NUREG/????
ORNL/TM-2005/???

Fracture Analysis of Vessels – Oak Ridge – Elastic-Plastic, FAVOR-EP, v05.1, Computer Code: User's Guide

Prepared by
P. T. Williams, T. L. Dickson, S. Yin, and B. R. Bass

Oak Ridge National Laboratory

Prepared for
U.S. Nuclear Regulatory Commission

CAUTION

This document has not been given final patent clearance and is for internal use only. If this document is to be given public release, it must be cleared through the site Technical Information Office, which will see that the proper patent and technical information reviews are completed in accordance with the policies of Oak Ridge National Laboratory and UT-Battelle, LLC.

NUREG-????
ORNL/TM-2005/???

Fracture Analysis of Vessels – Oak Ridge – Elastic-Plastic, FAVOR-EP, v05.1, Computer Code:

User's Guide

Manuscript Completed: October 2005
Date Published:

Prepared by

P. T. Williams, T. L. Dickson, S. Yin, and B. R. Bass

Oak Ridge National Laboratory
Managed by UT-Battelle, LLC
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6085

Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6533

FOREWORD

During plant operation, the walls of reactor pressure vessels (RPV) are exposed to neutron radiation, resulting in a localized embrittlement of the vessel steel and weld materials in the core area. If an embrittled RPV had an existing flaw of critical size and certain severe system transients were to occur, this flaw could very rapidly propagate through the vessel, resulting in a through-wall crack and challenging the integrity of the RPV. The severe transients of concern, known as pressurized thermal shock (PTS), are characterized by a rapid cooling (i.e., thermal shock) of the internal reactor pressure vessel surface in combination with re-pressurization of the RPV. The coincident occurrence of critical size flaws, embrittled vessel steel and weld material, and a severe PTS transient is a very low probability event. In fact, only a few of the currently operating pressurized water reactors are projected to closely approach the current statutory limit on embrittlement level during their planned operational life.

Advancements in our understanding and knowledge of materials behavior, our ability to realistically model plant systems and operational characteristics, and our ability to better evaluate PTS transients to estimate loads on vessel walls led to the realization that the earlier analysis, conducted as part of development of the PTS rule in the 1980s, contained significant conservatisms in several aspects. Consistent with the NRC's Strategic Plan and the strategy to use realistically conservative, safety-focused research programs to resolve safety-related issues, the NRC Office of Nuclear Regulatory Research undertook a project in 1999 to develop a technical basis to support a risk-informed revision of current PTS Rule. Two central features of the research approach were a focus on the use of realistic input values and models and an explicit treatment of uncertainties (using currently available uncertainty analysis tools and techniques). This approach improved significantly upon that employed to establish the 10CFR50.61 embrittlement limits, wherein intentional and unquantified conservatisms were included in many aspects of the analysis and uncertainties were treated implicitly by incorporating them into the models. The work reported herein combined the probabilities of through-wall cracking and the frequency with which the PTS transient can occur. This combination established an estimate of the yearly frequency of through-wall cracking that can be expected due to PTS-significant events.

This report is one of a number of reports that document the details of these analyses. This report is the user's guide for the probabilistic fracture mechanics code Fracture Analysis of Vessels, Oak Ridge (FAVOR-EP). The FAVOR-EP code is used to assess structural integrity of pressurized-water reactor pressure vessels during postulated pressurized thermal shock transients.

This report and other supporting reports documenting the details of the analyses and the results have been forwarded to the Office of Nuclear Reactor Regulation for its consideration for a potential revision of 10CFR50.61.

Carl J. Paperiello, Director
Office of Nuclear Regulatory Research

Fracture Analysis of Vessels – Oak Ridge
FAVOR-EP, v05.1, Computer Code: USER'S GUIDE

T. L. Dickson, P. T. Williams, S. Yin, and B. R. Bass

ABSTRACT

The current regulations to insure that nuclear reactor pressure vessels (RPVs) maintain structural integrity when subjected to transients such as pressurized thermal shock (PTS) events were derived from computational models developed in the early-to-mid 1980s. Since that time, advancements and refinements in relevant technologies that impact RPV integrity assessment have led to an effort by the NRC to re-evaluate its PTS regulations. Updated computational methodologies have evolved through interactions between experts in the relevant disciplines of thermal hydraulics, probabilistic risk assessment, materials embrittlement, fracture mechanics, and inspection (flaw characterization). Contributors to the development of these methodologies include the NRC staff, their contractors, and representatives from the nuclear industry. These updated methodologies have been integrated into the **F**racture **A**nalysis of **V**essels – **O**ak **R**idge (FAVOR-EP, v05.1) computer code developed for the NRC by the Heavy Section Steel Technology (HSST) program at Oak Ridge National Laboratory (ORNL). The FAVOR-EP, v05.1, code represents the baseline NRC-selected applications tool for re-assessing the current PTS regulations. Intended as a user's guide to the computer system requirements, installation, input data-deck preparation, and execution of the FAVOR-EP, v05.1, deterministic and probabilistic fracture mechanics code, this report is one of a series of software quality assurance documentation deliverables being prepared according to the guidance provided in IEEE Std. 730.1-1995, *IEEE Guide for Software Quality Assurance Planning* and IEEE Std. 1063-1987, *IEEE Standard for Software User Documentation.* Additional documents in this series include (1) *FAVOR-EP, v05.1, Computer Code: Software Requirements Specification,* (2) *FAVOR-EP, v05.1, Computer Code: Software Design Description*, and (3) *FAVOR-EP, v05.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations.*

CONTENTS

Page

Acronyms

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

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

Acknowledgments

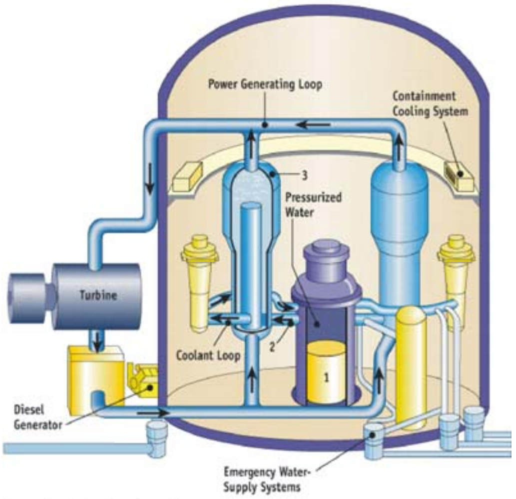
The development of the new methodologies and models incorporated into FAVOR-EP, 05.1, has been the result of a long and fruitful collaboration with many colleagues. The contributions of the NRC staff including Dr. L. Abramson, D. Bessette, Dr. N. Chokshi, Dr. E. Hackett, D. Jackson, W. Jones, D. Kalinousky, Dr. M. Kirk, Dr. S. Malik, M. Mayfield, T. Santos, Dr. N. Siu, and R. 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-EP. 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. 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-EP, 05.1. In addition to developing the ductile-tearing model implemented in this version of FAVOR-EP, Dr. M. Kirk of the NRC lead a Working Group in the development of the new fracture-toughness models in FAVOR-EP. 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. M. Natishan 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. Several conversations with Prof. R. Dodds of the University of Illinois, Prof. K. Wallin of VTT, Finland, and Dr. C. Faidy of Electricté de France were most helpful in the course of this effort. There were also contributions from many members of the nuclear industry.

1. Introduction

1.1 Background

The **F**racture **A**nalysis of **V**essels – **O**ak **R**idge – **E**lastic-**P**lastic (FAVOR-EP, v05.1) computer program has been developed to perform a risk-informed probabilistic analysis of the structural integrity of a nuclear reactor pressure vessel (RPV) when subjected to an overcooling event. The focus of this analysis is the *beltline* region of the RPV wall as shown in Fig. 1. *Overcooling events*, where the temperature of the coolant in contact with the inner surface of the RPV wall rapidly decreases with time, produce temporally-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 surface-breaking or embedded flaws. 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.

In 1999, Dickson et al. [1] illustrated that the application of fracture-related technology developed since the derivation of the current PTS regulations (established in the early-mid 1980s) had the potential for providing a technical basis for a re-evaluation of these regulations. Based on these results, the U.S. Nuclear Regulatory Commission (NRC) began the *PTS Re-Evaluation Project* to establish a technical basis 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 has evolved through interactions between 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 (FAVOR-EP, v05.1) computer code developed for the NRC by the Heavy Section Steel Technology (HSST) program at Oak Ridge National Laboratory (ORNL). The FAVOR-EP, v05.1, code represents the baseline NRC-selected applications tool for re-assessing the current PTS regulations. This report is intended as a user's guide to the computer system requirements, installation, and execution of the FAVOR-EP, v05.1, 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-EP is presented in the companion report *FAVOR-EP (v05.1): Theory and Implementation of Algorithms, Methods, and Correlations* [2].



Source: Nuclear Regulatory Commission

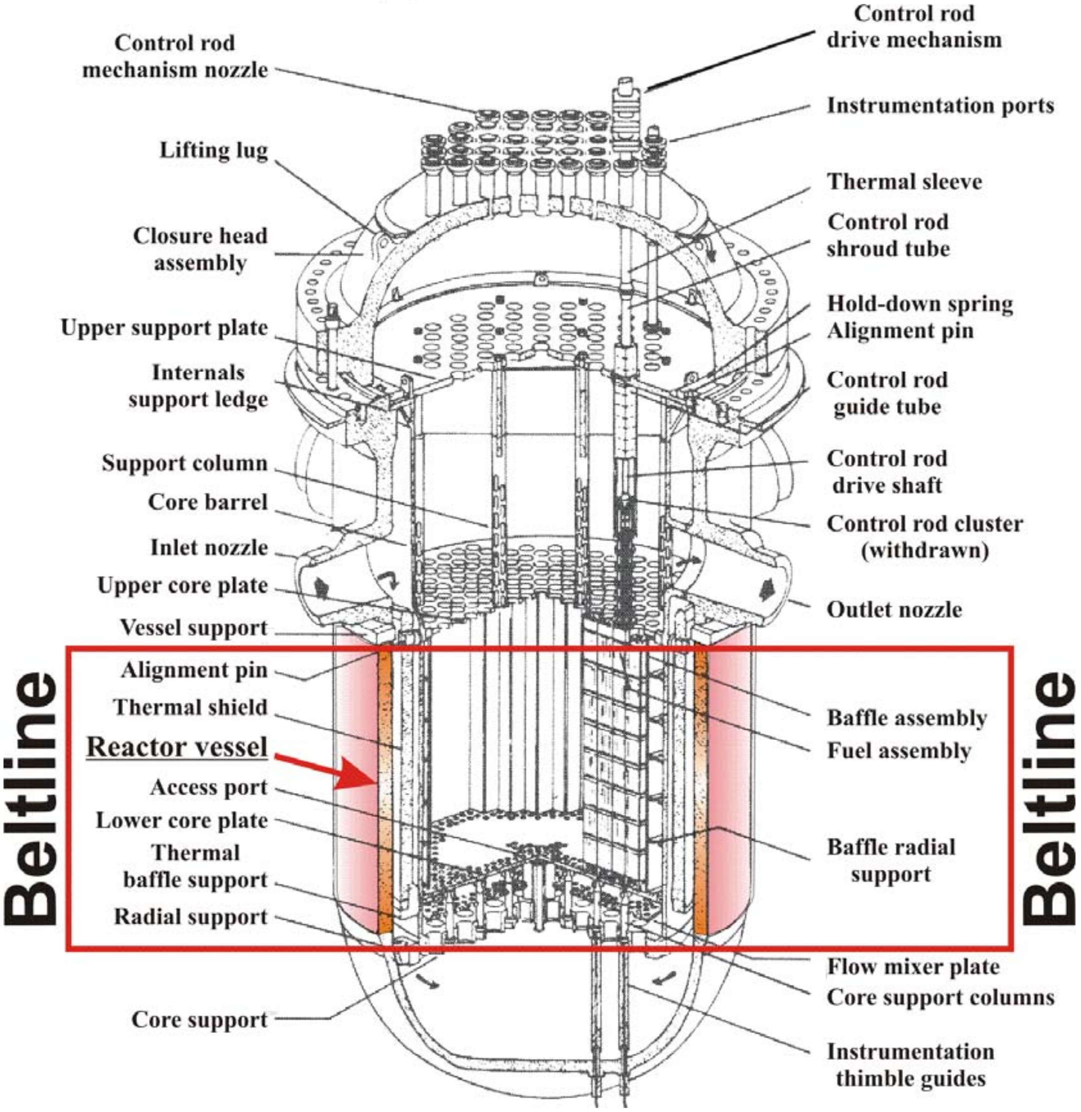


Fig. 1. The beltline region of the reactor pressure vessel wall extends from approximately one foot above the active reactor core to one foot below the core (adapted from [3]) for a pressurized water reactor (PWR).

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

The PTS issue has been under investigation for many years. Most of the early PTS analyses were of a deterministic nature. In an effort to establish more realistic limiting values of vessel embrittlement, the United States Nuclear Regulatory Commission (NRC) funded during the 1980s the Integrated Pressurized Thermal Shock (IPTS) Program [4-6] 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* [7], 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) [8].

The *PTS rule* specifies *screening criteria* in the form of limiting irradiated values of RT_{NDT} (designated by the rule as RT_{PTS}) of 270 °F for axially-oriented welds, plates, and forgings and 300 °F for circumferentially-oriented welds. The PTS rule also prescribes a method to estimate RT_{PTS} for materials in an RPV in Regulatory Guide 1.99, Revision 2 [9]. 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. Regulatory Guide 1.154 recommends the content and format for these plant-specific integrated PTS analyses with the objective of calculating an estimate for the frequency of vessel failure caused by pressurized thermal-shock events. Regulatory Guide 1.154 also presents the *primary PTS acceptance criterion* for acceptable failure risk to be a mean frequency of less than 5×10^{-6} vessel failures per reactor-operating year.

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 [10] and VISA-II [11] 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 [12].

Previous efforts at obtaining the same probabilistic solutions to a specified PTS problem using different PFM codes have met with varying degrees of success [13-15]. 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-EP (**F**racture **A**nalysis of **V**essels – **O**ak **R**idge) computer code was initially developed in the early 1990s [16] (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-EP 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-EP), deterministic and probabilistic fracture mechanics, and probabilistic risk assessment (PRA).

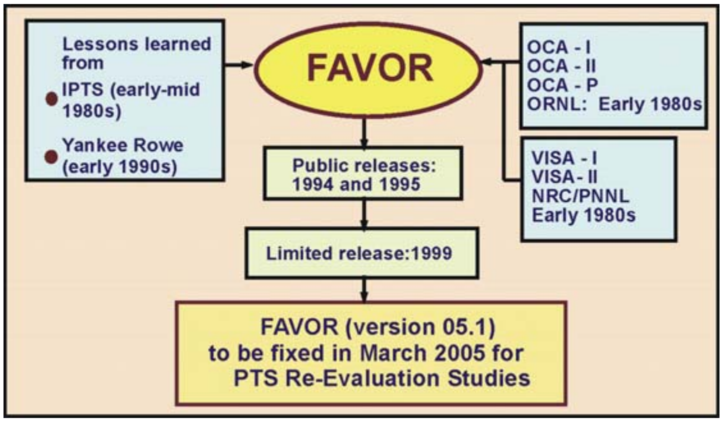


Fig. 2. Depiction of the development history of the FAVOR-EP PFM code

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 has 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 has been implemented into the FAVOR-EP code which represents the NRC-selected applications tool for re-assessing the current PTS regulations.

As depicted in Fig. 3, the current release of FAVOR-EP (version control code 05.1) implements the results of the PTS Re-evaluation Project in an improved PFM model for calculating the conditional probability of fracture (by plane-strain cleavage initiation) and the conditional probability of vessel failure. Although the analysis of PTS has been the primary motivation in the development of FAVOR-EP, it should also be noted that the problem class for which FAVOR-EP is applicable encompasses a broad range of events that include normal operational transients (such as start-up and shut-down) 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 could be an appropriate candidate for a FAVOR-EP analysis of the vessel's structural integrity.

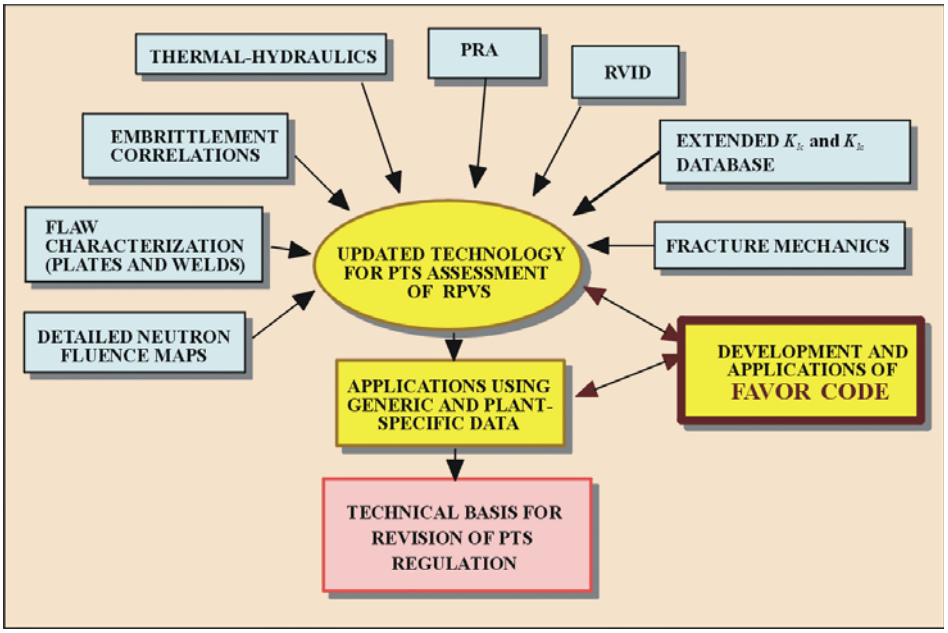


Fig. 3. The PTS Re-Evaluation Project incorporates advancements across a range of technical disciplines relevant to PTS assessment methodologies.

In support of the PTS Re-Evaluation Project, the following advanced technologies have been incorporated into the current release of FAVOR-EP, 05.1:

- **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,**
- **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-EP,**
- **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 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.**

1.3 Overview – Structure and Organization of the FAVOR-EP Code

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

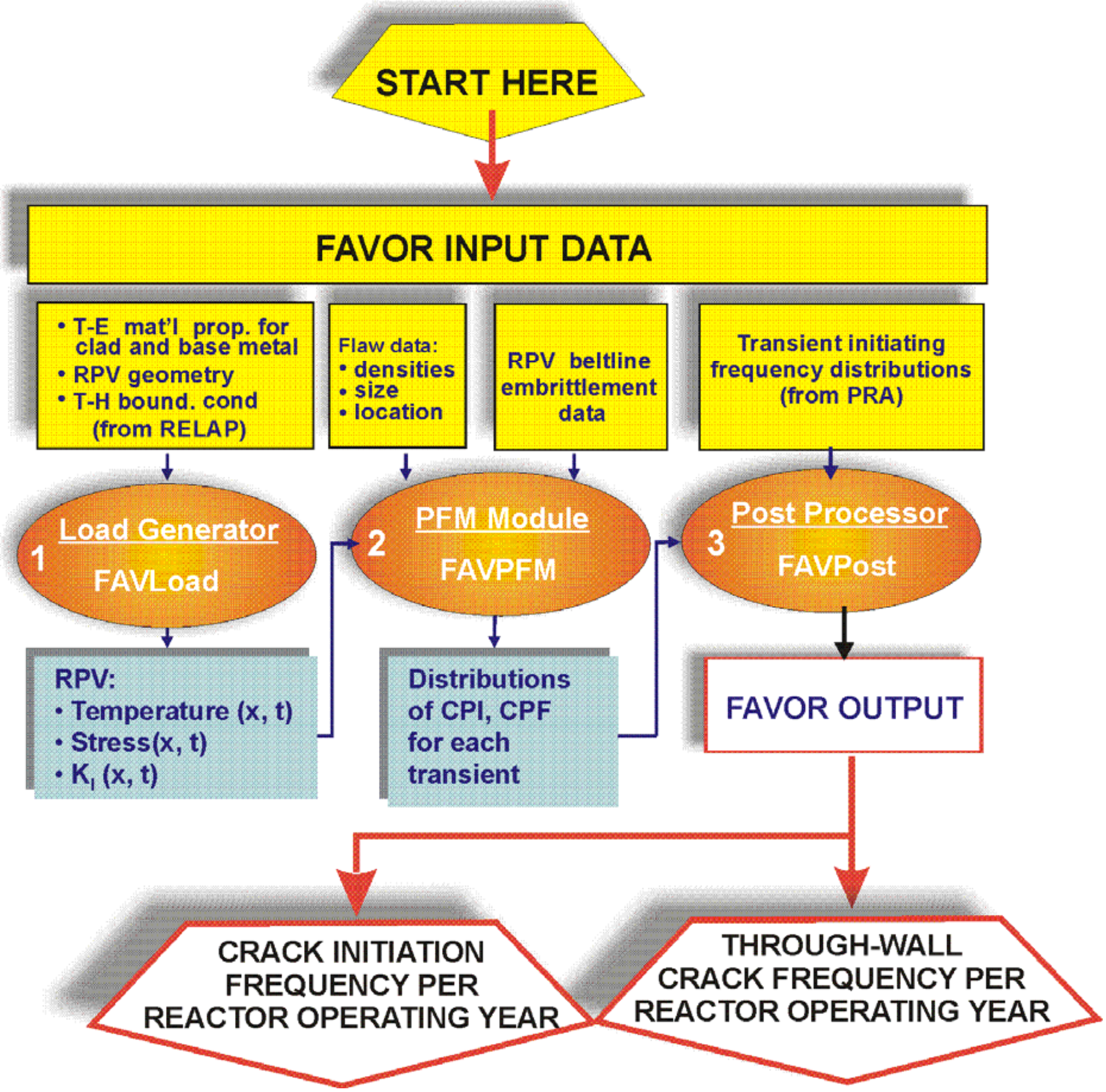


Fig. 4. FAVOR-EP data streams flow through three modules: (1) FAVLoad-EP, (2) FAVPFM-EP, and (3) FAVPost-EP.

The PFM model in FAVOR-EP 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.

