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Fracture Analysis of Vessels – Oak Ridge FAVOR, v12.1, Computer Code: User's Guide

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Fracture Analysis of Vessels – Oak Ridge FAVOR, v12.1, Computer Code: USER'S GUIDE

T. L. Dickson , P. T. Williams and S. Yin

ABSTRACT

Over the last three decades, there have been significant advancements and refinements in technologies that have impacted established fracture mechanics and risk-informed methodologies. Updated computational methodologies have been developed through interactions between experts in the relevant disciplines of thermal hydraulics, probabilistic risk assessment, materials embrittlement, fracture mechanics, and inspection (flaw characterization). These methodologies have been and continue to be applied in the assessment and updating of regulations designed to insure that the structural integrity of aging nuclear reactor pressure vessels (RPVs) is maintained throughout the licensing period of the reactor.

These updated methodologies have been implemented into the **F**racture **A**nalysis of **V**essels – **O**ak **R**idge (FAVOR) computer code developed at Oak Ridge National Laboratory (ORNL) for the NRC. The analysis of Pressurized Thermal Shock (PTS) transients in nuclear power plants was the primary motivation for the initial development of FAVOR; therefore, earlier versions of FAVOR were limited to performing fracture analyses of pressurized water reactors (PWRs) subjected to cool-down transients.

The 12.1 version of FAVOR represents a significant generalization over previous versions, because the problem class for FAVOR has been extended to encompass a broader range of events that include normal operational transients (start-up, shut-down, and leak-test) as well as upset conditions such as PTS. This latest version also extends FAVOR's capability to perform deterministic and risk-informed probabilistic fracture analyses of boiling water reactors (BWRs) as well as PWRs subjected to heat-up and / or cool-down transients.

Intended to document the technical bases for the assumptions, algorithms, methods, and correlations employed in the development of FAVOR, v12.1, this report is a companion to the *FAVOR, v12.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations.*

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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 can also be analyzed using FAVOR. FAVOR, v12.1 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. The differences between the various versions of FAVOR are detailed in the FAVOR revision history later in this report.

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 early-mid 1980s) had the potential for providing a technical basis for a re-evaluation of the 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 (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 internal surface-breaking flaws,
- a new ductile-fracture model simulating stable and unstable ductile tearing,
- new embrittlement trend correlations,
- the ability to include multiple transients in one execution of FAVOR,
- input from the Reactor Vessel Integrity Database, Revision 2, (RVID2) of relevant RPV material properties,
- fracture-toughness models based on extended databases and improved statistical distributions,
- removal of the implicit conservatism in the RT_{NDT} transition temperature,
- 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 (internal and external) and embedded-flaw models,
- through-wall weld residual stresses, and an
- 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 have been implemented in the **F**racture **A**nalysis of **V**essels – **O**ak **R**idge (FAVOR) computer code developed for the NRC originally by the Heavy Section Steel Technology (HSST) program and more recently by the Probabilistic Pressure Boundary Integrity Safety Assessment (PISA) program, both at Oak Ridge National Laboratory (ORNL). This report is intended to document the technical bases for the assumptions, algorithms, methods, and correlations employed in the development of the FAVOR code.

ABBREVIATIONS

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

ACKNOWLEDGMENTS

The development of the new methodologies and models incorporated into FAVOR, v12.1, has been the result of a long and fruitful collaboration with many colleagues. The contributions of the NRC staff including Dr. L. Abramson, D. Bessette, Dr. N. Chokshi, Dr. E. Hackett, D. Jackson, W. Jones, D. Kalinousky, Dr. M. T. Kirk, Dr. S. Malik, M. Mayfield, C. Santos, Dr. N. Siu, and Dr. H. W. Woods are gratefully acknowledged. The new approaches to conditional probability of initiation and failure and the treatment of multiple flaws were developed in collaboration with Professors M. Modarres, A. Mosleh, and Dr. F. Li of the University of Maryland Center for Technology Risk Studies. The new flaw-characterization distributions were developed by D. Jackson of the NRC and Drs. F. Simonen, S. Doctor, and G. Schuster at Pacific Northwest National Laboratory, and the new detailed fluence maps were developed by W. Jones and T. Santos of the NRC and Dr. J. Carew of Brookhaven National Laboratory. Dr. K. Bowman of the Computer Science and Mathematics Division at Oak Ridge National Laboratory (ORNL) developed the statistical procedures that were applied in the development of the Weibull fracture-toughness model for FAVOR. Drs. M. Sokolov and S. K. Iskander of the Metals and Ceramics Division at ORNL carried out the survey of fracture-toughness data that produced the ORNL 99/27 extended fracture-toughness database. Dr. B. R. Bass, head of the Heavy Section Steel Technology Program at ORNL, provided the survey of fracture-arrest data from the Large-Specimen experiments carried out in the 1980s. Dr. R. K. Nanstad of ORNL, Drs. E. Eason and J. Wright of Modeling and Computing Services, Boulder, Colorado, and Prof. G. R. Odette of the University of California at Santa Barbara developed the new irradiation-shift model implemented in FAVOR, v07.1. In addition to developing the ductile-tearing model implemented in this version of FAVOR, Dr. M. T. Kirk of the NRC led a Working Group in the development of the new fracture-toughness models in FAVOR. Other members of this Working Group included, in addition to the authors, Dr. R. K. Nanstad and J. G. Merkle of the Metals and Ceramics Division at ORNL, Professor Modarres and Dr. F. Li of the University of Maryland Center for Technology Risk Studies, Dr. Marjorie Erickson of PEAI, and Dr. B. R. Bass. J. G. Merkle with Dr. Nanstad developed the lower-bounding reference temperature approach that was adopted in the uncertainty analysis of the reference-nil-ductility transition temperature. Dr. Marjorie Erickson developed the fundamental uncertainty analysis framework used to classify uncertainties as aleatory or epistemic and to quantify these uncertainties, therby permitting their numerical simulation. Several conversations with Prof. R. Dodds of the University of Illinois, Prof. K. Wallin of VTT, Finland, and Dr. C. Faidy of Electricité de France were most helpful in the course of this effort. There were also contributions from many members of the nuclear industry, including B. Bishop and R. Gamble.

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) regulations (established in the early-mid 1980s) had the potential for providing relief to the original 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 50.61a.

The FAVOR computer code continues to evolve and to be employed by analysts from the nuclear industry and regulators at the NRC to apply established fracture mechanics and risk-informed methodologies to assess and update regulations designed to insure that the structural integrity of aging and increasingly radiation-embrittled 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 additional 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 the FAVOR computer program 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 were specifically designed to perform analyses of reactor vessels with an internal radius, R_i, to wall thickness, t, (R_i/t), ratio of approximately 10; which is characteristic of pressurized water reactors (PWRs). Most boiling water reactors (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. This limitation has been removed in FAVOR, v12.1.

An objective of FAVOR, v12.1, is 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, v12.1, 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, v12.1, 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 (v12.1): Theory and Implementation of Algorithms, Methods, and Correlations* [2].

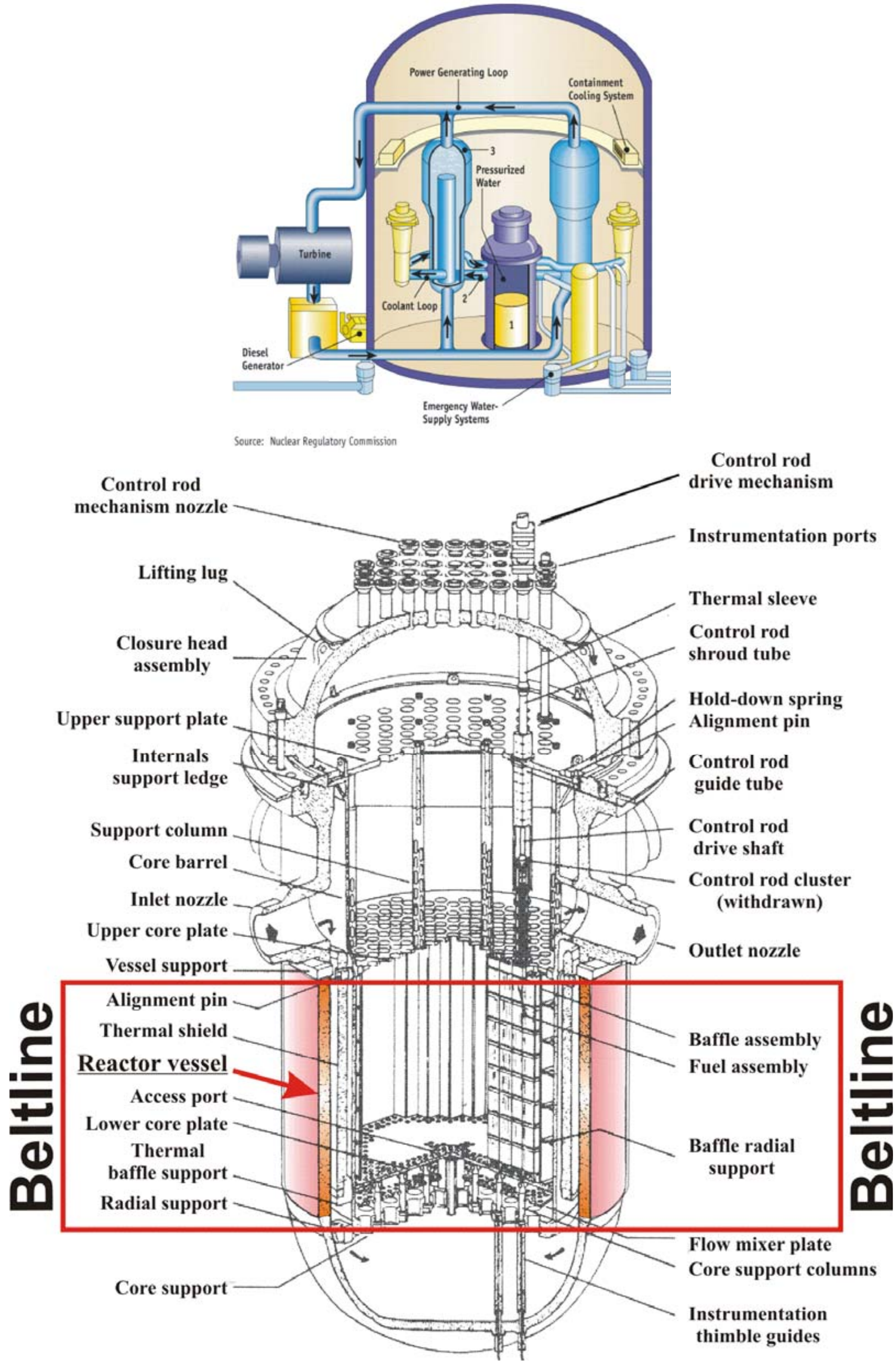


Fig. 1. The beltline region of the reactor pressure vessel wall extends from approximately one foot above the active reactor core to one foot below the core (adapted from [3]) for a pressurized water reactor (PWR).

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, the stress is the highest 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, which is the same approach as usded 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, or implement remedial actions (e.g., flux reduction, annealing).

In 2007, the NRC published a proposed amendment [9] (10CFR50.61a) to the *PTS Rule*. In 10CFR50.61a, the NRC provides alternative fracture toughness requirements for protection against PTS events for PWRs. These 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 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 operating 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).

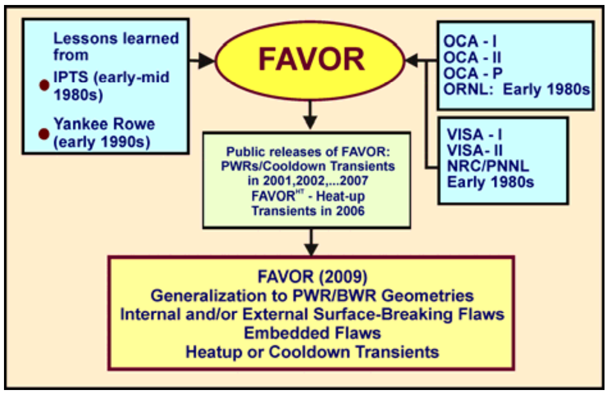


Fig. 2. Depiction of the development history of the FAVOR PFM code

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 for a relaxation to 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 for a possible relaxation to the regulations (per ASME Code, Section XI, Appendix G) for normal operational transients such as those associated with reactor start-up (heat-up) reactor shutdown (cool-down). Specifically, FAVOR, version 12.1, 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.

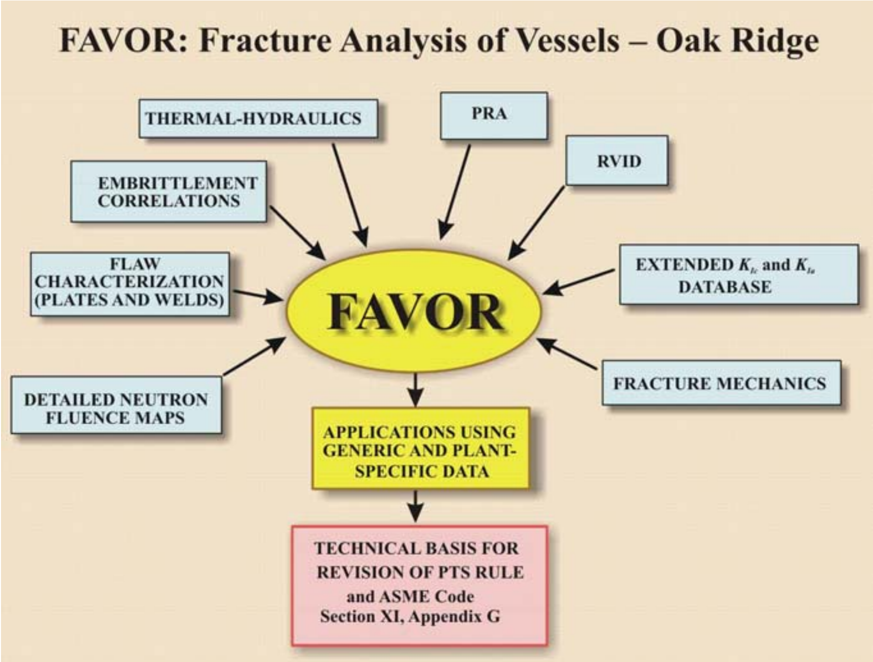


Fig. 3. The PTS Re-Evaluation Project incorporates advancements across a range of technical disciplines relevant to PTS assessment methodologies.

In support of the PTS Re-Evaluation Project, the following advanced technologies have been incorporated into the current release of FAVOR, 12.1:

- **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,**
- **a new ductile-fracture model simulating stable and unstable ductile tearing,**
- **a new embrittlement correlation,**
- **the ability to include multiple transients in one execution of FAVOR,**
- **input from the Reactor Vessel Integrity Database, Revision 2, (RVID2) of relevant RPV 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 (internal and external) and embedded-flaw models,**
- **through-wall weld residual stresses,**

- **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.

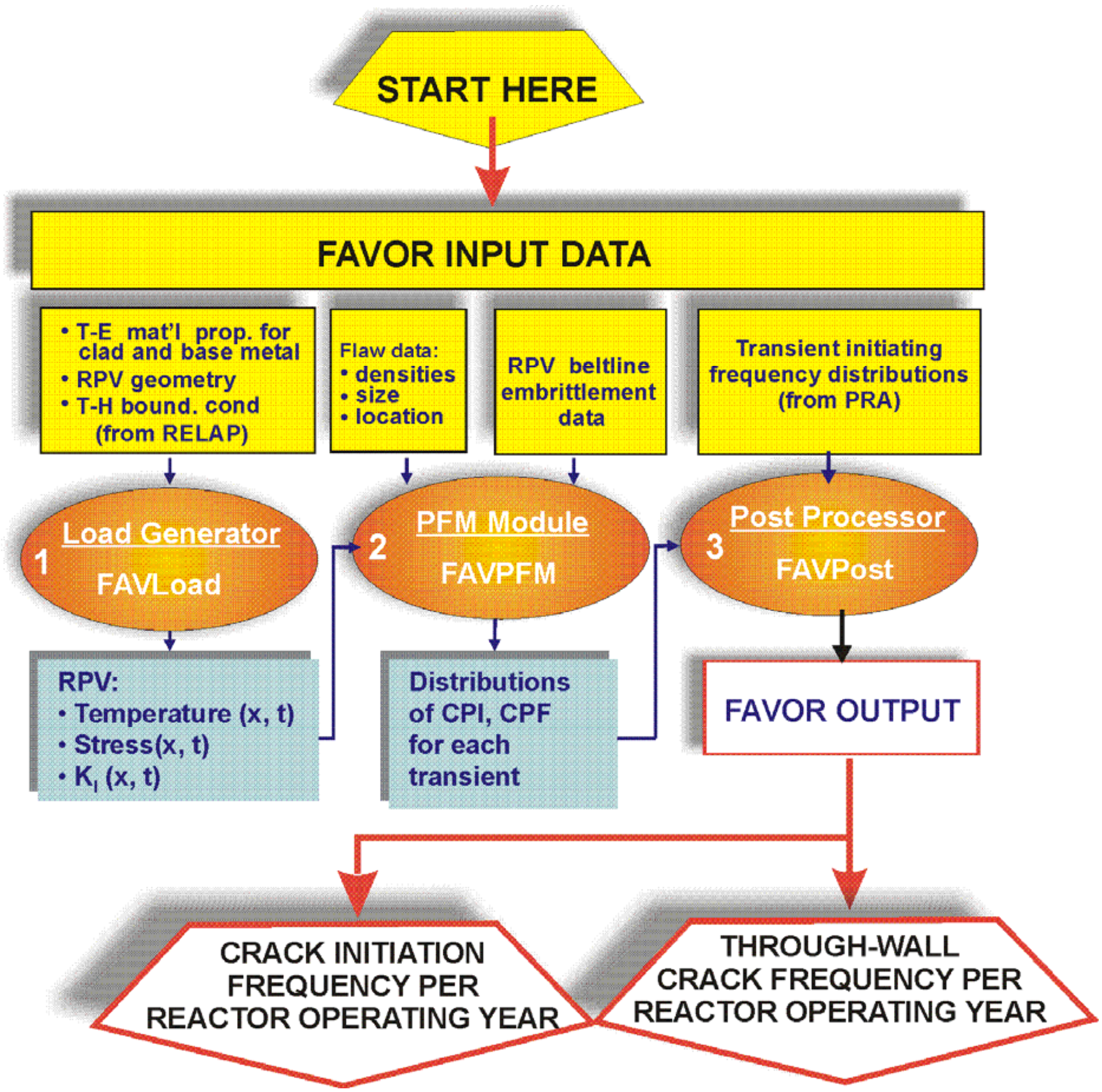


Fig. 4. FAVOR data streams flow through three modules: (1) FAVLoad, (2) FAVPFM, and (3) FAVPost.

