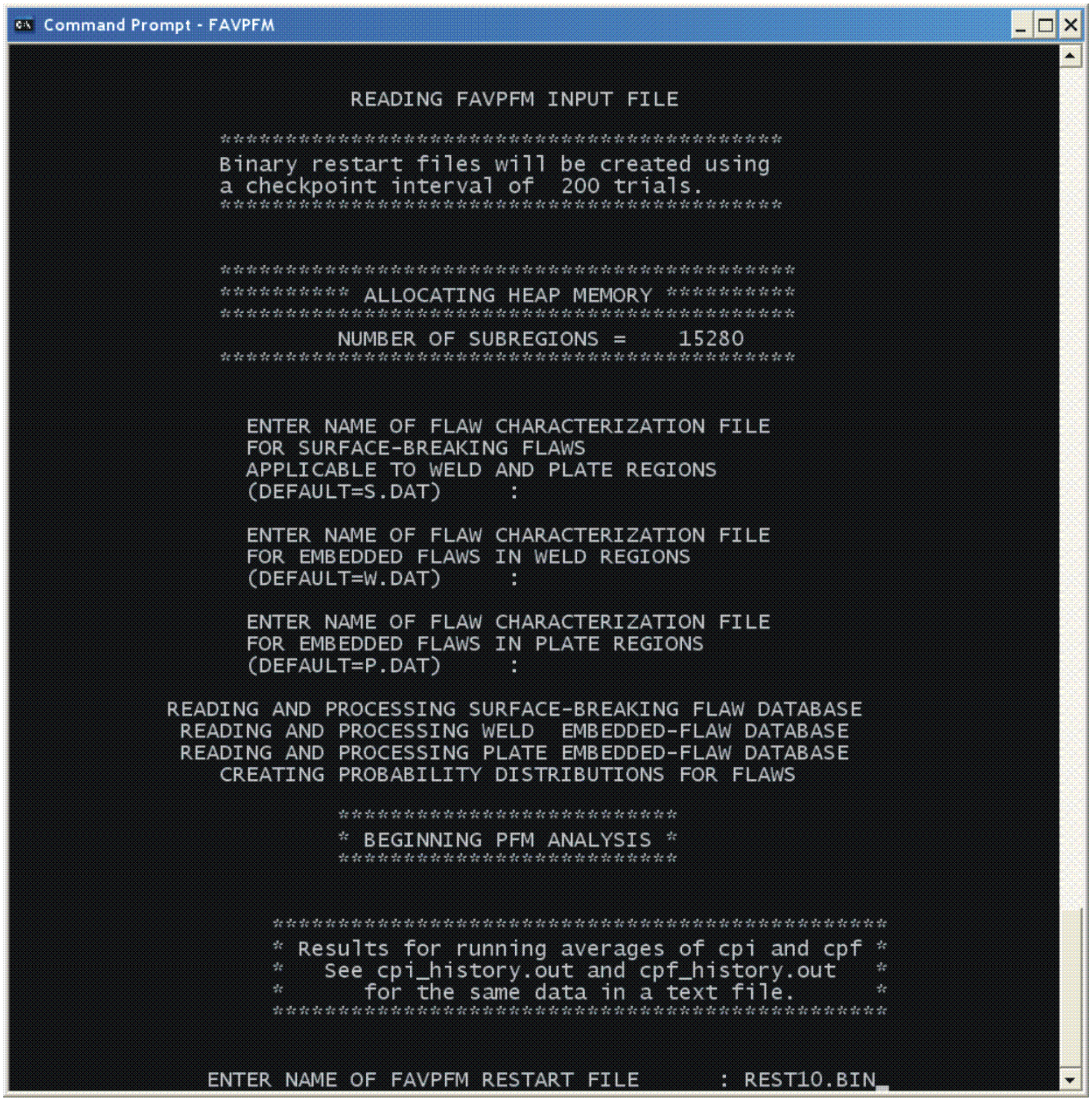
```
               ENTER NAME OF FAVLOAD OUTPUT FILE     : load4.out

               SEE FILE:load4.echo FOR CHECK OF INPUT DATA

                ********************************************
                ******** ALLOCATING HEAP MEMORY ************
                ********************************************
                         NUMBER OF TRANSIENTS =    4
                ********************************************


               PERFORMING THERMAL/STRESS/KI ANALYSIS

               TRANSIENT NUMBER     1
               TRANSIENT NUMBER     2
               TRANSIENT NUMBER     3
               TRANSIENT NUMBER     4

      PERFORMING STRESS/KI ANALYSIS INCLUDING THRU-WALL WELD RESIDUAL STR

               TRANSIENT NUMBER     1
               TRANSIENT NUMBER     2
               TRANSIENT NUMBER     3
               TRANSIENT NUMBER     4
** Normal Termination **

C:\FAVOR v16.1>FAVPFM_
```

Fig. 13. Type FAVPFM at the Command Prompt to begin execution of the FAVPFM module.



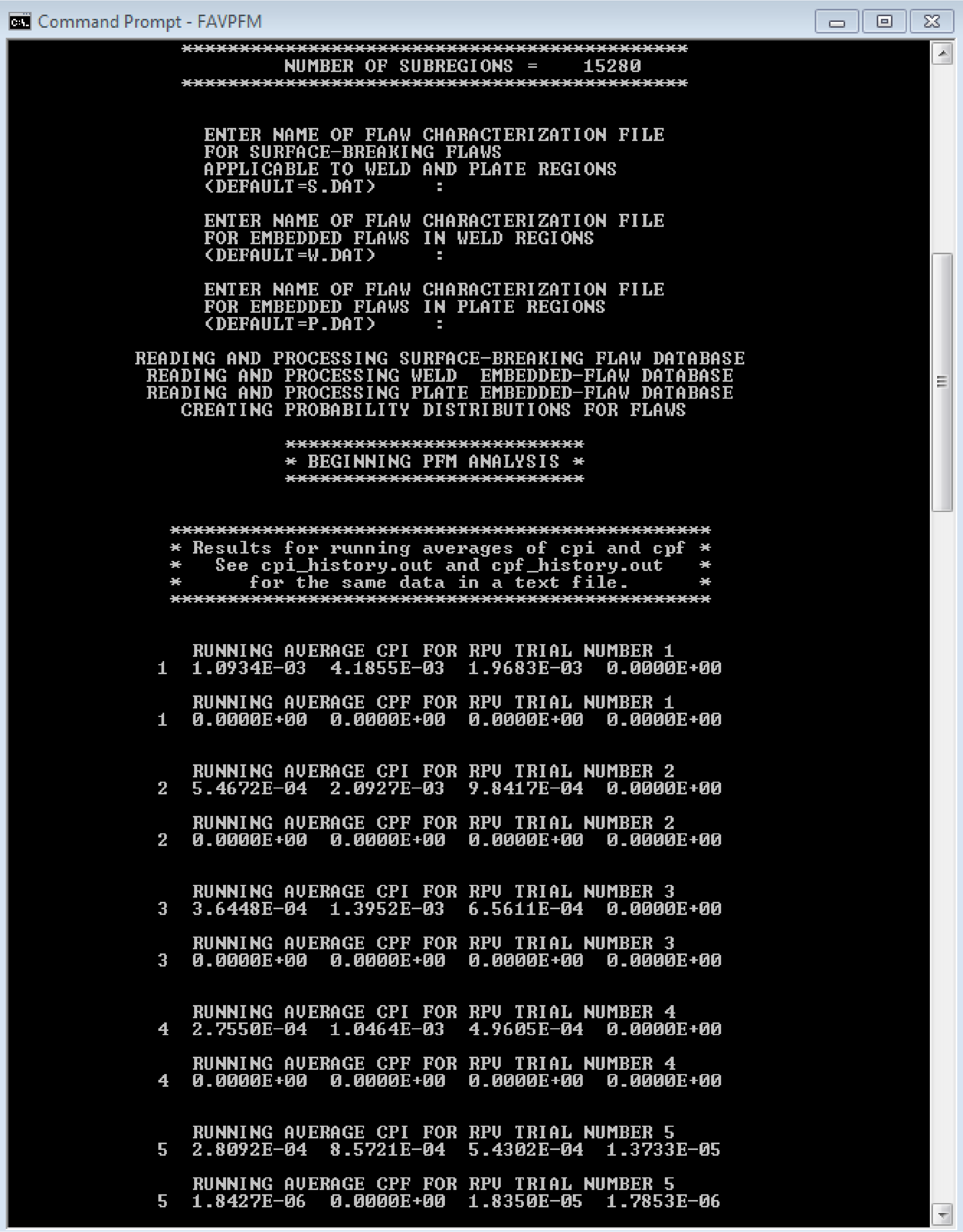
```
*     FAVPFM MODULE: PERFORMS PROBABILISTIC    *
*          FRACTURE MECHANICS ANALYSES         *
*                                              *
*     PROBLEMS OR QUESTIONS REGARDING FAVOR    *
*              SHOULD BE DIRECTED TO:          *
*                                              *
*                 TERRY DICKSON                *
*        OAK RIDGE NATIONAL LABORATORY         *
*                                              *
*         e-mail: dicksontl@ornl.gov           *
*                                              *
************************************************

ENTER NAME OF FAVPFM INPUT FILE      : FAVPFM.in

ENTER NAME FOR FAVLOAD OUTPUT FILE   : load4.out

ENTER NAME OF FAVPFM OUTPUT FILE     : PFM1.out

              READING LOAD FILE

 ********************************************
 ********** ALLOCATING HEAP MEMORY **********
 ********************************************
          NUMBER OF TRANSIENTS =   4
 ********************************************


           READING FAVPFM INPUT FILE

 *******************************************
 Binary restart files will be created using
 a checkpoint interval of  200 trials.
 *******************************************


 ********************************************
 ********** ALLOCATING HEAP MEMORY **********
 ********************************************
          NUMBER OF SUBREGIONS =       33
 ********************************************


   ENTER NAME OF FLAW CHARACTERIZATION FILE
   FOR SURFACE-BREAKING FLAWS
   APPLICABLE TO WELD AND PLATE REGIONS
   (DEFAULT=S.DAT)      :

   ENTER NAME OF FLAW CHARACTERIZATION FILE
   FOR EMBEDDED FLAWS IN WELD REGIONS
   (DEFAULT=W.DAT)      :

   ENTER NAME OF FLAW CHARACTERIZATION FILE
   FOR EMBEDDED FLAWS IN PLATE REGIONS
   (DEFAULT=P.DAT)      :
```

Fig. 14. (a) FAVPFM prompts for the names of the (1) FAVPFM input file, (2) FAVLoad-generated load-definition file, (3) FAVPFM output file, (4) flaw-characterization file for surface-breaking flaws in welds and plates, (5) flaw-characterization file for embedded flaws in welds, and (6) flaw-characterization file for embedded flaws in plates.



```
                    READING FAVPFM INPUT FILE

            ********************************************
            Binary restart files will be created using
            a checkpoint interval of  200 trials.
            ********************************************


            *********************************************
            ********** ALLOCATING HEAP MEMORY **********
            *********************************************
                     NUMBER OF SUBREGIONS =    15280
            *********************************************


              ENTER NAME OF FLAW CHARACTERIZATION FILE
              FOR SURFACE-BREAKING FLAWS
              APPLICABLE TO WELD AND PLATE REGIONS
              (DEFAULT=S.DAT)      :

              ENTER NAME OF FLAW CHARACTERIZATION FILE
              FOR EMBEDDED FLAWS IN WELD REGIONS
              (DEFAULT=W.DAT)      :

              ENTER NAME OF FLAW CHARACTERIZATION FILE
              FOR EMBEDDED FLAWS IN PLATE REGIONS
              (DEFAULT=P.DAT)      :

        READING AND PROCESSING SURFACE-BREAKING FLAW DATABASE
         READING AND PROCESSING WELD  EMBEDDED-FLAW DATABASE
         READING AND PROCESSING PLATE EMBEDDED-FLAW DATABASE
            CREATING PROBABILITY DISTRIBUTIONS FOR FLAWS

                     ***************************
                     * BEGINNING PFM ANALYSIS *
                     ***************************


                ***********************************************
                * Results for running averages of cpi and cpf *
                *   See cpi_history.out and cpf_history.out   *
                *      for the same data in a text file.      *
                ***********************************************


           ENTER NAME OF FAVPFM RESTART FILE      : REST10.BIN_
```

Fig. 14. (b) For a restart case, FAVPFM will also prompt for the binary restart file created in a previous execution (see Record 1 – CNT 1 for details regarding restart cases).



```
               ********************************************
                        NUMBER OF SUBREGIONS =    15280
               ********************************************


                 ENTER NAME OF FLAW CHARACTERIZATION FILE
                 FOR SURFACE-BREAKING FLAWS
                 APPLICABLE TO WELD AND PLATE REGIONS
                 <DEFAULT=S.DAT>     :

                 ENTER NAME OF FLAW CHARACTERIZATION FILE
                 FOR EMBEDDED FLAWS IN WELD REGIONS
                 <DEFAULT=W.DAT>     :

                 ENTER NAME OF FLAW CHARACTERIZATION FILE
                 FOR EMBEDDED FLAWS IN PLATE REGIONS
                 <DEFAULT=P.DAT>     :

           READING AND PROCESSING SURFACE-BREAKING FLAW DATABASE
            READING AND PROCESSING WELD  EMBEDDED-FLAW DATABASE
            READING AND PROCESSING PLATE EMBEDDED-FLAW DATABASE
               CREATING PROBABILITY DISTRIBUTIONS FOR FLAWS

                        **************************
                        * BEGINNING PFM ANALYSIS *
                        **************************


              ***********************************************
              * Results for running averages of cpi and cpf *
              *   See cpi_history.out and cpf_history.out   *
              *      for the same data in a text file.      *
              ***********************************************


                RUNNING AVERAGE CPI  FOR RPV TRIAL NUMBER 1
             1  1.0934E-03  4.1855E-03  1.9683E-03  0.0000E+00

                RUNNING AVERAGE CPF  FOR RPV TRIAL NUMBER 1
             1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00


                RUNNING AVERAGE CPI  FOR RPV TRIAL NUMBER 2
             2  5.4672E-04  2.0927E-03  9.8417E-04  0.0000E+00

                RUNNING AVERAGE CPF  FOR RPV TRIAL NUMBER 2
             2  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00


                RUNNING AVERAGE CPI  FOR RPV TRIAL NUMBER 3
             3  3.6448E-04  1.3952E-03  6.5611E-04  0.0000E+00

                RUNNING AVERAGE CPF  FOR RPV TRIAL NUMBER 3
             3  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00


                RUNNING AVERAGE CPI  FOR RPV TRIAL NUMBER 4
             4  2.7550E-04  1.0464E-03  4.9605E-04  0.0000E+00

                RUNNING AVERAGE CPF  FOR RPV TRIAL NUMBER 4
             4  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00


                RUNNING AVERAGE CPI  FOR RPV TRIAL NUMBER 5
             5  2.8092E-04  8.5721E-04  5.4302E-04  1.3733E-05

                RUNNING AVERAGE CPF  FOR RPV TRIAL NUMBER 5
             5  1.8427E-06  0.0000E+00  1.8350E-05  1.7853E-06
```

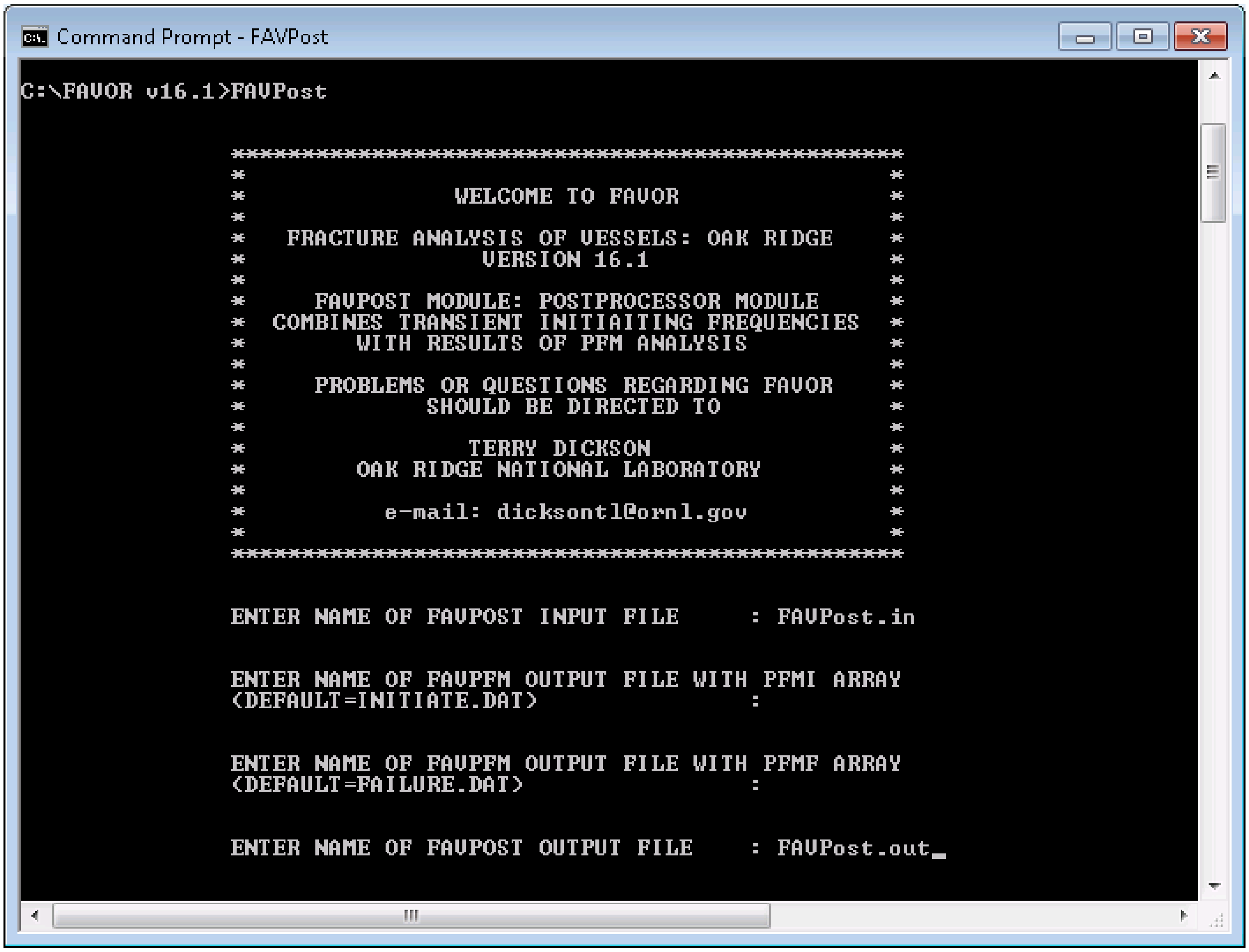
Fig. 15. FAVPFM continually writes out progress reports in terms of running average CPI/CPF values for each transient as the code proceeds through the required number of RPV trials.

FAVPost Execution – The FAVPost module may be run while FAVPFM is still executing. This feature is particularly helpful when FAVPFM is executing a run that could take hours or possibly days. Here is the procedure:

1. While FAVPFM is running in one Command Prompt Window, bring up a second Command Prompt Window and navigate to a directory that is not the FAVOR working directory.
2. Copy the FAVPost.exe executable and the current files INITIATE.DAT, FAILURE.DAT, and NSIM.DAT from the current FAVOR working directory to the directory selected in Step 1.
3. Start the copied FAVPost executable in the directory selected in Step 1 by typing FAVPost and then <Enter> at the prompt.
4. Respond to the prompt for the FAVPost input filename.
5. Take the defaults for the INITIATE.DAT and FAILURE.DAT file names by hitting the <Enter> key twice.
6. Respond to the prompt for the FAVPost output file name.
7. Respond to the prompt for the number of RPV trials to be processed.
8. FAVPost will interrogate the INITIATE.DAT file to determine the current number of completed RPV trials.
9. FAVPost reports the number of RPV trials completed and asks how many trials the user wishes to process.
10. Respond to the query with either a number (less than the total completed) or take the default "ALL" by hitting the <Enter> key.

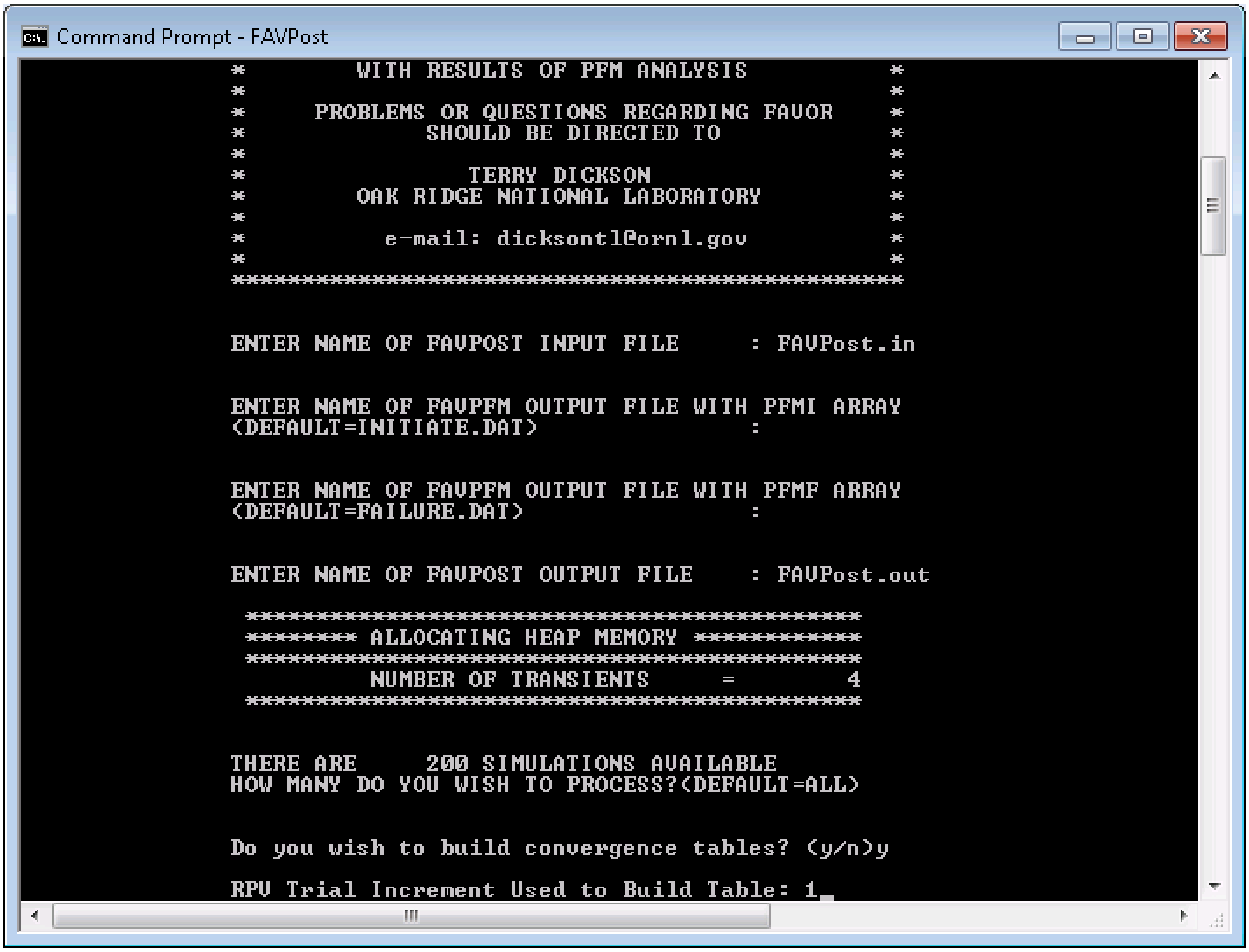
The above capability is also convenient for calculating convergence statistics as a function of RPV trials, even when the FAVPFM run has completed. For example, the analyst might wish to calculate the 99th percentile of the failure frequency vs RPV trials as a check for convergence. Just run FAVPost several times asking for 1000, 2000, 3000, …NSIM RPV trials, and then plot the relevant statistics.

In Fig. 16, FAVOR's post-processing module is executed by typing FAVPost at the line prompt. The code will then prompt the user for the names of four files (see Fig. 16): (1) a FAVPost input file, (2) the file created by the FAVPFM execution that contains the conditional probability of initiation matrix (DEFAULT=INITIATE.DAT), (3) the file created by the FAVPFM execution that contains the conditional probability of failure matrix (DEFAULT=FAILURE.DAT), and (4) the name of the output file to be created by FAVPost that will have the histograms for vessel fracture and failure frequencies. Again, for files (2) and (3), the user may accept the defaults by hitting the RETURN/ENTER key.



```
C:\FAVOR v16.1>FAVPost

               ************************************************
               *                                              *
               *               WELCOME TO FAVOR               *
               *                                              *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
               *                VERSION 16.1                  *
               *                                              *
               *     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          *
               *                                              *
               ************************************************


               ENTER NAME OF FAVPOST INPUT FILE     : FAVPost.in


               ENTER NAME OF FAVPFM OUTPUT FILE WITH PFMI ARRAY
               (DEFAULT=INITIATE.DAT)               :


               ENTER NAME OF FAVPFM OUTPUT FILE WITH PFMF ARRAY
               (DEFAULT=FAILURE.DAT)                :


               ENTER NAME OF FAVPOST OUTPUT FILE    : FAVPost.out_
```

Fig. 16(a). Type in FAVPost at the Command Prompt to execute the FAVPost module. FAVPost prompts for the (1) FAVPost input file, (2) CPI matrix file generated by FAVPFM, (3) CPF matrix file generated by FAVPFM, and (4) the FAVPost output file.



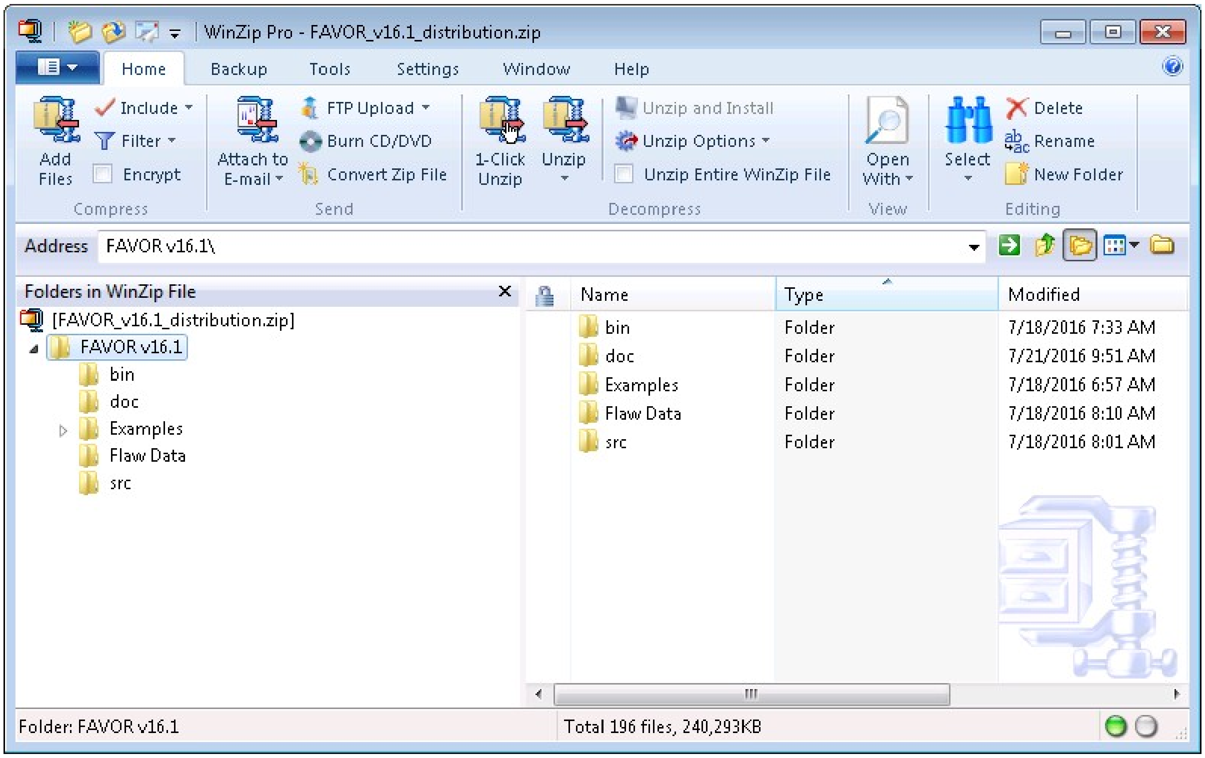
```
               *        WITH RESULTS OF PFM ANALYSIS          *
               *                                              *
               *     PROBLEMS OR QUESTIONS REGARDING FAVOR    *
               *             SHOULD BE DIRECTED TO            *
               *                                              *
               *                TERRY DICKSON                 *
               *        OAK RIDGE NATIONAL LABORATORY         *
               *                                              *
               *          e-mail: dicksontl@ornl.gov          *
               *                                              *
               ************************************************


               ENTER NAME OF FAVPOST INPUT FILE     : FAVPost.in


               ENTER NAME OF FAVPFM OUTPUT FILE WITH PFMI ARRAY
               (DEFAULT=INITIATE.DAT)               :


               ENTER NAME OF FAVPFM OUTPUT FILE WITH PFMF ARRAY
               (DEFAULT=FAILURE.DAT)                :


               ENTER NAME OF FAVPOST OUTPUT FILE    : FAVPost.out

                ********************************************
                ******** ALLOCATING HEAP MEMORY ************
                ********************************************
                         NUMBER OF TRANSIENTS     =        4
                ********************************************


               THERE ARE     200 SIMULATIONS AVAILABLE
               HOW MANY DO YOU WISH TO PROCESS?(DEFAULT=ALL)


               Do you wish to build convergence tables? (y/n)y

               RPV Trial Increment Used to Build Table: 1_
```

Fig. 16(b) Set the total number of simulations to be processed and build convergence tables, if required.

1.6 Distribution WINZIP package file

The distribution WINZIP file, “FAVOR_v16.1_distribution.zip”, contains the following folders and files:

Main Folder: .\FAVOR_v16.1



Address: FAVOR v16.1\

[FAVOR_v16.1_distribution.zip]
- FAVOR v16.1
  - bin
  - doc
  - Examples
  - Flaw Data
  - src

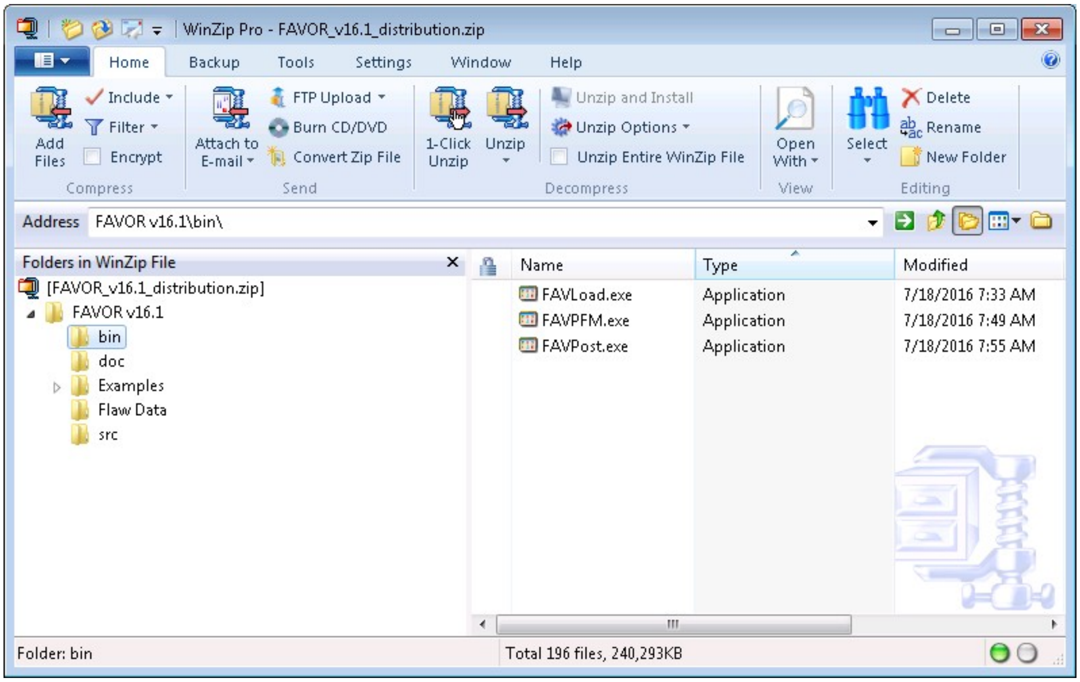
Name	Type	Modified
bin	Folder	7/18/2016 7:33 AM
doc	Folder	7/21/2016 9:51 AM
Examples	Folder	7/18/2016 6:57 AM
Flaw Data	Folder	7/18/2016 8:10 AM
src	Folder	7/18/2016 8:01 AM

Folder: FAVOR v16.1

Total 196 files, 240,293KB

The main folder .\FAVOR_v16.1\ contains five subfolders. After installation, the FAVOR, v16.1, documentation may be viewed by double-clicking on the individual “.pdf” files in the \docs\ subfolder if a PDF Reader application has been associated with the PDF extension on the user’s computer.

Subfolder: .\FAVOR_v16.1\bin



Address FAVOR v16.1\bin\

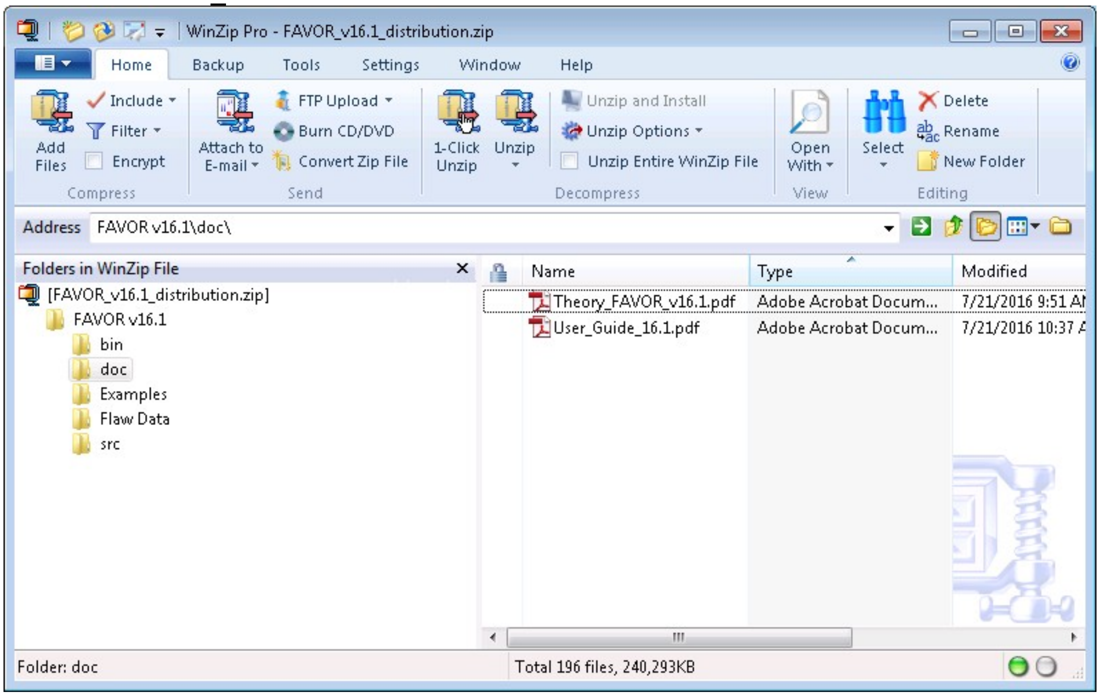
Name	Type	Modified
FAVLoad.exe	Application	7/18/2016 7:33 AM
FAVPFM.exe	Application	7/18/2016 7:49 AM
FAVPost.exe	Application	7/18/2016 7:55 AM

Folder: bin

Total 196 files, 240,293KB

.\FAVOR_v16.1\bin contains the executables for a PC running under a Microsoft Windows operating system.

Subfolder: .\FAVOR_v16.1\doc



Address FAVOR v16.1\doc\

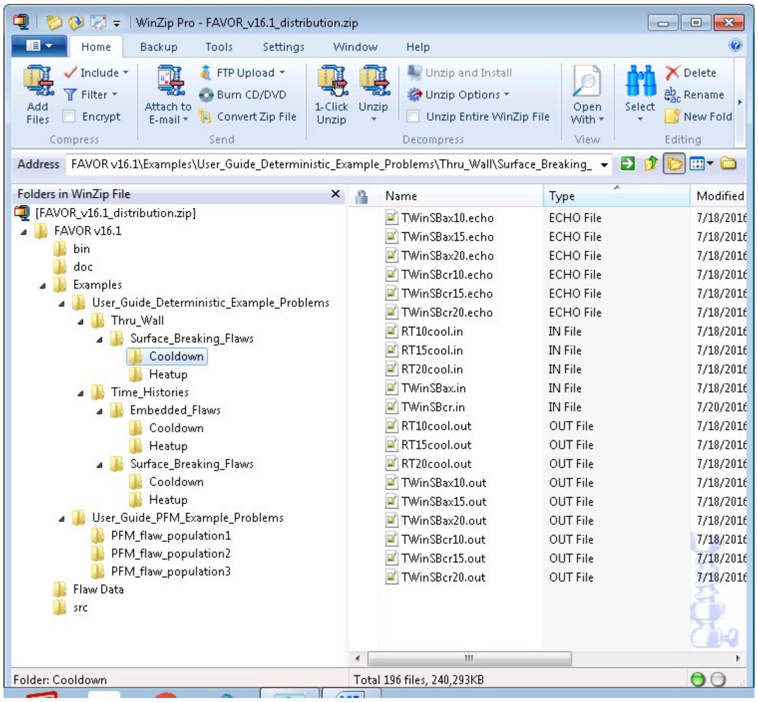
Name	Type	Modified
Theory_FAVOR_v16.1.pdf	Adobe Acrobat Docum...	7/21/2016 9:51 A
User_Guide_16.1.pdf	Adobe Acrobat Docum...	7/21/2016 10:37

Folder: doc

Total 196 files, 240,293KB

.\FAVOR_v16.1\doc contains the Theory and User’s Guide in PDF.

Subfolder: .\FAVOR_v16.1\Examples\User_Guide_Deterministic_Example_Problems\Thru_Wall\Surface Breaking_Flaws\Cooldown



Address: FAVOR v16.1\Examples\User_Guide_Deterministic_Example_Problems\Thru_Wall\Surface_Breaking_

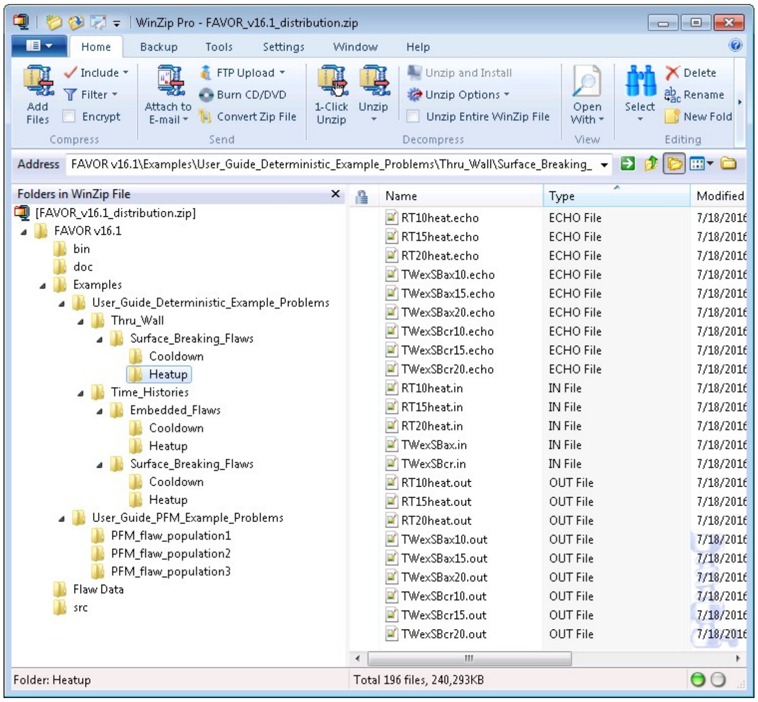
- [FAVOR_v16.1_distribution.zip]
  - FAVOR v16.1
    - bin
    - doc
    - Examples
      - User_Guide_Deterministic_Example_Problems
        - Thru_Wall
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
        - Time_Histories
          - Embedded_Flaws
            - Cooldown
            - Heatup
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
      - User_Guide_PFM_Example_Problems
        - PFM_flaw_population1
        - PFM_flaw_population2
        - PFM_flaw_population3
    - Flaw Data
    - src

Name	Type	Modified
TWinSBax10.echo	ECHO File	7/18/2016
TWinSBax15.echo	ECHO File	7/18/2016
TWinSBax20.echo	ECHO File	7/18/2016
TWinSBcr10.echo	ECHO File	7/18/2016
TWinSBcr15.echo	ECHO File	7/18/2016
TWinSBcr20.echo	ECHO File	7/18/2016
RT10cool.in	IN File	7/18/2016
RT15cool.in	IN File	7/18/2016
RT20cool.in	IN File	7/18/2016
TWinSBax.in	IN File	7/18/2016
TWinSBcr.in	IN File	7/20/2016
RT10cool.out	OUT File	7/18/2016
RT15cool.out	OUT File	7/18/2016
RT20cool.out	OUT File	7/18/2016
TWinSBax10.out	OUT File	7/18/2016
TWinSBax15.out	OUT File	7/18/2016
TWinSBax20.out	OUT File	7/18/2016
TWinSBcr10.out	OUT File	7/18/2016
TWinSBcr15.out	OUT File	7/18/2016
TWinSBcr20.out	OUT File	7/18/2016

Folder: Cooldown

Total 196 files, 240,293KB

Subfolder: .\FAVOR_v16.1\Examples\User_Guide_Deterministic_Example_Problems\Thru_Wall\Surface Breaking_Flaws\Heatup



Address: FAVOR v16.1\Examples\User_Guide_Deterministic_Example_Problems\Thru_Wall\Surface_Breaking_

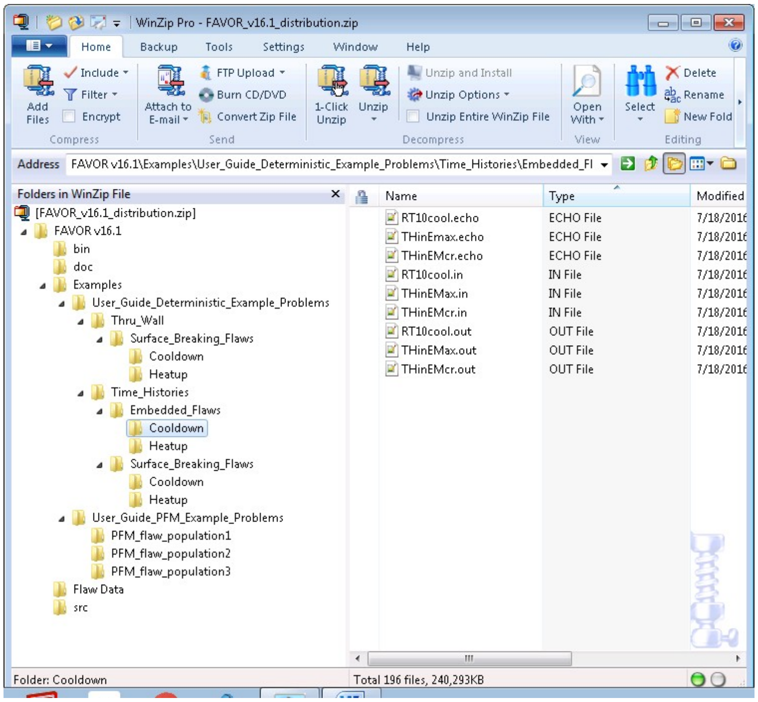
- [FAVOR_v16.1_distribution.zip]
  - FAVOR v16.1
    - bin
    - doc
    - Examples
      - User_Guide_Deterministic_Example_Problems
        - Thru_Wall
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
        - Time_Histories
          - Embedded_Flaws
            - Cooldown
            - Heatup
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
      - User_Guide_PFM_Example_Problems
        - PFM_flaw_population1
        - PFM_flaw_population2
        - PFM_flaw_population3
    - Flaw Data
    - src

Name	Type	Modified
RT10heat.echo	ECHO File	7/18/2016
RT15heat.echo	ECHO File	7/18/2016
RT20heat.echo	ECHO File	7/18/2016
TWexSBax10.echo	ECHO File	7/18/2016
TWexSBax15.echo	ECHO File	7/18/2016
TWexSBax20.echo	ECHO File	7/18/2016
TWexSBcr10.echo	ECHO File	7/18/2016
TWexSBcr15.echo	ECHO File	7/18/2016
TWexSBcr20.echo	ECHO File	7/18/2016
RT10heat.in	IN File	7/18/2016
RT15heat.in	IN File	7/18/2016
RT20heat.in	IN File	7/18/2016
TWexSBax.in	IN File	7/18/2016
TWexSBcr.in	IN File	7/18/2016
RT10heat.out	OUT File	7/18/2016
RT15heat.out	OUT File	7/18/2016
RT20heat.out	OUT File	7/18/2016
TWexSBax10.out	OUT File	7/18/2016
TWexSBax15.out	OUT File	7/18/2016
TWexSBax20.out	OUT File	7/18/2016
TWexSBcr10.out	OUT File	7/18/2016
TWexSBcr15.out	OUT File	7/18/2016
TWexSBcr20.out	OUT File	7/18/2016

Folder: Heatup

Total 196 files, 240,293KB

Subfolder:
.\FAVOR_v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\ Embedded Flaws\Cooldown

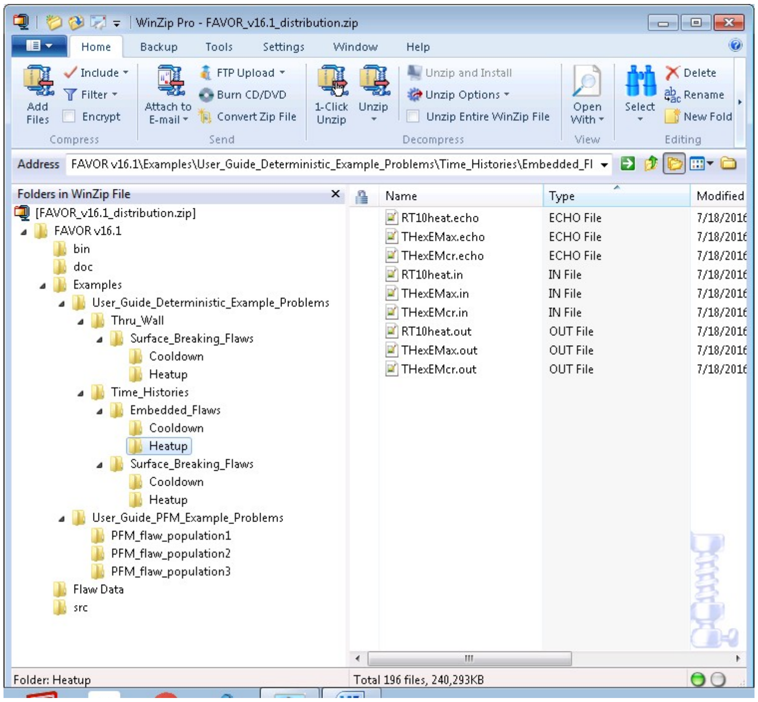


Address: FAVOR v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\Embedded_Fl

[FAVOR_v16.1_distribution.zip]
- FAVOR v16.1
  - bin
  - doc
  - Examples
    - User_Guide_Deterministic_Example_Problems
      - Thru_Wall
        - Surface_Breaking_Flaws
          - Cooldown
          - Heatup
      - Time_Histories
        - Embedded_Flaws
          - Cooldown
          - Heatup
        - Surface_Breaking_Flaws
          - Cooldown
          - Heatup
    - User_Guide_PFM_Example_Problems
      - PFM_flaw_population1
      - PFM_flaw_population2
      - PFM_flaw_population3
  - Flaw Data
  - src

Name	Type	Modified
RT10cool.echo	ECHO File	7/18/2016
THinEmax.echo	ECHO File	7/18/2016
THinEMcr.echo	ECHO File	7/18/2016
RT10cool.in	IN File	7/18/2016
THinEMax.in	IN File	7/18/2016
THinEMcr.in	IN File	7/18/2016
RT10cool.out	OUT File	7/18/2016
THinEMax.out	OUT File	7/18/2016
THinEMcr.out	OUT File	7/18/2016

Subfolder:
.\FAVOR_v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\ Embedded Flaws\ Heatup

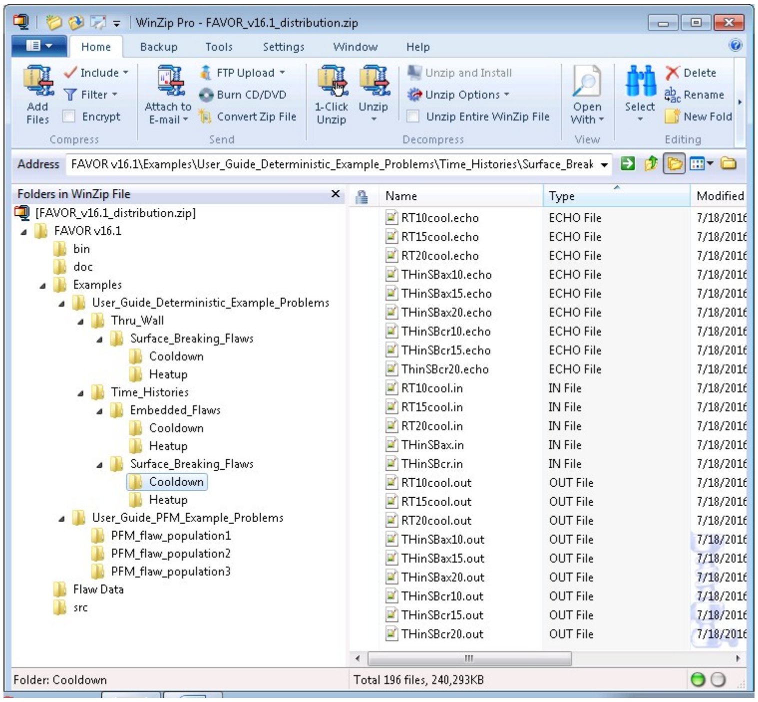


Address: FAVOR v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\Embedded_Fl

[FAVOR_v16.1_distribution.zip]
- FAVOR v16.1
  - bin
  - doc
  - Examples
    - User_Guide_Deterministic_Example_Problems
      - Thru_Wall
        - Surface_Breaking_Flaws
          - Cooldown
          - Heatup
      - Time_Histories
        - Embedded_Flaws
          - Cooldown
          - Heatup
        - Surface_Breaking_Flaws
          - Cooldown
          - Heatup
    - User_Guide_PFM_Example_Problems
      - PFM_flaw_population1
      - PFM_flaw_population2
      - PFM_flaw_population3
  - Flaw Data
  - src

Name	Type	Modified
RT10heat.echo	ECHO File	7/18/2016
THexEMax.echo	ECHO File	7/18/2016
THexEMcr.echo	ECHO File	7/18/2016
RT10heat.in	IN File	7/18/2016
THexEMax.in	IN File	7/18/2016
THexEMcr.in	IN File	7/18/2016
RT10heat.out	OUT File	7/18/2016
THexEMax.out	OUT File	7/18/2016
THexEMcr.out	OUT File	7/18/2016

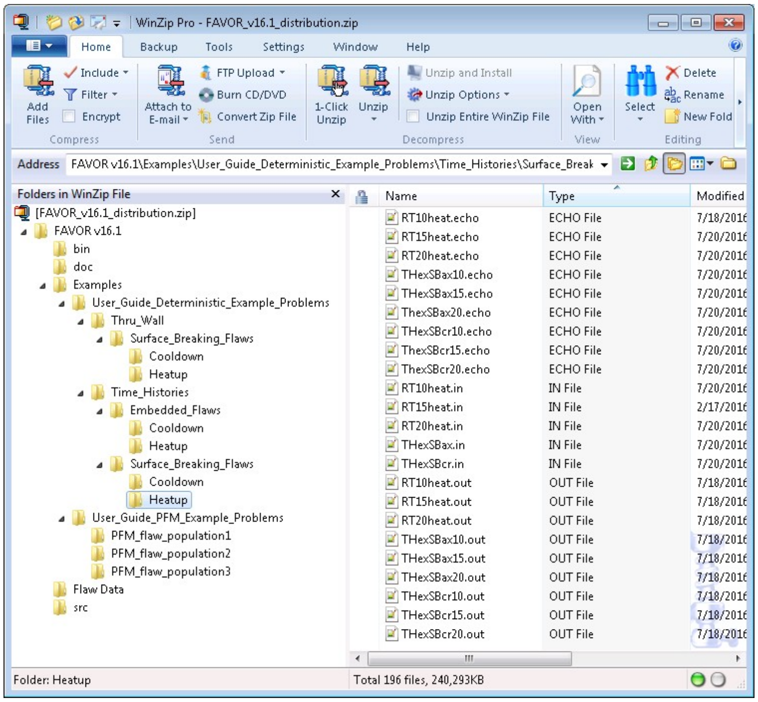
Subfolder:
.\FAVOR_v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\Surface_Breaking_Flaws\Cooldown



Address: FAVOR v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\Surface_Break

Name	Type	Modified
RT10cool.echo	ECHO File	7/18/201
RT15cool.echo	ECHO File	7/18/201
RT20cool.echo	ECHO File	7/18/201
THinSBax10.echo	ECHO File	7/18/201
THinSBax15.echo	ECHO File	7/18/201
THinSBax20.echo	ECHO File	7/18/201
THinSBcr10.echo	ECHO File	7/18/201
THinSBcr15.echo	ECHO File	7/18/201
ThinSBcr20.echo	ECHO File	7/18/201
RT10cool.in	IN File	7/18/201
RT15cool.in	IN File	7/18/201
RT20cool.in	IN File	7/18/201
THinSBax.in	IN File	7/18/201
THinSBcr.in	IN File	7/18/201
RT10cool.out	OUT File	7/18/201
RT15cool.out	OUT File	7/18/201
RT20cool.out	OUT File	7/18/201
THinSBax10.out	OUT File	7/18/201
THinSBax15.out	OUT File	7/18/201
THinSBax20.out	OUT File	7/18/201
THinSBcr10.out	OUT File	7/18/201
THinSBcr15.out	OUT File	7/18/201
THinSBcr20.out	OUT File	7/18/201

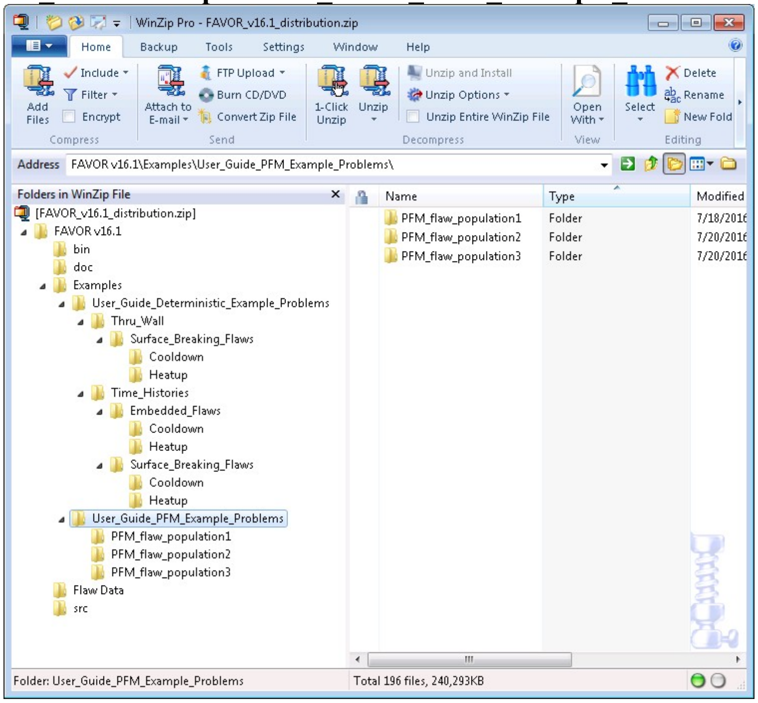
Subfolder:
.\FAVOR_v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\Surface_Breaking_Flaws\Heatup



Address: FAVOR v16.1\Examples\User_Guide_Deterministic_Example_Problems\Time_Histories\Surface_Break

Name	Type	Modified
RT10heat.echo	ECHO File	7/18/201
RT15heat.echo	ECHO File	7/20/201
RT20heat.echo	ECHO File	7/20/201
THexSBax10.echo	ECHO File	7/20/201
THexSBax15.echo	ECHO File	7/20/201
ThexSBax20.echo	ECHO File	7/20/201
THexSBcr10.echo	ECHO File	7/20/201
ThexSBcr15.echo	ECHO File	7/20/201
ThexSBcr20.echo	ECHO File	7/20/201
RT10heat.in	IN File	7/20/201
RT15heat.in	IN File	2/17/201
RT20heat.in	IN File	7/20/201
THexSBax.in	IN File	7/20/201
THexSBcr.in	IN File	7/20/201
RT10heat.out	OUT File	7/18/201
RT15heat.out	OUT File	7/18/201
RT20heat.out	OUT File	7/18/201
THexSBax10.out	OUT File	7/18/201
THexSBax15.out	OUT File	7/18/201
THexSBax20.out	OUT File	7/18/201
THexSBcr10.out	OUT File	7/18/201
THexSBcr15.out	OUT File	7/18/201
THexSBcr20.out	OUT File	7/18/201

Subfolder: .\FAVOR_v16.1\Examples\User_Guide_PFM_Example_Problems



Address: FAVOR v16.1\Examples\User_Guide_PFM_Example_Problems\

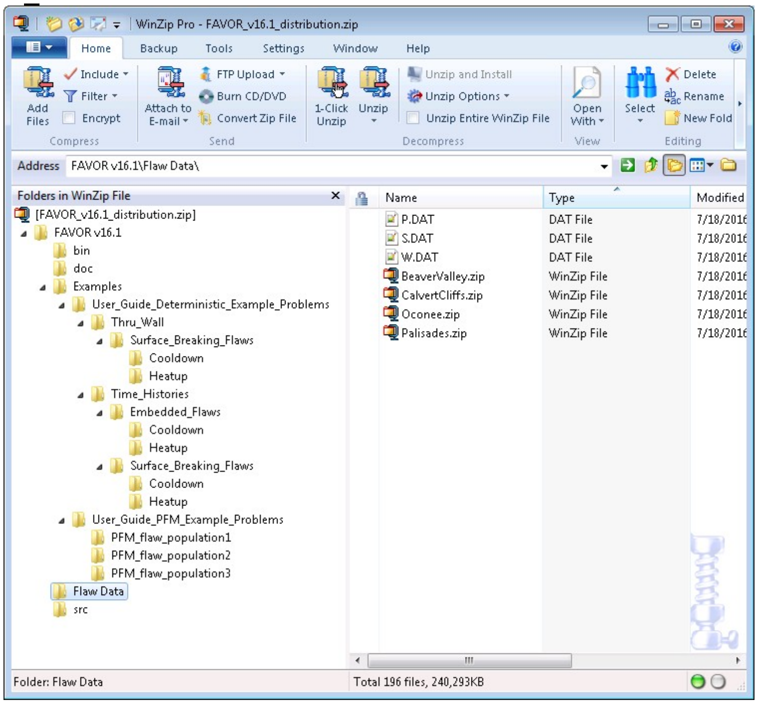
Name	Type	Modified
PFM_flaw_population1	Folder	7/18/201
PFM_flaw_population2	Folder	7/20/201
PFM_flaw_population3	Folder	7/20/201

Folder: User_Guide_PFM_Example_Problems

Total 196 files, 240,293KB

These are the deterministic and PFM input and output files for the example case discussed in Chapter 3 of this User's Guide.