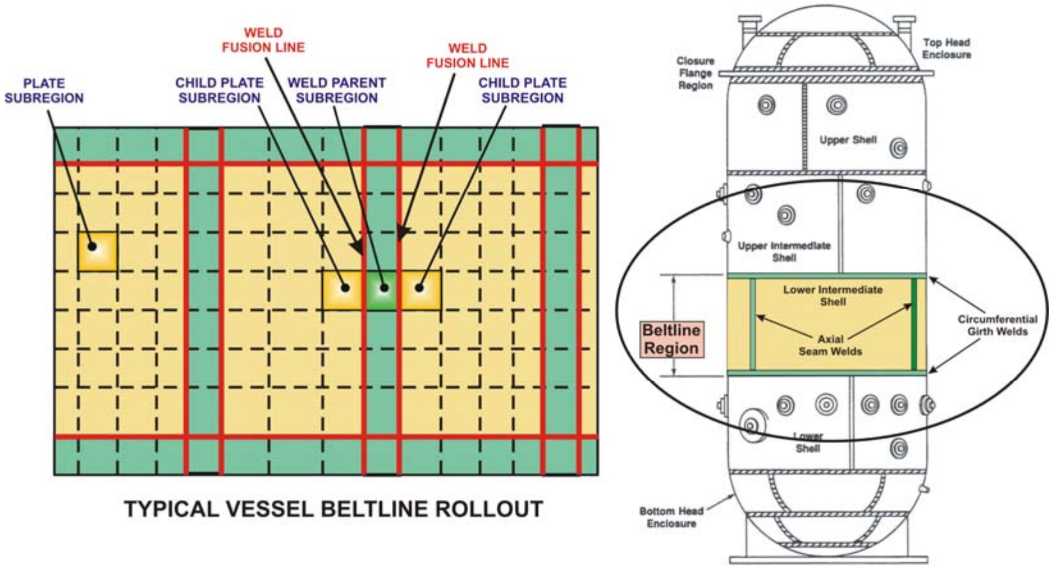


Fig. 5. The global modeling approach in FAVOR-EP allows the entire beltline to be simulated in one model definition.

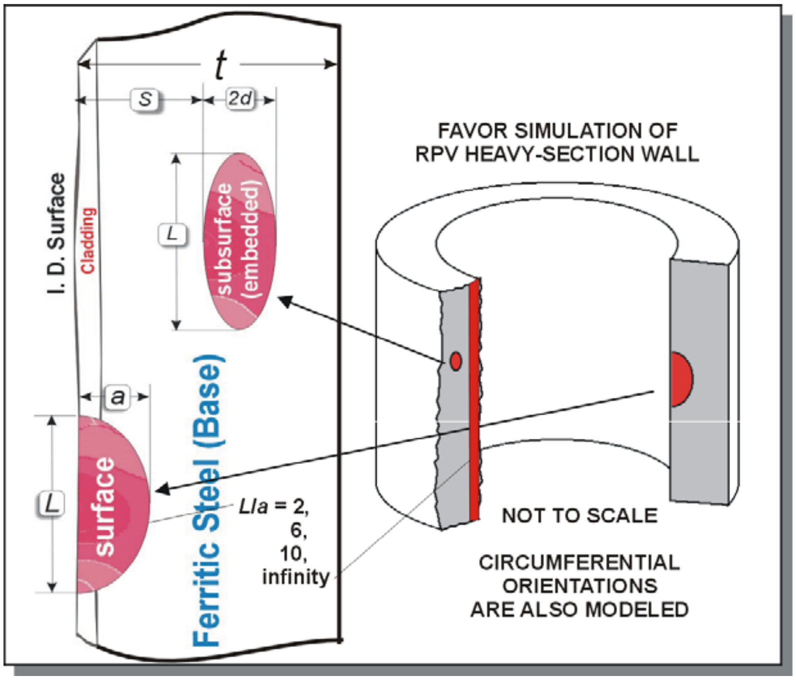


Fig. 6. Flaw models available in FAVOR-EP include infinite-length surface-breaking flaws, finite-length semi-elliptic surface flaws (with aspect ratios *L* / *a* = 2, 6, and 10), and fully-elliptic embedded flaws. All flaw models can be oriented in either the axial or circumferential directions.

Figure 6 shows the three categories of flaws that are available in FAVOR-EP:

- **Category 1 – surface-breaking flaws**
  infinite length – aspect ratio $L/a = \infty$
  semi-elliptic – aspect ratio $L/a = 2$
  semi-elliptic – aspect ratio $L/a = 6$
  semi-elliptic – aspect ratio $L/a = 10$
- **Category 2 – embedded flaws – fully-elliptic geometry with inner crack tip located between the clad/base interface and 1/8*t* from the inner surface (*t* = thickness of the RPV wall)**
- **Category 3 – embedded flaws – fully-elliptic geometry with inner crack tip located between 1/8*t* and 3/8*t* from the inner surface**

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-EP, 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-EP 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-EP 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-EP

- **FAVPFM-EP 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-EP 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-EP 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-EP
    15) Output file with the conditional probability of through-wall cracking matrix for input to FAVPost-EP

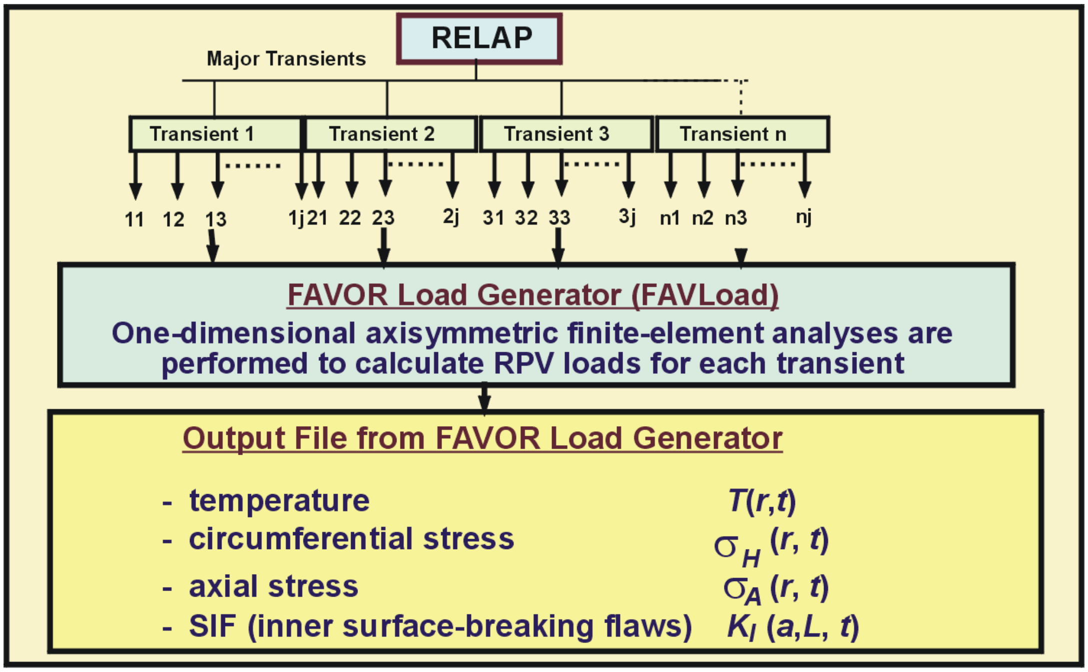


Fig. 7. **The FAVOR-EP load generator module FAVLoad-EP performs deterministic analyses for a range of thermal-hydraulic transients.**

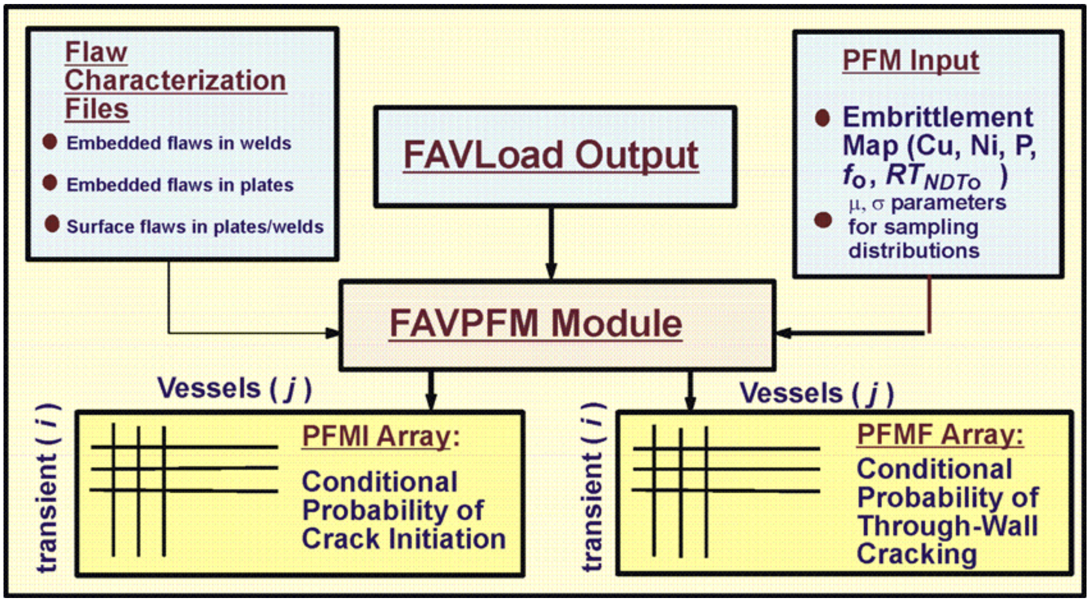


Fig. 8. **The FAVPFM-EP module takes output from FAVLoad-EP and user-supplied data on flaw distributions and embrittlement of the RPV beltline and generates PFMI (INITIATE.DAT) and PFMF (FAILURE.DAT) arrays.**

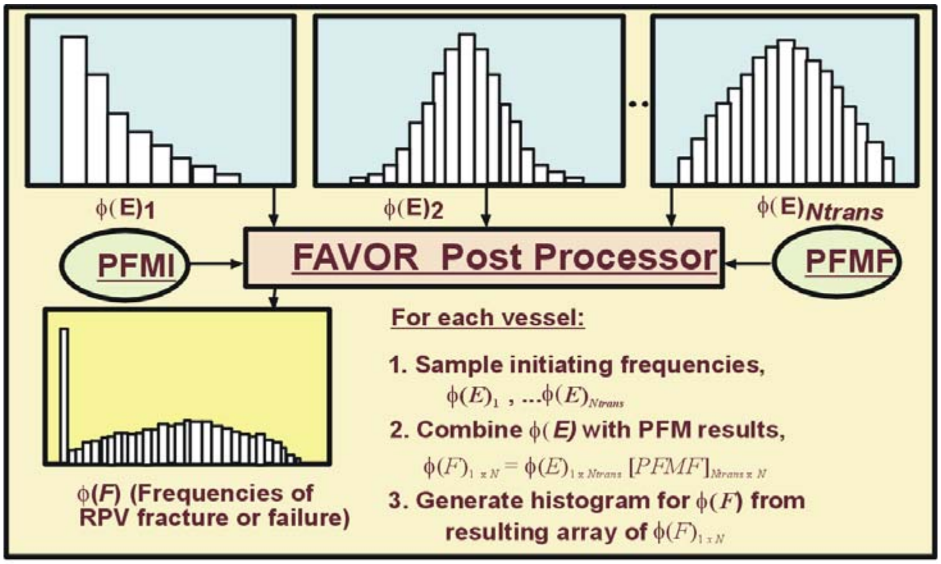


Fig. 9. The FAVOR-EP post-processor FAVPost-EP combines the distributions of conditional probability of initiation and failure calculated by FAVPFM-EP with initiating frequency distributions for all of the transients under study to create distributions of frequencies of RPV fracture and failure.

- **FAVPost-EP 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-EP containing the conditional probability of initiation matrix

  18) Input file from FAVPFM-EP 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 Hardware Requirements

The three FAVOR-EP modules have been successfully compiled and executed on the following computers, operating systems, and compilers:

- Pentium II and III with Windows NT 4.0 (SP6) – Lahey/Fujitsu Fortran 95 compiler
- Pentium II and III with Windows NT 4.0 (SP6) – Compaq 6.1 Fortran 95 compiler
- 80486DX with Windows 98 (DOS 7.1) – Compaq 6.1 Fortran 95 compiler
- Power Macintosh 9600/200MP with OS 8.6 – Absoft Pro Fortran 90 compiler
- Compaq XP1000 with TRU64 UNIX 4.0F – Compaq Fortran 90 v5.3-1120 compiler

- Dell Precision™ Workstation 330 Pentium IV with Windows 2000 Professional – Compaq 6.1 Fortran 95 compiler
- Dell Precision™ Workstation 330 Pentium IV with Windows 2000 Professional – Lahey/Fujitsu Fortran 95 compiler
- Dell Precision™ Workstation 340 Pentium IV with Windows XP Professional – Compaq 6.1 Fortran 95 compiler
- Dell Precision™ Workstation 340 Pentium IV with Windows XP Professional – Lahey/Fujitsu Fortran 95 compiler
- Hewlett-Packard Pavilion Workstation a574n with Windows XP Professional – Compaq 6.1 Fortran 95 compiler
- Hewlett-Packard Pavilion Workstation a574n with Windows XP Professional – Lahey/Fujitsu Fortran 95 compiler

The recommended computer for execution of FAVOR-EP, v05.1, is a Pentium III or IV (or equivalent) with the Windows XP Professional operating system and 2 Gbytes of RAM. The installation requires approximately 280 Mbytes of free disk space for executables, documentation, source code, and example input files.

All three FAVOR-EP modules make use of *dynamic memory management* where the required internal memory is calculated based on the size of the problem and then allocated from the global *heap*[1] at run time; therefore, the only limitation on the number of thermal hydraulic transients, the number of RPV trials, the number of simulated flaws, or the number of subregions (employed in defining the model of the RPV beltline) is the memory capacity of the computer being used. For all of the models tested by the developers to date, 2 Gbytes of RAM was sufficient to run FAVOR-EP; however, be advised that larger models in the future may require more memory. In addition, some problems have been encountered when running large cases (e.g., 60,000 subregions with 30 transients) on a PC with Windows 2000 Professional and 512 Mbytes of RAM. Windows XP (with the latest Service Pack installed) is the recommended operating system.

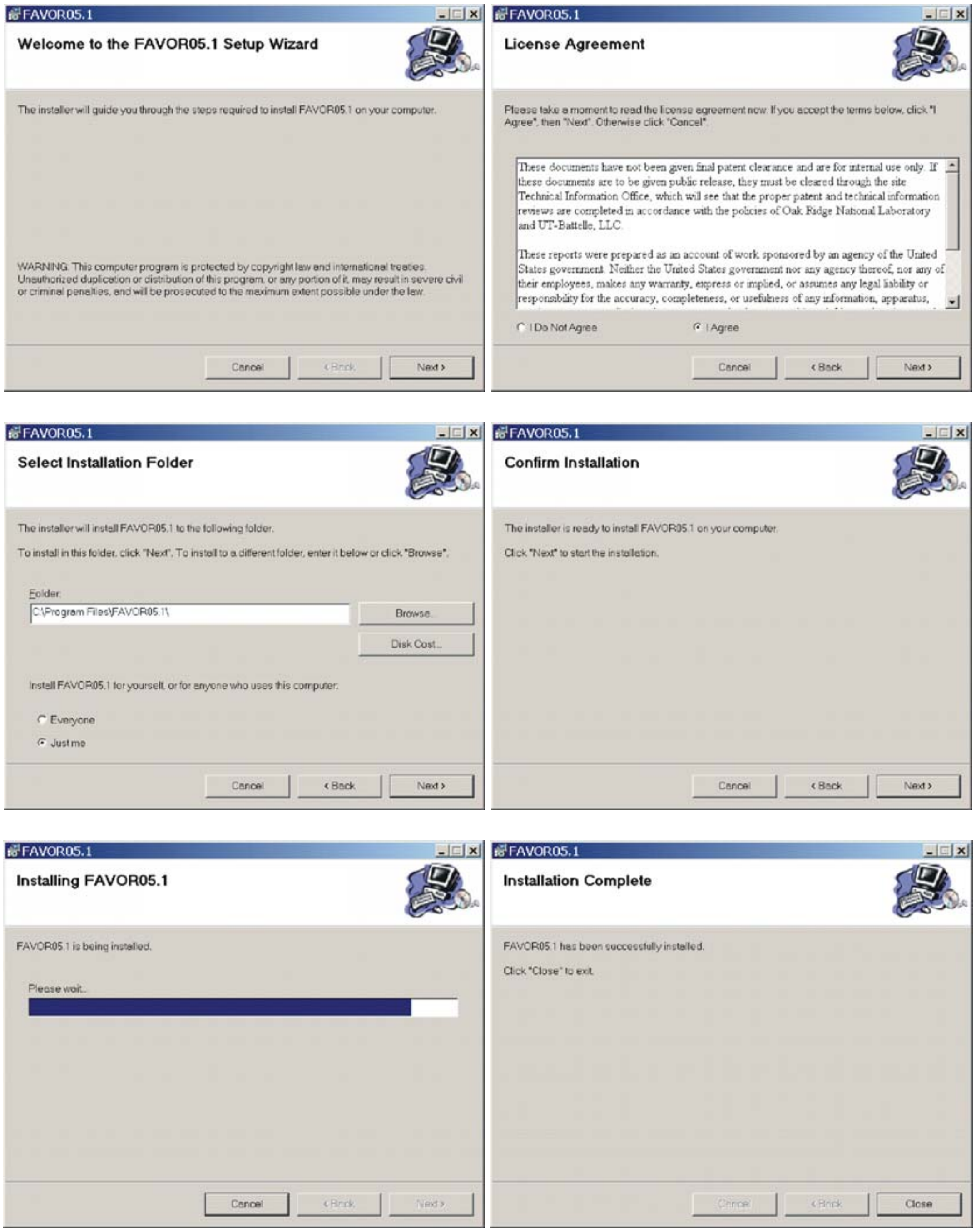
1.5 Installation

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 .\FAVOR-EP5.1\setup subfolder on the CD. If the "autorun" feature on the user's computer is

---

[1] The *heap* is an internal memory pool, controlled by the computer's operating system, and available for dynamic allocation during run time.

enabled, then the Windows® Installer application will automatically run when the FAVOR-EP distribution CD is loaded into the drive. The Windows® installer will prompt the user for the target installation folder (See Fig. 10).



Welcome to the FAVOR05.1 Setup Wizard

The installer will guide you through the steps required to install FAVOR05.1 on your computer.

WARNING: This computer program is protected by copyright law and international treaties. Unauthorized duplication or distribution of this program, or any portion of it, may result in severe civil or criminal penalties, and will be prosecuted to the maximum extent possible under the law.

License Agreement

Please take a moment to read the license agreement now. If you accept the terms below, click "I Agree", then "Next". Otherwise click "Cancel".

These documents have not been given final patent clearance and are for internal use only. If these documents are to be given public release, they must be cleared through the site Technical Information Office, which will see that the proper patent and technical information reviews are completed in accordance with the policies of Oak Ridge National Laboratory and UT-Battelle, LLC.

These reports were prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus,

Select Installation Folder

The installer will install FAVOR05.1 to the following folder.

To install in this folder, click "Next". To install to a different folder, enter it below or click "Browse".

Folder: C:\Program Files\FAVOR05.1\

Install FAVOR05.1 for yourself, or for anyone who uses this computer:

Confirm Installation

The installer is ready to install FAVOR05.1 on your computer.

Click "Next" to start the installation.

Installing FAVOR05.1

FAVOR05.1 is being installed.

Please wait...

Installation Complete

FAVOR05.1 has been successfully installed.

Click "Close" to exit.

Fig. 10. The Windows® Installer application can be used to copy the FAVOR-EP, v05.1, executables, source code, documentation, and example files to the user's computer.

The User's Guide and Theory Manual files are in Adobe Acrobat PDF format. The installer for the free Adobe Reader 7.0.0 is included on the distribution CD. Execute **"AdbeRdr70_enu_full.exe"** from the CD to install the Acrobat Reader on the user's computer, if it is not already installed.

Installation on Windows 2000\NT\98 Operating Systems – If the contents of "FAVOR-EP 05.1" folder and its subfolders were manually copied from the distribution CD to the user's hard-drive, it will be necessary to remove the "Read Only" attribute on the data files in the ".\FAVOR-EP 05.1\Flaw Data\", ".\FAVOR-EP 05.1\Examples\", and ".\FAVOR-EP 05.1\Examples\Installation Examples\" folders. The "Read Only" attribute is set automatically by the Windows 2000\NT\ME\98 operating systems for files copied from a CD[2]. One way to change the attributes for a file or collection of files is through the Windows Explorer utility. Here is the procedure:

1. Bring up Windows Explorer (e.g., right-click[3] on the "Start" button at the lower left-hand corner of the main window and select[4] "Explore")
2. Navigate to the ".\FAVOR-EP 05.1\Examples" folder
3. On the Explorer menu bar at the top of the window, select View>Details
4. Click[4] on the "Type" bar at the top of the file window to sort the files by their file extension, if not already sorted this way.
5. Select the file "FAVLoad-EP.in" by left-clicking once on the filename.
6. Hold down the <Shift> key and select the data file at the bottom of the list. This procedure will select all of the data files at one time. It is not necessary to change the attributes of the application files: FAVLoad-EP.exe, FAVPFM-EP.exe, and FAVPost-EP.exe.
7. Continue holding down the <Shift> key and with the cursor positioned over the selected files right-click to bring up a *pop-up menu*.
8. Select "Properties" at the bottom of the pop-up menu.
9. Deselect the "Read-only" attribute by left-clicking on its check box, if it is checked.
10. Select the "OK" button, and release the <Shift> key.

All of the data files in this folder should now be ready for execution with FAVOR-EP. Repeat Steps 3 through 10 for all of the data files in the ".\FAVOR-EP 05.1\Flaw Data\" and ".\FAVOR-EP 05.1\Examples\ Installation Examples\" folders.

---

[2] The "Read Only" attribute is not assigned automatically when running under the Windows XP operating system, or if the Windows® Installer setup.exe application is used to carry out the transfer of files from the CD.