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 new 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.

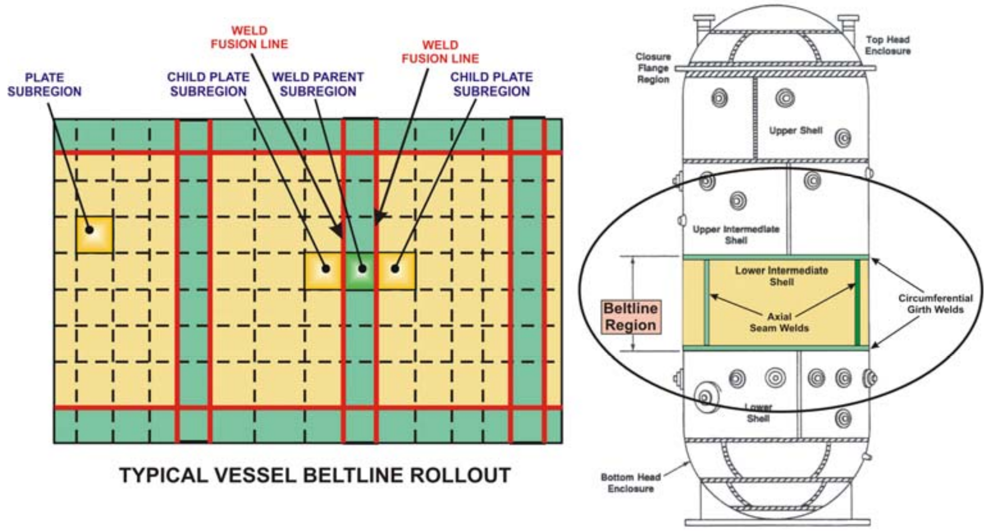


Fig. 5. The global modeling approach in FAVOR allows the entire beltline to be simulated in one model definition.

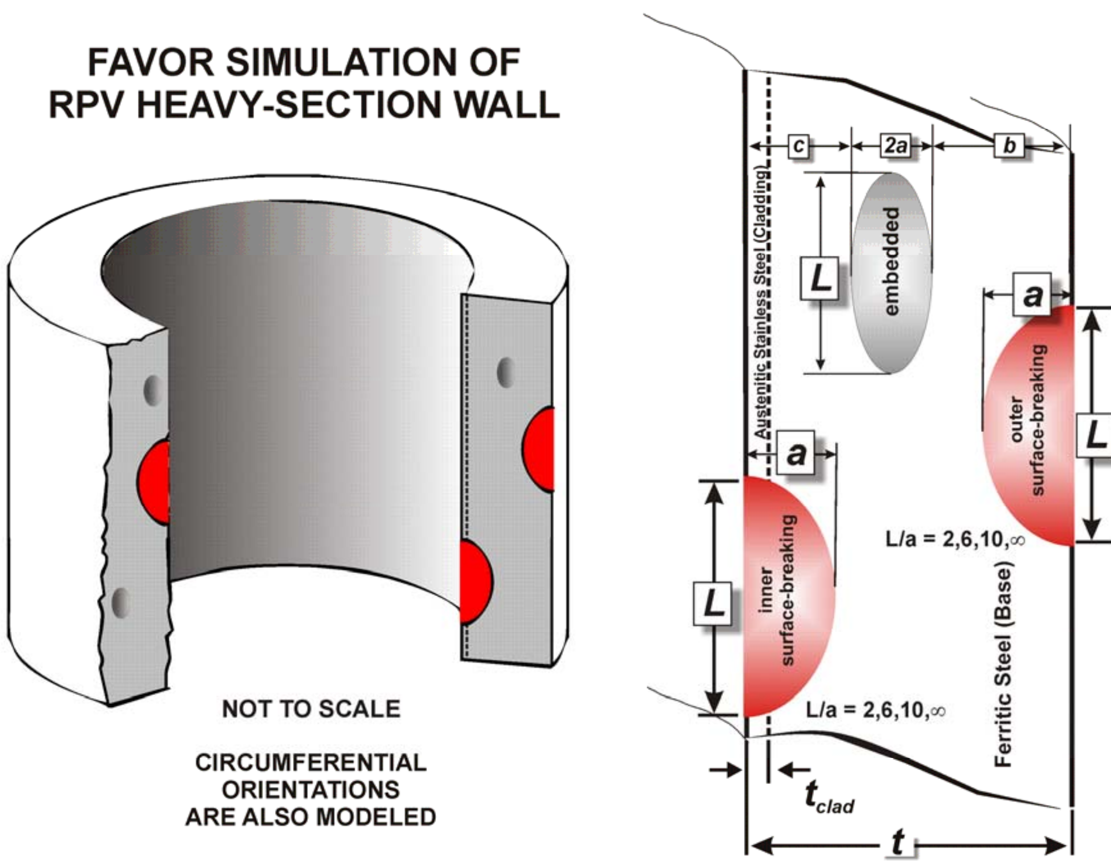


Fig. 6. Flaw models available in FAVOR.

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

A significant part of the generalization included in FAVOR, v12.1, 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, v12.1, has 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 databases for BWR vessel geometry (R_i/t ~ 20) are distinctly different from those generated for the PWR geometry (R_i/t ~ 10); therefore, there are two SIFIC databases for each of the 16 surface breaking flaw types in FAVOR; one each for PWR geometry $R_i/t = 10$ and BWR geometry R_i/t ~ 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 databases in previous versions of FAVOR. Also, algorithms have been developed and verified such that the SIFIC databases for $R_i/t = 10$ and BWR geometry $R_i/t = 20$ for internal and external surface-breaking flaws are appropriately interpolated for application to RPVs for which $10 < R_i/t < 20$; therefore, FAVOR, v12.1, 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 databases 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 1/8th 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 1/8th 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 1/8th and 3/8th 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 1/8th and 3/8th 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

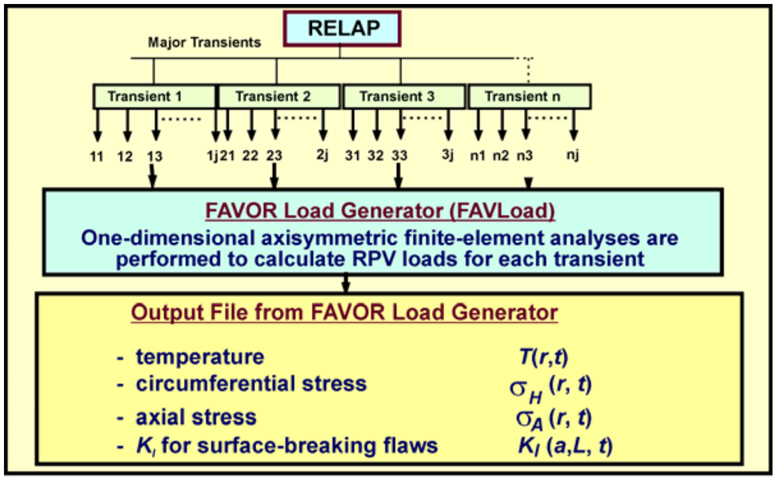


Fig. 7. The FAVOR load generator module FAVLoad performs deterministic analyses for a range of thermal-hydraulic transients.

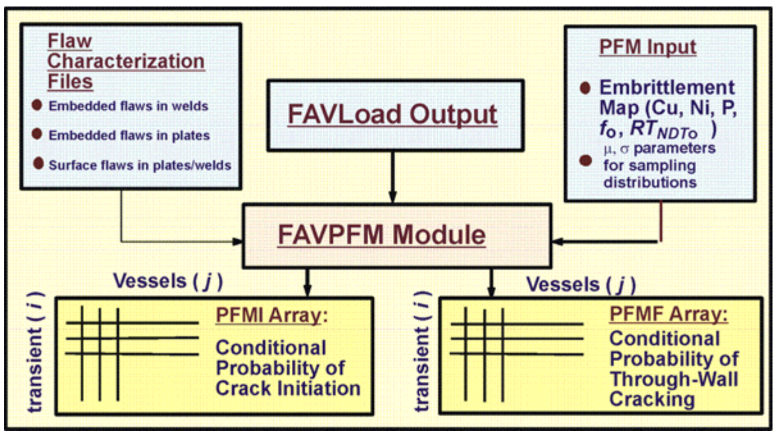


Fig. 8. The FAVPFM module takes output from FAVLoad and user-supplied data on flaw distributions and embrittlement of the RPV beltline and generates PFMI (INITIATE.DAT) and PFMF (FAILURE.DAT) arrays.

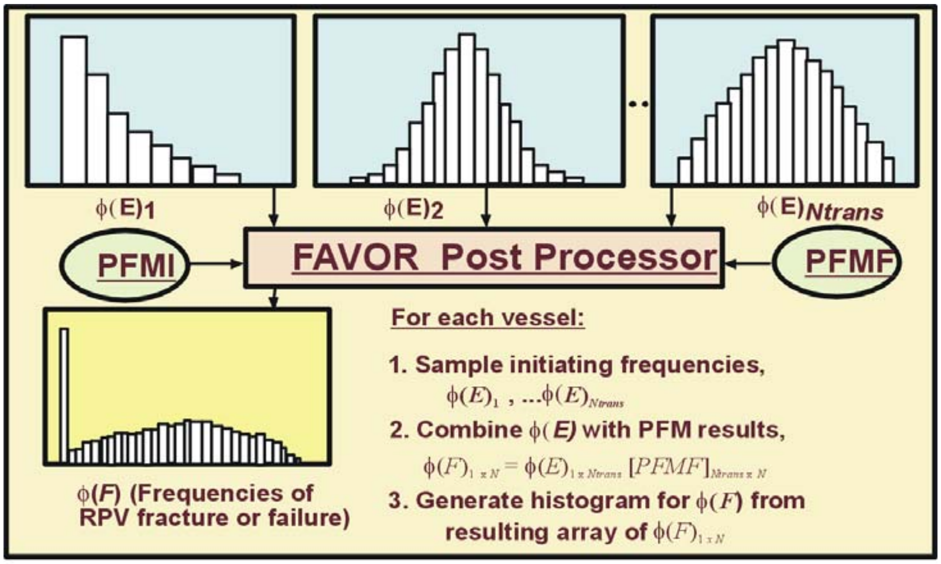


Fig. 9. The FAVOR post-processor FAVPost combines the distributions of conditional probability of initiation and failure calculated by FAVPFM with initiating frequency distributions for all of the transients under study to create distributions of frequencies of RPV fracture and failure.

- **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

Copy all of the files on the distribution CD (with the exception of the setup subfolder) to the user's hard drive. These files may be copied manually by using Windows® Explorer or by running the "SETUP.EXE" application created by Microsoft's Windows® Installer and available in the .\FAVOR12.1\setup subfolder on the CD. If the "autorun" feature on the user's computer is enabled, then the Windows® Installer application will automatically run when the FAVOR distribution CD is loaded into the drive. The Windows® installer will prompt the user for the target installation folder (See Fig. 10).

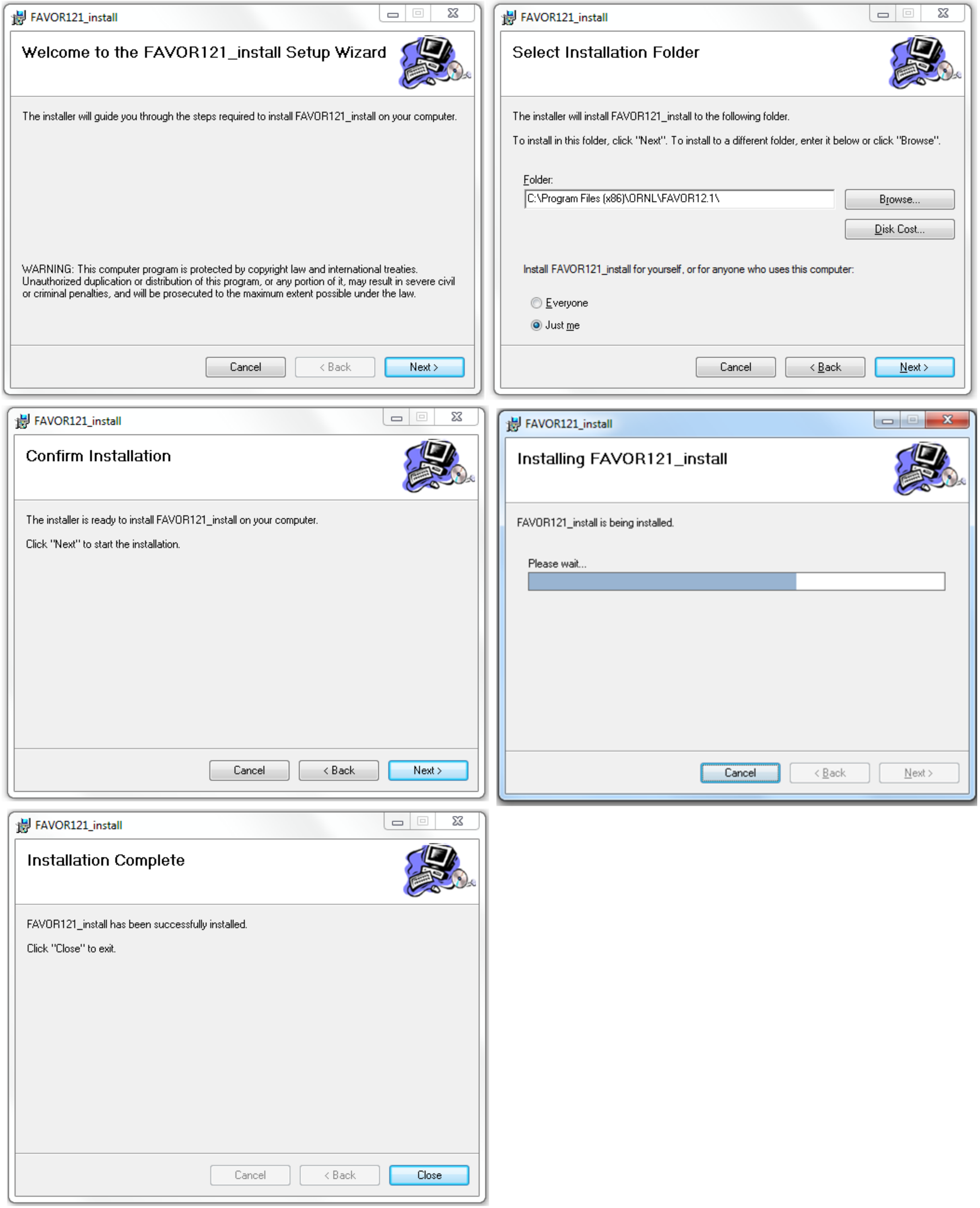


Fig. 10. The Windows® Installer application can be used to copy the FAVOR, v12.1, executables, source code, documentation, and example files to the user's computer.

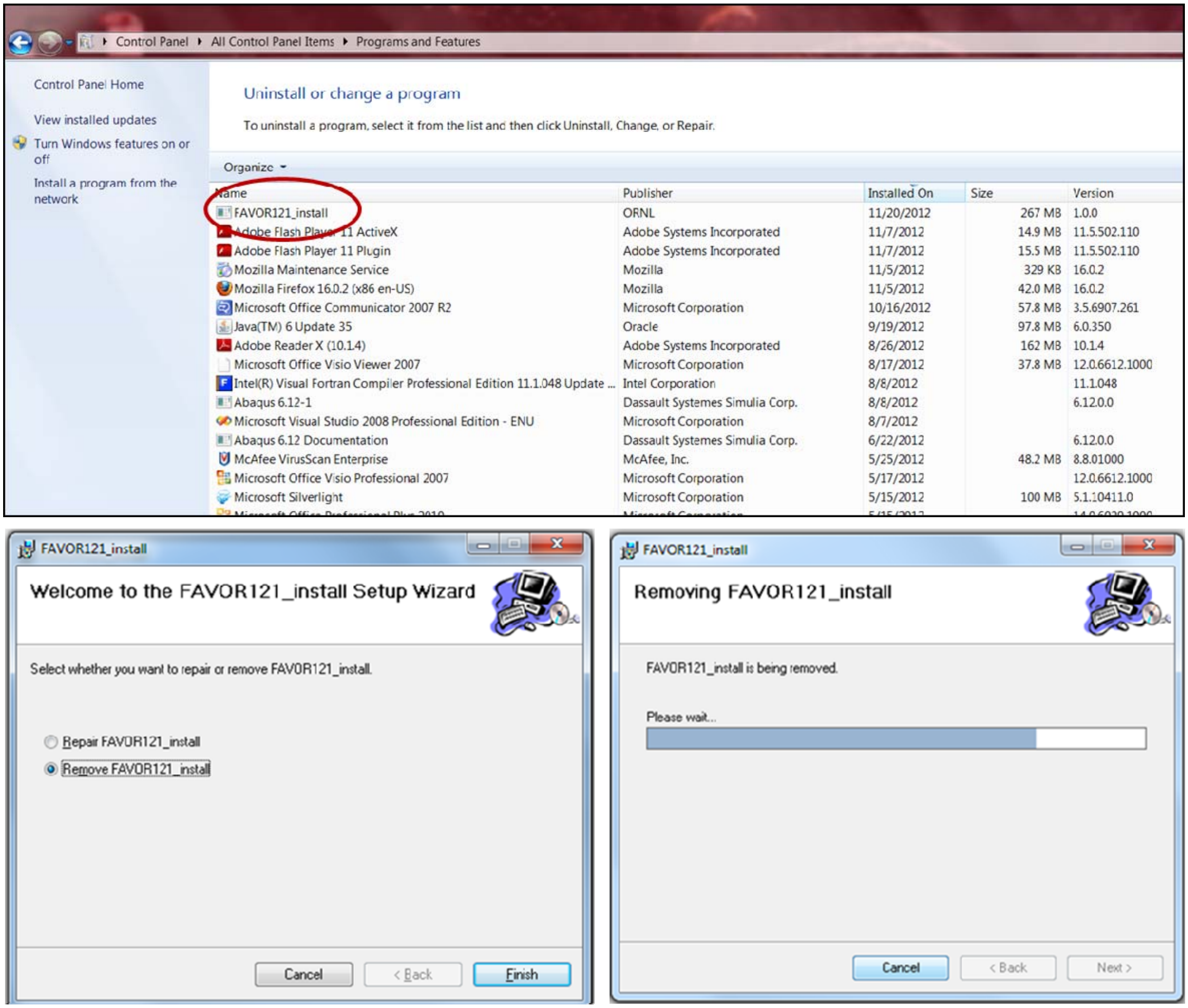


Fig. 10 (continued) FAVOR, v12.1, can be removed from the user's computer using the Windows utility "Add or Remove Programs" available from the Control Panel

The User's Guide and Theory Manual files are in Adobe Acrobat PDF format. The installer for the free the latest version of Adobe Reader is available at the URL http://get.adobe.com/reader/ .