Subfolder: FAVOR_v16.1\flaw data



Address: FAVOR v16.1\Flaw Data\

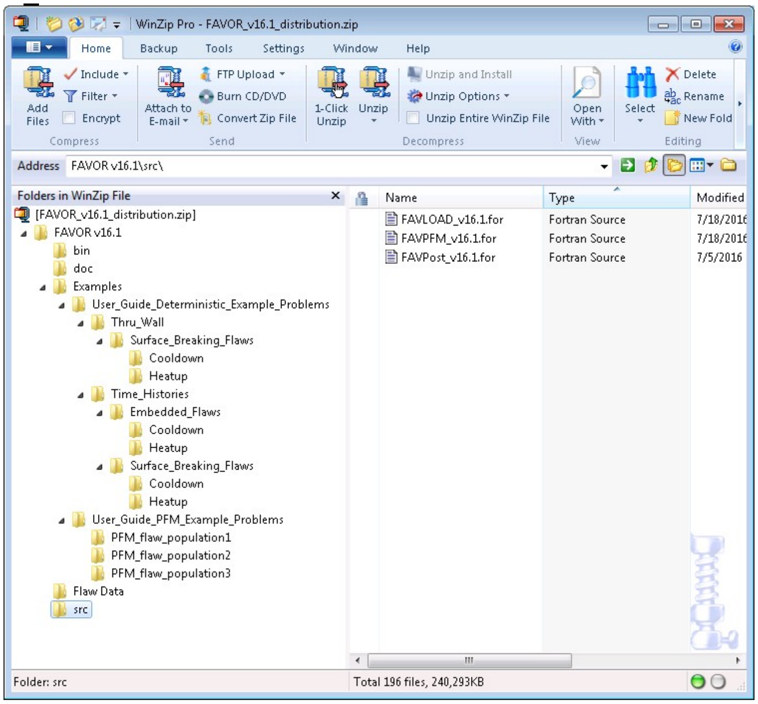
Name	Type	Modified
P.DAT	DAT File	7/18/201
S.DAT	DAT File	7/18/201
W.DAT	DAT File	7/18/201
BeaverValley.zip	WinZip File	7/18/201
CalvertCliffs.zip	WinZip File	7/18/201
Oconee.zip	WinZip File	7/18/201
Palisades.zip	WinZip File	7/18/201

Folder: Flaw Data

Total 196 files, 240,293KB

The four flaw-characterization files developed for the PTS Re-Evaluation Project are included in this subfolder for each of four nuclear power plants. The files “Palisades.zip” (Palisades NPP, South Haven, MI), “Oconee.zip” (Oconee NPP, Greeneville, SC), “CalvertCliffs.zip” (Calvert Cliffs NPP, Annapolis, MD), and “BeaverValley.zip” (Beaver Valley NPP, McCandless, PA) are zipped file archives containing the four plant-specific flaw-characterization files. The files “W.dat”, “S.dat”, and “P.dat” are the example files used in the installation examples.

Subfolder: FAVOR_v16.1\src\



Address FAVOR v16.1\src\

- [FAVOR_v16.1_distribution.zip]
  - FAVOR v16.1
    - bin
    - doc
    - Examples
      - User_Guide_Deterministic_Example_Problems
        - Thru_Wall
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
        - Time_Histories
          - Embedded_Flaws
            - Cooldown
            - Heatup
          - Surface_Breaking_Flaws
            - Cooldown
            - Heatup
      - User_Guide_PFM_Example_Problems
        - PFM_flaw_population1
        - PFM_flaw_population2
        - PFM_flaw_population3
    - Flaw Data
    - src

Name	Type	Modified
FAVLOAD_v16.1.for	Fortran Source	7/18/2016
FAVPFM_v16.1.for	Fortran Source	7/18/2016
FAVPost_v16.1.for	Fortran Source	7/5/2016

Folder: src

Total 196 files, 240,293KB

The source code for the three FAVOR modules is included in this subfolder. FAVOR is written in the Fortran computer language. A Fortran compiler that is compliant with the Fortran 90/95 standard (ISO/IEC 1539-1:1997) is required to compile the FAVOR source code.

2. FAVOR Input Requirements

FAVOR employs ASCII text files either created by the user or created by previous executions of the FAVOR modules. User-created input files are organized by a sequence of keyword records with *free-field format* for the placement of parameter data located on the same line record as the keyword or on data lines following the keyword record. The data must be input exactly in the sequence and order prescribed in the sections below. Omission of data fields is not allowed. The 4-letter keywords always begin in column 1.

Comment lines are designated by an asterisk, "*", in column 1. The user is encouraged to take full advantage of including comments in the input files as a method for internal documentation of the model. It has proven beneficial by the developers of FAVOR to use the input files (included in the example cases in the distribution package) as templates for the creation of new input datasets.

In developing input datasets, the user should pay careful attention to the required units for each data record. FAVOR carries out conversions internally to insure a consistent set of units for all analyses; however, the input data must be entered in the units specified in the sections below.

2.1 FAVOR Load Module – FAVLoad

A total of 12 data records, listed in Table 1, are required in the FAVLoad input file, where each record may involve more than one line of data. A detailed description of each data record is given below.

Table 1. Record Keywords and Parameter Fields for FAVLoad Input File

1	**GEOM**	**IRAD=[in]**	**W=[in]**	**CLTH=[in]**				
2	**BASE**	**K=[Btu/hr-ft-°F]**	**C=[Btu/lbm-°F]**	**RHO=[lbm/ft^3]**	**E=[ksi]**	**ALPHA=[°F $^{-1}$]**	**NU=[-]**	**NTE=[0|1]**
2a	**NBK**	**NK=[-]**	**if NTE=1**					
	input NK data lines with {T, K(T) } [°F, Btu/h-ft-°F] pairs - one pair per line							
2b	**NBC**	**NC=[-]**	**if NTE=1**					
	input NC data lines with {T, C(T) } [°F, Btu/lbm-°F] pairs - one pair per line							
2c	**NBE**	**NE=[-]**	**if NTE=1**					
	input NE data lines with {T, E(T) } [°F, ksi] pairs - one pair per line							
2d	**NALF**	**NA=[-]**	**Tref0=[°F]**	**if NTE=1**				
	input NA data lines with {T, ALPHA(T) } [°F, °F $^{-1}$] pairs - one pair per line							
2e	**NNU**	**NU=[-]**	**if NTE=1**					
	input NU data lines with {T, NU(T) } [°F, -] pairs - one pair per line							
3	**CLAD**	**K=[Btu/hr-ft-°F]**	**C=[Btu/lbm-°F]**	**RHO=[lbm/ft^3]**	**E=[ksi]**	**ALPHA=[°F^{-1}]**	**NU=[-]**	**NTE=[0|1]**
3a	**NCK**	**NK=[-]**	**if NTE=1**					
	input NK data lines with {T, K(T) } [°F, Btu/h-ft-°F] pairs - one pair per line							
3b	**NCC**	**NC=[-]**	**if NTE=1**					
	input NC data lines with {T, C(T) } [°F, Btu/lbm-°F] pairs - one pair per line							
3c	**NCE**	**NE=[-]**	**if NTE=1**					
	input NE data lines with {T, E(T) } [°F, ksi] pairs - one pair per line							
3d	**NALF**	**NA=[-]**	**Tref0=[°F]**	**if NTE=1**				
	input NA data lines with {T, ALPHA(T) } [°F, °F $^{-1}$] pairs - one pair per line							
3e	**NNU**	**NU=[-]**	**if NTE=1**					
	input NU data lines with {T, NU(T) } [°F, -] pairs - one pair per line							
4	**SFRE**	**T=[°F]**	**CFP=[0|1]**					
5	**RESA**	**NRAX=[-]**						
6	**RESC**	**NRCR=[-]**						
7	**TIME**	**TOTAL=[min]**	**DT=[min]**					
8	**NPRA**	**NTRAN=[-]**						
	Repeat data records 9 through 12 for each NTRAN transients							
9	**TRAN**	**ITRAN=[-]**	**ISEQ=[-]**					
10	**NHTH**	**NC=[-]**						
	input NC data lines with { t, $h(t)$ } [min, Btu/hr-ft^2-°F] pairs - one pair per line							
11	**NTTH**	**NT=[-]**						
	input NT data lines with (t, $T(t)$) [min, °F] pairs - one pair per line							
	or							
11	**NTTH**	**NT=101**						
	STYL	**TINIT=[°F]**	**TFINAL=[°F]**	**BETA=[min^{-1}]**				
12	**NPTH**	**NP=[-]**						
	input NP data lines with (t, $P(t)$) [min, ksi] pairs - one pair per line							

Record 1 – GEOM

Record No. 1 inputs vessel geometry data, specifically the internal radius, **IRAD**, in inches, the wall thickness (inclusive of cladding), **W**, in inches, and the cladding thickness, **CLTH,** in inches. The thickness of the base metal is, therefore, **W – CLTH**.

EXAMPLE

```
********************************************************************************
*  ====================                                                        *
*     Record GEOM                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  IRAD = INTERNAL RADIUS OF PRESSURE VESSEL                              [IN] *
*   W   = THICKNESS OF PRESSURE VESSEL WALL (INCLUDING CLADDING)          [IN] *
*  CLTH = CLADDING THICKNESS                                              [IN] *
*------------------------------------------------------------------------------*
********************************************************************************
GEOM  IRAD=78.5   W=8.031    CLTH=0.156
********************************************************************************
```

Records 2 and 3– BASE and CLAD

Records 2 and 3 input thermo-elastic property data for the base (typically a ferritic steel) and cladding (typically an austenitic stainless steel), respectively: thermal conductivity, **K**, in Btu/hr-ft-°F, **C**, mass-specific heat capacity in Btu/lbm-°F, mass density, **RHO**, in lbm/ft^3, Young’s modulus of elasticity, **E**, in ksi, coefficient of thermal expansion, **ALPHA**, in °F^{-1}, and Poisson’s ratio, **NU**. All property data are assumed to be independent of temperature if **NTE = 0**.

EXAMPLE

```
********************************************************************************
*  ===========================                                                 *
*     Records BASE and CLAD                                                    *
*  ===========================                                                 *
*    THERMO-ELASTIC MATERIAL PROPERTIES FOR BASE AND CLADDING                  *
*------------------------------------------------------------------------------*
*     K     = THERMAL CONDUCTIVITY                              [BTU/HR-FT-F] *
*     C     = SPECIFIC HEAT                                       [BTU/LBM-F] *
*     RHO   = DENSITY                                             [LBM/FT**3] *
*     E     = YOUNG'S ELASTIC MODULUS                                  [KSI]  *
*     ALPHA = THERMAL EXPANSION COEFFICIENT                          [F**-1]  *
*     NU    = POISSON'S RATIO                                          [-]    *
*     NTE   = TEMPERATURE DEPENDANCY FLAG                                     *
*     NTE   = 0 ==> PROPERTIES ARE TEMPERATURE INDEPENDENT (CONSTANT)         *
*     NTE   = 1 ==> PROPERTIES ARE TEMPERATURE DEPENDENT                      *
*     IF NTE EQUAL TO 1, THEN ADDITIONAL DATA RECORDS ARE REQUIRED            *
*------------------------------------------------------------------------------*
********************************************************************************
BASE  K=24.0  C=0.120  RHO=489.00  E=28000  ALPHA=.00000777  NU=0.3  NTE=0
CLAD  K=10.0  C=0.120  RHO=489.00  E=22800  ALPHA=.00000945  NU=0.3  NTE=0
********************************************************************************
```

If **NTE = 1** on Records 2 or 3, then tables of temperature-dependent properties will be input.

EXAMPLE

```
********************************************************************************
*  ===========================                                                 *
*     Records BASE and CLAD                                                    *
*  ===========================                                                 *
*    THERMO-ELASTIC MATERIAL PROPERTIES FOR BASE AND CLADDING                  *
*------------------------------------------------------------------------------*
*     K     = THERMAL CONDUCTIVITY                              [BTU/HR-FT-F] *
*     C     = SPECIFIC HEAT                                       [BTU/LBM-F] *
*     RHO   = DENSITY                                             [LBM/FT**3] *
*     E     = YOUNG'S ELASTIC MODULUS                                  [KSI]  *
*     ALPHA = THERMAL EXPANSION COEFFICIENT                          [F**-1]  *
*     NU    = POISSON'S RATIO                                          [-]    *
*     NTE   = TEMPERATURE DEPENDANCY FLAG                                      *
*     NTE   = 0 ==> PROPERTIES ARE TEMPERATURE INDEPENDENT (CONSTANT)          *
*     NTE   = 1 ==> PROPERTIES ARE TEMPERATURE DEPENDENT                       *
*     IF NTE EQUAL TO 1, THEN ADDITIONAL DATA RECORDS ARE REQUIRED             *
*------------------------------------------------------------------------------*
********************************************************************************
BASE  K=24.0  C=0.120  RHO=489.00  E=28000  ALPHA=.00000777  NU=0.3  NTE=1
********************************************************************************
*---------------------------
* THERMAL CONDUCTIVITY TABLE
*---------------------------
NBK   NK=16
*---------------------------
 70    24.8
100    25.0
150    25.1
200    25.2
250    25.2
300    25.1
350    25.0
400    25.1
450    24.6
500    24.3
550    24.0
600    23.7
650    23.4
700    23.0
750    22.6
800    22.2
*---------------------------
* SPECIFIC HEAT TABLE
*---------------------------
NBC   NC=16
*----------------
 70    0.1052
100    0.1072
150    0.1101
200    0.1135
250    0.1166
300    0.1194
350    0.1223
400    0.1267
450    0.1277
500    0.1304
550    0.1326
600    0.1350
650    0.1375
700    0.1404
750    0.1435
800    0.1474
*---------------------------
* YOUNG'S MODULUS TABLE
*---------------------------
NBE   NE=8
*----------------
 70    29200
```

```
200    28500
300    28000
400    27400
500    27000
600    26400
700    25300
800    23900
*----------------------------
* COEFF. OF THERMAL EXPANSION
* ASME Sect. II, Table TE-1
* Material Group D, pp. 580-581
*----------------------------
NALF   NA=15  Tref0=70
*----------------------------
100     0.00000706
150     0.00000716
200     0.00000725
250     0.00000734
300     0.00000743
350     0.00000750
400     0.00000758
450     0.00000763
500     0.00000770
550     0.00000777
600     0.00000783
650     0.00000790
700     0.00000794
750     0.00000800
800     0.00000805
*----------------------------
*     POISSON'S RATIO
*----------------------------
NBNU   NU=2
*----------------
  0.  0.3
1000. 0.3
********************************************************************************
CLAD  K=10.0  C=0.120  RHO=489.00  E=22800  ALPHA=.00000945  NU=0.3  NTE=1
********************************************************************************
*---------------------------
* THERMAL CONDUCTIVITY TABLE
*---------------------------
NK  N=16
*----------------
 70     8.1
100     8.4
150     8.6
200     8.8
250     9.1
300     9.4
350     9.6
400     9.9
450    10.1
500    10.4
550    10.6
600    10.9
650    11.1
700    11.4
750    11.6
800    11.9
*---------------------------
* SPECIFIC HEAT TABLE
*---------------------------
NC  N=16
*----------------
 70    0.1158
100    0.1185
150    0.1196
200    0.1208
250    0.1232
300    0.1256
350    0.1258
400    0.1281
450    0.1291
500    0.1305
550    0.1306
600    0.1327
650    0.1335
700    0.1348
750    0.1356
800    0.1367
```

```
*---------------------------
* YOUNG'S MODULUS TABLE
*---------------------------
NE   N=3
*---------------------------
 68    22045.7
302    20160.2
482    18419.8
*-------------------------------------
* COEFF. OF THERMAL EXPANSION
* ASME Sect. II, Table TE-1
* Material Group - 18Cr-8Ni pp. 582-583
*-------------------------------------
NALF   N=15  Tref0=70
*-------------------
100     0.00000855
150     0.00000867
200     0.00000879
250     0.00000890
300     0.00000900
350     0.00000910
400     0.00000919
450     0.00000928
500     0.00000937
550     0.00000945
600     0.00000953
650     0.00000961
700     0.00000969
750     0.00000976
800     0.00000982
*---------------------------
*     POISSON'S RATIO
*---------------------------
NNU   N=2
*---------------
  0.  0.3
1000. 0.3
```

The following sources were consulted to develop the temperature-dependent tables shown above:

Base Steel

ASME Boiler and Pressure Vessel Code – Sect. II., Part D: Properties (1998) [19]
thermal conductivity – Table TCD – Material Group A – p. 592
thermal diffusivity – Table TCD – Material Group A – p. 592
Young's Modulus of Elasticity – Table TM-1 – Material Group A – p. 606
Coefficient of Expansion – Table TE-1 – Material Group D – p. 580-581
Density = 489 lbm/ft^3

Cladding

ASME Boiler and Pressure Vessel Code – Sect. II., Part D: Properties (1998) [19]
thermal conductivity – Table TCD – High Alloy Steels – p. 598
thermal diffusivity – Table TCD – High Alloy Steels – p. 598
Young's Modulus of Elasticity – NESC II Project – Final Report – p. 35 [20]
Coefficient of Expansion – Table TE-1 – High Chrome Steels – p. 582-583
Density = 489 lbm/ft^3

Methods for Interpolation within Property Look-Up Tables

FAVLoad constructs monotone piecewise cubic Hermite interpolants [21-23] for interpolation within the temperature-dependent property look-up tables. The following provides a summary of this interpolation procedure.

Monotone Piecewise Cubic Interpolation Algorithm

The procedure assumes that the data to be interpolated are at least locally monotone, either monotonically increasing or decreasing. We begin by letting $\pi : a = x_1 < x_2 < \cdots < x_n = b$ be a partition of the interval $I = [a,b]$, and let $\{f_i : i = 1,2,\cdots,n\}$ be a given set of *monotone* data values at the partition points (knots); i.e., we assume that either $f_i \le f_{i+1}\,(i = 1,2,\cdots,n-1)$ or $f_i \ge f_{i+1}\,(i = 1,2,\cdots,n-1)$. Construct on π a piecewise cubic function $p(x) \in \mathbb{C}^1(I)$ such that

$$p(x_i) = f_i, \qquad i = 1,2,\ldots,n \tag{1}$$

and $p(x)$ is monotone, and within each subinterval $I_i = [x_i, x_{i+1}]$ $p(x)$ is a cubic polynomial represented by

$$p(x) = f_i H_1(x) + f_{i+1} H_2(x) + d_i H_3(x) + d_{i+1} H_4(x) \tag{2}$$

where $d_j = p'(x_j),\ j = i, i+1$ are the derivatives of *f* at the knots, and $H_k(x)$ are cubic Hermite basis functions for the interval I_i with the form

$$\begin{aligned} H_1(x) &= \phi\left[\frac{x_{i+1}-x}{h_i}\right], & H_2(x) &= \phi\left[\frac{x-x_i}{h_i}\right], \\ H_3(x) &= -h_i\,\psi\left[\frac{x_{i+1}-x}{h_i}\right], & H_4(x) &= h_i\,\psi\left[\frac{x-x_i}{h_i}\right], \end{aligned} \tag{3}$$

where

$$h_i = x_{i+1} - x_i$$
$$\phi(t) = 3t^2 - 2t^3$$
$$\psi(t) = t^3 - t^2$$

A method for estimating the derivatives, $d_j = p'(x_j)$, at the knots is given in ref. [22]. Let $\Delta_i \equiv (f_{i+1} - f_i)/(x_{i+1} - x_i)$ and as above $h_i = x_{i+1} - x_i$, then

$$d_i = G\left(\Delta_{i-1},\Delta_i,h_{i-1,}h_i\right), \qquad i = 1,\cdots,n-1 \tag{4}$$

where the *G*-function is defined by

$$G\left(\Delta_{i-1},\Delta_i,h_{i-1},h_i\right) \equiv \begin{cases} \dfrac{\Delta_{i-1}\Delta_i}{\alpha\Delta_i + (1-\alpha)\Delta_{i-1}} & \text{if } \Delta_{i-1}\Delta_i > 0 \\ 0 & \text{otherwise,} \end{cases}$$

and **(5)**

$$\alpha \equiv \frac{h_{i-1}+2h_i}{3\left(h_{i-1}+h_i\right)}$$

The above algorithm has been coded into Fortran in the open source PCHIP [21] numerical package, available from the *netlib.org* repository, and implemented into FAVLoad.

Treatment of Thermal Expansion Coefficient Data

As discussed in ref. [2], the thermal expansion coefficient data available in the ASME BPV Code, Sect. II, Part D, include both the *instantaneous* coefficient of linear thermal expansion, α_T, (or *thermal expansivity*) at a specified temperature *T* and the *mean* coefficient of linear thermal expansion, $\overline{\alpha}_{(T_{ref},T)}$, where the two are related by:

$$\overline{\alpha}_{(T_{ref\,0},T)} = \frac{1}{(T-T_{ref})}\int_{T_{ref\,0}}^{T} \alpha_T \, dT \tag{6}$$

For the implementation in FAVLoad, the correct data input should be the mean coefficient of linear thermal expansion. Values for $\overline{\alpha}_{(T_{ref\,0},T)}$ were obtained from Table TE-1 of the ASME Code, Sect. II, Part D, Material Group D (includes A533B) and High Alloy Steels (includes SS304). When temperature-dependency is included in the thermal stress analysis, FAVLoad requires expansion coefficient data to be input that define the total thermal expansion from a specified reference temperature, T_{ref0}. With $\overline{\alpha}_{(T_{ref\,0},T)}$ data from handbook sources, this reference temperature is typically at room temperature and must be input in °F on the NALF data card, for example, Tref0=70.

Record 4 – SFRE

Record 4 inputs the thermal stress-free temperature for both the base and cladding in °F. In addition, crack-face pressure loading on surface-breaking flaws can be applied with **CFP = 1**. If **CFP = 0**, then no crack-face pressure loading will be applied. The derivation of the recommended value of 488 °F is discussed in ref. [2].

EXAMPLE

```
********************************************************************************
********************************************************************************
*  ===================                                                         *
*     Record SFRE                                                              *
*  ===================                                                         *
*     T   = BASE AND CLADDING STRESS-FREE TEMPERATURE                      [F] *
*     CFP = crack-face pressure loading flag                                   *
*     CFP = 0 ==> no crack-face pressure loading                               *
*     CFP = 1 ==> crack-face pressure loading applied                          *
********************************************************************************
SFRE  T=488  CFP=1
********************************************************************************
```

Records 5 and 6 – RESA and RESC

Records 5 and 6 set weld residual stress flags, NRAX and NRCR, for axial and circumferential welds, respectively. If NRAX or NRCR are set to a value of 101, then weld residual stresses will be included in the FAVLoad output file. If NRAX or NRCR are set to a value of 0, then weld residual stresses will not be included in the FAVLoad output file.

EXAMPLE

```
********************************************************************************
*  ========================                                                    *
*     Records RESA AND RESC                                                    *
*  ========================                                                    *
*     SET FLAGS FOR RESIDUAL STRESSES IN WELDS                                 *
*------------------------------------------------------------------------------*
*     NRAX = 0        AXIAL       WELD RESIDUAL STRESSES OFF                   *
*     NRAX = 101      AXIAL       WELD RESIDUAL STRESSES ON                    *
*     NRCR = 0    CIRCUMFERENTIAL WELD RESIDUAL STRESSES OFF                   *
*     NRCR = 101  CIRCUMFERENTIAL WELD RESIDUAL STRESSES ON                    *
*------------------------------------------------------------------------------*
********************************************************************************
RESA  NRAX=101
RESC  NRCR=101
********************************************************************************
```

Record 7 – TIME

Record 7 inputs the total elapsed time, **TIME**, in minutes for which the transient analysis is to be performed and the time increment, **DT**, also in minutes, to be used in the time integration in FAVPFM. Internally, the FAVLoad module uses a constant time step of 1.0 second to perform finite-element through-wall heat-conduction analyses (1D axisymmetric).

EXAMPLE

```
********************************************************************************
*  =========================                                                   *
*     Record TIME                                                              *
*  =========================                                                   *
*------------------------------------------------------------------------------*
*     TOTAL = TIME PERIOD FOR WHICH TRANSIENT ANALYSIS IS TO BE PERFORMED [MIN]*
*     DT    = TIME INCREMENT                                              [MIN]*
*------------------------------------------------------------------------------*
********************************************************************************
TIME  TOTAL=80.0  DT=0.5
********************************************************************************
```

DT is the time-step size for which load results (temperatures, stresses, etc.) are saved during execution of the FAVLoad module; therefore, **DT** is the time-step size that will be used for all fracture analyses in subsequent FAVPFM executions. Some testing with different values of **DT** is typically necessary to insure that a sufficiently small value is used that will capture the critical characteristics of the transients under study. Note that there is no internal limit to the size of the time step; however, the computational time required to perform a PFM analysis is inversely proportional to **DT**.

Record 8 – NPRA

Record 8 inputs the number of thermal-hydraulic transients, **NTRAN**, to be defined for this case. The following Records 9 through 12 should be repeated for each of the NTRAN transients to be defined.

EXAMPLE

```
********************************************************************************
*  ===============                                                             *
*     Record NPRA                                                              *
*  ===============                                                             *
*     NTRAN = NUMBER OF TRANSIENTS TO BE INPUT                             [-] *
********************************************************************************
NPRA  NTRAN=4
********************************************************************************
```

Record 9 – TRAN

Record 9 provides a mechanism for cross-indexing the internal FAVOR transient numbering system with the initiating-event sequence numbering system used in the thermal-hydraulic analyses that were performed to develop input to FAVOR. The internal FAVOR transient number, **ITRAN**, is linked with the thermal-hydraulic initiating-event sequence number, **ISEQ**, with this record. Whereas, the value of **ITRAN** will depend upon the arbitrary ordering of transients in the FAVLoad transient input stack, the value of **ISEQ** is a unique identifier for each transient. **ITRAN** begins with 1 and is incremented by 1 up to **NTRAN** transients.

EXAMPLE

```
********************************************************************************
*  ==========================                                                  *
*     Record TRAN                                                              *
*  ==========================                                                  *
*------------------------------------------------------------------------------*
*     ITRAN = PFM TRANSIENT NUMBER                                             *
*     ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                *
*------------------------------------------------------------------------------*
********************************************************************************
TRAN  ITRAN= 1   ISEQ=7
               :
TRAN  ITRAN= 2   ISEQ=9
               :
TRAN  ITRAN= 3   ISEQ=56
               :
TRAN  ITRAN= 4   ISEQ=97
               :
************************************************************************
```

Record 10 – NHTH

Record 10 inputs the time history table for the convective film coefficient boundary conditions. There are **NC** data pairs of time, τ, in minutes and film coefficient, *h*, in Btu/hr-ft^2-°F entered following the **NHTH** keyword record line. The number of data pairs is limited only by the memory capacity of the computer. The film coefficient, $h(\tau)$, is used in imposing a Robin forced-convection boundary condition at the inner vessel wall, R_i, defined by,

$$q(R,\tau) = h(\tau)\left[T_\infty(\tau) - T_{wall}(R,\tau)\right] \text{ for } R = R_i, \tau \ge 0$$

where $q\ (R,\tau)$ is the heat flux in Btu/hr-ft^2, $T_\infty(\tau)$ is the coolant temperature near the RPV wall in °F, and $T_{wall}(R,\tau)$ is the wall temperature in °F.

EXAMPLE

```
********************************************************************************
*  ==========================                                                  *
*     Record NHTH                                                              *
*  ==========================                                                  *
*     CONVECTIVE HEAT TRANSFER COEFFICIENT TIME HISTORY                        *
*     NC = NUMBER OF (TIME,h) RECORD PAIRS FOLLOWING THIS LINE                 *
*     (CAN INPUT UP TO 1000 PAIRS OF t,h(t) data records                       *
********************************************************************************
NHTH  NC=2
* =====================================
*     TIME [MIN] h[BTU/HR-FT**2-F]
* =====================================
           0.          500.
         120.          500.
********************************************************************************
```

Record 11 – NTTH

Record 11 inputs the time history definition for the coolant temperature, $T_\infty(\tau)$, which is applied in the Robin boundary condition discussed above. The time history can take two forms depending on the value of the **NT** parameter. If **NT** is equal to an integer other than 101, then an ordered table with **NT** lines of time, τ, in minutes and temperature, *T*, in °F data pairs will follow the **NTTH** keyword record. The number of data pairs is limited only by the memory capacity of the computer. If **NT** = 101, then a stylized exponentially decaying time history will be used where the parameters are the initial coolant temperature, **TINIT,** in °F, the asymptote for the coolant temperature, **TFINAL,** decay curve in °F, and the decay time constant, **BETA,** in minutes^{-1}. These parameters define the time history of the coolant temperature by the following equation:

$$T_\infty(\tau) = T_{\infty-FINAL} + (T_{\infty-INIT} - T_{\infty-FINAL})\exp(-\beta\tau)$$

EXAMPLES

```
********************************************************************************
*  =========================                                                   *
*     Record NTTH                                                              *
*  =========================                                                   *
*     THERMAL TRANSIENT: COOLANT TEMPERATURE TIME HISTORY                      *
*     NT = NUMBER OF (TIME,TEMPERATURE) DATA PAIRS                             *
*     (CAN INPUT UP TO 1000 PAIRS OF t,T∞(t) data records                     *
********************************************************************************
NTTH  NT=12
* ============================
*   TIME[MIN]   T∞(t)[F]
* ============================
       0.0       550.0
       2.0       469.0
       5.0       412.0
       7.0       361.0
      11.0       331.0
      16.0       300.0
      29.0       260.0
      45.0       235.0
      63.0       217.0
      87.0       205.0
     109.0       199.0
     120.0       190.0
********************************************************************************
```

or

```
********************************************************************************
*  =========================                                                   *
*     Record NTTH                                                              *
*  =========================                                                   *
*     THERMAL TRANSIENT: COOLANT TEMPERATURE TIME HISTORY                      *
*     NT = 101 ==> STYLIZED EXPONENTIAL DECAYING COOLANT TEMPERATURE           *
*                                                                              *
*     TINIT  = INITIAL COOLANT TEMPERATURE (at time=0) (F)                     *
*     TFINAL = LOWEST TEMPERATURE IN TRANSIENT (F)                             *
*     BETA   = DECAY CONSTANT (MIN**-1)                                        *
*                                                                              *
*     FAVLoad CALCULATES AND STORES THE COOLANT TEMPERATURE AT                 *
*     100 EQUALLY-SPACED TIME STEPS ACCORDING TO THE RELATION                  *
*                                                                              *
*     T∞(t) = T∞-FINAL + (T∞INIT - T∞FINAL) * EXP( -BETA*TIME(min)          *
********************************************************************************
NTTH  NT=101
STYL  TINIT=550  TFINAL=190  BETA=0.15
********************************************************************************
```

Record 12 – NPTH

Record 12 inputs the time history table for the internal coolant pressure boundary condition. There are **NP** data pairs of time, *t*, in minutes and internal coolant pressure, *p*, in kilo-pounds force per square inch (ksi) entered following the **NPTH** keyword record line. The number of data pairs is limited only by the memory capacity of the computer.

EXAMPLE

```
*********************************************************************************
*  =========================                                                    *
*     Record NPTH                                                               *
*  =========================                                                    *
*     PRESSURE TRANSIENT: PRESSURE vs TIME HISTORY                              *
*     NP = NUMBER OF (TIME,PRESSURE) DATA PAIRS                                 *
*     (CAN INPUT UP TO 1000 PAIRS OF t,P(t) data records                        *
*********************************************************************************
NPTH  NP=2
* ==============================
*       TIME[MIN]  P(t)[ksi]
* ==============================
          0.0        1.0
        120.0        1.0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

2.2 FAVOR PFM Module – FAVPFM

A total of 11 + NT + NWSUB + NPSUB data records (the value of NT is defined in Record 9, NWSUB is defined in Record 10 + NT, and NPSUB is defined in Record 11 + NT), listed in Table 2, are required in the FAVPFM input file, where each record may involve more than one line of data. A detailed description of each data record is given below.

Record 1 – CNT1

Record No. 1 inputs the number of simulations, **NSIM**, for the plant-specific analysis of this RPV, the number of trials/realizations.

The **IPFLAW** flag sets the distributions of surface-breaking and embedded flaws within the RPV wall that are assumed for this analysis.

IPFLAW = 1: surface-breaking flaws are internal (reside on the inside surface of the RPV) and embedded flaws are uniformly distributed within the inner 3/8^{ths} of the RPV base metal;

IPFLAW = 2: surface-breaking flaws are external (reside on the outside surface of the RPV) and embedded flaws are uniformly distributed in the outer 3/8^{ths} of RPV base metal;

IPFLAW = 3: surface-breaking flaws are both internal and external with 50% external surface-breaking and 50% internal surface-breaking flaws. Embedded flaws are distributed uniformly throughout the entire RPV base metal thickness.

The **IGATR** flag (where **IGATR** is bounded from 100 to 1000, i.e., $100 \leq$ **IGATR** ≤ 1000.), is applied per flaw in the *Initiation-Growth-Arrest* (IGA) model,

WPS_OPTION sets the warm-prestressing option **(WPS_OPT=1|2|3)** on or off **(WPS_OPT=0).**

WPS_OPTION = 0 do not include warm-prestressing in analysis

WPS_OPTION ={ 1|2|3 }– enter into WPS state when $dK/dt < 0$

Three options are available for recovery from a WPS state

WPS_OPTION = 1 exit WPS and be available for initiation when applied-K_I exceeds maximum K_I determined from all previous discrete transient time steps i.e., $dK/dt > 0$ and $K_I > \text{alpha}^*K_{Imax}$ where alpha = 1 **;**

WPS_OPTION = 2 exit WPS and be available for initiation when $dK/dt > 0$ and $K_I > \text{alpha}^*K_{Imax}$ where alpha = 0 **;**

WPS_OPTION = 3 exit WPS and be available for initiation when applied K_I exceeds maximum K_I determined from all previous discrete transient time steps i.e., $dK/dt > 0$ and $K_I > \text{alpha}^*K_{Imax}$ where alpha is sampled from a log-logistic distribution as discussed in the *Theory Manual* [2] with location parameter = 0, scale parameter = 1.15643, and shape parameter = 20.12346**.**

The **PC3_OPT** flag sets the Category 3-flaws-in-plate-material option (**PC3_OPT = 0** don't perform or **= 1** do perform analysis). In a typical PFM analysis, a substantial fraction of the total flaws are Category 3 flaws in plate regions. Based on experience and some deterministic fracture analyses, these flaws rarely contribute to the *CPI* or *CPF* with the plate flaw size distributions typically used. Therefore, setting **PC3_OPT = 0** can result in significantly shorter execution times without affecting the solution, unless there are unusual circumstances such as using a new flaw-size distribution for plate flaws. In either case, the Category 3 plate flaws are included in the bookkeeping reports.

The **CHILD_OPT** flag sets the child reports option (**CHILD_OPT = 0** don't include child subregion reports or **= 1** include child subregion reports in the FAVPFM output file). The discretization and organization of major regions and subregions in the beltline includes a special treatment of *weld-fusion lines.* These fusion lines can be visualized as approximate boundaries between the weld subregion and its neighboring plate or forging subregions. FAVOR checks for the possibility that the plate subregions adjacent to a weld subregion (termed *parent* subregions) could have a higher degree of radiation-induced embrittlement than the weld. The irradiated value of RT_{NDT} for the weld parent subregion of interest is compared to the corresponding values of the adjacent (i.e., nearest-neighbor) plate subregions. Each parent weld subregion will have at most two adjacent child plate subregions. The embrittlement-related properties of the most-limiting (either the weld or the adjacent plate subregion with the highest value of irradiated RT_{NDT}) material are used when evaluating the fracture toughness of the weld subregion. A given *parent* weld subregion will have either itself or an adjacent plate subregion as its *child* subregion from which it will draw its chemistry.

Table 2. Record Keywords and Parameter Fields for FAVPFM Input File

Record	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8
1	CNT1	NSIM=[-]	IPFLAW=[1|2|3]	IGATR=[-]	WPS_OPT=[0|1|2|3]	PC3_OPT=[0|1]	CHILD_OPT=[0|1]	RESTART_OPTION=[≤0|≥1]	
2	CNT2	IRTNDT=[992|2000|2006]	TC=[°F]	EFPY=[yr]	IDT_OPT=[0|1|2]	IDT_INI=[0|1]	ILONG_OUT=[0|1]		
3	CNT3	FLWSTR=[ksi]	USKIA=[ksi√in]	K_{Ia}_Model=[1|2]	LAYER_OPT=[0|1]	FAILCR=[-]			
4	GENR	SIGFGL=[-]	SIGFLC=[-]						
5	SIGW	WSIGCU=[wt%]	WSIGNI=[wt%]	WSIGP=[wt%]					
6	SIGP	PSIGCU=[wt%]	PSIGNI=[wt%]	PSIGP=[wt%]					
7	TRAC	ITRAN=[-]	IRPV=[-]	KFLAW=[-]	LOG_OPT=[0|1]				
8	LDQA	IQA=[0|1]	IOPT=[1|2]	IFLOR=[1|2]	IWELD=0|1]	IKIND=[1|2][3]	XIN=[in]	XVAR=[in|min]	ASPECT=[-]
9	DTRF	NT=[-]							
10	ISQ	ITRAN=[-]	ISEQ=[-]	TSTART=[min]	TEND=[min]				
11	ISQ	ITRAN=[-]	ISEQ=[-]	TSTART=[min]	TEND=[min]				
	…								
9+NT	ISQ	ITRAN=[-]	ISEQ=[-]	TSTART=[min]	TEND=[min]				
10+NT	WELD	NWSUB=[-]	NWMAJ=[-]						
11+NT	PLAT	NPSUB=[-]	NPMAJ=[-]						

Record	Embrittlement and Flaw-Distribution Map Records																			
	Input NWSUB records for all weld subregions followed by NPSUB records for all plate subregions 11+NT+NWSUB+NPSUB records: Each record has 20 fields with one line per record																			
Fields	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Field	Description	Units
1	RPV Subregion Number (parent)	[-]
2	adjacent subregion number (1st child)	[-]
3	adjacent subregion number (2nd child)	[-]
4	RPV Major Region Number	[-]
5	best-estimate fast-neutron fluence at RPV inside surface	[10^{19} n/cm^2]
6	heat-estimate copper content	[wt% Cu]
7	heat-estimate nickel content	[wt% Ni]
8	heat-estimate phosphorous content	[wt% P]
9	heat-estimate manganese content	[wt% Mn]
10	product-form flags for ΔT_{30} shift correlation	
	Welds: set distribution for sampling for standard deviation for Ni content in welds	
	1 = normal distribution	[-]
	2 = Weibull distribution	[-]
	Plates: set flag for Combustion Engineering (CE) vessel	
	1 = CE vessel (if IRTNDT=2000 then B will be set to 206)	[-]
	2 = not a CE vessel (if IRTNDT=2000 then B will be to 156)	[-]
11	Cu saturation flag =	
	0 for plates and forgings	[-]
	1 for Linde 80 and Linde 0091 weld fluxes	[-]
	2 for all weld fluxes other than L80, L0091, and L1092	[-]
	3 for L1092 weld flux	[-]
12	best-estimate (mean) for unirradiated RT_{NDT0}	[°F]
13	best-estimate for standard deviation for unirradiated RT_{NDT0}	[°F]
14	product-form flag for chemistry-factor (CF) override	
	11 = weld with no CF override	[-]
	12 = weld with CF override	[-]
	21 = plate with no CF override	[-]
	22 = plate with CF override	[-]
	31 = forging	[-]
15	angle of subregion element	[degrees]
16	axial height of subregion element	[in]
17	weld fusion area	[in^2]
18	flaw orientation: 1 = axial; 2 = circumferential	[-]
19	chemistry-factor override	[-]
20	best-estimate for unirradiated upper-shelf CVN energy	[ft-lbf]

The flaw orientation, location, size, fast-neutron fluence, and category are not linked. A *parent* plate subregion always has no *child* subregion dependency. For each transient, the basic major region and flaw-distribution reports are given in terms of the *parent* weld subregions. By setting CHILD_OPT = 1, in addition to the *parent* reports, major region and flaw-distribution reports will also be output in terms of the *child* subregions (i.e., the subregions that control the allocation of embrittlement properties to weld subregions). If this option is set, additional data will be passed onto FAVPost where *child* subregion reports will also be generated.

With the older ductile-tearing model (see Record 2 – CNT2 for details on the ductile-tearing models) turned on (IDT_OPTION=2), a second independent set of parent/child relationships are established to determine the source for ductile-tearing property data including chemistry content and USE_i. For ductile tearing the controlling property is the relative magnitude of the irradiated upper-shelf CVN energy, USE_i. FAVOR checks for the possibility that the plate subregions adjacent to a weld subregion (termed *parent* subregions) could have a lower level of ductility than the parent weld subregion. The irradiated value of the upper-shelf CVN energy (USE_i) for the weld parent subregion of interest is compared to the corresponding values of the adjacent (i.e., nearest-neighbor) plate subregions. Each weld subregion will have at most two adjacent plate subregions. The embrittlement-related properties of the most-limiting (either the weld or the adjacent plate subregion with the lowest value of USE_i) material are used when evaluating the ductile-fracture properties of the weld subregion. A given *parent* weld subregion will have either itself or an adjacent plate subregion as its *child* subregion from which it will inherit its chemistry and USE_i. This model has been superseded by a newer ductile-tearing model (IDT_OPTION=1) which is not based on the USE_i, and does not require a second parent/child dependency structure.

A restart option is included in FAVPFM. If **RESTART_OPTION ≤ 0**, the current execution is not based on a restart of a previous run. At user-selected checkpoints during FAVPFM execution, a binary restart file will be created (RESTART.BIN) which during a subsequent execution can be used to restart FAVPFM from the point in the solution at which the restart file was created. By default, this restart file is created at intervals of 200 RPV trials. The user can change this checkpoint interval by setting **RESTART_OPTION** to a negative integer. For example, if **RESTART_OPTION = -500**, then the effect will be the same as **RESTART_OPTION = 0**, except that the restart checkpoint interval will be 500 RPV trials. If **RESTART_OPTION ≥ 1**, then this execution will be treated as a restart case, and the user will be prompted for the name of a binary restart file created during a previous execution. For this restart case, new restart files will be created at user-selected checkpoint intervals where, for **RESTART_OPTION = 1**, the default checkpoint interval is 200. For

RESTART_OPTION > 1, then the checkpoint interval is equal to the value of the flag setting, (e.g., **RESTART_OPTION = 500** indicates a checkpoint interval of 500 RPV trials).

EXAMPLE

```
**********************************************************************************************************
*  ====================                                                                                  *
*                                                                                                        *
*  Control Record CNT1                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*  NSIM           = NUMBER OF RPV SIMULATIONS                                                            *
*--------------------------------------------------------------------------------------------------------*
*  IPFLAW         = FLAW POPULATION MODEL                                                                *
*                                                                                                        *
*  IPFLAW         = 1 Identical to previous version of FAVOR - primarily for cooldown transients.        *
*                                                                                                        *
*                     All Surface flaws (in surface flaw characterization file) will be inner surface   *
*                     breaking flaws. Only those embedded flaws (in weld and plate flaw characterization *
*                     files) in the inner 3/8 of the RPV wall thickness would be included in the model.  *
*                                                                                                        *
* IPFLAW         = 2  Similar to previous version of FAVOR-HT - primarily for heat-up transients.        *
*                                                                                                        *
*                     All surface breaking flaws (in surface flaw characterization file) would be        *
*                     external surface breaking flaws. Only those embedded flaws in the outer 3/8 of the *
*                     RPV wall thickness would be included in the model.                                 *
*                                                                                                        *
* IPFLAW         = 3  The number of postulated surface breaking flaws (in surface flaw characterization  *
*                     file) would be double that of options 1 and 2; evenly divided between internal     *
*                     and external surface breaking flaws. All of the embedded flaws uniformly           *
*                     distributed through the RPV wall thickness would be included in the model.         *
*                                                                                                        *
* See Theory Manual for further discussion.                                                              *
*--------------------------------------------------------------------------------------------------------*
*  IGATR          =   NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                           *
*--------------------------------------------------------------------------------------------------------*
*  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                       *
*  WPS_OPTION     = 1        INCLUDE TRADITIONAL FAVOR BASELINE WARM-PRESTRESSING Model IN ANALYSIS      *
*  WPS_OPTION     = 2        INCLUDE Conservative Principal WARM-PRESTRESSING MODEL IN ANALYSIS          *
*  WPS_OPTION     = 3        INCLUDE Best-Estimate WARM-PRESTRESSING MODEL IN ANALYSIS                   *
*                                                                                                        *
*  See Theory Manual for details regarding WARM_PRESTRESS Models                                         *
*  Note: Previous Versions of FAVOR prior to the 15.1 included only options 0 and 1.                     *
*--------------------------------------------------------------------------------------------------------*
*  CHILD_OPTION   = 0 DO NOT INCLUDE CHILD SUBREGION REPORTS                                         [-] *
*  CHILD_OPTION   = 1        INCLUDE CHILD SUBREGION REPORTS                                         [-] *
*--------------------------------------------------------------------------------------------------------*
*  RESTART_OPTION = 0 THIS IS NOT A RESTART CASE                                                     [-] *
*  RESTART_OPTION = 1 THIS IS A RESTART CASE                                                         [-] *
*--------------------------------------------------------------------------------------------------------*
*  =============================                                                                         *
*  Notes for Control Record CNT1                                                                         *
*  =============================                                                                         *
*  IN A TYPICAL PFM ANALYSIS, A SUBSTANTIAL FRACTION OF THE TOTAL FLAWS ARE CATEGORY 3 FLAWS IN          *
*  PLATE REGIONS. BASED ON EXPERIENCE AND SOME DETERMINISTIC FRACTURE ANALYSES, THESE FLAWS VERY         *
*  RARELY CONTRIBUTE TO THE CPI OR CPF WITH THE PLATE FLAW SIZE DISTRIBUTIONS TYPICALLY USED.            *
*  THEREFORE, INVOKING IP3OPT = 0 CAN RESULT IN A SIGNIFICANT REDUCTION IN EXECUTION TIME WITHOUT        *
*  AFFECTING THE SOLUTION, UNLESS THERE ARE UNUSUAL CIRCUMSTANCES SUCH AS A NEW FLAW-SIZE                *
*  DISTRIBUTION FOR PLATE FLAWS. IN EITHER CASE, CATEGORY 3 PLATE FLAWS ARE INCLUDED IN ALL REPORTS.     *
*                                                                                                        *
*  IF IPFLAW = 3; THEN PC3_OPTION AUTOMATICALLY OVER-RIDES AND SETS PC3_OPTION = 1                       *
*                                                                                                        *
*  Notes on Restart Option:                                                                              *
*                                                                                                        *
*  The restart option flag can also be used to control the frequency with which restart files are        *
*  created. If RESTART_OPTION is given a value other than 0 or 1, then the absolute value of this flag   *
*  sets the checkpoint interval at which the restart file will be created during the run. For example,   *
*                                                                                                        *
* 1.RESTART_OPTION = -200 ==> This is not a restart case; restart files will be created every 200 trials *
* 2.RESTART_OPTION =    0 ==> Same as example No. 1.                                                     *
* 3.RESTART_OPTION =  200 ==> This is a restart case;     restart files will be created every 200 trials.*
* 4.RESTART_OPTION =    1 ==> Same as example No. 3.                                                     *
* 5.RESTART_OPTION =  -50 ==> This is not a restart case; restart files will be created every 50 trials. *
*                                                                                                        *
*--------------------------------------------------------------------------------------------------------*
**********************************************************************************************************
CNT1  NSIM=100  IPFLAW=1 IGATR=100   WPS_OPTION=1    PC3_OPTION=0    CHILD_OPTION=1   RESTART_OPTION=0
**********************************************************************************************************
```

Record 2 – CNT2

Record No. 2 inputs a flag, **IRTNDT**, that designates the correlation to be used for irradiation shift calculations, where

IRTNDT = 992 ➔ use Regulatory Guide 1.99, Rev. 2, for irradiation shift in RT_{NDT}

IRTNDT = 2000 ➔ use Eason 2000 [24, 25] correlation for irradiation shift in RT_{NDT}

IRTNDT = 2006 ➔ use the Eason 2006 [26] correlation for irradiation shift in RT_{NDT}
IRTNDT = 20071 ➔ use the Kirk 2007 correlation for irradiation shift in RT_{NDT}
IRTNDT = 20072 ➔ use the RADAMO 2007 correlation for irradiation shift in RT_{NDT}
IRTNDT = 20073 ➔ use the combined EasonKirk/RADAMO 2007 correlation for irradiation shift

the normal operating coolant temperature, **TC**, in °F, the plant operating time, **EFPY**, to be assumed for this case in effective full-power years, and a flag **IDT_OPTION** to turn on (**IDT_OPTION ≥ 1**) or off (**IDT_OPTION=0**) the ductile-tearing model in the *IGA* submodel. If **IDT_OPTION=2**, the ductile-tearing model introduced in v03.1 can be activated; however, this model is no longer supported and is maintained in FAVOR for backward compatibility with v03.1 executions only. The newer ductile-tearing model (**IDT_OPTION=1**) is recommended when investigating the effects of ductile tearing. The flag **IDT_INI** provides additional reporting concerning flaw initiation due to ductile tearing. Currently, there is no model in FAVOR to determine the probability of flaw initiation by ductile tearing. The ductile-tearing model simulates reinitiation by tearing only after a flaw has arrested. The additional reporting when **IDT_INI=1** provides a log of the number of potential ductile-tearing flaw initiations (when $J_{applied} > J_{Ic}$) that occurred during the analysis. It should be noted that setting **IDT_INI=1** has the potential of significantly increasing the computational time for a given run. When **IDT_INI=0**, the checks for ductile-tearing initiation are not carried out. When the ductile-tearing option is activated, however, checks for ductile-tearing reinitiation of an arrested flaw will always be performed. The flag **ILONG_OUT** provides additional reporting concerning the contribution to the CPI and CPF from the major regions in the belt line for each transient. When **ILONG_OUT=1,** a series of files named *History_***itran_iseq**.*out* (where **itran** is the FAVOR transient number and **iseq** is the associated thermal-hydraulic initiating-event sequence number from the RELAP5 cases) will be created during the execution that will contain results data for all of the RPV trials. The user should note that for long FAVPFM executions, these files could become quite large and their creation may have an impact on run times. When **ILONG_OUT=0,** these files are not created.

EXAMPLE

```
***********************************************************************************************************
***********************************************************************************************************
*  ====================                                                                                   *
*  Control Record CNT2                                                                                    *
*  ====================                                                                                   *
*---------------------------------------------------------------------------------------------------------*
* IRTNDT     = 992   ==> USE RG 1.99, REV 2,  FOR ESTIMATING RADIATION SHIFT IN RTNDT                     *
* IRTNDT     = 2000  ==> USE E2000 CORRELATION FOR ESTIMATING RADIATION SHIFT IN RTNDT                    *
* IRTNDT     = 2006  ==> USE E2006 CORRELATION FOR ESTIMATING RADIATION SHIFT IN RTNDT                    *
* IRTNDT     = 20071 ==> USE EricksonKirk 2007 CORRELATION FOR ESTIMATING RADIATION SHIFT IN RTNDT         *
* IRTNDT     = 20072 ==> USE RADAMO CORRELATION FOR ESTIMATING RADIATION SHIFT IN RTNDT                   *
* IRTNDT     = 20073 ==> USE COMBINED EricksonKirk 2007 + RADAMO CORRELATIONS FOR RADIATION SHIFT          *
*---------------------------------------------------------------------------------------------------------*
* TC         = INITIAL RPV COOLANT TEMPERATURE (applicable only when IRTNDT=2000 or 2006)             [F] *
*---------------------------------------------------------------------------------------------------------*
* EFPY       = EFFECTIVE FULL-POWER YEARS OF OPERATION                                            [YEARS] *
*---------------------------------------------------------------------------------------------------------*
* IDT_OPTION = 0  DO NOT INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE                         [-] *
* IDT_OPTION = 1         INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE                         [-] *
```

```
*---------------------------------------------------------------------------------------------------------*
* IDT_INI    = 0  DO NOT CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                       [-] *
* IDT_INI    = 1         CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                       [-] *
*---------------------------------------------------------------------------------------------------------*
* ILONG_OUT  = 0  DO NOT CREATE Major-Region ITRAN Files                                              [-] *
* ILONG_OUT  = 1         CREATE Major-Region ITRAN Files                                              [-] *
***********************************************************************************************************
CNT2 IRTNDT=2006 TC=556 EFPY=60  IDT_OPTION=1  IDT_INI=0  ILONG_OUT=1*  ====================
***********************************************************************************************************
```

Record 3 – CNT3

Record No. 3 inputs values for the flow stress, **FLWSTR**, in ksi to be used in the failure model of plastic collapse (ligament instability), the upper bound for K_{Ic} and K_{Ia} , **USKIA**, in $\text{ksi}\sqrt{\text{in.}}$, a flag **KIa_Model** to designate which arrest model (1 or 2) to use in checking for stable arrest, the weld layer resampling option, **LAYER_OPT**, (on or off), and the fraction of the total wall thickness, **FAILCR**, used in the vessel failure criterion. If a flaw, propagating from the inner surface of the vessel, grows to this depth into the wall (relative to the inner surface), then the event will be designated as a *vessel failure*, where $0.25 \le \text{FAILCR} \le 0.95$.

EXAMPLE

```
***********************************************************************************************************
*  ====================                                                                                   *
*  Control Record CNT3                                                                                    *
*  ====================                                                                                   *
*---------------------------------------------------------------------------------------------------------*
* FLWSTR = UNIRRADIATED FLOW STRESS USED IN PREDICTING FAILURE BY REMAINING LIGAMENT INSTABILITY    [ksi] *
*---------------------------------------------------------------------------------------------------------*
* USKIA  = MAXIMUM VALUE ALLOWED FOR KIc or KIa                                              [ksi-in^1/2] *
*---------------------------------------------------------------------------------------------------------*
* KIa_Model    = 1 Use high-constraint KIa model based on CCA specimens                               [-] *
* KIa_Model    = 2 Use KIa model based on CCA + large specimen data                                   [-] *
*---------------------------------------------------------------------------------------------------------*
* LAYER_OPTION = 0 DONOT RESAMPLE PF WHEN ADVANCING INTO NEW WELD LAYER                               [-] *
* LAYER_OPTION = 1       RESAMPLE PF WHEN ADVANCING INTO NEW WELD LAYER                               [-] *
*---------------------------------------------------------------------------------------------------------*
* FAILCR       = FRACTION OF WALL THICKNESS FOR VESSEL FAILURE BY THROUGH-WALL CRACK PROPAGATION     [-] *
*---------------------------------------------------------------------------------------------------------*
*  ==============================                                                                         *
*  Notes for Control Record CNT3                                                                          *
*  ==============================                                                                         *
*        If ductile tearing model is included, then the values for USKIA and KIa_Model are ignored.       *
*        They are automatically set internally to KIa_Model=2 and there is no upper limit on USKIa.       *
*        If ductile tearing is not included in the analysis (IDT_OPTION = 0 on CNT1), both the KIa_Model *
*        and USKIA are user-specified on CNT3.                                                            *
*                                                                                                         *
***********************************************************************************************************
CNT3 FLWSTR=80.  USKIA=200. KIa_Model=1  LAYER_OPTION=1  FAILCR=0.9
***********************************************************************************************************
```

Record 4 – GENR

Record No. 4 inputs the value of two multipliers, **SIGFGL** and **SIGFLC**, used to obtain the standard deviations of a global and local normal distribution for fluence sampling, where the fluence at the inner surface, $\overparen{f(0)}$[1], is sampled from two normal distributions such that

$$
\begin{aligned}
&\sigma_{global} = SIGFGL \times fluence_{subregion} \\
&\overparen{\overparen{f}} \leftarrow N(fluence_{subregion}, \sigma_{global}) \\
&\overparen{\sigma_{local}} = SIGFLC \times \overparen{\overparen{f}} \\
&\overparen{f(0)} \leftarrow N(\overparen{\overparen{f}}, \overparen{\sigma_{local}})
\end{aligned}
$$

where $fluence_{subregion}$ is the best-estimate for the subregion neutron fluence as input in the embrittlement map (to be described below).

EXAMPLE

```
**********************************************************************************************************
*  ====================                                                                                  *
*      Record GENR                                                                                       *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*   SIGFGL = A MULTIPLIER ON THE BEST ESTIMATE OF FLUENCE FOR A GIVEN SUBREGION                      [-] *
*            PRODUCES THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION USED TO SAMPLE THE MEAN         *
*            OF THE LOCAL FLUENCE DISTRIBUTION.                                                          *
*--------------------------------------------------------------------------------------------------------*
*   SIGFLC = A MULTIPLIER ON THE SAMPLED MEAN OF THE LOCAL FLUENCE FOR A GIVEN  SUBREGION            [-] *
*            PRODUCES THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION USED TO SAMPLE THE LOCAL FLUENCE*
*--------------------------------------------------------------------------------------------------------*
*  ======================                                                                                *
*  Notes for Record GENR                                                                                 *
*  ======================                                                                                *
*  Let "flue" be the best estimate for the subregion neutron fluence at inside surface of the RPV wall.  *
*  flue_STDEV_global = SIGFGL*flue                                                                       *
*  flue_MEAN_local  << Normal(flue,flue_STDEV_global)                                                    *
*  flue_STDEV_local  = SIGFLC*flue_MEAN_local                                                            *
*  flue_local       << Normal(flue_MEAN_local,flue_STDEV_local)                                          *
*                                                                                                        *
**********************************************************************************************************
GENR SIGFGL=0.01 SIGFLC=0.01
**********************************************************************************************************
```

Records 5 and 6 – SIGW AND SIGP

Records No. 5 and 6 input the values of the standard deviations of the initial normal sampling distributions for the weld and plate chemistries, respectively. On Record 5, the three data fields include the standard deviations for the weight % of copper, Cu, **WSIGCU**, nickel, Ni, **WSIGNI,** and phosphorous, P, **WSIGP** in welds. On Record 6, the three data fields include the standard deviations for the weight % of Cu, **PSIGCU**, Ni, **PSIGNI,** and P, **PSIGP** in plates and forgings. The heat estimates for Cu, Ni, and P given in the embrittlement map described below are used as the means of the normal sampling distributions for the weld and plate chemistries.

---

[1] A curved overbar indicates a sampled random variate, e.g., $\overparen{f} \leftarrow N(\mu,\sigma)$ means the random variate f has been sampled from a normal distribution with mean μ and standard deviation σ .

The **weld** chemistries are sampled using the following protocols:

$$\overline{Cu} = Cu_{Heat} \times WSIGCU$$
$$\sigma^*_{Cu} = \min(0.0718 \times Cu_{Heat}, 0.0185)$$
$$\widehat{\sigma_{Cu}} \leftarrow N(\overline{Cu}, \sigma^*_{Cu})$$
$$\widehat{Cu} \leftarrow N(Cu_{Heat}, \widehat{\sigma_{Cu}})$$

; For Ni-addition welds

Heats 34B009 &W5214

$$\widehat{Ni} \leftarrow N(Ni_{Heat}, WSIGNI)$$
$$WSIGNI = 0.162$$

For other heats

$$\widehat{\sigma_{Ni}} \leftarrow N(0.029, 0.0165)$$
$$\widehat{Ni} \leftarrow N(Ni_{Heat}, \widehat{\sigma_{Ni}})$$

; $\widehat{P} \leftarrow N(P_{Heat}, WSIGP)$

The **plate** chemistries are sampled using the following protocols:

$$\widehat{Cu} \leftarrow N(Cu_{Heat}, PSIGCU) \quad ; \; \widehat{Ni} \leftarrow N(Ni_{Heat}, PSIGNI) \quad ; \; \widehat{P} \leftarrow N(P_{Heat}, PSIGP)$$

EXAMPLE