[3] "right-click" → click once with the right mouse button

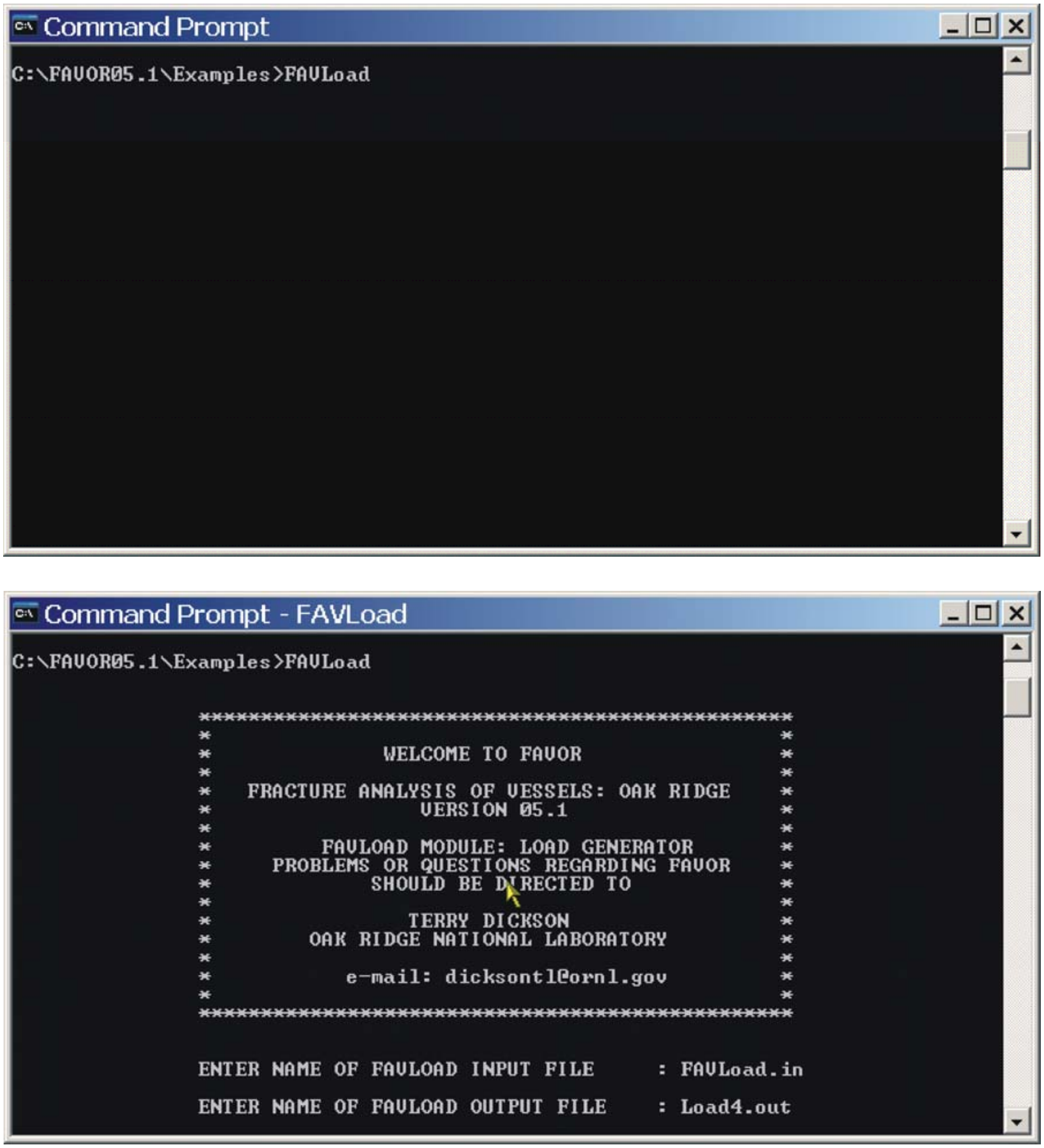
[4] "select" → "left-click" → click once with the left mouse button

1.6 Execution

On Microsoft Windows operating systems (Windows XP\2000\NT\ME\98), the three FAVOR-EP modules can be started either by double clicking on the executables' icon (named FAVLoad-EP.exe, FAVPFM-EP.exe, and FAVPost-EP.exe) in Windows Explorer or by opening an Command Prompt window (Start > Programs > Command Prompt on Windows 2000\NT\ME\98 or Start > All Programs > Accessories > Command Prompt on Windows XP) and typing in the name of the executable at the line prompt as shown in Fig. 11a for FAVLoad-EP execution. All input files and executables must reside in the same current working directory. For details on the creation of FAVOR-EP input files see Chapter 2. In Fig. 11b, the code prompts for the names of the FAVLoad-EP input and FAVLoad-EP output files. The FAVLoad-EP output file will be used as the load-definition input file for the FAVPFM-EP module. Figure 12 shows the messages written to the screen as FAVLoad-EP performs its calculations.

Upon creation of the load-definition file by FAVLoad-EP, FAVPFM-EP execution can be started by typing "FAVPFM-EP" at the line prompt (see Fig. 13). FAVPFM-EP will then prompt the user for the names of six files (see Fig. 14a): (1) the FAVPFM-EP input file, (2) load-definition file output from FAVLoad-EP, (3) a name for the output file to be created by FAVPFM-EP, (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-EP cannot find the named input files in the current execution directory, it will prompt the user for new file names. If the FAVPFM-EP 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-EP provides monitoring information during execution by writing the running averages of conditional probabilities of initiation and vessel failure for all of the transients defined in the load file for each RPV trial as shown in Fig. 15.



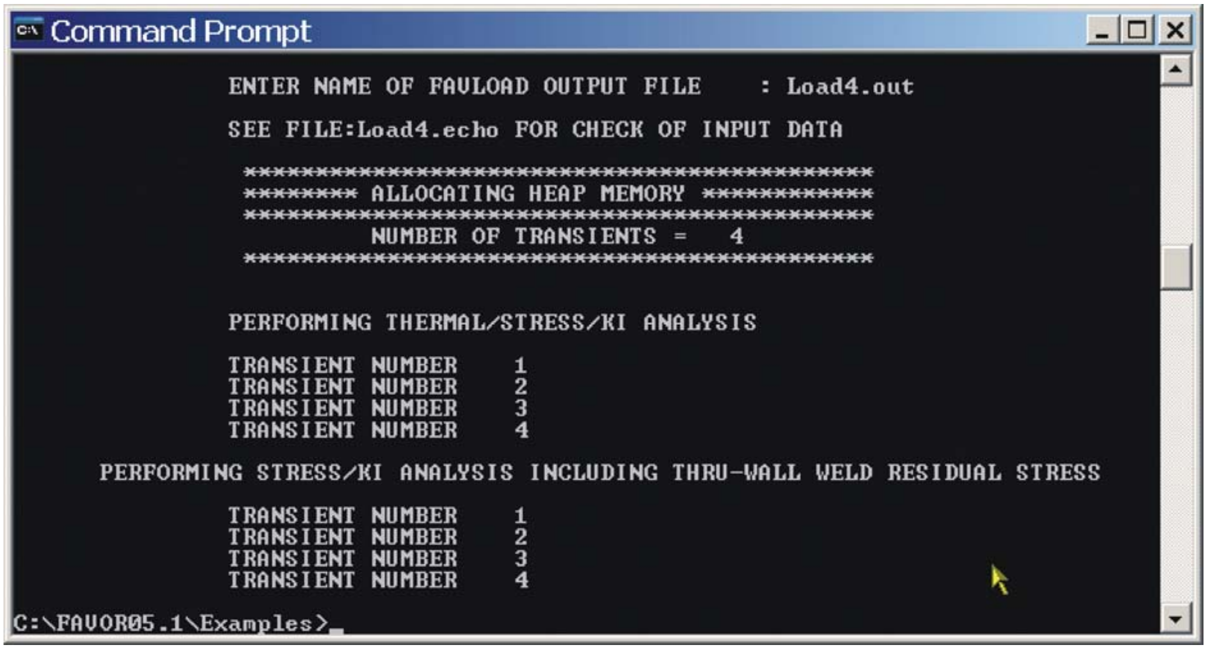
(a)

```
C:\FAVOR05.1\Examples>FAVLoad
```

(b)

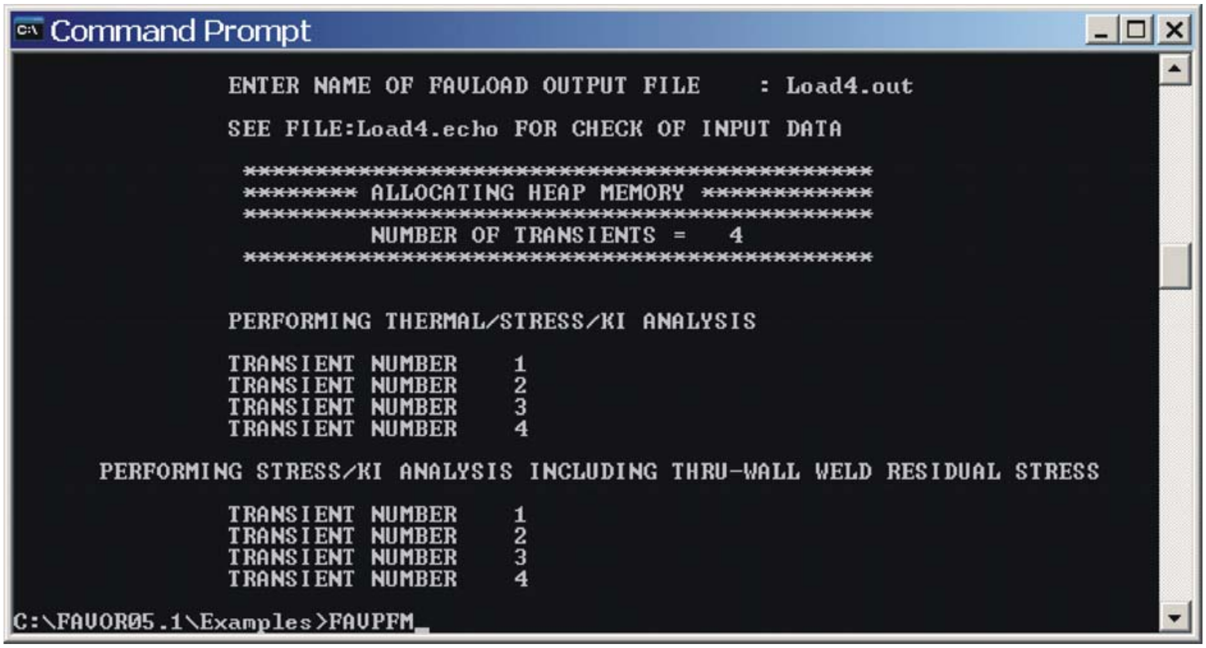
```
C:\FAVOR05.1\Examples>FAVLoad

               *************************************************
               *                                               *
               *              WELCOME TO FAVOR                 *
               *                                               *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE     *
               *                 VERSION 05.1                  *
               *                                               *
               *         FAVLOAD MODULE: LOAD GENERATOR        *
               *     PROBLEMS OR QUESTIONS REGARDING FAVOR     *
               *             SHOULD BE DIRECTED TO             *
               *                                               *
               *                TERRY DICKSON                  *
               *        OAK RIDGE NATIONAL LABORATORY          *
               *                                               *
               *           e-mail: dicksontl@ornl.gov          *
               *                                               *
               *************************************************


               ENTER NAME OF FAVLOAD INPUT FILE     : FAVLoad.in

               ENTER NAME OF FAVLOAD OUTPUT FILE    : Load4.out
```

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



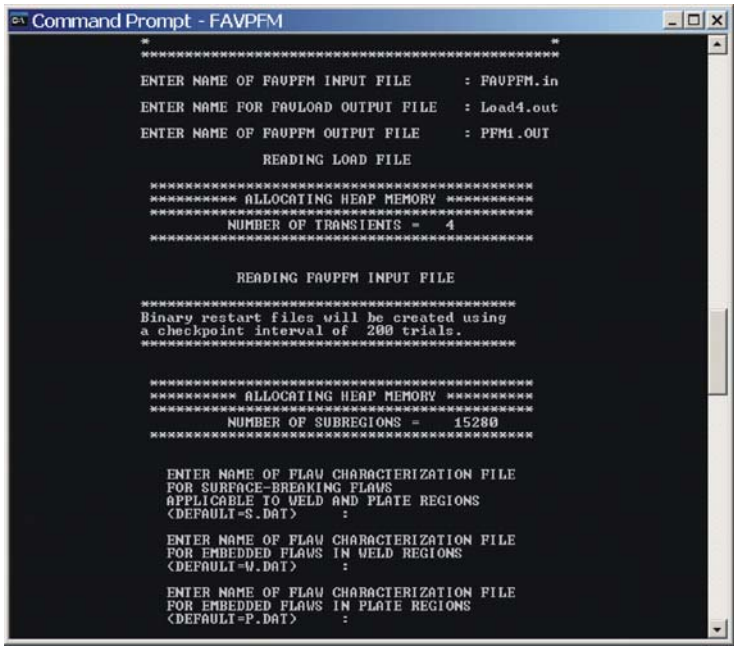
```
               ENTER NAME OF FAVLOAD OUTPUT FILE     : Load4.out

               SEE FILE:Load4.echo FOR CHECK OF INPUT DATA

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


               PERFORMING THERMAL/STRESS/KI ANALYSIS

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

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

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

C:\FAVOR05.1\Examples>_
```

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



```
               ENTER NAME OF FAVLOAD OUTPUT FILE     : Load4.out

               SEE FILE:Load4.echo FOR CHECK OF INPUT DATA

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


               PERFORMING THERMAL/STRESS/KI ANALYSIS

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

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

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

C:\FAVOR05.1\Examples>FAVPFM_
```

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

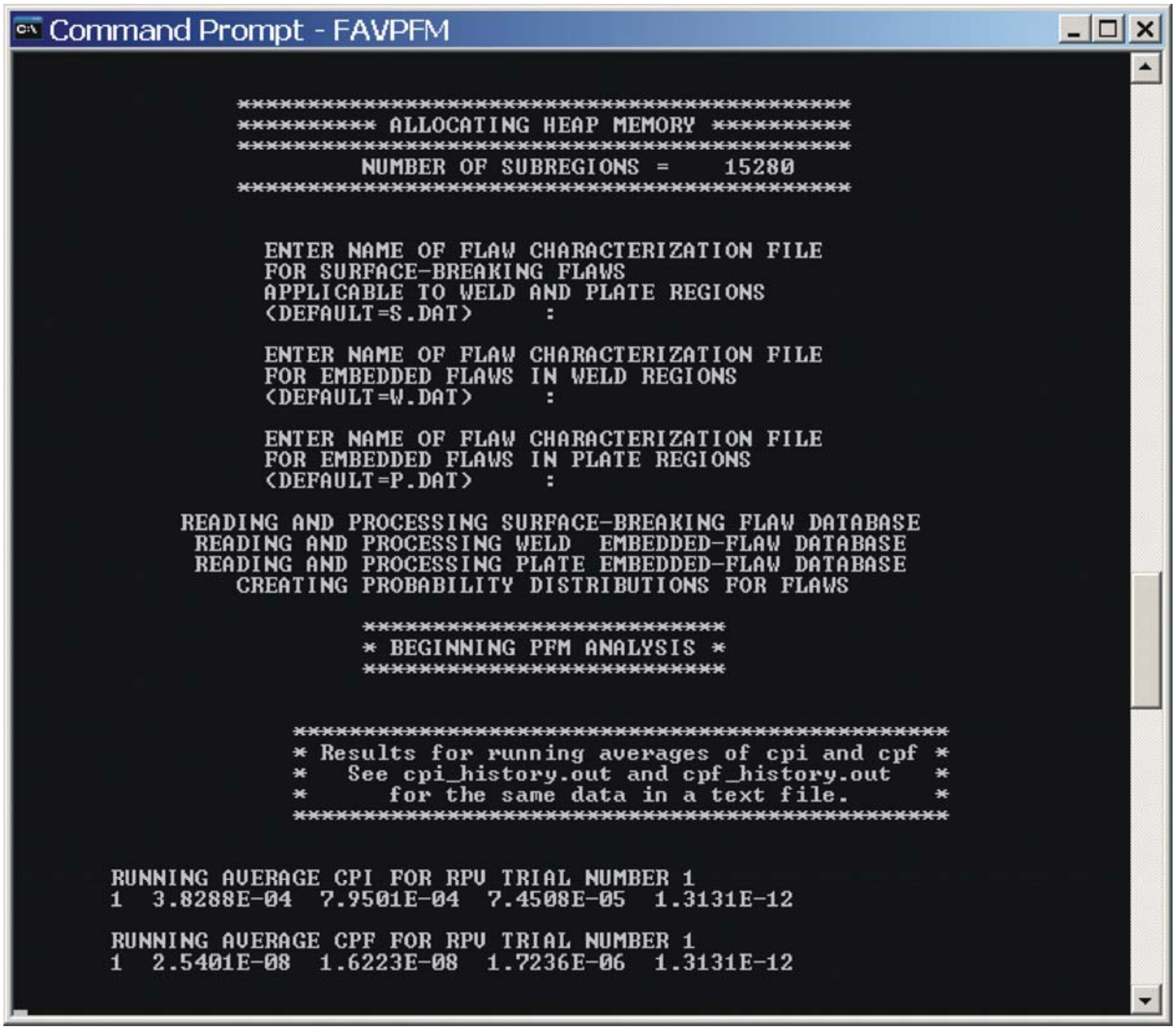


```
           *                                               *
           *************************************************

           ENTER NAME OF FAVPFM INPUT FILE      : FAVPFM.in

           ENTER NAME FOR FAVLOAD OUTPUT FILE   : Load4.out

           ENTER NAME OF FAVPFM OUTPUT FILE     : PFM1.OUT

                         READING LOAD FILE

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


                      READING FAVPFM INPUT FILE

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


            ********************************************
            ********** ALLOCATING HEAP MEMORY **********
            ********************************************
                     NUMBER OF SUBREGIONS =    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>      :
```

Fig. 14. (a) FAVPFM-EP prompts for the names of the (1) FAVPFM-EP input file, (2) FAVLoad-EP-generated load-definition file, (3) FAVPFM-EP 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.

```
           *        OAK RIDGE NATIONAL LABORATORY          *
           *                                               *
           *         e-mail: dicksontl@ornl.gov            *
           *                                               *
           *************************************************

           ENTER NAME OF FAVPFM INPUT FILE      : favpfm.in

           ENTER NAME FOR FAVLOAD OUTPUT FILE   : load4.out

           ENTER NAME OF FAVPFM OUTPUT FILE     : pfm1r.out

                         READING LOAD FILE

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


                      READING FAVPFM INPUT FILE

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


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

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

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



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


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

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

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

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

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


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


RUNNING AVERAGE CPI FOR RPV TRIAL NUMBER 1
1  3.8288E-04  7.9501E-04  7.4508E-05  1.3131E-12

RUNNING AVERAGE CPF FOR RPV TRIAL NUMBER 1
1  2.5401E-08  1.6223E-08  1.7236E-06  1.3131E-12
```

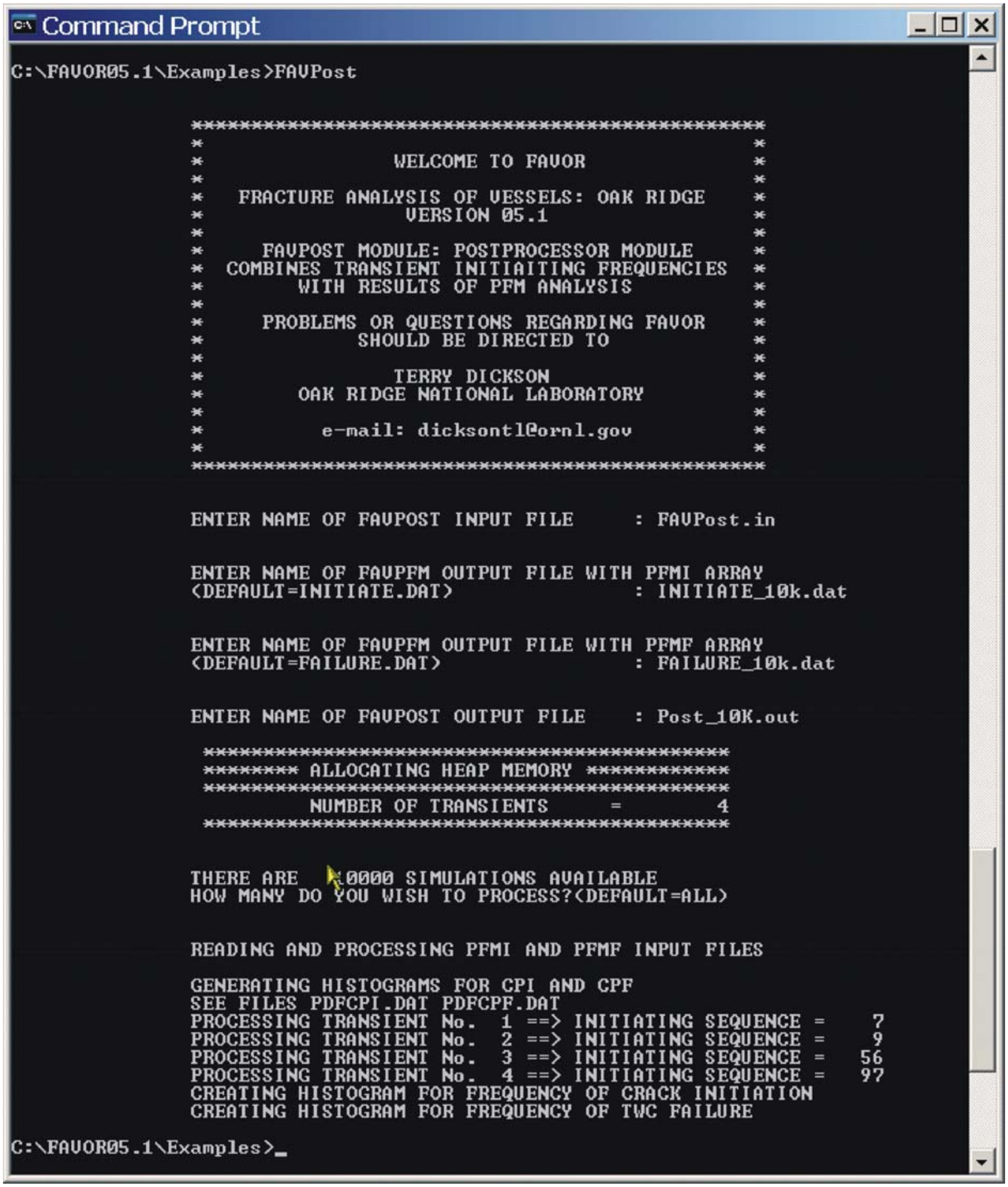
Fig. 15. FAVPFM-EP continually writes out progress reports in terms of running average CPI/CPF values for each transient as the code proceeds through the required number of RPV trials.

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

1. While FAVPFM-EP is running in one Command Prompt Window, bring up a second Command Prompt Window and navigate to a directory that is not the FAVOR-EP working directory.
2. Copy the FAVPost-EP.exe executable and the current files INITIATE.DAT, FAILURE.DAT, and NSIM.DAT from the current FAVOR-EP working directory to the directory selected in Step 1.
3. Start the copied FAVPost-EP executable in the directory selected in Step 1 by typing FAVPost-EP and then <Enter> at the prompt.
4. Respond to the prompt for the FAVPost-EP 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-EP output file name.
7. Respond to the prompt for the number of RPV trials to be processed.
8. FAVPost-EP will interrogate the INITIATE.DAT file to determine the current number of completed RPV trials.
9. FAVPost-EP 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-EP 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-EP several times asking for 1000, 2000, 3000, …NSIM RPV trials, and then plot the relevant statistics.

In Fig. 16, FAVOR-EP's post-processing module is executed by typing FAVPost-EP at the line prompt. The code will then prompt the user for the names of four files (see Fig. 16): (1) a FAVPost-EP input file, (2) the file created by the FAVPFM-EP execution that contains the conditional probability of initiation matrix (DEFAULT=INITIATE.DAT), (3) the file created by the FAVPFM-EP 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-EP 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.