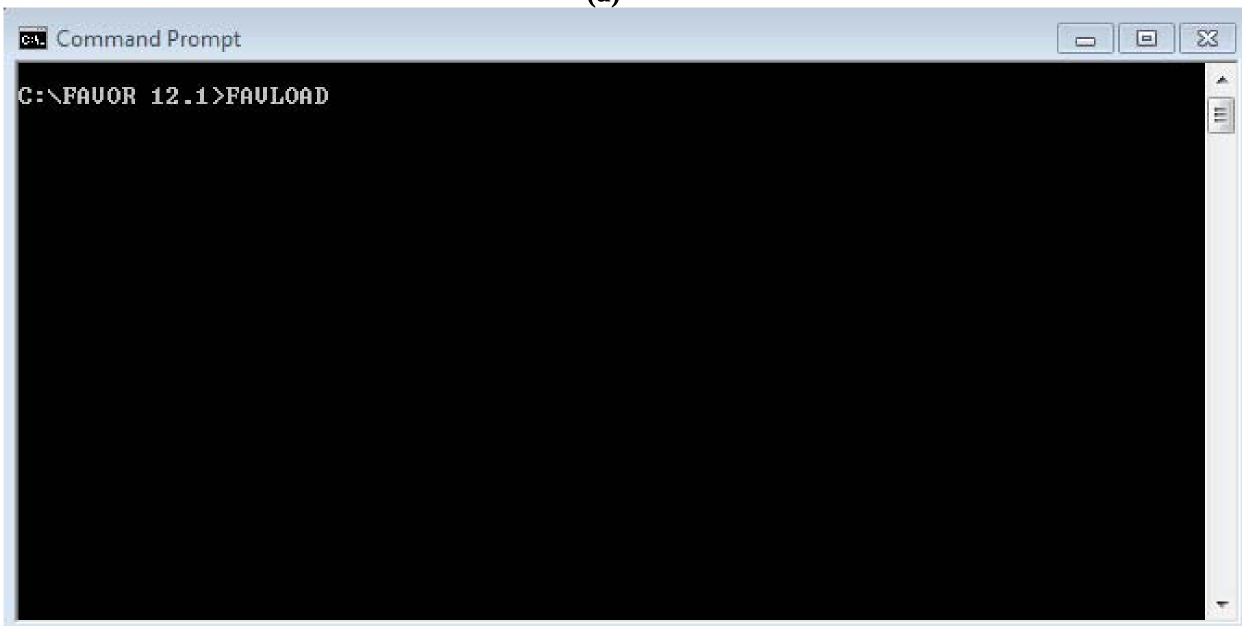
1.5 Execution

On Microsoft Windows operating systems (Windows XP/VISTA/7), 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 an 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 typing 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)



(b)

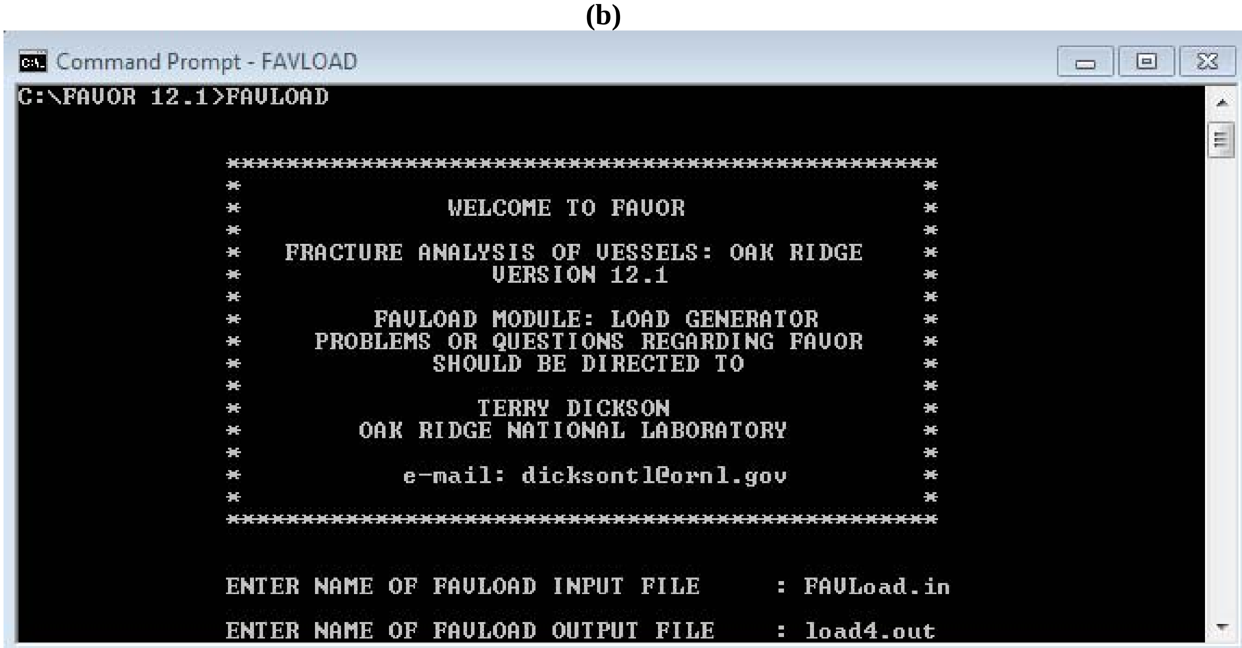


Fig. 11. Execution of the FAVLOAD module: (a) type in FAVLOAD at the line prompt and (b) respond to prompts for the input and output file names.

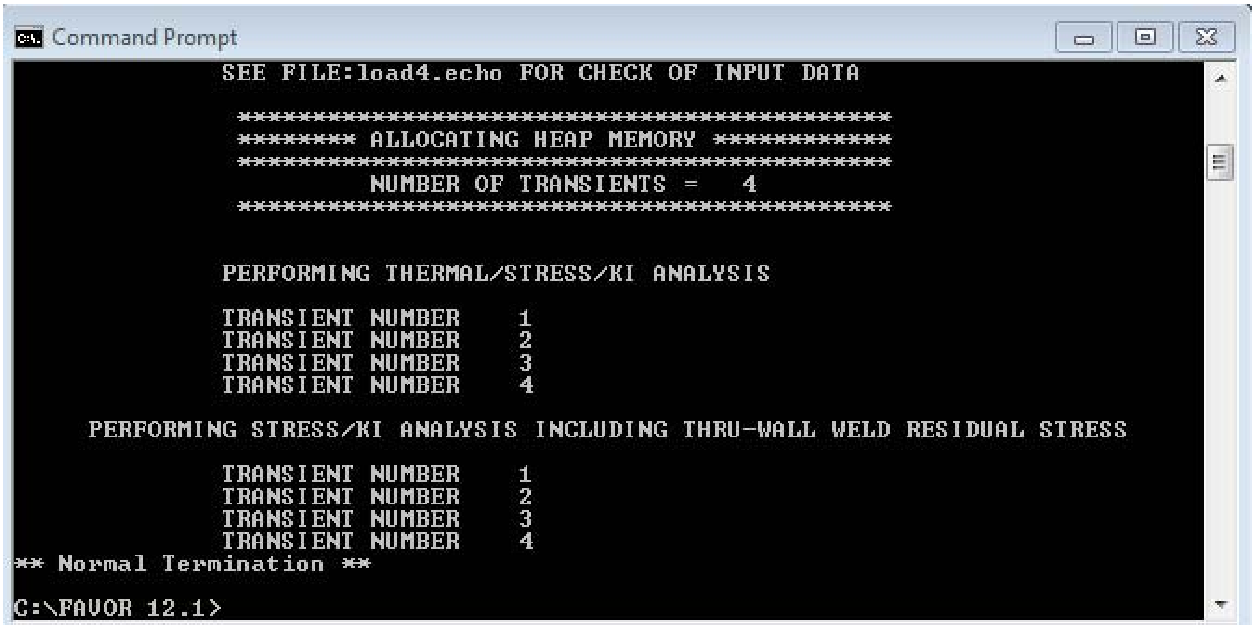


Fig. 12. FAVLOAD calculates thermal, stress, and applied KI loading for all of the transients defined in the input file.

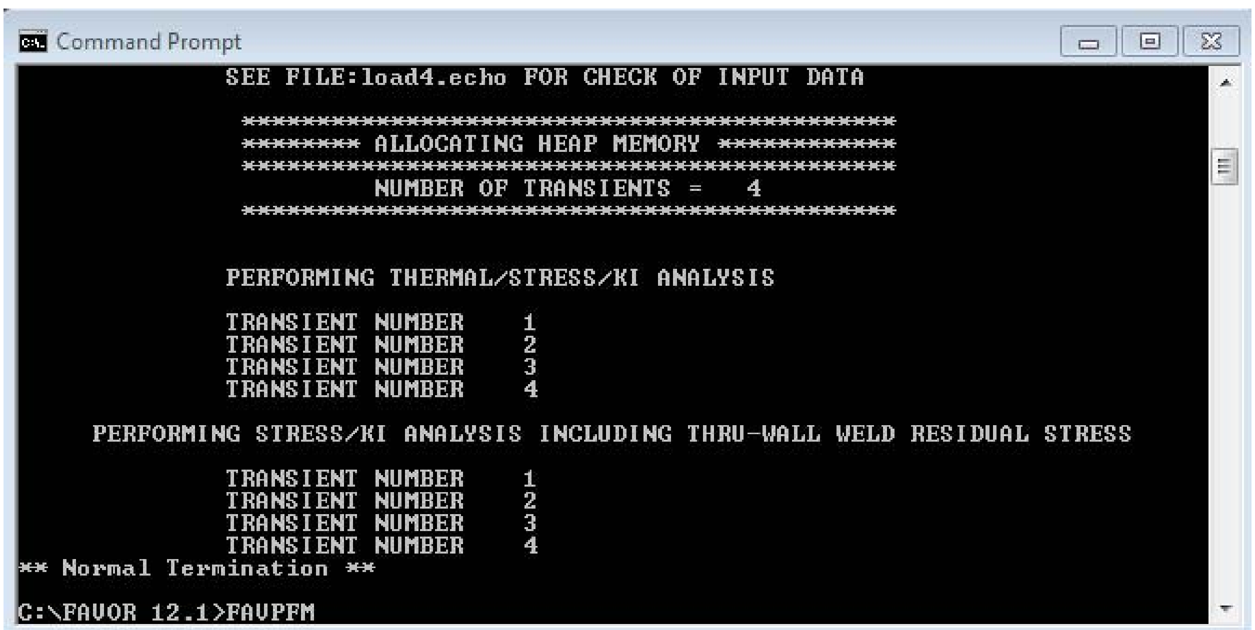


Fig. 13. Type FAVPFM at the Command Prompt to begin execution of the FAVPFM module.

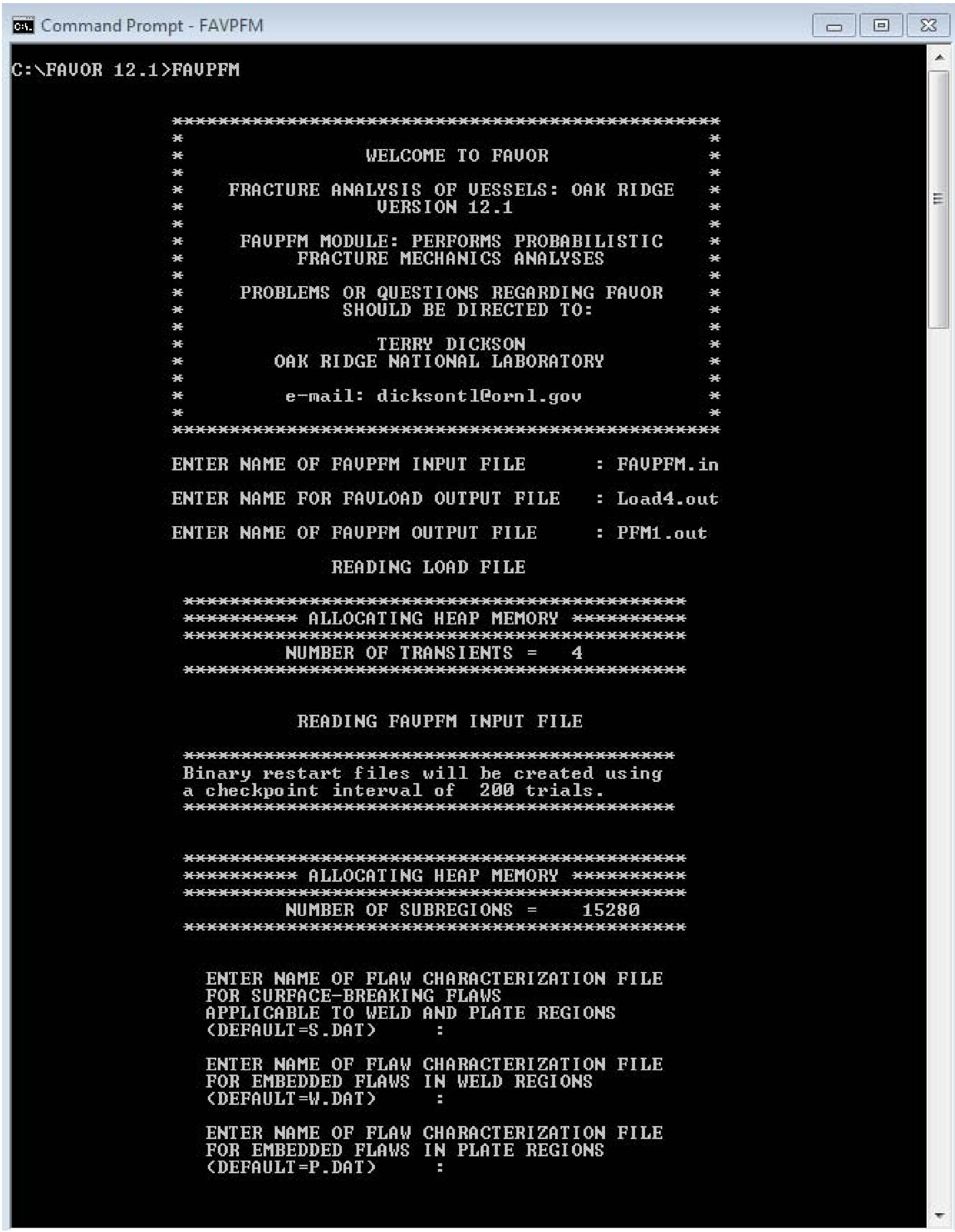


Fig. 14. (a) FAVPFM prompts for the names of the (1) FAVPFM input file, (2) FAVLoad-generated load-definition file, (3) FAVPFM output file, (4) flaw-characterization file for surface-breaking flaws in welds and plates, (5) flaw-characterization file for embedded flaws in welds, and (6) flaw-characterization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