```
***********************************************************************************************************
*  ====================                                                                                   *
*      Record SIGW                                                                                        *
*  ====================                                                                                   *
*  STANDARD DEVIATIONS (STDEV) OF NORMAL DISTRIBUTIONS FOR WELD CHEMISTRY SAMPLING:                       *
*  WSIGCU = STANDARD DEVIATION FOR COPPER CHEMISTRY SAMPLING IN WELDS                               [wt%] *
*  WSIGNI = STANDARD DEVIATION FOR NICKEL CHEMISTRY SAMPLING IN WELDS                               [wt%] *
*  WSIGP  = STANDARD DEVIATION FOR PHOSPHOROUS CHEMISTRY SAMPLING IN WELDS                          [wt%] *
*---------------------------------------------------------------------------------------------------------*
*  ======================                                                                                 *
*  Notes for Record SIGW                                                                                  *
*  ======================                                                                                 *
*  FOR NICKEL IN WELDS THERE ARE TWO POSSIBILITIES.                                                       *
*  (1) FOR HEATS 34B009 AND W5214 (Ni - addition welds)                                                   *
*      WSIGNI = 0.162 wt% using a normal distribution.                                                    *
*  (2) For other heats, the standard deviation (WSIGNI) shall be sampled from a normal distribution       *
*      with mean equal to 0.029 wt% and standard deviation = 0.0165 wt%                                   *
***********************************************************************************************************
SIGW   WSIGCU=0.167   WSIGNI=0.162    WSIGP=0.0013
***********************************************************************************************************
*  ====================                                                                                   *
*      Record SIGP                                                                                        *
*  ====================                                                                                   *
*  STANDARD DEVIATIONS (STDEV) OF NORMAL DISTRIBUTIONS FOR PLATE CHEMISTRY SAMPLING:                      *
*  PSIGCU = STANDARD DEVIATION FOR COPPER CHEMISTRY SAMPLING IN PLATES                              [wt%] *
*  PSIGNI = STANDARD DEVIATION FOR NICKEL CHEMISTRY SAMPLING IN PLATES                              [wt%] *
*  PSIGP  = STANDARD DEVIATION FOR PHOSPHOROUS CHEMISTRY SAMPLING IN PLATES                         [wt%] *
*---------------------------------------------------------------------------------------------------------*
*  ======================                                                                                 *
*  Notes for Record SIGP                                                                                  *
*  ======================                                                                                 *
*  RECOMMENDED VALUES ARE: 0.0073, 0.0244, 0.0013 for Cu, Ni, and P, respectively.                        *
***********************************************************************************************************
SIGP  PSIGCU=0.0073   PSIGNI=0.0244   PSIGP=0.0013
***********************************************************************************************************
*  ===============================                                                                        *
*  Notes for RecordS SIGW and SIGP                                                                        *
*  ===============================                                                                        *
*  THE ABOVE DISTRIBUTIONS ARE FOR THE 1ST FLAW POSITIONED IN A PARTICULAR SUBREGION.                     *
*  IF THE CURRENT FLAW IS THE 2ND OR MORE FLAW FOR THIS SUBREGION, THEN FAVPFM WILL USE                   *
*  THE LOCAL VARIABILITY SAMPLING PROTOCOLS PRESENTED IN THE THEORY MANUAL.                               *
***********************************************************************************************************
```

Record 7 – TRAC

Record No. 7 provides a mechanism for the user to put a trace on a particular flaw, **KFLAW**, in a specific simulation, **IRPV**, and for a specific transient, **ITRAN**. This facility provides a Quality Assurance tool to verify the computational models(s) used to calculate values of *CPI* and *CPF.* Data describing the initiation, crack growth, and arrest check calculations are written to the files TRACE.OUT and ARREST.OUT. The variable **ITRACK=1** creates flaw-tracking log tables to help identify values for **(ITRAN, IRPV, KFLAW)** to specify in later executions. These tables can be found in the file TRACE.OUT. An additional file is created called FLAW_TRACK.LOG which provides data for the first 10,000 flaws sampled during the execution.

EXAMPLE

```
**********************************************************************************************************
*  ====================                                                                                  *
*     Record TRAC                                                                                        *
*  ====================                                                                                  *
*   ITRAN           = TRANSIENT NUMBER                                                               [-] *
*   RPV             = RPV SIMULATION                                                                 [-] *
*   KFLAW           = FLAW NUMBER                                                                    [-] *
*   FLAW_LOG_OPTION = 0 DO NOT CREATE FLAW LOG TABLES                                                [-] *
*   FLAW_LOG_OPTION = 1 DO     CREATE FLAW LOG TABLES                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*  ===============================                                                                       *
*  Notes for Record TRAC                                                                                 *
*  ===============================                                                                       *
*  THE ABOVE FLAGS IDENTIFY A SPECIFIC TRANSIENT, RPV SIMULATION, AND FLAW NUMBER WHOSE COMPLETE         *
*  HISTORY WILL BE GIVEN IN THE FILES: "TRACE.OUT" AND "ARREST.OUT"                                      *
*  SEE THE USER'S GUIDE FOR DETAILS ON THE CONTENTS OF THESE FILES                                       *
*                                                                                                        *
**********************************************************************************************************
TRAC ITRAN=3  IRPV=5  KFLAW=2652 FLAW_LOG_OPTION=1
**********************************************************************************************************
```

Record 8 – LDQA

Record No. 8 provides a mechanism for the user to carry out, as a deterministic or diagnostic exercise, deterministic calculations for the transients received from the FAVLoad module. This utility allows the user to tailor output reports containing (1) time histories of load-related variables at a specific location in the RPV wall or (2) through-wall profiles of load-related variables at a specific transient time. There are eight parameters associated with this record appearing on a single data line.

(1) IQA = 1 activates the deterministic analysis module; no PFM analysis will be performed
IQA = 0 ignore the rest of the data on this data line and proceed with a PFM analysis

(2) IOPT = 1 ➔ generate time history results at a specific location in the RPV wall
IOPT = 2 ➔ generate through-wall profiles of stress and applied K_I at a specific time

(3) IFLOR = 1 ➔ flaw orientation is axial
IFLOR = 2 ➔ flaw orientation is circumferential

(4) IWELD = 0 ➔ do not include weld residual stresses
IWELD = 1 ➔ include weld residual stresses

(5) IKIND = 1 ➔ inner surface-breaking flaw
IKIND = 2 ➔ embedded flaw
IKIND = 3 ➔ outer surface-breaking flaw

(6) XIN – only used if IKIND = 2 (otherwise ignored)
if IOPT = 1; XIN = location of inner crack tip from inner surface (in.)
if IOPT = 2; XIN = 2*d* = flaw depth (see Fig. 6)

(7) XVAR – meaning depends on the value of IOPT
if IOPT = 1; XVAR = flaw depth (in.) (*a* for IKIND = 1; 2*d* for IKIND = 2 in Fig. 6)
if IOPT = 2; XVAR = elapsed time in minutes

(8) ASPECT ➔ aspect ratio = *L* / *a* for IKIND = 1; aspect ratio = *L* / *2d* for IKIND = 2
if IKIND = 1 or 3; ASPECT = 2, 6, 10, or 999
if IKIND = 2; ASPECT > 0.0

EXAMPLE

```
**********************************************************************************************************
*  ====================                                                                                  *
*     Record LDQA                                                                                        *
*  ====================                                                                                  *
* THE LDQA RECORD PROVIDES THE OPPORTUNITY TO CHECK LOAD-RELATED SOLUTIONS                               *
* SUCH AS TEMPERATURE, STRESSES, AND KI.                                                                 *
*                                                                                                        *
*   IQA   = 0 ==> THIS EXECUTION IS NOT FOR LOAD QA                                                  [-] *
*   IQA   = 1 ==> THIS EXECUTION IS FOR LOAD QA                                                      [-] *
*--------------------------------------------------------------------------------------------------------*
*   IOPT  = 1 ==> GENERATE TIME HISTORY AT SPECIFIC THROUGH WALL LOCATION                            [-] *
*   IOPT  = 2 ==> GENERATE THROUGH WALL DISTRIBUTION AT SPECIFIC TIME                                [-] *
*--------------------------------------------------------------------------------------------------------*
*   IFLOR = 1 ==> FLAW ORIENTATION IS AXIAL                                                          [-] *
*   IFLOR = 2 ==> FLAW ORIENTATION IS CIRCUMFERENTIAL                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*   IWELD = 0  ==> DOES NOT INCLUDE THRU-WALL WELD RESIDUAL STRESS                                   [-] *
*   IWELD = 1  ==> DOES INCLUDE THRU-WALL WELD RESIDUAL STRESS                                       [-] *
*--------------------------------------------------------------------------------------------------------*
*   IKIND = 1  ==> INNER-SURFACE BREAKING FLAW                                                       [-] *
*   IKIND = 2  ==> EMBEDDED FLAW                                                                     [-] *
*   IKIND = 3  ==> OUTER-SURFACE BREAKING FLAW                                                       [-] *
*--------------------------------------------------------------------------------------------------------*
*   XIN IS ONLY USED IF IKIND=2 (EMBEDDED FLAWS)                                                         *
*   XIN   =  IF IOPT=1; LOCATION OF INNER CRACK TIP FROM INNER SURF.                                [IN] *
*   XIN   =  IF IOPT=2; FLAW DEPTH                                                                  [IN] *
*--------------------------------------------------------------------------------------------------------*
*   XVAR:    IF IOPT=1; XVAR=FLAW DEPTH                                                             [IN] *
*            IF IOPT=2; XVAR=TIME                                                                  [MIN] *
*--------------------------------------------------------------------------------------------------------*
*   ASPECT = ASPECT RATIO; FOR SURFACE BREAKING FLAWS: 2,6,10,999 (infin)                            [-] *
*                          FOR EMBEDDED FLAWS: ANY VALUE > 0                                             *
*--------------------------------------------------------------------------------------------------------*
*  ===============================                                                                       *
*  Notes for Record LDQA                                                                                 *
*  ===============================                                                                       *
* IQA = 0 NO VALIDATION REPORTS WILL BE GENERATED, PFM ANALYSIS WILL BE PERFORMED                        *
* IQA = 1 LOAD PARAMETERS WILL BE GENERATED FOR VERIFICATION PURPOSES, PFM ANALYSIS WILL NOT BE PERFORMED*
**********************************************************************************************************
LDQA IQA=0 IOPT=2 IFLOR=2 IWELD=0 IKIND=1 XIN=0.53 XVAR=70 ASPECT=99
**********************************************************************************************************
```

Record 9 – DTRF

In some cases, the PFM solution(s) can be sensitive to the time-step size (specified as **DT** on Record 7 in FAVLoad input as discussed in Sect. 2.1) used in the analysis. Some preliminary analysis is useful in determining a suitable **DT** that provides a converged PFM solution, i.e., converged in the sense that a decrease in **DT** does not result in a significant change in the solution. Decreasing **DT** resolves the load and fracture toughness variables better; however, smaller values of **DT** increase the number of discrete time steps to cover the transient, thus increasing the amount of computational effort required to perform the PFM analysis. Ideally, one would like to use a relatively small time step in the PFM analysis for better accuracy, yet to perform the PFM analysis for only the time period during which all of the crack initiations and failures are predicted to occur.

Record 9 provides a mechanism to specify the starting and ending times for specific transients supplied in the FAVLoad output file. The variable **NT** sets the number of **ISQ** records that follow the **DTRF** record. The following **NT** records contain values for **ITRAN** (= the transient number in the transient stack supplied in the FAVLoad output file), **ISEQ** (= the corresponding identifying thermal-hydraulic sequence number), **TSTART** (= starting time in minutes), and **TEND** (= ending time in minutes). Only those transients in the FAVLoad transient stack for which the user wishes to set special values of **TSTART** and **TEND** need be identified by the DTRF records. All other transients in the stack, not explicitly specified in the DTRF records, will use the global transient start (always = 0.0) and ending times set by the execution of the FAVLoad module.

During preliminary analyses to determine a suitable **DT** that provides a converged solution, one may also determine for each transient the time period during which postulated cracks are predicted to initiate and propagate through-the-wall since this information is reported for each transient in the *Transient Time Distribution Report* (See example FAVPFM output in Sect. 2.6). Limiting the time period during which the PFM analysis is performed for each transient will reduce the computational effort.

EXAMPLE No. 1

```
**********************************************************************************************************
*  ====================                                                                                  *
*      Record DTRF                                                                                       *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*   NT = number of ISQ records that follow                                                           [-] *
*   NT = 0 no ISQ records follow                                                                         *
*--------------------------------------------------------------------------------------------------------*
*   FOLLOWING THE DTRF RECORD, THERE SHOULD BE "NT" SUBRECORDS                                           *
*--------------------------------------------------------------------------------------------------------*
*   ISQ  ITRAN=  ISEQ=  TSTART=   TEND=                                                                  *
*--------------------------------------------------------------------------------------------------------*
*   ITRAN  = sequential number in FAVLoad transient stack                                            [-] *
*   ISEQ   = Thermal Hydraulic trasient sequence number                                              [-] *
*   TSTART = starting time for FAVPFM analysis                                                     [MIN] *
*   TEND   = ending time for FAVPFM analysis                                                       [MIN] *
**********************************************************************************************************
DTRF NT=4
*--------------------------------------------------------------------------------------------------------*
ISQ ITRAN=1 ISEQ=7   TSTART=2  TEND=35
ISQ ITRAN=2 ISEQ=9   TSTART=1  TEND=29
ISQ ITRAN=3 ISEQ=56  TSTART=9  TEND=56
ISQ ITRAN=4 ISEQ=97  TSTART=11 TEND=85
**********************************************************************************************************
```

To use the global starting and ending times for all transients, set in FAVLoad Input Record 7, input the following:

EXAMPLE No. 2

```
**************************************************************************************************************
*  ====================                                                                                      *
*      Record DTRF                                                                                           *
*  ====================                                                                                      *
*------------------------------------------------------------------------------------------------------------*
*   NT = number of ISQ records that follow                                                               [-] *
*   NT = 0 no ISQ records follow                                                                             *
*------------------------------------------------------------------------------------------------------------*
*   FOLLOWING THE DTRF RECORD, THERE SHOULD BE "NT" SUBRECORDS                                               *
*------------------------------------------------------------------------------------------------------------*
*   ISQ  ITRAN=  ISEQ=  TSTART=   TEND=                                                                      *
*------------------------------------------------------------------------------------------------------------*
*   ITRAN  = sequential number in FAVLoad transient stack                                                [-] *
*   ISEQ   = Thermal Hydraulic trasient sequence number                                                  [-] *
*   TSTART = starting time for FAVPFM analysis                                                         [MIN] *
*   TEND   = ending time for FAVPFM analysis                                                           [MIN] *
**************************************************************************************************************
DTRF NT=0
**************************************************************************************************************
```

Records 10+NT and 11+NT

Records 10+NT and 11+NT give the number of major regions and subregions for welds and plates, respectively. The sum of the number of weld subregions, **NWSUB**, and the number of plate subregions, **NPSUB,** gives the total number of embrittlement map records to follow this keyword line. **NWMAJ** is the number of major weld regions, and **NPMAJ** is the number of major plate regions.

EXAMPLE

```
**************************************************************************************************************
*  ====================                                                                                      *
*     Record WELD                                                                                            *
*  ====================                                                                                      *
*  NWSUB = NUMBER OF WELD SUBREGIONS                                                                     [-] *
*  NWMAJ = NUMBER OF WELD MAJOR REGIONS                                                                  [-] *
**************************************************************************************************************
WELD NWSUB=838   NWMAJ=5
**************************************************************************************************************
*  ====================                                                                                      *
*     Record PLAT                                                                                            *
*  ====================                                                                                      *
* NPSUB = NUMBER OF PLATE SUBREGIONS                                                                     [-] *
* NPMAJ = NUMBER OF PLATE MAJOR REGIONS                                                                  [-] *
**************************************************************************************************************
PLAT NPSUB=14442  NPMAJ=4
**************************************************************************************************************
```

Records 12+NT through 11+NT+NWSUB+NPSUB

Following **Record 11+NT**, there will be **NWSUB + NPSUB** data lines (one record per subregion and one data line per record) that contain the embrittlement map for all of the weld and plate subregions. Note that the data records for the weld subregions must precede the data records for the plate subregions. There are 20 fields in each record.

(1) subregion number – subregion numbers should start with 1 and then increment by 1 for the complete embrittlement map.

Flaws in welds have been observed to reside along the fusion line between the weld and adjacent plate; therefore, it is possible that the adjacent plate(s) could have a higher degree of embrittlement and/or less ductility than the weld. The embrittlement/ductility-related properties of the most limiting (of the weld or the adjacent plate) material shall be used when evaluating flaw advancement by cleavage propagation or ductile tearing. If this subregion is a weld region, FAVOR will determine if one of the adjacent plate(s), located in adjacent-plate subregions, is more limiting, i.e., has a higher RT_{NDT} for cleavage propagation and a lower value of USE_i for flaw advancement by ductile tearing (**IDT_OPTION=2** only). If so, FAVOR will use the embrittlement/ductility properties of the more limiting subregion, where separate sets of parent/child relationships are determined for cleavage propagation and ductile tearing. The next two fields are valid only if the subregion designated in field 1 is a weld subregion. From a roll-out map of the RPV beltline, select the plate subregions that are adjacent to the weld subregion in field 1. If field 1 refers to a plate subregion, just repeat the subregion number from field 1 in fields 2 and 3.

(2) left-adjacent plate subregion number

(3) right-adjacent plate subregion

(4) major region number

(5) best estimate for fast-neutron fluence at inside surface of RPV wall (10^{19} neutrons/cm^2)

(6) heat estimate for copper content (wt% Cu), Cu_{Heat}

(7) heat estimate for nickel content (wt% Ni), Ni_{Heat}

(8) heat estimate for phosphorous content (wt% P), P_{Heat}

(9) heat estimate for manganese content (wt% Mn), Mn_{Heat}

(10) if field 1 is a weld subregion ➔ select the method for determining the standard deviation for the normal distribution used to simulate the Ni content

= 1 ➔ use the constant value given in the WSIGNI field on Record 5. (These are Ni-addition welds from heats 34B009 and W5214 in the RVID2 database.)

= 2 ➔ sample from a normal distribution with $\widehat{\sigma_{Ni}} \leftarrow N(0.029, 0.0165)$ (all other heats)

(10) if field 1 is a plate subregion with IRTNDT=2000 or 2006 on Record 2 (ignored if IRTNDT=992)

= 1 ➔ Combustion Engineering (CE) plate

= 2 ➔ all other plates and forgings

(11) copper saturation flag when IRTNDT = 2000 or 2006 on Record 2 (ignored if IRTNDT=992)

= 0 for plates and forgings

= 1 for Linde 80 and Linde 0091 weld fluxes

= 2 for all weld fluxes other than Linde 80, Linde 0091, or Linde 1092

= 3 for Linde 1092 weld flux

(12) RVID2 heat estimate for unirradiated value of RT_{NDT} (RT_{NDT0}) (°F) (see Appendix B)

(13) standard deviation for RT_{NDT0} (°F). If the $RT_{NDT(u)}$ Method in Appendix B is either MTEB 5-2 or ASME NB-2331, enter a 0.0. If the $RT_{NDT(u)}$ Method in Appendix B is *Generic*, enter a best-estimate for the standard deviation.

(14) Irradiation-shift-correlation flag when IRTNDT=2000 or 2006 on Record 2

= 11 ➔ weld major region

= 21 ➔ plate major region

= 31 ➔ forging major region

(14) Irradiation-shift-correlation flag when IRTNDT = 992 on Record 2

= 11 ➔ weld major region; no chemistry-factor override

= 12 ➔ weld major region; with chemistry-factor override

= 21 ➔ plate major region; no chemistry-factor override

= 22 ➔ plate major region; with chemistry-factor override

= 31 ➔ forging major region

(15) Angle of subregion element, $d\theta$ (degrees) (see Fig. 17 on the following page)

(16) Axial height of subregion element, dz (inches) (see Fig. 17 on the following page)

(17) Weld fusion area (=0.0 for plate subregions) (in^2) (see Figs. 17a and b)

(18) Weld orientation; =1 ➔ axial; =2 ➔ circumferential (ignored if Plate subregion)

(19) Chemistry-factor override; (if IRTNDT=992 on Record 2 and irradiation shift correlation flag (field 13) = 12 or 22), otherwise set to 0.

(20) Unirradiated upper-shelf CVN energy (USE0) in [ft-lbf] from RVID2, (used only if IDT_OPTION=2

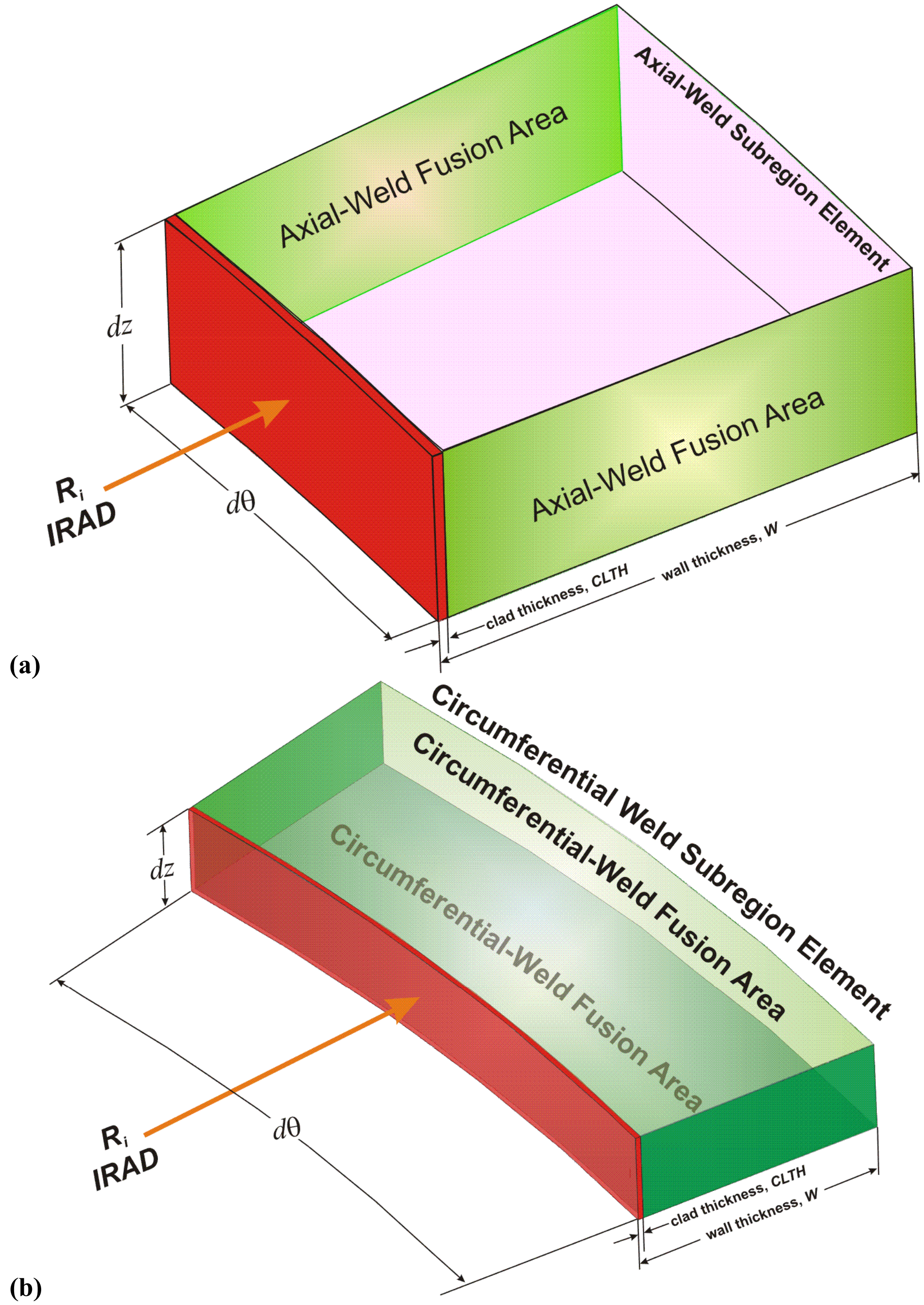


Fig. 17. Weld fusion area definitions for (a) axial-weld subregion elements and (b) circumferential-weld subregion elements.

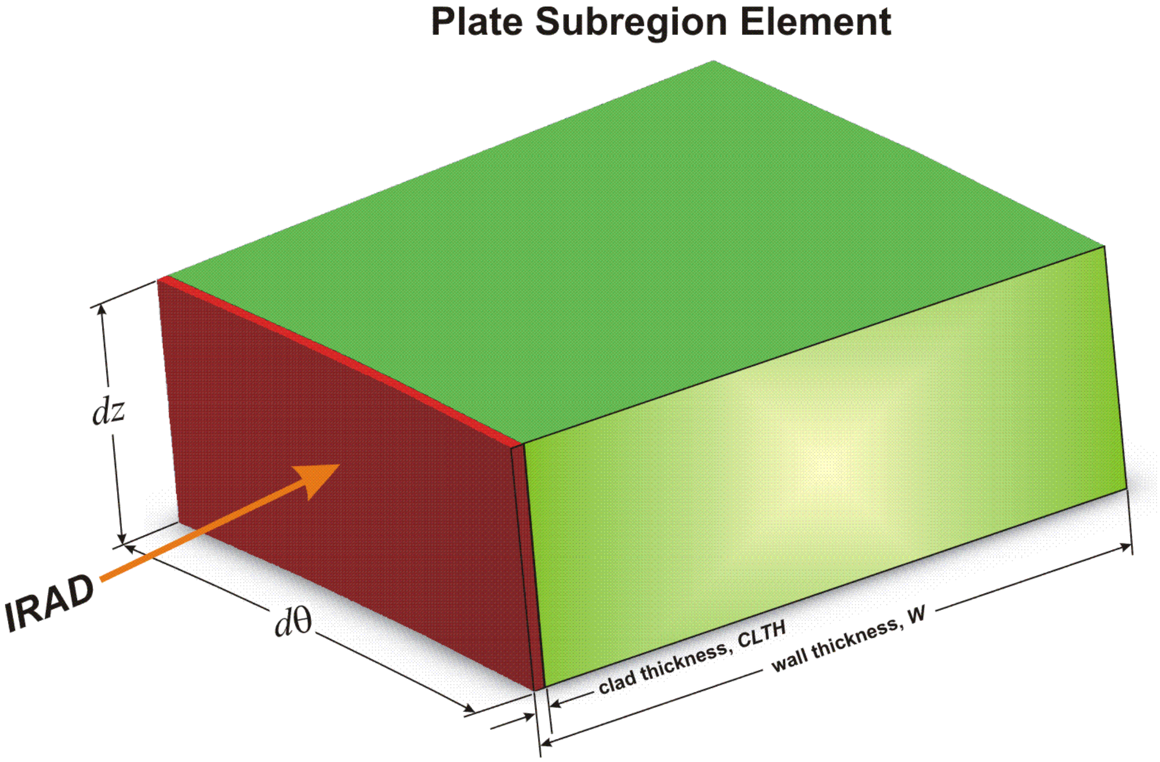


Fig. 17. (continued) (c) Plate subregion element.

EXAMPLE

```
************************************************************************************************************
*                       EMBRITTLEMENT / FLAW DISTRIBUTION MAP RECORDS                                     *
************************************************************************************************************
*==========================================================================================================*
*  Field             DESCRIPTION                                                                   [UNITS] *
*==========================================================================================================*
*----------------------------------------------------------------------------------------------------------*
*  (1) RPV subregion number   -   parent                                                               [-] *
*----------------------------------------------------------------------------------------------------------*
*  (2) adjacent RPV subregion - 1st child                                                              [-] *
*----------------------------------------------------------------------------------------------------------*
*  (3) adjacent RPV subregion - 2nd child                                                              [-] *
*----------------------------------------------------------------------------------------------------------*
*  (4) RPV major region number                                                                         [-] *
*----------------------------------------------------------------------------------------------------------*
*  (5) best estimate neutron fluence at RPV inside surface                           [10^19 neutrons/cm^2] *
*----------------------------------------------------------------------------------------------------------*
*  (6) heat estimate copper content                                                               [wt% Cu] *
*----------------------------------------------------------------------------------------------------------*
*  (7) heat estimate nickel content                                                               [wt% Ni] *
*----------------------------------------------------------------------------------------------------------*
*  (8) heat estimate phosphorus content                                                           [wt%  P] *
*----------------------------------------------------------------------------------------------------------*
*  (8) best estimate phosphorus (P) content                                                       [wt%  P] *
*----------------------------------------------------------------------------------------------------------*
*  (9) best estimate manganese (Mn) content                                                       [wt% Mn] *
*----------------------------------------------------------------------------------------------------------*
*  (10) product form flags for DT30 shift correlation                                                      *
*                                                                                                          *
*      Welds : set distribution for sampling standard                                                      *
*              deviation for Ni content in welds                                                           *
*             = 1 use normal distribution                                                              [-] *
*             = 2 use Weibull distribution                                                             [-] *
*      Plates:                                                                                             *
*          CE = 1 (if IRTNDT=2000 then set B = 206)                                                    [-] *
*      Not CE = 2 (if IRTNDT=2000 then set B = 156)                                                    [-] *
*      where CE is a Combustion Engineering vessel                                                         *
*----------------------------------------------------------------------------------------------------------*
* (11) copper saturation flag = 0 for plates and forgings                                              [-] *
*                             = 1 for Linde 80 and Linde 0091 weld fluxes                                  *
*                             = 2 for all weld fluxes other than L80, L0091, and L1092                     *
*                             = 3 for Linde 1092 weld flux                                                 *
*       N.B.:                                                                                              *
*         for IRTNDT = 2000                                                                                *
*               maximum value of copper content (copper saturation)                                        *
*             = 0.25 for Linde 80 and = 0.305 for all others                                               *
*         for IRTNDT = 2006                                                                                *
*               maximum value of copper content (copper saturation)                                        *
*             = 0.37 for Ni < 0.5 wt%                                                                      *
*             = 0.2435 for 0.5 <= Ni <= 0.75 wt%                                                           *
*             = 0.301 for Ni > 0.75 wt% (all welds with Linde 1092 weld flux)                              *
*                                                                                                          *
*----------------------------------------------------------------------------------------------------------*
* (12) unirradiated best estimate (mean) for RTNDT0                                                    [F] *
*----------------------------------------------------------------------------------------------------------*
* (13) unirradiated standard deviation for RTNDT0                                                      [F] *
*----------------------------------------------------------------------------------------------------------*
* (14) PF flag      Product Form         CF Override                                                       *
*      -------      ------------         ------------                                                      *
*      = 11             weld                 no                                                        [-] *
*      = 12             weld                 yes                                                       [-] *
*      = 21             plate                no                                                        [-] *
*      = 22             plate                yes                                                       [-] *
*      = 31            forging               NA                                                        [-] *
*----------------------------------------------------------------------------------------------------------*
* (15) angle of subregion element                                                                [degrees] *
*----------------------------------------------------------------------------------------------------------*
* (16) axial height of subregion element:                                                        [inches]  *
*----------------------------------------------------------------------------------------------------------*
* (17) weld fusion area:                                                                        [inches^2] *
*----------------------------------------------------------------------------------------------------------*
* (18) weld orientation: 1 ===> axial; 2===> circumferential                                           [-] *
*----------------------------------------------------------------------------------------------------------*
* (19) chemistry factor override                                                                       [-] *
*----------------------------------------------------------------------------------------------------------*
* (20) unirradiated upper shelf CVN engergy                                                       [ft-lbf] *
*==========================================================================================================*
*    Notes:                                                                                                *
*                                                                                                          *
*    1. Fields 1-4  : contain RPV beltline discretization and connectivity data for weld fusion line       *
*    2. Fields 5-20 : contain RPV beltline embrittlement-related data                                      *
*    3. Field   13  : PF means Product Form                                                                *
*    4. Field   13  : CF means chemistry factor override                                                   *
*    5. Field   18  : only applies to weld subregions. For plates set to 0.                                *
*    6. Field   20  : applicable only if IRTNDT=2000 on CNT2 and Field 13 = 12 or 22                       *
*                                                                                                          *
*==========================================================================================================*
*==========================================================================================================*
************************************************************************************************************
```

```
* 1   2    3    4   5     6    7    8     9 10  11  12   13  14   15    16    17    18 19 20
*********************************************************************************************
001 3593 3661   1 .0675 .337 .609 .012 1.44 2   3 -56.   17. 11   1.    1.2  9.45   1  0 98
002 3594 3662   1 .1173 .337 .609 .012 1.44 2   3 -56.   17. 11   1. 1.1996  9.4469 1  0 98
003 3595 3663   1 .1682 .337 .609 .012 1.44 2   3 -56.   17. 11   1. 2.3996 18.8969 1  0 98
004 3596 3664   1 .2317 .337 .609 .012 1.44 2   3 -56.   17. 11   1. 2.2047 17.3622 1  0 98
005 3597 3665   1 .3100 .337 .609 .012 1.44 2   3 -56.   17. 11   1. 2.3996 18.8969 1  0 98
                :
*********************************************************************************************
```

Note that fields 6 through 14 are major-region variables and should be the same for all subregions in a given major region. As FAVPFM reads in the embrittlement/flaw distribution map records, it checks to make sure that the data in fields in 6 throught 14 are the same within each major region. If any differences are found, the code flags the error and stops the execution of FAVPFM.

2.3 FAVOR Post-Processing Module – FAVPost

(2 × **NTRAN)** + 1 data records, listed in Table 3, are required in the FAVPost input file, where each record may involve more than one line of data. A detailed description of each data record is given below.

Table 3. Record Keywords and Parameters for FAVPost Input File

Record	Keyword	Field 1	Field 2	Field 3	
1	**CNTL**	**NTRAN=[-]**			
	Repeat data records 2 through 3 for each of the NTRAN transients				
2	**ITRN**	**ITRAN=[-]**	**NHIST=[-]**	**ISEQ=[-]**	
3	input NHIST data lines with (*initiating frequency*, probability density)				
	data pairs – one pair per line				
	f_{init}	***Density***			
	[events/yr]	**[%]**			

Record 1 – CNTL

Record No. 1 inputs the number of transients, **NTRAN**, for which initiating frequency probability density distributions (histograms) are being input.

Records 2 and 3 are repeated for each of the **NTRAN** transients.

Record 2 – ITRN

Record 2 inputs the FAVOR transient number, **ITRAN**, the number of lines, **NHIST,** in Record 3 which contains the initiating frequency histogram (in terms of relative frequency), and the initiating-sequence event number, **ISEQ**, from the thermal-hydraulic studies that supplied the transient for input to FAVOR.

Record 3 – Initiating Event Sequence Probability Density Functions (Histograms)

Input **NHIST** lines containing one histogram data pair per line, where the first field is the value of the transient initiating frequency in *events per reactor-operating year* and the second field is the probability density (as a relative frequency in percent).

EXAMPLE

```
********************************************************************************
*      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY           *
********************************************************************************
*                EXAMPLE INPUT DATASET FOR FAVPost, v16.1              [UNITS]*
********************************************************************************
*  ====================                                                        *
*     Record CNTL                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  NTRAN = NUMBER OF T-H TRANSIENTS                                        [-] *
*------------------------------------------------------------------------------*
********************************************************************************
CNTL  NTRAN=6
********************************************************************************
*  ====================                                                        *
*     Record ITRN                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  ITRAN = TRANSIENT NUMBER                                                [-] *
*  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION         [-] *
*  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                               [-] *
*------------------------------------------------------------------------------*
********************************************************************************
ITRN ITRAN=1  NHIST=19    ISEQ=3
********************************************************************************
*------------------------------
* freq[events/year] Density [%]
*------------------------------
    0.000005730       0.50
    0.000007380       0.50
    0.000008760       1.50
    0.000010100       2.50
    0.000012300       5.00
    0.000016100      10.00
    0.000017700       5.00
    0.000019400       5.00
    0.000022700      10.00
    0.000026100      10.00
    0.000030000      10.00
    0.000035100      10.00
    0.000038100       5.00
    0.000040800       5.00
    0.000054300      10.00
    0.000068700       5.00
    0.000085300       2.50
    0.000112000       1.50
    0.000124000       1.00
********************************************************************************
*  ====================                                                        *
*     Record ITRN                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  ITRAN = PFM TRANSIENT NUMBER                                            [-] *
*  ITRAN = TRANSIENT NUMBER                                                [-] *
*  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION         [-] *
*  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                               [-] *
*------------------------------------------------------------------------------*
ITRN ITRAN=2  NHIST=19    ISEQ=4
********************************************************************************
*------------------------------
* freq[events/year] Density [%]
```

```
*------------------------------
    0.000000016      0.50
    0.000000020      0.50
    0.000000030      1.50
    0.000000042      2.50
```

2.4 Content and Format for Flaw Distribution Databases

By convention, flaws have been defined as Categories 1, 2, or 3 using the following designations:

(1) *Category 1* – surface breaking flaws

(2) *Category 2* – embedded flaws in which the inner tip of the flaw is located between the clad-base interface and *t*/8 where *t* is the RPV wall thickness

(3) *Category 3* – embedded flaws in which the inner tip of the flaw is located between *t*/8 and 3*t*/8.

When executing the FAVPFM module, the user is prompted for three flaw-characterization files as follows: (1) inner surface-breaking flaws (2) embedded flaws in welds, and (3) embedded flaws in plates or forgings. The flaw-characterization file for inner-surface breaking flaws is applicable to both welds and plates/forgings.

The format is the following:

Each of the flaw-characterization files consists of 1000 file records, where each file record has 100 rows and several columns. The first and second columns in each row are:

Column (1) – the integer row number

Column (2) – the flaw density corresponding to a flaw depth equal to (row number/100) * vessel wall thickness.

For example, the flaw density in the 1st row corresponds to flaw depths of 1/100th of the RPV wall thickness, the flaw density in the 19th row corresponds to flaw depths of (0.19)(wall thickness), etc.

The remaining columns are a probability distribution function (histogram) of aspect ratios (ratio of flaw length to flaw depth); i.e., each flaw depth has its own probability distribution of flaw length as will be discussed in more detail below.

2.4.1 Method of Quantifying Uncertainty in Flaw Characterization

The method used to quantify the uncertainty in the flaw characterization is to include 1000 flaw-characterization file records for each of the three flaw data files (surface-breaking, weld embedded, and plate embedded) discussed above. Each of these file records contains separate flaw-density, flaw-size, and aspect-ratio distributions with the format as discussed above. The format for the three characterization files is discussed in more detail below.

During the Monte Carlo PFM analysis, the RPV flaw-characterization data for the 1st stochastically-generated RPV trial are taken from the 1st group of file records, i.e., the first inner-surface breaking file record, the first embedded-flaw weld material file record, and the first embedded-flaw plate material file record. The RPV flaw characterization for the 2nd stochastically generated RPV trial is determined from the 2nd group of file records, etc. The RPV trials cycle through the flaw-characterization file records sequentially up to 1000, and then restarts at the first file record.

2.4.2 Flaw-Characterization File Names and Sizes

The flaw-characterization file for inner-surface-breaking flaws is 100,000 rows with 5 columns. The name of the example ASCII text file in the distribution package is “S.DAT” with a size of 7.0 MBytes. The flaw-characterization file for embedded flaws in welded regions is 100,000 rows with 13 columns. The name of this ASCII text file on the distribution disk is “W.DAT” with a size of 15.2 MBytes. The flaw-characterization file for embedded flaws in plate regions is 100,000 rows with 13 columns. The name of this ASCII text file on the distribution disk is ”P.DAT”, and its size is 15.2 MBytes. The distribution package also includes flaw-characterization files that are specific to the four plants under study in the PTS Re-evaluation Program, specifically BVsurf.DAT, BVweld.DAT, and BVplate.DAT for Beaver Valley, S_CC.DAT, W_CC.DAT, and P_CC.DAT for Calvert Cliffs, OCsurf.DAT, OCweld.DAT, and OCplate.DAT for Oconee, and PLsurf.DAT, PLweld.DAT, and PLplate.DAT for Palisades.

2.4.3 Surface Breaking Flaws (Flaw Category 1)

A more detailed explanation of the format of the surface breaking flaw data is given by way of example:

```
                              Histogram of
                              Aspect ratio (AR)
                              (%)
                              AR=2  AR=6 AR=10 AR=infinite

1       density of flaw depths 1/100 RPV thickness  35.0  30.0 20.0 15.0
2       density of flaw depths 2/100 RPV thickness  40.0  30.0 25.0  5.0
3       density of flaw depths 3/100 RPV thickness          :
:                                                           :
:                                                           :
:       density of flaw depths = RPV thickness              :
1       density of flaw depths 1/100 RPV thickness          :
2       density of flaw depths 2/100 RPV thickness          :
3       density of flaw depths 3/100 RPV thickness          :
:                                                           :
:                                                           :
100     density of flaw depths = RPV thickness              :
```

```
:                              :
: through the 1000th file      :
:                              :
:                              :
```

As illustrated above, for each flaw depth, there is a histogram for the aspect ratio (flaw depth / length) where the bins are aspect ratios of 2, 6, 10, and infinity. The reason for these specific aspect ratios is that they correspond to the flaw geometries for which stress intensity factor influence coefficients were generated and implemented into the FAVLoad module. The histograms will be sampled during the PFM analysis to stochastically determine the aspect ratio for the corresponding sampled flaw depth.

The FORTRAN subroutine in the FAVPFM module that reads the file containing flaw characterization data for inner-surface breaking flaws is:

```
      SUBROUTINE RDSURF(ISMAX)
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      IMPLICIT REAL*8 (A-H,O-Z)
C***********************************************************************
C***                                                                 ***
C***  Revisions:                                                     ***
C***                                                                 ***
C***  Date        |    Modification                                  ***
C***  ============|==================================================***
C***                                                                 ***
C***                                                                 ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
C   SUBROUTINE RDSURF READS DATA FROM THE FILE THAT CHARACTERIZES      *
C   SURFACE-BREAKING FLAWS (CATEGORY 1 FLAWS) AND IS APPLICABLE TO     *
C   BOTH WELD AND PLATE REGIONS.                                       *
C                                                                      *
C   THE UNITS OF THE CATEGORY 1 SURFACE-BREAKING FLAWS ARE FLAWS PER   *
C   SQUARE FOOT OF AREA ON THE INNER SURFACE OF THE RPV.               *
C                                                                      *
C   THE (I,J) ENTRY READ INTO ARRAY WDEPTH(100,1,IFILE) IS THE FLAW    *
C   DENSITY OF INNER-SURFACE BREAKING FLAWS (CATEGORY 1 FLAWS) THAT    *
C   HAVE A DEPTH OF (i/100)*WALL THICKNESS.                            *
C                                                                      *
C   SINCE THE DATA IS ALSO APPLICABLE TO PLATE MATERIAL, THE SAME DATA *
C   IS READ INTO PDEPTH(100,1,IFILE)                                   *
C***********************************************************************
      INTEGER :: IVER, IERR
C=======================================================================
      COMMON /PROG/WDEPTH (100, 3,1000),WELDCAT(3,1000),PLATCAT(3,1000),
     &             WCATCDF(100, 3,1000),WSUM(3,1000),   PSUM   (3,1000),
     &             WCATPDF(100, 3,1000),PDEPTH  (100, 3,1000),
     &             PCATCDF(100, 3,1000),PCATPDF (100, 3,1000),
     &             WFLASPT(100,12,1000),PFLASPT (100,12,1000),
     &             WASPCDF(100,12,1000),PASPCDF (100,12,1000),
     &             SFLASPT(100, 4,1000),SASPCDF (100, 4,1000)
C======================================================================
      REAL*8, PARAMETER :: ZERO=0.
C======================================================================
      WRITE (*,1004)
      WRITE (*,8769)
1004  FORMAT (' ' )
8769  FORMAT (11X,' READING AND PROCESSING SURFACE-BREAKING',
     &            ' FLAW DATABASE')
C***********************************************************************
C READ THE SURFACE-BREAKING FLAW CHARACTERIZATION FILE. THE FORMAT OF  *
C THIS FILE IS:                                                        *
C                                                                      *
C K, FLAW DENSITY, FOLLOWED BY 4 NUMBERS THAT ARE A  HISTOGRAM OF      *
C ASPECT RATIOS FOR FLAWS OF THIS DEPTH WHERE THE HISTOGRAM IS         *
C EXPRESSED IN PERCENT. A CDF WILL BE CONSTRUCTED FOR EACH OF THE      *
C HISTOGRAMS THAT CAN BE SAMPLED DURING THE PFM ANALYSIS TO            *
```

```
C APPROPRIATELY POSTULATE ASPECT RATIO FOR SURFACE BREAKING            *
C (CATEGORY 1) FLAWS.                                                  *
C                                                                      *
C THE CORRESPONCE BETWEEN THE POSITION (OUT OF THE 4  BINS) AND THE    *
C ASPECT RATIO IS AS FOLLOWS:                                          *
C                                                                      *
C BIN NUMBER         ASPECT            ARRAY                           *
C                    RATIO            LOCATION                         *
C                                                                      *
C     1                2         SFLASPT(J,1,IFILE)                    *
C     2                6         SFLASPT(J,2,IFILE)                    *
C     3               10         SFLASPT(J,3,IFILE)                    *
C     4            INFINITE      SFLASPT(J,4,IFILE)                    *
C                                                                      *
C J VARIES FROM 1==>100 TO COVER THE ENTIRE RANGE OF POSSIBLE FLAW     *
C DEPTHS                                                               *
C                                                                      *
C IFILE VARIES FROM 1==> 1000 TO COVER THE ENTIRE RANGE OF WELD        *
C SURFACE BREAKING FLAW CHARACTERIZATION FILES USED TO INCLUDE THE     *
C QUANTIFICATION OF UNCERTAINTY.                                       *
C***********************************************************************
      READ (48,*) IVER
      if (IVER .NE. 161) then
         call xermsg ('FAVPFM','RDSURF',
     &      'SURFACE-BREAKING FLAW FILE NOT VERSION 15.1',17,1)
         call xerdmp
         call xerabt('xerror -- invalid input',23)
      endif
      ISMAX = 0
      DO 10 IFILE=1,1000
         DO 20 J=1,100
            READ (48,*,IOSTAT=IERR) K,WDEPTH(J,1,IFILE),
     &                  SFLASPT(J,1,IFILE),SFLASPT(J,2,IFILE),
     &                  SFLASPT(J,3,IFILE),SFLASPT(J,4,IFILE)
            IF (IERR .NE. 0) GOTO 998
            PDEPTH(J,1,IFILE) = WDEPTH(J,1,IFILE)
            IF (WDEPTH(J,1,IFILE) .GT. ZERO) THEN
               IF (J.GT.ISMAX) ISMAX = J
            ENDIF
20       CONTINUE
10    CONTINUE
      GOTO 999
C=======================================================================
998   CONTINUE
      write(*,1000) IFILE, J, IFILE*J, IERR
1000  FORMAT(/'IFILE=',I4,' K=',I4,' LINE NUMBER=',I5,' IERR=',I4/)
      call xermsg ('FAVPFM','RDSURF',
     &      'ERROR READING SURFACE-BREAKING FLAW DATA',18,1)
      call xerdmp
      call xerabt('xerror -- invalid input',23)
C=======================================================================
999   CONTINUE
C
      RETURN
      END
```

where **WDEPTH** (1:100, 1:3, 1:1000) is an array in FAVPFM in which the (*J*,1,*IFILE*) address contains flaw densities of Category 1 (surface breaking flaws) for welds and PDEPTH (1:100,1:3,1:1000) is a three-dimensional array in which the (*J*,1,*IFILE*) address contains flaw densities of Category 1 (surface breaking flaws) for plates/forgings.

SFLASPT (1:100,1:4,1:1000) is an array in FAVPFM in which the (*J*,1,*IFILE*) address contains the percentage of flaws with an aspect ratio of 2, the (*J*,2,*IFILE*) address contains the percentage of flaws with an aspect ratio of 6, the (*J*,3,*IFILE*) address contains the percentage of flaws with an aspect ratio of 10, and the (*J*,4,*IFILE*) address contains the percentage of flaws with an aspect ratio of infinity.

Inner-surface breaking flaws with a depth less than the clad thickness are not considered as candidates for cleavage initiation since the austenitic stainless steel cladding plane-strain cleavage fracture toughness is considerably more ductile than the ferritic base metal. Also, all inner-surface breaking flaws are assumed to be circumferentially oriented (even if the flaw is located in an axially oriented weld or plate) since all inner-surface breaking flaws are assumed to be a result of the process in which the cladding was applied.

2.4.4 Embedded flaw Characterization for Welds (Categories 2 and 3 flaws)

As with Category 1 surface breaking flaws, the first and second columns in each row are (1) the integer row number and (2) the flaw density corresponding to a flaw depth equal to (row number/100) * vessel wall thickness, and the remaining columns are a probability distribution function (histogram) of aspect ratios (ratio of flaw length to flaw depth). Again, a more detailed explanation of the format of the inner-surface breaking flaw data is given by way of example as follows:

```
                                                                     Histogram of
                                                                   Aspect ratio (AR)
                                                                        (11 bins)
                                                                            (%)

1      density of flaw depths t/100
2      density of flaw depths 2t/100 RPV thickness
3      density of flaw depths 3t/100 RPV thickness                 :
:                                                                  :
:                                                                  :
density of flaw depths = RPV thickness                             :
1      density of flaw depths t/100 RPV thickness                  :
2      density of flaw depths 2t/100 RPV thickness                 :
density of flaw depths 3t/100 RPV thickness
:
density of flaw depths = RPV thickness
:
:
: through 1000th file
:
```

The FORTRAN subroutine in the FAVPFM module that reads the file containing flaw characterization data for embedded flaws in welds is as follows:

```
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      SUBROUTINE RDWELD(IWMAX)
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      IMPLICIT REAL*8 (A-H,O-Z)
C***********************************************************************
C***                                                                 ***
C***  Revisions:                                                     ***
C***                                                                 ***
C***  Date        |    Modification                                  ***
C***  ============|==================================================***
C***                                                                 ***
C***                                                                 ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
C   SUBROUTINE RDWELD READS DATA FROM THE FILE THAT CHARACTERIZES      *
C   EMBEDDED FLAWS POSTULATED TO RESIDE IN WELD REGIONS.               *
C                                                                      *
C   THIS SUBROUTINE READS THE FLAW CHARACTERIZATION FLAW DATA FOR      *
C   EMBEDDED FLAWS IN WELD MATERIAL INTO ARRAYS THAT WILL BE SAMPLED   *
C   DURING THE PFM ANALYSIS TO STOCHASTICALLY POSTULATE FLAWS          *
C   IN THE RPV A MANNER CONSISTENT WITH THE FLAW CHARACTERIZATION.     *
```

```
C                                                                      *
C   THE (I,J) ENTRY READ INTO ARRAY WDEPTH(100,1,IFILE) IS THE FLAW    *
C   DENSITY OF INNER-SURFACE BREAKING FLAWS (CATEGORY 1 FLAWS) THAT    *
C   HAVE A DEPTH OF (i/100)*WALL THICKNESS. THIS READ IS PERFORMED IN  *
C   SUBROUTINE RDSURF. THE UNITS OF THIS FLAW DENSITY ARE FLAWS PER    *
C   SQUARE FOOT OF AREA ON THE INNER SURFACE OF THE RPV.               *
C                                                                      *
C   THE (I,J) ENTRY READ INTO ARRAY WDEPTH(100,2,IFILE) IS THE FLAW    *
C   DENSITY OF CATEGORY 2 EMBEDDED FLAWS (EMBEDDED FLAWS SUCH THAT     *
C   THE INNER FLAW TIP RESIDES IN THE FIRST 1/8 OF THE WALL THICKNESS) *
C   THAT HAVE A THROUGH-WALL DEPTH OF (i/100)*WALL THICKNESS. THE      *
C   UNITS OF THIS FLAW DENSITY ARE FLAWS PER SQUARE FOOT OF WELD       *
C   FUSION LINE AREA (ON ONE SIDE OF THE WELD).                        *
C                                                                      *
C   THE (I,J) ENTRY READ INTO ARRAY WDEPTH(100,3,IFILE) IS THE FLAW    *
C   DENSITY OF CATEGORY 3 EMBEDDED FLAWS (EMBEDDED FLAWS SUCH THAT     *
C   THE INNER FLAW TIP RESIDES IN BETWEEN 1/8 T AND 3/8 T) THAT HAVE   *
C   A THROUGH-WALL DEPTH OF (i/100)*WALL THICKNESS. THE UNITS OF THIS  *
C   FLAW DENSITY ARE FLAWS PER SQUARE FOOT OF WELD FUSION LINE AREA    *
C   (ON ONE SIDE OF THE WELD).                                         *
C                                                                      *
C   THE EMDEDDED FLAW DENSITY FOR WELD MATERIAL IS ASSUMED TO BE       *
C   UNIFORM THROUGH THE WALL THICKNESS; THEREFORE THE DENSITY FOR      *
C   CATEGORY 3 EMBEDDED FLAWS WOULD BE IDENTICAL TO THE DENSITY FOR    *
C   CATEGORY 2 EMBEDDED FLAWS.                                         *
C                                                                      *
C   THE METHOD TO INCLUDE THE UNCERTAINTY IN THE WELD FLAW             *
C   CHARACTERIZATION IS TO INCLUDE MULTIPLE (1000) FILES, EACH WITH    *
C   THE FORMAT DESCRIBED ABOVE, EACH WITH DIFFERENT DENSITIES, SIZE    *
C   AND ASPECT DISTRIBUTIONS, AND FLAW SIZE TRUNCATIONS.               *
C***********************************************************************
      COMMON /PROG/WDEPTH (100, 3,1000),WELDCAT(3,1000),PLATCAT(3,1000),
     &             WCATCDF(100, 3,1000),   WSUM(3,1000),   PSUM(3,1000),
     &             WCATPDF(100, 3,1000), PDEPTH (100, 3,1000),
     &             PCATCDF(100, 3,1000), PCATPDF(100, 3,1000),
     &             WFLASPT(100,12,1000), PFLASPT(100,12,1000),
     &             WASPCDF(100,12,1000), PASPCDF(100,12,1000),
     &             SFLASPT(100, 4,1000), SASPCDF(100, 4,1000)
C======================================================================
      DIMENSION NDIV(1000)
C***********************************************************************
      INTEGER           :: IVER, IERR, IFILE, J, IWMAX
C***********************************************************************
      REAL*8, PARAMETER :: ZERO=0.
C***********************************************************************
      WRITE (*,8769)
8769  FORMAT (12X,' READING AND PROCESSING WELD',
     &            '  EMBEDDED-FLAW DATABASE')
C***********************************************************************
C READ THE WELD FLAW CHARACTERIZATION FILE, THE FORMAT OF THIS FILE IS:*
C                                                                      *
C K, FLAW DENSITY, FOLLOWED BY 11 NUMBERS THAT ARE ASPECT RATIOS       *
C THE 11 NUMBERS ARE A HISTOGRAM OF ASPECT RATIO FOR FLAWS OF THIS     *
C DEPTH                                                                *
C                                                                      *
C WHERE:                                                               *
C                                                                      *
C FLAW DENSITY IS EXPRESSED IN FLAWS PER CUBIC FOOT OF RPV MATERIAL    *
C                                                                      *
C THE HISTOGRAM IS EXPRESSED IN PERCENT. A CDF WILL BE CONSTRUCTED     *
C FOR EACH OF THE HISTOGRAMS THAT CAN BE SAMPLED TO DETERMINE ASPECT   *
C RATIO.                                                               *
C                                                                      *
C THE CORRESPONCE BETWEEN THE POSITION (OUT OF THE 11 BINS) AND THE    *
C ASPECT RATIO (l/2a) IS AS FOLLOWS:                                   *
C                                                                      *
C BIN NUMBER         RANGE OF       ARRAY                              *
C                  ASPECT RATIO   LOCATION                             *
C                                                                      *
C     1            1.00 - 1.25   WFLASPT(J,1,IFILE)                    *
C     2            1.25 - 1.50   WFLASPT(J,2,IFILE)                    *
C     3            1.50 - 2.00   WFLASPT(J,3,IFILE)                    *
C     4            2.00 - 3.00   WFLASPT(J,4,IFILE)                    *
C     5            3.00 - 4.00   WFLASPT(J,5,IFILE)                    *
C     6            4.00 - 5.00   WFLASPT(J,6,IFILE)                    *
C     7            5.00 - 6.00   WFLASPT(J,7,IFILE)                    *
C     8            6.00 - 8.00   WFLASPT(J,8,IFILE)                    *
C     9            8.00 - 10.0   WFLASPT(J,9,IFILE)                    *
C    10            10.0 - 15.0   WFLASPT(J,10,IFILE)                   *
C    11               > 15.0     WFLASPT(J,11,IFILE)                   *
C                                                                      *
```

```
C    J VARIES FROM 1==>100 TO COVER THE ENTIRE RANGE OF POSSIBLE       *
C    FLAW DEPTHS                                                        *
C                                                                       *
C    IFILE VARIES FROM 1==> 1000 TO COVER THE ENTIRE RANGE OF WELD     *
C    FLAW CHARACTERIZATION FILES USED TO INCLUDE THE QUANTIFICATION    *
C    OF UNCERTAINTY.                                                    *
C***********************************************************************
      READ (49,*) IVER
      if ( IVER .NE. 161 ) then
         call xermsg ('FAVPFM','RDWELD',
     &      'EMBEDDED-FLAW WELD FILE NOT VERSION 15.1',19,1)
         call xerdmp
         call xerabt('xerror -- invalid input',23)
      endif
      IWMAX = 0
      DO 210 IFILE=1,1000
         DO 220 J=1,100
            READ (49,*,IOSTAT=IERR) K,
     &      WDEPTH (J, 2,IFILE),WFLASPT(J, 1,IFILE),
     &      WFLASPT(J, 2,IFILE),WFLASPT(J, 3,IFILE),
     &      WFLASPT(J, 4,IFILE),WFLASPT(J, 5,IFILE),
     &      WFLASPT(J, 6,IFILE),WFLASPT(J, 7,IFILE),
     &      WFLASPT(J, 8,IFILE),WFLASPT(J, 9,IFILE),
     &      WFLASPT(J,10,IFILE),WFLASPT(J,11,IFILE)
            IF (IERR .NE. 0) GOTO 998
            WDEPTH(J,3,IFILE) = WDEPTH(J,2,IFILE)
            IF (WDEPTH (J,2,IFILE) .GT. ZERO) THEN
               IF (J.GT.IWMAX) IWMAX = J
            ENDIF
220      CONTINUE
210   CONTINUE
      GOTO 999
998   CONTINUE
      write(*,1000) IFILE, J, IFILE*J, IERR
      call xermsg ('FAVPFM','RDWELD',
     &      'ERROR READING WELD EMB. FLAW DATA',20,1)
      call xerdmp
      call xerabt('xerror -- invalid input',23)
C
999   CONTINUE
      RETURN
1000  FORMAT(/'IFILE=',I4,' K=',I4,' LINE NUMBER=',I5,' IERR=',I4/)
      END
```

where **WDEPTH** (1:100,1:3,1:1000) is an array in FAVPFM in which the (*J*,2,*IFILE*) and the (*J*,3,*IFILE*) addresses contain flaw densities for Category 2 and Category 3 flaws, respectively, for welds.

WFLASPT(1:100,1:11,1:1000) is an array in FAVPFM in which the (*J*,1,*IFILE*) address contains the percentage of flaws with an aspect ratio between 1.00 and 1.25, and the (*J*,2,*IFILE*) address contains the percentage of flaws with an aspect ratio between 1.25 and 1.50. The range of aspect ratios corresponding to each of the 11 bins used to develop the histogram that will be sampled for each flaw depth is given in the following table.

Bin Number	Range of flaw aspect ratio
1	1.00 – 1.25
2	1.25 - 1.50
3	1.50 – 2.00
4	2.00 – 3.00
5	3.00 – 4.00

6	4.00 – 5.00
7	5.00 – 6.00
8	6.00 – 8.00
9	8.00 – 10.0
10	10.0 – 15.0
11	> 15

2.4.5 Embedded-Flaw Characterization for Plates

The data format for embedded flaws in plates/forgings is identical to that described above for embedded flaws in welds. The following subroutine reads in the characterization file for embedded flaws in plates.