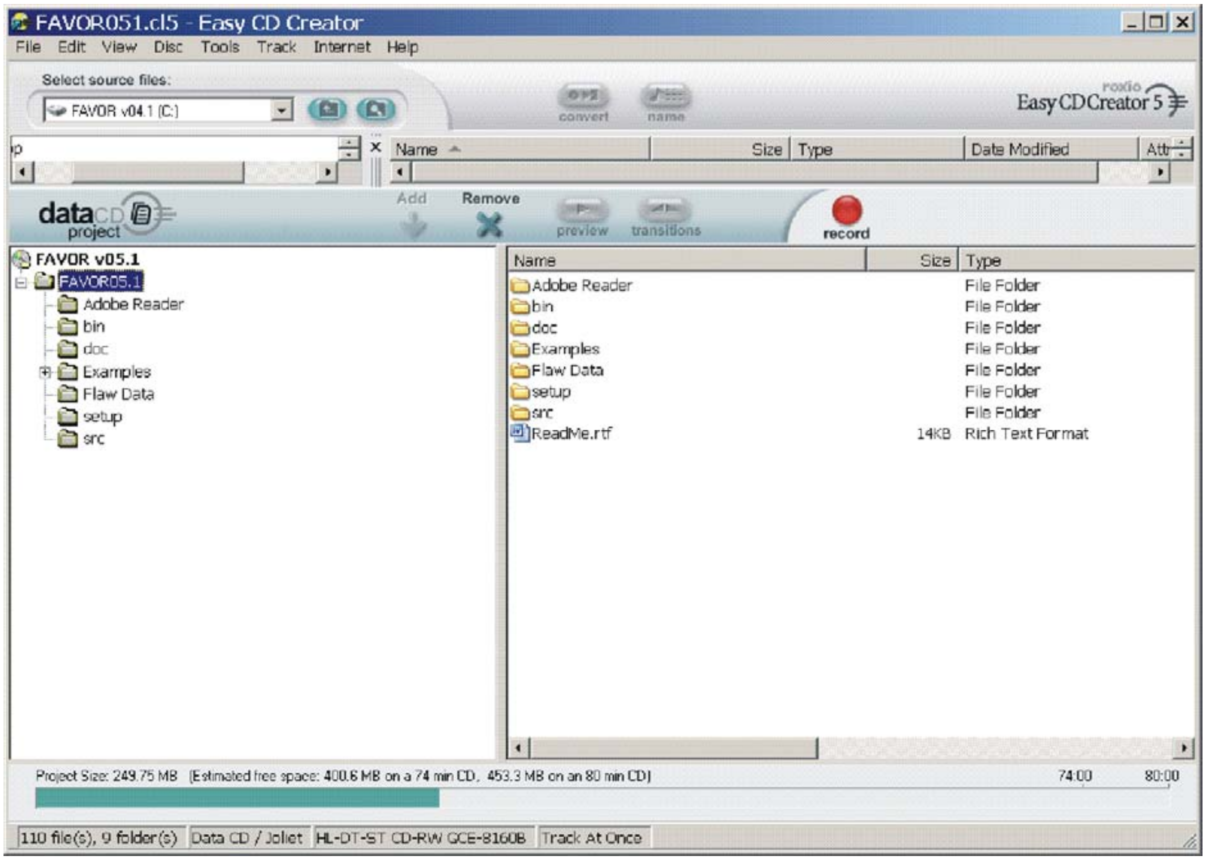
```
C:\FAVOR05.1\Examples>FAVPost

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


               ENTER NAME OF FAVPOST INPUT FILE     : FAVPost.in


               ENTER NAME OF FAVPFM OUTPUT FILE WITH PFMI ARRAY
               (DEFAULT=INITIATE.DAT)               : INITIATE_10k.dat


               ENTER NAME OF FAVPFM OUTPUT FILE WITH PFMF ARRAY
               (DEFAULT=FAILURE.DAT)                : FAILURE_10k.dat


               ENTER NAME OF FAVPOST OUTPUT FILE    : Post_10K.out

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


               THERE ARE    10000 SIMULATIONS AVAILABLE
               HOW MANY DO YOU WISH TO PROCESS?(DEFAULT=ALL)


               READING AND PROCESSING PFMI AND PFMF INPUT FILES

               GENERATING HISTOGRAMS FOR CPI AND CPF
               SEE FILES PDFCPI.DAT PDFCPF.DAT
               PROCESSING TRANSIENT No.  1 ==> INITIATING SEQUENCE =     7
               PROCESSING TRANSIENT No.  2 ==> INITIATING SEQUENCE =     9
               PROCESSING TRANSIENT No.  3 ==> INITIATING SEQUENCE =    56
               PROCESSING TRANSIENT No.  4 ==> INITIATING SEQUENCE =    97
               CREATING HISTOGRAM FOR FREQUENCY OF CRACK INITIATION
               CREATING HISTOGRAM FOR FREQUENCY OF TWC FAILURE

C:\FAVOR05.1\Examples>_
```

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

1.7 Distribution CD – What's on the CD

The distribution CD contains the following folders and files:

Main Folder: .\FAVOR-EP05.1



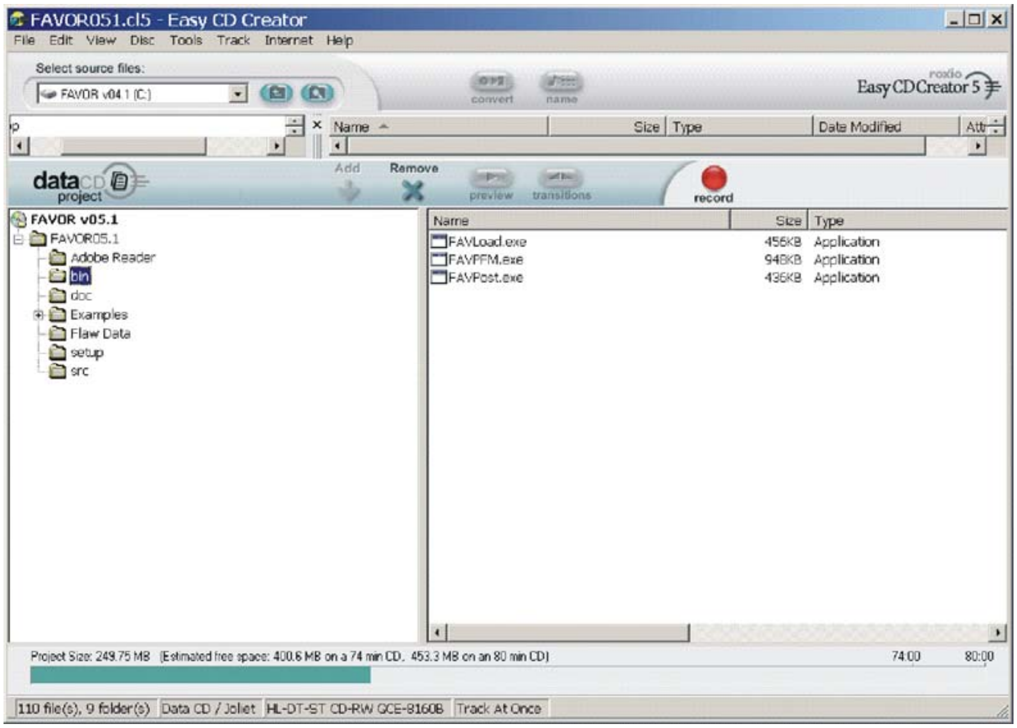
Name	Size	Type
Adobe Reader		File Folder
bin		File Folder
doc		File Folder
Examples		File Folder
Flaw Data		File Folder
setup		File Folder
src		File Folder
ReadMe.rtf	14KB	Rich Text Format

Project Size: 249.75 MB (Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD)

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

The main folder .\FAVOR-EP05.1 contains seven subfolders. The file "AdbeRdr70_enu_full.exe" in the Adobe Reader folder is the Adobe Reader 7.0.0 installer application. If the free Acrobat Reader does not exist on the user's PC, just double-click on the installer, and Acrobat Reader will be installed and the ".pdf" extension will be associated with the Reader application. The installer may require the user to restart the PC to complete the installation. After installation, the FAVOR-EP, 05.1, documentation may be viewed by double-clicking on the individual ".pdf" files.

Subfolder: .\FAVOR-EP05.1\bin



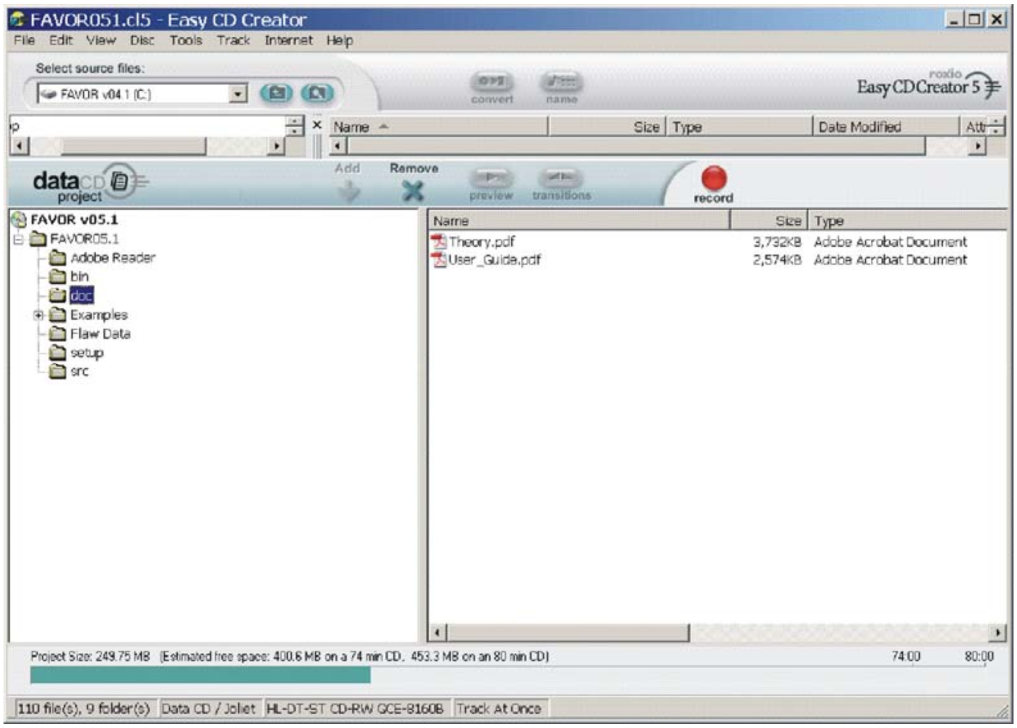
Name	Size	Type
FAVLoad.exe	456KB	Application
FAVPFM.exe	948KB	Application
FAVPost.exe	436KB	Application

Project Size: 249.75 MB [Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD] 74:00 80:00

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

.\FAVOR-EP05.1\bin contains the executables for a PC running under the Microsoft Windows operating system.

Subfolder: .\FAVOR-EP05.1\doc



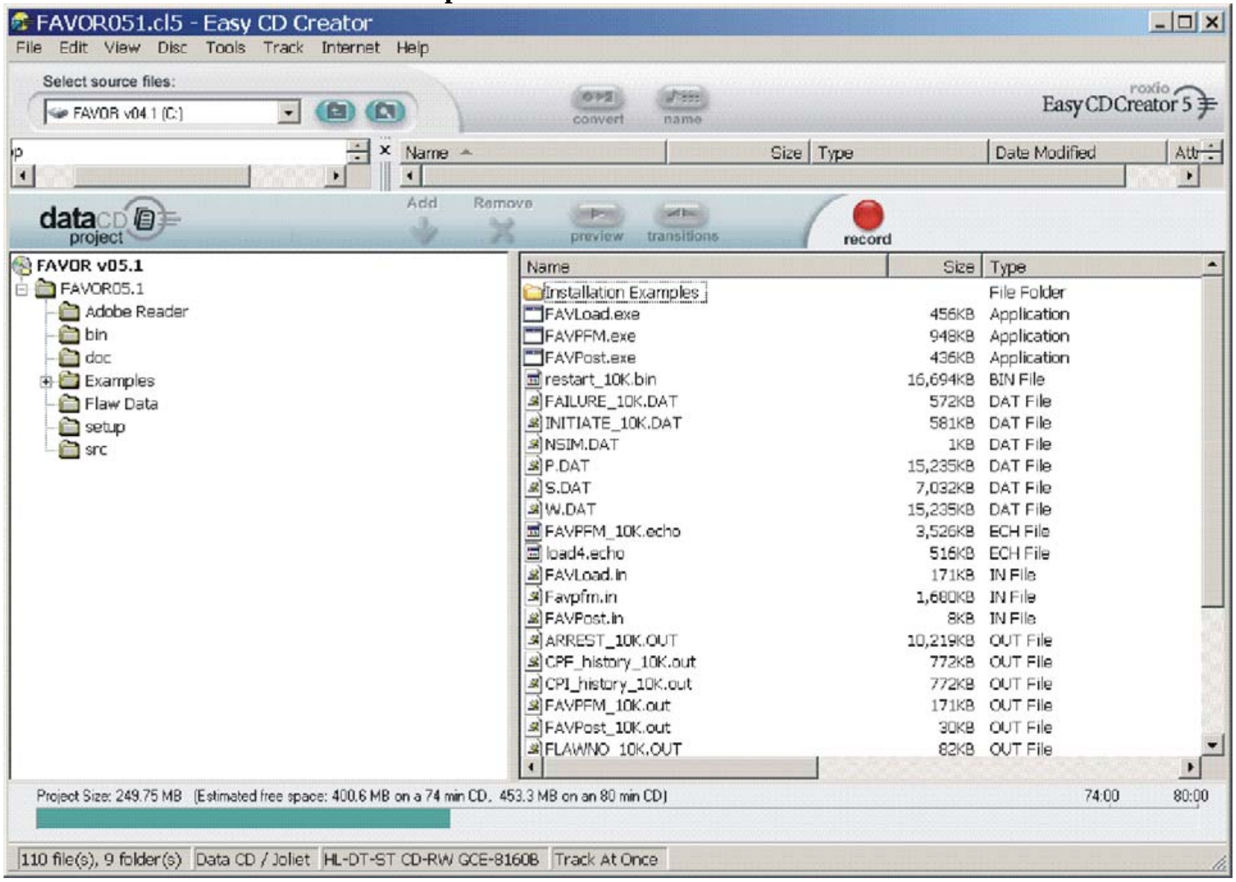
Name	Size	Type
Theory.pdf	3,732KB	Adobe Acrobat Document
User_Guide.pdf	2,574KB	Adobe Acrobat Document

Project Size: 249.75 MB [Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD] 74:00 80:00

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

.\FAVOR-EP05.1\doc contains the Theory and User's Guides in Adobe Acrobat PDF format. The free Adobe Reader 7.0.0 installation file is included in the Adobe Reader directory.

Subfolder: .\FAVOR-EP05.1\Examples



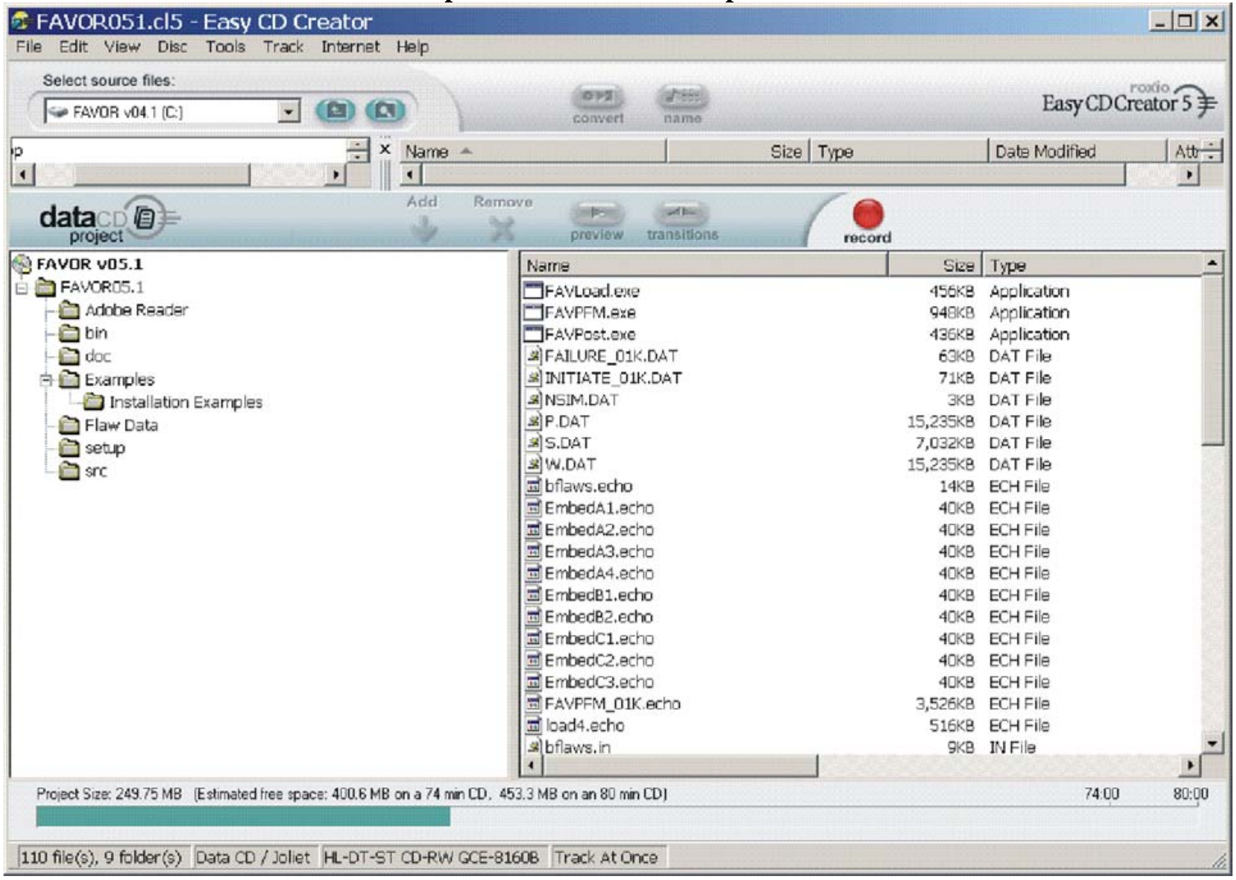
Name	Size	Type
Installation Examples		File Folder
FAVLoad.exe	456KB	Application
FAVPFM.exe	948KB	Application
FAVPost.exe	436KB	Application
restart_10K.bin	16,694KB	BIN File
FAILURE_10K.DAT	572KB	DAT File
INITIATE_10K.DAT	581KB	DAT File
NSIM.DAT	1KB	DAT File
P.DAT	15,235KB	DAT File
S.DAT	7,032KB	DAT File
W.DAT	15,235KB	DAT File
FAVPFM_10K.echo	3,526KB	ECH File
load4.echo	516KB	ECH File
FAVLoad.in	171KB	IN File
Favpfm.in	1,680KB	IN File
FAVPost.in	8KB	IN File
ARREST_10K.OUT	10,219KB	OUT File
CPF_history_10K.out	772KB	OUT File
CPI_history_10K.out	772KB	OUT File
FAVPFM_10K.out	171KB	OUT File
FAVPost_10K.out	30KB	OUT File
FLAWNO 10K.OUT	82KB	OUT File

Project Size: 249.75 MB (Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD) 74:00 80:00

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

These are the input and output files for the example case discussed in Chapter 3 of this User's Guide. Several of the files, e.g., ARREST.OUT, created automatically by FAVOR-EP have been renamed to save them for comparison checks by the user.

Subfolder: .\FAVOR-EP05.1\Examples\Installation Examples



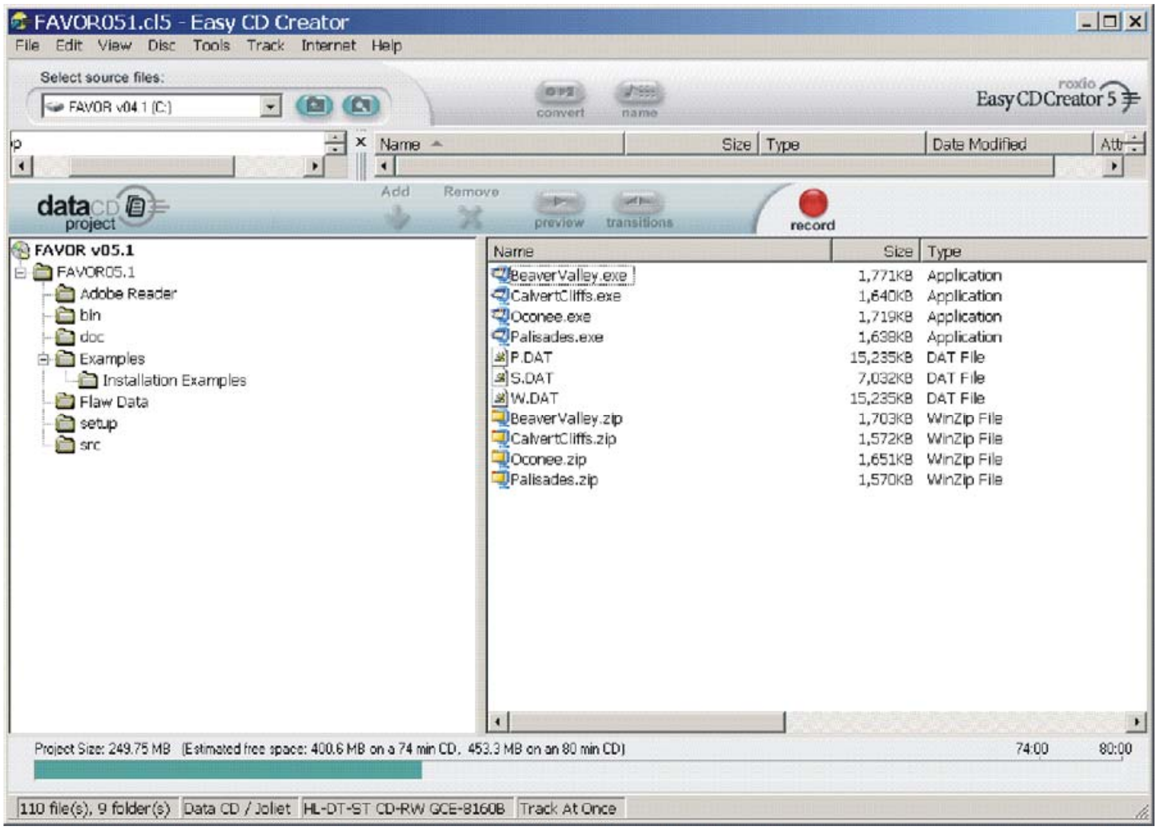
Name	Size	Type
FAVLoad.exe	456KB	Application
FAVPFM.exe	948KB	Application
FAVPost.exe	436KB	Application
FAILURE_01K.DAT	63KB	DAT File
INITIATE_01K.DAT	71KB	DAT File
NSIM.DAT	3KB	DAT File
P.DAT	15,235KB	DAT File
S.DAT	7,032KB	DAT File
W.DAT	15,235KB	DAT File
bflaws.echo	14KB	ECH File
EmbedA1.echo	40KB	ECH File
EmbedA2.echo	40KB	ECH File
EmbedA3.echo	40KB	ECH File
EmbedA4.echo	40KB	ECH File
EmbedB1.echo	40KB	ECH File
EmbedB2.echo	40KB	ECH File
EmbedC1.echo	40KB	ECH File
EmbedC2.echo	40KB	ECH File
EmbedC3.echo	40KB	ECH File
FAVPFM_01K.echo	3,526KB	ECH File
load4.echo	516KB	ECH File
bflaws.in	9KB	IN File

Project Size: 249.75 MB (Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD) 74:00 80:00

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

The files in this subfolder exercise the deterministic capabilities of FAVOR-EP. The file “bflaws.in” is a FAVLoad-EP input file for all of the “EmbedA?.in, EmbedB?.in, and EmbedC?.in” input files that calculate time-histories for embedded flaws using the case matrix developed for the Embedded Flaw Verification Study. The “FAVLoad-EP.in, FAVPFM-EP.in, and FAVPost-EP.in” files are input files for the same example case in Chapter 3, except that the number of RPV simulations have been reduced to 1000.