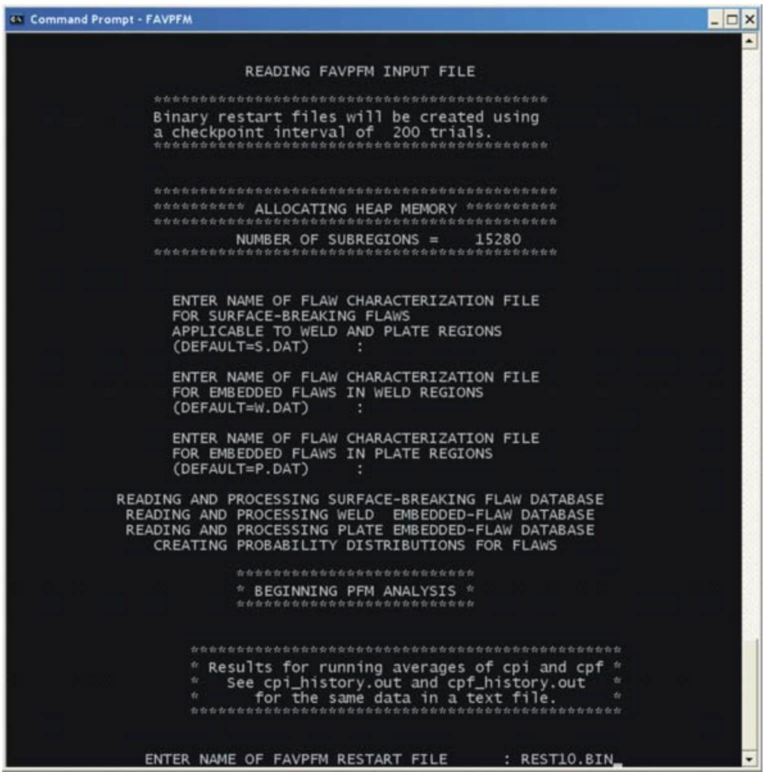
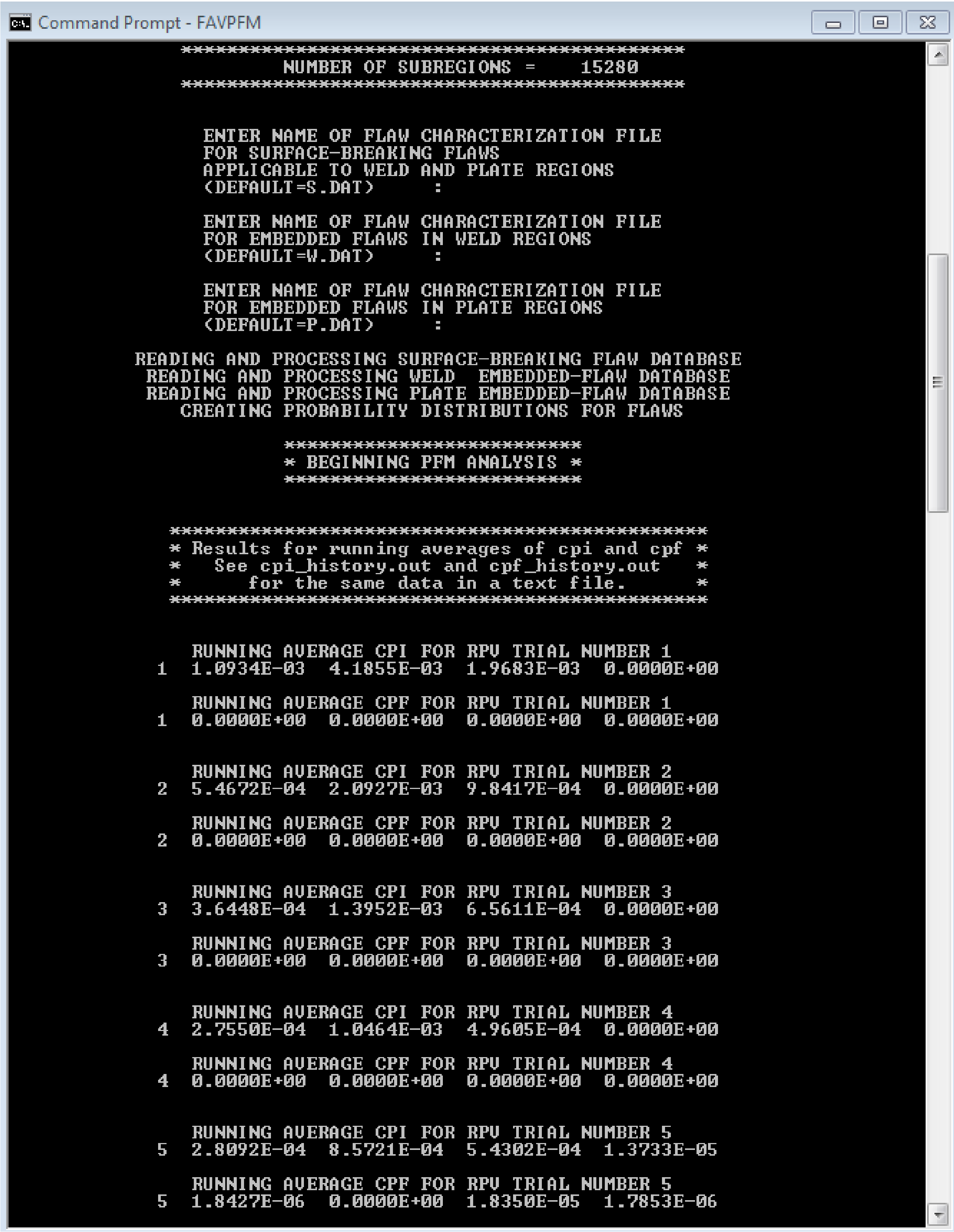