```
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      SUBROUTINE RDPLAT(THICK,IPMAX,RO,RI)
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      IMPLICIT REAL*8 (A-H,O-Z)
C***********************************************************************
C***                                                                 ***
C***  Revisions:                                                     ***
C***                                                                 ***
C***  Date        |    Modification                                  ***
C***  ============|==================================================***
C***                                                                 ***
C***                                                                 ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
C   DEFINITION OF ARRAYS:                                              *
C                                                                      *
C   PDEPTH(100,3,1000) - HOLDS DATA AS READ FROM EXTERNAL FILE        *
C                        CONTAINING FLAW DATA FOR PLATE
C                                                                      *
C   PLATCAT(3,1000) -CDF FROM WHICH FLAW CATEGORY IS SAMPLED FOR FLAW  *
C                   LOCATED IN PLATE MATERIAL                          *
C                                                                      *
C   PCATPDF(100,3)  HISTOGRAM EXPRESSING RELATIVE FREQUENCY OF PLATE   *
C                   FLAW DENSITIES FOR EACH FLAW CATEGORY              *
C                                                                      *
C   PCATCDF(100,3)  CDF FOR EACH OF THE 3 FLAW CATEGORIES FOR PLATE    *
C                   EACH COLUMN IS OBTAINED BY INTEGRATING PCATPDF     *
C***********************************************************************
      COMMON /PROG/WDEPTH (100, 3,1000),WELDCAT(3,1000),PLATCAT(3,1000),
     &             WCATCDF(100, 3,1000),   WSUM(3,1000),   PSUM(3,1000),
     &             WCATPDF(100, 3,1000), PDEPTH (100, 3,1000),
     &             PCATCDF(100, 3,1000), PCATPDF(100, 3,1000),
     &             WFLASPT(100,12,1000), PFLASPT(100,12,1000),
     &             WASPCDF(100,12,1000), PASPCDF(100,12,1000),
     &             SFLASPT(100, 4,1000), SASPCDF(100, 4,1000)
C***********************************************************************
      INTEGER           :: IVER, IERR
C***********************************************************************
      REAL*8, PARAMETER :: ZERO=0.
C***********************************************************************
      WRITE (*,9835)
9835  FORMAT (12X,' READING AND PROCESSING PLATE EMBEDDED-FLAW',
     &            ' DATABASE')
C***********************************************************************
C            READ THE PLATE FLAW CHARACTERIZATION FILE                 *
C***********************************************************************
C***********************************************************************
C  THE DATA PROVIDED BY PNL ASSUME THAT THE DENSITY OF PLATE EMBEDDED  *
C  FLAWS ARE UNIFORM THROUGH THE WALL; THEREFORE, THE FLAW DENSITY     *
C  FOR CATEGORY 3 FLAWS IS IDENTICAL TO THAT FOR CATEGORY 2 FLAWS.     *
C***********************************************************************
      READ (39,*) IVER
      if ( IVER .NE. 161 ) then
         call xermsg ('FAVPFM','RDPLAT',
     &      'EMBEDDED-FLAW PLATE FILE NOT VERSION 15.1',21,1)
         call xerdmp
         call xerabt('xerror -- invalid input',23)
      endif
```

```
      IPMAX = 0
      DO 110 IFILE=1,1000
         DO 120 J=1,100
            READ (39,*,IOSTAT=IERR) K,
     &      PDEPTH (J, 2,IFILE),PFLASPT(J, 1,IFILE),
     &      PFLASPT(J, 2,IFILE),PFLASPT(J, 3,IFILE),
     &      PFLASPT(J, 4,IFILE),PFLASPT(J, 5,IFILE),
     &      PFLASPT(J, 6,IFILE),PFLASPT(J, 7,IFILE),
     &      PFLASPT(J, 8,IFILE),PFLASPT(J, 9,IFILE),
     &      PFLASPT(J,10,IFILE),PFLASPT(J,11,IFILE)
            PDEPTH(J,3,IFILE) = PDEPTH(J,2,IFILE)
            IF (IERR .NE. 0) GOTO 998
            IF (PDEPTH (J,2,IFILE) .GT. ZERO ) THEN
               IF  (J.GT.IPMAX) IPMAX=J
            ENDIF
120      CONTINUE
110   CONTINUE
      GOTO 999
998   CONTINUE
      write(*,1000) IFILE, J, IFILE*J, IERR
1000  FORMAT(/'IFILE=',I4,' K=',I4,' LINE NUMBER=',I5,' IERR=',I4/)
      call xermsg ('FAVPFM','RDPLAT',
     &       'ERROR READING PLATE EMB. FLAW DATA',22,1)
      call xerdmp
      call xerabt('xerror -- invalid input',23)
999   CONTINUE
C***********************************************************************
C  DETERMINE THE TOTAL FLAW DENSITY FOR EACH OF THE 3 FLAW CATEGORIES: *
C                                                                      *
C  PSUM(1,IFILE) = TOTAL FLAW DENSITY FOR CATEGORY 1 FLAWS IN PLATES   *
C  PSUM(2,IFILE) = TOTAL FLAW DENSITY FOR CATEGORY 2 FLAWS IN PLATES   *
C  PSUM(3,IFILE) = TOTAL FLAW DENSITY FOR CATEGORY 3 FLAWS IN PLATES   *
C***********************************************************************
      DO 15 IFILE=1,1000
         DO 20 J=1,100
            PSUM(1,IFILE) = PSUM(1,IFILE) + PDEPTH(J,1,IFILE)
            PSUM(2,IFILE) = PSUM(2,IFILE) + PDEPTH(J,2,IFILE)
            PSUM(3,IFILE) = PSUM(3,IFILE) + PDEPTH(J,3,IFILE)
20       CONTINUE
15    CONTINUE
C***********************************************************************
C   GENERATE PROBABILITY DISTRIBUTION FUNCTION (PCATCDF), IN THIS CASE *
C   A RELATIVE FREQUENCY HISTOGRAM OF PLATE FLAW DENSITIES FOR EACH    *
C   OF THE 3 FLAW CATEGORIES.                                          *
C                                                                      *
C   COLUMN 1 OF ARRAY PCATPDF IS A RELATIVE FREQ HIST FOR CAT 1 FLAWS  *
C   COLUMN 2 OF ARRAY PCATPDF IS A RELATIVE FREQ HIST FOR CAT 2 FLAWS  *
C   COLUMN 3 OF ARRAY PCATPDF IS A RELATIVE FREQ HIST FOR CAT 3 FLAWS  *
C***********************************************************************
      DO 80 K=1,3
         DO 91 IFILE=1,1000
            DO 90 J=1,100
               IF (PSUM(K,IFILE).NE.ZERO) THEN
                  PCATPDF(J,K,IFILE) = PDEPTH(J,K,IFILE)/PSUM(K,IFILE)
               ENDIF
90          CONTINUE
91       CONTINUE
C***********************************************************************
C   GENERATE CUMULATIVE DISTRIBUTION FUNCTION (PCATCDF)FOR EACH OF     *
C   THE 3 FLAW CATEGORIES BY INTEGRATING THE PROBABILITY DISTRIBUTION  *
C   FUNCTION (PCATPDF).EACH OF THESE CDFs CAN BE SAMPLED TO DETERMINE  *
C   THE FLAW SIZE OF A FLAW IN ITS RESPECTIVE CATEGORY                 *
C                                                                      *
C   COLUMN 1 OF ARRAY PCATCDF CONTAINS THE CDF FOR CATEGORY 1 FLAWS    *
C   COLUMN 2 OF ARRAY PCATCDF CONTAINS THE CDF FOR CATEGORY 2 FLAWS    *
C   COLUMN 3 OF ARRAY PCATCDF CONTAINS THE CDF FOR CATEGORY 3 FLAWS    *
C***********************************************************************
         DO 95 IFILE=1,1000
            PCATCDF(1,K,IFILE)   = PCATPDF(1,K,IFILE)
            DO 97 J=2,100
               PCATCDF(J,K,IFILE) = PCATCDF(J-1,K,IFILE) +
     &                              PCATPDF(J,K,IFILE)
97          CONTINUE
95       CONTINUE
80    CONTINUE
      RETURN
      END
```

2.4.6 Total Number of Flaws

Surface breaking flaw density data are expressed in flaws per unit RPV-surface area and weld subregion embedded flaws are flaws per unit area on the fusion line between the weld and adjacent plate subregions. These conventions are consistent with the physical model utilized by Pacific Northwest National Laboratory to derive the flaw characterization data input to FAVOR. Embedded flaws in plate regions are expressed on a volumetric basis.

Figure 17a and 17b illustrate axial and circumferential weld subregion elements, respectively. The number of flaws in each of these weld elements is calculated (internally by FAVOR) as the sum of the number of inner- surface breaking flaws and the number of embedded flaws as follows:

$$\begin{pmatrix}\text{Number of Flaws}\\ \text{in Weld Subregions}\end{pmatrix} = \rho_{SB}\left[\alpha\left(\frac{2\pi}{360}\right)R_i\ dz\ d\theta\right] + \rho_{EW}\left[2\beta dA\right] \tag{7}$$

$\alpha =$ 1 when surface-breaking flaws are located on either inner or external vessel surface only

$\alpha =$ 2 when surface-breaking flaws are located on both inner and external vessel surfaces

$\beta =$ 3/8 when embedded flaws with inner crack tip residing in either the inner or outer 3/8 of base metal thickness are included in PFM analysis

$\beta =$ 1 when all through-wall embedded flaws are included in PFM analysis

$\rho_{SB} =$ inner surface-breaking flaw density (per unit surface area - flaws/in^2)

$\rho_{EW} =$ weld embedded-flaw density (per unit weld-fusion area - flaws/in^2)

$dA =$ user-input weld-fusion area (for one side of weld) (in^2 - input by user)

$R_i =$ internal radius of RPV (in. - input by user)

$dz =$ height of subregion element (in. - input by user)

$d\theta =$ subtended angle of subregion element (degrees - input by user)

where ρ_{SB} and ρ_{EW} are summed over all flaw depths.

For axial welds, the fusion lines are on the sides of the weld, whereas for circumferential welds, the fusion lines are on the top and bottom of the welds. In the term $\left[2\beta dA\right]$, the factor of 2 accounts for the fact that the user input data is the area on one side of the fusion line whereas flaws reside in fusion lines on both sides of the welds. The β variable depends on the user-specified option regarding which flaw population is to be included in the analysis. All embedded flaw densities are assumed to be uniform through the RPV wall thickness.

Figure 17c illustrates a plate subregion element. The number of flaws in each of these plate elements is calculated (internally by FAVOR) as the sum of the number of surface-breaking flaws and the number of embedded flaws as follows:

$$\begin{pmatrix}\text{Number of Flaws}\\ \text{in Plate Subregions}\end{pmatrix} = \rho_{SB}\left[\alpha\left(\frac{2\pi}{360}\right)R_i\ dz\ d\theta\right] + \rho_{EP}\left[\beta\pi\left(R_o^2 - \left(R_i + CLTH\right)^2\right)dz\left(\frac{d\theta}{360}\right)\right]$$

$\alpha =$ 1 when surface-breaking flaws are located on either inner or external vessel surface only (user-specified option)
$\alpha =$ 2 when surface-breaking flaws are located on both inner and external vessel surfaces (user-specified option)
$\beta =$ 3/8 when embedded flaws with inner crack tip residing in either the inner or outer 3/8 of base metal thickness are included in PFM analysis
$\beta =$ 1 when all through-wall embedded flaws are included in PFM analysis
$\rho_{SB} =$ inner surface-breaking flaw density (per unit surface area - flaws/in^2) **(8)**
$\rho_{EP} =$ plate embedded-flaw density summed over all flaw depths (flaws per unit volume - flaws/in^3)
$R_o =$ external radius of RPV (in - input by user)
$R_i =$ internal radius of RPV (in. - input by user)
$CLTH =$ cladding thickness (in. - input by user)
$dz =$ height of subregion element (in. - input by user)
$d\theta =$ subtended angle of subregion element (degrees - input by user)

where ρ_{SB} and ρ_{EP} are summed over all flaw depths.

2.5 FAVOR Load Module – FAVLoad Output

FAVLoad creates two output files – (1) the load definition file (user-defined filename at time of execution) that will be input to FAVPFM (*.out) and (2) *.echo which provides a date and time stamp of the execution and an echo of the FAVLoad input file. The following page gives a partial listing of a typical FAVLoad *.echo file. The name of the FAVLoad *.echo is constructed from the root of the FAVLoad output file with .echo extension added, e.g., FAVLoad.out ⇒FAVLoad.echo.

FAVLoad.echo

```
               *************************************************
               *                                               *
               *                WELCOME TO FAVOR               *
               *                                               *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE     *
               *                 VERSION 16.1                  *
               *                                               *
               *         FAVLOAD MODULE: LOAD GENERATOR        *
               *     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.                                 *
          *                                                         *
          ***********************************************************


 FAVLOAD INPUT  DATASET NAME   = favload2.in
 FAVLOAD OUTPUT DATASET NAME   = favload2.out
 FAVLOAD ECHO INPUT FILE NAME  = favload2.echo


         **************************************************
         *           ECHO OF FAVLOAD INPUT FILE           *
         **************************************************


********************************************************************************
*                            Example Heat-up transients                        *
* Note: These transients are not to be taken as actual postulated transients   *
*       but are constructed for purely illustrative purposes such that         *
*       several flaws are initiated thus illustrating (and verifying) the      *
*       PFM output reports.                                                    *
********************************************************************************
*  ====================                                                        *
*     Record GEOM                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  IRAD = INTERNAL RADIUS OF PRESSURE VESSEL                              [IN] *
*   W   = THICKNESS OF PRESSURE VESSEL WALL (INCLUDING CLADDING)          [IN] *
*  CLTH = CLADDING THICKNESS                                              [IN] *
*------------------------------------------------------------------------------*
********************************************************************************
GEOM  IRAD=86.0   W=8.75    CLTH=0.25
********************************************************************************
*  ==========================                                                  *
*     Records BASE and CLAD                                                    *
*  ==========================                                                  *
*    THERMO-ELASTIC MATERIAL PROPERTIES FOR BASE AND CLADDING                  *
*------------------------------------------------------------------------------*
*     K      = THERMAL CONDUCTIVITY                              [BTU/HR-FT-F] *
*     C      = SPECIFIC HEAT                                       [BTU/LBM-F] *
*     RHO    = DENSITY                                             [LBM/FT**3] *
*     E      = YOUNG'S ELASTIC MODULUS                                  [KSI]  *
*     ALPHA  = THERMAL EXPANSION COEFFICIENT                          [F**-1]  *
*     NU     = POISSON'S RATIO                                          [-]    *
*     NTE    = TEMPERATURE DEPENDANCY FLAG                                     *
*     NTE    = 0 ==> PROPERTIES ARE TEMPERATURE INDEPENDENT (CONSTANT)         *
*     NTE    = 1 ==> PROPERTIES ARE TEMPERATURE DEPENDENT                      *
*     IF NTE EQUAL TO 1, THEN ADDITIONAL DATA RECORDS ARE REQUIRED             *
*------------------------------------------------------------------------------*
********************************************************************************
BASE  K=24.0  C=0.120  RHO=489.00  E=28000  ALPHA=.00000777  NU=0.3  NTE=1
********************************************************************************
*----------------------------
* THERMAL CONDUCTIVITY TABLE
*----------------------------
```

2.6 FAVOR PFM Module – FAVPFM Output

FAVPFM produces the following files:

General Output Files

(1) Filename defined by user at execution (e.g., FAVPFM.OUT)

(2) Echo of input file with filename defined by user at execution (e.g., FAVPFM.echo)

(3) Binary restart file – restart.bin

Input files for FAVPost

(4) FAILURE.DAT

(5) INITIATE.DAT

QA Verification Files

(6) ARREST.OUT

(7) FLAWNO.OUT

(8) FLAWSIZE.OUT

(9) TRACE.OUT

(10) FLAW_TRACK.LOG

(11) History_**itran**_**iseq**.out (NTRAN files where **itran** is the FAVOR transient number and **iseq** is its associated and unique thermal-hydraulic initiating-event sequence number)

The following pages present partial listings of example files: (1) FAVPFM.OUT, (2) FAVPFM.echo, (6) ARREST.OUT, (7) FLAWNO.OUT, (8) FLAWSIZE.OUT, (9) TRACE.OUT, (10) FLAW_TRACK.LOG, and (11) History_**itran**_**iseq**.out.

FAVPFM.echo includes two sections:

(1) Echo of all input data from FAVPFM.IN file.
(2) Summary of structure of Major Regions and Subregions

FAVPFM.out includes results for all transients in this case definition including:

Mean value of conditional probability of initiation (CPI)
Mean value of conditional probability of failure (CPF)
Mean value of RT_{NDT} at crack tip
Flaw distribution report by material and category
Weld Flaw-Size Distribution Report
Plate Flaw-Size Distribution Report
Transient Time Distribution Report
Multiple Flaw Statistics

FAVPFM.echo

```
               ************************************************
               *                                              *
               *               WELCOME TO FAVOR               *
               *                                              *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
               *                VERSION 16.1                  *
               *                                              *
               *     FAVPFM MODULE: PERFORMS PROBABILISTIC    *
               *          FRACTURE MECHANICS ANALYSES         *
               *                                              *
               *    PROBLEMS OR QUESTIONS REGARDING FAVOR     *
               *            SHOULD BE DIRECTED TO             *
               *                                              *
               *                TERRY DICKSON                 *
               *         OAK RIDGE NATIONAL LABORATORY        *
               *                                              *
               *           e-mail: dicksontl@ornl.gov         *
               *                                              *
               ************************************************

          ***********************************************************
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          * 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.                                 *
          *                                                         *
          ***********************************************************




               FAVPFM INPUT FILE NAME       = favpfm2.in
               FAVLOAD OUTPUT FILE NAME     = favload2.out
               FAVPFM OUTPUT FILE NAME      = favpfm2.out
               FAVPFM INPUT ECHO FILE NAME  = favpfm2.echo



 no./col.
1.......10........20........30........40........50........60........70........80........90.......100.......110.......120.....
..130
     1    ***********************************************************************************************************
     2    *                    ALL RECORDS WITH AN ASTERISK(*) IN COLUMN 1 ARE COMMENT ONLY                           *
     3    ***********************************************************************************************************
     4    *    EXAMPLE INPUT DATASET FOR FAVPFM, v16.1 - Small EMBRITTLEMENT MAP subjected to multiple heat-up      *
     5    *    transients                                                                                           *
     6    ***********************************************************************************************************
     7    *  ====================                                                                                   *
     8    *  Control Record CNT1                                                                                    *
     9    *  ====================                                                                                   *
    10    *-------------------------------------------------------------------------------------------------------*
    11    *  NSIM           = NUMBER OF RPV SIMULATIONS                                                             *
    12    *-------------------------------------------------------------------------------------------------------*
    13    *  IPFLAW         = FLAW POPULATION MODEL                                                                 *
    14    *                                                                                                         *
    15    *  IPFLAW         = 1 Identical to previous version of FAVOR - primarily for cooldown transients.           *
    16    *                                                                                                         *
    17    *                     All Surface flaws (in surface flaw characterizatiuon file) will be inner surface    *
    18    *                     breaking flaws. Only those embedded flaws (in weld and plate flaw characterization *
    19    *                     files) in the inner 3/8 of the RPV wall thickness would be included in the model.  *
    20    *                                                                                                         *
    21    * IPFLAW         = 2  Similar to previous version of FAVOR-HT - primarily for heat-up transients.         *
    22    *                                                                                                         *
    23    *                     All surface breaking flaws (in surface flaw characterization file) would be         *
    24    *                     external surface breaking flaws. Only those embedded flaws in the outer 3/8 of the *
    25    *                     RPV wall thickness would be included in the model.                                  *
    26    *                                                                                                         *
    27    *                     It should be noted that the 09.1 version is not able to propagate external flaws    *
    28    *                     surface-breaking flaws through-the-thickness toward the inner surface to determine *
    29    *                     if they cause failure; therefore, for IPFLAW=2, this version of FAVOR is only       *
    30    *                     capable of calculating the conditional probability of initiation but not the         *
    31    *                     conditional probability of vessel failure; therefore, the CPF will be zero.          *
    32    *                                                                                                         *
    33    *                     Note: It is recommended that if the vessel model is postulated to contain surface   *
    34    *                     breaking flaws that IPFLAW=2 not be used, but rather IPFLAW=3, since, based on      *
    35    *                     experience, inner surface breaking flaws can also be predicted to initiate          *
    36    *                     during a heat-up transient. IPFLAW=3 postulates and equal number of surface         *
    37    *                     breaking flaws on the vessel inner surface and the vessel outer surface.            *
    38    *                                                                                                         *
    39    * IPFLAW         = 3  The number of postulated surface breaking flaws (in surface flaw characterization   *
    40    *                     file) would be double that of options 1 and 2; evenly divided between internal      *
    41    *                     and external surface breaking flaws. All of the embedded flaws uniformly            *
    42    *                     distributed through the RPV wall thickness would be included in the model.          *
    43    *                                                                                                         *
    44    * See Theory Manual for further discussion.                                                               *
    45    *-------------------------------------------------------------------------------------------------------*
    46    *  IGATR          =   NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                              *
    47    *-------------------------------------------------------------------------------------------------------*
    48    *  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                          *
    49    *  WPS_OPTION     = 1       INCLUDE TRADITIONAL FAVOR BASELINE WARM-PRESTRESSING Model IN ANALYSIS          *
```

FAVPFM.out

```
              *************************************************
              *                                               *
              *                WELCOME TO FAVOR               *
              *                                               *
              *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE     *
              *                 VERSION 16.1                  *
              *                                               *
              *     FAVPFM MODULE: PERFORMS PROBABILISTIC     *
              *          FRACTURE MECHANICS ANALYSES          *
              *                                               *
              *    PROBLEMS OR QUESTIONS REGARDING FAVOR      *
              *            SHOULD BE DIRECTED TO              *
              *                                               *
              *                TERRY DICKSON                  *
              *        OAK RIDGE NATIONAL LABORATORY          *
              *                                               *
              *           e-mail: dicksontl@ornl.gov          *
              *                                               *
              *************************************************

         ***********************************************************
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         * 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.                                 *
         *                                                         *
         ***********************************************************



              FAVPFM INPUT FILE NAME       = favpfm2.in
              FAVLOAD OUTPUT FILE NAME     = favload2.out
              FAVPFM OUTPUT FILE NAME      = favpfm2.out
              FAVPFM INPUT ECHO FILE NAME  = favpfm2.echo



               *******************************************
               Binary restart files will be created using
               a checkpoint interval of  200 trials.
               *******************************************

NUMBER OF TIME STEPS IN FAVLoad FILE   =   301

NUMBER OF IGA TRIALS PER FLAW          =   100
FLOW STRESS - USED IN FAILURE ANALYSIS =  80.0 ksi
Maximum value used for KIc and KIa     = 800.0 ksi-in^1/2
KIc/KIa cap not used if ductile-tearing model is invoked.

Stochastic model for crack arrest KIa  =     2
where
  1 = model based on high-constraint CCA specimens
  2 = model based on CCA and large-specimen data
  KIa model set to 2 if ductile-tearing model is invoked.

Radiation embrittlement correlation    =  2006
where
    992 = Regulatory Guide 1.99, revision 2
   2000 = Eason 2000
   2006 = Eason 2006
  20071 = EricksonKirk 2007
  20072 = RADAMO 2007
  20073 = Combined EricksonKirk 2007 + RADAMO 2007

Steady-state cooling water temperature  =  556. degrees F

Effective full-power years of operation =   60.


DEFINITION OF STANDARD DEVIATIONS FOR SIMULATING
THE FOLLOWING PARAMETERS

SURFACE NEUTRON FLUENCE - GLOBAL =   0.118* BEST ESTIMATE VALUE
SURFACE NEUTRON FLUENCE - LOCAL  =   0.056* BEST ESTIMATE VALUE
COPPER      - WELD   =       0.167 wt %
COPPER      - PLATE  =      0.0073 wt %
NICKEL      - WELD   =      0.1620 wt %
NICKEL      - PLATE  =      0.0244 wt %
PHOSPHORUS  - WELD   =      0.0013 wt %
PHOSPHORUS  - PLATE  =      0.0013 wt %

NUMBER OF VESSEL SUBREGIONS:    WELD=   15 PLATE=   18 TOTAL=   33
NUMBER OF VESSEL MAJOR REGIONS: WELD=    7 PLATE=    6 TOTAL=   13

      SURF-BREAKING FLAW CHARACTERIZATION DATASET FILE NAME  = S.DAT
      EMBEDDED WELD FLAW CHARACTERIZATION DATASET FILE NAME  = W.DAT
      EMBEDDED PLATE FLAW CHARACTERIZATION DATASET FILE NAME = P.DAT


                         ***********************************************************
                         *                                                         *
                         *                   PFM ANALYSIS RESULTS                  *
                         *                                                         *
```

FAVPFM.OUT (continued)

```
                       ***********************************************************
                        *                                                         *
                        *                   PFM ANALYSIS RESULTS                  *
                        *                                                         *
                        ***********************************************************


            ****************************************************************************
            * INITIAL RANDOM NUMBER GENERATOR SEEDS   :      1234567890      123456789 *
            ****************************************************************************

                                ************************************************
                                ** IPFLAW=2: SURFACE BREAKING FLAWS ARE       **
                                ** EXTERNAL SURFACE BREAKING                  **
                                **                                            **
                                ** EMBEDDED FLAWS ARE UNIFORMLY               **
                                ** DISTRIBUTED IN OUTER 3/8 OF RPV BASE       **
                                **                                            **
                                **                                            **
                                ** WELD LAYER RESAMPLING TURNED OFF           **
                                ************************************************

                            ****************************************************
                            ** WARM-PRESTRESS OPTION 1 CHOSEN:                **
                            **                                                **
                            ** TO HAVE A NON-ZERO instantaneous conditional   **
                            ** probability of crack initiation at a discrete  **
                            ** transient time step:                           **
                            **                                                **
                            ** applied KI must be greater than the Weibull    **
                            ** "a" parameter                                  **
                            **                                                **
                            **  AND                                           **
                            **                                                **
                            ** applied KI MUST EXCEED MAXIMUM KI at all       **
                            ** previous discrete transient time steps         **
                            ****************************************************

                                ************************************************
                                ** DO NOT ANALYZE CATEGORY 3 PLATE FLAWS      **
                                ** DUCTILE TEARING MODEL TURNED ON            **
                                ** FAILURE CRITERIA a/t =    0.90             **
                                ************************************************


                                *********************************************
                                *********************************************
                                **  PFM RESULTS FOR TRANSIENT NUMBER     1 **
                                *********************************************
                                *********************************************

                                *********************************************
                                **                                         **
                                **  NUMBER OF COMPLETED TRIALS =     100   **
                                **                                         **
                                *********************************************

                                       MEAN VALUE OF CPI =     1.766E-04
                                       MEAN VALUE OF CPF =     1.766E-04

                                    *************************************
                                    *  RPV BELTLINE MAJOR REGION REPORT *
                                    *       BY PARENT SUBREGION         *
                                    *************************************
====================================================================================================
                                       |---Initiation---|   |----Cleavage----| |------Ductile-----|
 MAJOR     RTndt  % OF     SIMULATED    # of FLAWS  % of      # of FLAWS  % of   # of FLAWS     % of
 REGION    (MAX)  FLAWS       FLAWS      CPI > 0    CPI         CPF > 0     CPF        CPF > 0     CPF
====================================================================================================
   1       277.6   3.15      15873         6       98.96         6       98.96         0        0.00
   2       277.6   3.15      16107         6        0.25         6        0.25         0        0.00
   3       272.0   3.15      15914         1        0.29         1        0.29         0        0.00
   4       271.9   1.88       9547         1        0.00         1        0.00         0        0.00
   5       277.3   1.88       9432         2        0.00         2        0.00         0        0.00
   6       277.3   1.88       9549         4        0.50         4        0.50         0        0.00
   7       261.7  21.76     109923         0        0.00         0        0.00         0        0.00
   8       178.6  13.18      66292         0        0.00         0        0.00         0        0.00
   9       207.3  13.18      66335         0        0.00         0        0.00         0        0.00
  10       179.5  13.18      66258         0        0.00         0        0.00         0        0.00
  11       154.4   7.87      39518         0        0.00         0        0.00         0        0.00
  12       185.9   7.87      40018         0        0.00         0        0.00         0        0.00
  13       140.4   7.87      39801         0        0.00         0        0.00         0        0.00
====================================================================================================
          TOTALS 100.00     504567        20      100.00        20      100.00         0        0.00
====================================================================================================

                               NOTE: MEAN VALUE OF RTNDT AT CRACK TIP=  143.63

                                    *************************************
                                    *  RPV BELTLINE MAJOR REGION REPORT *
                                    *       BY CHILD SUBREGION          *
                                    *************************************
====================================================================================================
                                       |---Initiation---|   |----Cleavage----| |------Ductile-----|
 MAJOR     RTndt  % OF     SIMULATED    # of FLAWS  % of      # of FLAWS  % of   # of FLAWS     % of
 REGION    (MAX)  FLAWS       FLAWS      CPI > 0    CPI         CPF > 0     CPF        CPF > 0     CPF
====================================================================================================
   1       277.6   3.15      15873         6       98.96         6       98.96         0        0.00
   2       277.6   3.15      16107         6        0.25         6        0.25         0        0.00
   3       272.0   3.15      15914         1        0.29         1        0.29         0        0.00
   4       271.9   1.88       9547         1        0.00         1        0.00         0        0.00
```

FAVPFM.OUT (continued)

```
                                       *************************************
                                       *  RPV BELTLINE MAJOR REGION REPORT *
                                       *       BY PARENT SUBREGION         *
                                       *************************************
====================================================================================================
                                       |---Initiation---|  |----Cleavage----| |------Ductile-----|
 MAJOR      RTndt  % OF      SIMULATED  # of FLAWS  % of     # of FLAWS  % of   # of FLAWS    % of
 REGION     (MAX)  FLAWS       FLAWS      CPI > 0   CPI        CPF > 0   CPF      CPF > 0     CPF
====================================================================================================
   1        277.6   3.15       15873        2       94.86        2       94.86        0        0.00
   2        277.6   3.15       16107        2        1.47        2        1.47        0        0.00
   3        272.0   3.15       15914        1        2.77        1        2.77        0        0.00
   4        271.9   1.88        9547        1        0.00        1        0.00        0        0.00
   5        277.3   1.88        9432        1        0.89        1        0.89        0        0.00
   6        277.3   1.88        9549        0        0.00        0        0.00        0        0.00
   7        261.7  21.76      109923        0        0.00        0        0.00        0        0.00
   8        178.6  13.18       66292        0        0.00        0        0.00        0        0.00
   9        207.3  13.18       66335        0        0.00        0        0.00        0        0.00
  10        179.5  13.18       66258        0        0.00        0        0.00        0        0.00
  11        154.4   7.87       39518        0        0.00        0        0.00        0        0.00
  12        185.9   7.87       40018        0        0.00        0        0.00        0        0.00
  13        140.4   7.87       39801        0        0.00        0        0.00        0        0.00
====================================================================================================
           TOTALS 100.00      504567        7      100.00        7      100.00        0        0.00
====================================================================================================

                                  NOTE: MEAN VALUE OF RTNDT AT CRACK TIP=  143.63

                                       *************************************
                                       *  RPV BELTLINE MAJOR REGION REPORT *
                                       *       BY CHILD SUBREGION          *
                                       *************************************
====================================================================================================
                                       |---Initiation---|  |----Cleavage----| |------Ductile-----|
 MAJOR      RTndt  % OF      SIMULATED  # of FLAWS  % of     # of FLAWS  % of   # of FLAWS    % of
 REGION     (MAX)  FLAWS       FLAWS      CPI > 0   CPI        CPF > 0   CPF      CPF > 0     CPF
====================================================================================================
   1        277.6   3.15       15873        2       94.86        2       94.86        0        0.00
   2        277.6   3.15       16107        2        1.47        2        1.47        0        0.00
   3        272.0   3.15       15914        1        2.77        1        2.77        0        0.00
   4        271.9   1.88        9547        1        0.00        1        0.00        0        0.00
   5        277.3   1.88        9432        1        0.89        1        0.89        0        0.00
   6        277.3   1.88        9549        0        0.00        0        0.00        0        0.00
   7        261.7  21.76      109923        0        0.00        0        0.00        0        0.00
   8        178.6  13.18       66292        0        0.00        0        0.00        0        0.00
   9        207.3  13.18       66335        0        0.00        0        0.00        0        0.00
  10        179.5  13.18       66258        0        0.00        0        0.00        0        0.00
  11        154.4   7.87       39518        0        0.00        0        0.00        0        0.00
  12        185.9   7.87       40018        0        0.00        0        0.00        0        0.00
  13        140.4   7.87       39801        0        0.00        0        0.00        0        0.00
====================================================================================================
           TOTALS 100.00      504567        7      100.00        7      100.00        0        0.00

                    FOR IPFLAW = 2: CATEGORY 1 FLAWS ARE ON THE
                                    EXTERNAL SURFACE

                    CATEGORY 2 FLAWS ARE EMBEDDED IN EXTERNAL 1/8
                               OF BASE METAL THICKSS

                    CATEGORY 3 FLAWS ARE EMBEDDED BETWEEN EXTERNAL
                     1/8 AND EXTERNAL 3/8 OF BASE METAL THICKNESS

                    **********************************************
                    * FLAW DISTRIBUTION BY MATERIAL AND CATEGORY *
                    *             BY PARENT SUBREGION            *
                    **********************************************
                   ==================================================
                                    WELD MATERIAL
                   ==================================================
                    number of   number    % of      number    % of
                    simulated    with     total      with     total
                       flaws    CPI>0      CPI      CPF>0      CPF
                   ==================================================
FLAW CATEGORY 1(ext)       2        0      0.00        0       0.00
FLAW CATEGORY 2(ext)   62174        3      1.47        3       1.47
FLAW CATEGORY 3(ext)  124169        4     98.53        4      98.53
                   ==================================================
          TOTALS      186345        7    100.00        7     100.00
                   ==================================================


                   ==================================================
                                   PLATE MATERIAL
                   ==================================================
                    number of   number    % of      number    % of
                    simulated    with     total      with     total
                       flaws    CPI>0      CPI      CPF>0      CPF
                   ==================================================
FLAW CATEGORY 1(ext)     173        0      0.00        0       0.00
FLAW CATEGORY 2(ext)  106448        0      0.00        0       0.00
FLAW CATEGORY 3(ext)  211601        0      0.00        0       0.00
                   ==================================================
          TOTALS      318222        0      0.00        0       0.00
```

FAVPFM.OUT (continued)

```
                   **********************************************************
                   * FLAW DISTRIBUTION BY MATERIAL, CATEGORY, & ORIENTATION *
                   *                  BY PARENT SUBREGION                  *
                   **********************************************************
                     ==================================================
                                         WELD MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         2       0      0.00       0       0.00
AXIAL FLAW CATEGORY 2     25599       3      1.47       3       1.47
AXIAL FLAW CATEGORY 3     50821       4     98.53       4      98.53
                     ==================================================
AXIAL SUBTOTALS           76422       7    100.00       7     100.00
                     ==================================================

CIRC. FLAW CATEGORY 1         0       0      0.00       0       0.00
CIRC. FLAW CATEGORY 2     36575       0      0.00       0       0.00
CIRC. FLAW CATEGORY 3     73348       0      0.00       0       0.00
                     ==================================================
CIRC. SUBTOTALS          109923       0      0.00       0       0.00
                     ==================================================
WELD TOTALS              186345       7    100.00       7     100.00
                     ==================================================


                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1        87       0      0.00       0       0.00
AXIAL FLAW CATEGORY 2     53103       0      0.00       0       0.00
AXIAL FLAW CATEGORY 3    105922       0      0.00       0       0.00
                     ==================================================
AXIAL SUBTOTALS          159112       0      0.00       0       0.00
                     ==================================================
CIRC. FLAW CATEGORY 1        86       0      0.00       0       0.00
CIRC. FLAW CATEGORY 2     53345       0      0.00       0       0.00
CIRC. FLAW CATEGORY 3    105679       0      0.00       0       0.00
                     ==================================================
CIRC. SUBTOTALS          159110       0      0.00       0       0.00
                     ==================================================
PLATE TOTALS             318222       0      0.00       0       0.00
                     ==================================================


                     ==================================================
                   **********************************************************
                   * FLAW DISTRIBUTION BY MATERIAL, CATEGORY, & ORIENTATION *
                   *                  BY CHILD SUBREGION                    *
                   **********************************************************
                     ==================================================
                                         WELD MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         2       0      0.00       0       0.00
AXIAL FLAW CATEGORY 2     25599       3      1.47       3       1.47
AXIAL FLAW CATEGORY 3     50821       4     98.53       4      98.53
                     ==================================================
AXIAL SUBTOTALS           76422       7    100.00       7     100.00
                     ==================================================
CIRC. FLAW CATEGORY 1         0       0      0.00       0       0.00
CIRC. FLAW CATEGORY 2     36575       0      0.00       0       0.00
CIRC. FLAW CATEGORY 3     73348       0      0.00       0       0.00
                     ==================================================
CIRC. SUBTOTALS           73348       0      0.00       0       0.00
                     ==================================================
WELD TOTALS              149770       7    100.00       7     100.00

                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1        87       0      0.00       0       0.00
```

FAVPFM.OUT (continued)

```
                   **********************************************************
                   * FLAW DISTRIBUTION BY MATERIAL, CATEGORY, & ORIENTATION *
                   *                  BY CHILD SUBREGION                    *
                   **********************************************************
                     ==================================================
                                         WELD MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         2       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2     25599       3      1.47       3      1.47
AXIAL FLAW CATEGORY 3     50821       4     98.53       4     98.53
                     ==================================================
AXIAL SUBTOTALS           76422       7    100.00       7    100.00
                     ==================================================
CIRC. FLAW CATEGORY 1         0       0      0.00       0      0.00
CIRC. FLAW CATEGORY 2     36575       0      0.00       0      0.00
CIRC. FLAW CATEGORY 3     73348       0      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS           73348       0      0.00       0      0.00
                     ==================================================
WELD TOTALS              149770       7    100.00       7    100.00

                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1        87       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2     53103       0      0.00       0      0.00
AXIAL FLAW CATEGORY 3    105922       0      0.00       0      0.00
                     ==================================================
AXIAL SUBTOTALS          159112       0      0.00       0      0.00
                     ==================================================
CIRC. FLAW CATEGORY 1        86       0      0.00       0      0.00
CIRC. FLAW CATEGORY 2     53345       0      0.00       0      0.00
CIRC. FLAW CATEGORY 3    105679       0      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS          159110       0      0.00       0      0.00
                     ==================================================
PLATE TOTALS             318222       0      0.00       0      0.00

                  CHILD SUBREGION REPORTS SHOW LOCATIONS OF CONTROLLING
                   RTNDTO AND CHEMISTRY CONTENT FOR WELD FUSION LINES




              *********************************************
              *     WELD FLAW-SIZE DISTRIBUTION REPORT    *
              * FOR CONDITIONAL PROBABILITY OF INITIATION *
              *********************************************
=========================================================================
flaw  simulated  #   % of     simulated  #   % of     simulated  #   % of
depth  catgy 1 with total      catgy 2 with total      catgy 3 with  total
(in)    flaws  CPI>0 CPI        flaws  CPI>0 CPI        flaws  CPI>0  CPI
=========================================================================
 0.088      0     0   0.00     33008      0   0.00     66174     0   0.00
 0.175      0     0   0.00     23497      0   0.00     46770     0   0.00
 0.263      2     0   0.00      4559      0   0.00      8893     0   0.00
 0.350      0     0   0.00       690      0   0.00      1383     0   0.00
 0.438      0     0   0.00       180      0   0.00       452     0   0.00
 0.525      0     0   0.00       116      0   0.00       213     0   0.00
 0.613      0     0   0.00        56      0   0.00       113     0   0.00
 0.700      0     0   0.00        26      0   0.00        75     0   0.00
 0.787      0     0   0.00        12      0   0.00        31     0   0.00
 0.875      0     0   0.00         8      0   0.00        24     0   0.00
 0.963      0     0   0.00         3      0   0.00        11     0   0.00
 1.050      0     0   0.00         8      1   1.07        11     0   0.00
 1.137      0     0   0.00         4      0   0.00         2     0   0.00
 1.225      0     0   0.00         0      0   0.00         2     1  94.56
 1.312      0     0   0.00         3      1   0.40         4     0   0.00
 1.400      0     0   0.00         2      0   0.00         4     0   0.00
 1.488      0     0   0.00         0      0   0.00         3     0   0.00
 1.575      0     0   0.00         0      0   0.00         0     0   0.00
 1.663      0     0   0.00         0      0   0.00         0     0   0.00
 1.750      0     0   0.00         1      1   0.00         1     0   0.00
 1.837      0     0   0.00         0      0   0.00         0     0   0.00
 1.925      0     0   0.00         0      0   0.00         0     0   0.00
 2.013      0     0   0.00         0      0   0.00         1     1   0.89
 2.100      0     0   0.00         0      0   0.00         1     1   0.30
 2.188      0     0   0.00         1      0   0.00         0     0   0.00
 2.275      0     0   0.00         0      0   0.00         1     1   2.77
 2.363      0     0   0.00         0      0   0.00         0     0   0.00
 2.450      0     0   0.00         0      0   0.00         0     0   0.00
```

FAVPFM.OUT (continued)

```
              *********************************************
              *    PLATE FLAW-SIZE DISTRIBUTION REPORT    *
              * FOR CONDITIONAL PROBABILITY OF INITIATION *
              *********************************************
==========================================================================
flaw  simulated  #   % of    simulated  #   % of    simulated  #   % of
depth  catgy 1 with total     catgy 2 with total     catgy 3 with  total
(in)    flaws  CPI>0 CPI       flaws  CPI>0 CPI       flaws  CPI>0  CPI
==========================================================================
 0.088       0     0   0.00     39767      0   0.00     78996     0   0.00
 0.175       0     0   0.00     49049      0   0.00     97132     0   0.00
 0.263     173     0   0.00     13265      0   0.00     26590     0   0.00
 0.350       0     0   0.00      3337      0   0.00      6788     0   0.00
 0.438       0     0   0.00       919      0   0.00      1849     0   0.00
 0.525       0     0   0.00        58      0   0.00       136     0   0.00
 0.613       0     0   0.00        53      0   0.00       110     0   0.00
==========================================================================
TOTALS   173     0    0.00    106448      0   0.00    211601     0   0.00
==========================================================================


              *********************************************
              *     WELD FLAW-SIZE DISTRIBUTION REPORT    *
              *   FOR CONDITIONAL PROBABILITY OF FAILURE  *
              *********************************************
==========================================================================
flaw  simulated  #   % of    simulated  #   % of    simulated  #   % of
depth  catgy 1 with total     catgy 2 with total     catgy 3 with  total
(in)    flaws  CPF>0 CPF       flaws  CPF>0 CPF       flaws  CPF>0  CPF
==========================================================================
 0.088       0     0   0.00     33008      0   0.00     66174     0   0.00
 0.175       0     0   0.00     23497      0   0.00     46770     0   0.00
 0.263       2     0   0.00      4559      0   0.00      8893     0   0.00
 0.350       0     0   0.00       690      0   0.00      1383     0   0.00
 0.438       0     0   0.00       180      0   0.00       452     0   0.00
 0.525       0     0   0.00       116      0   0.00       213     0   0.00
 0.613       0     0   0.00        56      0   0.00       113     0   0.00
 0.700       0     0   0.00        26      0   0.00        75     0   0.00
 0.787       0     0   0.00        12      0   0.00        31     0   0.00
 0.875       0     0   0.00         8      0   0.00        24     0   0.00
 0.963       0     0   0.00         3      0   0.00        11     0   0.00
 1.050       0     0   0.00         8      1   1.07        11     0   0.00
 1.137       0     0   0.00         4      0   0.00         2     0   0.00
 1.225       0     0   0.00         0      0   0.00         2     1  94.56
 1.312       0     0   0.00         3      1   0.40         4     0   0.00
 1.400       0     0   0.00         2      0   0.00         4     0   0.00
 1.488       0     0   0.00         0      0   0.00         3     0   0.00
 1.575       0     0   0.00         0      0   0.00         0     0   0.00
 1.663       0     0   0.00         0      0   0.00         0     0   0.00
 1.750       0     0   0.00         1      1   0.00         1     0   0.00
 1.837       0     0   0.00         0      0   0.00         0     0   0.00
 1.925       0     0   0.00         0      0   0.00         0     0   0.00
 2.013       0     0   0.00         0      0   0.00         1     1   0.89
 2.100       0     0   0.00         0      0   0.00         1     1   0.30
 2.188       0     0   0.00         1      0   0.00         0     0   0.00
 2.275       0     0   0.00         0      0   0.00         1     1   2.77
 2.363       0     0   0.00         0      0   0.00         0     0   0.00
 2.450       0     0   0.00         0      0   0.00         0     0   0.00
 2.537       0     0   0.00         0      0   0.00         0     0   0.00
 2.625       0     0   0.00         0      0   0.00         0     0   0.00
 2.712       0     0   0.00         0      0   0.00         0     0   0.00
 2.800       0     0   0.00         0      0   0.00         0     0   0.00
 2.888       0     0   0.00         0      0   0.00         0     0   0.00
 2.975       0     0   0.00         0      0   0.00         0     0   0.00
==========================================================================
TOTALS     2     0    0.00     62174      3   1.47    124169     4  98.53
==========================================================================

              *********************************************
              *    PLATE FLAW-SIZE DISTRIBUTION REPORT    *
              *   FOR CONDITIONAL PROBABILITY OF FAILURE  *
              *********************************************
==========================================================================
flaw  simulated  #   % of    simulated  #   % of    simulated  #   % of
```

FAVPFM.OUT (continued)

```
  ==============================================
     ***************************************
     * TRANSIENT TIME DISTRIBUTION REPORT *
     *    for transient sequence     2    *
     ***************************************
  ==============================================
  TIME   TIME    % of    CDF of    % of    CDF of
  STEP   (min)   total   total     total   total
                 CDCPI   CDCPI     CDCPF   CDCPF
  ==============================================
    1     0.0  4.8353   4.8353   4.8353   4.8353
    6     5.0  0.0083   4.8436   0.0083   4.8436
    7     6.0  0.0687   4.9123   0.0687   4.9123
   10     9.0  0.0539   4.9662   0.0539   4.9662
   11    10.0  0.1129   5.0791   0.1129   5.0791
   14    13.0  0.0537   5.1328   0.0537   5.1328
   15    14.0  0.0917   5.2246   0.0917   5.2246
   19    18.0  0.0154   5.2400   0.0154   5.2400
   20    19.0  0.0306   5.2706   0.0306   5.2706
   21    20.0  0.0227   5.2933   0.0227   5.2933
   22    21.0  0.0145   5.3078   0.0145   5.3078
   23    22.0  0.0060   5.3139   0.0060   5.3139
   28    27.0  0.1290   5.4429   0.1290   5.4429
  142   141.0  0.0000   5.4429   0.0000   5.4429
  143   142.0  0.0000   5.4429   0.0000   5.4429
  145   144.0  0.0002   5.4431   0.0002   5.4431
  146   145.0  0.0005   5.4436   0.0005   5.4436
  148   147.0  0.0010   5.4446   0.0010   5.4446
  149   148.0  0.0020   5.4466   0.0020   5.4466
  150   149.0  0.0033   5.4498   0.0033   5.4498
  152   151.0  0.0037   5.4536   0.0037   5.4536
  153   152.0  0.0063   5.4599   0.0063   5.4599
  154   153.0  0.0085   5.4683   0.0085   5.4683
  155   154.0  0.0109   5.4793   0.0109   5.4793
  156   155.0  0.0137   5.4929   0.0137   5.4929
  157   156.0  0.0166   5.5095   0.0166   5.5095
  158   157.0  0.0197   5.5293   0.0197   5.5293
  159   158.0  0.0230   5.5523   0.0230   5.5523
  160   159.0  0.0723   5.6246   0.0723   5.6246
  161   160.0  0.0364   5.6610   0.0364   5.6610
  162   161.0  0.0400   5.7010   0.0400   5.7010
  163   162.0  0.0436   5.7446   0.0436   5.7446
  164   163.0  0.1350   5.8796   0.1350   5.8796
  165   164.0  0.0584   5.9380   0.0584   5.9380
  166   165.0  0.1832   6.1212   0.1832   6.1212
  167   166.0  0.0730   6.1942   0.0730   6.1942
  168   167.0  0.2351   6.4293   0.2351   6.4293
  169   168.0  0.0861   6.5154   0.0861   6.5154
  170   169.0  0.2888   6.8042   0.2888   6.8042
  171   170.0  0.3334   7.1376   0.3334   7.1376
  172   171.0  0.1054   7.2430   0.1054   7.2430
  173   172.0  0.3868   7.6298   0.3868   7.6298
  174   173.0  0.4323   8.0621   0.4323   8.0621
  175   174.0  0.4780   8.5401   0.4780   8.5401
  176   175.0  0.5233   9.0634   0.5233   9.0634
  177   176.0  0.5679   9.6313   0.5679   9.6313
  178   177.0  0.6115  10.2429   0.6115  10.2429
  179   178.0  1.2385  11.4813   1.2385  11.4813
  180   179.0  0.7423  12.2236   0.7423  12.2236
  181   180.0  0.7796  13.0032   0.7796  13.0032
  182   181.0  1.5957  14.5989   1.5957  14.5989
  183   182.0  0.8918  15.4908   0.8918  15.4908
  184   183.0  1.8545  17.3452   1.8545  17.3452
  185   184.0  2.0324  19.3777   2.0324  19.3777
  186   185.0  1.0424  20.4201   1.0424  20.4201
  187   186.0  2.2565  22.6766   2.2565  22.6766
  188   187.0  2.4126  25.0891   2.4126  25.0891
  189   188.0  2.5582  27.6473   2.5582  27.6473
  190   189.0  4.3293  31.9766   4.3293  31.9766
  191   190.0  2.9303  34.9069   2.9303  34.9069
  192   191.0  3.0319  37.9388   3.0319  37.9388
  193   192.0  5.1953  43.1341   5.1953  43.1341
  194   193.0  3.2948  46.4289   3.2948  46.4289
  195   194.0  5.7364  52.1653   5.7364  52.1653
  196   195.0  6.0719  58.2372   6.0719  58.2372
  197   196.0  6.3754  64.6126   6.3754  64.6126
  198   197.0  6.6427  71.2553   6.6427  71.2553
  199   198.0 10.2185  81.4737  10.2185  81.4737
  200   199.0  7.2596  88.7333   7.2596  88.7333
  201   200.0 11.2667 100.0000  11.2667 100.0000
```

FAVPFM.OUT (continued)

```
     ***********************************************************
     *      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)      *
     *           FOR THE INITIATING DRIVING FORCES             *
     *              FOR TRANSIENT SEQUENCE     2               *
     ***********************************************************
           ===============================================
                               RELATIVE    CUMULATIVE
             KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
             (bin midpoint)      (%)          (%)
           ===============================================
                  21.00           28.5714      28.5714
                  23.00           14.2857      42.8571
                  25.00           42.8571      85.7143
                  35.00           14.2857     100.0000
           ===============================================
                               RELATIVE    CUMULATIVE
             KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
             (bin midpoint)      (%)          (%)
           ===============================================


====================================================================================================
                     FAILURE MECHANISM REPORT FOR TRANSIENT SEQUENCE     2
====================================================================================================

                                                                 NUMBER OF     % OF TOTAL
                                                                   FAILURE       FAILURE
                                                                    TRIALS        TRIALS

 UNSTABLE DUCTILE TEARING                                             0            0.00
 STABLE DUCTILE TEAR TO PLASTIC INSTABILITY                           0            0.00
 CLEAVAGE PROPAGATION TO PLASTIC INSTABILITY                          0            0.00
 STABLE DUCTILE TEAR EXCEEDS  WALL DEPTH FAILURE CRITERIA             0            0.00
 CLEAVAGE PROPAGATION EXCEEDS WALL DEPTH FAILURE CRITERIA             0            0.00


        ***************************************************
        ***************************************************
        *               MULTIPLE FLAW STATISTICS          *
        ***************************************************
        ***************************************************

                          NUMBER OF OCCASIONS
                        WHEN SIMULATED RPV HAD

               X FLAWS        % OF         X FLAWS       % OF
 X FLAWS     WITH CPI > 0    TOTAL CPI    WITH CPF > 0   TOTAL CPF

    1            21            87.50          21           87.50
    2             3            12.50           3           12.50

   TOTALS        24           100.00          24          100.00

   Note: One Occasion is 1 simulated RPV subjected to 1 transient
```

TRACE.OUT file

```
==================================================================================================================|
                                   Flaws that Produce Vessel Failures                                             |
==================================================================================================================|
Parent Flaw |         Category 1              |         Category 2              |         Category 3              |
Orientation |  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|
============|=================================|=================================|=================================|
axial weld  |                                 |      1     8   8500      2     2|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
axial plate |                                 |      0     0      0      0     0|      0     0      0      0     0|
============|=================================|=================================|=================================|


==================================================================================================================|
                                      Flaws that Experience Stable Arrests                                        |
==================================================================================================================|
Parent Flaw |         Category 1              |         Category 2              |         Category 3              |
Orientation |  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|
============|=================================|=================================|=================================|
axial weld  |                                 |      1    16   7761      1     1|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
axial plate |                                 |      0     0      0      0     0|      0     0      0      0     0|
============|=================================|=================================|=================================|


==================================================================================================================|
                                             Flaws that Reinitiate                                                |
==================================================================================================================|
Parent Flaw |         Category 1              |         Category 2              |         Category 3              |
Orientation |  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|
============|=================================|=================================|=================================|
axial weld  |                                 |      0     0      0      0     0|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
axial plate |                                 |      0     0      0      0     0|      0     0      0      0     0|
============|=================================|=================================|=================================|


==================================================================================================================|
                                      Flaws that Experience Stable Ductile Tearing                                |
==================================================================================================================|
Parent Flaw |         Category 1              |         Category 2              |         Category 3              |
Orientation |  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|
============|=================================|=================================|=================================|
axial weld  |                                 |      1    16   7761      1     1|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
axial plate |                                 |      0     0      0      0     0|      0     0      0      0     0|
============|=================================|=================================|=================================|


==================================================================================================================|
                                      Flaws that Experience Unstable Ductile Tearing                              |
==================================================================================================================|
Parent Flaw |         Category 1              |         Category 2              |         Category 3              |
Orientation |  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|
============|=================================|=================================|=================================|
axial weld  |                                 |      1    16   7761      1     1|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
axial plate |                                 |      0     0      0      0     0|      0     0      0      0     0|
============|=================================|=================================|=================================|
==================================================================================================================|
Parent Flaw |         Category 1              |         Category 2              |         Category 3              |
Orientation |  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|  itran  irpv  kflaw parent child|
============|=================================|=================================|=================================|
axial weld  |                                 |      2     1   1375     79  6493|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      0     0      0      0     0|      0     0      0      0     0|
axial plate |                                 |      2     2    285  14936 14936|      0     0      0      0     0|
============|=================================|=================================|=================================|=
===========|=================================|=================================|=================================|
```

The flaw log tables are created only when ITRACK=1 on the TRAC record. These logged flaws are the first flaws sampled that meet the different criteria in the tables.

ITRAN = transient number
IRPV = RPV simulation
FLAW = flaw number
SUBREGION =subregion number
SCU = sampled $\widehat{Cu}$ content wt%
SNI = sampled $\widehat{Ni}$ content wt%
SPHOS = sampled $\widehat{P}$ content wt%
SMN= sampled $\widehat{Mn}$ content wt%
SFID = sampled/attenuated fluence $\widehat{f_0}(r)$ $\times 10^{19}$ neutrons/cm^2 at the crack tip
RTNDTO = sampled unirradiated $\widehat{RT}_{NDT0}$ [°F]
DRTEPI = sampled $\widehat{\Delta RT}_{epistemic}$ [°F] epistemic uncertainty term in $\widehat{RT}_{NDT0}$
DRTNDT = sampled $\widehat{\Delta T_{30}}$ [°F] CVN shift term from Eason and Wright model
SDRTNDT = sampled $\widehat{\Delta RT}_{NDT}$ irradiation shift [°F]
RTNDT = sampled irradiated $\widehat{RT}_{NDT}$ [°F] at crack tip
FLAW CAT = flaw category
DEPTH = flaw depth, *a* [inches]
XINNER = inner crack tip position for embedded flaws [inches]
ASPECT = flaw aspect ratio
I = time increment counter
TIME = elapsed time in transient [minutes]
KI = applied K_I [ksi$\sqrt{\text{in.}}$]
TEMP = temperature at crack tip [°F]
CPI = current conditional probability of initiation
CDCPI = current Δcpi
FAIL = number of trials failing the vessel at this time increment
CDCPF = current Δcpf at this time station
CPFTOT = *CPF*— conditional probability of failure

FLAW_TRACK.LOG file

The file “FLAW_TRACK.LOG” is created only when ITRACK=1 on TRAC record.