Subfolder: FAVOR-EP05.1\Flaw Data



- FAVOR v05.1
  - FAVOR05.1
    - Adobe Reader
    - bin
    - doc
    - Examples
      - Installation Examples
    - Flaw Data
    - setup
    - src

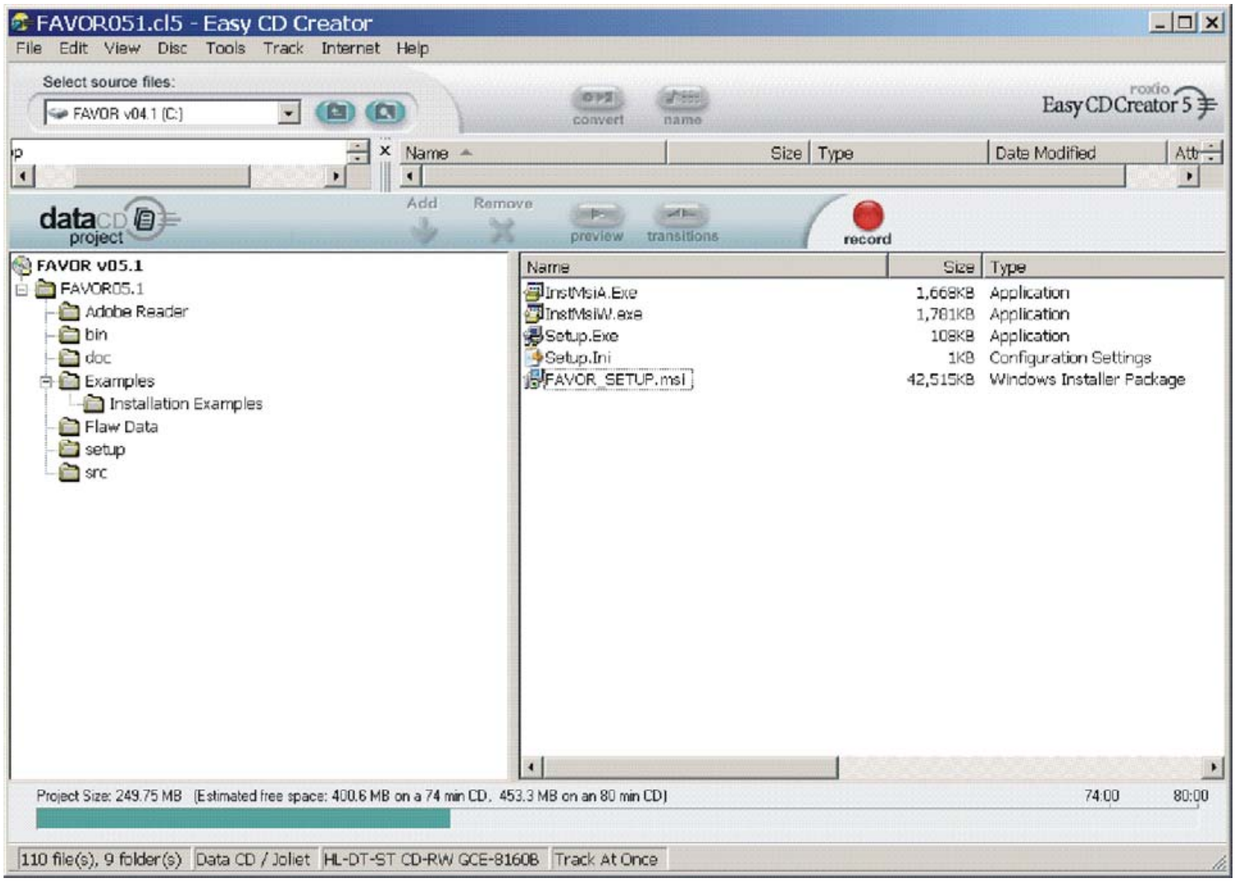
Name	Size	Type
BeaverValley.exe	1,771KB	Application
CalvertCliffs.exe	1,640KB	Application
Oconee.exe	1,719KB	Application
Palisades.exe	1,638KB	Application
P.DAT	15,235KB	DAT File
S.DAT	7,032KB	DAT File
W.DAT	15,235KB	DAT File
BeaverValley.zip	1,703KB	WinZip File
CalvertCliffs.zip	1,572KB	WinZip File
Oconee.zip	1,651KB	WinZip File
Palisades.zip	1,570KB	WinZip File

Project Size: 249.75 MB (Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD) 74:00 80:00

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

The three 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.exe” (Palisades NPP, South Haven, MI), “Oconee.exe” (Oconee NPP, Greeneville, SC), “CalvertCliffs.exe” (Calvert Cliffs NPP, Annapolis, MD), and “BeaverValley.exe” (Beaver Valley NPP, McCandless, PA) are self-extracting WINZIP archives containing the four plant-specific flaw-characterization files. Just execute the self-extracting archive file on the PC, and the user will be prompted for the files’ current FAVOR-EP working directory. The files “W.dat”, “S.dat”, and “P.dat” are the example files used in the installation examples.

Subfolder: FAVOR-EP05.1\setup



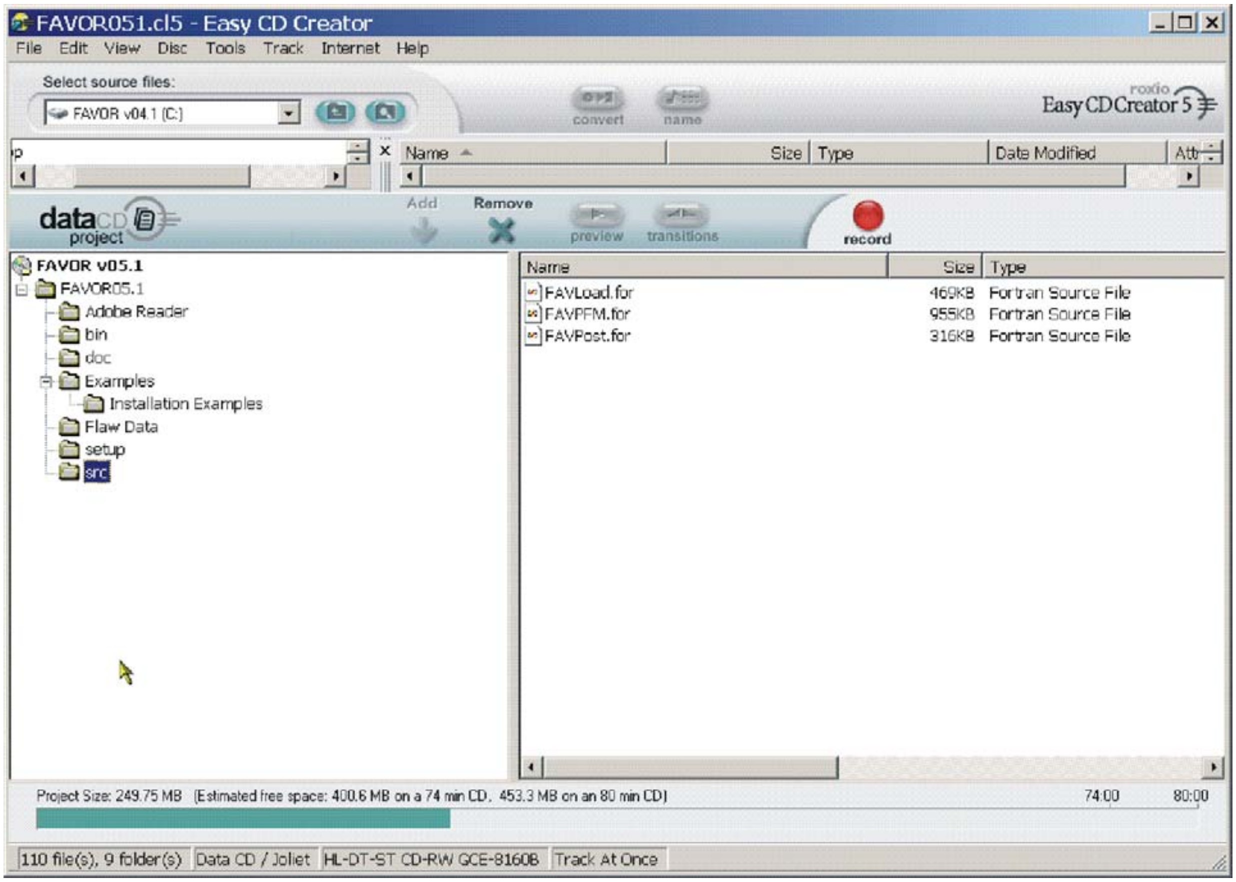
Name	Size	Type
InstMsiA.Exe	1,668KB	Application
InstMsiW.exe	1,781KB	Application
Setup.Exe	108KB	Application
Setup.Ini	1KB	Configuration Settings
FAVOR_SETUP.msi	42,515KB	Windows Installer Package

Project Size: 249.75 MB (Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD)

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

An automated procedure for installing FAVOR-EP on the user’s computer is provided in the .\FAVOR-EP05.1\setup subfolder. The user may execute the “SETUP.EXE” application in this folder, and the necessary files will be copied to a user-selected installation folder on the user’s hard drive. If the “autorun” feature on the user’s computer is enabled, then the Windows® Installer application will automatically run when the FAVOR-EP distribution CD is loaded into the CD drive. The Windows® installer will prompt the user for the target installation folder.

Subfolder: FAVOR-EP05.1\SRC



Name	Size	Type
FAVLoad.for	469KB	Fortran Source File
FAVPFM.for	955KB	Fortran Source File
FAVPost.for	316KB	Fortran Source File

Project Size: 249.75 MB (Estimated free space: 400.6 MB on a 74 min CD, 453.3 MB on an 80 min CD)

110 file(s), 9 folder(s) | Data CD / Joliet | HL-DT-ST CD-RW GCE-8160B | Track At Once

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

2. FAVOR-EP Input Requirements

FAVOR-EP employs ASCII files either created by the user or created by previous executions of the FAVOR-EP 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-EP 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-EP 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-EP Load Module – FAVLoad-EP^{EP}

A total of 12 data records, listed in Table 1, are required in the FAVLoad-EP^{EP} 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-EP Input File

Record	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
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	Tsfree=[°F]	CFP=[0|1]	s0=[ksi]	n_exp=[-]	m_Weibull=[-]		
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) [17]
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) [17]
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 [18]
Coefficient of Expansion – Table TE-1 – High Chrome Steels – p. 582-583
Density = 489 lbm/ft^3

FAVLoad-EP constructs monotone piecewise cubic-Hermite interpolants [19,20] for interpolation within the temperature-dependant property look-up tables.

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 recommended value of 468 °F was derived in reference [21].

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=468  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-EP output file. If NRAX or NRCR are set to a value of 0, then weld residual stresses will not be included in the FAVLoad-EP 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-EP. Internally, the FAVLoad-EP 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-EP module; therefore, **DT** is the time-step size that will be used for all fracture analyses in subsequent FAVPFM-EP 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-EP transient numbering system with the initiating-event sequence numbering system used in the thermal-hydraulic analyses that were performed to develop input to FAVOR-EP. The internal FAVOR-EP 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-EP 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 is used in imposing a Robin 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, $T_\infty\left(t\right)$ is the coolant temperature near the RPV wall in °F, and $T_{wall}\left(R,t\right)$ 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-EP 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-EP PFM Module – FAVPFM-EP

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-EP 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, **IGATR** (where **IGATR** is bounded from 100 to 1000, i.e., $100 \le \mathbf{IGATR} \le 1000$.), applied per flaw in the *Initiation-Growth-Arrest* (IGA) model, and sets the warm-prestressing option (**WPS_OPT=1)** on or off (**WPS_OPT=0).**

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-EP 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-EP 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. 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-EP 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-EP 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-EP. If **RESTART_OPTION** $\leq$ **0**, the current execution is not based on a restart of a previous run. At user-selected checkpoints during FAVPFM-EP execution, a binary restart file will be created (RESTART.BIN) which during a subsequent execution can be used to restart FAVPFM-EP 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** $\geq$ **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).

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

Record	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8
1	CNT1	NSIM=[-]	IGATR=[-]	WPS_OPT=[0|1]	PC3_OPT=[0|1]	CHILD_OPT=[0|1]	RESTART_OPTION=[≤0|≥1]		
2	CNT2	IRTNDT=[992|993]	TC=[°F]	EFPY=[yr]	IDT_OPT=[0|1|2]	IDT_INI=[0|1]			
3	CNT3	FLWSTR=[ksi]	USKIA=[ksi√in]	K_{Ia}_Model=[1|2]	LAYER_OPT=[0|1]	FAILCR=[-]			
4	GENR	SIGFGL=[-]	SIGFLC=[-]						
5	SIGW	WSIGCU=[wt%]	WSIGNI=[wt%]	WSIGP=[wt%]					
6	SIGP	PSIGCU=[wt%]	PSIGNI=[wt%]	PSIGP=[wt%]					
7	TRAC	ITRAN=[-]	IRPV=[-]	KFLAW=[-]	LOG_OPT=[0|1]				
8	LDQA	IQA=[0|1]	IOPT=[1|2]	IFLOR=[1|2]	IWELD=0|1]	IKIND=[1|2]	XIN=[in]	XVAR=[in|min]	ASPECT=[-]
9	DTRF	NT=[-]							
10	ISQ	ITRAN=[-]	ISEQ=[-]	TSTART=[min]	TEND=[min]				
11	ISQ	ITRAN=[-]	ISEQ=[-]	TSTART=[min]	TEND=[min]				
	…								
9+NT	ISQ	ITRAN=[-]	ISEQ=[-]	TSTART=[min]	TEND=[min]				
10+NT	WELD	NWSUB=[-]	NWMAJ=[-]						
11+NT	PLAT	NPSUB=[-]	NPMAJ=[-]						

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

Field	Description	Units
1	RPV Subregion Number (parent)	[-]
2	adjacent subregion number (1st child)	[-]
3	adjacent subregion number (2nd child)	[-]
4	RPV Major Region Number	[-]
5	best-estimate fast-neutron fluence at RPV inside surface	$[10^{19}$ n/cm$^2]$
6	heat-estimate copper content	[wt%]
7	heat-estimate nickel content	[wt%]
8	heat-estimate phosphorous content	[wt%]
9	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	[-]
	2 = not a CE vessel	[-]
10	Cu saturation flag	
	0 = plates and forgings	[-]
	1 = Linde 80 and Linde 91 weld fluxes	[-]
	2 = all other weld fluxes	[-]
11	best-estimate (mean) for unirradiated RT_{NDT0}	[°F]
12	best-estimate for standard deviation for unirradiated $RT_{NDT\,0}$	[°F]
13	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	[-]
14	standard deviation for ΔRT_{NDT} shift correlation	[°F]
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]

EXAMPLE

```
***********************************************************************************************************
*  ====================                                                                                   *
*  Control Record CNT1                                                                                    *
*  ====================                                                                                   *
*---------------------------------------------------------------------------------------------------------*
*  NSIM           = NUMBER OF RPV SIMULATIONS                                                         [-] *
*---------------------------------------------------------------------------------------------------------*
*  IGATR          = NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                          [-] *
*---------------------------------------------------------------------------------------------------------*
*  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                    [-] *
*  WPS_OPTION     = 1        INCLUDE WARM-PRESTRESSING IN ANALYSIS                                    [-] *
*---------------------------------------------------------------------------------------------------------*
*  PC3_OPTION     = 0 DO NOT PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                  [-] *
*  PC3_OPTION     = 1        PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                  [-] *
*---------------------------------------------------------------------------------------------------------*
*  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.      *
*                                                                                                         *
*  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=10000   IGATR=100    WPS_OPTION=1    PC3_OPTION=0    CHILD_OPTION=1   RESTART_OPTION=-50
***********************************************************************************************************
```

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 = 993 ➔ use the E900 correlation for irradiation shift in RT_{NDT}

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 v05.1 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-EP 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.

EXAMPLE

```
**********************************************************************************************************
*  ====================                                                                                  *
*  Control Record CNT2                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
* IRTNDT     = 992 ==> USE RG 1.99, REV 2,  FOR ESTIMATING RADIATION-INDUCED SHIFT IN RTNDT              *
* IRTNDT     = 993 ==> USE E900 CORRELATION FOR ESTIMATING RADIATION-INDUCED SHIFT IN RTNDT              *
*--------------------------------------------------------------------------------------------------------*
* TC         = INITIAL RPV COOLANT TEMPERATURE (applicable only when IRTNDT=993)                     [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 (recommended)          [-] *
* IDT_OPTION = 2         INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE (v03.1 model)          [-] *
*--------------------------------------------------------------------------------------------------------*
* IDT_INI    = 0  DO NOT CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                       [-] *
* IDT_INI    = 1         CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                       [-] *
*--------------------------------------------------------------------------------------------------------*
**********************************************************************************************************
CNT2 IRTNDT=993 TC=550 EFPY=32  IDT_OPTION=1  IDT_INI=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 $\mathrm{ksi}\sqrt{\mathrm{in.}}$, 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 $0.25 \le \mathrm{FAILCR} \le 0.95$.

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, $\widehat{f(0)}$ [5], is sampled from two normal distributions such that

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

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

---

[5] 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.

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=0.056 SIGFLC=0.118
***********************************************************************************************************
```

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.

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

$$
\begin{array}{lll}
 & \text{For Ni-addition welds} & \\
\overline{Cu} = Cu_{Heat} \times WSIGCU & \text{Heats 34B009 \&W5214} & \\
\sigma^{*}_{Cu} = \min(0.0718 \times Cu_{Heat}, 0.0185) & \widehat{Ni} \leftarrow N(Ni_{Heat}, WSIGNI) & \\
\widehat{\sigma_{Cu}} \leftarrow N(\overline{Cu}, \sigma^{*}_{Cu}) & ;\ WSIGNI = 0.162 & ;\ \widehat{P} \leftarrow N(P_{Heat}, WSIGP) \\
\widehat{Cu} \leftarrow N(Cu_{Heat}, \widehat{\sigma_{Cu}}) & \text{For other heats} & \\
 & \widehat{\sigma_{Ni}} \leftarrow N(0.029, 0.0165) & \\
 & \widehat{Ni} \leftarrow N(Ni_{Heat}, \widehat{\sigma_{Ni}}) &
\end{array}
$$

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-EP 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=12  KFLAW=270   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-EP 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

(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; 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                                                                     [-] *
*--------------------------------------------------------------------------------------------------------*
*   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-EP 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-EP 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-EP 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-EP 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-EP 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-EP 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-EP transient stack                                            [-
] *
*   ISEQ   = Thermal Hydraulic trasient sequence number                                              [-] *
*   TSTART = starting time for FAVPFM-EP analysis
[MIN] *
*   TEND   = ending time for FAVPFM-EP 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-EP 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-EP transient stack                                            [-
] *
*   ISEQ   = Thermal Hydraulic trasient sequence number                                              [-] *
*   TSTART = starting time for FAVPFM-EP analysis
[MIN] *
```

```
*   TEND   = ending time for FAVPFM-EP 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-EP 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-EP 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_{Heat}

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

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

(9) 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)

(9) if field 1 is a plate subregion with IRTNDT=993 on Record 2 (ignored if IRTNDT=992)

= 1 ➔ Combustion Engineering (CE) plate

= 2 ➔ all other plates and forgings

(10) copper saturation flag when IRTNDT = 993 on Record 2 (ignored if IRTNDT=992)

= 0 for plates and forgings

= 1 for Linde 80 and Linde 91 weld fluxes

= 2 for all other weld fluxes

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

(12) 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.

(13) Irradiation-shift-correlation flag when IRTNDT=993 on Record 2

= 11 ➔ weld major region

= 21 ➔ plate major region

= 31 ➔ forging major region

(13) 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

(14) Standard deviation for irradiation shift (°F) (not currently used in calculations)

(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)

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

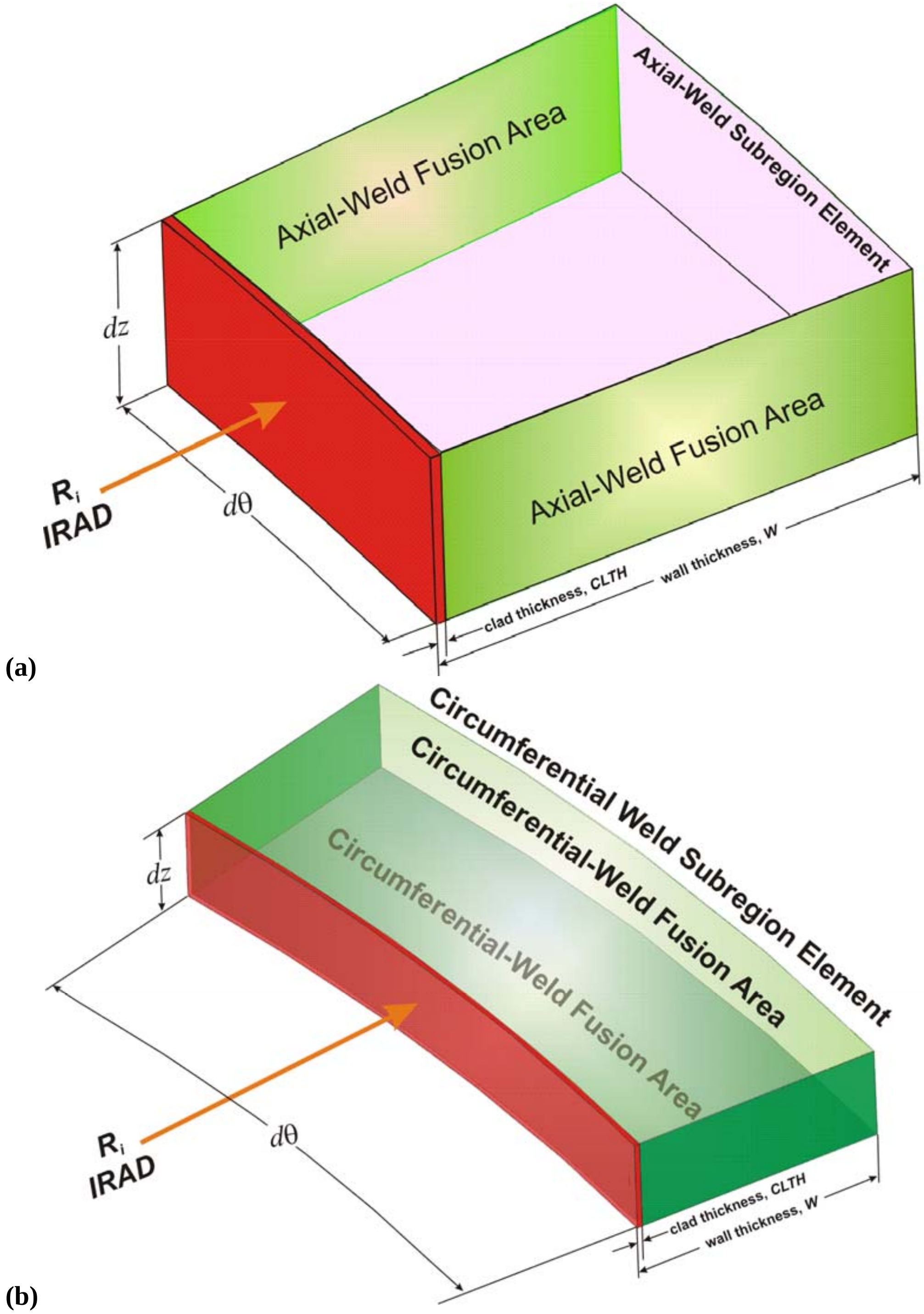


Fig. 17. Weld fusion area definitions for (a) axial-weld subregion elements and (b) circumferential-weld subregion elements.