Fig. 14. (b) For a restart case, FAVPFM will also prompt for the binary restart file created in a previous execution (see Record 1 – CNT 1 for details regarding restart cases).



```
Command Prompt - FAVPFM
          ********************************************
                   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 typing the RETURN/ENTER key.

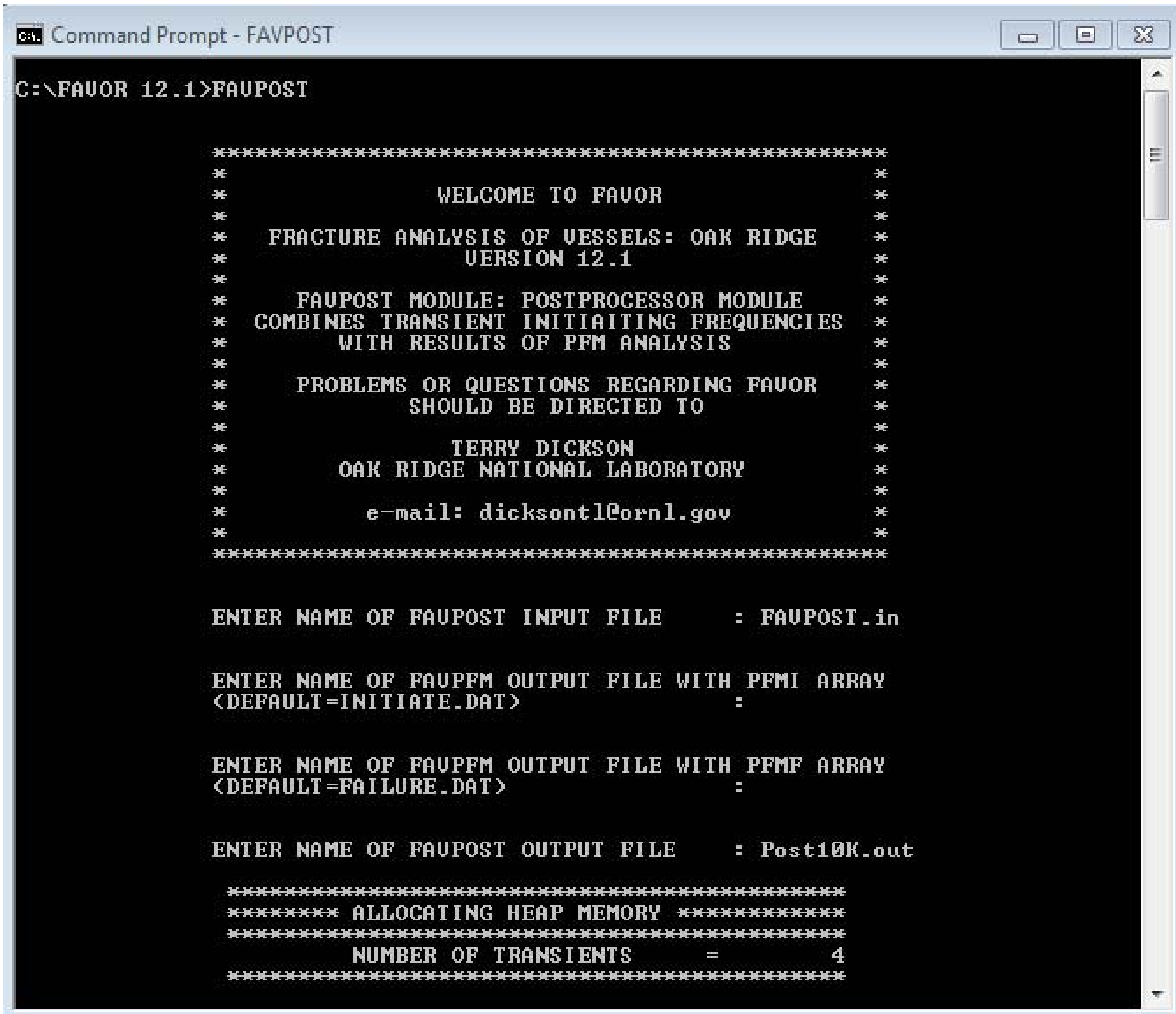


Fig. 16(a). Type in FAVPost at the Command Prompt to execute the FAVPost module. FAVPost prompts for the (1) FAVPost input file, (2) CPI matrix file generated by FAVPFM, (3) CPF matrix file generated by FAVPFM, and (4) the FAVPost output file.

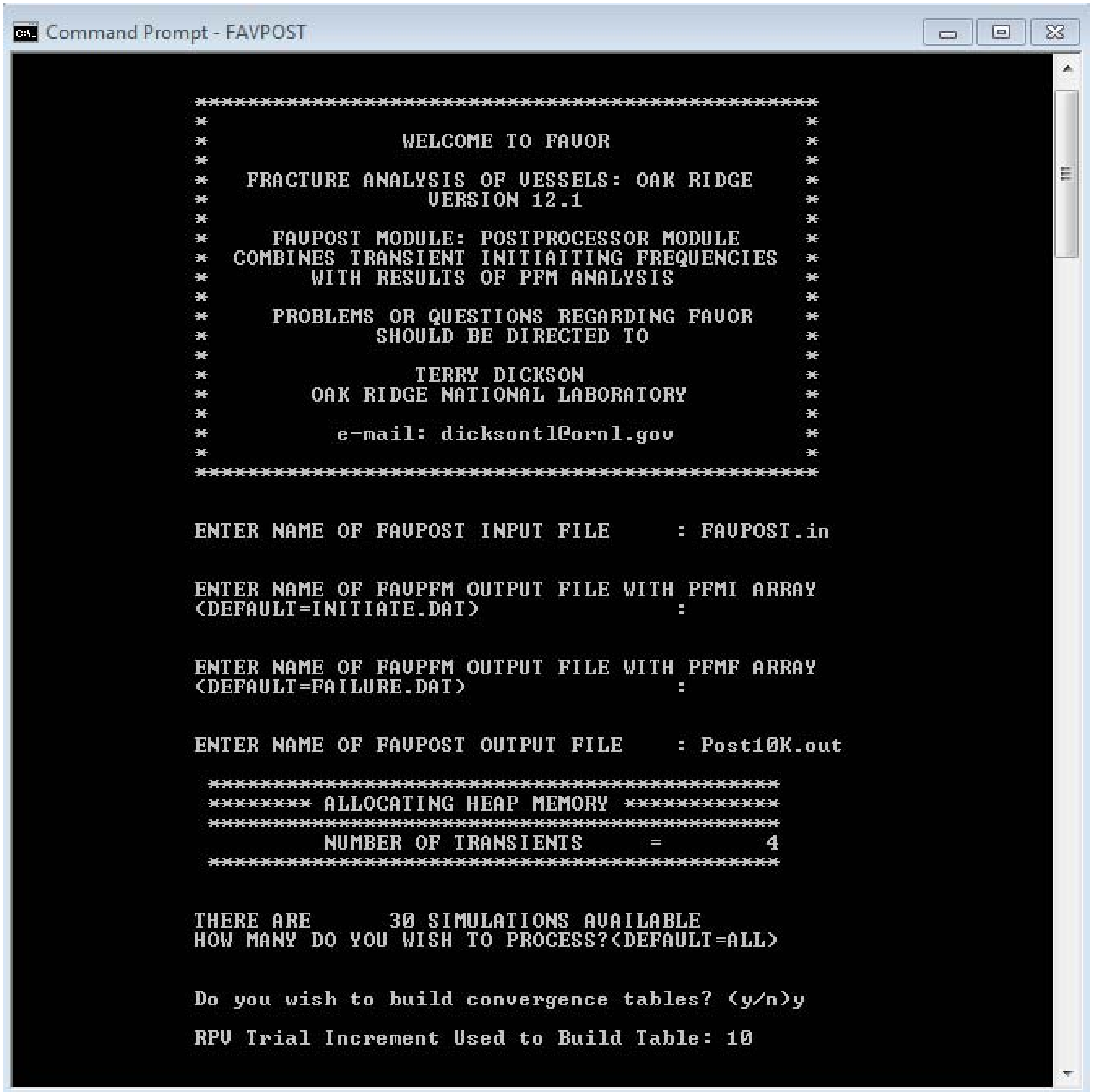
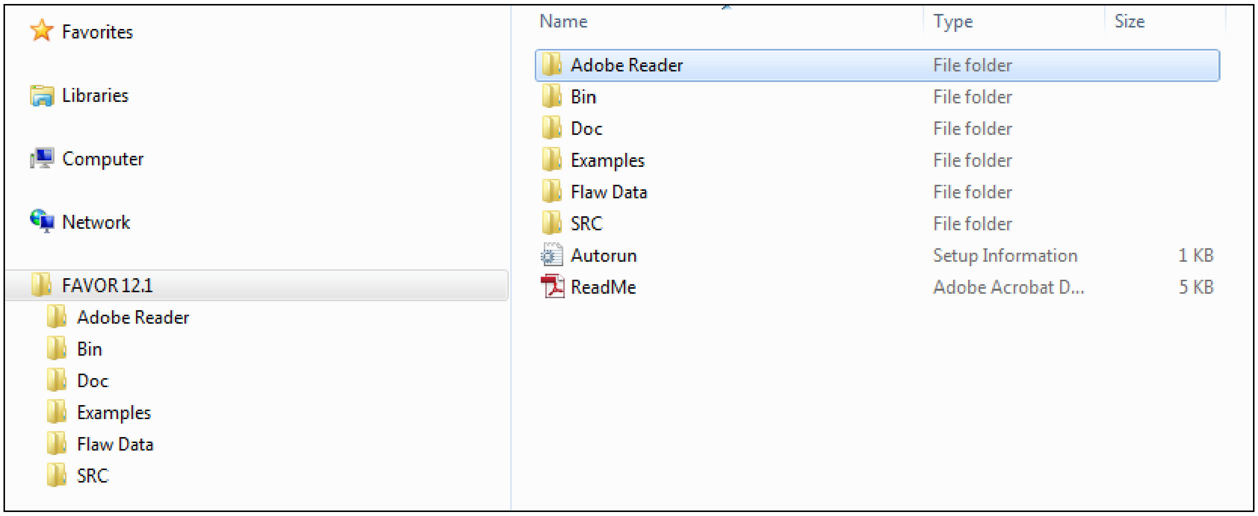


Fig. 16(b) Set the total number of simulations to be processed and build convergence tables, if required.

1.6 Distribution CD – What's on the CD

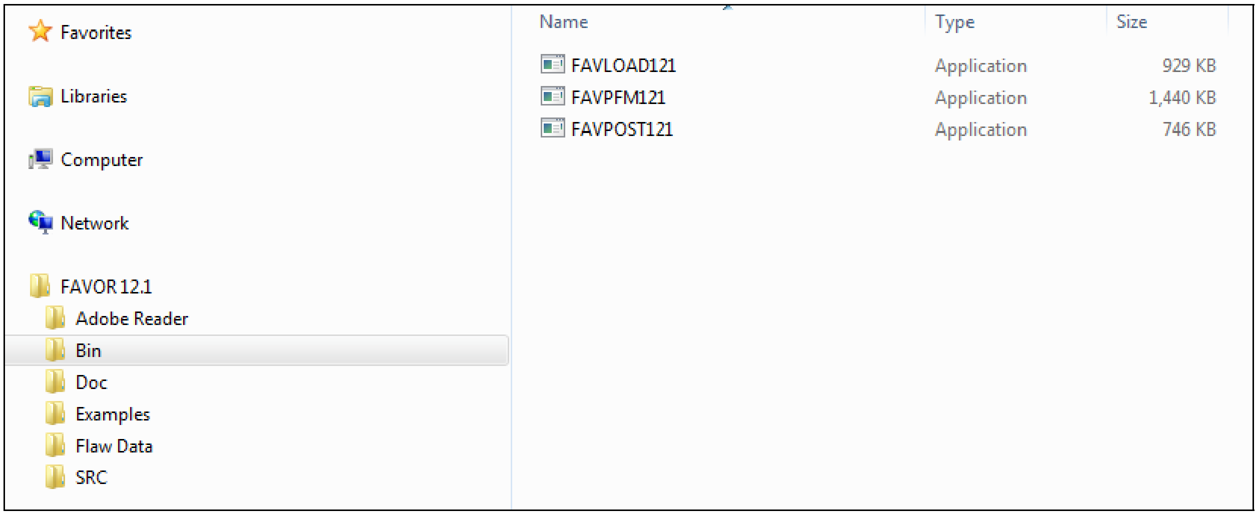
The distribution CD contains the following folders and files:

Main Folder: .\FAVOR12.1



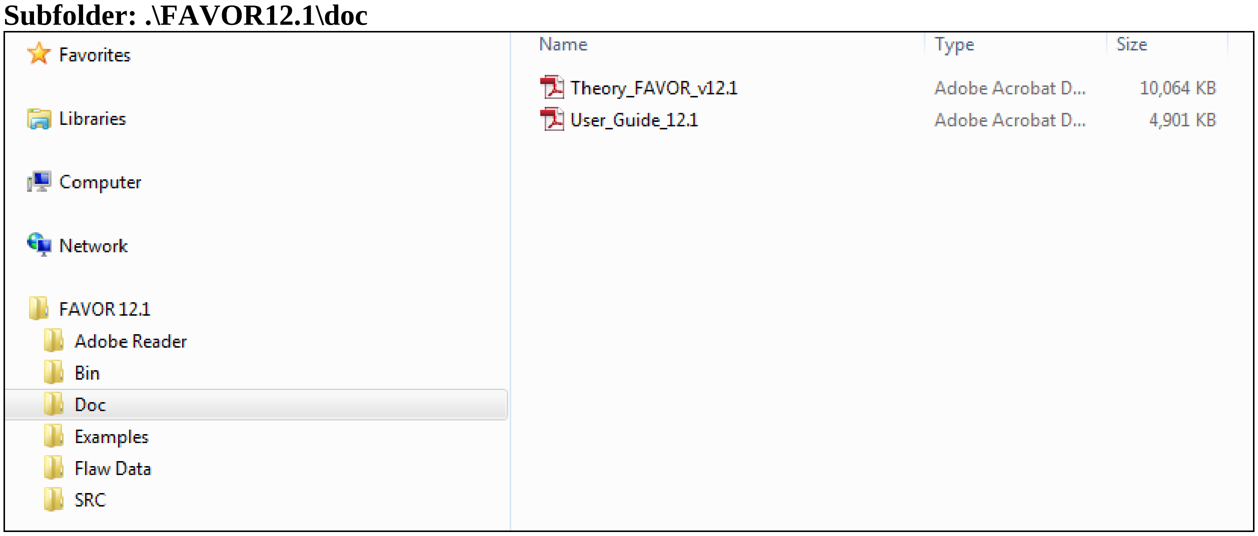
The main folder .\FAVOR12.1 contains seven subfolders. After installation, the FAVOR, 12.1, documentation may be viewed by double-clicking on the individual ".pdf" files if the free Adobe Reader is available on the user's computer.

Subfolder: .\FAVOR12.1\bin



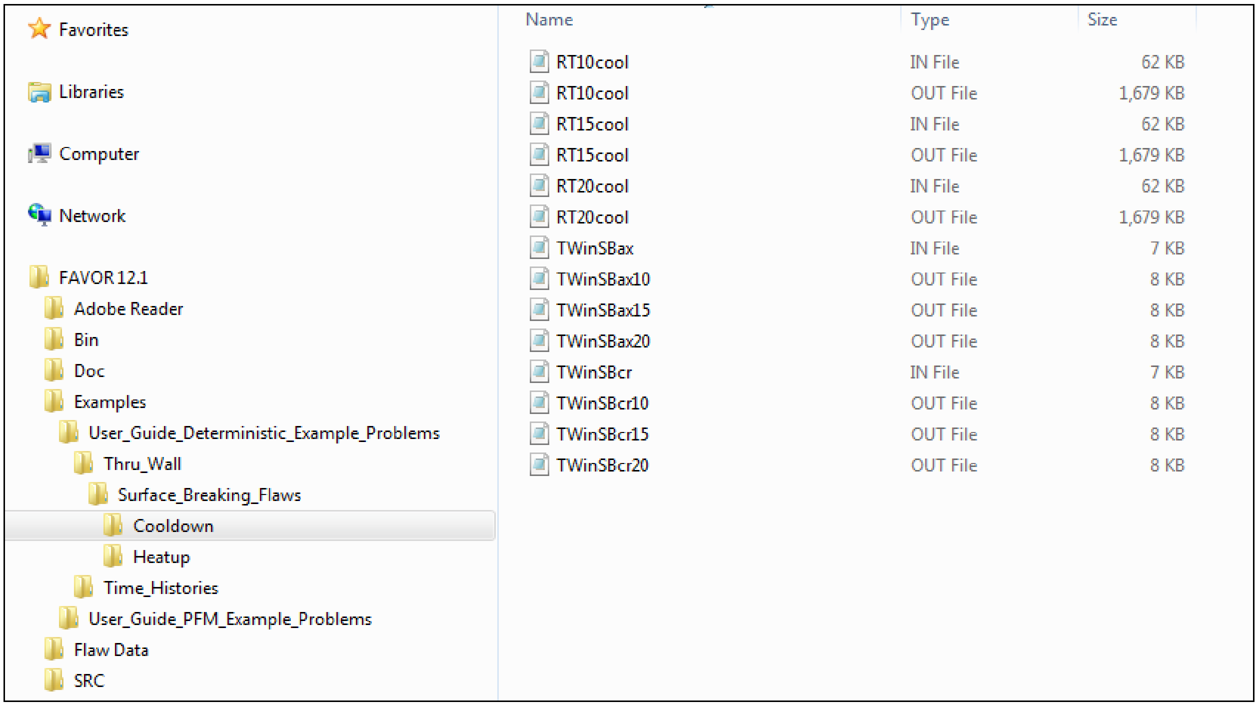
.\FAVOR12.1\bin contains the executables for a PC running under the Microsoft Windows operating system.

Subfolder: .\FAVOR12.1\doc

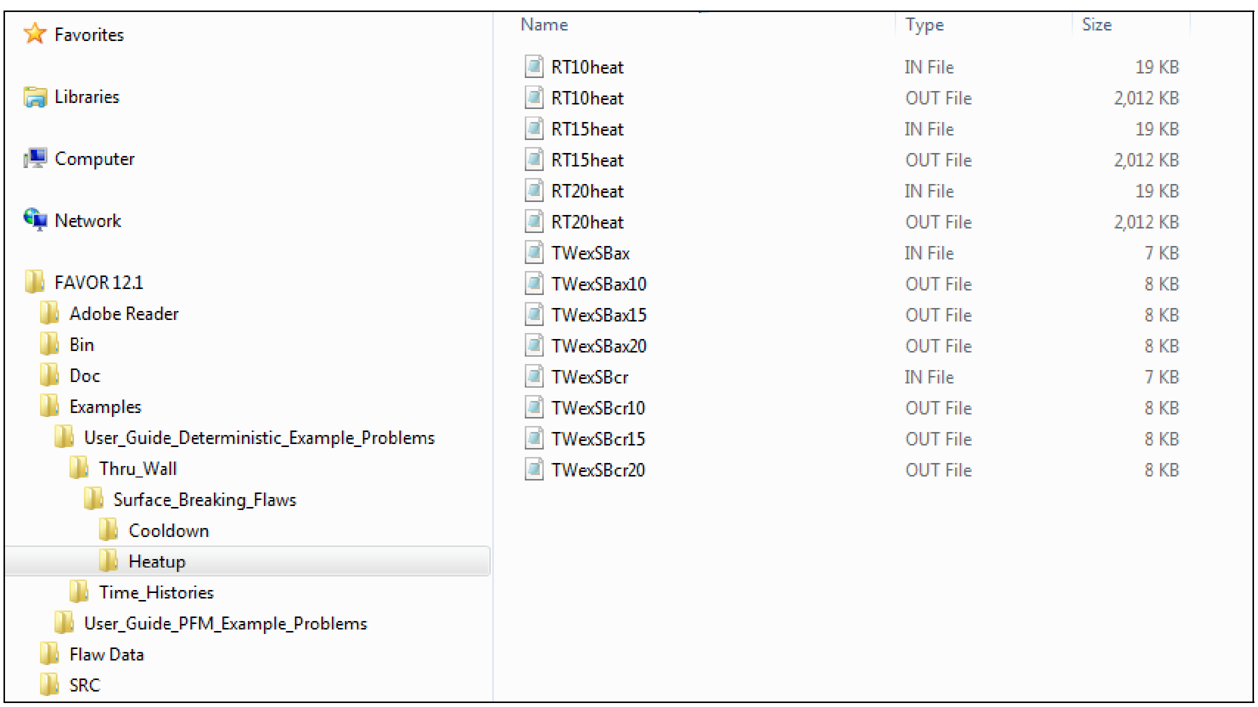


.\FAVOR12.1\doc contains the Theory and User's Guide in Adobe Acrobat PDF format.

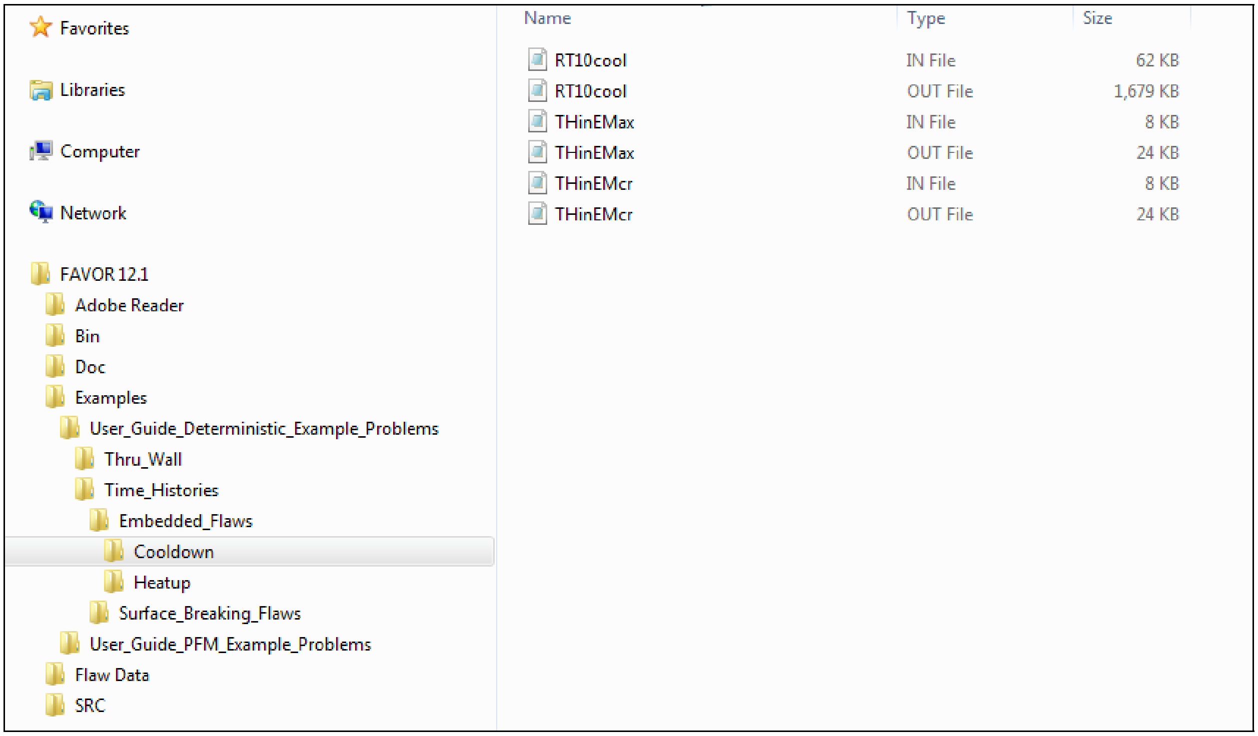
Subfolder: .\FAVOR12.1\Examples\User_Guide_Deterministic_Example_Problems\Thru_Wall\Surface Breaking_Flaws\Cooldown



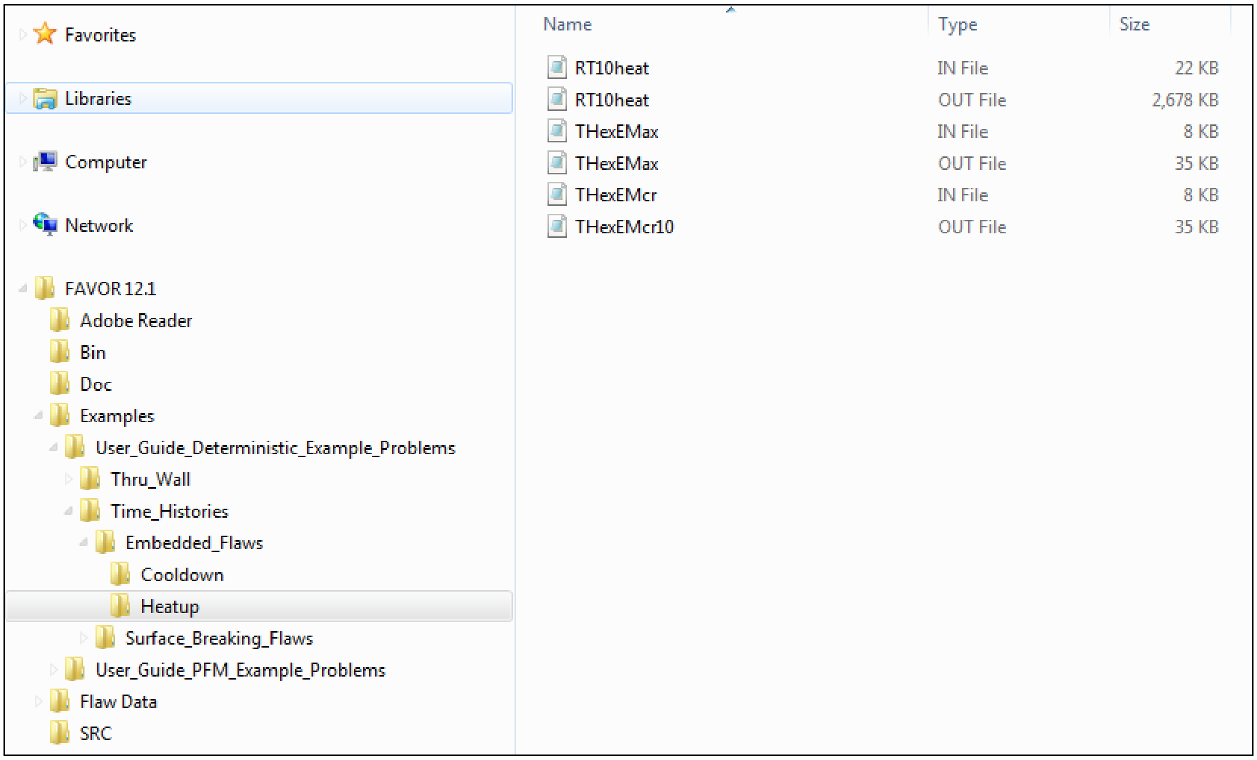
Subfolder: .\FAVOR12.1\Examples\User_Guide_Deterministic_Example_Problems\Thru_Wall\Surface Breaking_Flaws\Heatup



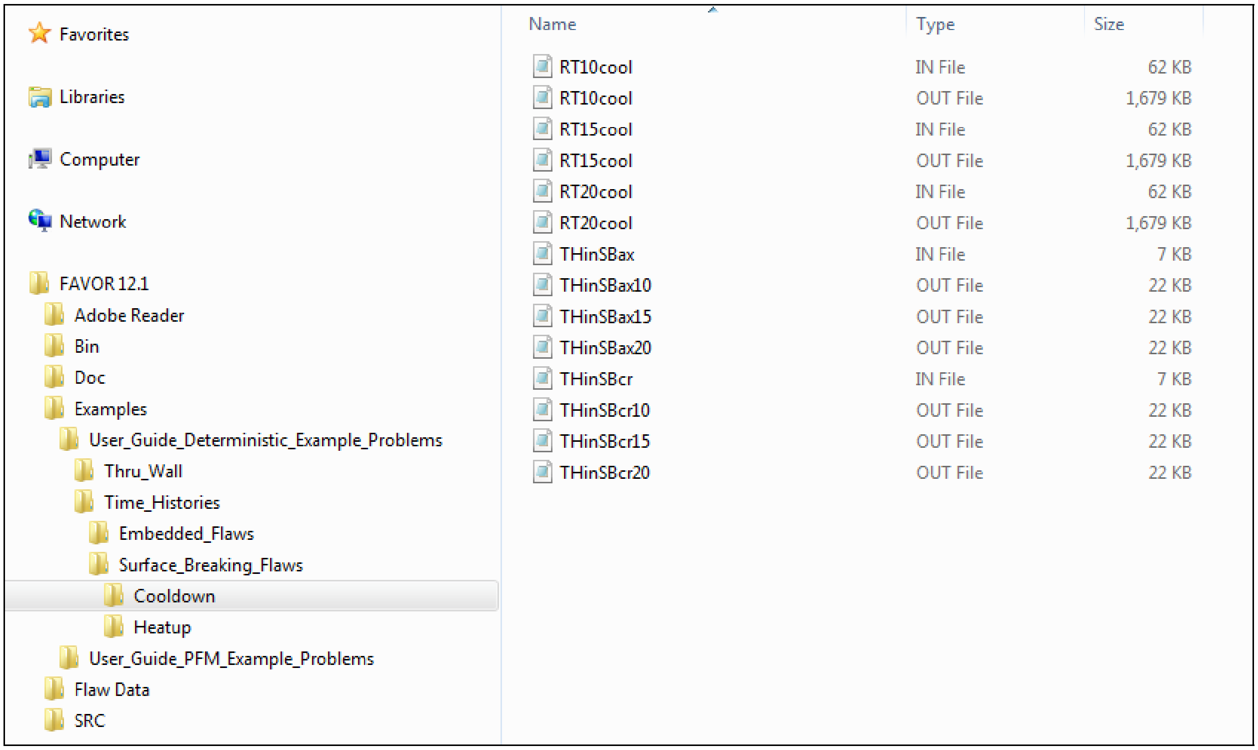
Subfolder: .\FAVOR12.1\Examples\User_Guide_Deterministic_Example_Problems\Time_histories\Embedded Flaws\Cooldown



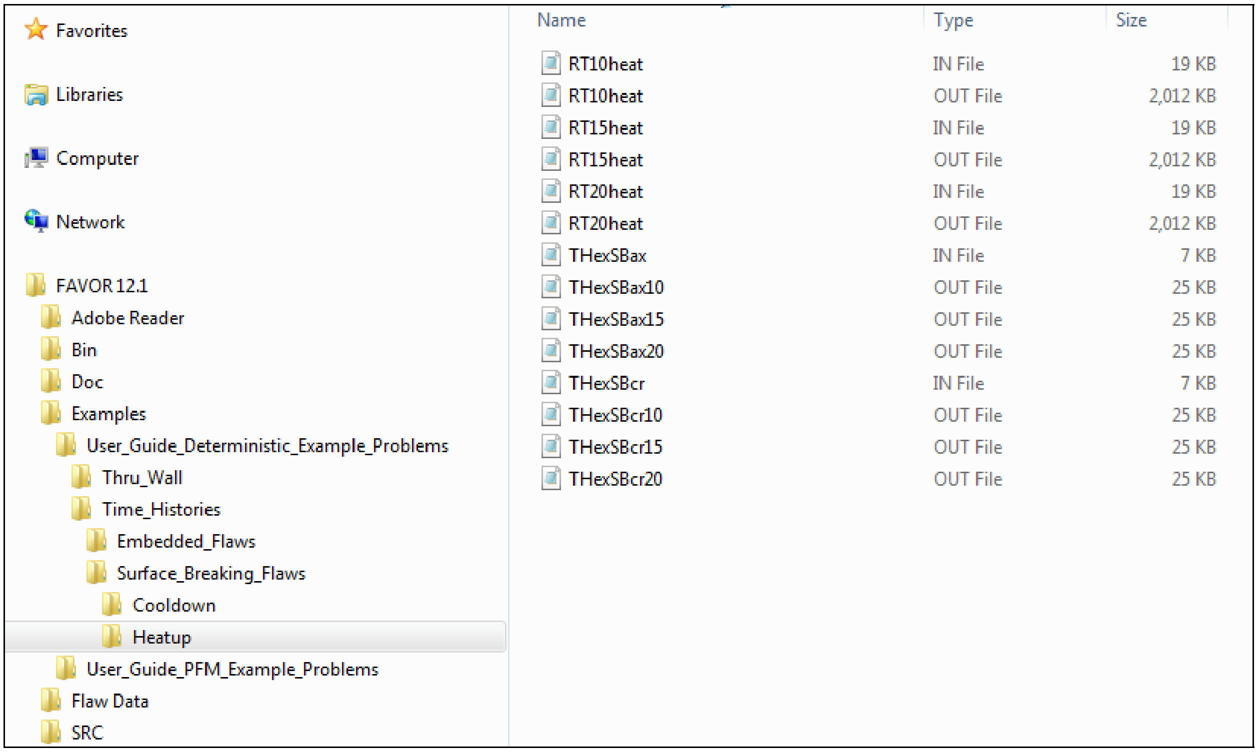
Subfolder:
.\FAVOR12.1\Examples\User_Guide_Deterministic_Example_Problems\Time_histories\Embedded Flaws\Heatup



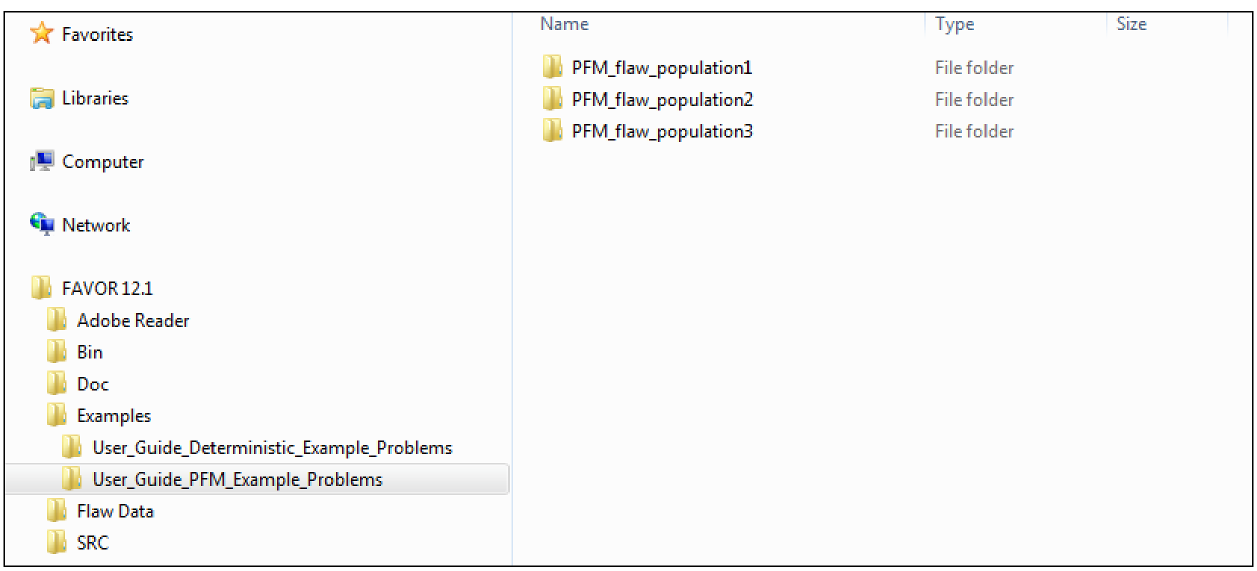
Subfolder: .\FAVOR12.1\Examples\User_Guide_Deterministic_Example_Problems\Time_histories\Surface_Breaking_Flaws\Cooldown



Subfolder: .\FAVOR12.1\Examples\User_Guide_Deterministic_Example_Problems\Time_histories\Surface_Breaking_Flaws\Heatup

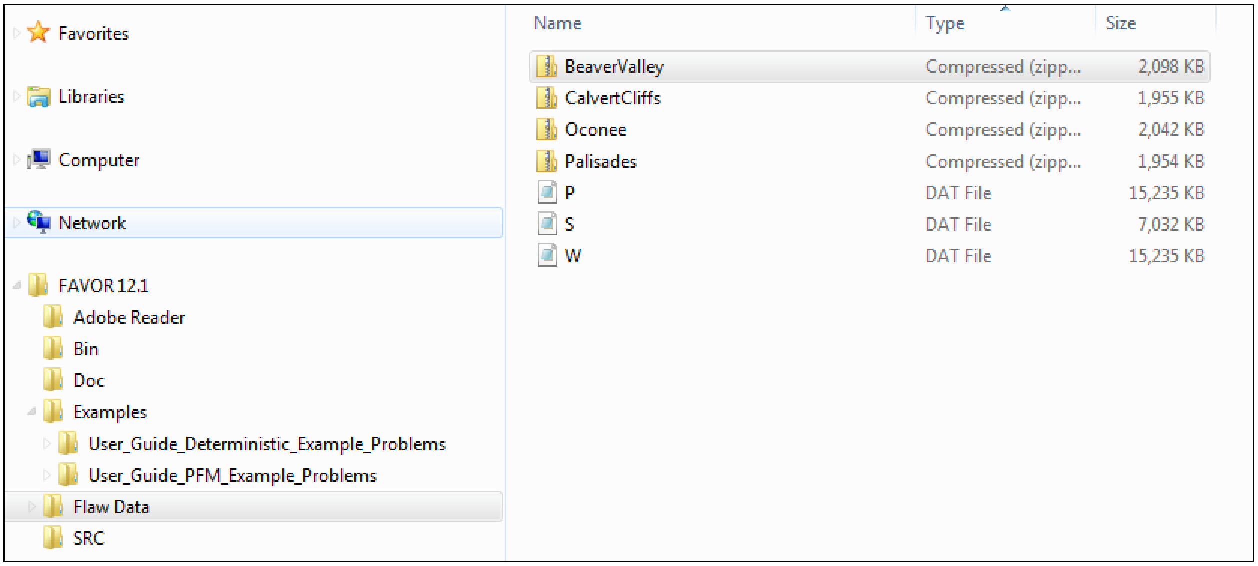


Subfolder: .\FAVOR12.1\Examples\User_Guide_PFM_Example_Problems



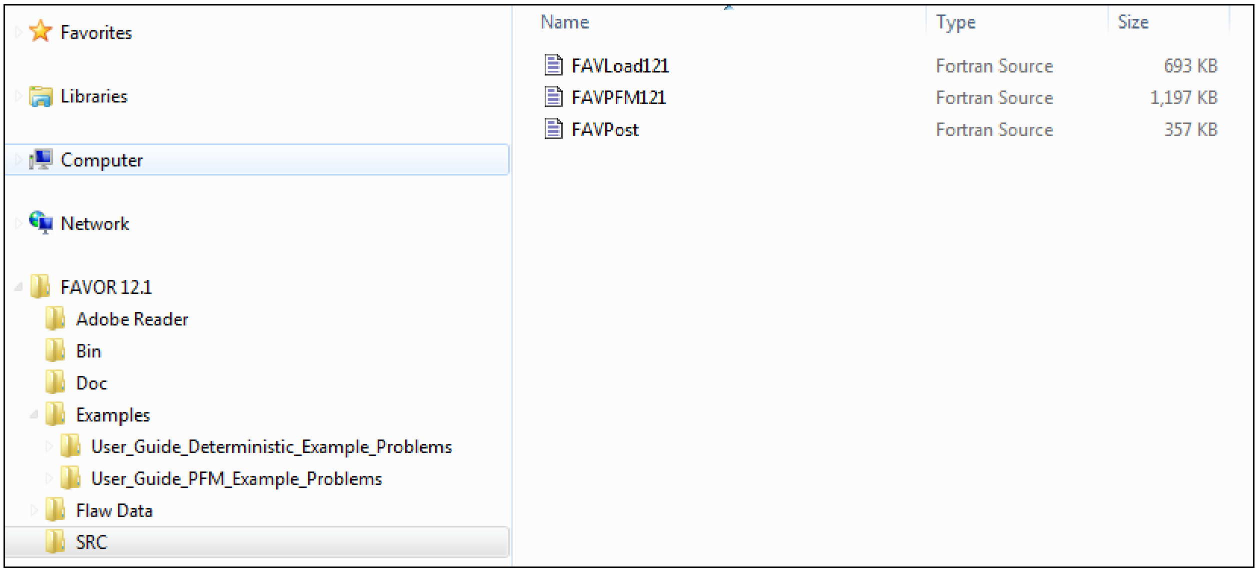
These are the deterministic and PFM input and output files for the example case discussed in Chapter 3 of this User's Guide.

Subfolder: FAVOR12.1\Flaw Data



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: FAVOR12.1\SRC



The Fortran source code for the three FAVOR modules is included in this subfolder.

2. FAVOR Input Requirements

FAVOR employs ASCII 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 on the distribution CD) 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-dependant 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 is 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 $f_i \le f_{i+1} \left(i = 1,2,\cdots,n-1 \right)$ or $f_i \ge f_{i+1} \left(i = 1,2,\cdots,n-1 \right)$. 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

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