```
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=       520 parent subr=   696 child subr=  9610
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=       658 parent subr=   812 child subr=  9451
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=       817 parent subr=   671 child subr= 10776
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      1001 parent subr=   696 child subr=  9610
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      1375 parent subr=    79 child subr=  6493
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     1 kflaw=      1601 parent subr=   231 child subr=  7861
STABLE ARREST :parent axial  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      1957 parent subr=   118 child subr=  6532
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      2602 parent subr=   207 child subr=  9133
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      2736 parent subr=   674 child subr= 10776
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     1 kflaw=      2843 parent subr=   836 child subr= 10723
STABLE ARREST :parent axial  weld category 2 flaw: itran=   2 irpv=     1 kflaw=      3471 parent subr=   141 child subr=  6502
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      3759 parent subr=   692 child subr=  9822
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      3788 parent subr=   463 child subr= 12949
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      3861 parent subr=   619 child subr=  8020
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=       231 parent subr=   208 child subr=  9080
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=       285 parent subr= 14936 child subr= 14936
STABLE ARREST :parent axial plate category 2 flaw: itran=   2 irpv=     2 kflaw=       430 parent subr=  8022 child subr=  8022
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=       636 parent subr=   719 child subr=  8391
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     2 kflaw=       658 parent subr=   237 child subr=  7543
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=       795 parent subr=   706 child subr=  9080
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=       828 parent subr=   835 child subr= 10670
STABLE TEARING:parent circ. plate category 2 flaw: itran=   1 irpv=     2 kflaw=       837 parent subr=  9087 child subr=  9087
STABLE ARREST :parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=       931 parent subr=  9243 child subr=  9243
STABLE ARREST :parent axial  weld category 2 flaw: itran=   2 irpv=     2 kflaw=      1183 parent subr=   111 child subr=  6525
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      1502 parent subr=   176 child subr= 10776
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      1647 parent subr=   764 child subr=  6907
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     2 kflaw=      1669 parent subr=   631 child subr=  8656
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      1691 parent subr=   672 child subr= 10829
VESSEL FAILURE:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      1716 parent subr=    99 child subr=  6513
STABLE ARREST :parent axial  weld category 2 flaw: itran=   2 irpv=     2 kflaw=      1795 parent subr=   158 child subr=  6519
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     2 kflaw=      1898 parent subr=   746 child subr=  6960
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      2125 parent subr=   703 child subr=  9239
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      2229 parent subr=   529 child subr= 14062
STABLE ARREST :parent circ. plate category 2 flaw: itran=   2 irpv=     2 kflaw=      2508 parent subr=  9302 child subr=  9302
STABLE ARREST :parent circ. plate category 2 flaw: itran=   2 irpv=     2 kflaw=      2607 parent subr=  6859 child subr=  6859
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=      2775 parent subr= 10642 child subr= 10642
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     2 kflaw=      2805 parent subr=   593 child subr=  6642
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      3063 parent subr=   106 child subr=  6520
VESSEL FAILURE:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      3191 parent subr=    90 child subr=  6504
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      3251 parent subr=   681 child subr= 10405
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=      3416 parent subr= 10858 child subr= 10858
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=      3467 parent subr=  9664 child subr=  9664
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      3726 parent subr=   835 child subr= 10670
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      3741 parent subr=   243 child subr=  7225
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4010 parent subr=   787 child subr=  8126
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4048 parent subr=   211 child subr=  8921
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4103 parent subr=   834 child subr= 10617
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4303 parent subr=   811 child subr=  9398
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4415 parent subr=   133 child subr=  6494
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4501 parent subr=   670 child subr= 10723
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      4626 parent subr=    81 child subr=  6495
STABLE ARREST :parent circ. plate category 1 flaw: itran=   1 irpv=     4 kflaw=       515 parent subr=  8907 child subr=  8907
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=      4385 parent subr=   646 child subr=  9451
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=       120 parent subr=   209 child subr=  9027
STABLE ARREST :parent circ. plate category 1 flaw: itran=   1 irpv=     5 kflaw=       291 parent subr= 12510 child subr= 12510
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=       492 parent subr=   195 child subr=  9769
STABLE ARREST :parent axial  weld category 2 flaw: itran=   1 irpv=     5 kflaw=       687 parent subr=    65 child subr=  3623
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=       875 parent subr=   208 child subr=  9080
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=       958 parent subr=   674 child subr= 10776
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      1122 parent subr=   679 child subr= 10511
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=      1367 parent subr=   337 child subr=   974
STABLE TEARING:parent circ. plate category 1 flaw: itran=   1 irpv=     5 kflaw=      2110 parent subr= 10830 child subr= 10830
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      2652 parent subr=   104 child subr=  6518
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      2861 parent subr=   838 child subr= 10829
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      3094 parent subr=   415 child subr=  3388
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      3612 parent subr=   108 child subr=  6522
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      3839 parent subr=   179 child subr= 10617
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=      4301 parent subr=   491 child subr= 14433
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      4428 parent subr=   142 child subr=  6503
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      4580 parent subr=   190 child subr= 10034
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     7 kflaw=       307 parent subr=   314 child subr=  1756
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     7 kflaw=      2820 parent subr=   312 child subr=  1824
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=       257 parent subr=   672 child subr= 10829
STABLE ARREST :parent circ. plate category 2 flaw: itran=   1 irpv=     8 kflaw=       418 parent subr=  7812 child subr=  7812
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=       978 parent subr=   511 child subr= 15016
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     8 kflaw=       983 parent subr=   160 child subr=  6521
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=      1868 parent subr=   667 child subr= 10564
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=      3119 parent subr=   190 child subr= 10034
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=      3173 parent subr=   830 child subr= 10405
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=      3244 parent subr=   215 child subr=  8709
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     8 kflaw=      3831 parent subr=    59 child subr=  3617
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     8 kflaw=      4037 parent subr=   713 child subr=  8709
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     8 kflaw=      4118 parent subr=   308 child subr=  1960
```

ARREST.OUT file (warm-prestress option turned off)

```
=============================================================================================================================================
       ARREST TRIAL =     1 PF = 0.56551 PARENT =    104 CHILD =    6518 XDEPTH = 0.1607 XINNER = 0.1618 IFLCAT = 2 ASPECT =    2.53
=============================================================================================================================================
N.B. The variables DT30, DRTNDX, RTNDTA, RTNDT, TADJA, TADJI, KI, KIc, KIA, AND KJIc are evaluated at position ZSURF in the RPV wall.
=============================================================================================================================================
       NFLAW TIME  L ZSURF TEMP     P      DT30  RTNDTO -DTEPA  DTARR DRTNDX RTNDTA RTNDT    TADJA  TADJI    KI    KIC    KIA    KJIc   KJR*
=============================================================================================================================================
INITIA 2652  17.0  4 0.321 272.94         165.29  73.00                             227.53                  76.14
=============================================================================================================================================
 PROPA 2652  17.0  6 0.482 279.44 4.4E-01 164.62  73.00  13.83  59.00 181.08 326.91 226.79  -47.47  52.65  89.89          65.81
 PROPA 2652  17.0  8 0.643 289.73 4.4E-01 163.95  73.00  13.83  59.00 180.34 326.18 226.05  -36.45  63.68 101.13          70.12
 PROPA 2652  17.0 10 0.804 303.25 4.4E-01 163.28  73.00  13.83  59.00 179.61 325.44 225.32  -22.19  77.93 109.88          76.36
 PROPA 2652  17.0 12 0.964 315.94 4.4E-01 162.61  73.00  13.83  59.00 178.87 324.71 224.58   -8.76  91.36 117.52          83.02
 PROPA 2652  17.0 14 1.125 327.22 4.4E-01 161.95  73.00  13.83  59.00 178.14 323.98 223.85    3.24 103.36 124.41          89.70
 PROPA 2652  17.0 16 1.286 337.43 4.4E-01 161.28  73.00  13.83  59.00 177.41 323.25 223.12   14.18 114.31 130.62          96.44
 PROPA 2652  17.0 18 1.446 346.95 4.4E-01 160.62  73.00  13.83  59.00 176.68 322.52 222.39   24.43 124.56 136.20         103.39
 PROPA 2652  17.0 20 1.607 356.15 4.4E-01 159.96  73.00  13.83  59.00 175.95 321.79 221.66   34.36 134.49 141.23         110.76
 PROPA 2652  17.0 22 1.768 365.32 4.4E-01 159.29  73.00  13.83  59.00 175.22 321.06 220.93   44.26 144.39 145.78         118.80
 PROPA 2652  17.0 24 1.929 374.43 4.4E-01 158.63  73.00  13.83  59.00 174.49 320.33 220.20   54.11 154.23 149.98         127.53
*********************************************************************************************************************************************
 RECHM  SCU =    0.172 SNI =  0.644 SPHOS=  0.014 SMN=  1.381 RESAMPLE NEXT WELD LAYER CHEMISTRY
*********************************************************************************************************************************************
 ARRES 2652  17.0 26 2.259 392.59 4.4E-01 126.30  73.00  13.83  59.00 138.93 284.77 184.64  107.82 207.95 158.17         191.51
*********************************************************************************************************************************************
TREINI 2652  17.5 27 2.509 399.48 4.4E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57  115.79 207.95 159.63 1064.57        134.70 262.03
*********************************************************************************************************************************************
 ARRES 2652  17.5 27 2.509 399.48 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57  115.79 215.91 166.17         227.13
STABLE 2652  18.0 27 2.509 393.67 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57  109.98 109.98 165.40 1241.32        134.30 262.03
STABLE 2652  18.5 27 2.509 387.98 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57  104.29 104.29 164.41 1115.50        134.75 262.03
STABLE 2652  19.0 27 2.509 382.72 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   99.03  99.03 162.61 1011.90        135.17 262.03
STABLE 2652  19.5 27 2.509 378.14 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   94.45  94.45 159.78  930.79        135.55 262.03
STABLE 2652  20.0 27 2.509 373.98 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   90.29  90.29 159.65  863.39        135.90 262.03
STABLE 2652  20.5 27 2.509 369.77 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   86.08  86.08 164.64  800.91        136.26 262.03
STABLE 2652  21.0 27 2.509 365.55 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   81.86  81.86 159.45  743.59        136.62 262.03
STABLE 2652  21.5 27 2.509 361.71 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   78.02  78.02 160.25  695.59        136.96 262.03
STABLE 2652  22.0 27 2.509 358.29 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   74.60  74.60 157.22  655.90        137.27 262.03
STABLE 2652  22.5 27 2.509 355.12 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   71.43  71.43 155.14  621.60        137.55 262.03
STABLE 2652  23.0 27 2.509 352.18 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   68.49  68.49 155.28  591.63        137.83 262.03
STABLE 2652  23.5 27 2.509 349.14 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   65.45  65.45 154.81  562.51        138.11 262.03
STABLE 2652  24.0 27 2.509 346.10 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   62.41  62.41 151.44  535.10        138.39 262.03
STABLE 2652  24.5 27 2.509 343.38 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   59.69  59.69 149.40  512.04        138.65 262.03
STABLE 2652  25.0 27 2.509 340.82 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   57.13  57.13 148.66  491.41        138.90 262.03
STABLE 2652  25.5 27 2.509 338.05 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   54.36  54.36 148.07  470.25        139.17 262.03
STABLE 2652  26.0 27 2.509 335.10 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   51.41  51.41 145.78  448.92        139.46 262.03
STABLE 2652  26.5 27 2.509 332.33 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   48.64  48.64 144.47  430.05        139.74 262.03
STABLE 2652  27.0 27 2.509 329.67 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   45.98  45.98 144.27  412.86        140.01 262.03
STABLE 2652  27.5 27 2.509 326.74 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   43.05  43.05 143.56  394.96        140.31 262.03
STABLE 2652  28.0 27 2.509 323.66 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   39.97  39.97 141.90  377.22        140.63 262.03
STABLE 2652  28.5 27 2.509 320.73 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57   37.04  37.04 140.75  361.27        140.93 262.03
                                                  •
                                                  •
                                                  •
STABLE 2652  80.0 27 2.509 179.20 5.7E-01 125.32  73.00  13.83  59.00 137.86 283.69 183.57 -104.49-104.49  42.60   88.08        157.50 262.03
 STABLE ARREST
```

NTEST = trial number in IGA model
PF = P_f value for this trial
PROPA = the flaw is propagating by cleavage fracture
STEAR= the flaw is extending by stable ductile tearing
UTEAR= the flaw has experienced an unstable ductile tearing event
REINI= the flaw has re-initiated by cleavage
TREINI= the flaw has re-initiated by ductile tearing
ARRES = the flaw is arrested
STABLE= the flaw has arrested or stopped tearing and is stable for this time step
RECHM = resample weld chemistry content; the flaw had advanced into the next weld layer
SCU = sampled Cu content wt%
SNI = sampled Ni content wt%
SPHOS = sampled P content wt%
SMN= sample Mn content wt%
NFLAW = flaw number
TIME = elapsed time in transient [minutes]
L = node number in IGA model mesh
ZSURF = position of crack tip relative to inner surface [inches]
TEMP = temperature at crack tip [°F]
P = scaled quantile in K_{Ia} statistical model

DT30= sampled $\widehat{\Delta T_{30}}$ shift due to irradiation [°F]

RTNDTO = sampled unirradiated value of RT_{NDT0} [°F]

-DTEPA = sampled $-\widehat{\Delta RT}_{epistemic-arrest}$ [°F] epistemic uncertainty term in RT_{Arrest}

DTARR = sampled $\widehat{\Delta RT}_{Arrest}$ [°F]

DRTNDX = ΔRT_{NDT} [°F] irradiation shift

RTNDTA = RT_{Arrest} [°F] arrest reference temperature used in K_{Ia} lognormal model

RTNDT = RT_{NDT} [°F] irradiated reference temperature used in K_{Ic} Weibull model

TADJA = $\Delta T_{RELATIVE}$ [°F] temperature used in K_{Ia} lognormal model

TADJ = $\Delta T_{RELATIVE}$ [°F] temperature used in K_{Ic} Weibull model

KI = applied K_I [ksi$\sqrt{\text{in.}}$] driving force for crack

KIC = current value of K_{Ic} [ksi$\sqrt{\text{in.}}$]

KIA = current value of K_{Ia} [ksi$\sqrt{\text{in.}}$]

KJIc= current value of J_{Ic} converted to K_{JIc} [ksi$\sqrt{\text{in.}}$]

KJR*= current value of J_R^* converted to K_{JR*} [ksi$\sqrt{\text{in.}}$]

USEI= current value of irradiated upper-shelf CVN energy [ft-lbf]

C_DT= coefficient for sampled J_R curve where $J_R = C_{DT}\left(\Delta a^{m_{DT}}\right)$ [in-kips/in^2]

m_DT= exponent for sampled J_R curve where $J_R = C_{DT}\left(\Delta a^{m_{DT}}\right)$ [-]

da0= accumulated flaw advancement under stable ductile tearing [in]

P_T0= cumulative probability used in sampling for T0 (IDT_OPTION=1)

P_JIc= cumulative probability used in sampling for JIc (IDT_OPTION=1)

P_m= cumulative probability used in sampling for m_DT (IDT_OPTION=1)

sflow= sampled flow stress [ksi]

ARREST.OUT file (continued) statistics at end of file

```
           ***************************************************
           ***************************************************
           *               STABLE ARREST STATISTICS          *
           ***************************************************
           ***************************************************

                          NUMBER OF OCCASIONS
                        WHEN SIMULATED RPV HAD

                          X STABLE      No. of
                        CRACK ARRESTS     RPVs

                              1          471
                              2          348
                              3          214
                              4          209
                              5          141
                              6          137
                              7          108
                              8           77
                              9           80
                             10           65
                             11           56
                             12           54
                             13           52
                             14           48
                             15           39
                             16           48
                             17           38
                             18           25
                             19           30
                             20           22
                             21           20
                             22           20
                             23           13
                             24           17
                             25           18
                             26            9
                             27           16
                             28           11
                             29           20
                             30           14
                             31           12
                             32            8
                             33            8
                             34           10
                             35            8
                             36            7
                             37            9
                             38            5
                             39            4
                             40            2
                             41            2
                             42            3
                             43            3
                             44            1
                             45            2
                             49            5
                             50            1
                             55            1
                             56            2
                             58            1

      Note: One Occasion is 1 simulated RPV subjected to 1 transient

          ****************************************************
          * HISTOGRAM OF CRACK DEPTHS AT WHICH STABLE ARRESTS *
          *         PREDICTED TO OCCUR FOR EACH TRANSIENT      *
          ****************************************************

        TRANSIENT NUMBER =  1 TRANSIENT SEQUENCE NUMBER=   7

                       DEPTH       % OF STABLE ARRESTS

                       0.402            0.00
                       0.482            0.00
                       0.563            0.00
                       0.643            0.00
                       0.723            0.00
```

FLAWNO.OUT

```
              FAVPFM INPUT FILE NAME   = favpfm.in
              FAVLOAD OUTPUT FILE NAME = FAVLoad.out
      SURF-BREAKING FLAW CHARACTERIZATION DATASET FILE NAME  = S.DAT
      EMBEDDED WELD FLAW CHARACTERIZATION DATASET FILE NAME  = W.DAT
      EMBEDDED PLATE FLAW CHARACTERIZATION DATASET FILE NAME = P.DAT
      FAVPFM OUTPUT FILE NAME  = favpfm.out

                   REPORTING FROM SUBROUTINE GEOMQA:

         ***************************************************
             REPORT CLAD SURFACE AREA WHICH IS USED IN THE
            DETERMINATION OF THE NUMBER OF SURFACE BREAKING
                         CATEGORY 1 FLAWS
         ***************************************************

                      MAJOR          AREA ON RPV
                      REGION       INSIDE SURFACE
                                    (SQUARE FEET)

                         1              0.587
                         2              0.587
                         3              0.946
                         4              0.946
                         5              4.282
                         6            105.038
                         7            105.038
                         8            169.372
                         9            169.372

         ***************************************************
            REPORT WELD FUSION LINE AREA WHICH IS USED IN
          THE DETERMINATION OF THE NUMBER OF EMBEDDED FLAWS
                          IN WELDED REGIONS
         ***************************************************

                       USER-INPUT     CAT 2 FLAW     CAT3 FLAW
            MAJOR     WELD FUSION    WELD FUSION    WELD FUSION
            REGION     LINE AREA      LINE AREA      LINE AREA
                     (SQUARE FEET)  (SQUARE FEET)  (SQUARE FEET)

               1         3.373          0.843          1.686
               2         3.373          0.843          1.686
               3         5.439          1.360          2.719
               4         5.439          1.360          2.719
               5        28.380          7.095         14.190
NOTES:

(1) USER-INPUT FUSION LINE AREA IS FOR ONE SIDE OF WELD

(2) CATEGORY 2 FUSION LINE AREA IS IN THE FIRST 1/8th OF
    RPV WALL - ACCOUNTS FOR BOTH SIDES OF WELD

(3) CATEGORY 3 FUSION LINE AREA IS BETWEEN FIRST 1/8 AND 3/8 OF
    RPV WALL - ACCOUNTS FOR BOTH SIDES OF WELD

THIS IS CONSISTENT WITH DEFINITIONS OF CATEGORIES 2 AND 3 EMBEDDED FLAWS
FOR IHEAT = 1


         ***************************************************
               REPORT PLATE VOLUME WHICH IS USED IN THE
            DETERMINATION OF THE NUMBER OF EMBEDDED FLAWS
                         IN PLATE REGIONS
         ***************************************************

                      MAJOR             PLATE
                      REGION           VOLUME
                                   (CUBIC  FEET)

                         6             72.574
                         7             72.574
                         8            117.024
                         9            117.024

                   REPORTING FROM SUBROUTINE FLWDIS:

         ***************************************************
             REPORT NUMBER OF FLAWS IN EACH MAJOR REGION
```

FLAWSIZE.OUT

```
           FAVPFM INPUT FILE NAME   = favpfm.in
           FAVLOAD OUTPUT FILE NAME = FAVLoad.out
   SURF-BREAKING FLAW CHARACTERIZATION DATASET FILE NAME  = S.DAT
   EMBEDDED WELD FLAW CHARACTERIZATION DATASET FILE NAME  = W.DAT
   EMBEDDED PLATE FLAW CHARACTERIZATION DATASET FILE NAME = P.DAT
   FAVPFM OUTPUT FILE NAME  = favpfm.out

       FLAW SIZE-DISTRIBUTION HISTOGRAMS FOR CATEGORIES 1-3 FOR FLAW FILE    1
          DERIVED FROM INPUT FLAW CHARACTERIZATION FILES

           CATEGORY 1          CATEGORY 2          CATEGORY 3
   DEPTH  WELD   PLATE        WELD   PLATE        WELD   PLATE
            %         %         %        %          %         %

0.0804    0.0000    0.0000   91.9564   75.7314   91.9564   75.7314
0.1607    0.0000    0.0000    7.0583   23.3408    7.0583   23.3408
0.2411  100.0000  100.0000    0.6743    0.8302    0.6743    0.8302
0.3214    0.0000    0.0000    0.1906    0.0976    0.1906    0.0976
0.4018    0.0000    0.0000    0.0557    0.0000    0.0557    0.0000
0.4822    0.0000    0.0000    0.0238    0.0000    0.0238    0.0000
0.5625    0.0000    0.0000    0.0135    0.0000    0.0135    0.0000
0.6429    0.0000    0.0000    0.0087    0.0000    0.0087    0.0000
0.7232    0.0000    0.0000    0.0059    0.0000    0.0059    0.0000
0.8036    0.0000    0.0000    0.0040    0.0000    0.0040    0.0000
0.8840    0.0000    0.0000    0.0028    0.0000    0.0028    0.0000
0.9643    0.0000    0.0000    0.0019    0.0000    0.0019    0.0000
1.0447    0.0000    0.0000    0.0013    0.0000    0.0013    0.0000
1.1250    0.0000    0.0000    0.0009    0.0000    0.0009    0.0000
1.2054    0.0000    0.0000    0.0006    0.0000    0.0006    0.0000
1.2858    0.0000    0.0000    0.0004    0.0000    0.0004    0.0000
1.3661    0.0000    0.0000    0.0003    0.0000    0.0003    0.0000
1.4465    0.0000    0.0000    0.0002    0.0000    0.0002    0.0000
1.5268    0.0000    0.0000    0.0001    0.0000    0.0001    0.0000
1.6072    0.0000    0.0000    0.0001    0.0000    0.0001    0.0000
1.6876    0.0000    0.0000    0.0001    0.0000    0.0001    0.0000
1.7679    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
1.8483    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
1.9286    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.0090    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.0894    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.1697    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.2501    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.3304    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.4108    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.4912    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.5715    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.6519    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.7322    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.8126    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.8930    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
2.9733    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.0537    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.1340    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.2144    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.2948    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.3751    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.4555    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.5358    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.6162    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.6966    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.7769    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.8573    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
3.9376    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.0180    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.0984    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.1787    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.2591    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.3394    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.4198    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.5002    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.5805    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.6609    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.7412    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.8216    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.9020    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
4.9823    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
5.0627    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
5.1430    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

History_001_007.out

```
Plant ID        = favpfm @  60. EFPY
Transient No.   = 001
TH Sequence No. = 007
PFM model consists of  9 major regions.

                               Mean Value of
  Major Region   Product Form     RTNDT(u)
     1            axial weld      -56.00
     2            axial weld      -56.00
     3            axial weld      -56.00
     4            axial weld      -56.00
     5            circ. weld      -56.00
     6              plate          27.00
     7              plate          20.00
     8              plate          73.00
     9              plate          43.00

***************************************************************
*                       Data Format                           *
***************************************************************
*  1st column = RPV trial number                              *
*  2nd column = major region number                           *
*  3rd column = sampled value of unirradiated RTNDT           *
*  4th column = sampled value of DRTepistemic                 *
*  5th column = number of axial flaws for which CPI > 0       *
*  6th column = CPI for axial cracks in this region           *
*  7th column = CPF for axial cracks in this region           *
*  8th column = number of circ. flaws for which CPI > 0       *
*  9th column = CPI for circ. cracks in this region           *
* 10th column = CPF for circ. cracks in this region           *
***************************************************************
*-------------------------------------------------------------------------------
*  (1) (2)    (3)    (4)   (5)     (6)        (7)     (8)     (9)       (10)
*-------------------------------------------------------------------------------
     1   1  -43.28  18.74     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     1   2  -41.09  17.46     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     1   3 -104.02 -21.05     2 1.7493E-06 1.7360E-07     0 0.0000E+00 0.0000E+00
     1   4  -66.52  19.37     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     1   5  -64.54  22.95     0 0.0000E+00 0.0000E+00    10 2.4743E-04 1.0495E-08
     1   6   27.00  65.11     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     1   7   20.00 -10.29     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     1   8   73.00   0.81     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     1   9   43.00  30.85     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     2   1  -59.17   8.56     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
     2   2  -42.02   2.08     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
                                             .
                                             .
                                             .
   800   1  -67.28   2.93     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
   800   2  -44.04  35.34     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
   800   3  -58.99 107.84     1 6.8049E-10 2.3934E-10     0 0.0000E+00 0.0000E+00
   800   4  -48.34  31.19     5 1.5364E-04 3.8197E-05     0 0.0000E+00 0.0000E+00
   800   5  -53.95  16.44     0 0.0000E+00 0.0000E+00    22 4.9255E-03 1.4290E-08
   800   6   27.00  44.83     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
   800   7   20.00  40.87     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00
   800   8   73.00 -14.21     2 4.3105E-08 2.9737E-08     4 2.9849E-05 0.0000E+00
   800   9   43.00  59.49     0 0.0000E+00 0.0000E+00     0 0.0000E+00 0.0000E+00

***************************************************************
        Summary Data Format
***************************************************************
*  1st column = major region number                           *
*  2nd column = mean CPI for all axial flaws                  *
*  3rd column = mean CPF for all axial flaws                  *
*  4th column = mean CPI for all circ. flaws                  *
*  5th column = mean CPF for all circ. flaws                  *
***************************************************************
*--------------------------------------------------
*   (1)     (2)        (3)        (4)        (5)
*--------------------------------------------------
     1  2.2925E-05 2.7052E-06 0.0000E+00 0.0000E+00
     2  1.2930E-05 1.6615E-06 0.0000E+00 0.0000E+00
     3  2.4798E-04 4.2143E-05 0.0000E+00 0.0000E+00
     4  4.8499E-04 7.5957E-05 1.7613E-05 6.5088E-12
     5  0.0000E+00 0.0000E+00 2.0435E-03 9.5477E-07
     6  3.0595E-08 1.5210E-08 1.4556E-04 5.8439E-12
     7  7.8208E-09 2.7636E-09 1.7461E-05 8.1872E-12
     8  3.6250E-05 1.9089E-05 1.6818E-03 1.8073E-06
     9  1.2527E-07 6.4594E-08 3.7449E-04 8.2994E-09
```

2.7 FAVOR Post-Processing Module – FAVPost Output

FAVPost reads in three files: (1) FAVPOST.IN containing PRA transient-initiating frequency histogram data, (2) INITIATE.DAT (or another filename determined by user) that contains the conditional-probability-of-initiation matrix for all transients and all vessel simulations, and (3) FAILURE.DAT (or another filename determined by user) that contains the conditional-probability-of-failure matrix for all transients and all vessel simulations. The following pages present a partial listing of an example of the FAVPost output file. Two additional files, called PDFCPI.OUT and PDFCPF.OUT, are automatically generated containing histograms of the discrete distributions for *CPI* and *CPF* for each transient.

FAVPOST.OUT contains first a summary of the (1) mean conditional probability of initiation and the 95th and 99th percentiles for all transients and (2) the mean conditional probability of vessel failure and the 95th and 99th percentiles for all transients. The next section in FAVPOST.OUT contains a histogram (probability density distribution function) for the frequency of crack initiation. Both the relative density and cumulative distribution are given in this section along with several descriptive statistics including the 5th percentile, the median, 95th percentile, 99th percentile, 99.9th percentile, the mean, the standard deviation., the standard error, the unbiased and biased variance, two measures of skewness, and the kurtosis. A histogram and descriptive statistics are then presented for the frequency of through-wall cracking (designated as vessel failure). Finally, a fractionalization of the frequencies of crack initiation and vessel failure are given as functions of transient, material, flaw category, flaw orientation, and major beltline regions.

The statistical data in the form of relative densities, cumulative probabilities, and estimated percentiles presented in tabulated histograms and summary tables for the various discrete distributions calculated by FAVOR are estimated both by binning procedures and through the construction of empirical distribution functions as described in the following.

Construction of Empirical Distribution Functions Using Order Statistics in FAVPost

Following the discussion in ref. [27], consider the observations $\left(x_1,\ldots,x_n\right)$ from an unknown population *assumed to have a probability density* $f\left(x\right)$. These sampled observations can be ordered by rank such that

$$\begin{aligned}
x_{(1)} &= \text{ smallest of } \left(\mathrm{x}_1,\ldots,x_n\right), \\
x_{(2)} &= \text{ second smallest of } \left(\mathrm{x}_1,\ldots,x_n\right), \\
&\vdots \\
x_{(k)} &= \text{ k-th smallest of } \left(\mathrm{x}_1,\ldots,x_n\right), \\
&\vdots \\
x_{(n)} &= \text{ largest of } \left(\mathrm{x}_1,\ldots,x_n\right).
\end{aligned}$$

where the quantities $x_{(1)}, x_{(2)}, \ldots x_{(n)}$ are random variates and are called the *order statistics* of the sample. The quantity $x_{(1)}$ is the *smallest* element in the sample, $x_{(n)}$ is the *largest*, $x_{(k)}$ is the *kth-order statistic*, and $x_{(m+1)}$ is the *median* of a sample size $n = 2m + 1$. Since the probability density, $f(x)$, for the unknown population is assumed *a priori* to exist, the population's *cumulative distribution function,* c.d.f, $F(x)$, can, therefore, be defined by

$$F(x) = \int_{-\infty}^{x} f(x)\,dx \tag{9}$$

The estimator applied in FAVPost for $F(x)$ is the Kaplan-Meier estimate [28] $\hat{F}\left(x_{(i)}\right) = i/n$. [2]

Following the recommendations in ref. [29], FAVPost uses the data values (sorted by rank) for *CPI*, *CPF, Frequency of Crack Initiation,* and *Through-Wall Cracking Frequency* to construct mixed empirical-exponential distribution functions from which cumulative probabilities with their corresponding percentiles can be estimated. As discussed in [29], one difficulty with using a purely empirical c.d.f. based on the estimator $\hat{F}\left(x_{(i)}\right) = i/n$ is that it is discrete and when interpolated can possibly provide a poor fit to the true underlying distribution in the right tail. Fitting a shifted exponential distribution to represent the extreme right tail alleviates this problem [29]. The shifted exponential distribution for the right tail also replaces the unrealistic estimate of $\hat{F}\left(x_{(n)}\right) = n/n = 1$. The following procedure is applied in FAVPost (see Fig. 18).

---

[2] Other estimators are also in common use, including the *mean rank* $\hat{F}\left(x_{(i)}\right) = i/(n+1)$ and *median rank* $\hat{F}\left(x_{(i)}\right) = (i-0.3)/(n+0.4)$ estimators.

Construction of Mixed Empirical/Exponential Distribution Functions

(1) Order the data by rank such that $X_1 \le X_2 \le \cdots \le X_n$.

(2) Fit a piecewise linear c.d.f. to the first $n-k$ ordered data points and a shifted exponential to the *k* largest data points. Assuming $F(0)=0$ and defining $X_0 = 0$, the constructed mixed empirical-exponential c.d.f. is

$$F(t) = \begin{cases} \dfrac{i}{n} + \dfrac{\left(t - X_{(i)}\right)}{n\left(X_{(i+1)} - X_{(i)}\right)} & \text{for } X_{(i)} \le t \le X_{(i+1)}, i = 0,1,\ldots,n-k-1 \\ 1 - \left(\dfrac{k}{n}\right)\exp\left[-\dfrac{\left(t - X_{(n-k)}\right)}{\theta}\right] & \text{for } t > X_{(n-k)} \end{cases}$$

where **(10)**

$$\theta = \frac{\left[\left(\frac{1}{2} - k\right) X_{(n-k)} + \sum_{i=n-k+1}^{n} X_{(i)}\right]}{k}$$

The value of *k* is selected automatically in FAVPost such that only cumulative probabilities greater than 0.999 are estimated by the fitted shifted-exponential distribution. The mean of this mixed distribution is $\left(X_{(1)} + X_{(2)} + \cdots + X_{(n)}\right)/n$ for $1 \le k \le n$, thus recovering the original sample mean. An estimator for the variance is

$$\operatorname{var}(X) = \frac{1}{3n}\left[2\sum_{i=1}^{n-k-1} X_{(i)}^2 + \sum_{i=1}^{n-k-1} X_{(i)}X_{(i+1)} + X_{(n-k)}^2\right] + \frac{k}{n}\left[\left(\theta + X_{(n-k)}\right)^2 + \theta^2\right] - \left[\frac{1}{n}\sum_{i=1}^{n} X_{(i)}\right]^2 \qquad \textbf{(11)}$$

Given a specified probability $0 < P_i < 1$, then the corresponding percentile (quantile) is calculated by:

(1) if $P_i > 1 - \dfrac{k}{n}$, then estimate from the fitted exponential right tail

$$X_{P_i} = X_{n-k} - \theta \ln\left[\frac{n\left(1-P_i\right)}{k}\right] \tag{12}$$

(2) else if $P_i \le 1 - \dfrac{k}{n}$, then estimate from a piecewise linear interpolation within the empirical distribution

$$X_{P_i} = \left(P_i - \frac{I}{n}\right)\left(X_{I+1} - X_I\right) + X_I \tag{13}$$

where I satisfies the relation

$$I \le nP_i < I + 1$$

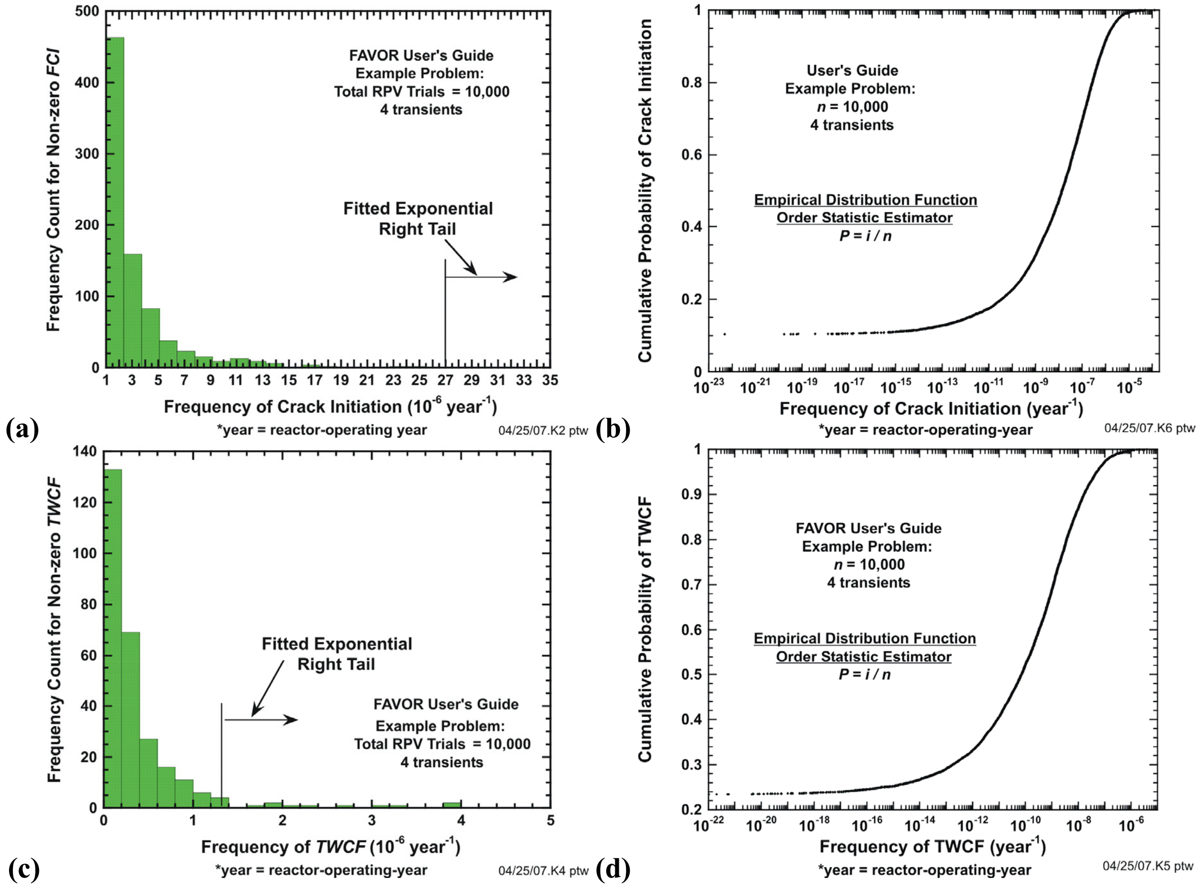
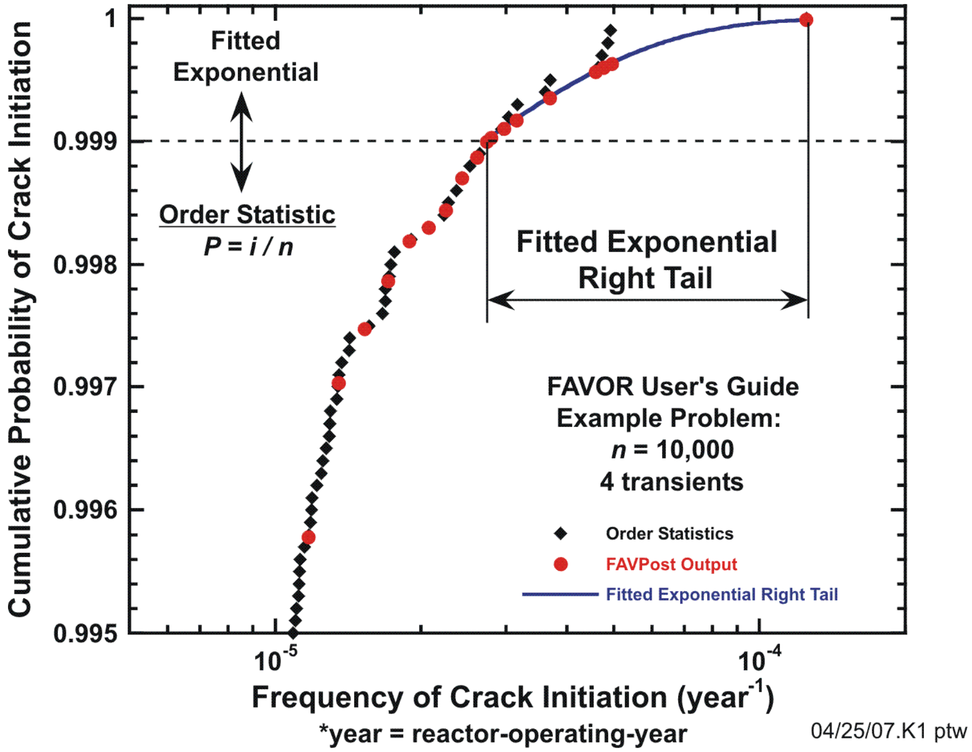
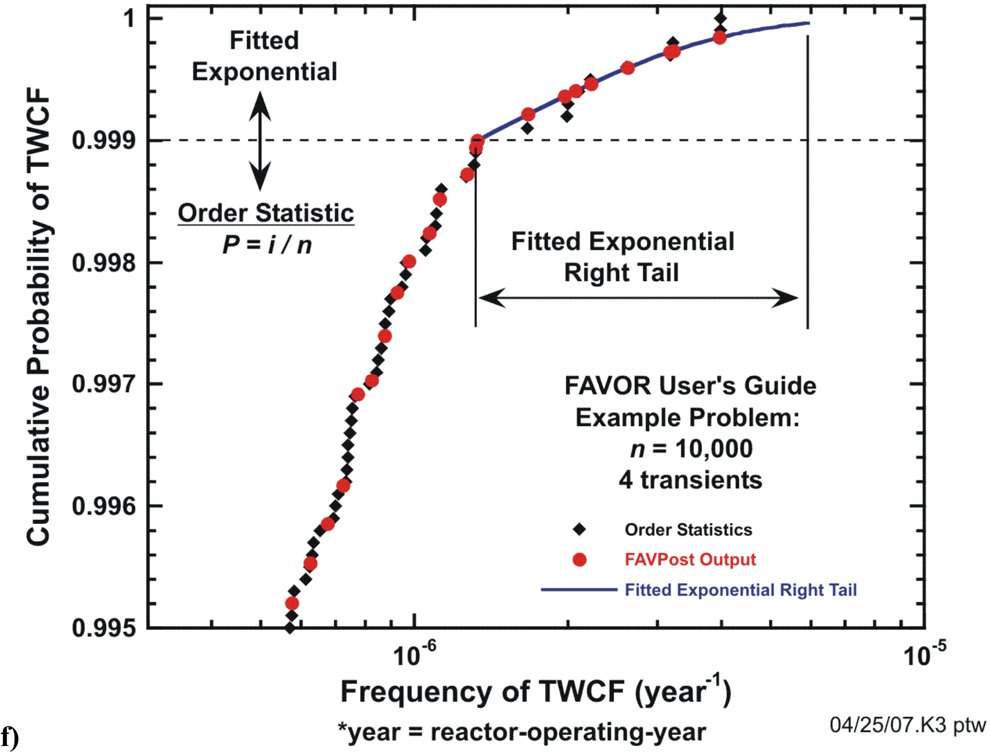


Fig. 18. Empirical distribution functions for *n* = 10,000 example problem: (a) histogram and (b) semi-log plot of empirical c.d.f. for frequency of crack initiation, (c) histogram and (d) semi-log plot empirical c.d.f. for through-wall cracking frequency.



(e)



(f)

Fig. 18. (continued) Semi-log plots of empirical distribution functions with fitted exponential right tail for n = 10,000 example problem: (e) mixed empirical/exponential c.d.f. for frequency of crack initiation and (f) mixed empirical/exponential c.d.f. for through-wall cracking frequency.

The following *descriptive statistics* are calculated and reported in the FAVPost output:

m_1 – 1st crude moment of the sample (sample mean) = $\bar{x} = \dfrac{\sum_{i=1}^{n} x_i}{n}$

unbiased variance $s^2 = \dfrac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}$

biased variance = $\dfrac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}$

standard deviation, $s = \sqrt{\dfrac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}$

standard error = $\sqrt{\dfrac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n\left(n-1\right)}}$

moment coefficient of skewness, $\sqrt{\beta_1} = \dfrac{m_3}{\sqrt{\left(m_2\right)^3}}$; $m_2 = \sum_{i=1}^{n}\dfrac{\left(x_i - \bar{x}\right)^2}{n}$; $m_3 = \sum_{i=1}^{n}\dfrac{\left(x_i - \bar{x}\right)^3}{n}$

Pearson's second coefficient of skewness = $3\left(\dfrac{\bar{x} - median}{s}\right)$

moment coefficient of kurtosis, $\beta_2 = \dfrac{m_4}{(m_2)^2}$; $m_2 = \sum_{i=1}^{n}\dfrac{\left(x_i - \bar{x}\right)^2}{n}$; $m_4 = \sum_{i=1}^{n}\dfrac{\left(x_i - \bar{x}\right)^4}{n}$

FAVPOST.OUT

```
              *************************************************
              *                                               *
              *               WELCOME TO FAVOR                *
              *                                               *
              *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE     *
              *                 VERSION 16.1                  *
              *                                               *
              *     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.                                  *
         ************************************************************





               Begin echo of FAVPost input data deck

no./col. 1.......10........20........30........40........50........60........70........80
    1    ********************************************************************************
    2    *      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY           *
    3    ********************************************************************************
    4    *                EXAMPLE INPUT DATASET FOR FAVPost, v16.1                      *
    5    ********************************************************************************
    6    *  ====================                                                        *
    7    *     Record CNTL                                                              *
    8    *  ====================                                                        *
    9    *------------------------------------------------------------------------------*
   10    *  NTRAN = NUMBER OF T-H TRANSIENTS                                            *
   11    *------------------------------------------------------------------------------*
   12    ********************************************************************************
   13    CNTL  NTRAN=4
   14    ********************************************************************************
   15    *  ====================                                                        *
   16    *     Record ITRN                                                              *
   17    *  ====================                                                        *
   18    *------------------------------------------------------------------------------*
   19    *  ITRAN = PFM TRANSIENT NUMBER                                                *
   20    *  ITRAN = TRANSIENT NUMBER                                                    *
   21    *  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION             *
   22    *  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                   *
   23    *------------------------------------------------------------------------------*
   24    ********************************************************************************
   25    ITRN ITRAN=1  NHIST=20    ISEQ=7
   26    ********************************************************************************
   27    *------------------------------
   28    * freq[events/year] Density [%]
   29    *------------------------------
   30         2.11E-07          0.50
   31         3.01E-07          0.50
   32         5.19E-07          1.50
   33         7.92E-07          2.50
   34         1.32E-06          5.00
   35         2.43E-06         10.00
   36         3.08E-06          5.00
   37         3.79E-06          5.00
   38         5.55E-06         10.00
```

FAVPOST.OUT (continued)

```
           Range                             = 3.3019E-07

           Number of Simulations             =     30

           5th Percentile                    = 0.0000E+00
           Median                            = 6.4017E-10
           95.0th Percentile                 = 1.6982E-07
           99.0th Percentile                 = 3.0989E-07
           99.9th Percentile                 = 5.1028E-07

           Mean                              = 3.0950E-08
           Standard Deviation                = 7.3242E-08
           Standard Error                    = 1.3372E-08
           Variance (unbiased)               = 5.3643E-15
           Variance (biased)                 = 5.1855E-15
           Moment Coeff. of Skewness         = 2.9456E+00
           Pearson's 2nd Coeff. of Skewness  = 1.2677E+00
           Kurtosis                          = 1.1328E+01


 ************************************************************
 *      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)       *
 *      FOR THROUGH-WALL CRACKING FREQUENCY (FAILURE)       *
 ************************************************************
          FREQUENCY OF         RELATIVE    CUMULATIVE
          TWC FAILURES         DENSITY    DISTRIBUTION
   (PER REACTOR-OPERATING YEAR)  (%)          (%)
           0.0000E+00         73.3333       73.3333
           1.1464E-09         16.6667       84.7477
           3.4391E-09          6.6667       96.8066
           5.7319E-09          3.3333       99.3314


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

           Minimum                           = 0.0000E+00
           Maximum                           = 6.6424E-09
           Range                             = 6.6424E-09

           Number of Simulations             =     30

           5th Percentile                    = 0.0000E+00
           Median                            = 0.0000E+00
           95.0th Percentile                 = 2.7817E-09
           99.0th Percentile                 = 5.1416E-09
           99.9th Percentile                 = 8.5178E-09

           Mean                              = 4.8876E-10
           Standard Deviation                = 1.4473E-09
           Standard Error                    = 2.6425E-10
           Variance (unbiased)               = 2.0948E-18
           Variance (biased)                 = 2.0250E-18
           Moment Coeff. of Skewness         = 3.2312E+00
           Pearson's 2nd Coeff. of Skewness  =-3.1383E-01
           Kurtosis                          = 1.2937E+01


 ************************************************************
 *  FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION      *
 *      AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -     *
 *       WEIGHTED BY TRANSIENT INITIATING FREQUENCIES       *
 ************************************************************
                        % of total         % of total
                       frequency of       frequency of
                     crack initiation    of TWC failure
             7            3.47                0.33
             9            1.05                0.00
            56           95.42               99.16
            97            0.07                0.50
                TOTALS  100.00              100.00




 1.045     0.00     0.00     0.00     0.00     0.00     0.00
 1.125     0.00     0.00     0.00     0.00     0.00     0.00
 1.205     0.00     0.00     0.00     0.00     0.00     0.00
 1.286     0.00     0.00     0.00     0.00     0.00     0.00
 1.366     0.00     0.00     0.00     0.00     0.00     0.00
 1.446     0.00     0.00     0.00     0.00     0.00     0.00
 1.527     0.00     0.00     0.00     0.00     0.00     0.00
 1.607     0.00     0.00     0.00     0.00     0.00     0.00
 1.688     0.00     0.00     0.00     0.00     0.00     0.00
 1.768     0.00     0.00     0.00     0.00     0.00     0.00
 1.848     0.00     0.00     0.00     0.00     0.00     0.00
TOTALS     0.00    58.45     0.00     0.00    37.77     0.00
```

FAVPOST.OUT (continued)

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

REGION   (MAX)   flaws  crack initiation  cleavage ductile   total
   1    160.02   2.29          0.00          0.00     0.00     0.00
   2    160.02   2.29          0.24          0.40     0.08     0.48
   3    150.36   3.70         12.41         21.22    12.70    33.93
   4    150.36   3.70          0.93          2.95     0.42     3.36
   5     67.56  19.29         44.86          0.00     0.00     0.00
   6    195.48  13.15          0.00          0.00     0.00     0.00
   7    166.28  13.15          0.00          0.00     0.00     0.00
   8    226.00  21.21         34.96         57.84     4.30    62.14
   9    196.00  21.21          6.60          0.10     0.00     0.10
        TOTALS  99.99        100.00         82.50    17.50   100.00

    ************************************************************
    *    FRACTIONALIZATION OF FREQUENCY OF CRACK INITIATION    *
    *      AND THROUGH-WALL CRACKING FREQUENCY (FAILURE) -     *
    *                         BY                               *
    *               RPV BELTLINE MAJOR REGION                  *
    *                   BY CHILD SUBREGION                     *
    *                                                          *
    *       WEIGHTED BY % CONTRIBUTION OF EACH TRANSIENT       *
    *           TO FREQUENCY OF CRACK INITIATION AND           *
    *        THROUGH-WALL CRACKING FREQUENCY (FAILURE)         *
    ************************************************************
                                                 % of total
                 % of      % of total        through-wall crack
MAJOR    RTndt   total    frequency of           frequency
REGION   (MAX)   flaws  crack initiation  cleavage ductile   total
   1    160.02   2.29          0.00          0.00     0.00     0.00
   2    160.02   2.29          0.00          0.00     0.00     0.00
   3    150.36   3.70          0.00          0.00     0.00     0.00
   4    150.36   3.70          0.00          0.00     0.00     0.00
   5     67.56  19.29          0.00          0.00     0.00     0.00
   6    195.48  13.15          0.41          0.40     0.08     0.48
   7    166.28  13.15          0.00          0.00     0.00     0.00
   8    226.00  21.21         92.26         82.00    17.43    99.43
   9    196.00  21.21          7.32          0.10     0.00     0.10
        TOTALS  99.99        100.00         82.49    17.51   100.00


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

                  % of total frequency      % of total through-wall
                   of crack initiation          crack frequency
        FLAW
        DEPTH    CAT I    CAT 2    CAT 3    CAT 1    CAT 2    CAT 3
        (in)     flaws    flaws    flaws    flaws    flaws    flaws
        0.080     0.00     0.10     0.00     0.00     0.12     0.00
        0.161     0.00    57.37     0.00     0.00    37.17     0.00
        0.241     0.00     0.25     0.00     0.00     0.48     0.00
        0.321     0.00     0.18     0.00     0.00     0.00     0.00
        0.402     0.00     0.55     0.00     0.00     0.00     0.00
        0.482     0.00     0.00     0.00     0.00     0.00     0.00
        0.563     0.00     0.00     0.00     0.00     0.00     0.00
        0.643     0.00     0.00     0.00     0.00     0.00     0.00
        0.723     0.00     0.00     0.00     0.00     0.00     0.00
```

```
     0.804      0.00      0.00      0.00      0.00      0.00      0.00
     0.884      0.00      0.00      0.00      0.00      0.00      0.00
     0.964      0.00      0.00      0.00      0.00      0.00      0.00
     1.045      0.00      0.00      0.00      0.00      0.00      0.00
     1.125      0.00      0.00      0.00      0.00      0.00      0.00
     1.205      0.00      0.00      0.00      0.00      0.00      0.00
     1.286      0.00      0.00      0.00      0.00      0.00      0.00
     1.366      0.00      0.00      0.00      0.00      0.00      0.00
     1.446      0.00      0.00      0.00      0.00      0.00      0.00
     1.527      0.00      0.00      0.00      0.00      0.00      0.00
     1.607      0.00      0.00      0.00      0.00      0.00      0.00
     1.688      0.00      0.00      0.00      0.00      0.00      0.00
     1.768      0.00      0.00      0.00      0.00      0.00      0.00
     1.848      0.00      0.00      0.00      0.00      0.00      0.00
    TOTALS      0.00     44.86      0.00      0.00      0.00      0.00

                               ******************
                               *   CIRC. PLATE  *
                               ******************

               % of total frequency      % of total through-wall
                of crack initiation           crack frequency
     FLAW
     DEPTH     CAT I     CAT 2     CAT 3     CAT 1     CAT 2     CAT 3
     (in)      flaws     flaws     flaws     flaws     flaws     flaws
     0.080      0.00      0.00      0.00      0.00      0.00      0.00
     0.161      0.00      0.00      0.00      0.00      0.00      0.00
     0.241     37.08      0.00      0.00      0.49      0.00      0.00
     0.321      0.00      0.57      0.00      0.00      0.00      0.00
     0.402      0.00      0.00      0.00      0.00      0.00      0.00
     0.482      0.00      0.00      0.00      0.00      0.00      0.00
     0.563      0.00      0.00      0.00      0.00      0.00      0.00
    TOTALS     37.08      0.57      0.00      0.49      0.00      0.00

                  DATE: 19-Nov-2012  TIME: 11:15:43
     1.286      0.00      0.34      0.00      0.00      0.14      0.00
     1.366      0.00      0.14      0.00      0.00      0.24      0.00
     1.446      0.00      0.01      0.00      0.00      0.08      0.00
     1.527      0.00      0.00      0.00      0.00      0.10      0.00
     1.607      0.00      0.06      0.00      0.00      0.56      0.00
     1.688      0.00      0.02      0.00      0.00      0.02      0.00
     1.768      0.00      0.00      0.00      0.00      0.00      0.00
     1.848      0.00      0.00      0.00      0.00      0.00      0.00
    TOTALS      3.31     50.96      0.00      1.03     68.84      0.05

                               ******************
                               * PLATE MATERIAL *
                               ******************

               % of total frequency      % of total through-wall
                of crack initiation           crack frequency
     FLAW
     DEPTH     CAT I     CAT 2     CAT 3     CAT 1     CAT 2  CAT 3
     (in)      flaws     flaws     flaws     flaws     flaws  flaws
     0.080      0.00      0.00      0.00      0.00      0.01      0.00
     0.161      0.00      0.12      0.00      0.00      0.90      0.00
     0.241     45.17      0.26      0.00     24.87      2.86      0.00
     0.321      0.00      0.18      0.00      0.00      1.45      0.00
    TOTALS     45.17      0.56      0.00     24.87      5.21      0.00
```

3. Example Case

Example input and output datasets have been included in the distribution package to illustrate the various deterministic and probabilistic capabilities that are available with FAVOR.

Deterministic – generation of time history of fracture-related variables at specified through-wall location

Table 4 provides a listing of FAVLoad input/output datasets for various RPV geometries subjected to cool-down and heat-up transients that are included in the distribution package.

Table 5 provides a listing of FAVPFM deterministic input/output datasets that are included in the distribution package for illustrating how to generate time histories of fracture-related variables for various surface breaking flaw geometries, orientations, and vessel geometries.

Table 6 provides a listing of FAVPFM deterministic input/output datasets that are included in the distribution package for illustrating how to generate time histories of fracture-related variables for various embedded flaw geometries, thru-wall locations, orientations, and vessel geometries.

Deterministic – generation of through-wall spatial profile of fracture-related variables at specified transient time

Table 7 provides a listing of FAVPFM deterministic input/output datasets that are included in the distribution package that illustrate how to generate through-wall spatial profiles of fracture-related variables for various surface-breaking flaw geometries, orientations, and vessel geometries.

Example FAVPFM files for Performing Probabilistic Fracture Mechanics (PFM) Analyses

Example PFM_flaw_population_1

This example performs a PFM analysis for a large embrittlement map (developed for the RPV beltline description shown in Figure 19) subjected to four cool-down transients. Since the flaw population model (IPFLAW = 1 on CNT1 record) is set to one, all surface breaking flaws postulated in the surface flaw characterization file (**s.dat**) are placed on the inner surface of the RPV and only those embedded flaws that are postulated in the weld (**w.dat**) and plate (**p.dat**) embedded flaw files to reside in the 3/8 of the base metal nearest the inner (wetted) surface are included in the analysis. This is identical to the previous versions of FAVOR and is designed primarily for cool-down transients since these are the typically the flaws of interest in a cool-down transient.

Example PFM_flaw_population_2

This example performs a PFM analysis for a smaller embrittlement map subjected to multiple heat-up transients. These transients are not to be taken as actual postulated transients but are constructed for purely illustrative purposes such that several flaws are initiated thus illustrating (and verifying) the PFM output reports.

Since the flaw population model (IPFLAW = 2 on CNT1 record) is set to two, all surface breaking flaws postulated in the surface flaw characterization file (**s.dat**) are placed on the external surface of the RPV and only those embedded flaws that are postulated in the weld (**w.dat**) and plate (**p.dat**) embedded flaw files to reside in the 3/8 of the base metal nearest the outer surface are included in the analysis.

Example PFM_flaw_population_3

This example performs a PFM analysis for a smaller embrittlement map subjected to both cool-down and heat-up transients. The surface breaking flaw file used in this example problem (**s23.dat** – surface breaking flaws are 23% of wall thickness in depth) is for illustrative purposes only in so far as these flaw geometries result in predicted fractures for both internal and external surface breaking flaws thus illustrating (and verifying) the PFM output reports.

Since the flaw population model (IPFLAW = 3 on CNT1 record) is set to three, the number of postulated surface breaking flaws (in surface flaw characterization file) would be double that of options 1 and 2; evenly divided between internal and external surface breaking flaws. All of the embedded flaws uniformly distributed through the RPV wall thickness would be included in the model; therefore, application of this option results in 8/3 as many embedded flaws as options 1 and 2 as discussed above. Clearly this model is more general, but also takes considerably more computational time to achieve a converged solution.

Partial input listings for the three FAVOR modules are given on the following pages.

Table 4. Example FAVLoad Load Input and Output Datasets

Transient Type	RPV Geometry	FAVLoad input file name	FAVLoad output file name
Cool-down	**$R_i/t \sim 10$**	**RT10cool.in**	**RT10cool.out**
Cool-down	**$R_i/t \sim 15$**	**RT15cool.in**	**RT15cool.out**
Cool-down	**$R_i/t \sim 20$**	**RT20cool.in**	**RT20cool.out**
Heat-up	**$R_i/t \sim 10$**	**RT10heat.in**	**RT10heat.out**
Heat-up	**$R_i/t \sim 15$**	**RT15heat.in**	**RT15heat.out**
Heat-up	**$R_i/t \sim 20$**	**RT20heat.in**	**RT20heat.out**

Table 5. Example FAVPFM Input and Output Files for Deterministic Time Histories for Various Surface Breaking Flaws Geometries, Orientations, and Vessel Geometries

Transient Type	Vessel geometry (R_i/t)	Flaw Type	Flaw Orient	FAVPFM Input File name	FAVLoad output File name	FAVPFM output File name
Cool-down	**10**	**ISB**	**Axial**	**THinSBax.in**	**RT10cool.out**	**THinSBax10.out**
Cool-down	**15**	**ISB**	**Axial**	**THinSBax.in**	**RT15cool.out**	**THinSBax15.out**
Cool-down	**20**	**ISB**	**Axial**	**THinSBax.in**	**RT20cool.out**	**THinSBax20.out**
Cool-down	**10**	**ISB**	**Circ**	**THinSBcr.in**	**RT10cool.out**	**THinSBcr10.out**
Cool-down	**15**	**ISB**	**Circ**	**THinSBcr.in**	**RT15cool.out**	**THinSBcr15.out**
Cool-down	**20**	**ISB**	**Circ**	**THinSBcr.in**	**RT20cool.out**	**THinSBcr20.out**
Heat-up	**10**	**ESB**	**Axial**	**THexSBax.in**	**RT10heat.out**	**THexSBax10.out**
Heat-up	**15**	**ESB**	**Axial**	**THexSBax.in**	**RT15heat.out**	**THexSBax15.out**
Heat-up	**20**	**ESB**	**Axial**	**THexSBax.in**	**RT20heat.out**	**THexSBax20.out**
Heat-up	**10**	**ESB**	**Circ**	**THexSBcr.in**	**RT10heat.out**	**THexSBcr10.out**
Heat-up	**15**	**ESB**	**Circ**	**THexSBcr.in**	**RT15heat.out**	**THexSBcr15.out**
Heat-up	**20**	**ESB**	**Circ**	**THexSBcr.in**	**RT20heat.out**	**THexSBcr20.out**

Note: ISB is internal surface breaking; ESB is external surface breaking.

Table 6. Example FAVPFM Input and Output Files for Deterministic Time Histories for Various Embedded Flaws Geometries, Orientations

Transient Type	Flaw Type	Flaw Orientation	FAVPFM Input File	FAVLoad output File	FAVPFM output file
Cool-down	Embedded$^{(1)}$	Axial	THinEMax.in	RT10cool.out	THinEMax.out
Cool-down	Embedded$^{(1)}$	Circ	THinEMcr.in	RT10cool.out	THinEMcr.out
Heat-up	Embedded$^{(2)}$	Axial	THexEMax.in	RT10heat.out	THexEMax.out
Heat-up	Embedded$^{(2)}$	Circ	THexEMcr.in	RT10heat.out	THexEMcr.out

(1) Embedded flaw resides in the inner half of RPV wall thickness

(2) Embedded flaw resides in the outer half of RPV wall thickness

Table 7. Example FAVPFM Input and Output Files for Deterministic Through-Wall Spatial Profiles of Fracture-Related Variables for Various Surface Breaking Flaws Geometries, Orientations, and Vessel Geometries

Transient Type	Vessel geometry (R_i/t)	Flaw Type	Flaw Orient	FAVPFM Input File name	FAVLoad output File name	FAVPFM output File name
Cool-down	10	ISB	Axial	TWinSBax.in	RT10cool.out	TWinSBax10.out
Cool-down	15	ISB	Axial	TWinSBax.in	RT15cool.out	TWinSBax15.out
Cool-down	20	ISB	Axial	TWinSBax.in	RT20cool.out	TWinSBax20.out
Cool-down	10	ISB	Circ	TWinSBcr.in	RT10cool.out	TWinSBcr10.out
Cool-down	15	ISB	Circ	TWinSBcr.in	RT15cool.out	TWinSBcr15.out
Cool-down	20	ISB	Circ	TWinSBcr.in	RT20cool.out	TWinSBcr20.out
Heat-up	10	ESB	Axial	TWexSBax.in	RT10heat.out	TWexSBax10.out
Heat-up	15	ESB	Axial	TWexSBax.in	RT15heat.out	TWexSBax15.out
Heat-up	20	ESB	Axial	TWexSBax.in	RT20heat.out	TWexSBax20.out
Heat-up	10	ESB	Circ	TWexSBcr.in	RT10heat.out	TWexSBcr10.out
Heat-up	15	ESB	Circ	TWexSBcr.in	RT15heat.out	TWexSBcr15.out
Heat-up	20	ESB	Circ	TWexSBcr.in	RT20heat.out	TWexSBcr20.out

Note: ISB is internal surface breaking; ESB is external surface breaking.

Example Case FAVLoad input file (partial listing)