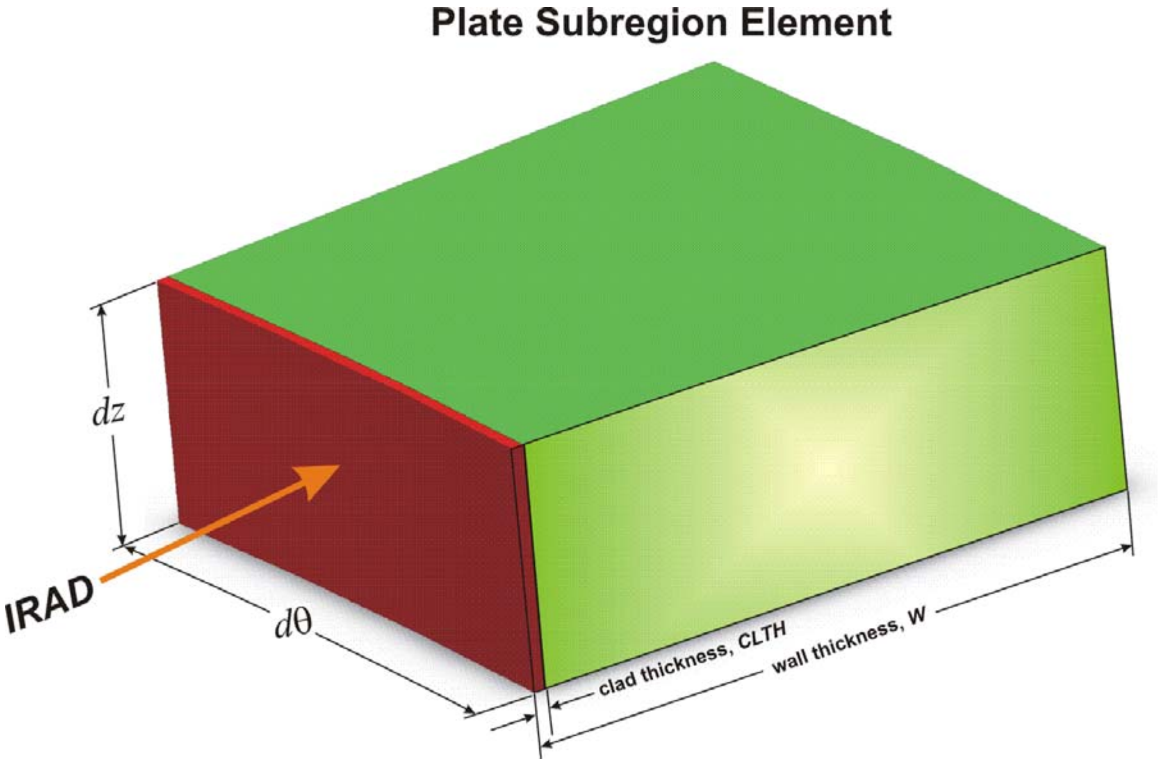


Fig. 17. (continued) (c) Plate subregion element.

EXAMPLE

```
**********************************************************************************************************
*                       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) heat estimate copper content                                                             [wt% Cu] *
*--------------------------------------------------------------------------------------------------------*
*  (7) heat estimate nickel content                                                             [wt% Ni] *
*--------------------------------------------------------------------------------------------------------*
*  (8) heat estimate phosphorus content                                                         [wt%  P] *
*--------------------------------------------------------------------------------------------------------*
*  (9) 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=993 then set B = 206)                                                   [-] *
*      Not CE = 2 (if IRTNDT=993 then set B = 156)                                                   [-] *
*      where CE is a Combustion Engineering vessel                                                       *
*--------------------------------------------------------------------------------------------------------*
* (10) copper saturation flag = 0 for plates and forgings                                            [-] *
*                             = 1 for Linde 80 and Linde 91 weld fluxes                                  *
*                             = 2 for all other weld fluxes                                              *
*       N.B.: maximum value of copper content (copper saturation)                                        *
*             = 0.25 for Linde 80 and = 0.305 for all others                                             *
*--------------------------------------------------------------------------------------------------------*
* (11) unirradiated best estimate (mean) for RTNDT0                                                  [F] *
*--------------------------------------------------------------------------------------------------------*
* (12) unirradiated standard deviation for RTNDT0                                                    [F] *
*--------------------------------------------------------------------------------------------------------*
* (13) PF flag      Product Form         CF Override                                                     *
*      -------      ------------         ------------                                                    *
*      = 11             weld                  no                                                     [-] *
*      = 12             weld                  yes                                                    [-] *
*      = 21             plate                 no                                                     [-] *
*      = 22             plate                 yes                                                    [-] *
*      = 31            forging                NA                                                     [-] *
*--------------------------------------------------------------------------------------------------------*
* (14) standard deviation for DRTNDT correlation                                                     [F] *
*--------------------------------------------------------------------------------------------------------*
* (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  (ignored if plate subregion)           [-] *
*--------------------------------------------------------------------------------------------------------*
* (19) chemistry factor override                                                                     [-] *
*--------------------------------------------------------------------------------------------------------*
* (20) unirradiated upper shelf CVN engergy (used only if IDT_OPTION=2)                         [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   17  : only applies to weld subregions. For plates set to 0.                              *
*    6. Field   19  : applicable only if IRTNDT=992 on CNT2 and Field 13 = 12 or 22                      *
*    7. Field   20  : applicable only if IDT_OPTION=2                                                    *
*========================================================================================================*
**********************************************************************************************************
* 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  2  2  -56.0 17.00 11 23.6  1.000  1.200  9.4500  1   0   98
00002 03594 03662  1 0.1173 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.000  1.199  9.4469  1   0   98
00003 03595 03663  1 0.1682 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.000  2.399 18.8969  1   0   98
00004 03596 03664  1 0.2317 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.000  2.204 17.3622  1   0   98
00005 03597 03665  1 0.3100 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.000  2.399 18.8969  1   0   98
                 :
                 .
**********************************************************************************************************
```

2.3 FAVOR-EP Post-Processing Module – FAVPost-EP

(2 × **NTRAN)** + 1 data records, listed in Table 3, are required in the FAVPost-EP 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-EP 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-EP 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-EP.

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-EP, v05.1               [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* – inner-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-EP 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 Inner-surface Breaking Flaws (Flaw Category 1)

A more detailed explanation of the format of the inner-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-EP 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-EP 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-EP','RDSURF',
     &       'SURFACE-BREAKING FLAW FILE NOT VERSION 05.1',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-EP','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-EP in which the (*J*,1,*IFILE*) address contains flaw densities of Category 1 (inner-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 (inner-surface breaking flaws) for plates/forgings.

SFLASPT (1:100,1:4,1:1000) is an array in FAVPFM-EP 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 inner-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-EP 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-EP','RDWELD',
     &      'EMBEDDED-FLAW WELD FILE NOT VERSION 05.1',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-EP','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-EP 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-EP 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-EP','RDPLAT',
     &      'EMBEDDED-FLAW PLATE FILE NOT VERSION 05.1',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-EP','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

Inner-surface breaking flaw density data are expressed in flaws per unit RPV-inner-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-EP. 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-EP) as the sum of the number of inner- surface breaking flaws and the number of embedded flaws as follows:

$$\begin{pmatrix}\text{Number of Flaws}\\ \text{in Weld Subregions}\end{pmatrix} = \rho_{SB}\left[\left(\frac{2\pi}{360}\right)R_i\; dz\; d\theta\right] + \rho_{EW}\left[2\left(\frac{3}{8}\right)dA\right]$$

$$\begin{aligned} \rho_{SB} &= \text{inner-surface breaking flaw density (per unit surface area - flaws/in}^2\text{)}\\ \rho_{EW} &= \text{weld embbed-flaw density (per unit weld-fusion area - flaws/in}^2\text{)}\\ dA &= \text{user-input weld-fusion area (for one side of weld) (in}^2\text{ - input by user)}\\ R_i &= \text{inner radius of RPV (in. - input by user)}\\ dz &= \text{height of subregion element (in. - input by user)}\\ d\theta &= \text{subtended angle of subregion element (degrees - input by user)} \end{aligned} \qquad \textbf{(1)}$$

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 (see Figs. 17a and 17b). In the term {2 (3/8) dA }, 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 (3/8) accounts for the fact that embedded flaws that reside beyond the first 3/8 of the base metal are not included in a PTS analysis. All 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-EP) as the sum of the number of inner-surface-breaking flaws and the number of embedded flaws as follows:

$$\begin{pmatrix}\text{Number of Flaws}\\ \text{in Plate Subregions}\end{pmatrix} = \rho_{SB}\left[\left(\frac{2\pi}{360}\right)R_i\ dz\ d\theta\right] + \rho_{EP}\left[\left(\frac{3}{8}\right)\pi\left(R_o^2-\left(R_i-CLTH\right)^2\right)dz\left(\frac{d\theta}{360}\right)\right] \tag{2}$$

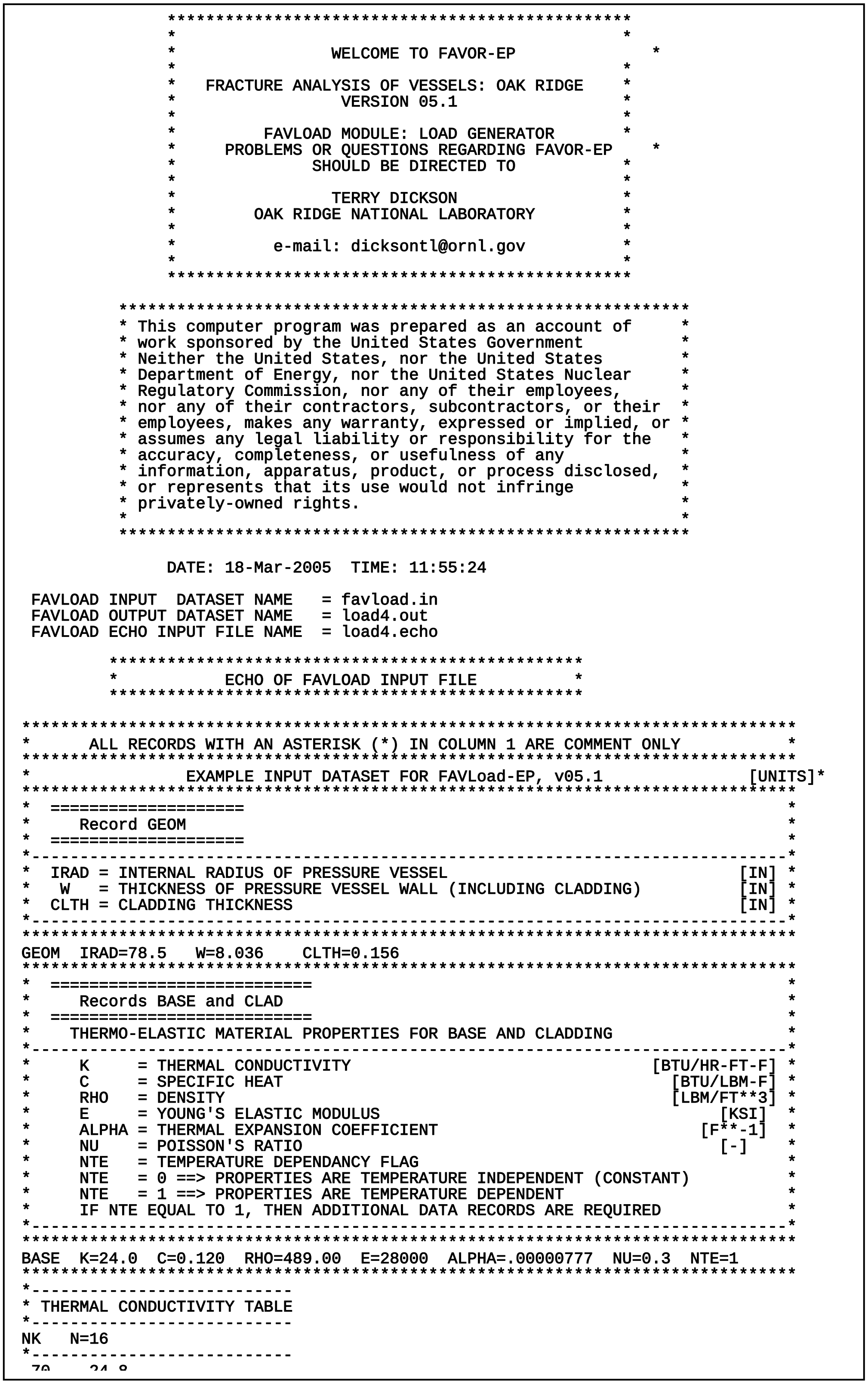
$\rho_{SB} =$ inner-surface breaking flaw density (per unit surface area - flaws/in^2)
$\rho_{EP} =$ plate embbed-flaw density summed over all flaw depths (flaws per unit volume - flaws/in^3)
$R_o =$ outer radius of RPV wall (in - input by user)
$R_i =$ inner radius of RPV wall (in. - input by user)
$CLTH =$ 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-EP Load Module – FAVLoad-EP Output

FAVLoad-EP creates two output files – (1) the load definition file (user-defined filename at time of execution) that will be input to FAVPFM-EP (*.out) and (2) *.echo which provides a date and time stamp of the execution and an echo of the FAVLoad-EP 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., LOAD4.out ⇒ LOAD4.echo.

LOAD4.echo



```
                *************************************************
                *                                               *
                *                WELCOME TO FAVOR-EP               *
                *                                               *
                *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE     *
                *                 VERSION 05.1                  *
                *                                               *
                *         FAVLOAD MODULE: LOAD GENERATOR        *
                *     PROBLEMS OR QUESTIONS REGARDING FAVOR-EP     *
                *              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: 18-Mar-2005  TIME: 11:55:24

 FAVLOAD INPUT  DATASET NAME   = favload.in
 FAVLOAD OUTPUT DATASET NAME   = load4.out
 FAVLOAD ECHO INPUT FILE NAME  = load4.echo

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

********************************************************************************
*      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY           *
********************************************************************************
*                EXAMPLE INPUT DATASET FOR FAVLoad-EP, v05.1               [UNITS]*
********************************************************************************
*  ====================                                                        *
*     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
*--------------------------
NK   N=16
*--------------------------
 70     24.8
```

2.6 FAVOR-EP PFM Module – FAVPFM-EP Output

FAVPFM-EP produces the following ten files:

General Output Files

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

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

(3) Binary restart file – restart.bin

Input files for FAVPost-EP

(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

The following pages present partial listings of example files: (1) FAVPFM-EP.OUT, (2) FAVPFM-EP.echo, (6) ARREST.OUT, (7) FLAWNO.OUT, (8) FLAWSIZE.OUT, (9) TRACE.OUT, and (10) FLAW_TRACK.LOG

FAVPFM-EP.echo includes two sections:

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

FAVPFM-EP.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-EP.echo

```
               ************************************************
               *                                              *
               *                WELCOME TO FAVOR-EP              *
               *                                              *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
               *                 VERSION 05.1                 *
               *                                              *
               *     FAVPFM-EP MODULE: PERFORMS PROBABILISTIC    *
               *          FRACTURE MECHANICS ANALYSES         *
               *                                              *
               *    PROBLEMS OR QUESTIONS REGARDING FAVOR-EP     *
               *            SHOULD BE DIRECTED TO             *
               *                                              *
               *                TERRY DICKSON                 *
               *        HEAVY SECTION STEEL TECHNOLOGY        *
               *        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: 18-Mar-2005  TIME: 11:59:41

               FAVPFM-EP INPUT FILE NAME       = FAVPFM-EP.IN
               FAVLOAD OUTPUT FILE NAME     = LOAD4.OUT
               FAVPFM-EP OUTPUT FILE NAME      = FAVPFM-EP_10K.OUT
               FAVPFM-EP INPUT ECHO FILE NAME  = FAVPFM-EP_10K.echo


                Begin echo of first 200 lines of FAVPFM-EP input data deck          11:59:41   18-Mar-2005

 no./col.
1.......10........20........30........40........50........60........70........80........90.......100.......110.......120....
     1    **********************************************************************************************************
     2    *              ALL RECORDS WITH AN ASTERISK(*) IN COLUMN 1 ARE COMMENT ONLY                              *
     3    **********************************************************************************************************
     4    *                         EXAMPLE INPUT DATASET FOR FAVPFM-EP, v05.1                                 [UNITS]*
     5    **********************************************************************************************************
     6    *  ====================                                                                                  *
     7    *  Control Record CNT1                                                                                   *
     8    *  ====================                                                                                  *
     9    *--------------------------------------------------------------------------------------------------------*
    10    *  NSIM           = NUMBER OF RPV SIMULATIONS                                                        [-] *
    11    *--------------------------------------------------------------------------------------------------------*
    12    *  IGATR          = NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                         [-] *
    13    *--------------------------------------------------------------------------------------------------------*
    14    *  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                   [-] *
    15    *  WPS_OPTION     = 1        INCLUDE WARM-PRESTRESSING IN ANALYSIS                                   [-] *
    16    *--------------------------------------------------------------------------------------------------------*
    17    *  PC3_OPTION     = 0 DO NOT PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                 [-] *
    18    *  PC3_OPTION     = 1        PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                 [-] *
    19    *--------------------------------------------------------------------------------------------------------*
    20    *  CHILD_OPTION   = 0 DO NOT INCLUDE CHILD SUBREGION REPORTS                                         [-] *
    21    *  CHILD_OPTION   = 1        INCLUDE CHILD SUBREGION REPORTS                                         [-] *
    22    *--------------------------------------------------------------------------------------------------------*
    23    *  RESTART_OPTION = 0 THIS IS NOT A RESTART CASE                                                     [-] *
    24    *  RESTART_OPTION = 1 THIS IS A RESTART CASE                                                         [-] *
    25    *--------------------------------------------------------------------------------------------------------*
    26    *  =============================                                                                         *
    27    *  Notes for Control Record CNT1                                                                         *
    28    *  =============================                                                                         *
    29    *  IN A TYPICAL PFM ANALYSIS, A SUBSTANTIAL FRACTION OF THE TOTAL FLAWS ARE CATEGORY 3 FLAWS IN          *
    30    *  PLATE REGIONS. BASED ON EXPERIENCE AND SOME DETERMINISTIC FRACTURE ANALYSES, THESE FLAWS VERY         *
    31    *  RARELY CONTRIBUTE TO THE CPI OR CPF WITH THE PLATE FLAW SIZE DISTRIBUTIONS TYPICALLY USED.            *
    32    *  THEREFORE, INVOKING IP3OPT = 0 CAN RESULT IN A SIGNIFICANT REDUCTION IN EXECUTION TIME WITHOUT        *
    33    *  AFFECTING THE SOLUTION, UNLESS THERE ARE UNUSUAL CIRCUMSTANCES SUCH AS A NEW FLAW-SIZE                *
    34    *  DISTRIBUTION FOR PLATE FLAWS. IN EITHER CASE, CATEGORY 3 PLATE FLAWS ARE INCLUDED IN ALL REPORTS.     *
    35    *                                                                                                        *
    36    *  Notes on Restart Option:                                                                              *
    37    *                                                                                                        *
    38    *  The restart option flag can also be used to control the frequency with which restart files are        *
    39    *  created. If RESTART_OPTION is given a value other than 0 or 1, then the absolute value of this flag   *
    40    *  sets the checkpoint interval at which the restart file will be created during the run. For example,   *
    41    *                                                                                                        *
    42    * 1.RESTART_OPTION = -200 ==> This is not a restart case; restart files will be created every 200 trials *
    43    * 2.RESTART_OPTION =    0 ==> Same as example No. 1.                                                     *
    44    * 3.RESTART_OPTION =  200 ==> This is a restart case;     restart files will be created every 200 trials.*
    45    * 4.RESTART_OPTION =    1 ==> Same as example No. 3.                                                     *
    46    * 5.RESTART_OPTION =  -50 ==? This is not a restart case; restart files will be created every 50 trials. *
    47    *                                                                                                        *
    48    *                                                                                                        *
    49    *--------------------------------------------------------------------------------------------------------*
    50    **********************************************************************************************************
    51    CNT1  NSIM=10000    IGATR=100    WPS_OPTION=0    PC3_OPTION=0    CHILD_OPTION=1   RESTART_OPTION=0
    52    **********************************************************************************************************
          *                                                                                                        *
```