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

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

where the *G*-function is defined by

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

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:

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

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, *t*, 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, $h(t)$, is used in imposing a Robin forced-convection boundary condition at the inner vessel wall, R_i, defined by,

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

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

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

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.

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., $100 \le \textbf{IGATR} \le 1000$.), 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 > alpha*K_{Imax} where alpha = 1 **;**

WPS_OPTION = 2 exit WPS and be available for initiation when dK/dt > 0 and K_I > 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 > alpha*K_{Imax} where alpha is sampled from a log-logisitic 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

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

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 has been included in this version of 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 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 12.1 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 EricksonKirk 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 v12.1 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, $\widehat{f(0)}$ [1], is sampled from two normal distributions such that

$$\sigma_{global} = SIGFGL \times fluence_{subregion}$$
$$\overset{\frown}{\overline{f}} \leftarrow N(fluence_{subregion}, \sigma_{global})$$
$$\widehat{\sigma_{local}} = SIGFLC \times \overset{\frown}{\overline{f}}$$
$$\widehat{f(0)} \leftarrow N(\overset{\frown}{\overline{f}}, \widehat{\sigma_{local}})$$

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., $\widehat{f} \leftarrow N(\mu, \sigma)$ 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:

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

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 Quality Assurance (QA) 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 QA 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 A)

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

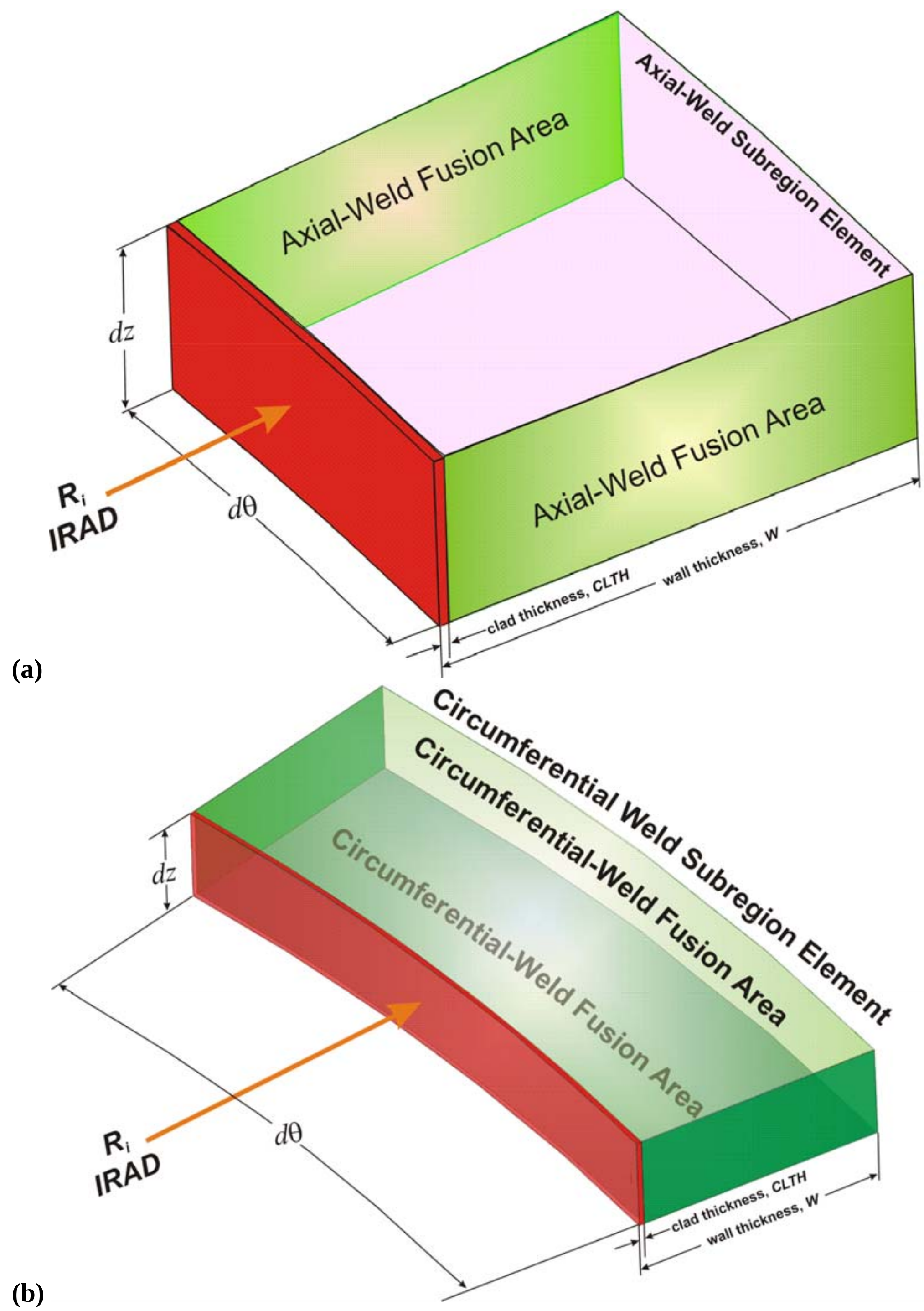


Fig. 17. Weld fusion area definitions for (a) axial-weld subregion elements and (b) circumferential-weld subregion elements.

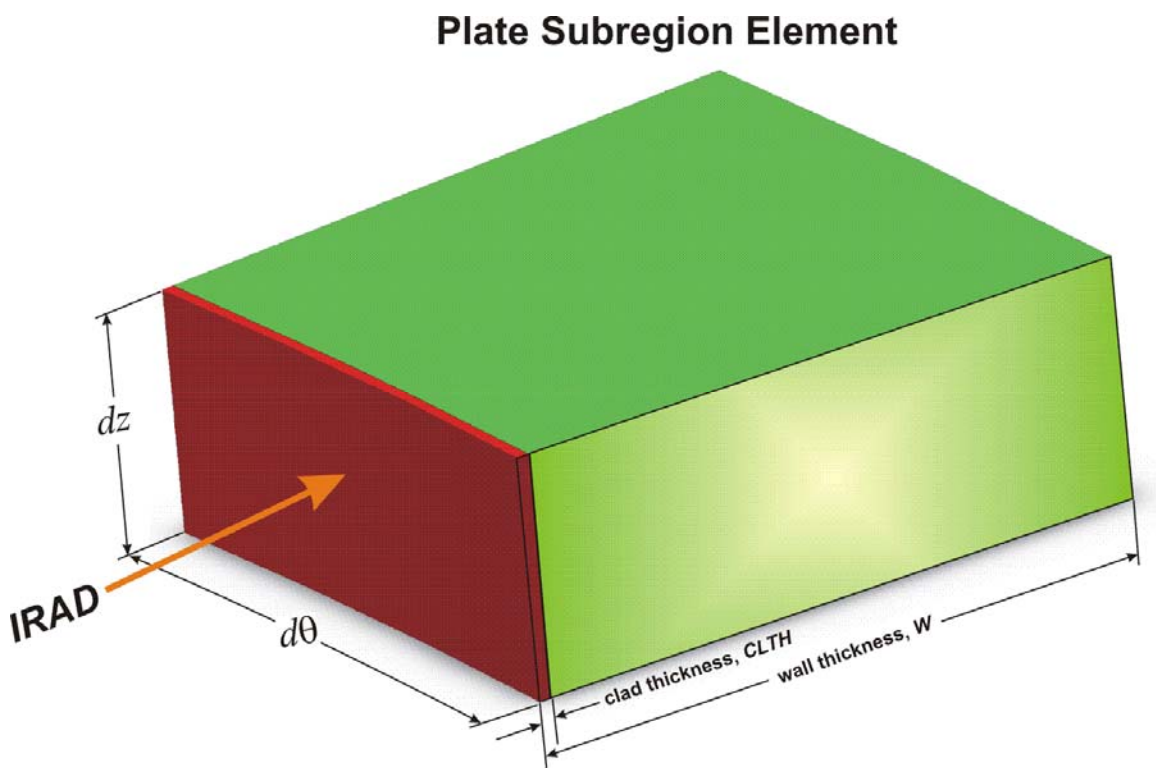


Fig. 17. (continued) (c) Plate subregion element.

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, v12.1              [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 on the distribution CD 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 CD 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. 41) then
         call xermsg ('FAVPFM','RDSURF',
     &      'SURFACE-BREAKING FLAW FILE NOT VERSION 12.1',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. 41) then
         call xermsg ('FAVPFM','RDWELD',
     &      'EMBEDDED-FLAW WELD FILE NOT VERSION 12.1',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. 41) then
         call xermsg ('FAVPFM','RDPLAT',
     &      'EMBEDDED-FLAW PLATE FILE NOT VERSION 12.1',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 $\Rightarrow$ FAVLoad.echo.

FAVLOAD.echo