```
********************************************************************************
*      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY            *
********************************************************************************
*                EXAMPLE INPUT DATASET FOR FAVLoad, v16.1                       *
********************************************************************************
*  ====================                                                         *
*     Record GEOM                                                               *
*  ====================                                                         *
*-------------------------------------------------------------------------------*
*  IRAD = INTERNAL RADIUS OF PRESSURE VESSEL                               [IN] *
*   W   = THICKNESS OF PRESSURE VESSEL WALL (INCLUDING CLADDING)           [IN] *
*  CLTH = CLADDING THICKNESS                                               [IN] *
*-------------------------------------------------------------------------------*
********************************************************************************
GEOM  IRAD=78.5   W=8.036    CLTH=0.156
********************************************************************************
*  ===========================                                                  *
*     Records BASE and CLAD                                                     *
*  ===========================                                                  *
*    THERMO-ELASTIC MATERIAL PROPERTIES FOR BASE AND CLADDING                   *
*-------------------------------------------------------------------------------*
*     K     = THERMAL CONDUCTIVITY                                [BTU/HR-FT-F] *
*     C     = SPECIFIC HEAT                                         [BTU/LBM-F] *
*     RHO   = DENSITY                                               [LBM/FT**3] *
*     E     = YOUNG'S ELASTIC MODULUS                                    [KSI]  *
*     ALPHA = THERMAL EXPANSION COEFFICIENT                            [F**-1]  *
*     NU    = POISSON'S RATIO                                            [-]    *
*     NTE   = TEMPERATURE DEPENDANCY FLAG                                       *
*     NTE   = 0 ==> PROPERTIES ARE TEMPERATURE INDEPENDENT (CONSTANT)           *
*     NTE   = 1 ==> PROPERTIES ARE TEMPERATURE DEPENDENT                        *
*     IF NTE EQUAL TO 1, THEN ADDITIONAL DATA RECORDS ARE REQUIRED              *
*-------------------------------------------------------------------------------*
********************************************************************************
BASE  K=24.0  C=0.120  RHO=489.00  E=28000  ALPHA=.00000777  NU=0.3  NTE=1
********************************************************************************
*---------------------------
* THERMAL CONDUCTIVITY TABLE
*---------------------------
NBK   NK=16
*---------------------------
 70    24.8
100    25.0
150    25.1
200    25.2
250    25.2
300    25.1
350    25.0
400    25.1
450    24.6
500    24.3
550    24.0
600    23.7
650    23.4
700    23.0
750    22.6
800    22.2
*---------------------------
* SPECIFIC HEAT TABLE
*---------------------------
NBC   NC=16
*----------------
 70    0.1052
100    0.1072
150    0.1101
200    0.1135
250    0.1166
300    0.1194
350    0.1223
400    0.1267
```

Example Case FAVLoad input file (partial listing) (continued)

```
*----------------------------------------
* COEFF. OF THERMAL EXPANSION
* ASME Sect. II, Table TE-1
* Material Group - 18Cr-8Ni pp. 582-583
*----------------------------------------
NALF   N=15  Tref0=70
*--------------------
100     0.00000855
150     0.00000867
200     0.00000879
250     0.00000890
300     0.00000900
350     0.00000910
400     0.00000919
450     0.00000928
500     0.00000937
550     0.00000945
600     0.00000953
650     0.00000961
700     0.00000969
750     0.00000976
800     0.00000982
*----------------------------
*     POISSON'S RATIO
*----------------------------
NNU   N=2
*----------------
  0.  0.3
1000. 0.3
********************************************************************************
*  ====================                                                        *
*     Record SFRE                                                              *
*  ====================                                                        *
*     T   = BASE AND CLADDING STRESS-FREE TEMPERATURE                      [F] *
*     CFP = crack-face pressure loading flag                                   *
*     CFP = 0 ==> no crack-face pressure loading                               *
*     CFP = 1 ==> crack-face pressure loading applied                          *
********************************************************************************
SFRE  T=488  CFP=1
********************************************************************************
*  =========================                                                   *
*     Records RESA AND RESC                                                    *
*  =========================                                                   *
*     SET FLAGS FOR RESIDUAL STRESSES IN WELDS                                 *
*------------------------------------------------------------------------------*
*     NRAX = 0        AXIAL       WELD RESIDUAL STRESSES OFF                   *
*     NRAX = 101      AXIAL       WELD RESIDUAL STRESSES ON                    *
*     NRCR = 0    CIRCUMFERENTIAL WELD RESIDUAL STRESSES OFF                   *
*     NRCR = 101  CIRCUMFERENTIAL WELD RESIDUAL STRESSES ON                    *
*------------------------------------------------------------------------------*
********************************************************************************
RESA  NRAX=101
RESC  NRCR=101
********************************************************************************
*  =========================                                                   *
*     Record TIME                                                              *
*  =========================                                                   *
*------------------------------------------------------------------------------*
*     TOTAL = TIME PERIOD FOR WHICH TRANSIENT ANALYSIS IS TO BE PERFORMED [MIN]*
*     DT    = TIME INCREMENT                                              [MIN]*
*------------------------------------------------------------------------------*
********************************************************************************
TIME  TOTAL=80.0  DT=0.5
********************************************************************************
*  ===============                                                             *
*     Record NPRA                                                              *
*  ===============                                                             *
*     NTRAN = NUMBER OF TRANSIENTS TO BE INPUT                             [-] *
********************************************************************************
NPRA  NTRAN=4
********************************************************************************
*  =========================                                                   *
*     Record TRAN                                                              *
*  =========================                                                   *
*------------------------------------------------------------------------------*
*     ITRAN = PFM TRANSIENT NUMBER                                             *
*     ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                *
*------------------------------------------------------------------------------*
********************************************************************************
TRAN  ITRAN=1   ISEQ=7
********************************************************************************
*  =========================                                                   *
*     Record NHTH                                                              *
*  =========================                                                   *
*     CONVECTIVE HEAT TRANSFER COEFFICIENT TIME HISTORY                        *
*     NC = NUMBER OF (TIME,h) RECORD PAIRS FOLLOWING THIS LINE                 *
********************************************************************************
NHTH  NC=500
```

Example Case FAVPFM input file (partial listing)

```
**********************************************************************************************************
*                     ALL RECORDS WITH AN ASTERISK(*) IN COLUMN 1 ARE COMMENT ONLY                       *
**********************************************************************************************************
*    EXAMPLE INPUT DATASET FOR FAVPFM, v16.1 - LARGLE EMBRITTLEMENT MAP subjected to multiple cooldown   *
*    transients                                                                                          *
**********************************************************************************************************
*  ====================                                                                                  *
*  Control Record CNT1                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*  NSIM           = NUMBER OF RPV SIMULATIONS                                                            *
*--------------------------------------------------------------------------------------------------------*
*  IPFLAW         = FLAW POPULATION MODEL                                                                *
*                                                                                                        *
*  IPFLAW         = 1 Identical to previous version of FAVOR - primarily for cooldown transients.       *
*                                                                                                        *
*                     All Surface flaws (in surface flaw characterizatiuon file) will be inner surface   *
*                     breaking flaws. Only those embedded flaws (in weld and plate flaw characterization *
*                     files) in the inner 3/8 of the RPV wall thickness would be included in the model.  *
*                                                                                                        *
* IPFLAW         = 2  Similar to previous version of FAVOR-HT - primarily for heat-up transients.       *
*                                                                                                        *
*                     All surface breaking flaws (in surface flaw characterization file) would be        *
*                     external surface breaking flaws. Only those embedded flaws in the outer 3/8 of the *
*                     RPV wall thickness would be included in the model.                                 *
*                                                                                                        *
* IPFLAW         = 3  The number of postulated surface breaking flaws (in surface flaw characterization  *
*                     file) would be double that of options 1 and 2; evenly divided between internal     *
*                     and external surface breaking flaws. All of the embedded flaws uniformly           *
*                     distributed through the RPV wall thickness would be included in the model.         *
*                                                                                                        *
* See Theory Manual for further discussion.                                                              *
*--------------------------------------------------------------------------------------------------------*
*  IGATR          =   NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                           *
*--------------------------------------------------------------------------------------------------------*
*  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                       *
*  WPS_OPTION     = 1        INCLUDE TRADITIONAL FAVOR BASELINE WARM-PRESTRESSING Model IN ANALYSIS      *
*  WPS_OPTION     = 2        INCLUDE Conservative Principal WARM-PRESTRESSING MODEL IN ANALYSIS          *
*  WPS_OPTION     = 3        INCLUDE Best-Estimate WARM-PRESTRESSING MODEL IN ANALYSIS                   *
*                                                                                                        *
*  See Theory Manual for details regarding WARM_PRESTRESS Models                                         *
*  Note: Previous Versions of FAVOR prior to the 09.1 included only options 0 and 1.                     *
*--------------------------------------------------------------------------------------------------------*
*  CHILD_OPTION   = 0 DO NOT INCLUDE CHILD SUBREGION REPORTS                                         [-] *
*  CHILD_OPTION   = 1        INCLUDE CHILD SUBREGION REPORTS                                         [-] *
*--------------------------------------------------------------------------------------------------------*
*  RESTART_OPTION = 0 THIS IS NOT A RESTART CASE                                                     [-] *
*  RESTART_OPTION = 1 THIS IS A RESTART CASE                                                         [-] *
*--------------------------------------------------------------------------------------------------------*
*  =============================                                                                         *
*  Notes for Control Record CNT1                                                                         *
*  =============================                                                                         *
*  IN A TYPICAL PFM ANALYSIS, A SUBSTANTIAL FRACTION OF THE TOTAL FLAWS ARE CATEGORY 3 FLAWS IN          *
*  PLATE REGIONS. BASED ON EXPERIENCE AND SOME DETERMINISTIC FRACTURE ANALYSES, THESE FLAWS VERY         *
*  RARELY CONTRIBUTE TO THE CPI OR CPF WITH THE PLATE FLAW SIZE DISTRIBUTIONS TYPICALLY USED.            *
*  THEREFORE, INVOKING IP3OPT = 0 CAN RESULT IN A SIGNIFICANT REDUCTION IN EXECUTION TIME WITHOUT        *
*  AFFECTING THE SOLUTION, UNLESS THERE ARE UNUSUAL CIRCUMSTANCES SUCH AS A NEW FLAW-SIZE                *
*  DISTRIBUTION FOR PLATE FLAWS. IN EITHER CASE, CATEGORY 3 PLATE FLAWS ARE INCLUDED IN ALL REPORTS.     *
*                                                                                                        *
*  IF IPFLAW = 3; THEN PC3_OPTION AUTOMATICALLY OVER-RIDES AND SETS PC3_OPTION = 1                       *
*                                                                                                        *
*  Notes on Restart Option:                                                                              *
*                                                                                                        *
*  The restart option flag can also be used to control the frequency with which restart files are       *
*  created. If RESTART_OPTION is given a value other than 0 or 1, then the absolute value of this flag   *
*  sets the checkpoint interval at which the restart file will be created during the run. For example,   *
*                                                                                                        *
* 1.RESTART_OPTION = -200 ==> This is not a restart case; restart files will be created every 200 trials *
* 2.RESTART_OPTION =    0 ==> Same as example No. 1.                                                     *
* 3.RESTART_OPTION =  200 ==> This is a restart case;     restart files will be created every 200 trials.*
* 4.RESTART_OPTION =    1 ==> Same as example No. 3.                                                     *
* 5.RESTART_OPTION =  -50 ==? This is not a restart case; restart files will be created every 50 trials. *
*
*--------------------------------------------------------------------------------------------------------*
**********************************************************************************************************
CNT1  NSIM=100  IPFLAW=1 IGATR=100   WPS_OPTION=1    PC3_OPTION=0    CHILD_OPTION=1   RESTART_OPTION=0
**********************************************************************************************************
*  ====================                                                                                  *
*  Control Record CNT2                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
* EMBRITTLEMENT CORRELATION FOR ESTIMATING RADIATION-INDUCED SHIFT IN RTNDT                              *
* IRTNDT     = 992   ==> USE RG 1.99, REV                                                                *
* IRTNDT     = 2000  ==> USE E2000                                                                       *
* IRTNDT     = 2006  ==> USE modified E2006                                                              *
* IRTNDT     = 20071 ==> USE EricksonKirk 2007                                                           *
* IRTNDT     = 20072 ==> USE RADAMO                                                                      *
* IRTNDT     = 20073 ==> USE COMBINED EricksonKirk 2007 + RADAMO                                         *
*--------------------------------------------------------------------------------------------------------*
* TC         = INITIAL RPV COOLANT TEMPERATURE (applicable only when IRTNDT=2000 or 2006)            [F] *
*--------------------------------------------------------------------------------------------------------*
* EFPY       = EFFECTIVE FULL-POWER YEARS OF OPERATION                                           [YEARS] *
*--------------------------------------------------------------------------------------------------------*
* IDT_OPTION = 0  DO NOT INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE                        [-] *
* IDT_OPTION = 1         INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE                        [-] *
*--------------------------------------------------------------------------------------------------------*
* IDT_INI    = 0  DO NOT CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                       [-] *
* IDT_INI    = 1         CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                       [-] *
*--------------------------------------------------------------------------------------------------------*
```

Example Case FAVPFM input file (continued)

```
**********************************************************************************************************
*  ====================                                                                                  *
*  Control Record CNT3                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
* FLWSTR = UNIRRADIATED FLOW STRESS USED IN PREDICTING FAILURE BY REMAINING LIGAMENT INSTABILITY   [ksi] *
*--------------------------------------------------------------------------------------------------------*
* USKIA  = MAXIMUM VALUE ALLOWED FOR KIc or KIa                                             [ksi-in^1/2] *
*--------------------------------------------------------------------------------------------------------*
* KIa_Model    = 1 Use high-constraint KIa model based on CCA specimens                              [-] *
* KIa_Model    = 2 Use KIa model based on CCA + large specimen data                                  [-] *
*--------------------------------------------------------------------------------------------------------*
* LAYER_OPTION = 0 DONOT RESAMPLE PF WHEN ADVANCING INTO NEW WELD LAYER                              [-] *
* LAYER_OPTION = 1       RESAMPLE PF WHEN ADVANCING INTO NEW WELD LAYER                              [-] *
*--------------------------------------------------------------------------------------------------------*
* FAILCR       = FRACTION OF WALL THICKNESS FOR VESSEL FAILURE BY THROUGH-WALL CRACK PROPAGATION     [-] *
*--------------------------------------------------------------------------------------------------------*
*  ===============================                                                                       *
*  Notes for Control Record CNT3                                                                         *
*  ===============================                                                                       *
*        If ductile tearing model is included, then the values for USKIA and KIa_Model are ignored.      *
*        They are automatically set internally to KIa_Model=2 and there is no upper limit on USKIa.      *
*        If ductile tearing is not included in the analysis (IDT_OPTION = 0 on CNT1), both the KIa_Model *
*        and USKIA are user-specified on CNT3.                                                           *
*                                                                                                        *
**********************************************************************************************************
CNT3 FLWSTR=80.  USKIA=800. KIa_Model=2  LAYER_OPTION=0  FAILCR=0.9
**********************************************************************************************************
*  ====================                                                                                  *
*      Record GENR                                                                                       *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*   SIGFGL = A MULTIPLIER ON THE BEST ESTIMATE OF FLUENCE FOR A GIVEN SUBREGION                      [-] *
*           PRODUCES THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION USED TO SAMPLE THE MEAN         *
*           OF THE LOCAL FLUENCE DISTRIBUTION.                                                           *
*--------------------------------------------------------------------------------------------------------*
*   SIGFLC = A MULTIPLIER ON THE SAMPLED MEAN OF THE LOCAL FLUENCE FOR A GIVEN  SUBREGION            [-] *
*           PRODUCES THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION USED TO SAMPLE THE LOCAL FLUENCE*
*--------------------------------------------------------------------------------------------------------*
*  ======================                                                                                *
*  Notes for Record GENR                                                                                 *
*  ======================                                                                                *
*  Let "flue" be the best estimate for the subregion neutron fluence at inside surface of the RPV wall.  *
*  flue_STDEV_global = SIGFGL*flue                                                                       *
*  flue_MEAN_local  << Normal(flue,flue_STDEV_global)                                                    *
*  flue_STDEV_local  = SIGFLC*flue_MEAN_local                                                            *
*  flue_local       << Normal(flue_MEAN_local,flue_STDEV_local)                                          *
*                                                                                                        *
**********************************************************************************************************
GENR SIGFGL=0.118 SIGFLC=0.056
**********************************************************************************************************
*  ====================                                                                                  *
*      Record SIGW                                                                                       *
*  ====================                                                                                  *
*  STANDARD DEVIATIONS (STDEV) OF NORMAL DISTRIBUTIONS FOR WELD CHEMISTRY SAMPLING:                      *
*  WSIGCU = STANDARD DEVIATION FOR COPPER CHEMISTRY SAMPLING IN WELDS                              [wt%] *
*  WSIGNI = STANDARD DEVIATION FOR NICKEL CHEMISTRY SAMPLING IN WELDS                              [wt%] *
*  WSIGP  = STANDARD DEVIATION FOR PHOSPHOROUS CHEMISTRY SAMPLING IN WELDS                         [wt%] *
*--------------------------------------------------------------------------------------------------------*
*  ======================                                                                                *
*  Notes for Record SIGW                                                                                 *
*  ======================                                                                                *
*  FOR NICKEL IN WELDS THERE ARE TWO POSSIBILITIES.                                                      *
*  (1) FOR HEATS 34B009 AND W5214 (Ni - addition welds)                                                  *
*      WSIGNI = 0.162 wt% using a normal distribution.                                                   *
*  (2) For other heats, the standard deviation (WSIGNI) shall be sampled from a normal distribution      *
*      with mean equal to 0.029 wt% and standard deviation = 0.0165 wt%                                  *
**********************************************************************************************************
SIGW   WSIGCU=0.167   WSIGNI=0.162    WSIGP=0.0013
**********************************************************************************************************
*  ====================                                                                                  *
*      Record SIGP                                                                                       *
*  ====================                                                                                  *
*  STANDARD DEVIATIONS (STDEV) OF NORMAL DISTRIBUTIONS FOR PLATE CHEMISTRY SAMPLING:                     *
*  PSIGCU = STANDARD DEVIATION FOR COPPER CHEMISTRY SAMPLING IN PLATES                             [wt%] *
*  PSIGNI = STANDARD DEVIATION FOR NICKEL CHEMISTRY SAMPLING IN PLATES                             [wt%] *
*  PSIGP  = STANDARD DEVIATION FOR PHOSPHOROUS CHEMISTRY SAMPLING IN PLATES                        [wt%] *
*--------------------------------------------------------------------------------------------------------*
*  ======================                                                                                *
*  Notes for Record SIGP                                                                                 *
*  ======================                                                                                *
*  RECOMMENDED VALUES ARE: 0.0073, 0.0244, 0.0013 for Cu, Ni, and P, respectively.                       *
**********************************************************************************************************
SIGP  PSIGCU=0.0073   PSIGNI=0.0244   PSIGP=0.0013
**********************************************************************************************************
*  ===============================                                                                       *
*  Notes for RecordS SIGW and SIGP                                                                       *
*  ===============================                                                                       *
*  THE ABOVE DISTRIBUTIONS ARE FOR THE 1ST FLAW POSITIONED IN A PARTICULAR SUBREGION.                    *
*  IF THE CURRENT FLAW IS THE 2ND OR MORE FLAW FOR THIS SUBREGION, THEN FAVPFM WILL USE                  *
*  THE LOCAL VARIABILITY SAMPLING PROTOCOLS PRESENTED IN THE THEORY MANUAL.                              *
**********************************************************************************************************
*  ====================                                                                                  *
*     Record TRAC                                                                                        *
*  ====================                                                                                  *
*   ITRAN           = TRANSIENT NUMBER                                                               [-] *
*   RPV             = RPV SIMULATION                                                                 [-] *
*   KFLAW           = FLAW NUMBER                                                                    [-] *
*   FLAW_LOG_OPTION = 0 DO NOT CREATE FLAW LOG TABLES                                                [-] *
*   FLAW_LOG_OPTION = 1 DO     CREATE FLAW LOG TABLES                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*  ===============================                                                                       *
*  Notes for Record TRAC                                                                                 *
*  ===============================                                                                       *
```

Example Case FAVPFM input file (partial listing) (continued)

```
**********************************************************************************************************
*  ====================                                                                                  *
*     Record TRAC                                                                                        *
*  ====================                                                                                  *
*   ITRAN           = TRANSIENT NUMBER                                                               [-] *
*   RPV             = RPV SIMULATION                                                                 [-] *
*   KFLAW           = FLAW NUMBER                                                                    [-] *
*   FLAW_LOG_OPTION = 0 DO NOT CREATE FLAW LOG TABLES                                                [-] *
*   FLAW_LOG_OPTION = 1 DO     CREATE FLAW LOG TABLES                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*  ==============================                                                                        *
*  Notes for Record TRAC                                                                                 *
*  ==============================                                                                        *
*  THE ABOVE FLAGS IDENTIFY A SPECIFIC TRANSIENT, RPV SIMULATION, AND FLAW NUMBER WHOSE COMPLETE         *
*  HISTORY WILL BE GIVEN IN THE FILES: "TRACE.OUT" AND "ARREST.OUT"                                      *
*  SEE THE USER'S GUIDE FOR DETAILS ON THE CONTENTS OF THESE FILES                                       *
*                                                                                                        *
**********************************************************************************************************
TRAC ITRAN=1  IRPV=1  KFLAW=1  FLAW_LOG_OPTION=0
**********************************************************************************************************
*  ====================                                                                                  *
*     Record LDQA                                                                                        *
*  ====================                                                                                  *
* THE LDQA RECORD PROVIDES THE OPPORTUNITY TO CHECK LOAD-RELATED SOLUTIONS                               *
* SUCH AS TEMPERATURE, STRESSES, AND KI.                                                                 *
*                                                                                                        *
*   IQA   = 0 ==> THIS EXECUTION IS NOT FOR LOAD QA                                                  [-] *
*   IQA   = 1 ==> THIS EXECUTION IS FOR LOAD QA                                                      [-] *
*--------------------------------------------------------------------------------------------------------*
*   IOPT  = 1 ==> GENERATE TIME HISTORY AT SPECIFIC THROUGH WALL LOCATION                            [-] *
*   IOPT  = 2 ==> GENERATE THROUGH WALL DISTRIBUTION AT SPECIFIC TIME                                [-] *
*--------------------------------------------------------------------------------------------------------*
*   IFLOR = 1 ==> FLAW ORIENTATION IS AXIAL                                                          [-] *
*   IFLOR = 2 ==> FLAW ORIENTATION IS CIRCUMFERENTIAL                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*   IWELD = 0  ==> DOES NOT INCLUDE THRU-WALL WELD RESIDUAL STRESS                                   [-] *
*   IWELD = 1  ==> DOES INCLUDE THRU-WALL WELD RESIDUAL STRESS                                       [-] *
*--------------------------------------------------------------------------------------------------------*
*   IKIND = 1  ==> INNER-SURFACE BREAKING FLAW                                                       [-] *
*   IKIND = 2  ==> EMBEDDED FLAW                                                                     [-] *
*   IKIND = 3  ==> OUTER-SURFACE BREAKING FLAW                                                       [-] *
*--------------------------------------------------------------------------------------------------------*
*   XIN IS ONLY USED IF IKIND=2 (EMBEDDED FLAWS)                                                         *
*   XIN   =  IF IOPT=1; LOCATION OF INNER CRACK TIP FROM INNER SURF.                                [IN] *
*   XIN   =  IF IOPT=2; FLAW DEPTH                                                                  [IN] *
*--------------------------------------------------------------------------------------------------------*
*   XVAR:    IF IOPT=1; XVAR=FLAW DEPTH                                                             [IN] *
*            IF IOPT=2; XVAR=TIME                                                                  [MIN] *
*--------------------------------------------------------------------------------------------------------*
*   ASPECT = ASPECT RATIO; FOR SURFACE BREAKING FLAWS: 2,6,10,999 (infin)                            [-] *
*                          FOR EMBEDDED FLAWS: ANY VALUE > 0                                             *
*--------------------------------------------------------------------------------------------------------*
*  ==============================                                                                        *
*  Notes for Record LDQA                                                                                 *
*  ==============================                                                                        *
* IQA = 0 NO VALIDATION REPORTS WILL BE GENERATED, PFM ANALYSIS WILL BE PERFORMED                        *
* IQA = 1 LOAD PARAMETERS WILL BE GENERATED FOR VERIFICATION PURPOSES, PFM ANALYSIS WILL NOT BE PERFORMED*
**********************************************************************************************************
LDQA IQA=0 IOPT=2 IFLOR=1 IWELD=1 IKIND=1 XIN=2.0 XVAR=50 ASPECT=999
**********************************************************************************************************
*  ====================                                                                                  *
*      Record DTRF                                                                                       *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*   NT = number of ISQ records that follow                                                           [-] *
*   NT = 0 no ISQ records follow                                                                         *
*--------------------------------------------------------------------------------------------------------*
*   FOLLOWING THE DTRF RECORD, THERE SHOULD BE "NT" SUBRECORDS                                           *
*--------------------------------------------------------------------------------------------------------*
*   ISQ  ITRAN=  ISEQ=  TSTART=   TEND=                                                                  *
*--------------------------------------------------------------------------------------------------------*
*   ITRAN  = sequential number in FAVLoad transient stack                                            [-] *
*   ISEQ   = Thermal Hydraulic trasient sequence number                                              [-] *
*   TSTART = starting time for FAVPFM analysis                                                     [MIN] *
*   TEND   = ending time for FAVPFM analysis                                                       [MIN] *
**********************************************************************************************************
* DTRF NT=0
DTRF NT=4
ISQ ITRAN=1 ISEQ=7   TSTART=2   TEND=35
ISQ ITRAN=2 ISEQ=9   TSTART=1   TEND=29
ISQ ITRAN=3 ISEQ=56  TSTART=12  TEND=54
ISQ ITRAN=4 ISEQ=97  TSTART=30  TEND=82
**********************************************************************************************************
*  ====================                                                                                  *
*     Record WELD                                                                                        *
*  ====================                                                                                  *
*  NWSUB = NUMBER OF WELD SUBREGIONS                                                                 [-] *
*  NWMAJ = NUMBER OF WELD MAJOR REGIONS                                                              [-] *
**********************************************************************************************************
WELD NWSUB=838   NWMAJ=5
**********************************************************************************************************
*  ====================                                                                                  *
*     Record PLAT                                                                                        *
*  ====================                                                                                  *
* NPSUB = NUMBER OF PLATE SUBREGIONS                                                                 [-] *
* NPMAJ = NUMBER OF PLATE MAJOR REGIONS                                                              [-] *
**********************************************************************************************************
PLAT NPSUB=14442  NPMAJ=4
```

Example Case FAVPFM input file (partial listing) (continued)

```
************************************************************************************************************
*                        PLATE/WELD EMBRITTLEMENT / FLAW DISTRIBUTION MAP RECORDS                          *
************************************************************************************************************
*==========================================================================================================*
*  Field            DESCRIPTION                                                                    [UNITS] *
*==========================================================================================================*
*----------------------------------------------------------------------------------------------------------*
*  (1) RPV subregion number   -   parent                                                               [-] *
*----------------------------------------------------------------------------------------------------------*
*  (2) adjacent RPV subregion - 1st child                                                              [-] *
*----------------------------------------------------------------------------------------------------------*
*  (3) adjacent RPV subregion - 2nd child                                                              [-] *
*----------------------------------------------------------------------------------------------------------*
*  (4) RPV major region number                                                                         [-] *
*----------------------------------------------------------------------------------------------------------*
*  (5) best estimate neutron fluence at RPV inside surface                          [10^19 neutrons/cm^2] *
*----------------------------------------------------------------------------------------------------------*
*  (6) best estimate copper (Cu) content                                                         [wt% Cu] *
*----------------------------------------------------------------------------------------------------------*
*  (7) best estimate nickel (Ni) content                                                         [wt% Ni] *
*----------------------------------------------------------------------------------------------------------*
*  (8) best estimate phosphorus (P) content                                                      [wt%  P] *
*----------------------------------------------------------------------------------------------------------*
*  (9) best estimate manganese (Mn) content                                                      [wt% Mn] *
*----------------------------------------------------------------------------------------------------------*
*  (10) product form flags for DT30 shift correlation                                                      *
*                                                                                                          *
*      Welds : set distribution for sampling standard                                                      *
*              deviation for Ni content in welds                                                           *
*             = 1 use normal distribution                                                          [-] *
*             = 2 use Weibull distribution                                                         [-] *
*      Plates:                                                                                             *
*          CE = 1 (if IRTNDT=2000 then set B = 206)                                                [-] *
*      Not CE = 2 (if IRTNDT=2000 then set B = 156)                                                [-] *
*      where CE is a Combustion Engineering vessel                                                         *
*----------------------------------------------------------------------------------------------------------*
* (11) copper saturation flag = 0 for plates and forgings                                          [-] *
*                             = 1 for Linde 80 and Linde 0091 weld fluxes                                  *
*                             = 2 for all weld fluxes other than L80, L0091, and L1092                     *
*                             = 3 for Linde 1092 weld flux                                                 *
*       N.B.:                                                                                              *
*         for IRTNDT = 2000                                                                                *
*               maximum value of copper content (copper saturation)                                        *
*             = 0.25 for Linde 80 and = 0.305 for all others                                               *
*         for IRTNDT = 2006                                                                                *
*               maximum value of copper content (copper saturation)                                        *
*             = 0.37 for Ni < 0.5 wt%                                                                      *
*             = 0.2435 for 0.5 <= Ni <= 0.75 wt%                                                           *
*             = 0.301 for Ni > 0.75 wt% (all welds with Linde 1092 weld flux)                              *
*                                                                                                          *
*----------------------------------------------------------------------------------------------------------*
* (12) unirradiated best estimate (mean) for RTNDT0                                                    [F] *
*----------------------------------------------------------------------------------------------------------*
* (13) unirradiated standard deviation for RTNDT0                                                      [F] *
*----------------------------------------------------------------------------------------------------------*
* (14) PF flag      Product Form        CF Override                                                        *
*      -------      ------------        ------------                                                       *
*      = 11             weld                 no                                                    [-] *
*      = 12             weld                 yes                                                   [-] *
*      = 21             plate                no                                                    [-] *
*      = 22             plate                yes                                                   [-] *
*      = 31            forging               NA                                                    [-] *
*----------------------------------------------------------------------------------------------------------*
* (15) angle of subregion element                                                                [degrees] *
*----------------------------------------------------------------------------------------------------------*
* (16) axial height of subregion element:                                                         [inches]  *
*----------------------------------------------------------------------------------------------------------*
* (17) weld fusion area:                                                                        [inches^2] *
*----------------------------------------------------------------------------------------------------------*
* (18) weld orientation: 1 ===> axial; 2===> circumferential                                           [-] *
*----------------------------------------------------------------------------------------------------------*
* (19) chemistry factor override                                                                       [-] *
*----------------------------------------------------------------------------------------------------------*
* (20) unirradiated upper shelf CVN engergy                                                        [ft-lbf] *
*==========================================================================================================*
*    Notes:                                                                                                *
*                                                                                                          *
*    1. Fields 1-4  : contain RPV beltline discretization and connectivity data for weld fusion line       *
*    2. Fields 5-20 : contain RPV beltline embrittlement-related data                                      *
*    3. Field   13  : PF means Product Form                                                                *
*    4. Field   13  : CF means chemistry factor override                                                   *
*    5. Field   18  : only applies to weld subregions. For plates set to 0.                                *
*    6. Field   20  : applicable only if IRTNDT=2000 on CNT2 and Field 13 = 12 or 22                       *
*                                                                                                          *
*==========================================================================================================*
*************************************************************************************************************
* 1     2     3    4    5      6     7     8      9  10  11    12      13  14    15      16      17   18 19   20
*************************************************************************************************************
00001 03593 03661  1 0.0675 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  1.2000  9.4500  1  0   98
00002 03594 03662  1 0.1173 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  1.1996  9.4469  1  0   98
00003 03595 03663  1 0.1682 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  2.3996 18.8969  1  0   98
00004 03596 03664  1 0.2317 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  2.2047 17.3622  1  0   98
00005 03597 03665  1 0.3100 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  2.3996 18.8969  1  0   98
00006 03598 03666  1 0.4193 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  2.3760 18.7109  1  0   98
00007 03599 03667  1 0.5191 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  1.6043 12.6341  1  0   98
00008 03600 03668  1 0.6065 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  1.2500  9.8438  1  0   98
00009 03601 03669  1 0.7145 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  1.5728 12.3861  1  0   98
00010 03602 03670  1 0.8412 0.337 0.609 0.012 1.440  2  3   -56.0   17.0 11  1.0000  1.8720 14.7424  1  0   98
                                                  •
                                                  •
                                                  •
15277 15277 15277  9 1.4176 0.140 0.620 0.015 1.400  1  0    43.0    0.0 21  8.7511  2.3543  0.0000  2  0   90
15278 15278 15278  9 1.1209 0.140 0.620 0.015 1.400  1  0    43.0    0.0 21  8.7511  1.9724  0.0000  2  0   90
15279 15279 15279  9 0.9166 0.140 0.620 0.015 1.400  1  0    43.0    0.0 21  8.7511  1.2500  0.0000  2  0   90
15280 15280 15280  9 0.7084 0.140 0.620 0.015 1.400  1  0    43.0    0.0 21  8.7511  0.9931  0.0000  2  0   90
***************************** END OF EMBRITTLEMENT MAP ******************************************************
```

Example Case FAVPost input file

```
********************************************************************************
*       ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY          *
********************************************************************************
*                    EXAMPLE INPUT DATASET FOR FAVPost, v16.1                  *
********************************************************************************
*  ===================                                                         *
*     Record CNTL                                                              *
*  ===================                                                         *
*------------------------------------------------------------------------------*
*  NTRAN = NUMBER OF T-H TRANSIENTS                                            *
*------------------------------------------------------------------------------*
********************************************************************************
CNTL  NTRAN=4
********************************************************************************
*  ===================                                                         *
*     Record ITRN                                                              *
*  ===================                                                         *
*------------------------------------------------------------------------------*
*  ITRAN = PFM TRANSIENT NUMBER                                                *
*  ITRAN = TRANSIENT NUMBER                                                    *
*  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION             *
*  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                   *
*------------------------------------------------------------------------------*
********************************************************************************
ITRN ITRAN=1  NHIST=20    ISEQ=7
********************************************************************************
*------------------------------
* freq[events/year] Density [%]
*------------------------------
     2.11E-07         0.50
     3.01E-07         0.50
     5.19E-07         1.50
     7.92E-07         2.50
     1.32E-06         5.00
     2.43E-06        10.00
     3.08E-06         5.00
     3.79E-06         5.00
     5.55E-06        10.00
     7.90E-06        10.00
     1.12E-05        10.00
     1.64E-05        10.00
     2.03E-05         5.00
     2.57E-05         5.00
     4.74E-05        10.00
     7.82E-05         5.00
     1.24E-04         2.50
     2.12E-04         1.50
     3.09E-04         0.50
     1.02E-03         0.50
********************************************************************************
*  ===================                                                         *
*     Record ITRN                                                              *
*  ===================                                                         *
*------------------------------------------------------------------------------*
*  ITRAN = TRANSIENT NUMBER                                                    *
*  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION             *
*  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                   *
*------------------------------------------------------------------------------*
ITRN ITRAN=2  NHIST=20    ISEQ=9
********************************************************************************
*------------------------------
* freq[events/year] Density [%]
*------------------------------
     6.48E-08         0.50
     1.01E-07         0.50
     1.71E-07         1.50
     2.64E-07         2.50
     4.40E-07         5.00
     8.10E-07        10.00
     1.02E-06         5.00
     1.26E-06         5.00
     1.85E-06        10.00
     2.63E-06        10.00
     3.76E-06        10.00
     5.46E-06        10.00
     6.78E-06         5.00
     8.54E-06         5.00
     1.57E-05        10.00
     2.60E-05         5.00
     4.12E-05         2.50
```

Example Case FAVPost input file (continued)