FAVPFM-EP.out

```
               *************************************************
               *                                              *
               *                WELCOME TO FAVOR-EP              *
               *                                              *
               *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
               *                 VERSION 05.1                 *
               *                                              *
               *     FAVPFM-EP MODULE: PERFORMS PROBABILISTIC    *
               *          FRACTURE MECHANICS ANALYSES         *
               *                                              *
               *    PROBLEMS OR QUESTIONS REGARDING FAVOR-EP     *
               *            SHOULD BE DIRECTED TO             *
               *                                              *
               *                TERRY DICKSON                 *
               *        HEAVY SECTION STEEL TECHNOLOGY        *
               *        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: 18-Mar-2005  TIME: 11:59:41

               FAVPFM-EP INPUT FILE NAME       = FAVPFM-EP.IN
               FAVLOAD OUTPUT FILE NAME     = LOAD4.OUT
               FAVPFM-EP OUTPUT FILE NAME      = FAVPFM-EP_10K.OUT
               FAVPFM-EP INPUT ECHO FILE NAME  = FAVPFM-EP_10K.echo



                Begin echo of first 200 lines of FAVPFM-EP input data deck         11:59:41   18-Mar-2005
no./col.
1.......10........20........30........40........50........60........70........80........90.......100.......110.......120....
     1    **********************************************************************************************************
     2    *              ALL RECORDS WITH AN ASTERISK(*) IN COLUMN 1 ARE COMMENT ONLY                              *
     3    **********************************************************************************************************
     4    *                         EXAMPLE INPUT DATASET FOR FAVPFM-EP, v05.1                                 [UNITS]*
     5    **********************************************************************************************************
     6    *  ====================                                                                                  *
     7    *  Control Record CNT1                                                                                   *
     8    *  ====================                                                                                  *
     9    *--------------------------------------------------------------------------------------------------------*
    10    *  NSIM           = NUMBER OF RPV SIMULATIONS                                                        [-] *
    11    *--------------------------------------------------------------------------------------------------------*
    12    *  IGATR          = NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                         [-] *
    13    *--------------------------------------------------------------------------------------------------------*
    14    *  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                   [-] *
    15    *  WPS_OPTION     = 1        INCLUDE WARM-PRESTRESSING IN ANALYSIS                                   [-] *
    16    *--------------------------------------------------------------------------------------------------------*
    17    *  PC3_OPTION     = 0 DO NOT PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                 [-] *
    18    *  PC3_OPTION     = 1        PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                 [-] *
    19    *--------------------------------------------------------------------------------------------------------*
    20    *  CHILD_OPTION   = 0 DO NOT INCLUDE CHILD SUBREGION REPORTS                                         [-] *
    21    *  CHILD_OPTION   = 1        INCLUDE CHILD SUBREGION REPORTS                                         [-] *
    22    *--------------------------------------------------------------------------------------------------------*
    23    *  RESTART_OPTION = 0 THIS IS NOT A RESTART CASE                                                     [-] *
    24    *  RESTART_OPTION = 1 THIS IS A RESTART CASE                                                         [-] *
    25    *--------------------------------------------------------------------------------------------------------*
    26    *  =============================                                                                         *
    27    *  Notes for Control Record CNT1                                                                         *
    28    *  =============================                                                                         *
    29    *  IN A TYPICAL PFM ANALYSIS, A SUBSTANTIAL FRACTION OF THE TOTAL FLAWS ARE CATEGORY 3 FLAWS IN          *
    30    *  PLATE REGIONS. BASED ON EXPERIENCE AND SOME DETERMINISTIC FRACTURE ANALYSES, THESE FLAWS VERY         *
    31    *  RARELY CONTRIBUTE TO THE CPI OR CPF WITH THE PLATE FLAW SIZE DISTRIBUTIONS TYPICALLY USED.            *
    32    *  THEREFORE, INVOKING IP3OPT = 0 CAN RESULT IN A SIGNIFICANT REDUCTION IN EXECUTION TIME WITHOUT        *
    33    *  AFFECTING THE SOLUTION, UNLESS THERE ARE UNUSUAL CIRCUMSTANCES SUCH AS A NEW FLAW-SIZE                *
    34    *  DISTRIBUTION FOR PLATE FLAWS. IN EITHER CASE, CATEGORY 3 PLATE FLAWS ARE INCLUDED IN ALL REPORTS.     *
    35    *                                                                                                        *
    36    *  Notes on Restart Option:                                                                              *
    37    *                                                                                                        *
    38    *  The restart option flag can also be used to control the frequency with which restart files are        *
    39    *  created. If RESTART_OPTION is given a value other than 0 or 1, then the absolute value of this flag   *
    40    *  sets the checkpoint interval at which the restart file will be created during the run. For example,   *
    41    *                                                                                                        *
    42    * 1.RESTART_OPTION = -200 ==> This is not a restart case; restart files will be created every 200 trials *
    43    * 2.RESTART_OPTION =    0 ==> Same as example No. 1.                                                     *
    44    * 3.RESTART_OPTION =  200 ==> This is a restart case;     restart files will be created every 200 trials.*
    45    * 4.RESTART_OPTION =    1 ==> Same as example No. 3.                                                     *
    46    * 5.RESTART_OPTION =  -50 ==? This is not a restart case; restart files will be created every 50 trials. *
    47    *                                                                                                        *
    48    *                                                                                                        *
    49    *--------------------------------------------------------------------------------------------------------*
    50    **********************************************************************************************************
```

FAVPFM-EP.OUT (continued)

```
15643    ************************************************************************************************************
 15644    ***************************************** END OF EMBRITTLEMENT MAP *****************************************
 15645    ************************************************************************************************************
 no./col.
1.......10........20........30........40........50........60........70........80........90.......100.......110.......120.....
..130

                End echo of FAVPFM-EP input data deck          11:59:41   18-Mar-2005

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

 NUMBER OF TIME STEPS IN FAVLoad-EP FILE   =   161
 NUMBER OF CONTRACTED TIME WINDOWS      =     4
 ITRAN =    1 ISEQ =    7   TIME_FIRST(  5)=   2.0 TIME_LAST( 71)=  35.0
 ITRAN =    2 ISEQ =    9   TIME_FIRST(  3)=   1.0 TIME_LAST( 59)=  29.0
 ITRAN =    3 ISEQ =   56   TIME_FIRST( 19)=   9.0 TIME_LAST(113)=  56.0
 ITRAN =    4 ISEQ =   97   TIME_FIRST( 23)=  11.0 TIME_LAST(161)=  85.0

 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.

 DEFINITION OF STANDARD DEVIATIONS FOR SIMULATING
 THE FOLLOWING PARAMETERS

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

 NUMBER OF VESSEL SUBREGIONS:    WELD=  838 PLATE=14442 TOTAL=15280
 NUMBER OF VESSEL MAJOR REGIONS: WELD=    5 PLATE=    4 TOTAL=    9

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

                                  *******************************************
                                  ** WELD LAYER RESAMPLING TURNED ON       **
                                  ** WARM-PRESTRESSING TURNED OFF          **
                                  ** DO NOT ANALYZE CATEGORY 3 PLATE FLAWS **
                                  ** DUCTILE TEARING MODEL TURNED ON       **
                                  ** FAILURE CRITERIA a/t =   0.90         **
                                  *******************************************


                                  *********************************************
                                  *********************************************
                                  **  PFM RESULTS FOR TRANSIENT NUMBER   7   **
                                  *********************************************
                                  *********************************************

                                  *********************************************
                                  **                                         **
                                  **  NUMBER OF COMPLETED TRIALS =   10000   **
                                  **                                         **
                                  *********************************************

                                         MEAN VALUE OF CPI =     3.928E-03
                                         MEAN VALUE OF CPF =     8.257E-05

                                      *************************************
                                      *  RPV BELTLINE MAJOR REGION REPORT *
                                      *       BY PARENT SUBREGION         *
                                      *************************************
  ====================================================================================================
                                         |---Initiation---|  |----Cleavage----| |------Ductile-----|
   MAJOR     RTndt  % OF     SIMULATED    # of FLAWS  % of     # of FLAWS  % of   # of FLAWS    % of
   REGION    (MAX)  FLAWS      FLAWS       CPI > 0   CPI       CPF > 0     CPF       CPF > 0     CPF
  ====================================================================================================
     1       170.7   2.30    1115117       827        0.50       30        0.32       717         0.61
     2       170.7   2.30    1114104       877        0.30       23        0.13       768         0.30
     3       158.0   3.70    1799159      4428        3.47      664       12.49      3555         6.96
     4       158.0   3.70    1801693      4448        4.73      683       17.43      3525        10.45
     5        95.4  19.31    9384437     60181       87.74      650        0.25        93         0.02
     6       225.7  13.15    6366567      1214        0.12      671        1.35         5         0.30
     7       204.0  13.15    6365674       300        0.01      160        0.07         9         0.03
```

FAVPFM-EP.OUT (continued)

```
                                *********************************************
                                *********************************************
                                **  PFM RESULTS FOR TRANSIENT NUMBER   7   **
                                *********************************************
                                *********************************************

                                *********************************************
                                **                                         **
                                **  NUMBER OF COMPLETED TRIALS =   10000   **
                                **                                         **
                                *********************************************

                                       MEAN VALUE OF CPI =     3.928E-03
                                       MEAN VALUE OF CPF =     8.257E-05

                                    *************************************
                                    *  RPV BELTLINE MAJOR REGION REPORT *
                                    *       BY PARENT SUBREGION         *
                                    *************************************
====================================================================================================
                                       |---Initiation---|   |----Cleavage----| |------Ductile-----|
 MAJOR     RTndt  % OF     SIMULATED    # of FLAWS  % of      # of FLAWS  % of   # of FLAWS    % of
 REGION    (MAX)  FLAWS      FLAWS       CPI > 0   CPI        CPF > 0     CPF       CPF > 0     CPF
====================================================================================================
   1       170.7   2.30    1115117       827        0.50        30        0.32       717        0.61
   2       170.7   2.30    1114104       877        0.30        23        0.13       768        0.30
   3       158.0   3.70    1799159      4428        3.47       664       12.49      3555        6.96
   4       158.0   3.70    1801693      4448        4.73       683       17.43      3525       10.45
   5        95.4  19.31    9384437     60181       87.74       650        0.25        93        0.02
   6       225.7  13.15    6366567      1214        0.12       671        1.35         5        0.30
   7       204.0  13.15    6365674       300        0.01       160        0.07         9        0.03
   8       260.9  21.20   10263653      9692        2.63      6368       40.36        57        4.65
   9       230.9  21.20   10265316      2481        0.49      1363        3.48        47        0.81
====================================================================================================
          TOTALS 100.00   48475720     84448      100.00     10612       75.87      8776       24.13
====================================================================================================

                               NOTE: MEAN VALUE OF RTNDT AT CRACK TIP=  125.51
                                    *************************************
                                    *  RPV BELTLINE MAJOR REGION REPORT *
                                    *       BY CHILD SUBREGION          *
                                    *************************************
====================================================================================================
                                       |---Initiation---|   |----Cleavage----| |------Ductile-----|
 MAJOR     RTndt  % OF     SIMULATED    # of FLAWS  % of      # of FLAWS  % of   # of FLAWS    % of
 REGION    (MAX)  FLAWS      FLAWS       CPI > 0   CPI        CPF > 0     CPF       CPF > 0     CPF
====================================================================================================
   1       170.7   2.30          0         0        0.00         0        0.00         0        0.00
   2       170.7   2.30          0         0        0.00         0        0.00         0        0.00
   3       158.0   3.70          0         0        0.00         0        0.00         0        0.00
   4       158.0   3.70          0         0        0.00         0        0.00         0        0.00
   5        95.4  19.31          0         0        0.00         0        0.00         0        0.00
   6       225.7  13.15   10339823      6874        4.06       724        1.80      1490        1.21
   7       204.0  13.15    6365674       300        0.01       160        0.07         9        0.03
   8       260.9  21.20   18545941     61357       78.29      8352       70.52      7212       22.07
   9       230.9  21.20   13224282     15917       17.64      1376        3.48        65        0.81
====================================================================================================
          TOTALS 100.00   48475720     84448      100.00     10612       75.87      8776       24.13
====================================================================================================


              *******************************************************
              **     DUCTILE TEARING MODEL TURNED ON               **
              *******************************************************
              **  NUMBER OF NUMBER OF CL    INITIATIONS    1834418 **
              **  NUMBER OF NUMBER OF CL/DT INITIATIONS          0 **
              **  NUMBER OF NUMBER OF DT INITIATIONS             0 **
              *******************************************************
```

FAVPFM-EP.OUT (continued)

```
                ********************************************** 
                * FLAW DISTRIBUTION BY MATERIAL AND CATEGORY *
                *             BY PARENT SUBREGION            *
                **********************************************
               ==================================================
                                   WELD MATERIAL
               ==================================================
                number of   number    % of     number    % of
                simulated    with     total     with     total
                   flaws    CPI>0      CPI     CPF>0     CPF
               ==================================================
FLAW CATEGORY 1         0       0      0.00       0      0.00
FLAW CATEGORY 2   5069800   70750     96.74   10708     48.95
FLAW CATEGORY 3  10144710      11      0.00       0      0.00
               ==================================================
     TOTALS      15214510   70761     96.74   10708     48.95
               ==================================================


               ==================================================
                                  PLATE MATERIAL
               ==================================================
                number of   number    % of     number    % of
                simulated    with     total     with     total
                   flaws    CPI>0      CPI     CPF>0     CPF
               ==================================================
FLAW CATEGORY 1         0       0      0.00       0      0.00
FLAW CATEGORY 2  11089013   13687      3.26    8680     51.05
FLAW CATEGORY 3  22172197       0      0.00       0      0.00
               ==================================================
     TOTALS      33261210   13687      3.26    8680     51.05
               ==================================================

                **********************************************
                * FLAW DISTRIBUTION BY MATERIAL AND CATEGORY *
                *             BY CHILD SUBREGION             *
                **********************************************
               ==================================================
                                   WELD MATERIAL
               ==================================================
                number of   number    % of     number    % of
                simulated    with     total     with     total
                   flaws    CPI>0      CPI     CPF>0     CPF
               ==================================================
FLAW CATEGORY 1         0       0      0.00       0      0.00
FLAW CATEGORY 2         0       0      0.00       0      0.00
FLAW CATEGORY 3         0       0      0.00       0      0.00
               ==================================================
     TOTALS             0       0      0.00       0      0.00
               ==================================================


               ==================================================
                                  PLATE MATERIAL
               ==================================================
                number of   number    % of     number    % of
                simulated    with     total     with     total
                   flaws    CPI>0      CPI     CPF>0     CPF
               ==================================================
FLAW CATEGORY 1         0       0      0.00       0      0.00
FLAW CATEGORY 2  16158813   84437    100.00   19388    100.00
FLAW CATEGORY 3  32316907      11      0.00       0      0.00
               ==================================================
     TOTALS      48475720   84448    100.00   19388    100.00
               ==================================================


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

```
                   **********************************************************
                   * FLAW DISTRIBUTION BY MATERIAL, CATEGORY, & ORIENTATION *
                   *                  BY PARENT SUBREGION                   *
                   **********************************************************
                     ==================================================
                                         WELD MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2   1942438   35702     47.45    5414     24.23
AXIAL FLAW CATEGORY 3   3887635       4      0.00       0      0.00
                     ==================================================
AXIAL SUBTOTALS         5830073   35706     47.45    5414     24.23
                     ==================================================

CIRC. FLAW CATEGORY 1         0       0      0.00       0      0.00
CIRC. FLAW CATEGORY 2   3127362   35048     49.29    5294     24.72
CIRC. FLAW CATEGORY 3   6257075       7      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS         9384437   35055     49.29    5294     24.72
                     ==================================================
WELD TOTALS            15214510   70761     96.74   10708     48.95
                     ==================================================


                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2   5545405    7115      1.93    7104     50.74
AXIAL FLAW CATEGORY 3  11086058       0      0.00       0      0.00
                     ==================================================
AXIAL SUBTOTALS        16631463    7115      1.93    7104     50.74
                     ==================================================
CIRC. FLAW CATEGORY 1         0       0      0.00       0      0.00
CIRC. FLAW CATEGORY 2   5543608    6572      1.33    1576      0.31
CIRC. FLAW CATEGORY 3  11086139       0      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS        16629747    6572      1.33    1576      0.31
                     ==================================================
PLATE TOTALS           33261210   13687      3.26    8680     51.05
                     ==================================================


                     ==================================================
                   **********************************************************
                   * 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         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 3         0       0      0.00       0      0.00
                     ==================================================
AXIAL SUBTOTALS               0       0      0.00       0      0.00
                     ==================================================
CIRC. FLAW CATEGORY 1         0       0      0.00       0      0.00
CIRC. FLAW CATEGORY 2         0       0      0.00       0      0.00
CIRC. FLAW CATEGORY 3         0       0      0.00       0      0.00
                     ==================================================
CIRC. SUBTOTALS               0       0      0.00       0      0.00
                     ==================================================
WELD TOTALS                   0       0      0.00       0      0.00

                     ==================================================
                                         PLATE MATERIAL
                     ==================================================
                      number of   number    % of     number    % of
                      simulated    with     total     with     total
                         flaws    CPI>0      CPI     CPF>0     CPF
                     ==================================================
AXIAL FLAW CATEGORY 1         0       0      0.00       0      0.00
AXIAL FLAW CATEGORY 2   8079999   42817     49.38   12518     74.97
AXIAL FLAW CATEGORY 3  16157861       4      0.00       0      0.00
                     ==================================================
```

FAVPFM-EP.OUT (continued)

```
              *********************************************
              *     WELD FLAW-SIZE DISTRIBUTION REPORT    *
              * FOR CONDITIONAL PROBABILITY OF INITIATION *
              *********************************************
=========================================================================
flaw  simulated  #   % of    simulated  #   % of    simulated  #   % of
depth  catgy 1 with total     catgy 2 with total     catgy 3 with  total
(in)    flaws  CPI>0 CPI       flaws  CPI>0 CPI       flaws  CPI>0  CPI
=========================================================================
0.080     0     0   0.00   4045055  21366   1.08   8090336     0   0.00
0.161     0     0   0.00    912017  39264  34.49   1827831     0   0.00
0.241     0     0   0.00     81771   6323  20.49    164759     0   0.00
0.321     0     0   0.00     17959   1835  10.99     36184     1   0.00
0.402     0     0   0.00      7057    892   9.61     13979     2   0.00
0.482     0     0   0.00      2942    483   5.09      5754     4   0.00
0.563     0     0   0.00      1351    230   2.39      2685     1   0.00
0.643     0     0   0.00       688    116   4.53      1290     0   0.00
0.723     0     0   0.00       341     83   1.93       694     2   0.00
0.804     0     0   0.00       220     61   2.19       413     0   0.00
0.884     0     0   0.00       122     23   0.38       267     0   0.00
0.964     0     0   0.00        89     23   1.35       152     0   0.00
1.045     0     0   0.00        49     13   0.61        98     0   0.00
1.125     0     0   0.00        42     14   0.23        72     1   0.00
1.205     0     0   0.00        28      9   1.06        53     0   0.00
1.286     0     0   0.00        21      8   0.14        42     0   0.00
1.366     0     0   0.00        18      0   0.00        34     0   0.00
1.446     0     0   0.00         4      0   0.00        17     0   0.00
1.527     0     0   0.00         6      1   0.01        16     0   0.00
1.607     0     0   0.00         4      0   0.00        10     0   0.00
1.688     0     0   0.00         5      2   0.00        10     0   0.00
1.768     0     0   0.00         2      0   0.00         7     0   0.00
1.848     0     0   0.00         7      4   0.17         4     0   0.00
1.929     0     0   0.00         2      0   0.00         3     0   0.00
=========================================================================
TOTALS     0     0   0.00   5069800  70750  96.74  10144710    11   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
=========================================================================
0.080     0     0   0.00   6632873    824   0.01  13263042     0   0.00
0.161     0     0   0.00   3752674   5627   0.55   7502148     0   0.00
0.241     0     0   0.00    640234   5529   0.87   1281442     0   0.00
0.321     0     0   0.00     56175   1338   0.97    111704     0   0.00
0.402     0     0   0.00      7057    369   0.86     13861     0   0.00
=========================================================================
TOTALS     0     0   0.00  11089013  13687   3.26  22172197     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
=========================================================================
0.080     0     0   0.00   4045055   2410   0.23   8090336     0   0.00
0.161     0     0   0.00    912017   6453  16.72   1827831     0   0.00
0.241     0     0   0.00     81771   1126  10.87    164759     0   0.00
0.321     0     0   0.00     17959    338   6.66     36184     0   0.00
0.402     0     0   0.00      7057    164   5.12     13979     0   0.00
0.482     0     0   0.00      2942     97   3.87      5754     0   0.00
0.563     0     0   0.00      1351     45   3.84      2685     0   0.00
0.643     0     0   0.00       688     25   0.91      1290     0   0.00
0.723     0     0   0.00       341     19   0.66       694     0   0.00
0.804     0     0   0.00       220     11   0.03       413     0   0.00
0.884     0     0   0.00       122      4   0.02       267     0   0.00
0.964     0     0   0.00        89      4   0.01       152     0   0.00
1.045     0     0   0.00        49      4   0.01        98     0   0.00
1.125     0     0   0.00        42      2   0.00        72     0   0.00
1.205     0     0   0.00        28      2   0.00        53     0   0.00
1.286     0     0   0.00        21      2   0.00        42     0   0.00
1.366     0     0   0.00        18      0   0.00        34     0   0.00
1.446     0     0   0.00         4      0   0.00        17     0   0.00
1.527     0     0   0.00         6      0   0.00        16     0   0.00
1.607     0     0   0.00         4      0   0.00        10     0   0.00
```

FAVPFM-EP.OUT (continued)

```
              *********************************************
              *    PLATE 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
=========================================================================
0.080      0     0   0.00   6632873    635   0.22  13263042     0   0.00
0.161      0     0   0.00   3752674   3806   8.88   7502148     0   0.00
0.241      0     0   0.00    640234   3300  13.91   1281442     0   0.00
0.321      0     0   0.00     56175    739  16.82    111704     0   0.00
0.402      0     0   0.00      7057    200  11.23     13861     0   0.00
=========================================================================
TOTALS     0     0   0.00  11089013   8680  51.05  22172197     0   0.00
=========================================================================


             ===============================================
                 **************************************
                 * TRANSIENT TIME DISTRIBUTION REPORT *
                 *    for transient sequence   7      *
                 **************************************
             ===============================================
             TIME   TIME    % of    CDF of    % of    CDF of
             STEP   (min)   total   total     total   total
                            CDCPI   CDCPI     CDCPF   CDCPF
             ===============================================
             13     6.0   0.0000   0.0000   0.0000   0.0000
             14     6.5   0.0079   0.0079   0.0000   0.0000
             15     7.0   0.0889   0.0968   0.0114   0.0114
             16     7.5   0.0513   0.1481   0.0088   0.0201
             17     8.0   0.2208   0.3689   0.0848   0.1049
             18     8.5   0.5465   0.9154   0.3191   0.4240
             19     9.0   0.5257   1.4411   0.3591   0.7831
             20     9.5   1.4260   2.8671   1.2452   2.0283
             21    10.0   2.2632   5.1303   2.1962   4.2245
             22    10.5   4.4667   9.5970   5.0623   9.2868
             23    11.0   8.1260  17.7229  10.0058  19.2926
             24    11.5  11.9966  29.7195  15.5053  34.7979
             25    12.0  10.7333  40.4528  13.3448  48.1427
             26    12.5   8.1521  48.6049   8.8631  57.0057
             27    13.0  10.9371  59.5420  10.0241  67.0299
             28    13.5   5.0358  64.5777   2.5665  69.5964
             29    14.0   0.8463  65.4240   0.1859  69.7823
             30    14.5   2.9130  68.3370   0.7514  70.5338
             31    15.0   3.8742  72.2112   1.2326  71.7664
             32    15.5   2.1901  74.4013   0.8379  72.6043
             33    16.0   3.0453  77.4466   1.3805  73.9848
             34    16.5   1.0688  78.5154   0.4140  74.3988
             35    17.0   0.0540  78.5693   0.0107  74.4095
             36    17.5   0.4985  79.0678   0.1728  74.5823
             37    18.0   0.1895  79.2573   0.0978  74.6801
             38    18.5  16.7466  96.0039  22.1564  96.8364
             39    19.0   0.0224  96.0263   0.0031  96.8395
             40    19.5   3.9097  99.9360   3.1402  99.9798
             41    20.0   0.0544  99.9904   0.0161  99.9959
             50    24.5   0.0018  99.9922   0.0005  99.9964
             51    25.0   0.0060  99.9982   0.0026  99.9989
             54    26.5   0.0000  99.9982   0.0000  99.9989
             55    27.0   0.0000  99.9983   0.0000  99.9989
             57    28.0   0.0000  99.9983   0.0000  99.9989
             58    28.5   0.0000  99.9983   0.0000  99.9989
             59    29.0   0.0013  99.9995   0.0008  99.9997
             60    29.5   0.0005 100.0000   0.0003 100.0000