```
                ************************************************
                *                                              *
                *               WELCOME TO FAVOR               *
                *                                              *
                *    FRACTURE ANALYSIS OF VESSELS: OAK RIDGE   *
                *                 VERSION 12.1                 *
                *                                              *
                *        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          *
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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.                                 *
           *                                                         *
           ***********************************************************


                DATE: 15-Nov-2012  TIME: 15:34:45

 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
********************************************************************************
*
```

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 12.1                   *
                *                                               *
                *     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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           * employees, makes any warranty, expressed or implied, or *
           * assumes any legal liability or responsibility for the   *
           * accuracy, completeness, or usefulness of any            *
           * information, apparatus, product, or process disclosed,  *
           * or represents that its use would not infringe           *
           * privately-owned rights.                                 *
           *                                                         *
           ***********************************************************


                DATE: 15-Nov-2012  TIME: 15:35:14


                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


                 Begin echo of FAVPFM input data deck         15:35:14   15-Nov-2012

 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, v12.1 - 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 conditonal probability of initiation but not the         *
    31     *                     conditonal 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     *---------------------------------------------------------------------------------------------------------*
```

FAVPFM.out

```
               ************************************************
               *                                              *
               *               WELCOME TO FAVOR               *
               *                                              *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
               *                VERSION 12.1                  *
               *                                              *
               *     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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          * employees, makes any warranty, expressed or implied, or *
          * assumes any legal liability or responsibility for the   *
          * accuracy, completeness, or usefulness of any            *
          * information, apparatus, product, or process disclosed,  *
          * or represents that its use would not infringe           *
          * privately-owned rights.                                 *
          *                                                         *
          ************************************************************


               DATE: 15-Nov-2012  TIME: 15:35:14


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


       *****************************************************************************
       * 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         *
                               *************************************
```

MAJOR REGION	RTndt (MAX)	% OF FLAWS	SIMULATED FLAWS	Initiation: # of FLAWS CPI > 0	Initiation: % of CPI	Cleavage: # of FLAWS CPF > 0	Cleavage: % of CPF	Ductile: # of FLAWS CPF > 0	Ductile: % of 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          *
                               *************************************
```

MAJOR REGION	RTndt (MAX)	% OF FLAWS	SIMULATED FLAWS	Initiation: # of FLAWS CPI > 0	Initiation: % of CPI	Cleavage: # of FLAWS CPF > 0	Cleavage: % of CPF	Ductile: # of FLAWS CPF > 0	Ductile: % of 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         *
*************************************
```

MAJOR REGION	RTndt (MAX)	% OF FLAWS	SIMULATED FLAWS	|---Initiation---| # of FLAWS CPI > 0	% of CPI	|----Cleavage----| # of FLAWS CPF > 0	% of CPF	|------Ductile-----| # of FLAWS CPF > 0	% of 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          *
*************************************
```

MAJOR REGION	RTndt (MAX)	% OF FLAWS	SIMULATED FLAWS	|---Initiation---| # of FLAWS CPI > 0	% of CPI	|----Cleavage----| # of FLAWS CPF > 0	% of CPF	|------Ductile-----| # of FLAWS CPF > 0	% of 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 simulated flaws	number with CPI>0	% of total CPI	number with CPF>0	% of total 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 simulated flaws	number with CPI>0	% of total CPI	number with CPF>0	% of total 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 simulated flaws	number with CPI>0	% of total CPI	number with CPF>0	% of total 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 simulated flaws	number with CPI>0	% of total CPI	number with CPF>0	% of total 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 depth (in)	simulated catgy 1 flaws	# with CPI>0	% of total CPI	simulated catgy 2 flaws	# with CPI>0	% of total CPI	simulated catgy 3 flaws	# with CPI>0	% of total 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

```
              ***********************************************
              *    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 STEP	TIME (min)	% of total CDCPI	CDF of total CDCPI	% of total CDCPF	CDF of total 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

```
   ***********************************************************
   *      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

             DATE: 15-Nov-2012  TIME: 15:37:49
```

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 $(x_1,\ldots,x_n)$ from an unknown population *assumed to have a probability density* $f(x)$. These sampled observations can be ordered by rank such that

$$
\begin{aligned}
x_{(1)} &= \text{smallest of } (x_1,\ldots,x_n), \\
x_{(2)} &= \text{second smallest of } (x_1,\ldots,x_n), \\
&\vdots \\
x_{(k)} &= \text{k-th smallest of } (x_1,\ldots,x_n), \\
&\vdots \\
x_{(n)} &= \text{largest of } (x_1,\ldots,x_n).
\end{aligned}
$$

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

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

The estimator applied in FAVPost for $F(x)$ is the Kaplan-Meier estimate [28] $\hat{F}(x_{(i)}) = i/n$. [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 $\hat{F}(x_{(i)}) = i/n$ 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 $\hat{F}(x_{(n)}) = n/n = 1$**.** The following procedure is applied in FAVPost (see Fig. 18).

---

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

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

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

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

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

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

where I satisfies the relation

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

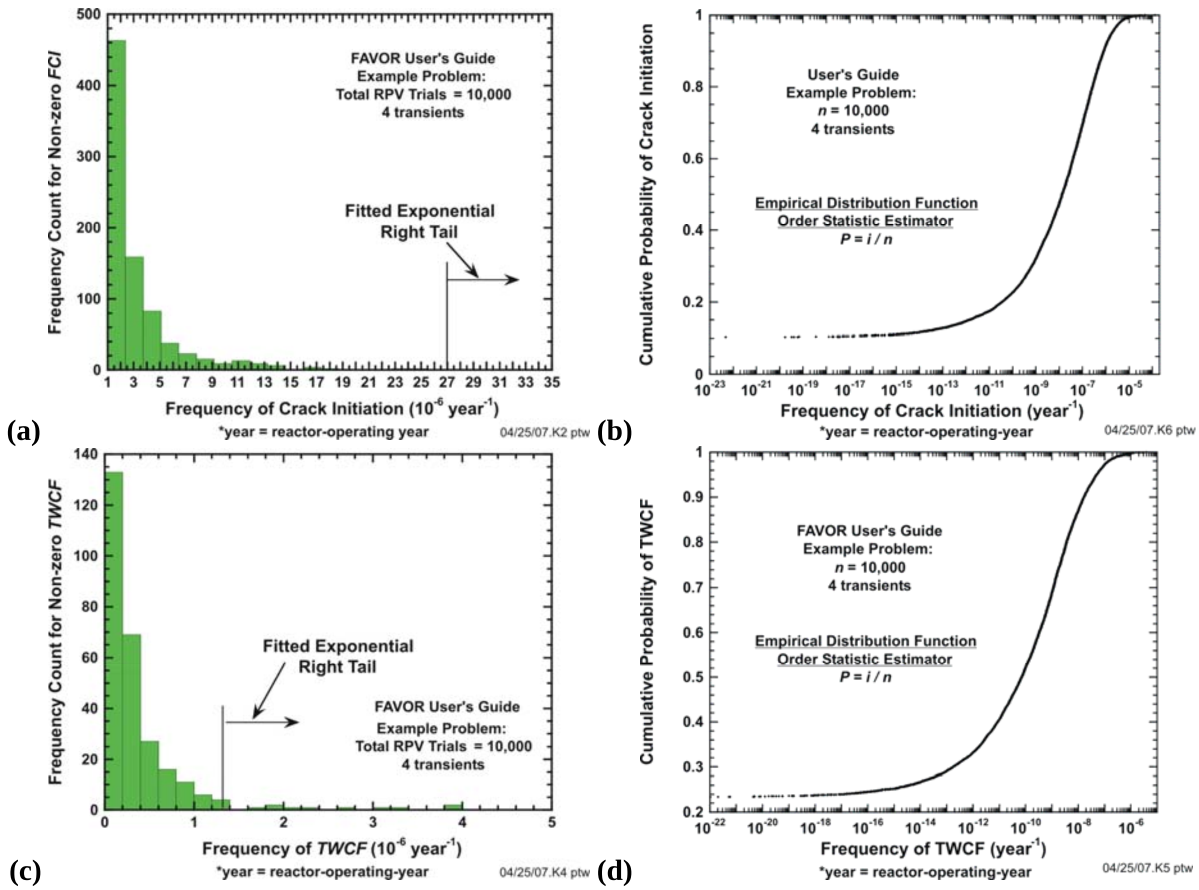
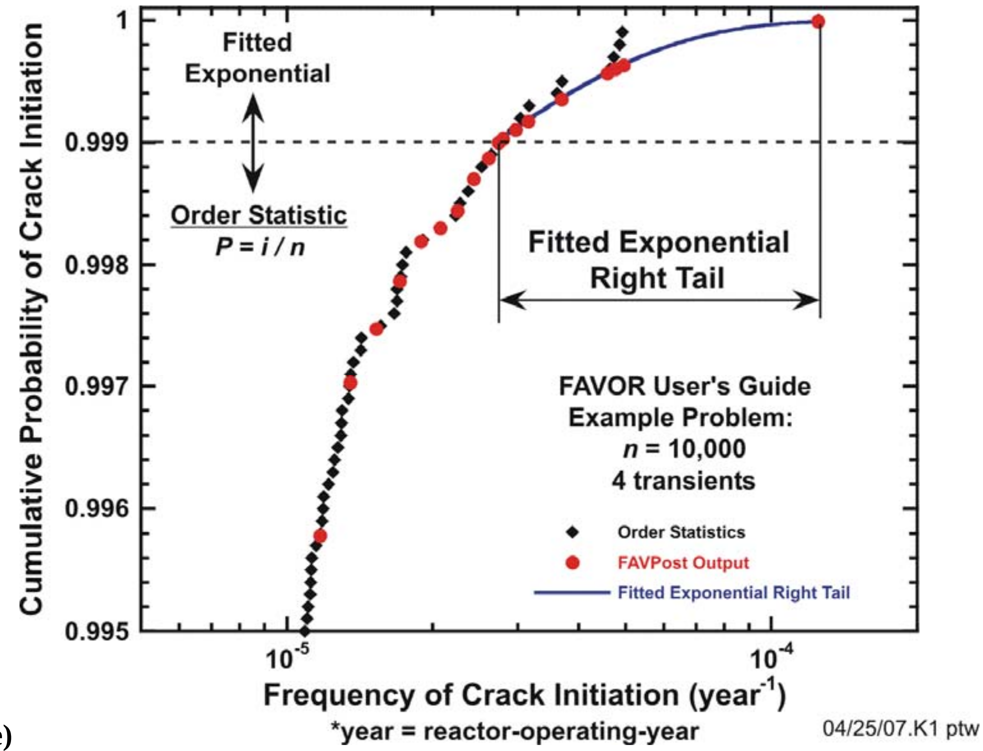
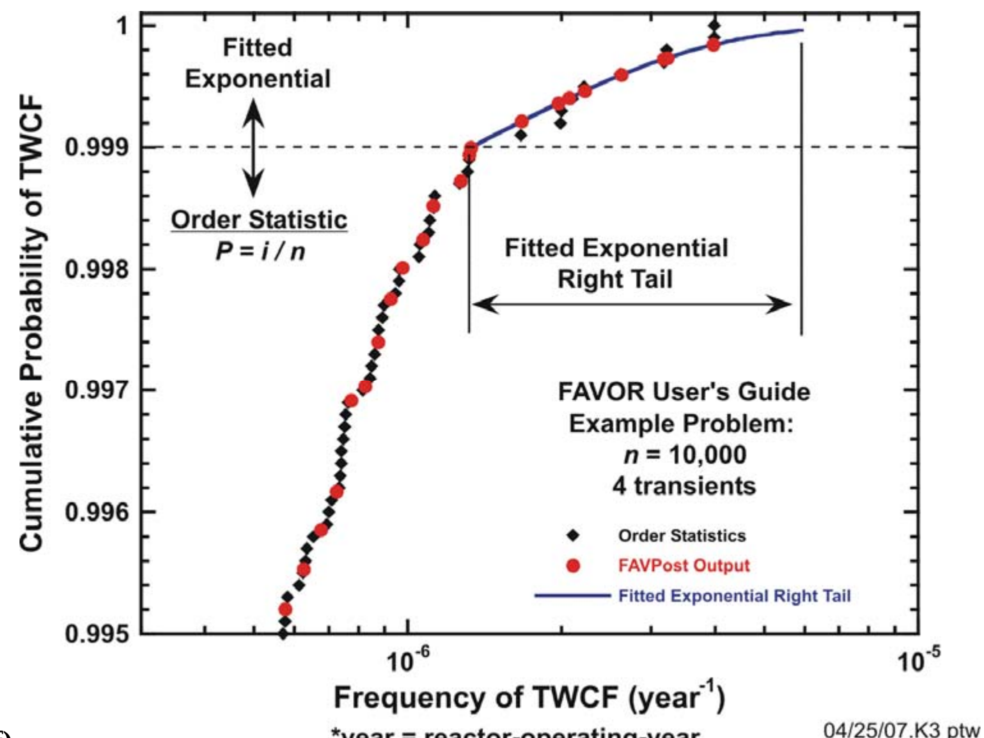


Fig. 18. Empirical distribution functions for *n* = 10,000 example problem: (a) histogram and (b) semi-log plot of empirical c.d.f. for frequency of crack initiation, (c) histogram and (d) semi-log plot empirical c.d.f. for through-wall cracking frequency.



(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) = $\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n}$

unbiased variance $s^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}$

biased variance = $\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n}$

standard deviation, $s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}}$

standard error = $\sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n(n-1)}}$

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

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

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

FAVPOST.OUT

```
          ************************************************
          *                                              *
          *               WELCOME TO FAVOR               *
          *                                              *
          *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
          *                 VERSION 12.1                 *
          *                                              *
          *     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.                                 *
     ***********************************************************



          DATE: 19-Nov-2012  TIME: 11:15:40


           Begin echo of FAVPost input data deck          11:15:40   19-Nov-2012

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, v12.1                      *
    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
```

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   *
****

FLAW DEPTH (in)	% of total frequency of crack initiation CAT I flaws	CAT 2 flaws	CAT 3 flaws	% of total through-wall crack frequency CAT 1 flaws	CAT 2 flaws	CAT 3 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 *
****

FLAW DEPTH (in)	% of total frequency of crack initiation CAT I flaws	CAT 2 flaws	CAT 3 flaws	% of total through-wall crack frequency CAT 1 flaws	CAT 2 flaws	CAT 3 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 on the distribution CD to illustrate the various deterministic and probabilistic capabilities that are available with the 12.1 version of 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 on the distribution CD.

Table 5 provides a listing of FAVPFM deterministic input/output datasets that are included on the distribution CD 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 on the distribution CD 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 on the distribution CD 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. Complete input and output listings are included on the distribution CD as discussed above.

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 ~ 10	RT10cool.in	RT10cool.out
Cool-down	R_i/t ~ 15	RT15cool.in	RT15cool.out
Cool-down	R_i/t ~ 20	RT20cool.in	RT20cool.out
Heat-up	R_i/t ~ 10	RT10heat.in	RT10heat.out
Heat-up	R_i/t ~ 15	RT15heat.in	RT15heat.out
Heat-up	R_i/t ~ 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, v12.1                      *
********************************************************************************
*  ====================                                                        *
*     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, v12.1 - 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)