```
********************************************************************************
*  ====================                                                        *
*     Record ITRN                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  ITRAN = TRANSIENT NUMBER                                                    *
*  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION             *
*  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                   *
*------------------------------------------------------------------------------*
********************************************************************************
ITRN ITRAN=3  NHIST=20    ISEQ=56
********************************************************************************
*------------------------------
* freq[events/year] Density [%]
*------------------------------
     1.70E-05         0.50
     1.96E-05         0.50
     2.68E-05         1.50
     3.29E-05         2.50
     4.24E-05         5.00
     5.58E-05        10.00
     6.17E-05         5.00
     6.89E-05         5.00
     8.35E-05        10.00
     9.89E-05        10.00
     1.17E-04        10.00
     1.41E-04        10.00
     1.54E-04         5.00
     1.72E-04         5.00
     2.33E-04        10.00
     2.97E-04         5.00
     3.56E-04         2.50
     4.55E-04         1.50
     6.00E-04         0.50
     1.21E-03         0.50
********************************************************************************
*  ====================                                                        *
*     Record ITRN                                                              *
*  ====================                                                        *
*------------------------------------------------------------------------------*
*  ITRAN = TRANSIENT NUMBER                                                    *
*  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION             *
*  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                   *
*------------------------------------------------------------------------------*
********************************************************************************
ITRN ITRAN=4  NHIST=20    ISEQ=97
********************************************************************************
*------------------------------
* freq[events/year] Density [%]
*------------------------------
     3.97E-08          0.50
     8.40E-08          0.50
     1.33E-07          1.50
     1.92E-07          2.50
     3.10E-07          5.00
     5.57E-07         10.00
     7.38E-07          5.00
     9.21E-07          5.00
     1.36E-06         10.00
     1.81E-06         10.00
     2.49E-06         10.00
     3.55E-06         10.00
     4.26E-06          5.00
     5.30E-06          5.00
     8.53E-06         10.00
     1.29E-05          5.00
     1.96E-05          2.50
     2.90E-05          1.50
     3.56E-05          0.50
     8.62E-05          0.50
```

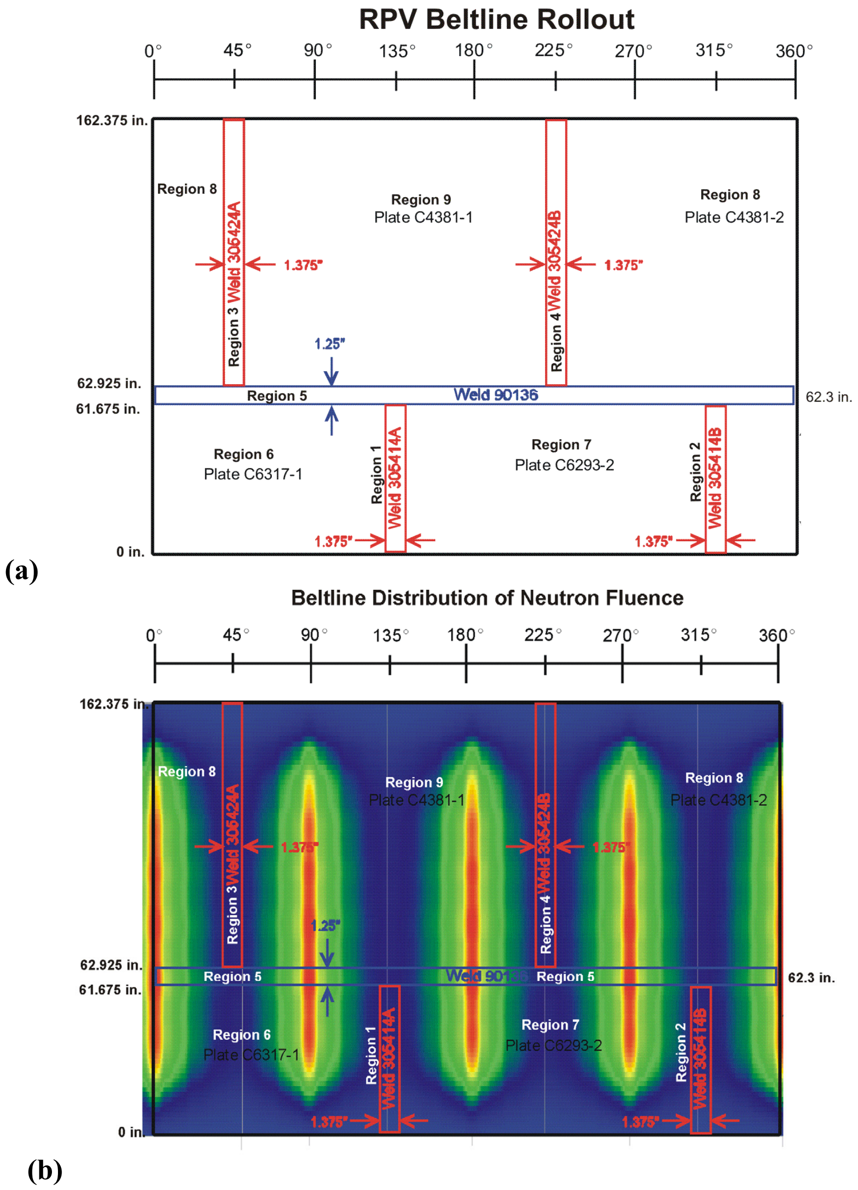


Fig. 19. Example case – (a) rollout of beltline region of vessel showing layout of plates and welds and (b) axial and circumferential distribution of fast-neutron fluence across the beltline.

Figures 20, 21, and 22 present the time histories for the coolant temperature, convection coefficient, and internal pressure, respectively, that are included for all four transients in the input data for FAVOR example PFM_flaw_population1. Figure 23 shows the initiating-event frequency histograms for the four transients that are used as input to FAVPost for this example.

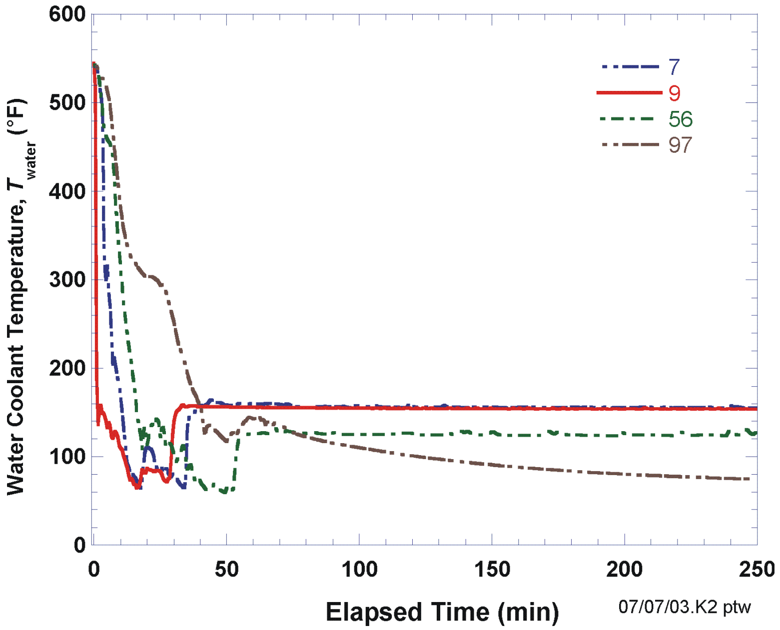


Fig. 20. Time histories of coolant temperature for four PTS transients.

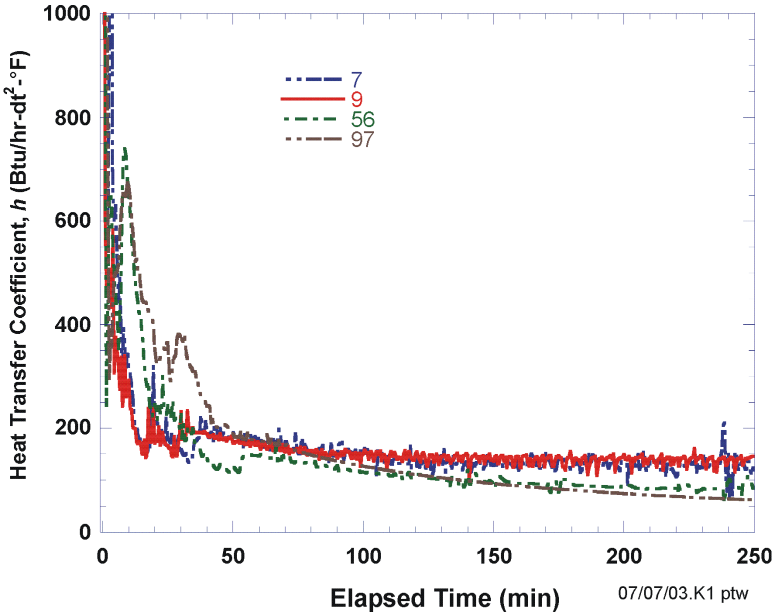


Fig. 21.Time histories of convection heat transfer coefficient four PTS transients.

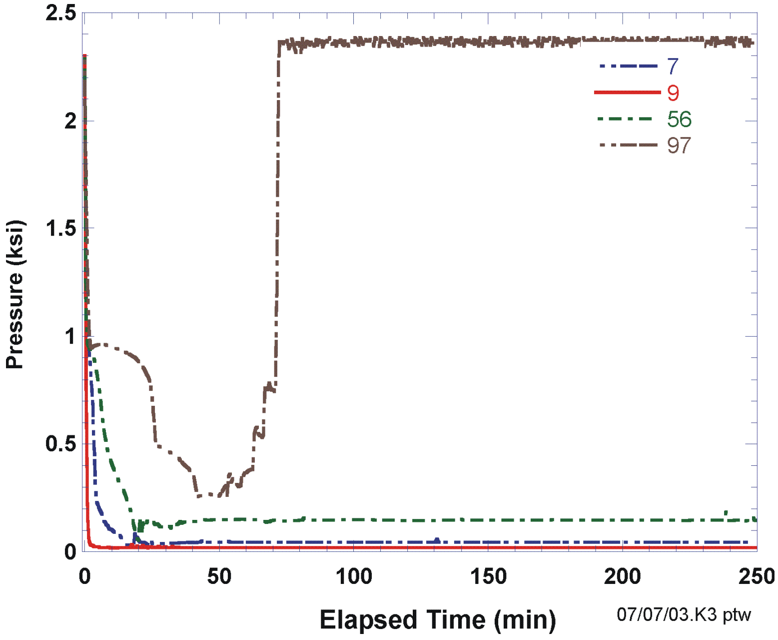


Fig. 22. Time histories for internal pressure for four PTS transients.

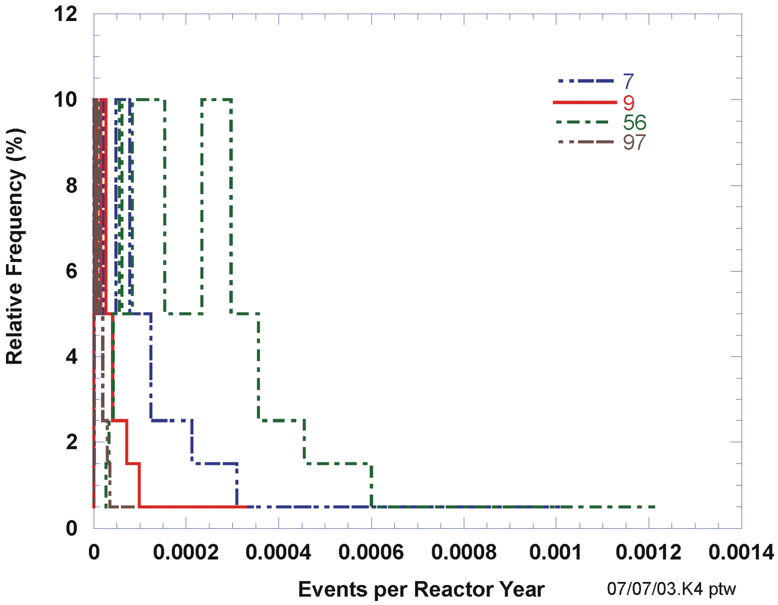


Fig. 23. Initiation event frequency distribution for PTS Transients 7, 9, 56, and 97.

4. Summary and Conclusions

The FAVOR computer code has been developed under NRC funding to perform probabilistic fracture mechanics analyses of nuclear reactor pressure vessels subjected to pressurized thermal shock and other pressure-thermal events. The following advanced technologies and new capabilities have been incorporated into FAVOR:

- **the ability to incorporate new detailed flaw-characterization distributions from NRC research (with Pacific Northwest National Laboratory, PNNL),**
- **the ability to incorporate detailed neutron fluence regions – detailed fluence maps from Brookhaven National Laboratory, BNL,**
- **the ability to incorporate warm-prestressing effects into the analysis,**
- **the ability to include temperature-dependencies in the thermo-elastic properties of base and cladding,**
- **the ability to include crack-face pressure loading for surface-breaking flaws,**
- **new embrittlement correlations,**
- **a new ductile-tearing model simulating stable and unstable ductile fracture,**
- **the ability to handle multiple transients in one execution of FAVOR,**
- **RVID2 database of relevant material properties,**
- **fracture-toughness models based on extended databases and improved statistical distributions,**
- **a variable failure criterion, i.e., how far must a flaw propagate into the RPV wall for the vessel simulation to be considered as "failed" ?**
- **semi-elliptic surface-breaking and embedded-flaw models,**
- **through-wall weld residual stresses,**
- **the addition of base material SIFIC(s) from the proposed ASME code, Section XI, Appendix A, Article A-3000, *Method of K_I Determination*, for infinite and finite axial and 360° continuous and finite circumferential flaws into the FAVOR SIFIC database, and**
- **improved PFM methodology that incorporates modern PRA procedures for the classification and propagation of input uncertainties and the characterization of output uncertainties as statistical distributions.**

This report has provided a detailed description of the computer system requirements, installation, and execution of the FAVOR, v16.1, deterministic and probabilistic fracture mechanics code. Detailed instructions on input data deck preparation have been presented along with descriptions of all output files. Example input and output cases were included. The companion report *Fracture Analysis of Vessels – Oak Ridge, FAVOR, v16.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations* [2] gives a detailed review of the computational methodologies implemented into FAVOR.

5. References

1. T. L. Dickson, S. N. M. Malik, J. W. Bryson, and F. A. Simonen, "Revisiting the Integrated Pressurized Thermal Shock Studies of an Aging Pressurized Water Reactor," ASME PVP-Volume 388, *Fracture, Design Analysis of Pressure Vessels, Heat Exchangers, Piping Components, and Fitness for Service*, *ASME Pressure Vessels and Piping Conference*, August, 1999.

2. P. T. Williams, T. L. Dickson, B.R. Bass, and H.B. Klasky, *Fracture Analysis of Vessels – FAVOR (v16.1) Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations*, ORNL/TM-2016/309, Oak Ridge National Laboratory, Oak Ridge, TN, 2016.

3. D. L. Selby, et al., *Pressurized Thermal Shock Evaluation of the Calvert Cliffs Unit 1 Nuclear Power Plant*, NUREG/CR-4022 (ORNL/TM-9408), Oak Ridge National Laboratory, Oak Ridge, TN, September 1985.

4. D. L. Selby, et al., *Pressurized Thermal Shock Evaluation of the H.B. Robinson Nuclear Power Plant,* NUREG/CR-4183 (ORNL/TM-9567), September 1985.

5. T. J. Burns, et al., *Preliminary Development of an Integrated Approach to the Evaluation of Pressurized Thermal Shock as Applied to the Oconee Unit 1 Nuclear Power Plant*, NUREG/CR-3770 (ORNL/TM-9176), May 1986.

6. *U.S. Code of Federal Regulations,* Title 10, Part 50, Section 50.61 and Appendix G.

7. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.154 (1987), *Format and Content of Plant-Specific Pressurized Thermal Shock Safety Analysis Reports for Pressurized Water Reactors*.

8. U. S. Nuclear Regulatory Commission, Regulatory Guide 1.99, Revision 2 (1988), *Radiation Embrittlement of Reactor Vessel Materials*.

9. Proposed Rules 10CFR50.61a (RIN 3150-A101) – Alternate Fracture Toughness Reguirements for Protection Against Pressurized Thermal Shock Events, *Federal Register* **72(1)**, October 3, 2007, 56275-56287.

10. M. Kirk, et al., *Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10 CFR 50.61)*, NUREG-1806, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC, August 2007.

11. M. T. Kirk and T. L. Dickson, *Recommended Screening Limits for Pressurized Thermal Shock (PTS)*, NUREG-1874, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC, March 2007.

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6. Appendix A – Treatment of Weld Fusion Lines

Figure A1 shows a typical rollout section of the beltline region. The user is required to discretize (subdivide) the beltline into several major regions that contain plates (or forgings), axial welds, and circumferential welds. These major regions are further discretized into subregions for greater resolution of the variation in radiation-induced embrittlement. An embrittlement-distribution map is defined in the input data for FAVPFM using these major region and subregion definitions.

In a FAVOR PFM analysis, flaws that are postulated to reside in a weld are assumed to reside on the *fusion line* between the weld and the adjacent plate or forging. Thus, decisions must be made as to how properties (chemistry and neutron fluence) of the weld or adjacent plate (or forging) should be assigned for the calculation of RT_{NDT} and the fracture toughness K_{Ic}.

Controlling Region

The discretization of the major regions and sub-regions of the RPV embrittlement model of the beltline includes a special treatment of these weld fusion lines. These fusion lines can be visualized as boundaries between a weld sub-region and its neighboring plate (or forging) sub-regions. Each weld sub-region will have at most two adjacent plate (or forging) sub-regions. FAVOR checks to determine if the value of RT_{NDT} of the weld sub-region of interest is higher than the corresponding values of the adjacent plate (or forging) sub-regions.

This determination of whether the weld sub-region or an adjacent plate (or forging) sub-region is controlling (i.e., has the higher RT_{NDT}) is performed one time before entering the PFM Monte Carlo looping structure. For each sub-region, the calculation uses the user-specified mean values of chemistry, RT_{NDTo}, and neutron fluence. Furthermore, the computation of RT_{NDT} for each sub-region includes the correction factors (i.e., 0.99 and 1.10) for weld and plate, respectively. The latter is necessary for consistency, since those factors are applied for all crack tip RT_{NDT} computations performed inside of the Monte Carlo looping structure.

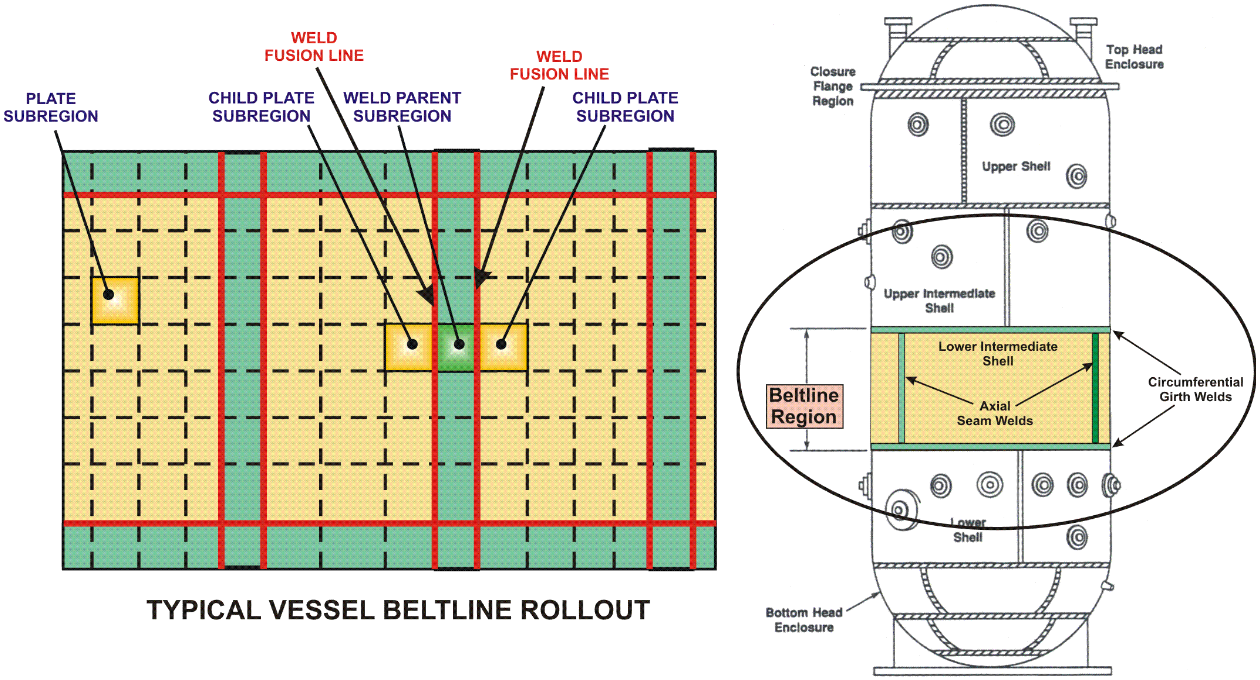

Fig. A1. FAVOR uses a discretization of the RPV beltline region to resolve the variation in radiation damage in terms of plate, axial weld, and circumferential weld major regions which are further discretized into multiple subregions.

The output file "RTNDT.out" contains a summary of the one-time computation to determine which sub-region (weld or adjacent plate) is controlling for flaws analyzed in that weld sub-region. That file does not include results for each weld / adjacent plate, but only for the sub-region with the higher RT_{NDT}.

Also, values found in the file RTNDT.out will not correspond to values of RT_{NDT} reported in the FAVPFM output report. The value of RT_{NDT} reported for each major region in the FAVPFM output report is the maximum value of RT_{NDT} of any sub-region in that major region, calculated without the 0.99 and 1.10 correction factors discussed above.

Restriction on Embrittlement Map

Inside the Monte Carlo looping analysis, when a flaw is postulated to reside in a weld, the values of chemistry (sampled from the appropriate distributions) of the controlling sub-region and the *sampled value of fluence of the weld*, are used in the evaluation of RT_{NDT} at the crack tip. Flaw orientation is not transferred from a dominant plate sub-region to a weld sub-region.

To ensure that the FAVOR weld-fusion line methodology produces logically consistent solutions, it is essential that the *same neutron fluence* of a weld be assigned to its two adjacent neighbor plate sub-regions. The latter restriction on the embrittlement map input to FAVOR necessitates special treatment for certain problems to be analyzed with FAVOR.

An example would be the use of an embrittlement map constructed based only on knowledge of the maximum value of fluence in any weld, plate, or forging, and where these maximum values are assigned to represent the fluence for the entire major region. If that maximum value of fluence in the plate or forging resides far from the adjacent weld, the resultant model is likely to have an unrealistic discontinuity of fluence between the weld sub-regions and adjacent plates sub-regions that will produce an illogical solution.

For this example, it is recommended that two thin (i.e., very small values $\Delta\theta$) plate sub-regions be modelled between the weld and adjacent plates, one on each side of the weld. These two sub-regions should be modelled with (1) the chemistry and RT_{NDT0} of the respective adjacent plates and (2) a fluence equal (or close) to that of the weld, thus providing greater similarity of fluence between the weld and plate along the weld fusion line. This smoother transition in the fluence avoids a possibility of inconsistent results associated with discontinuities between fluence in welds and adjacent plates. Since the $\Delta\theta$ assigned to these regions is very small, they occupy negligible volume, have a negligible number of flaws, and thus have little or no other impact on the results of the PFM analysis.

Weld-Fusion-Line Dependency for Ductile Tearing Model

For the Ductile Tearing Model No. 2, implemented in FAVOR, v03.1, a second *weld-fusion-line dependency structure* is created based on the irradiated upper-shelf energy, *USE*. This weld-fusion-line dependency structure for sampling ductile-tearing properties is independent of the embrittlement-related dependency structure discussed above. For Ductile-tearing Model No. 2, the ductile-tearing-related properties of the most limiting (either the weld or the adjacent plate subregion with the lowest value of irradiated *USE*) material are used when evaluating ductile-tearing of a flaw located in the weld subregion. As with the embrittlement-related weld-fusion-line treatment, the flaw type and pre- and post-initiation orientation of flaws are not transferred from a dominant plate subregion to a weld subregion. Ductile-Tearing Model No. 1, implemented in FAVOR, v07.1, this second weld-fusion-line dependency structure for sampling ductile-tearing properties is not required.

For those conditions in which plate embrittlement properties are used to characterize the weld subregion fracture toughness, the weld chemistry re-sampling protocols continue to be applied.

7. Appendix B – Summary of RVID2 Data for Use in FAVOR Calculations

Product Form	Heat	Beltline	$\sigma_{flow(u)}$ [ksi]	$RT_{NDT(u)}$ [°F]			Composition(2)				$USE_{(u)}$ [ft-lb]
				$RT_{NDT(u)}$ Method	$RT_{NDT(u)}$ Value	$\sigma_{(u)}$ Value	Cu	Ni	P	Mn	
Beaver Valley 1, (Designer: Westinghouse, Manufacturer: CE) Coolant Temperature = 547°F, Vessel Thickness = 7-7/8 in.											
PLATE	C4381-1	INTERMEDIATE SHELL B6607-1	83.8	MTEB 5-2	43	0	0.14	0.62	0.015	1.4	90
	C4381-2	INTERMEDIATE SHELL B6607-2	84.3	MTEB 5-2	73	0	0.14	0.62	0.015	1.4	84
	C6293-2	LOWER SHELL B7203-2	78.8	MTEB 5-2	20	0	0.14	0.57	0.015	1.3	84
	C6317-1	LOWER SHELL B6903-1	72.7	MTEB 5-2	27	0	0.2	0.54	0.01	1.31	80
LINDE 1092 WELD	305414	LOWER SHELL AXIAL WELD 20-714	75.3	Generic	-56	17	0.337	0.609	0.012	1.44	98
	305424	INTER SHELL AXIAL WELD 19-714	79.9	Generic	-56	17	0.273	0.629	0.013	1.44	112
LINDE 0091 WELD	90136	CIRC WELD 11-714	76.1	Generic	-56	17	0.269	0.07	0.013	0.964	144
Oconee 1, (Designer and Manufacturer: B&W) Coolant Temperature = 556°F, Vessel Thickness = 8.44-in.											
FORGING	AHR54 (ZV2861)	LOWER NOZZLE BELT	(4)	B&W Generic	3	31	0.16	0.65	0.006	(5)	109
PLATE	C2197-2	INTERMEDIATE SHELL	(4)	B&W Generic	1	26.9	0.15	0.5	0.008	1.28	81
	C2800-1	LOWER SHELL	(4)	B&W Generic	1	26.9	0.11	0.63	0.012	1.4	81
	C2800-2	LOWER SHELL	69.9	B&W Generic	1	26.9	0.11	0.63	0.012	1.4	119
	C3265-1	UPPER SHELL	75.8	B&W Generic	1	26.9	0.1	0.5	0.015	1.42	108
	C3278-1	UPPER SHELL	(4)	B&W Generic	1	26.9	0.12	0.6	0.01	1.26	81
LINDE 80 WELD	1P0962	INTERMEDIATE SHELL AXIAL WELDS SA-1073	79.4	B&W Generic	-5	19.7	0.21	0.64	0.025	1.38	70
	299L44	INT./UPPER SHL CIRC WELD (OUTSIDE 39%) WF-25	(4)	B&W Generic	-7	20.6	0.34	0.68	(3)	1.573	81
	61782	NOZZLE BELT/INT. SHELL CIRC WELD SA-1135	(4)	B&W Generic	-5	19.7	0.23	0.52	0.011	1.404	80
	71249	INT./UPPER SHL CIRC WELD (INSIDE 61%) SA-1229	76.4	ASME NB-2331	10	0	0.23	0.59	0.021	1.488	67
	72445	UPPER/LOWER SHELL CIRC WELD SA-1585	(4)	B&W Generic	-5	19.7	0.22	0.54	0.016	1.436	65
	8T1762	LOWER SHELL AXIAL WELDS SA-1430	75.5	B&W Generic	-5	19.7	0.19	0.57	0.017	1.48	70
	8T1762	UPPER SHELL AXIAL WELDS SA-1493	(4)	B&W Generic	-5	19.7	0.19	0.57	0.017	1.48	70
	8T1762	LOWER SHELL AXIAL WELDS SA-1426	75.5	B&W Generic	-5	19.7	0.19	0.57	0.017	1.48	70
Pallisades, (Designer and Manufacturer: CE) Coolant Temperature = 532°F, Vessel Thickness = 8½ in.											
PLATE	A-0313	D-3803-2	(4)	MTEB 5-2	-30	0	0.24	0.52	0.01	1.35	87
	B-5294	D-3804-3	(4)	MTEB 5-2	-25	0	0.12	0.55	0.01	1.27	73
	C-1279	D-3803-3	(4)	ASME NB-2331	-5	0	0.24	0.5	0.011	1.293	102

Product Form	**Heat**	**Beltline**	**$\sigma_{flow(u)}$ [ksi]**	**$RT_{NDT(u)}$ [°F]**			**Composition$^{(2)}$**				**$USE_{(u)}$ [ft-lb]**
				$RT_{NDT(u)}$ Method	**$RT_{NDT(u)}$ Value**	**$\sigma_{(u)}$ Value**	**Cu**	**Ni**	**P**	**Mn**	
	C-1279	D-3803-1	74.7	ASME NB-2331	-5	0	0.24	0.51	0.009	1.293	102
	C-1308A	D-3804-1	(4)	ASME NB-2331	0	0	0.19	0.48	0.016	1.235	72
	C-1308B	D-3804-2	(4)	MTEB 5-2	-30	0	0.19	0.5	0.015	1.235	76
LINDE 0124 WELD	27204	CIRC. WELD 9-112	76.9	Generic	-56	17	0.203	1.018	0.013	1.147	98
LINDE 1092 WELD	34B009	LOWER SHELL AXIAL WELD 3-112A/C	76.1	Generic	-56	17	0.192	0.98	(3)	1.34	111
	W5214	LOWER SHELL AXIAL WELDS 3-112A/C	72.9	Generic	-56	17	0.213	1.01	0.019	1.315	118
	W5214	INTERMEDIATE SHELL AXIAL WELDS 2-112 A/C	72.9	Generic	-56	17	0.213	1.01	0.019	1.315	118

Notes:

(1) Information taken from the July 2000 release of the NRCs Reactor Vessel Integrity (RVID2) database.
(2) These composition values are as reported in RVID2 for Cu, Ni, and P and as in RPVDATA for Mn. In FAVOR calculations these values should be treated as the central tendency of the Cu, Ni, P, and Mn distributions.
(3) No values of phosphorus are recorded in RVID2 for these heats. A generic value of 0.012 should be used, which is the mean of 826 phosphorus values taken from the surveillance database used by Eason et al. to calibrate the embrittlement trend curve.
(4) No strength measurements are available in PREP4 for these heats [PREP]. A value of 77 ksi should be used, which is the mean of other flow strength values reported in this Appendix.
(5) No values of manganese strength in RPVDATA for these heats [ref]. A generic value of 0.80 should be used, which is the mean value of manganese for forgings taken from the surveillance database used by Eason et al. to calibrate the embrittlement trend curve.

References:

RVID2	U.S. Nuclear Regulatory Commission Reactor Vessel Integrity Database, Version 2.1.1, July 6, 2000.
PREP	PREP4: Power Reactor Embrittlement Program, Version 1.0," EPRI, Palo Alto, CA: 1996. SW-106276
RPVDATA	T. J. Griesbach, and J.F. Williams, “User’s Guide to RPVDATA,Reactor Vessel Materials Database,” Westinghouse Energy Systems Business Unit, WCAP-14616, 1996.

8. Appendix C – As-Found Flaw FAVPFM Version 20.1 Input

C.1 Introduction

The FAVOR code, specifically the FAVPFM subcode, has used the flaw characterization input from the previously developed VFLAW (References [1], [2], [3], and [4]) based approach on RPVs. VFLAW was developed at the Pacific Northwest National Laboratory (PNNL). The technical basis for VFLAW is based on from flaw data obtained from the destructive examination of RPV materials [1]. VFLAW provides statistical distributions of the number and the geometry of flaws that could exist in a reactor pressure vessel (RPV). This application has been useful in the generic evaluation of surface, plate, and weld flaws in RPVs, particularly in the Pressurized Thermal Shock (PTS) reevaluation. More recently, an approach was developed to evaluate a large number of quasi-laminar flaws identified by ultrasonic inspection of the Doel 3 and Tihange 2 RPV lower and upper core shells (Reference [5]). A modified version of FAVPFM was developed to perform a conservative deterministic evaluation of these Doel 3 and Tihange 2 RPV flaws (Note that this modification to FAVOR 16.1 was not released). Because concerns with these flaws could be resolved with this conservative deterministic analysis, a probabilistic fracture mechanics (PFM) evaluation was not required. Because future RPV examinations may require PFM analysis to support decisions on continued plant operation with newly identified flaws, an as-found flaw version of FAVPFM (Version 20.1) has been developed. This as-found flaw FAVOR code is designed to assess identified flaws from in-service inspections where specific and unique flaw characterizations are identified.

C.2 FAVPFM As-Found Flaw Input Flag - IPFLAW

The user-input variable IPFLAW (flaw population) in the FAVPFM input dataset activates the as-found flaw option of FAVPFM. All other FAVPFM input variable records remain the same in number, description, and format as FAVOR 16.1. In the 16.1 version of FAVOR, IPFLAW =1, 2, or 3 on **Record 1** (i.e., **CNT1**) defines the flaw population to be used in PFM analyses as follows:

- **IPFLAW = 1**: All surface breaking flaws are assumed to be on the inner surface of the RPV. Only those embedded flaws in the 3/8th of the base metal nearest the RPV inner (wetted) surface are included in the analyses and they are uniformly distributed. This option is meant for cool-down transients based on the assumption that external surface breaking flaws and embedded flaws beyond the inner 3/8th of the base metal are primarily in compressive stress fields during cool-down transients and would therefore would never initiate in fracture.

- **IPFLAW = 2**: All surface breaking flaws are assumed to be on the external surface of the RPV. Only those embedded flaws in the 3/8th of the base metal nearest the RPV outer surface are included in the analyses and they are uniformly distributed. This option is meant for heat-up transients based on the assumption that internal surface breaking flaws and embedded flaws in the inner 3/8th of the base metal are primarily in compressive stress fields during heat-up transients and would therefore would never initiate in fracture. It has since been found that this is not necessarily always a valid assumption as internal surface breaking flaws can also initiate exceedingly early in some cases during some heat-up transients.

- **IPFLAW = 3**: Results in double the number of surface breaking flaws in either of the above options. Half are internal and half are external of surface breaking flaws. Embedded flaws are uniformly distributed thru the entire wall thickness and results in (8/3) as many embedded flaws as either of the above options. This option can be used for any case; however, was primarily designed for the hydrostatic test load condition, which consists of both a heat-up and cool-down phase. This option requires more computational time to perform a PFM analysis; however, there are no questions regarding "what if" all possible flaws had been included in the analysis.

In the 20.1 version of FAVOR, IPFLAW = 1,2, or 3, FAVPFM will continue to prompt the user for three flaw characterization files discussed above and will generate identical solutions as the 16.1 version of FAVOR thus providing backward compatibility.

If **IPFLAW = 4**, FAVPFM will prompt the user for a single flaw file which characterizes the "as-found flaws" which, in the general case, can be any combination of surface breaking flaws / embedded flaws / material / flaw orientation. For IPFLAW=4, FAVPFM will generate PFM solutions for the set of as-found flaws.

C.3 Content and Format for As-Found Flaw Distribution File

User input is entered in free format style. The first record must contain "201" to indicate v20.1 of FAVPFM is being used. Each record following the first must include seven (7) free-formatted values as described in Table C.1 below.

Note that in-service inspection results are typically based on ASME flaw dimensional terminology which needs to be converted to FAVOR based input. As-found flaws as described herein are related to those found in non-destructive examinations and have been characterized per ASME code, ASME Boiler and Pressure Vessel Code – Rules for Inservice Inspection of Nuclear Power Plant Components [6]. The following sections of the ASME code can assist users to provide flaw specifications into the new FAVPFM module:

- IWA-3300, Flaw Characterization,
- IWB-3600, Analytical Evaluation of Planar Flaws,
- Nonmandatory Appendix A, Analytical Evaluation of Flaws, and
- Nonmandatory Appendix G, Fracture Toughness Criteria for Protection Against Failure.
- ASME Code Case N-848 [7].

The above referenced ASME sections layout the requirements on how to characterize and analyze flaws discovered in NDE of reactor vessels, particularly flaw characterization, multiple flaws, and proximity rules to other flaws. The current FAVOR code and associated modules do not take actual NDE surveillance data as direct input. The geometry of flaws assumed within the current v16.1 of FAVOR assume elliptical geometry, axial or circumferential, and discrete aspect ratios, whereas in reality, flaws found in surveillances are not exactly elliptical, axial, or circumferential, nor have a simple aspect ratio. Therefore, the translation from these NDE discovered flaws require a translation based on the ASME code or newly developed method to evaluate any geometry and type of flaw (e.g., surface, or embedded), and orientation. The user must interpret the NDE results and characterize the flaws according to the ASME code. An example application of this transformation is described in Appendix A of Reference [5].

IWA-3300 of the ASME Code describes the standard used for flaw characterization. A sample characterization of flaws from NDE is shown below. The guidance in IWA-3300 is used in characterization all flaws that can be modeled as elliptical flaws in the axial and/or circumferential direction as illustrated in the ASME evaluation of flaws in either IWB-3600, Analytical Evaluation of Planar Flaws or Appendix A, Analytical Evaluation of Flaws.

Application of FAVPFM to assessments of various oriented and sized flaws requires a flaw characterization that meets the following requirements:

- axial and/or circumferential flaws normal to principal stress directions of the RPV that are amenable to Mode I fracture mechanics analysis,
- for embedded (non-surface) flaws, the configuration must be fully elliptical, and
- flaws are assumed mechanically independent, i.e., flaws do not interact.

The effects of proximity of flaws, their interaction, and flaw orientation were examined in two papers [[8] - [9]] and translated into the ASME Code Case N-848 [7]. These documents provide acceptable rules to incorporate flaw interaction and orientation effects for quasi-laminar and planar flaws based on their alignment and distance between them. The approach described in ASME Code Case N-848 [7] is to characterize such flaws by defining a bounding box (Figure C.1 and Figure C.2) for an individual flaw, a grouped flaw (two or more quasi-laminar flaws), or an extended combined flaw (containing also a planar flaw). The bounding box (containing a single flaw or grouped flaws) is resolved into two rectangular planar flaws, each corresponding to the faces of the box normal to the principal stresses. The two planar flaws must be:

- normal to the hoop and axial stress directions,
- retain the surface/subsurface characterization defined for a combined flaw,
- assume the dimensions of the relevant surfaces of the bounding box, and
- have been evaluated (per ASME code requirements) such there are no interactions to other flaws outside the bounded box.

The major and minor axes of each ellipse are defined such that the major axes of the ellipse are in the same ratio as the sides of the rectangle, and the area of the ellipse is the same as the area of the corresponding rectangle. Thus, the flaw characterization as input to FAVPFM contains two elliptical flaws, one for the axial and one for the circumferential component, which are normal to the hoop and axial stresses, respectively.

Further detail on how the transformation is applied is described in Reference [5] and summarized below:

In order to define the elliptical flaws, the criteria used was that the major axes of the ellipse are in the same ratio as the sides of the rectangle, and the area of the ellipse is the same as the area of the corresponding rectangle. Using these two criteria, it is possible to determine the major and minor axes of the ellipse. As shown in Figure C.3: Rectangle and Ellipse Having the Same Area and Same Aspect Ratio Figure C.3, given a rectangle with sides *a* and *b*, we need to determine the semi-major and semi-minor axes *l* and *d*. The centers of the rectangle and ellipse are also assumed to be at the same point. If we require the major and minor axes of the ellipse to be in the same ratio as the length and width of the rectangle, and the area of the rectangle and ellipse to also be the same, then

$$\frac{a}{b} = \frac{l}{d} \text{ and } a \times b = \pi \times l \times d \,. \qquad \text{(Equation C.1)}$$

Using the above equations, $l = a/\pi$, and $d = \frac{b}{\pi}$

The quantities needed by FAVPFM to define the flaw geometry are the distance to the inner crack tip from the inside (pressure bearing) surface of the vessel, the depth, and the aspect ratio of the flaw. Note that FAVOR defines the aspect ratio as the reciprocal of the ASME based definition.

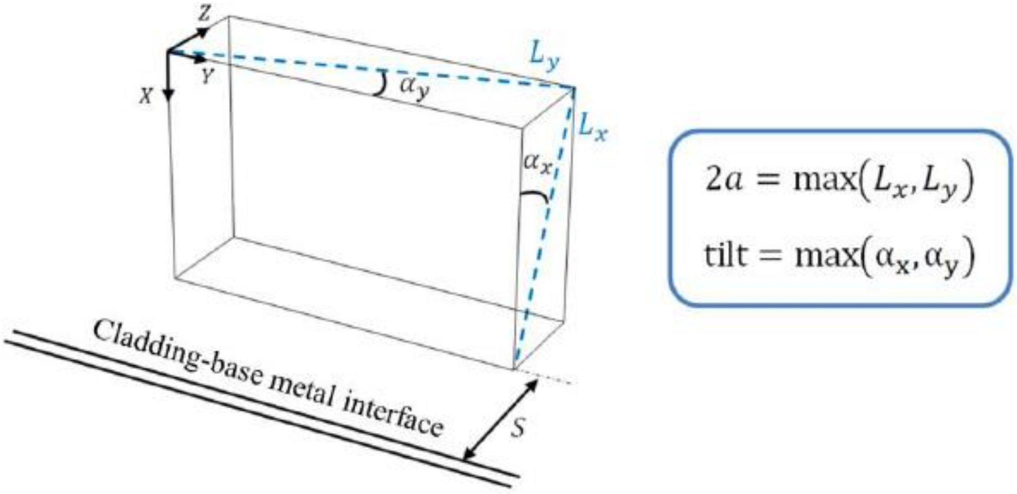

Figure C.1: Diagonals and Angles used to Specify the Flaw Indication

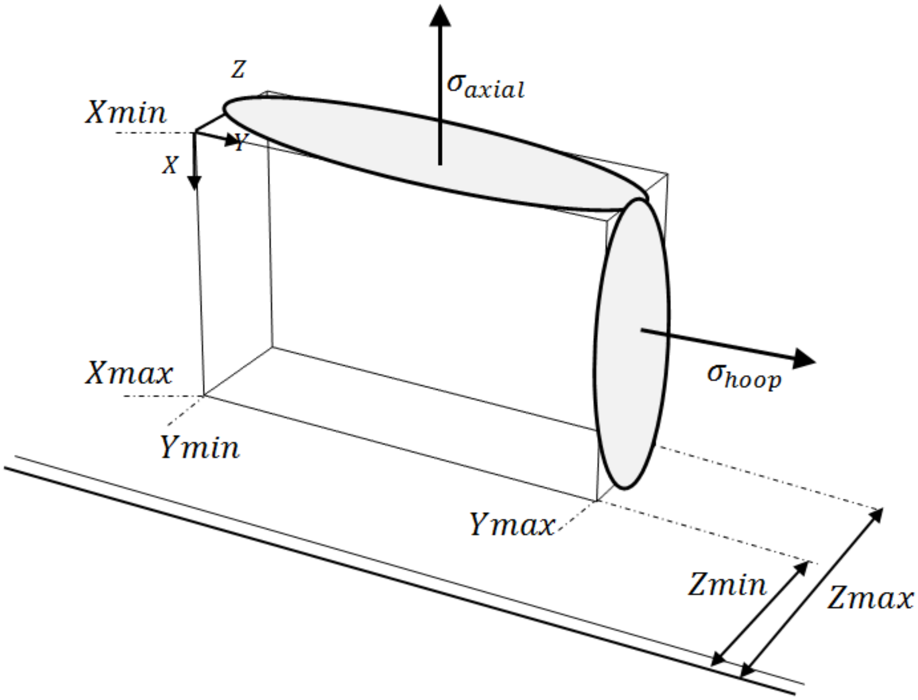

Figure C.2: Bounding Box for Flaw Indication Showing Two Resolved Elliptical Flaws Normal to the Axial and Hoop Stress Directions

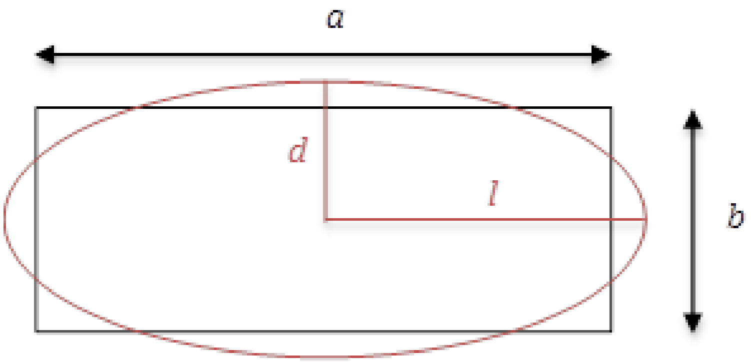

Figure C.3: Rectangle and Ellipse Having the Same Area and Same Aspect Ratio

Table C. 1: As-Found Flaw Input File

Flaw Unique ID Number – (Up to 5 characters)	Flaw Type(1) 1=ISB and 2=Embedded	Subregion In which flaw resides	Orientation(2) 1=Axial 2=Circum.	Depth(3) (inches)	Aspect(3) Ratio	Radial(4) Location (inches)
ABC12	1	13	1	2.1875	6	0
ABD45	2	10	2	0.8750	8.122	2.32
:	:	:	:	:	:	:
:	:	:	:	:	:	:
N	2	8	1	0.0875	3.108	1.038

1. Defines variable IKIND in the code, where 1=ISB → internal surface breaking flaw; and 2=EMB → embedded flaw. External surface breaking flaws are not modeled in v20.1.
2. Orientation: 1 = axial; 2 = circumferential
3. See Figures C.4 to C.7
4. Only applicable for embedded flaws. Value is variable xinner in the code, which is the location of inner crack tip of embedded flaw relative to wetted inner surface.

Sample As-Found File Input

```
201
   1   2  10   1   0.08750  8.122547752408  2.319516368985
   2   2  13   2   0.08750  3.676104057742  0.588145364364
   3   2   4   1   1.05000  8.970125137961  2.820941348826
   4   2   7   2   0.52500 17.904967736172  1.535381603127
   5   2   9   1   0.26250  2.738724758689  1.697111095184
   6   2   8   2   0.17500  9.272502839534  3.027352722223
   7   2   8   1   0.08750  3.108261145271  1.038243792798
   8   2   3   1   0.26250  1.687684417897  2.120970082038
   9   2   9   2   0.17500  1.354105412765  0.964943350649
  10   2   6   1   0.43750  5.169382196556  1.940942253535
  11   1   9   2   0.17500         6  0.000000000000
  12   2   7   2   0.17500  2.122181346809  1.724890895003
  13   1  13   2   2.18750         6  0.000000000000
                                   :
                                   :
                                   :
5254   2  10   1   0.26250  2.060330675969  1.278463196817
```

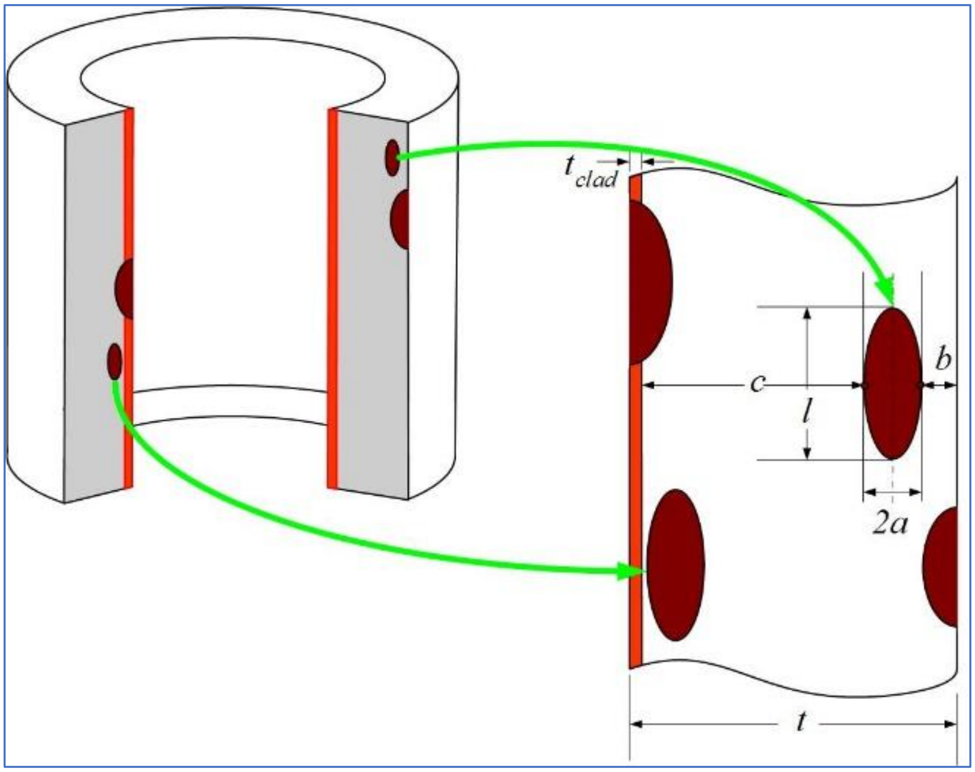

Figure C.4: Illustration of Axially Oriented ISB, ESB, and Embedded Flaws

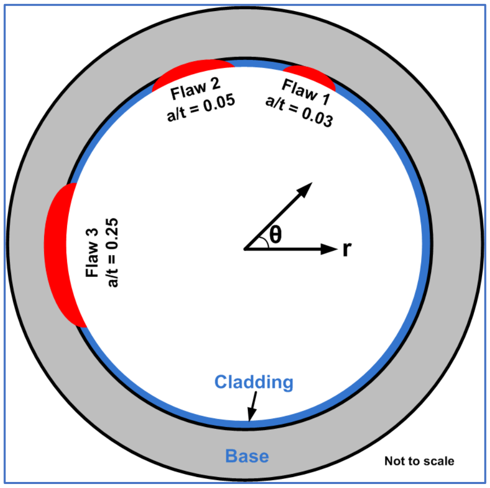

Figure C.5: Illustration of Circumferentially Oriented ISB Flaws

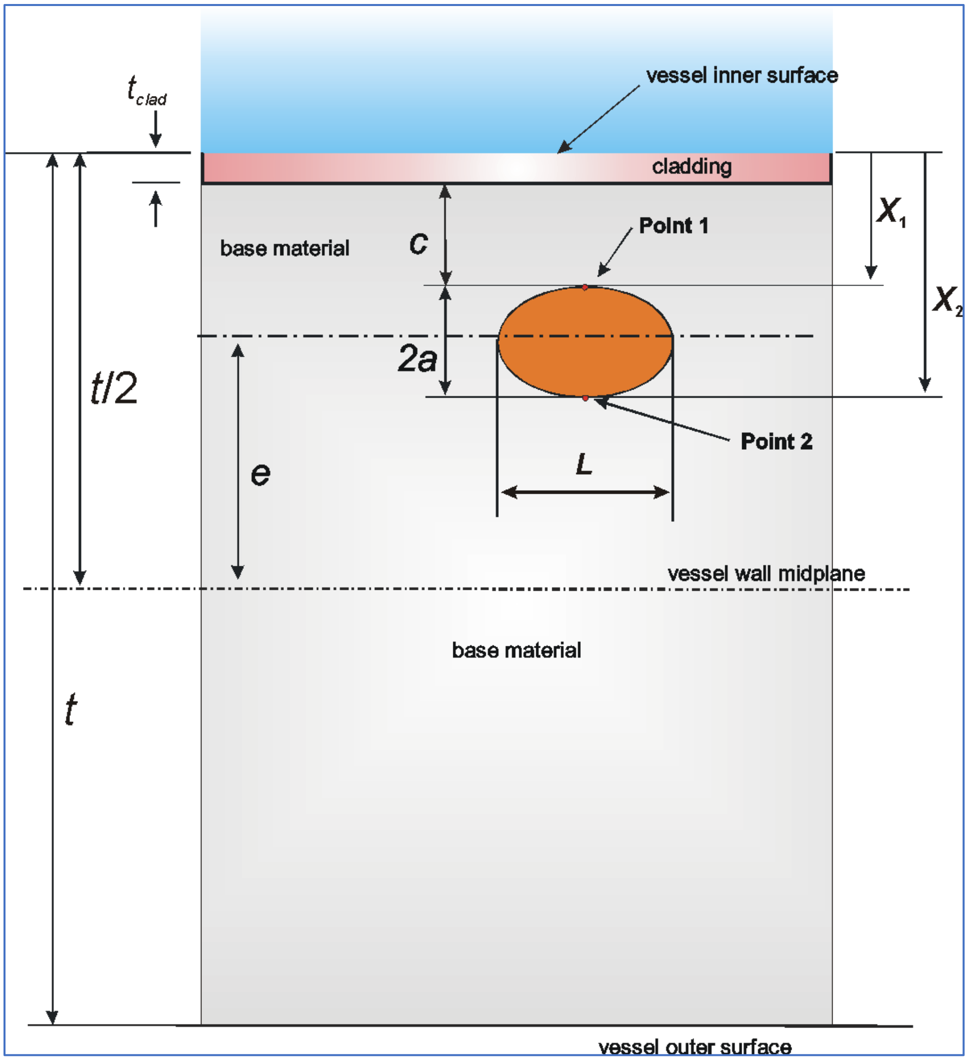

Figure C.6: Illustration of Embedded Flaw - Inner Half of RPV Wall Thickness : Depth = 2a, Aspect Ratio = L / 2a, Distance of Inner Crack Tip from Wetted Inner Surface = $X_1 = c + t_{clad}$

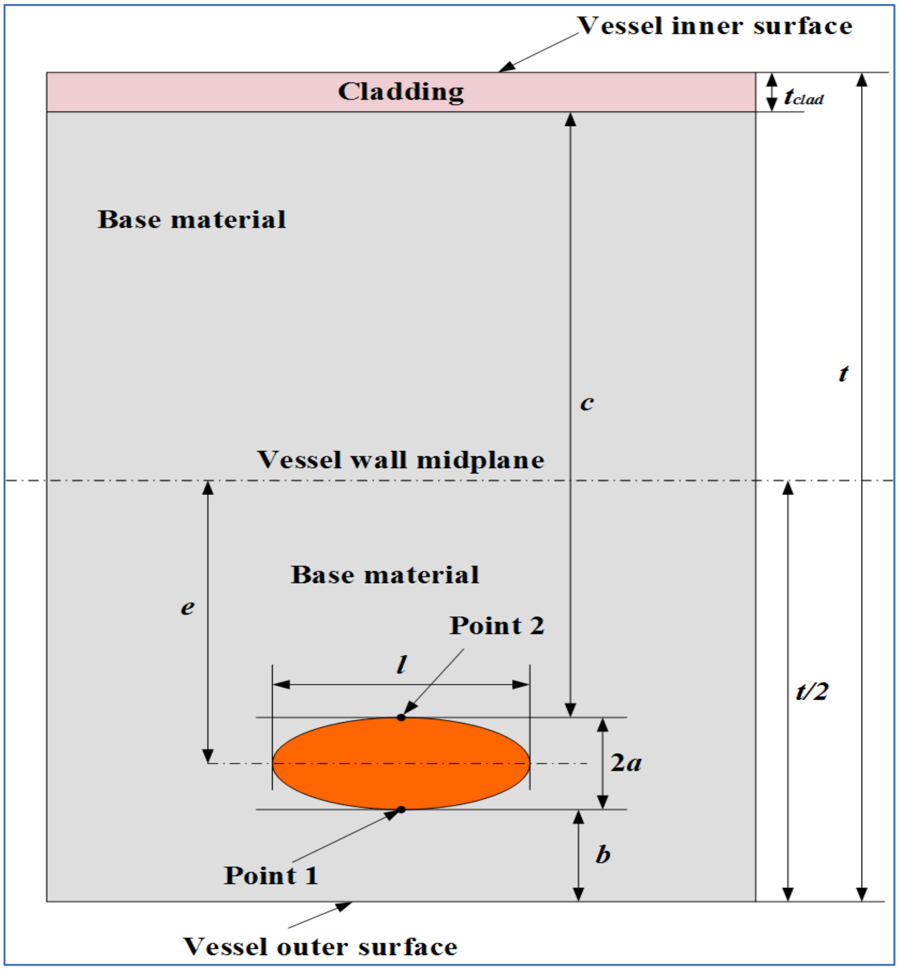

Figure C.7: Illustration of Embedded Flaw - Outer Half of RPV Wall Thickness : Depth = 2a, Aspect Ratio = l / 2a, Distance of Inner Crack Tip from Wetted Inner Surface = $c + t_{clad}$

C.4 FAVOR PFM Module – FAVPFM Output for As-Found Flaw Input

When both IPFLAW is set to 4 and IQA is set to 0 (PFM analysis), FAVPFM produces the following files:

General Output Files

(1) Filename defined by user at execution (e.g., FAVPFM.OUT)
(2) Echo of input file with filename defined by user at execution (e.g., FAVPFM.echo)
(3) Echo of the as-found flaw input file with filename defined by user at execution (e.g., FAVPFM.aff.echo)
(4) Binary restart file – restart.bin

Input files for FAVPost

(5) FAILURE.DAT
(6) INITIATE.DAT

QA Verification Files

(7) ARREST.OUT
(8) CPF_history.out
(9) CPI_history.out
(10) NSIM.DAT
(11) FLAWNO.OUT
(12) FLAWSIZE.OUT
(13) TRACE.OUT
(14) FLAW_TRACK.LOG
(15) History_itran_iseq.out (NTRAN files where **itran** is the FAVOR transient number and **iseq** is its associated and unique thermal-hydraulic initiating-event sequence number)

See the Version 16.1 User Guide for partial listings of example files: (2) FAVPFM.echo, (7) ARREST.OUT, (11) FLAWNO.OUT, (12) FLAWSIZE.OUT, (13) TRACE.OUT, (14) FLAW_TRACK.LOG, and (15) History_itran_iseq.out.

FAVPFM.aff.echo includes two sections:

(1) Echo of all input flaw data from the user specified as-found flaw file.
(2) Summary of the flaw characterization from the user input data.

FAVPFM.out includes results for all transients in this case definition including:

(1) Mean value of conditional probability of initiation (CPI)
(2) Mean value of conditional probability of failure (CPF)
(3) Flaw distribution report by RPV Beltline Region including maximum RT_{NDT}
(4) Mean value of RT_{NDT} at crack tip
(5) Allocation of Risk Table for each Transient – Sorted by % of **CPI** containing the following:
    a. Unique flaw ID and flaw characteristics (Kind, depth, aspect ratio, subregion flaw resides, crack tip location, orientation)
    b. Average RT_{NDT}
    c. Mean value of CPI from this unique flaw and % of total contribution to CPI due to all flaws
    d. Mean value of CPF from this unique flaw and % of total contribution to CPF due to all flaws
(6) Allocation of Risk Table for each Transient – Sorted by % of **CPF** containing the following:
    a. Unique flaw ID and flaw characteristics (same as for CPI)
    b. Average RT_{NDT}
    c. Mean value of CPI from this unique flaw and % of total contribution to CPI due to all flaws
    d. Mean value of CPF from this unique flaw and % of total contribution to CPF due to all flaws
(7) Flaw Distribution by Material and Category
(8) Flaw Distribution by Material, Category, and Orientation
(9) Weld Flaw-Size Distribution Report
(10) Plate Flaw-Size Distribution Report
(11) Transient Time Distribution Report
(12) Probability and Cumulative Distribution Functions for the Initiating Driving Force
(13) Failure Mechanism Report
(14) Following all reports for each transient, a Multiple Flaw Statistics Summary

FAVPFM As-Found File Echo (*.aff.echo) – (Partial Listing)

```
               ************************************************
               *                                              *
               *                WELCOME TO FAVOR              *
               *                                              *
               *    FRACTURE ANALYSIS OF VESSELS: OAK RIDGE   *
               *                 VERSION 20.1                 *
               *                                              *
               *         INCLUDES AS-FOUND FLAW OPTION        *
               *                                              *
               *     FAVPFM MODULE: PERFORMS PROBABILISTIC    *
               *          FRACTURE MECHANICS ANALYSES         *
               *                                              *
               *     PROBLEMS OR QUESTIONS REGARDING FAVOR    *
               *              SHOULD BE DIRECTED TO:          *
               *                                              *
               *               PATRICK RAYNAUD                *
               *  UNITED STATES NUCLEAR REGULATORY COMMISSION *
               *     Office of Nuclear Regulatory Research    *
               *                                              *
               *         e-mail: patrick.raynaud@nrc.gov      *
               *              phone: (301) 415-1987           *
               *                                              *
               ************************************************

          ************************************************************
          * 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      *
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          * nor any of their contractors, subcontractors, or their   *
          * employees, makes any warranty, express or implied, or    *
          * assumes any legal liability or responsibility for the    *
          * accuracy, completeness, or usefulness of any             *
          * information, apparatus, product, or process disclosed,   *
          * or represents that its use would not infringe            *
          * privately-owned rights.                                  *
          *                                                          *
          ************************************************************


               DATE: 29-Jul-2020  TIME: 11:58:55


               FAVPFM INPUT FILE NAME       = pfm1000.in
               FAVLOAD OUTPUT FILE NAME     = lpts1.out
               FAVPFM OUTPUT FILE NAME      = pfm46c-1000ordered.out
               FAVPFM INPUT ECHO FILE NAME  = pfm46c-1000ordered.echo

               AS-FOUND FLAW FILE NAME  = pws5254ext.dat
               AS-FOUND FLAW INPUT ECHO FILE NAME  = pfm46c-1000ordered.aff.echo


                Begin echo of FAVPFM input data deck          11:58:55   29-Jul-2020

 no./col.
1.......10........20........30........40........50........60........70........80........90.......100.......110.......12
0.......130
     1    201
     2       1   2  10   1   0.08750  8.122547752408  2.319516368985
     3       2   2  13   2   0.08750  3.676104057742  0.588145364364
     4       3   2   4   1   1.05000  8.970125137961  2.820941348826
     5       4   2   7   2   0.52500 17.904967736172  1.535381603127
     6       5   2   9   1   0.26250  2.738724758689  1.697111095184
     7       6   2   8   2   0.17500  9.272502839534  3.027352722223
     8       7   2   8   1   0.08750  3.108261145271  1.038243792798
     9       8   2   3   1   0.26250  1.687684417897  2.120970082038
    10       9   2   9   2   0.17500  1.354105412765  0.964943350649
    11      10   2   6   1   0.43750  5.169382196556  1.940942253535
    12      11   1   9   2   0.17500         6  0.000000000000
:
:
:
  5250    5249   2   1   1   0.08750  2.499498945366  3.141515258472
  5251    5250   2   9   1   0.17500  1.377335146559  0.399642828505
  5252    5251   2  12   2   0.08750  6.931782017943  0.326257855238
  5253    5252   2  11   1   0.08750  3.418544982793  2.144354387388
  5254    5253   2   9   2   0.08750  2.906510364213  2.534569708062
  5255    5254   2  10   1   0.26250  2.060330675969  1.278463196817
no./col.
1.......10........20........30........40........50........60........70........80........90.......100.......110.......12
0.......130

                End echo of FAVPFM input data deck          11:58:55   29-Jul-2020


                                 ==============================================
                                 *      Characteristics of As-Found Flaws     *
                                 ==============================================

                             Flaw    Flaw   Depth   Crack tip  Aspect  Flaw    Sub
                              ID#    KIND   (inch)   (inch)     ratio  ORNT   region
                                1       2    0.087    2.320         8    1      10
                                2       2    0.087    0.588         3    2      13
```

FAVPFM As-Found File Echo (*.aff.echo) – (Partial Listing) – (Continued)

```
   3     2    1.050    2.821      8    1      4
   4     2    0.525    1.535     17    2      7
   5     2    0.263    1.697      2    1      9
   6     2    0.175    3.027      9    2      8
   7     2    0.087    1.038      3    1      8
   8     2    0.263    2.121      1    1      3
   9     2    0.175    0.965      1    2      9
  10     2    0.438    1.941      5    1      6
  11     1    0.175    0.175      6    2      9
  12     2    0.175    1.725      2    2      7
  13     1    2.188    2.188      6    2     13

                             :
                             :
                             :

5242     2    0.087    3.159      1    2     11
5243     2    0.263    1.828      2    1     13
5244     2    0.087    1.247      1    1      3
5245     2    0.263    1.917      1    2      8
5246     2    0.087    2.055      4    1      2
5247     2    0.087    1.149     12    2      7
5248     2    0.087    1.032      7    1      3
5249     2    0.087    3.142      2    1      1
5250     2    0.175    0.400      1    1      9
5251     2    0.087    0.326      6    2     12
5252     2    0.087    2.144      3    1     11
5253     2    0.087    2.535      2    2      9
5254     2    0.263    1.278      2    1     10
```

FAVPFM As-Found Output File (*.out)

```
              ************************************************
              *                                              *
              *                WELCOME TO FAVOR              *
              *                                              *
              *    FRACTURE ANALYSIS OF VESSELS: OAK RIDGE   *
              *                 VERSION 20.1                 *
              *                                              *
              *         INCLUDES AS-FOUND FLAW OPTION        *
              *                                              *
              *     FAVPFM MODULE: PERFORMS PROBABILISTIC    *
              *          FRACTURE MECHANICS ANALYSES         *
              *                                              *
              *     PROBLEMS OR QUESTIONS REGARDING FAVOR    *
              *              SHOULD BE DIRECTED TO:          *
              *                                              *
              *               PATRICK RAYNAUD                *
              *  UNITED STATES NUCLEAR REGULATORY COMMISSION *
              *     Office of Nuclear Regulatory Research    *
              *                                              *
              *         e-mail: patrick.raynaud@nrc.gov      *
              *              phone: (301) 415-1987           *
              *                                              *
              ************************************************

         ***********************************************************
         * 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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         * assumes any legal liability or responsibility for the   *
         * accuracy, completeness, or usefulness of any            *
         * information, apparatus, product, or process disclosed,  *
         * or represents that its use would not infringe           *
         * privately-owned rights.                                 *
         *                                                         *
         ***********************************************************



              DATE: 29-Jul-2020  TIME: 11:58:36



              FAVPFM INPUT FILE NAME       = pfm1000.in
              FAVLOAD OUTPUT FILE NAME     = lpts1.out
              FAVPFM OUTPUT FILE NAME      = pfm46c-1000ordered.out
              FAVPFM INPUT ECHO FILE NAME  = pfm46c-1000ordered.echo



               *******************************************
               Binary restart files will be created using
               a checkpoint interval of **** trials.
               *******************************************

NUMBER OF TIME STEPS IN FAVLoad FILE   =   251

NUMBER OF IGA TRIALS PER FLAW          =   100
FLOW STRESS - USED IN FAILURE ANALYSIS =  80.0 ksi
Maximum value used for KIc and KIa     = 200.0 ksi-in^1/2
KIc/KIa cap not used if ductile-tearing model is invoked.

Stochastic model for crack arrest KIa  =     1
where
  1 = model based on high-constraint CCA specimens
  2 = model based on CCA and large-specimen data
  KIa model set to 2 if ductile-tearing model is invoked.

Radiation embrittlement correlation    =   992
where
    992 = Regulatory Guide 1.99, revision 2
   2000 = Eason 2000
   2006 = Eason 2006
  20071 = EricksonKirk 2007
  20072 = RADAMO 2007
  20073 = Combined EricksonKirk 2007 + RADAMO 2007

Steady-state cooling water temperature  =  550. degrees F

Effective full-power years of operation =   72.


DEFINITION OF STANDARD DEVIATIONS FOR SIMULATING
THE FOLLOWING PARAMETERS

SURFACE NEUTRON FLUENCE - GLOBAL =   0.118* BEST ESTIMATE VALUE
SURFACE NEUTRON FLUENCE - LOCAL  =   0.056* BEST ESTIMATE VALUE
COPPER      - WELD   =       0.167 wt %
COPPER      - PLATE  =      0.0073 wt %
NICKEL      - WELD   =      0.1620 wt %
NICKEL      - PLATE  =      0.0244 wt %
PHOSPHORUS  - WELD   =      0.0013 wt %
PHOSPHORUS  - PLATE  =      0.0013 wt %
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
NUMBER OF VESSEL SUBREGIONS:    WELD=    7 PLATE=    6 TOTAL=   13
NUMBER OF VESSEL MAJOR REGIONS: WELD=    7 PLATE=    6 TOTAL=   13


                         ***********************************************************
                         *                                                         *
                         *                   PFM ANALYSIS RESULTS                  *
                         *                                                         *
                         ***********************************************************


             ****************************************************************************
             * INITIAL RANDOM NUMBER GENERATOR SEEDS   :      1234567890      123456789 *
             ****************************************************************************

                                 ************************************************
                                 ** IPFLAW=4: AS-FOUND FLAW OPTION             **
                                 ** WELD LAYER RESAMPLING TURNED ON            **
                                 ************************************************

                             ****************************************************
                             ** WARM-PRESTRESS OPTION 1 CHOSEN:                **
                             **                                                **
                             ** TO HAVE A NON-ZERO instantaneous conditional   **
                             ** probability of crack initiation at a discrete  **
                             ** transient time step:                           **
                             **                                                **
                             ** applied KI must be greater than the Weibull    **
                             ** "a" parameter                                  **
                             **                                                **
                             **  AND                                           **
                             **                                                **
                             ** applied KI MUST EXCEED MAXIMUM KI at all       **
                             ** previous discrete transient time steps         **
                             ****************************************************

                                 ************************************************
                                 ** DO NOT ANALYZE CATEGORY 3 PLATE FLAWS      **
                                 ** DUCTILE-TEARING MODEL TURNED OFF           **
                                 ** FAILURE CRITERIA a/t =    0.90             **
                                 ************************************************


                                 *********************************************
                                 *********************************************
                                 **  PFM RESULTS FOR TRANSIENT NUMBER     1 **
                                 *********************************************
                                 *********************************************

                                 *********************************************
                                 **                                         **
                                 **  NUMBER OF COMPLETED TRIALS =    1000   **
                                 **                                         **
                                 *********************************************

                                        MEAN VALUE OF CPI =     4.921E-01
                                        MEAN VALUE OF CPF =     2.864E-02

                                     *************************************
                                     *  RPV BELTLINE MAJOR REGION REPORT *
                                     *       BY PARENT SUBREGION         *
                                     *************************************
 ====================================================================================================
                                  FAVPFM As-Found Output File (*.out) - (Continued)

                                     |---Initiation---|   |----Cleavage----| |------Ductile-----|
  MAJOR     RTndt  % OF     SIMULATED    # of FLAWS  % of      # of FLAWS  % of   # of FLAWS    % of
  REGION    (MAX)  FLAWS      FLAWS        CPI > 0   CPI         CPF > 0    CPF      CPF > 0     CPF
 ====================================================================================================
    1       241.6   3.24    170000       1789         2.74     1788        17.23          0         0.00
    2       254.9   2.66    140000       3391         0.87     3389        13.90          0         0.00
    3       254.9   2.53    133000       3257         3.00     3257        35.50          0         0.00
    4       255.5   4.26    224000       4830         4.09     3951        13.81          0         0.00
    5       242.1   4.23    222000       2184         0.43     2184         4.36          0         0.00
    6       255.5   4.61    242000       3429         4.05     3123         5.08          0         0.00
    7       260.7  26.99   1418000      36632        18.81        0         0.00          0         0.00
    8       179.8   6.62    348000       1997         1.56      216         0.06          0         0.00
    9       152.9   6.95    365000        439         0.25        7         0.00          0         0.00
   10        89.5   7.50    394000          0         0.00        0         0.00          0         0.00
   11       217.3  10.16    534000      12165        21.01     1763         1.12          0         0.00
   12       194.3  10.03    527000       6863         9.34      856         0.58          0         0.00
   13       215.3  10.22    537000      14466        33.85     2688         8.38          0         0.00
 ====================================================================================================
          TOTALS 100.00    5254000      91442       100.00    23222       100.00          0         0.00
 ====================================================================================================

                                NOTE: MEAN VALUE OF RTNDT AT CRACK TIP=  162.84

                   ===================================================================
                   * Allocation of Risk by Flaw for Transient  1 - sorted by % of CPI  *
                   ===================================================================

   Flaw Flaw Depth  Aspect   Sub  Crack tip  Flaw   average              % of              % of
    ID# KIND (inch)  ratio  Region (inch)    ORNT    RTNDT     CPImean     CPI    CPFmean     CPF
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
   3070  1   0.613  99.000    13    0.613    circf   193.20   0.644E-01    6.20   0.000E+00     0.00
   5102  1   0.438  99.000    13    0.438    circf   194.74   0.594E-01    5.72   0.000E+00     0.00
    721  1   0.787   6.000     7    0.787    circf   200.77   0.544E-01    5.24   0.000E+00     0.00
    800  1   0.787  99.000    11    0.787    circf   193.09   0.522E-01    5.02   0.356E-07     0.00
   4340  1   0.787  99.000    11    0.787    circf   192.83   0.511E-01    4.92   0.490E-08     0.00
    143  1   0.787  99.000    13    0.787    circf   192.01   0.505E-01    4.86   0.296E-08     0.00
   4618  1   0.787  99.000    13    0.787    circf   191.91   0.498E-01    4.80   0.243E-08     0.00
    295  1   1.575  99.000     6    1.575    circf   180.81   0.377E-01    3.63   0.000E+00     0.00
   3118  1   0.263  99.000    13    0.263    circf   196.40   0.326E-01    3.14   0.000E+00     0.00
   4312  2   0.525  12.429     1    0.270    axial   184.34   0.279E-01    2.68   0.492E-02    16.53
   2174  1   1.400   6.000     4    1.400    circf   183.30   0.232E-01    2.23   0.000E+00     0.00
    330  1   0.438  10.000    11    0.438    circf   196.18   0.204E-01    1.96   0.000E+00     0.00
   1936  1   0.438  99.000    12    0.438    circf   172.95   0.201E-01    1.94   0.924E-14     0.00
   1451  1   0.438  10.000    13    0.438    circf   194.86   0.187E-01    1.80   0.000E+00     0.00
   4019  2   0.438   5.171     7    0.274    circf   205.98   0.184E-01    1.77   0.000E+00     0.00
   1048  1   0.525   6.000    11    0.525    circf   195.34   0.164E-01    1.57   0.000E+00     0.00
   1050  1   0.525   6.000    11    0.525    circf   195.34   0.163E-01    1.57   0.000E+00     0.00
    532  1   0.350  10.000    11    0.350    circf   197.33   0.139E-01    1.33   0.693E-09     0.00
   3423  1   0.350  10.000    11    0.350    circf   196.79   0.136E-01    1.31   0.846E-10     0.00
   3074  2   0.700   4.424     3    0.491    axial   193.83   0.136E-01    1.31   0.515E-02    17.31
   2588  1   0.787  99.000    12    0.787    circf   170.03   0.131E-01    1.26   0.000E+00     0.00
   5085  2   0.787   2.310     7    0.459    circf   204.22   0.129E-01    1.25   0.000E+00     0.00
   3502  2   0.350   8.158     3    0.265    axial   196.86   0.129E-01    1.24   0.348E-02    11.69
   2283  1   0.787  99.000    12    0.787    circf   169.88   0.128E-01    1.23   0.000E+00     0.00
   2437  1   0.787  99.000    12    0.787    circf   169.68   0.128E-01    1.23   0.361E-08     0.00
   4257  1   0.350  10.000    13    0.350    circf   195.91   0.125E-01    1.21   0.529E-09     0.00
   2467  1   0.787  99.000    12    0.787    circf   169.75   0.125E-01    1.20   0.000E+00     0.00
   4871  2   0.525   2.875     7    0.374    circf   205.67   0.113E-01    1.08   0.000E+00     0.00
   3270  1   0.263  99.000    12    0.263    circf   174.43   0.112E-01    1.08   0.132E-08     0.00
   2487  2   0.350   6.147     7    0.268    circf   207.22   0.112E-01    1.08   0.000E+00     0.00
   3946  2   0.875   1.880     4    0.651    axial   192.69   0.395E-02    0.38   0.205E-02     6.88
   2566  2   0.525   2.466     3    0.482    axial   193.66   0.352E-02    0.34   0.142E-02     4.78
   4252  2   0.613   7.323     2    0.678    axial   191.11   0.314E-02    0.30   0.172E-02     5.77
   3900  2   0.613   8.316    13    0.443    axial   194.97   0.281E-02    0.27   0.143E-02     4.81
   4313  2   0.525   5.332     5    0.557    axial   184.63   0.184E-02    0.18   0.595E-03     2.00
   3551  2   0.438   4.107     2    0.558    axial   193.02   0.129E-02    0.12   0.556E-03     1.87
   4197  2   0.175   9.365     4    0.255    axial   197.94   0.126E-02    0.12   0.390E-03     1.31
   1061  2   0.525   2.533    13    0.376    axial   195.57   0.120E-02    0.12   0.622E-03     2.09
   3266  2   0.263   8.486     2    0.359    axial   195.72   0.112E-02    0.11   0.370E-03     1.24
    784  2   0.263   5.119     2    0.346    axial   195.53   0.104E-02    0.10   0.346E-03     1.16
   3956  2   0.175   9.941     6    0.250    axial   196.64   0.104E-02    0.10   0.341E-03     1.14
   2406  2   0.263  12.678     2    0.438    axial   194.69   0.927E-03    0.09   0.400E-03     1.34
   1123  2   0.613   1.640     6    0.614    axial   192.53   0.861E-03    0.08   0.487E-03     1.64
   5079  2   0.438   5.564     2    0.690    axial   191.38   0.754E-03    0.07   0.418E-03     1.40
   4041  2   0.875   1.437     4    0.764    axial   191.58   0.628E-03    0.06   0.374E-03     1.26

                   =====================================================================
                   * Allocation of Risk by Flaw for Transient  1 - sorted by % of CPF  *
                   =====================================================================

   Flaw Flaw Depth  Aspect   Sub  Crack tip  Flaw    average                % of                 % of
    ID# KIND (inch)  ratio  Region (inch)    ORNT     RTNDT     CPImean      CPI    CPFmean       CPF

   3074  2   0.700   4.424     3    0.491    axial   193.83   0.136E-01    1.31   0.515E-02    17.31
   4312  2   0.525  12.429     1    0.270    axial   184.34   0.279E-01    2.68   0.492E-02    16.53
   3502  2   0.350   8.158     3    0.265    axial   196.86   0.129E-01    1.24   0.348E-02    11.69
   3946  2   0.875   1.880     4    0.651    axial   192.69   0.395E-02    0.38   0.205E-02     6.88
   4252  2   0.613   7.323     2    0.678    axial   191.11   0.314E-02    0.30   0.172E-02     5.77
   3900  2   0.613   8.316    13    0.443    axial   194.97   0.281E-02    0.27   0.143E-02     4.81
   2566  2   0.525   2.466     3    0.482    axial   193.66   0.352E-02    0.34   0.142E-02     4.78
   1061  2   0.525   2.533    13    0.376    axial   195.57   0.120E-02    0.12   0.622E-03     2.09
   4313  2   0.525   5.332     5    0.557    axial   184.63   0.184E-02    0.18   0.595E-03     2.00
   3551  2   0.438   4.107     2    0.558    axial   193.02   0.129E-02    0.12   0.556E-03     1.87
   1123  2   0.613   1.640     6    0.614    axial   192.53   0.861E-03    0.08   0.487E-03     1.64
   5079  2   0.438   5.564     2    0.690    axial   191.38   0.754E-03    0.07   0.418E-03     1.40
   2406  2   0.263  12.678     2    0.438    axial   194.69   0.927E-03    0.09   0.400E-03     1.34
   4197  2   0.175   9.365     4    0.255    axial   197.94   0.126E-02    0.12   0.390E-03     1.31
   4041  2   0.875   1.437     4    0.764    axial   191.58   0.628E-03    0.06   0.374E-03     1.26
   3266  2   0.263   8.486     2    0.359    axial   195.72   0.112E-02    0.11   0.370E-03     1.24
    784  2   0.263   5.119     2    0.346    axial   195.53   0.104E-02    0.10   0.346E-03     1.16
   3956  2   0.175   9.941     6    0.250    axial   196.64   0.104E-02    0.10   0.341E-03     1.14


                     **********************************************
                     * FLAW DISTRIBUTION BY MATERIAL AND CATEGORY *
                     *             BY PARENT SUBREGION            *
                     **********************************************
                    ==================================================
                                        WELD MATERIAL