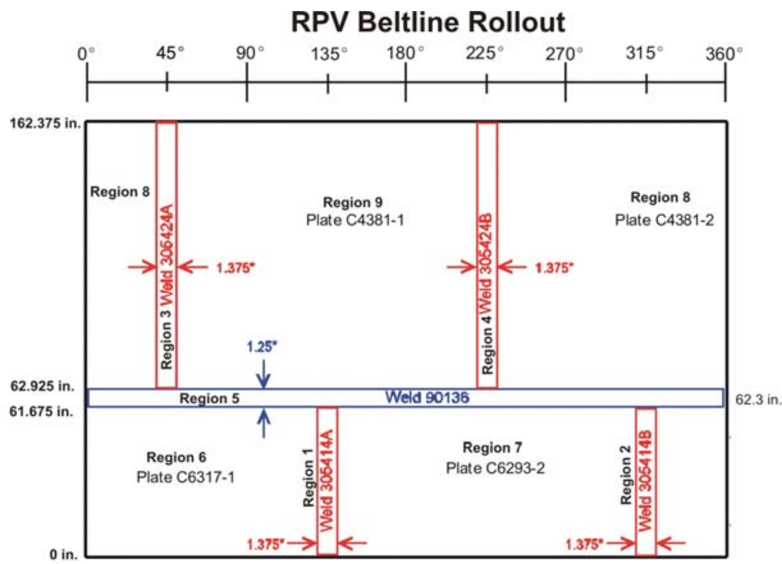
```
************************************************************************************************************
*                       PLATE/WELD EMBRITTLEMENT / FLAW DISTRIBUTION MAP RECORDS                          *
************************************************************************************************************
*==========================================================================================================*
*  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

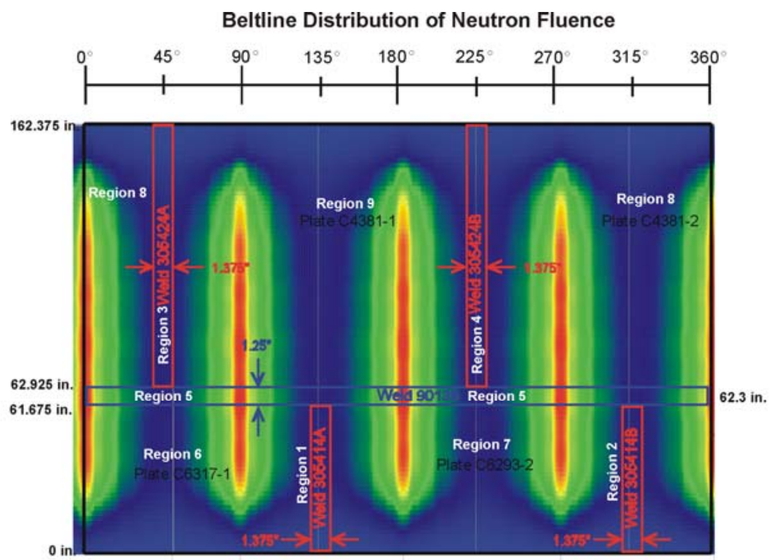
```
********************************************************************************
*      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY          *
********************************************************************************
*                 EXAMPLE INPUT DATASET FOR FAVPost, v09.1                     *
********************************************************************************
*  ====================                                                        *
*     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
```



(a)



(b)

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.

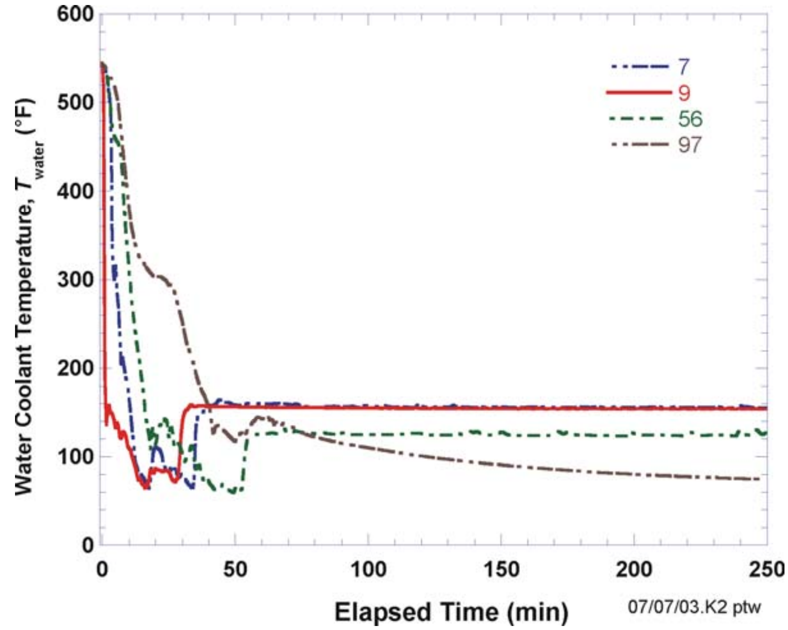


Fig. 20. Time histories of coolant temperature for four PTS transients.

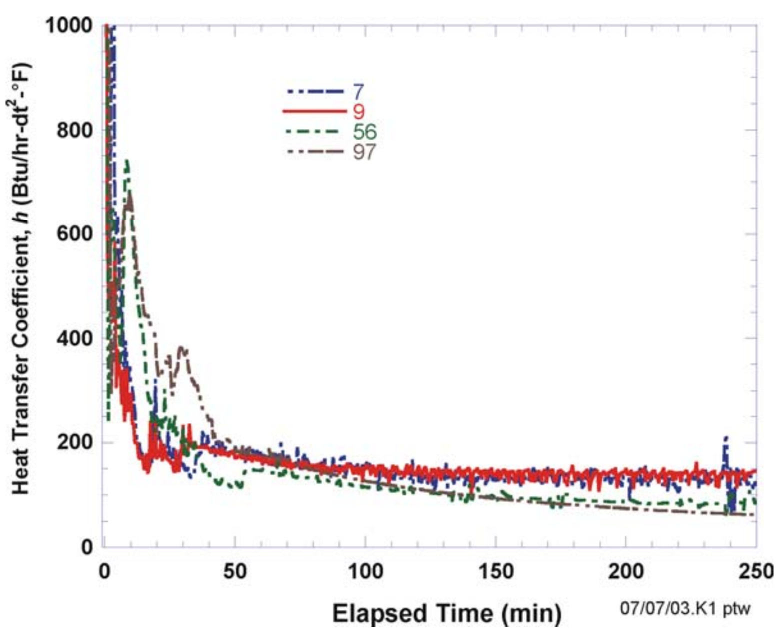


Fig. 21.Time histories of convection heat transfer coefficient four PTS transients.

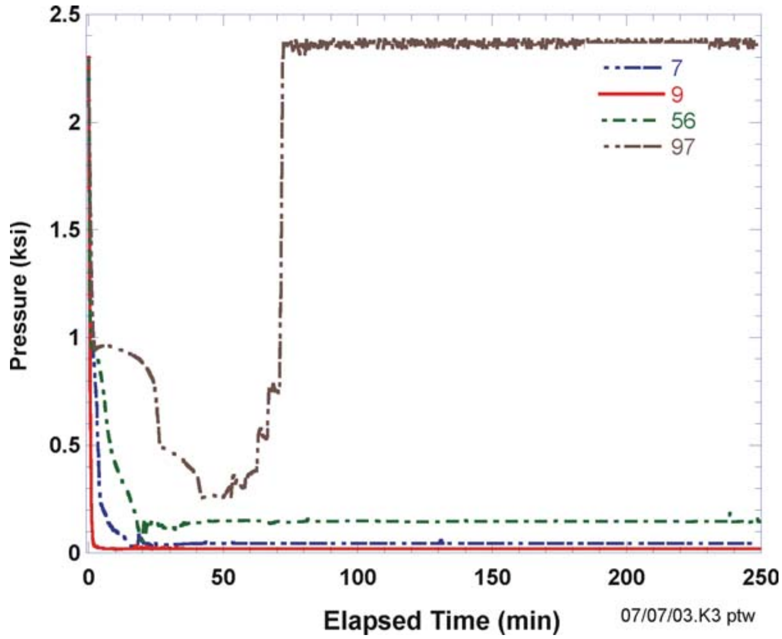


Fig. 22. Time histories for internal pressure for four PTS transients.

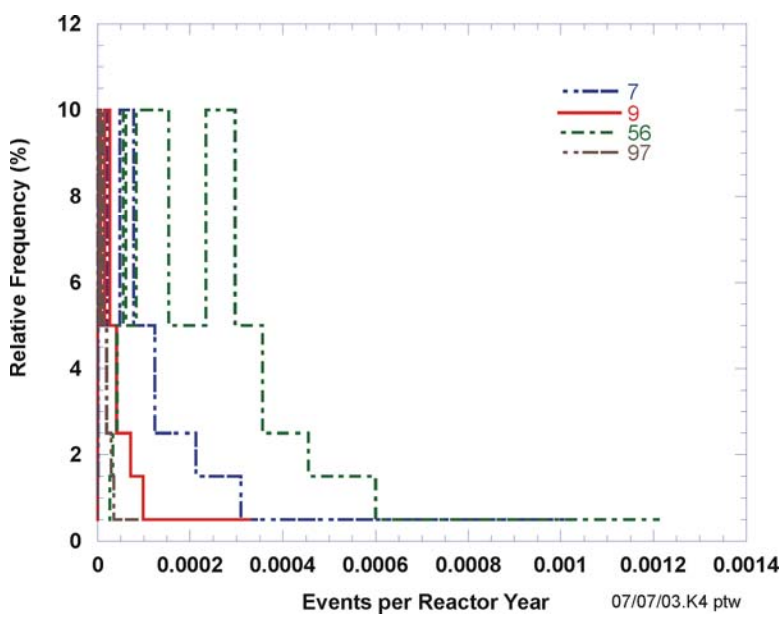
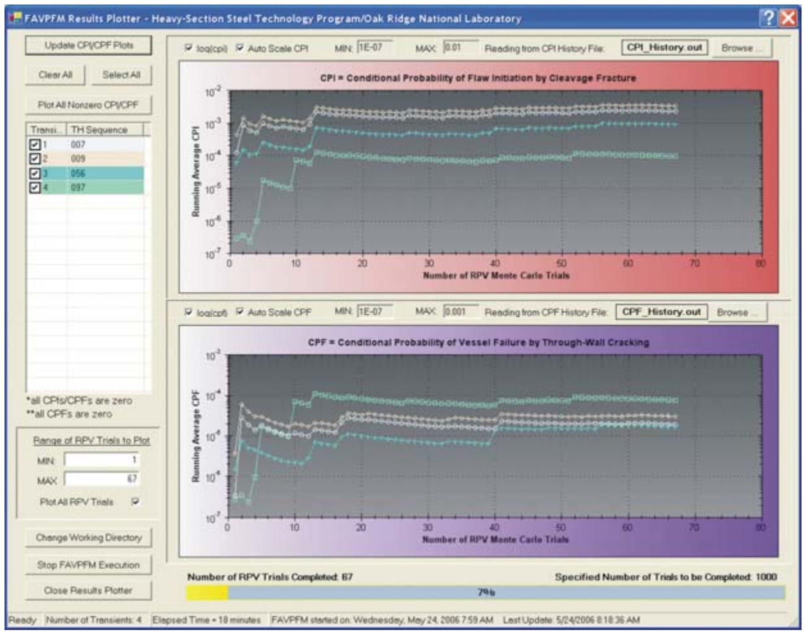
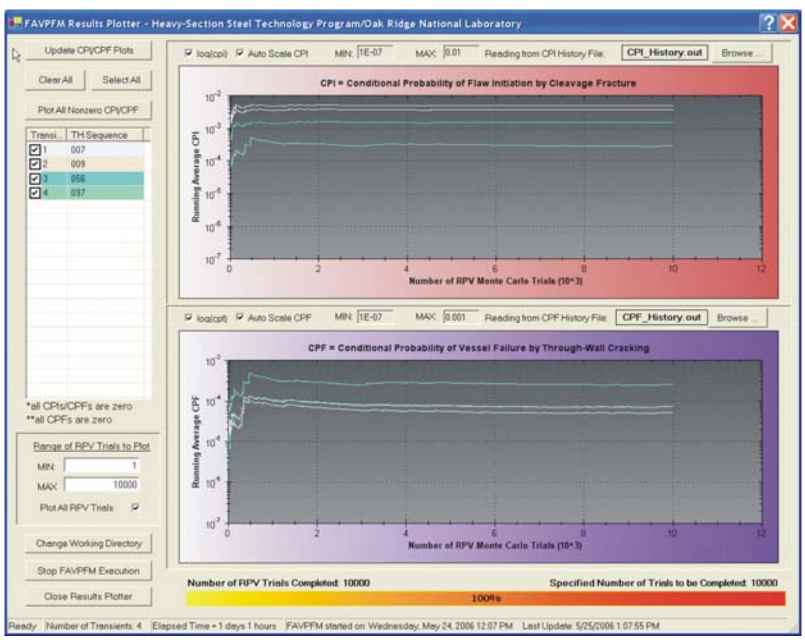
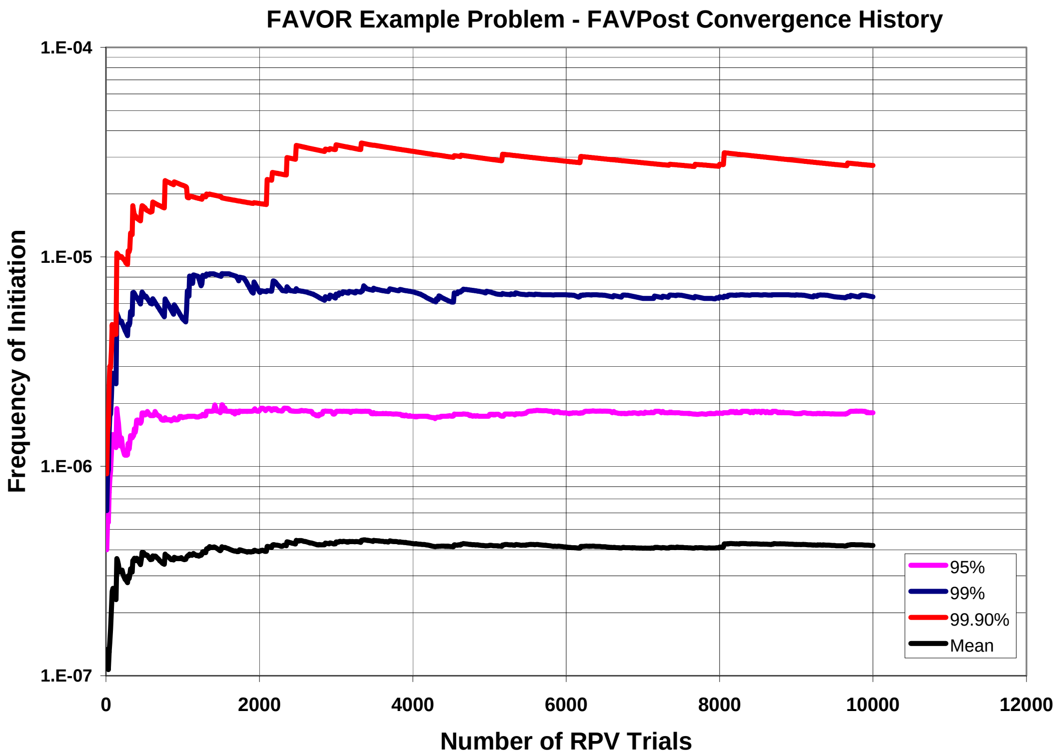


Fig. 23. Initiation event frequency distribution for PTS Transients 7, 9, 56, and 97.

The output files for this case are included on the distribution CD. The 10,000-RPV-trial simulation example case on the distribution CD required 48,469,610 flaws to be analyzed and took approximately 25 hours on a FAVOR-dedicated Pentium IV computer (Windows XP Professional, SP2, operating system) with 2048 MB of memory and a clock speed of 3.4 GHz. See the figures below for a demonstration of the convergence history for this example problem.







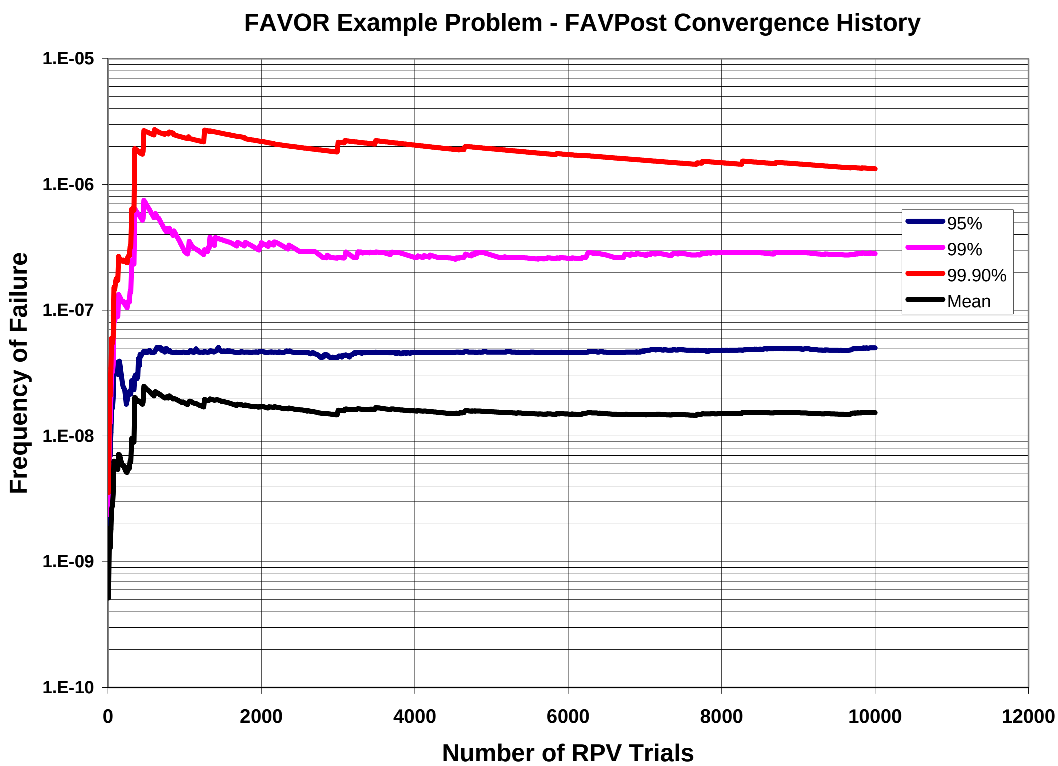


Fig. 24. Demonstration of the convergence history for the example problem.

4. Summary and Conclusions

The FAVOR, v12.1, 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. In support of the PTS Re-Evaluation Project, the following advanced technologies and new capabilities have been incorporated into FAVOR, v12.1:

- **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, and an**
- **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, v12.1, 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, v12.1 Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations* [2] gives a detailed review of the computational methodologies implemented into this version of FAVOR, v12.1.

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6. Appendix A – 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.

7. Appendix B – 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	(-)

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10. SUPPLEMENTARY NOTES

1 1. ABSTRACT *(200 words or less)*

Prior versions of FAVOR, and its predecessors, were developed primarily for application to the pressurized thermal shock (PTS) issue; therefore, they were limited to application to pressurized water reactors (PWRs) subjected to cool-down transients imposed on its inner surface. These earlier versions of FAVOR were applied in the PTS Re-evaluation Project to successfully establish a technical basis supporting a relaxation to the original PTS Rule (Title 10 of the Code of Federal Regulations, Chapter I, Part 50, Section 50.61, 10CFR50.61). The FAVOR computer code continues to evolve and to be extensively applied by analysts from the nuclear industry and regulators at the NRC to insure that the structural integrity of aging and increasingly radiation-embrittled nuclear reactor vessels (RPVs) is maintained throughout its licensing period. FAVOR, v12.1, represents a significant generalization over previous versions, because the problem class for FAVOR has been extended to encompass a broader range of transients and vessel geometries. FAVOR, v12.1, provides the capability to perform both deterministic and risk-informed fracture analyses of boiling water reactors (BWRs) as well as PWRs subjected to heat-up and cool-down transients.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

pressurized thermal shock, probabilistic fracture mechanics, reactor pressure vessels

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