                    ==================================================
                     number of   number    % of     number    % of
                     simulated    with     total     with     total
                        flaws    CPI>0     CPI      CPF>0     CPF
                    ==================================================
FLAW CATEGORY 1(int)       8000    1777     12.18        0     0.00
FLAW CATEGORY 2(int)     849000   53639     21.81    17648    89.85
FLAW CATEGORY 3(int)    1692000      96      0.00       44     0.02
                    ==================================================
          TOTALS        2549000   55512     33.98    17692    89.87
                    ==================================================
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
                     ==================================================
                                        PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
 FLAW CATEGORY 1(int)    212000   24790     64.51     233      0.01
 FLAW CATEGORY 2(int)    863000   11140      1.51    5297     10.12
 FLAW CATEGORY 3(int)   1630000       0      0.00       0      0.00
                     ==================================================
           TOTALS       2705000   35930     66.02    5530     10.13
                     ==================================================

                   **********************************************************
                   * FLAW DISTRIBUTION BY MATERIAL, CATEGORY, & ORIENTATION *
                   *                  BY PARENT SUBREGION                   *
                   **********************************************************
                     ==================================================
                                         WELD MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2    367000   17651      8.24   17648     89.85
AXIAL FLAW CATEGORY 3    758000      44      0.00      44      0.02
                     ==================================================
AXIAL SUBTOTALS         1125000   17695      8.24   17692     89.87
                     ==================================================

CIRC. FLAW CATEGORY 1      8000    1777     12.18       0      0.00
CIRC. FLAW CATEGORY 2    482000   35988     13.57       0      0.00
CIRC. FLAW CATEGORY 3    934000      52      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS         1424000   37817     25.74       0      0.00
                     ==================================================
WELD TOTALS             2549000   55512     33.98   17692     89.87
                     ==================================================


                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2    415000    5225      0.58    5225     10.12
AXIAL FLAW CATEGORY 3    832000       0      0.00       0      0.00
                     ==================================================
AXIAL SUBTOTALS         1247000    5225      0.58    5225     10.12
                     ==================================================
CIRC. FLAW CATEGORY 1    212000   24790     64.51     233      0.01
CIRC. FLAW CATEGORY 2    448000    5915      0.93      72      0.00
CIRC. FLAW CATEGORY 3    798000       0      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS         1458000   30705     65.43     538      0.01
                     ==================================================
PLATE TOTALS            2705000   35930     66.02    5763     10.13
                     ==================================================


                      *********************************************
                      *    WELD FLAW-SIZE DISTRIBUTION REPORT     *
                      * FOR CONDITIONAL PROBABILITY OF INITIATION *
                      *********************************************
=================================================================================
  flaw depth   simulated  #   % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total   catgy 2  with   total     catgy 3 with total
     (in)        flaws CPI>0   CPI      flaws  CPI>0   CPI      flaws CPI>0   CPI
=================================================================================
 0.000 - 0.088   1000     0   0.00    435000   3466   0.01    839000     0   0.00
 0.088 - 0.175      0     0   0.00    201000  14357   0.92    424000     0   0.00
 0.175 - 0.263      0     0   0.00    101000  13195   1.88    207000     0   0.00
 0.263 - 0.350      0     0   0.00     44000   6985   4.49    116000     2   0.00
 0.350 - 0.438      0     0   0.00     39000   8499   5.23     48000    21   0.00
 0.438 - 0.525   1000   423   0.72     12000   2809   4.87     26000    10   0.00
 0.525 - 0.613      0     0   0.00      5000   1148   0.43     16000    13   0.00
 0.613 - 0.700      0     0   0.00      5000   1134   1.41      7000     0   0.00
 0.700 - 0.787   1000   563   5.24      3000   1323   2.13      5000    50   0.00
 0.787 - 0.875      0     0   0.00      2000    585   0.44      2000     0   0.00
 0.875 - 0.963      0     0   0.00      2000    138   0.01         0     0   0.00
 0.963 - 1.050      0     0   0.00         0      0   0.00      1000     0   0.00
 1.050 - 1.137      0     0   0.00         0      0   0.00         0     0   0.00
 1.137 - 1.225   1000   194   0.28         0      0   0.00         0     0   0.00
 1.225 - 1.312      0     0   0.00         0      0   0.00         0     0   0.00
 1.312 - 1.400   1000   262   2.23         0      0   0.00      1000     0   0.00
 1.400 - 1.488      0     0   0.00         0      0   0.00         0     0   0.00
 1.488 - 1.575   1000   259   3.63         0      0   0.00         0     0   0.00
 1.575 - 1.663      0     0   0.00         0      0   0.00         0     0   0.00
 1.663 - 1.750      0     0   0.00         0      0   0.00         0     0   0.00
 1.750 - 1.838      0     0   0.00         0      0   0.00         0     0   0.00
```

```
 1.838 - 1.925   1000    29   0.00         0      0   0.00         0     0   0.00
 1.925 - 2.013      0     0   0.00         0      0   0.00         0     0   0.00
 2.013 - 2.100      0     0   0.00         0      0   0.00         0     0   0.00
 2.100 - 2.188   1000    47   0.08         0      0   0.00         0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00         0     0   0.00
=================================================================================
TOTALS           8000  1777  12.18    849000  53639  21.81   1692000    96   0.00
=================================================================================

                      *********************************************
                      *    PLATE FLAW-SIZE DISTRIBUTION REPORT    *
                      * FOR CONDITIONAL PROBABILITY OF INITIATION *
                      *********************************************

=================================================================================
  flaw depth   simulated  #   % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total   catgy 2  with   total     catgy 3 with total
     (in)        flaws CPI>0   CPI      flaws  CPI>0   CPI       flaws CPI>0  CPI
=================================================================================
 0.000 - 0.088   7000     0   0.00    450000     68   0.00    828000     0   0.00
 0.088 - 0.175  14000     0   0.00    200000   1105   0.01    420000     0   0.00
 0.175 - 0.263   7000  2663   5.26     95000   2142   0.09    193000     0   0.00
 0.263 - 0.350   8000  2782   4.97     62000   3891   0.34     79000     0   0.00
 0.350 - 0.438  12000  3509  12.41     23000   1567   0.40     55000     0   0.00
 0.438 - 0.525  17000  3530   4.00     18000   1106   0.14     33000     0   0.00
 0.525 - 0.613   8000  1623   6.52      6000    788   0.28     10000     0   0.00
 0.613 - 0.700   7000  1074   0.16      5000     16   0.00      6000     0   0.00
 0.700 - 0.787  12000  3949  24.91      2000      0   0.00      3000     0   0.00
 0.787 - 0.875  11000  1823   2.06      2000    457   0.25      2000     0   0.00
 0.875 - 0.963   7000   787   0.32         0      0   0.00         0     0   0.00
 0.963 - 1.050   4000   109   0.07         0      0   0.00      1000     0   0.00
 1.050 - 1.137   4000   517   0.83         0      0   0.00         0     0   0.00
 1.137 - 1.225   9000   420   0.06         0      0   0.00         0     0   0.00
 1.225 - 1.312   8000   225   0.04         0      0   0.00         0     0   0.00
 1.312 - 1.400   6000   521   0.46         0      0   0.00         0     0   0.00
 1.400 - 1.488   6000   182   0.14         0      0   0.00         0     0   0.00
 1.488 - 1.575   6000   555   1.60         0      0   0.00         0     0   0.00
 1.575 - 1.663   6000    75   0.03         0      0   0.00         0     0   0.00
 1.663 - 1.750   7000   232   0.51         0      0   0.00         0     0   0.00
 1.750 - 1.838  10000   113   0.14         0      0   0.00         0     0   0.00
 1.838 - 1.925  10000    72   0.02         0      0   0.00         0     0   0.00
 1.925 - 2.013   8000     8   0.00         0      0   0.00         0     0   0.00
 2.013 - 2.100  10000     4   0.00         0      0   0.00         0     0   0.00
 2.100 - 2.188   8000    17   0.00         0      0   0.00         0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00         0     0   0.00
=================================================================================
TOTALS         212000 24790  64.51    863000  11140   1.51   1630000     0   0.00
=================================================================================

                      *********************************************
                      *    WELD FLAW-SIZE DISTRIBUTION REPORT     *
                      *  FOR CONDITIONAL PROBABILITY OF FAILURE   *
                      *********************************************

=================================================================================
  flaw depth   simulated  #   % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total   catgy 2  with   total     catgy 3 with total
     (in)        flaws CPF>0   CPF      flaws  CPF>0    CPF      flaws CPF>0   CPF
=================================================================================
 0.000 - 0.088   1000     0   0.00    435000   1415   0.07    839000     0   0.00
 0.088 - 0.175      0     0   0.00    201000   4147   4.69    424000     0   0.00
 0.175 - 0.263      0     0   0.00    101000   4784   9.43    207000     0   0.00
 0.263 - 0.350      0     0   0.00     44000   1976  13.50    116000     2   0.00
 0.350 - 0.438      0     0   0.00     39000   2052   5.58     48000     1   0.00
 0.438 - 0.525   1000     0   0.00     12000   1258  23.33     26000     0   0.00
 0.525 - 0.613      0     0   0.00      5000    736   7.49     16000     7   0.00
 0.613 - 0.700      0     0   0.00      5000    557  17.37      7000     0   0.00
 0.700 - 0.787   1000     0   0.00      3000      0   0.00      5000    34   0.01
 0.787 - 0.875      0     0   0.00      2000    585   8.13      2000     0   0.00
 0.875 - 0.963      0     0   0.00      2000    138   0.26         0     0   0.00
 0.963 - 1.050      0     0   0.00         0      0   0.00      1000     0   0.00
 1.050 - 1.137      0     0   0.00         0      0   0.00         0     0   0.00
 1.137 - 1.225   1000     0   0.00         0      0   0.00         0     0   0.00
 1.225 - 1.312      0     0   0.00         0      0   0.00         0     0   0.00
 1.312 - 1.400   1000     0   0.00         0      0   0.00      1000     0   0.00
 1.400 - 1.488      0     0   0.00         0      0   0.00         0     0   0.00
 1.488 - 1.575   1000     0   0.00         0      0   0.00         0     0   0.00
 1.575 - 1.663      0     0   0.00         0      0   0.00         0     0   0.00
 1.663 - 1.750      0     0   0.00         0      0   0.00         0     0   0.00
 1.750 - 1.838      0     0   0.00         0      0   0.00         0     0   0.00
 1.838 - 1.925   1000     0   0.00         0      0   0.00         0     0   0.00
 1.925 - 2.013      0     0   0.00         0      0   0.00         0     0   0.00
 2.013 - 2.100      0     0   0.00         0      0   0.00         0     0   0.00
 2.100 - 2.188   1000     0   0.00         0      0   0.00         0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00         0     0   0.00
=================================================================================
TOTALS           8000     0   0.00    849000  17648  89.85   1692000    44   0.02
=================================================================================

                      *********************************************
                      *    PLATE FLAW-SIZE DISTRIBUTION REPORT    *
                      *  FOR CONDITIONAL PROBABILITY OF FAILURE   *
                      *********************************************

=================================================================================
  flaw depth   simulated  #   % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total   catgy 2  with   total     catgy 3 with total
     (in)        flaws CPF>0   CPF      flaws  CPF>0    CPF      flaws CPF>0   CPF
=================================================================================
 0.000 - 0.088   7000     0   0.00    450000     13   0.00    828000     0   0.00
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
 0.088 - 0.175  14000     0   0.00    200000    750   0.23    420000     0   0.00
 0.175 - 0.263   7000     7   0.00     95000   1047   0.89    193000     0   0.00
 0.263 - 0.350   8000    15   0.00     62000   1766   1.40     79000     0   0.00
 0.350 - 0.438  12000     5   0.00     23000    615   0.60     55000     0   0.00
 0.438 - 0.525  17000    12   0.00     18000    573   2.18     33000     0   0.00
 0.525 - 0.613   8000     2   0.00      6000    521   4.82     10000     0   0.00
 0.613 - 0.700   7000     6   0.00      5000     11   0.00      6000     0   0.00
 0.700 - 0.787  12000    19   0.00      2000      0   0.00      3000     0   0.00
 0.787 - 0.875  11000    28   0.00      2000      1   0.00      2000     0   0.00
 0.875 - 0.963   7000    19   0.00         0      0   0.00         0     0   0.00
 0.963 - 1.050   4000     1   0.00         0      0   0.00      1000     0   0.00
 1.050 - 1.137   4000    28   0.00         0      0   0.00         0     0   0.00
 1.137 - 1.225   9000    13   0.00         0      0   0.00         0     0   0.00
 1.225 - 1.312   8000    12   0.00         0      0   0.00         0     0   0.00
 1.312 - 1.400   6000    18   0.00         0      0   0.00         0     0   0.00
 1.400 - 1.488   6000     5   0.00         0      0   0.00         0     0   0.00
 1.488 - 1.575   6000    20   0.00         0      0   0.00         0     0   0.00
 1.575 - 1.663   6000     1   0.00         0      0   0.00         0     0   0.00
 1.663 - 1.750   7000    20   0.01         0      0   0.00         0     0   0.00
 1.750 - 1.838  10000     0   0.00         0      0   0.00         0     0   0.00
 1.838 - 1.925  10000     2   0.00         0      0   0.00         0     0   0.00
 1.925 - 2.013   8000     0   0.00         0      0   0.00         0     0   0.00
 2.013 - 2.100  10000     0   0.00         0      0   0.00         0     0   0.00
 2.100 - 2.188   8000     0   0.00         0      0   0.00         0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00         0     0   0.00
=================================================================================
TOTALS         212000   233   0.01    863000   5297  10.12   1630000     0   0.00
=================================================================================


             ===============================================
                  **************************************
                  * TRANSIENT TIME DISTRIBUTION REPORT *
                  *    for transient sequence     1    *
                  **************************************
             ===============================================
             TIME   TIME    % of     CDF of    % of    CDF of
             STEP   (min)   total    total    total    total
                            CDCPI    CDCPI    CDCPF    CDCPF
             ===============================================
               8     7.0   0.0002   0.0002   0.0000   0.0000
               9     8.0   0.0015   0.0017   0.0000   0.0000
             10      9.0   0.0217   0.0235   0.0009   0.0009
             11     10.0   0.3590   0.3824   0.0077   0.0086
             12     11.0   3.6030   3.9855   2.0058   2.0144
             13     12.0  13.2302  17.2157  13.8663  15.8807
             14     13.0  34.3807  51.5964  46.6605  62.5412
             15     14.0  41.4308  93.0272  27.4302  89.9714
             16     15.0   6.9072  99.9345   9.8435  99.8149
             17     16.0   0.0652  99.9997   0.1774  99.9922
             18     17.0   0.0003 100.0000   0.0073  99.9996
             20     19.0   0.0000 100.0000   0.0004 100.0000


       ***********************************************************
       *      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)      *
       *           FOR THE INITIATING DRIVING FORCES             *
       *              FOR TRANSIENT SEQUENCE     1               *
       ***********************************************************
             ===============================================
                                 RELATIVE    CUMULATIVE
               KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
               (bin midpoint)       (%)          (%)
             ===============================================
                  21.00            0.0295        0.0295
                  23.00            0.3675        0.3970
                  25.00            1.3835        1.7805
                  27.00            3.6386        5.4191
                  29.00            2.7560        8.1751
                  31.00            4.7607       12.9358
                  33.00            4.8909       17.8267
                  35.00            7.7398       25.5665
                  37.00            6.3728       31.9393
                  39.00            7.7726       39.7119
                  41.00            6.4099       46.1219
                  43.00            4.8427       50.9646
                  45.00            2.9321       53.8967
                  47.00            4.6098       58.5065
                  49.00            5.5919       64.0984
                  51.00            4.7531       68.8514
                  53.00            3.0294       71.8809
                  55.00            2.7407       74.6216
                  57.00            1.7695       76.3911
                  59.00            2.3798       78.7709
                  61.00            0.7404       79.5114
                  63.00            2.4553       81.9666
                  65.00            0.0317       81.9983
                  67.00            2.0911       84.0894
                  69.00            1.5814       85.6709
                  71.00            1.8199       87.4907
                  75.00            0.2592       87.7499
                  83.00            1.7761       89.5260
                  85.00            1.3988       90.9248
                  87.00            0.2537       91.1785
                  89.00            0.6999       91.8785
```

```
                91.00            0.5654       92.4439
                95.00            1.4021       93.8460
                97.00            0.2209       94.0669
                99.00            0.2078       94.2747
               103.00            4.6174       98.8921
               105.00            0.0536       98.9457
               107.00            0.0339       98.9796
               109.00            0.0306       99.0102
               113.00            0.0350       99.0452
               125.00            0.4320       99.4772
               127.00            0.0022       99.4794
               129.00            0.2373       99.7167
               135.00            0.2833      100.0000
           ===============================================
                               RELATIVE    CUMULATIVE
             KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
             (bin midpoint)      (%)          (%)
           ===============================================

====================================================================================================
                     FAILURE MECHANISM REPORT FOR TRANSIENT SEQUENCE     1
====================================================================================================

                                                            NUMBER OF     % OF TOTAL
                                                              FAILURE        FAILURE
                                                               TRIALS         TRIALS

 CLEAVAGE PROPAGATION TO PLASTIC INSTABILITY                       0           0.00
 CLEAVAGE PROPAGATION EXCEEDS WALL DEPTH FAILURE CRITERIA    1742999         100.00


                                ********************************************
                                ********************************************
                                **  PFM RESULTS FOR TRANSIENT NUMBER     2 **
                                ********************************************
                                ********************************************

                                ********************************************
                                **                                        **
                                **  NUMBER OF COMPLETED TRIALS =    1000   **
                                **                                        **
                                ********************************************

                                       MEAN VALUE OF CPI =     2.183E-01
                                       MEAN VALUE OF CPF =     1.858E-01

                                    *************************************
                                    *  RPV BELTLINE MAJOR REGION REPORT *
                                    *       BY PARENT SUBREGION         *
                                    *************************************
====================================================================================================
                                       |---Initiation---|   |----Cleavage----| |------Ductile-----|
 MAJOR     RTndt  % OF     SIMULATED   # of FLAWS  % of       # of FLAWS  % of   # of FLAWS    % of
 REGION    (MAX)  FLAWS      FLAWS      CPI > 0   CPI        CPF > 0    CPF       CPF > 0      CPF
====================================================================================================
   1       241.6  3.24       170000      1395        0.76      1394        0.89        0         0.00
   2       254.9  2.66       140000      3406        0.69      3406        0.81        0         0.00
   3       254.9  2.53       133000      2195        1.50      2194        1.75        0         0.00
   4       255.5  4.26       224000      4423        8.86      4423        6.76        0         0.00
   5       242.1  4.23       222000      2220        0.31      2220        0.36        0         0.00
   6       255.5  4.61       242000      3150       30.64      3150       22.55        0         0.00
   7       260.7 26.99      1418000      1085        2.95      1085        2.46        0         0.00
   8       179.8  6.62       348000      2046        1.39      2046        1.65        0         0.00
   9       152.9  6.95       365000       784        0.24       784        0.28        0         0.00
  10        89.5  7.50       394000         0        0.00         0        0.00        0         0.00
  11       217.3 10.16       534000     10370       22.73     10368       26.97        0         0.00
  12       194.3 10.03       527000      6036        3.32      6034        3.94        0         0.00
  13       215.3 10.22       537000     13070       26.62     13066       31.57        0         0.00
====================================================================================================
         TOTALS 100.00      5254000     50180      100.00     50170      100.00        0         0.00
====================================================================================================

                               NOTE: MEAN VALUE OF RTNDT AT CRACK TIP=  162.84

                  =================================================================
                  * Allocation of Risk by Flaw for Transient  2 - sorted by % of CPI  *
                  =================================================================

  Flaw Flaw Depth  Aspect   Sub  Crack tip  Flaw   average               % of                 % of
   ID# KIND (inch)  ratio Region (inch)     ORNT    RTNDT     CPImean     CPI     CPFmean      CPF

   295  1   1.575  99.000      6     1.575    circf   180.81   0.659E-01   24.01   0.407E-01    17.57
  4100  1   1.837  99.000     13     1.837    circf   182.24   0.217E-01    7.89   0.217E-01     9.37
  2760  1   1.750  99.000     11     1.750    circf   183.96   0.210E-01    7.63   0.210E-01     9.05
                                FAVPFM As-Found Output File (*.out) – (Continued)

  2174  1   1.400   6.000      4     1.400    circf   183.30   0.186E-01    6.78   0.101E-01     4.38
  4685  1   2.188   6.000      6     2.188    circf   171.74   0.179E-01    6.53   0.113E-01     4.87
  4223  1   1.575  99.000     11     1.575    circf   185.56   0.172E-01    6.26   0.172E-01     7.43
  3113  1   1.575  99.000     13     1.575    circf   184.31   0.159E-01    5.80   0.159E-01     6.88
   721  1   0.787   6.000      7     0.787    circf   200.77   0.770E-02    2.80   0.541E-02     2.34
    13  1   2.188   6.000     13     2.188    circf   178.53   0.461E-02    1.68   0.461E-02     1.99
  1297  1   1.925   6.000     11     1.925    circf   182.00   0.452E-02    1.64   0.452E-02     1.95
  5167  1   1.750   6.000     11     1.750    circf   184.04   0.411E-02    1.50   0.411E-02     1.78
  1249  1   1.925   6.000     13     1.925    circf   181.31   0.407E-02    1.48   0.407E-02     1.76
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
     217  1   1.750   6.000     11     1.750    circf   184.03   0.405E-02    1.47   0.405E-02    1.75
     986  1   1.925   6.000     13     1.925    circf   181.06   0.398E-02    1.45   0.398E-02    1.72
     800  1   0.787  99.000     11     0.787    circf   193.09   0.363E-02    1.32   0.363E-02    1.57
    4340  1   0.787  99.000     11     0.787    circf   192.83   0.357E-02    1.30   0.357E-02    1.54
     143  1   0.787  99.000     13     0.787    circf   192.01   0.342E-02    1.25   0.342E-02    1.48
    4618  1   0.787  99.000     13     0.787    circf   191.91   0.337E-02    1.23   0.337E-02    1.45
    3074  2   0.700   4.424      3     0.491    axial   193.83   0.337E-02    1.23   0.332E-02    1.43
    2128  1   1.575   6.000     11     1.575    circf   185.80   0.333E-02    1.21   0.333E-02    1.44
    1443  1   1.663   6.000     13     1.663    circf   183.68   0.317E-02    1.15   0.317E-02    1.37
    3052  1   1.488   6.000     13     1.488    circf   185.19   0.265E-02    0.96   0.265E-02    1.14
    3282  1   1.837  99.000      8     1.837    circf   145.06   0.237E-02    0.86   0.237E-02    1.02
    1981  1   1.400   6.000     13     1.400    circf   186.40   0.235E-02    0.86   0.235E-02    1.02

                  ====================================================================
                  * Allocation of Risk by Flaw for Transient  2 - sorted by % of CPF  *
                  ====================================================================

    Flaw Flaw Depth  Aspect   Sub  Crack tip  Flaw    average               % of                 % of
     ID# KIND (inch)  ratio  Region (inch)    ORNT     RTNDT      CPImean      CPI     CPFmean      CPF

     295  1   1.575  99.000      6     1.575    circf   180.81   0.659E-01   24.01   0.407E-01   17.57
    4100  1   1.837  99.000     13     1.837    circf   182.24   0.217E-01    7.89   0.217E-01    9.37
    2760  1   1.750  99.000     11     1.750    circf   183.96   0.210E-01    7.63   0.210E-01    9.05
    4223  1   1.575  99.000     11     1.575    circf   185.56   0.172E-01    6.26   0.172E-01    7.43
    3113  1   1.575  99.000     13     1.575    circf   184.31   0.159E-01    5.80   0.159E-01    6.88
    4685  1   2.188   6.000      6     2.188    circf   171.74   0.179E-01    6.53   0.113E-01    4.87
    2174  1   1.400   6.000      4     1.400    circf   183.30   0.186E-01    6.78   0.101E-01    4.38
     721  1   0.787   6.000      7     0.787    circf   200.77   0.770E-02    2.80   0.541E-02    2.34
      13  1   2.188   6.000     13     2.188    circf   178.53   0.461E-02    1.68   0.461E-02    1.99
    1297  1   1.925   6.000     11     1.925    circf   182.00   0.452E-02    1.64   0.452E-02    1.95
    5167  1   1.750   6.000     11     1.750    circf   184.04   0.411E-02    1.50   0.411E-02    1.78
    1249  1   1.925   6.000     13     1.925    circf   181.31   0.407E-02    1.48   0.407E-02    1.76
     217  1   1.750   6.000     11     1.750    circf   184.03   0.405E-02    1.47   0.405E-02    1.75
     986  1   1.925   6.000     13     1.925    circf   181.06   0.398E-02    1.45   0.398E-02    1.72
     800  1   0.787  99.000     11     0.787    circf   193.09   0.363E-02    1.32   0.363E-02    1.57
    4340  1   0.787  99.000     11     0.787    circf   192.83   0.357E-02    1.30   0.357E-02    1.54
     143  1   0.787  99.000     13     0.787    circf   192.01   0.342E-02    1.25   0.342E-02    1.48
    4618  1   0.787  99.000     13     0.787    circf   191.91   0.337E-02    1.23   0.337E-02    1.45
    2128  1   1.575   6.000     11     1.575    circf   185.80   0.333E-02    1.21   0.333E-02    1.44
    3074  2   0.700   4.424      3     0.491    axial   193.83   0.337E-02    1.23   0.332E-02    1.43
    1443  1   1.663   6.000     13     1.663    circf   183.68   0.317E-02    1.15   0.317E-02    1.37
    3052  1   1.488   6.000     13     1.488    circf   185.19   0.265E-02    0.96   0.265E-02    1.14
    3282  1   1.837  99.000      8     1.837    circf   145.06   0.237E-02    0.86   0.237E-02    1.02
    1981  1   1.400   6.000     13     1.400    circf   186.40   0.235E-02    0.86   0.235E-02    1.02


                   **********************************************
                    * FLAW DISTRIBUTION BY MATERIAL AND CATEGORY *
                    *            BY PARENT SUBREGION             *
                    **********************************************
                   ==================================================
                                       WELD MATERIAL
                   ==================================================
                    number of   number    % of     number    % of
                    simulated    with     total     with     total
                       flaws    CPI>0      CPI     CPF>0     CPF
                   ==================================================
 FLAW CATEGORY 1(int)      8000     3146     40.45    3146     29.42
 FLAW CATEGORY 2(int)    849000    13271      5.07   13269      5.95
 FLAW CATEGORY 3(int)   1692000     1457      0.19    1457      0.22
                   ==================================================
           TOTALS       2549000    17874     45.70   17872     35.59
                   ==================================================


                   ==================================================
                                      PLATE MATERIAL
                   ==================================================
                    number of   number    % of     number    % of
                    simulated    with     total     with     total
                       flaws    CPI>0      CPI     CPF>0     CPF
                   ==================================================
 FLAW CATEGORY 1(int)    212000    30083     54.20   30075     64.30
 FLAW CATEGORY 2(int)    863000     2223      0.09    2223      0.11
 FLAW CATEGORY 3(int)   1630000        0      0.00       0      0.00
                   ==================================================
           TOTALS       2705000    32306     54.30   32298     64.41
                   ==================================================

                 **********************************************************
                 * FLAW DISTRIBUTION BY MATERIAL, CATEGORY, & ORIENTATION *
                 *                   BY PARENT SUBREGION                  *
                 **********************************************************
                   ==================================================
                                       WELD MATERIAL
                   ==================================================
                    number of   number    % of     number    % of
                    simulated    with     total     with     total
                       flaws    CPI>0      CPI     CPF>0     CPF
                   ==================================================
AXIAL FLAW CATEGORY 1         0        0      0.00       0      0.00
AXIAL FLAW CATEGORY 2    367000    13156      5.07   13154      5.95
AXIAL FLAW CATEGORY 3    758000     1456      0.19    1456      0.22
                   ==================================================
AXIAL SUBTOTALS         1125000    14612      5.26   14610      6.17
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
                     ==================================================

CIRC. FLAW CATEGORY 1      8000    3146     40.45    3146     29.42
CIRC. FLAW CATEGORY 2    482000     115      0.00     115      0.00
CIRC. FLAW CATEGORY 3    934000       1      0.00       1      0.00
                     ==================================================

CIRC. SUBTOTALS         1424000    3262     40.45    3262     29.42
                     ==================================================
WELD TOTALS             2549000   17874     45.70   17872     35.59
                     ==================================================


                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2    415000    2223      0.09    2223      0.11
AXIAL FLAW CATEGORY 3    832000       0      0.00       0      0.00
                     ==================================================
AXIAL SUBTOTALS         1247000    2223      0.09    2223      0.11
                     ==================================================
CIRC. FLAW CATEGORY 1    212000   30083     54.20   30075     64.30
CIRC. FLAW CATEGORY 2    448000       0      0.00       0      0.00
CIRC. FLAW CATEGORY 3    798000       0      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS         1458000   30083     54.20   60150     64.30
                     ==================================================
PLATE TOTALS            2705000   32306     54.30   62373     64.41
                     ==================================================


                      *********************************************
                      *    WELD FLAW-SIZE DISTRIBUTION REPORT     *
                      * FOR CONDITIONAL PROBABILITY OF INITIATION *
                      *********************************************
=================================================================================
  flaw depth   simulated  #   % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total   catgy 2  with   total     catgy 3 with total
     (in)        flaws CPI>0   CPI      flaws  CPI>0   CPI      flaws CPI>0   CPI
=================================================================================
 0.000 - 0.088   1000     0   0.00    435000      0   0.00    839000     0   0.00
 0.088 - 0.175      0     0   0.00    201000    411   0.00    424000     0   0.00
 0.175 - 0.263      0     0   0.00    101000   2976   0.04    207000    12   0.00
 0.263 - 0.350      0     0   0.00     44000   1654   0.12    116000   241   0.00
 0.350 - 0.438      0     0   0.00     39000   2796   0.27     48000   306   0.00
 0.438 - 0.525   1000   229   0.01     12000   1693   0.96     26000    41   0.00
 0.525 - 0.613      0     0   0.00      5000   1074   0.61     16000   283   0.01
 0.613 - 0.700      0     0   0.00      5000   1029   1.35      7000    20   0.00
 0.700 - 0.787   1000   630   2.80      3000    110   0.00      5000   466   0.17
 0.787 - 0.875      0     0   0.00      2000    815   0.80      2000     0   0.00
 0.875 - 0.963      0     0   0.00      2000    713   0.92         0     0   0.00
 0.963 - 1.050      0     0   0.00         0      0   0.00      1000    72   0.00
 1.050 - 1.137      0     0   0.00         0      0   0.00         0     0   0.00
 1.137 - 1.225   1000   326   0.17         0      0   0.00         0     0   0.00
 1.225 - 1.312      0     0   0.00         0      0   0.00         0     0   0.00
 1.312 - 1.400   1000   541   6.78         0      0   0.00      1000    16   0.00
 1.400 - 1.488      0     0   0.00         0      0   0.00         0     0   0.00
 1.488 - 1.575   1000   619  24.01         0      0   0.00         0     0   0.00
 1.575 - 1.663      0     0   0.00         0      0   0.00         0     0   0.00
 1.663 - 1.750      0     0   0.00         0      0   0.00         0     0   0.00
 1.750 - 1.838      0     0   0.00         0      0   0.00         0     0   0.00
 1.838 - 1.925   1000   339   0.15         0      0   0.00         0     0   0.00
 1.925 - 2.013      0     0   0.00         0      0   0.00         0     0   0.00
 2.013 - 2.100      0     0   0.00         0      0   0.00         0     0   0.00
 2.100 - 2.188   1000   462   6.53         0      0   0.00         0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00         0     0   0.00
=================================================================================
TOTALS           8000  3146  40.45    849000  13271   5.07   1692000  1457   0.19
=================================================================================

                      *********************************************
                      *    PLATE FLAW-SIZE DISTRIBUTION REPORT    *
                      * FOR CONDITIONAL PROBABILITY OF INITIATION *
                      *********************************************
=================================================================================
  flaw depth   simulated  #   % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total   catgy 2  with   total     catgy 3 with total
     (in)        flaws CPI>0   CPI      flaws  CPI>0   CPI      flaws CPI>0   CPI
=================================================================================
 0.000 - 0.088   7000     0   0.00    450000      0   0.00    828000     0   0.00
 0.088 - 0.175  14000     0   0.00    200000      0   0.00    420000     0   0.00
 0.175 - 0.263   7000   999   0.04     95000     57   0.00    193000     0   0.00
 0.263 - 0.350   8000  1453   0.07     62000    425   0.00     79000     0   0.00
 0.350 - 0.438  12000  1816   0.31     23000    485   0.00     55000     0   0.00
 0.438 - 0.525  17000  1100   0.09     18000    638   0.01     33000     0   0.00
 0.525 - 0.613   8000   720   0.58      6000    610   0.08     10000     0   0.00
 0.613 - 0.700   7000   159   0.00      5000      8   0.00      6000     0   0.00
 0.700 - 0.787  12000  4264   6.47      2000      0   0.00      3000     0   0.00
 0.787 - 0.875  11000  1937   0.62      2000      0   0.00      2000     0   0.00
 0.875 - 0.963   7000   637   0.09         0      0   0.00         0     0   0.00
```

```
 0.963 - 1.050   4000   232   0.05         0      0   0.00       1000     0   0.00
 1.050 - 1.137   4000   879   0.65         0      0   0.00          0     0   0.00
 1.137 - 1.225   9000   758   0.02         0      0   0.00          0     0   0.00
 1.225 - 1.312   8000   605   0.02         0      0   0.00          0     0   0.00
 1.312 - 1.400   6000  1878   2.34         0      0   0.00          0     0   0.00
 1.400 - 1.488   6000   807   0.99         0      0   0.00          0     0   0.00
 1.488 - 1.575   6000  2439  14.06         0      0   0.00          0     0   0.00
 1.575 - 1.663   6000   645   1.26         0      0   0.00          0     0   0.00
 1.663 - 1.750   7000  1816  10.70         0      0   0.00          0     0   0.00
 1.750 - 1.838  10000  1483   8.80         0      0   0.00          0     0   0.00
 1.838 - 1.925  10000  1995   4.83         0      0   0.00          0     0   0.00
 1.925 - 2.013   8000  1060   0.09         0      0   0.00          0     0   0.00
 2.013 - 2.100  10000  1212   0.09         0      0   0.00          0     0   0.00
 2.100 - 2.188   8000  1189   2.04         0      0   0.00          0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00          0     0   0.00
=================================================================================
TOTALS         212000 30083  54.20    863000   2223   0.09    1630000     0   0.00
=================================================================================
                      **********************************************
                      *    WELD FLAW-SIZE DISTRIBUTION REPORT      *
                      *  FOR CONDITIONAL PROBABILITY OF FAILURE    *
                      **********************************************

=================================================================================
  flaw depth   simulated  #    % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total    catgy 2  with   total     catgy 3 with total
     (in)         flaws CPF>0   CPF      flaws  CPF>0    CPF       flaws CPF>0   CPF
=================================================================================
 0.000 - 0.088   1000     0   0.00    435000      0   0.00     839000     0   0.00
 0.088 - 0.175      0     0   0.00    201000    410   0.00     424000     0   0.00
 0.175 - 0.263      0     0   0.00    101000   2976   0.04     207000    12   0.00
 0.263 - 0.350      0     0   0.00     44000   1654   0.14     116000   241   0.00
 0.350 - 0.438      0     0   0.00     39000   2795   0.31      48000   306   0.00
 0.438 - 0.525   1000   229   0.01     12000   1693   1.13      26000    41   0.00
 0.525 - 0.613      0     0   0.00      5000   1074   0.72      16000   283   0.02
 0.613 - 0.700      0     0   0.00      5000   1029   1.58       7000    20   0.00
 0.700 - 0.787   1000   630   2.34      3000    110   0.00       5000   466   0.20
 0.787 - 0.875      0     0   0.00      2000    815   0.94       2000     0   0.00
 0.875 - 0.963      0     0   0.00      2000    713   1.09          0     0   0.00
 0.963 - 1.050      0     0   0.00         0      0   0.00       1000    72   0.00
 1.050 - 1.137      0     0   0.00         0      0   0.00          0     0   0.00
 1.137 - 1.225   1000   326   0.13         0      0   0.00          0     0   0.00
 1.225 - 1.312      0     0   0.00         0      0   0.00          0     0   0.00
 1.312 - 1.400   1000   541   4.38         0      0   0.00       1000    16   0.00
 1.400 - 1.488      0     0   0.00         0      0   0.00          0     0   0.00
 1.488 - 1.575   1000   619  17.57         0      0   0.00          0     0   0.00
 1.575 - 1.663      0     0   0.00         0      0   0.00          0     0   0.00
 1.663 - 1.750      0     0   0.00         0      0   0.00          0     0   0.00
 1.750 - 1.838      0     0   0.00         0      0   0.00          0     0   0.00
 1.838 - 1.925   1000   339   0.13         0      0   0.00          0     0   0.00
 1.925 - 2.013      0     0   0.00         0      0   0.00          0     0   0.00
 2.013 - 2.100      0     0   0.00         0      0   0.00          0     0   0.00
 2.100 - 2.188   1000   462   4.87         0      0   0.00          0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00          0     0   0.00
=================================================================================
TOTALS           8000  3146  29.42    849000  13269   5.95    1692000  1457   0.22
=================================================================================

                      **********************************************
                      *    PLATE FLAW-SIZE DISTRIBUTION REPORT     *
                      *  FOR CONDITIONAL PROBABILITY OF FAILURE    *
                      **********************************************
=================================================================================
  flaw depth   simulated  #    % of   simulated  #     % of    simulated  #   % of
   interval     catgy 1 with  total    catgy 2  with   total     catgy 3 with total
     (in)         flaws CPF>0   CPF      flaws  CPF>0    CPF       flaws CPF>0   CPF
=================================================================================
 0.000 - 0.088   7000     0   0.00    450000      0   0.00     828000     0   0.00
 0.088 - 0.175  14000     0   0.00    200000      0   0.00     420000     0   0.00
 0.175 - 0.263   7000   998   0.04     95000     57   0.00     193000     0   0.00
 0.263 - 0.350   8000  1453   0.08     62000    425   0.00      79000     0   0.00
 0.350 - 0.438  12000  1816   0.37     23000    485   0.00      55000     0   0.00
 0.438 - 0.525  17000  1100   0.11     18000    638   0.01      33000     0   0.00
 0.525 - 0.613   8000   720   0.69      6000    610   0.09      10000     0   0.00
 0.613 - 0.700   7000   159   0.00      5000      8   0.00       6000     0   0.00
 0.700 - 0.787  12000  4264   7.67      2000      0   0.00       3000     0   0.00
 0.787 - 0.875  11000  1935   0.74      2000      0   0.00       2000     0   0.00
 0.875 - 0.963   7000   637   0.11         0      0   0.00          0     0   0.00
                                    FAVPFM As-Found Output File (*.out) – (Continued)

 0.963 - 1.050   4000   232   0.06         0      0   0.00       1000     0   0.00
 1.050 - 1.137   4000   879   0.77         0      0   0.00          0     0   0.00
 1.137 - 1.225   9000   757   0.02         0      0   0.00          0     0   0.00
 1.225 - 1.312   8000   604   0.02         0      0   0.00          0     0   0.00
 1.312 - 1.400   6000  1878   2.78         0      0   0.00          0     0   0.00
 1.400 - 1.488   6000   807   1.18         0      0   0.00          0     0   0.00
 1.488 - 1.575   6000  2439  16.68         0      0   0.00          0     0   0.00
 1.575 - 1.663   6000   645   1.49         0      0   0.00          0     0   0.00
 1.663 - 1.750   7000  1816  12.69         0      0   0.00          0     0   0.00
 1.750 - 1.838  10000  1482  10.44         0      0   0.00          0     0   0.00
 1.838 - 1.925  10000  1995   5.73         0      0   0.00          0     0   0.00
 1.925 - 2.013   8000  1060   0.11         0      0   0.00          0     0   0.00
 2.013 - 2.100  10000  1210   0.10         0      0   0.00          0     0   0.00
 2.100 - 2.188   8000  1189   2.42         0      0   0.00          0     0   0.00
 2.188 - 2.275      0     0   0.00         0      0   0.00          0     0   0.00
=================================================================================
TOTALS         212000 30075  64.30    863000   2223   0.11    1630000     0   0.00
=================================================================================
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
           ===============================================
                **************************************
                * TRANSIENT TIME DISTRIBUTION REPORT *
                *    for transient sequence     2    *
                **************************************
           ===============================================
           TIME   TIME    % of    CDF of    % of    CDF of
           STEP   (min)   total   total    total    total
                          CDCPI   CDCPI    CDCPF    CDCPF
           ===============================================
           38    37.0   0.0000   0.0000   0.0000   0.0000
           39    38.0   0.0000   0.0000   0.0000   0.0000
           40    39.0   0.0000   0.0000   0.0000   0.0000
           41    40.0   0.0000   0.0000   0.0000   0.0000
           42    41.0   0.0000   0.0000   0.0000   0.0000
           43    42.0   0.0000   0.0000   0.0000   0.0000
           44    43.0   0.0000   0.0000   0.0000   0.0000
           45    44.0   0.0000   0.0000   0.0000   0.0000
           46    45.0   0.0000   0.0001   0.0000   0.0000
           47    46.0   0.0000   0.0001   0.0000   0.0000
           48    47.0   0.0000   0.0002   0.0000   0.0000
           49    48.0   0.0001   0.0002   0.0000   0.0000
           50    49.0   0.0002   0.0004   0.0000   0.0000
           51    50.0   0.0003   0.0007   0.0000   0.0000
           52    51.0   0.0005   0.0012   0.0000   0.0000
           53    52.0   0.0009   0.0021   0.0000   0.0000
           54    53.0   0.0014   0.0034   0.0000   0.0001
           55    54.0   0.0020   0.0054   0.0000   0.0001
           56    55.0   0.0028   0.0082   0.0001   0.0002
           57    56.0   0.0033   0.0115   0.0001   0.0003
           58    57.0   0.0045   0.0160   0.0002   0.0004
           59    58.0   0.0006   0.0166   0.0002   0.0006
           60    59.0   0.0000   0.0166   0.0000   0.0006
           61    60.0   0.0000   0.0166   0.0000   0.0006
           62    61.0   0.0000   0.0166   0.0000   0.0006
           65    64.0   0.0000   0.0166   0.0000   0.0006
           66    65.0   0.0000   0.0166   0.0000   0.0006
           70    69.0   0.0000   0.0166   0.0000   0.0006
           72    71.0   0.0000   0.0166   0.0000   0.0006
          111   110.0   0.0514   0.0681   0.0581   0.0588
          112   111.0   0.4248   0.4929   0.4894   0.5482
          113   112.0  22.3137  22.8065  22.2354  22.7835
          114   113.0  44.7522  67.5588  41.4736  64.2571
          115   114.0  29.1760  96.7348  32.1146  96.3717
          116   115.0   3.2645  99.9993   3.6274  99.9991
          120   119.0   0.0007 100.0000   0.0009 100.0000


     ***********************************************************
     *      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)      *
     *           FOR THE INITIATING DRIVING FORCES             *
     *              FOR TRANSIENT SEQUENCE     2               *
     ***********************************************************
           ===============================================
                               RELATIVE    CUMULATIVE
             KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
             (bin midpoint)      (%)          (%)
           ===============================================
                21.00            0.6717        0.6717
                23.00            2.1945        2.8663
                25.00            5.2661        8.1324
                27.00            7.8932       16.0255
                29.00            4.7379       20.7634
                31.00            9.6891       30.4525
                33.00            8.4732       38.9257
                35.00            4.2316       43.1573
                37.00            9.0193       52.1766
                39.00            3.3965       55.5731
                41.00            4.4489       60.0219
                43.00            2.9261       62.9480
                45.00            1.7520       64.7000
                47.00            9.7249       74.4250
                49.00            3.0098       77.4347
                51.00            2.8124       80.2472
                53.00            4.3711       84.6183
                55.00            0.1056       84.7239
                57.00            5.8362       90.5601
                59.00            1.5647       92.1248
                63.00            2.4935       94.6183
                65.00            1.0983       95.7166
                67.00            1.2478       96.9643
                69.00            1.8019       98.7662
                73.00            1.2338      100.0000
           ===============================================
                               RELATIVE    CUMULATIVE
             KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
             (bin midpoint)      (%)          (%)
           ===============================================

====================================================================================================
                     FAILURE MECHANISM REPORT FOR TRANSIENT SEQUENCE      2
====================================================================================================
                                                            NUMBER OF     % OF TOTAL
                                                              FAILURE        FAILURE
                                                               TRIALS         TRIALS
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
CLEAVAGE PROPAGATION TO PLASTIC INSTABILITY                12951118          89.10
CLEAVAGE PROPAGATION EXCEEDS WALL DEPTH FAILURE CRITERIA    1584576          10.90


       ***************************************************
       ***************************************************
       *               MULTIPLE FLAW STATISTICS          *
       ***************************************************
       ***************************************************

                        NUMBER OF OCCASIONS
                      WHEN SIMULATED RPV HAD

               X FLAWS        % OF         X FLAWS        % OF
X FLAWS     WITH CPI > 0    TOTAL CPI    WITH CPF > 0   TOTAL CPF

   1             1            0.05           14            0.70
   2             0            0.00           11            0.55
   3             0            0.00           19            0.95
   4             2            0.10           16            0.80
   5             4            0.20           21            1.05
   6             7            0.35           25            1.25
   7             7            0.35           23            1.15
   8             9            0.45           28            1.40
   9             5            0.25           24            1.20
  10            10            0.50           39            1.96
  11             7            0.35           35            1.76
  12             8            0.40           30            1.51
  13            10            0.50           43            2.16
  14            14            0.70           40            2.01
  15            15            0.75           42            2.11
  16            10            0.50           36            1.81
  17            18            0.90           47            2.36
  18            16            0.80           43            2.16
  19            16            0.80           43            2.16
  20            11            0.55           35            1.76
  21            13            0.65           33            1.66
  22            12            0.60           33            1.66
  23            17            0.85           37            1.86
  24            14            0.70           38            1.91
  25            16            0.80           34            1.71
  26            20            1.00           36            1.81
  27            13            0.65           28            1.40
  28            21            1.05           30            1.51
  29            17            0.85           36            1.81
  30            26            1.30           24            1.20
  31            25            1.25           44            2.21
  32            20            1.00           33            1.66
  33            28            1.40           43            2.16
  34            21            1.05           30            1.51
  35            21            1.05           21            1.05
  36            31            1.55           39            1.96
  37            26            1.30           30            1.51
  38            19            0.95           23            1.15
  39            21            1.05           24            1.20
  40            24            1.20           24            1.20
  41            25            1.25           25            1.25
  42            22            1.10           22            1.10
  43            21            1.05           21            1.05
  44            30            1.50           31            1.56
  45            20            1.00           17            0.85
  46            24            1.20           29            1.46
  47            24            1.20           25            1.25
  48            16            0.80           17            0.85
  49            21            1.05           15            0.75
  50            17            0.85           15            0.75
  51            21            1.05           17            0.85
  52            23            1.15           21            1.05
  53            20            1.00           16            0.80
  54            26            1.30           20            1.00
  55            16            0.80           17            0.85
  56            14            0.70           12            0.60
  57            34            1.70           27            1.35
  58            16            0.80           17            0.85
  59            25            1.25           23            1.15
  60            21            1.05           14            0.70
  61            19            0.95           11            0.55
  62            21            1.05           10            0.50
  63            20            1.00           15            0.75
  64            20            1.00           16            0.80
  65            27            1.35           11            0.55
  66            26            1.30           13            0.65
  67            15            0.75            7            0.35
  68            22            1.10           12            0.60
  69            15            0.75            9            0.45
  70            22            1.10           13            0.65
  71            12            0.60            5            0.25
  72            24            1.20           12            0.60
  73            21            1.05           13            0.65
  74            15            0.75           11            0.55
  75            19            0.95           13            0.65
  76            23            1.15           14            0.70
  77            11            0.55            6            0.30
  78            17            0.85            8            0.40
  79            19            0.95           10            0.50
  80            13            0.65            9            0.45
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
    81              16            0.80            11            0.55
    82              12            0.60             8            0.40
    83              10            0.50             3            0.15
    84              16            0.80             5            0.25
    85              16            0.80             9            0.45
    86              10            0.50             3            0.15
    87               6            0.30             3            0.15
    88              12            0.60             7            0.35
    89              12            0.60             4            0.20
    90              10            0.50             6            0.30
    91              14            0.70             3            0.15
    92              15            0.75             4            0.20
    93               7            0.35             2            0.10
    94              11            0.55             4            0.20
    95               5            0.25             2            0.10
    96               4            0.20             1            0.05
    97               4            0.20             3            0.15
    98               9            0.45             3            0.15
    99               8            0.40             4            0.20
   100               9            0.45             4            0.20
   101               6            0.30             3            0.15
   102               9            0.45             5            0.25
   103               7            0.35             2            0.10
   104               6            0.30             1            0.05
   105              11            0.55             2            0.10
   106               7            0.35             0            0.00
   107               8            0.40             1            0.05
   108               6            0.30             3            0.15
   109               6            0.30             0            0.00
   110               5            0.25             1            0.05
   111               6            0.30             0            0.00
   112               5            0.25             2            0.10
   113               9            0.45             1            0.05
   114               9            0.45             1            0.05
   115               6            0.30             1            0.05
   116              10            0.50             1            0.05
   117               5            0.25             2            0.10
   118               2            0.10             0            0.00
   119               8            0.40             0            0.00
   120               6            0.30             0            0.00
   121               5            0.25             1            0.05
   122               5            0.25             0            0.00
   123               3            0.15             0            0.00
   124               8            0.40             1            0.05
   125               7            0.35             0            0.00
   126               4            0.20             0            0.00
   127               3            0.15             0            0.00
   128               5            0.25             0            0.00
   129               3            0.15             0            0.00
   130               6            0.30             0            0.00
   131               7            0.35             0            0.00
   132               5            0.25             0            0.00
   133               3            0.15             0            0.00
   134               5            0.25             0            0.00
   135               1            0.05             0            0.00
   136               5            0.25             1            0.05
   137               7            0.35             0            0.00
   138               8            0.40             0            0.00
   139               1            0.05             0            0.00
   140               2            0.10             0            0.00
   141               3            0.15             0            0.00
   142               2            0.10             0            0.00
   143               4            0.20             0            0.00
   144               2            0.10             0            0.00
   145               3            0.15             1            0.05
   146               3            0.15             0            0.00
   147               5            0.25             0            0.00
   148               1            0.05             0            0.00
   149               2            0.10             0            0.00
   150               2            0.10             0            0.00
   151               2            0.10             0            0.00
   152               2            0.10             1            0.05
   156               4            0.20             0            0.00
   157               2            0.10             0            0.00
   158               1            0.05             0            0.00
   159               2            0.10             0            0.00
   160               3            0.15             0            0.00
   161               1            0.05             0            0.00
   162               4            0.20             0            0.00
   163               6            0.30             0            0.00
   164               2            0.10             0            0.00
   165               2            0.10             0            0.00
   166               2            0.10             0            0.00
   167               2            0.10             0            0.00
   168               1            0.05             0            0.00
   169               2            0.10             0            0.00
   170               1            0.05             0            0.00
   171               2            0.10             0            0.00
   172               1            0.05             0            0.00
   173               2            0.10             0            0.00
   174               4            0.20             0            0.00
   176               1            0.05             0            0.00
   177               2            0.10             0            0.00
   178               3            0.15             0            0.00
   179               4            0.20             0            0.00
```

FAVPFM As-Found Output File (*.out) – (Continued)

```
180             1           0.05            0           0.00
181             1           0.05            0           0.00
182             4           0.20            0           0.00
183             1           0.05            0           0.00
184             1           0.05            0           0.00
185             2           0.10            0           0.00
187             3           0.15            0           0.00
188             3           0.15            0           0.00
189             3           0.15            0           0.00
190             2           0.10            0           0.00
191             1           0.05            0           0.00
192             1           0.05            0           0.00
193             2           0.10            0           0.00
194             4           0.20            0           0.00
195             1           0.05            0           0.00
197             1           0.05            0           0.00
198             1           0.05            0           0.00
199             1           0.05            0           0.00
200             2           0.10            0           0.00
201             5           0.25            0           0.00
202             1           0.05            0           0.00
203             1           0.05            0           0.00
204             1           0.05            0           0.00
205             1           0.05            0           0.00
206             1           0.05            0           0.00
207             2           0.10            0           0.00
210             2           0.10            0           0.00
211             1           0.05            0           0.00
212             2           0.10            0           0.00
213             2           0.10            0           0.00
214             2           0.10            0           0.00
215             1           0.05            0           0.00
216             2           0.10            0           0.00
217             1           0.05            0           0.00
222             1           0.05            0           0.00
223             4           0.20            0           0.00
224             1           0.05            0           0.00
227             1           0.05            0           0.00
239             1           0.05            0           0.00
242             1           0.05            0           0.00
243             1           0.05            0           0.00
245             1           0.05            0           0.00
250             1           0.05            0           0.00
253             2           0.10            0           0.00
256             1           0.05            0           0.00
257             1           0.05            0           0.00
260             1           0.05            0           0.00
263             1           0.05            0           0.00
266             1           0.05            0           0.00
268             1           0.05            0           0.00
271             1           0.05            0           0.00
279             1           0.05            0           0.00
299             1           0.05            0           0.00
303             1           0.05            0           0.00
311             1           0.05            0           0.00
313             1           0.05            0           0.00
323             1           0.05            0           0.00

 TOTALS      2000         100.00         1993         100.00

 Note: One Occasion is 1 simulated RPV subjected to 1 transient

           DATE: 29-Jul-2020  TIME: 16:00:56
```

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[2] G. J. Schuster, S. R. Doctor and P. G. Heasler, "Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel, USNRC Report NUREG/CR-6471, Vol. 2," U.S. Nuclear Regulatory Commission, Washington, DC, 2000.

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[8] V. Lacroix, P. Dulieu and D. Couplet, "Alternative Characterization Rules for Quasi-Laminar Flaws," in *Proceedings of ASME 2014 Pressure Vessels and Piping Division Conference, July 20-24, 2014*, Anaheim, CA, 2014.

[9] V. Lacroix, P. Dulieu and A. S. Bogaert, "Alternative Characterization Rules for Quasi-Laminar Flaws Based on 3-D X-FEM Calculations," in *Proceedings of ASME 2015 Pressure Vessels and Piping Division Conference, July 19-23, 2015*, Boston, MA., 2015.

9. Appendix D – FAVOR Error Codes

Error Code	Description	Subroutine	User's Guide Section
	FAVLOAD Error Codes		
1	Error in data Record 1 - Keyword GEOM: Data required IRAD= W= CLTH=	RD79	2.1
2	Error in data Record 2 - Keyword BASE: Data required K= C= RHO= E= ALPHA= V=	RD79	2.1
3	Error in data Record 3 - Keyword CLAD: Data required K= C= RHO= E= ALPHA= V=	RD79	2.1
4	Error in data Record 4 - Keyword SFRE: Data required T=	RD79	2.1
5	Error in data Record 5 - Keyword RESA: Data required NRAX=	RD79	2.1
6	Error in data Record 6 - Keyword RESC: Data required NRCR=	RD79	2.1
7	Error in data Record 7 - Keyword TIME: TOTAL= DT=	RD79	2.1
8	Error in data Record 7 - Input Time step too small	RD79	2.1
9	Error in data Record 8 - Keyword NPRA: Data required NTRAN=	RD79	2.1
10	Error in data Record 9 - Keyword TRAN: Data required ITRAN= ISEQ=	RD79	2.1
11	Error in data Record 9 - ITRAN numbers must be in ascending order with no ommissions	RD79	2.1
101	Memory allocation error - insufficient memory available for this execution	CHECK_ALLOC	(-)
102	Singular matrix found in axial stress calculation	SYMSL3	(-)
103	Elliptical angle out of bounds during linear interpolation of surface-breaking flaw SIFICs	ANGINTBS2	(-)
104	Elliptical angle out of bounds during linear interpolation of surface-breaking flaw SIFICs	ANGINTBS6	(-)
105	Elliptical angle out of bounds during linear interpolation of surface-breaking flaw SIFICs	ANGINTBS10	(-)
106	Elliptical angle out of bounds during linear interpolation of surface-breaking flaw SIFICs	ANGINTCL1562	(-)
107	Elliptical angle out of bounds during linear interpolation of surface-breaking flaw SIFICs	ANGINTCL1566	(-)
	FAVPFM Error Codes		
1	Error in data Record 1 - Keyword CNT1: Data required NSIM= IGATR= WPS_OPT=	RD17	2.2
2	Error in data Record 2 - Keyword CNT2: Data required IRTNDT= TC= EFPY=	RD17	2.2
3	Error in data Record 3 - Keyword CNT3: Data required FLWSTR= USKIA= ILAYER_OPT= FAILCR=	RD17	2.2
4	Error in data Record 4 - Keyword GENR: Data required SIGFGL= SIGFLC=	RD17	2.2
5	Error in data Record 5 - Keyword SIGW: Data required WSIGCU= WSIGNI= WSIGP=	RD17	2.2
6	Error in data Record 6 - Keyword SIGP: Data required PSIGCU= PSIGNI= PSIGP=	RD17	2.2
7	Error in data Record 7 - Keyword TRAC: ITRAN= IRPV= IFLAW=	RD17	2.2
8	Error in data Record 8 - Keyword LDQA: Data required IQA= IOPT= IWELD= IKIND= XIN= XVAR= ASPI	RD17	2.2
9	Error in data Record 9 - Keyword WELD: Data required NWSUB= NWMAJ=	RD17	2.2
10	Error in data Record 10 - Keyword PLAT: Data required NPSUB= NPMAJ=	RD17	2.2
11	Error in data Record 8 - Keyword LDQA: IQA must be = 0 or 1	RD17	2.2
12	Load file not generated by FAVLoad 02.3: Rerun load module	RDDET	(-)
13	INVALID FLAW ORIENTATION	PROP	(-)
14	ISQ? CARD NEEDS FOUR VARS - SEE USER GUIDE	RD17	2.2
15	DTRF Record: ITRAN ISEQ mismatch	RD17	2.2
16	DTRF Record: ITRAN greater than MTRAN	RD17	2.2
17	SURFACE-BREAKING FLAW FILE NOT VERSION 04.1	RDSURF	(-)
18	ERROR READING SURFACE-BREAKING FLAW DATA	RDSURF	(-)
19	EMBEDDED-FLAW WELD FILE NOT VERSION 04.1	RDWELD	(-)
20	ERROR READING WELD EMB. FLAW DATA	RDWELD	(-)
21	EMBEDDED-FLAW PLATE FILE NOT VERSION 04.1	RDPLAT	(-)
22	ERROR READING PLATE EMB. FLAW DATA	RDPLAT	(-)
23	INVALID ICORR(NSBR)	EWO1998	(-)
24	ERROR IN WELD SUBREGION DEFINITIONS	RD17	2.2
25	ERROR IN PLATE SUBREGION DEFINITIONS:NSUBR(I,1)/=NSUBR(I,2)	RD17	2.2
101	Memory allocation error - insufficient memory available for this execution	CHECK_ALLOC	(-)
	FAVPost Error Codes		
1	PFM input files not generated by version 02.3: Rerun with FAVPFM 02.3	Main	(-)
2	Inconsistent input data. Incorrect number of transients specified	Main	(-)
3	Inconsistent input data. Transient sequence numbers do not match.	Main	(-)
4	Inconsistent input data. Incorrect number of transients specified	PRA	(-)
5	Error in construction of Histogram	PRA	(-)
6	Inconsistent input data. Transient sequence numbers do not match.	PRA	(-)
101	Memory allocation error - insufficient memory available for this execution	CHECK_ALLOC	(-)