       ***********************************************************
       *      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)      *
       *           FOR THE INITIATING DRIVING FORCES             *
       ***********************************************************
             ===============================================
                                 RELATIVE    CUMULATIVE
               KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
               (bin midpoint)      (%)          (%)
             ===============================================
                  19.00            0.0012         0.0012
                  21.00            0.6816         0.6828
                  23.00           17.6259        18.3087
                  25.00           22.7528        41.0614
                  27.00           16.3184        57.3798
                  29.00           13.6251        71.0049
                  31.00           12.0295        83.0344
                  33.00            9.0150        92.0495
                  35.00            3.7720        95.8214
```

FAVPFM-EP.OUT (continued)

```
       ************************************************************
       *      PROBABILITY DISTRIBUTION FUNCTION (HISTOGRAM)       *
       *           FOR THE INITIATING DRIVING FORCES              *
       ************************************************************
             ===============================================
                                 RELATIVE    CUMULATIVE
               KI(ksi-in^1/2)    DENSITY    DISTRIBUTION
               (bin midpoint)       (%)          (%)
             ===============================================
                  19.00            0.0012        0.0012
                  21.00            0.6816        0.6828
                  23.00           17.6259       18.3087
                  25.00           22.7528       41.0614
                  27.00           16.3184       57.3798
                  29.00           13.6251       71.0049
                  31.00           12.0295       83.0344
                  33.00            9.0150       92.0495
                  35.00            3.7720       95.8214
                  37.00            1.5837       97.4051
                  39.00            1.1048       98.5099
                  41.00            0.6034       99.1133
                  43.00            0.3473       99.4606
                  45.00            0.2193       99.6799
                  47.00            0.1292       99.8091
                  49.00            0.0735       99.8826
                  51.00            0.0474       99.9301
                  53.00            0.0202       99.9502
                  55.00            0.0130       99.9633
                  57.00            0.0142       99.9775
                  59.00            0.0047       99.9822
                  61.00            0.0059       99.9881
                  63.00            0.0071       99.9953
                  65.00            0.0024       99.9976
                  69.00            0.0012       99.9988
                  75.00            0.0012      100.0000


=======================================================================================
                       FAILURE MECHANISM REPORT FOR TRANSIENT SEQUENCE   7

=======================================================================================

                                                              NUMBER OF     % OF TOTAL
                                                                FAILURE        FAILURE
                                                                 TRIALS         TRIALS

   UNSTABLE DUCTILE TEARING                                     271532          15.56
   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    1473771          84.44
```

TRACE.OUT file

```
======================================================================================
 ITRAN =  3 IRPV  =      4 FLAW  =    190
======================================================================================
 PARENT SUBREGION                =  10708
 CHILD  SUBREGION - CLEAVAGE     =  10708
 CHILD  SUBREGION - DUCTILE      =  10708
 IPASS  PARENT SUBREGION         =      1

 SIMULATED CHEMISTRY FOR CLEAVAGE FRACTURE:

 SIMULATED COPPER                =  0.132
 SIMULATED NICKEL                =  0.598
 SIMULATED PHOSPHORUS            =  0.016
 SIMULATED FLUENCE @ RPV ID      =  7.896

 SIMULATED CHEMISTRY FOR DUCTILE  FRACTURE:

 SIMULATED COPPER                =  0.132
 SIMULATED NICKEL                =  0.598
 SIMULATED PHOSPHORUS            =  0.016
======================================================================================
  The variables DT30, SDRTNDT, and RTNDT are evaluated at XINNER in the RPV wall.
======================================================================================
 RTNDTO  =  73.00 DRTEPI =   3.61 DT30  = 180.49 SDRTNDT  = 198.54 RTNDT=267.93
 USE0    =  69.06 USEi   =  58.27
 FLAW CAT=      2 DEPTH  =  0.321 XINNER=  0.218 ASPECT   =   1.39 IORIENT = 1

======================================================================================
  The variables KI and TEMP are evaluated at the position XINNER in the RPV wall.
======================================================================================
  I   TIME    KI    TEMP     cpi        cdcpi    FAIL CL  FAIL DT   cdcpf      CPFTOT
======================================================================================
 31   15.0   34.2  291.4  0.8542E-08  0.8542E-08    50.     1.  0.4356E-08  0.4356E-08
 32   15.5   34.4  283.9  0.3399E-05  0.3391E-05    49.     2.  0.1729E-05  0.1734E-05
 33   16.0   34.7  276.2  0.3459E-04  0.3119E-04    46.     5.  0.1591E-04  0.1764E-04
 34   16.5   34.7  269.6  0.1057E-03  0.7110E-04    45.     6.  0.3626E-04  0.5390E-04
 35   17.0   34.7  263.7  0.2188E-03  0.1131E-03    45.     6.  0.5768E-04  0.1116E-03
 36   17.5   34.9  257.1  0.4574E-03  0.2386E-03    45.     6.  0.1217E-03  0.2333E-03
 37   18.0   34.6  251.2  0.6558E-03  0.1985E-03    45.     6.  0.1012E-03  0.3345E-03
 38   18.5   33.4  250.1  0.4298E-03  0.0000E+00     0.     0.  0.0000E+00  0.3345E-03
 39   19.0   32.2  251.4  0.1990E-03  0.0000E+00     0.     0.  0.0000E+00  0.3345E-03
 40   19.5   31.8  249.3  0.1922E-03  0.0000E+00     0.     0.  0.0000E+00  0.3345E-03

==================================================================================================================|
                                   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  |                                 |      4     1    751    124  6485|      4   101   4471    160  6521|
circ. weld  |      0     0      0      0     0|      1     1   1744    180 10564|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      3     1    814   9921  9921|      0     0      0      0     0|
axial plate |                                 |      1     2    415  10860 10860|      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     1    751    124  6485|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      2     1    588    511 15016|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      1     1    814   9921  9921|      0     0      0      0     0|
axial plate |                                 |      1     2    415  10860 10860|      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  |                                 |      1     1    751    124  6485|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      2     1    588    511 15016|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      1     1    814   9921  9921|      0     0      0      0     0|
axial plate |                                 |      1     2    415  10860 10860|      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     1    751    124  6485|      0     0      0      0     0|
circ. weld  |      0     0      0      0     0|      2     1    588    511 15016|      0     0      0      0     0|
circ. plate |      0     0      0      0     0|      1     1    814   9921  9921|      0     0      0      0     0|
axial plate |                                 |      1     2    415  10860 10860|      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%
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 axial  weld category 2 flaw: itran=   1 irpv=     1 kflaw=      751 parent subr=   124 child subr=  6485
STABLE TEARING:parent circ. plate category 2 flaw: itran=   1 irpv=     1 kflaw=      814 parent subr=  9921 child subr=  9921
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=     1155 parent subr=   477 child subr= 13691
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   2 irpv=     1 kflaw=     1643 parent subr=   837 child subr= 10776
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=     1744 parent subr=   180 child subr= 10564
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     1 kflaw=     2702 parent subr=   669 child subr= 10670
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      133 parent subr=   153 child subr=  6514
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=      415 parent subr= 10860 child subr= 10860
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      749 parent subr=   205 child subr=  9239
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      933 parent subr=   178 child subr= 10670
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=      979 parent subr=   506 child subr= 15228
STABLE ARREST :parent circ. plate category 2 flaw: itran=   1 irpv=     2 kflaw=     1026 parent subr= 10829 child subr= 10829
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     1198 parent subr=   680 child subr= 10458
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=     1481 parent subr=  9385 child subr=  9385
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     1605 parent subr=   192 child subr=  9928
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     1969 parent subr=   729 child subr=  7861
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     2704 parent subr=   141 child subr=  6502
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     2725 parent subr=   186 child subr= 10246
REINITIATION  :parent circ. plate category 2 flaw: itran=   2 irpv=     2 kflaw=     3488 parent subr= 10617 child subr= 10617
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     3556 parent subr=   206 child subr=  9186
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     3969 parent subr=   511 child subr= 15016
STABLE TEARING:parent axial  weld category 2 flaw: itran=   2 irpv=     2 kflaw=     4102 parent subr=    66 child subr=  3624
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     4146 parent subr=   669 child subr= 10670
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     4388 parent subr=   708 child subr=  8974
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     2 kflaw=     4407 parent subr= 10846 child subr= 10846
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     2 kflaw=     4539 parent subr=   291 child subr=  2538
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     3 kflaw=      130 parent subr=   642 child subr=  9239
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     3 kflaw=      416 parent subr=   107 child subr=  6521
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     3 kflaw=      722 parent subr=   423 child subr=  3660
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     3 kflaw=      834 parent subr= 10534 child subr= 10534
STABLE TEARING:parent circ. plate category 2 flaw: itran=   2 irpv=     3 kflaw=     1363 parent subr=  9156 child subr=  9156
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     3 kflaw=     1882 parent subr=   145 child subr=  6506
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     3 kflaw=     1929 parent subr=   145 child subr=  6506
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     3 kflaw=     2318 parent subr=   677 child subr= 10617
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   2 irpv=     3 kflaw=     2875 parent subr=   811 child subr=  9398
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     3 kflaw=     3359 parent subr=   668 child subr= 10617
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     3 kflaw=     3907 parent subr=   176 child subr= 10776
STABLE TEARING:parent axial plate category 2 flaw: itran=   1 irpv=     4 kflaw=      190 parent subr= 10708 child subr= 10708
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     4 kflaw=      273 parent subr=   700 child subr=  9398
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=      293 parent subr=   812 child subr=  9451
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=      449 parent subr=   672 child subr= 10829
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     1352 parent subr=   669 child subr= 10670
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     1602 parent subr=   270 child subr=  3252
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     2438 parent subr=   138 child subr=  6499
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     2784 parent subr=   189 child subr= 10087
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     3003 parent subr=   162 child subr=  6523
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     3117 parent subr=   836 child subr= 10723
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     3299 parent subr=   816 child subr=  9663
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   2 irpv=     4 kflaw=     3409 parent subr=   272 child subr=  3184
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     3505 parent subr=   508 child subr= 15175
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     3821 parent subr=   188 child subr= 10140
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     3995 parent subr=   153 child subr=  6514
STABLE TEARING:parent circ. plate category 2 flaw: itran=   1 irpv=     4 kflaw=     4003 parent subr= 10486 child subr= 10486
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     4277 parent subr=   249 child subr=  6907
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     4419 parent subr=   176 child subr= 10776
REINITIATION  :parent circ.  weld category 2 flaw: itran=   1 irpv=     4 kflaw=     4478 parent subr=   673 child subr= 10829
STABLE ARREST :parent circ. plate category 2 flaw: itran=   1 irpv=     5 kflaw=       46 parent subr=  1054 child subr=  1054
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     5 kflaw=      284 parent subr=   156 child subr=  6517
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=      704 parent subr=   349 child subr= 14804
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=     1185 parent subr=   688 child subr= 10034
REINITIATION  :parent circ. plate category 2 flaw: itran=   2 irpv=     5 kflaw=     1634 parent subr= 10630 child subr= 10630
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     1845 parent subr=   229 child subr=  7967
STABLE TEARING:parent axial  weld category 2 flaw: itran=   2 irpv=     5 kflaw=     2105 parent subr=    83 child subr=  6497
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     2211 parent subr=   177 child subr= 10723
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     2614 parent subr=   657 child subr= 10034
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     5 kflaw=     3039 parent subr=   209 child subr=  9027
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     3519 parent subr=   249 child subr=  6907
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     3568 parent subr=   241 child subr=  7331
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     3868 parent subr=   198 child subr=  9610
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     5 kflaw=     3962 parent subr=   340 child subr= 15228
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     6 kflaw=       70 parent subr=    88 child subr=  6502
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   2 irpv=     6 kflaw=      446 parent subr=   311 child subr=  1858
STABLE TEARING:parent axial plate category 2 flaw: itran=   2 irpv=     6 kflaw=      763 parent subr=   971 child subr=   971
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     6 kflaw=     1084 parent subr=    91 child subr=  6505
STABLE TEARING:parent axial  weld category 2 flaw: itran=   1 irpv=     6 kflaw=     1138 parent subr=   153 child subr=  6514
STABLE TEARING:parent circ.  weld category 2 flaw: itran=   1 irpv=     6 kflaw=     1307 parent subr=   176 child subr= 10776
STABLE TEARING:parent circ. plate category 2 flaw: itran=   1 irpv=     6 kflaw=     1452 parent subr= 10650 child subr= 10650
STABLE ARREST :parent circ.  weld category 2 flaw: itran=   2 irpv=     6 kflaw=     1567 parent subr=   603 child subr=  7172
```

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

```
=============================================================================================================================================
       ARREST TRIAL =    1 PF = 0.09260 PARENT =   162 CHILD =   6523 XDEPTH = 0.1607 XINNER = 0.1692 IFLCAT = 2 ASPECT =   7.36
=============================================================================================================================================
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 3003  17.0  4 0.321 272.94         126.35  73.00                             221.81                73.40
=============================================================================================================================================
 PROPA 3003  17.0  6 0.482 279.44 3.5E-02 125.43  73.00  24.23  37.39 137.97 272.58 220.80    6.86  58.65  86.94          52.17
 PROPA 3003  17.0  8 0.643 289.73 3.5E-02 124.50  73.00  24.23  37.39 136.95 271.57 219.78   18.16  69.95  98.11          56.27
 PROPA 3003  17.0 10 0.804 303.25 3.5E-02 123.58  73.00  24.23  37.39 135.94 270.56 218.77   32.69  84.48 106.82          62.18
 PROPA 3003  17.0 12 0.964 315.94 3.5E-02 122.66  73.00  24.23  37.39 134.93 269.54 217.76   46.40  98.19 114.44          68.51
 PROPA 3003  17.0 14 1.125 327.22 3.5E-02 121.74  73.00  24.23  37.39 133.91 268.53 216.74   58.69 110.47 121.33          74.89
 PROPA 3003  17.0 16 1.286 337.43 3.5E-02 120.82  73.00  24.23  37.39 132.90 267.52 215.73   69.91 121.70 127.57          81.37
 PROPA 3003  17.0 18 1.446 346.95 3.5E-02 119.89  73.00  24.23  37.39 131.88 266.50 214.71   80.45 132.24 133.20          88.08
 PROPA 3003  17.0 20 1.607 356.15 3.5E-02 118.97  73.00  24.23  37.39 130.87 265.48 213.70   90.67 142.45 138.29          95.21
 PROPA 3003  17.0 22 1.768 365.32 3.5E-02 118.05  73.00  24.23  37.39 129.85 264.47 212.68  100.85 152.64 142.91         103.01
 PROPA 3003  17.0 24 1.929 374.43 3.5E-02 117.12  73.00  24.23  37.39 128.83 263.45 211.66  110.98 162.77 147.19         111.51
*********************************************************************************************************************************************
 RECHM  SCU =   0.142 SNI =  0.679 SPHOS=  0.012 RESAMPLE NEXT WELD LAYER CHEMISTRY
*********************************************************************************************************************************************
 ARRES 3003  17.0 26 2.259 392.59 6.8E-01 111.76  73.00  24.23  70.86 122.94 291.03 205.77  101.56 186.82 155.54         224.99
*********************************************************************************************************************************************
TREINI 3003  17.5 27 2.509 399.48 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21  110.00 186.82 156.68  745.62         125.59 252.74
*********************************************************************************************************************************************
 ARRES 3003  17.5 27 2.509 399.48 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21  110.00 195.26 163.29         240.35
STABLE 3003  18.0 27 2.509 393.67 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21  104.20 104.20 162.20  867.46         125.33 252.74
STABLE 3003  18.5 27 2.509 387.98 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   98.51  98.51 160.99  785.16         125.73 252.74
STABLE 3003  19.0 27 2.509 382.72 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   93.24  93.24 159.07  717.19         126.11 252.74
STABLE 3003  19.5 27 2.509 378.14 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   88.67  88.67 156.08  663.83         126.45 252.74
STABLE 3003  20.0 27 2.509 373.98 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   84.51  84.51 155.68  619.37         126.76 252.74
STABLE 3003  20.5 27 2.509 369.77 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   80.29  80.29 160.44  578.04         127.09 252.74
STABLE 3003  21.0 27 2.509 365.55 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   76.08  76.08 155.14  540.02         127.42 252.74
STABLE 3003  21.5 27 2.509 361.71 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   72.24  72.24 155.85  508.09         127.73 252.74
STABLE 3003  22.0 27 2.509 358.29 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   68.81  68.81 152.72  481.62         128.01 252.74
STABLE 3003  22.5 27 2.509 355.12 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   65.65  65.65 150.57  458.69         128.28 252.74
STABLE 3003  23.0 27 2.509 352.18 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   62.70  62.70 150.52  438.61         128.53 252.74
STABLE 3003  23.5 27 2.509 349.14 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   59.66  59.66 149.94  419.04         128.79 252.74
STABLE 3003  24.0 27 2.509 346.10 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   56.62  56.62 146.53  400.59         129.05 252.74
STABLE 3003  24.5 27 2.509 343.38 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   53.91  53.91 144.42  385.02         129.30 252.74
STABLE 3003  25.0 27 2.509 340.82 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   51.35  51.35 143.49  371.06         129.53 252.74
STABLE 3003  25.5 27 2.509 338.05 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   48.58  48.58 142.74  356.71         129.78 252.74
STABLE 3003  26.0 27 2.509 335.10 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   45.62  45.62 140.38  342.21         130.05 252.74
STABLE 3003  26.5 27 2.509 332.33 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   42.85  42.85 138.97  329.34         130.31 252.74
STABLE 3003  27.0 27 2.509 329.67 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   40.19  40.19 138.54  317.60         130.56 252.74
STABLE 3003  27.5 27 2.509 326.74 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   37.27  37.27 137.65  305.33         130.84 252.74
STABLE 3003  28.0 27 2.509 323.66 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   34.19  34.19 135.87  293.13         131.14 252.74
STABLE 3003  28.5 27 2.509 320.73 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   31.25  31.25 134.59  282.14         131.43 252.74
STABLE 3003  29.0 27 2.509 317.89 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   28.42  28.42 133.15  272.06         131.72 252.74
STABLE 3003  29.5 27 2.509 315.15 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   25.67  25.67 131.73  262.78         132.00 252.74
STABLE 3003  30.0 27 2.509 312.47 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   23.00  23.00 131.46  254.18         132.27 252.74
STABLE 3003  30.5 27 2.509 309.70 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   20.22  20.22 130.31  245.67         132.56 252.74
STABLE 3003  31.0 27 2.509 306.84 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   17.37  17.37 129.53  237.35         132.87 252.74
STABLE 3003  31.5 27 2.509 303.97 6.8E-01 110.35  73.00  24.23  70.86 121.39 289.47 204.21   14.50  14.50 128.25  229.40         133.18 252.74
```

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%
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)

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

                          NUMBER OF OCCASIONS
                        WHEN SIMULATED RPV HAD

                           X STABLE      No. of
                        CRACK ARRESTS     RPVs

                              1         3684
                              2         2172
                              3         2059
                              4         2446
                              5         2862
                              6         3007
                              7         3046
                              8         2908
                              9         2696
                             10         2315
                             11         1937
                             12         1587
                             13         1213
                             14          943
                             15          634
                             16          444
                             17          269
                             18          192
                             19          116
                             20           68
                             21           39
                             22           16
                             23           20
                             24            6
                             25            3
                             26            3
                             27            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

                      0.321            0.00
                      0.402            0.00
                      0.482            0.00
                      0.563            0.00
                      0.643            0.00
                      0.723            0.00
                      0.804            0.00
                      0.884            0.00
                      0.964            0.00
                      1.045            0.01
                      1.125            0.02
                      1.205            0.05
                      1.286            0.09
                      1.366            0.13
                      1.446            0.29
                      1.527            0.32
                      1.607            0.66
                      1.688            0.77
                      1.768            1.42
                      1.848            1.87
                      1.929            2.74
                      2.009           10.66
                      2.259           19.40
                      2.509           16.64
                      2.759           10.23
                      3.009            8.52
                      3.259            7.00
                      3.509            5.08
```

FLAWNO.OUT

```
              FAVPFM-EP INPUT FILE NAME   = FAVPFM-EP.in
              FAVLOAD OUTPUT FILE NAME = load4.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-EP OUTPUT FILE NAME  = FAVPFM-EP_10K.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 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


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

FLAWSIZE.OUT

```
                FAVPFM-EP INPUT FILE NAME   = FAVPFM-EP.in
                FAVLOAD OUTPUT FILE NAME = load4.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-EP OUTPUT FILE NAME  = FAVPFM-EP_10K.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   91.0573   67.9584   91.0573   67.9584
     0.1607    0.0000    0.0000    7.8899   29.5897    7.8899   29.5897
     0.2411    0.0000    0.0000    0.6566    2.2366    0.6566    2.2366
     0.3214    0.0000    0.0000    0.2461    0.1512    0.2461    0.1512
     0.4018    0.0000    0.0000    0.0722    0.0640    0.0722    0.0640
     0.4822    0.0000    0.0000    0.0290    0.0000    0.0290    0.0000
     0.5625    0.0000    0.0000    0.0157    0.0000    0.0157    0.0000
     0.6429    0.0000    0.0000    0.0101    0.0000    0.0101    0.0000
     0.7232    0.0000    0.0000    0.0069    0.0000    0.0069    0.0000
     0.8036    0.0000    0.0000    0.0048    0.0000    0.0048    0.0000
     0.8840    0.0000    0.0000    0.0034    0.0000    0.0034    0.0000
     0.9643    0.0000    0.0000    0.0024    0.0000    0.0024    0.0000
     1.0447    0.0000    0.0000    0.0017    0.0000    0.0017    0.0000
     1.1250    0.0000    0.0000    0.0012    0.0000    0.0012    0.0000
     1.2054    0.0000    0.0000    0.0008    0.0000    0.0008    0.0000
     1.2858    0.0000    0.0000    0.0006    0.0000    0.0006    0.0000
     1.3661    0.0000    0.0000    0.0004    0.0000    0.0004    0.0000
     1.4465    0.0000    0.0000    0.0003    0.0000    0.0003    0.0000
     1.5268    0.0000    0.0000    0.0002    0.0000    0.0002    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    0.0001    0.0000    0.0001    0.0000
     1.8483    0.0000    0.0000    0.0001    0.0000    0.0001    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
```

2.7 FAVOR-EP Post-Processing Module – FAVPost-EP Output

FAVPost-EP 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-EP 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 function of transient, material, flaw category, flaw orientation, and major beltline regions.

Percentiles for the various discrete distributions calculated by FAVOR-EP are estimated both by binning procedures and through the use of order statistics. The specific order statistic used in FAVPost-EP is the median-rank estimate

$$P_{(i)} = \frac{i - 0.3}{n + 0.4} \qquad \textbf{(3)}$$

where $P_{(i)}$ is the estimated cumulative probability for the i^{th} data point in a rank-ordered sample of size n.

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

m₁ – 1st crude moment of the sample (sample mean) = $\overline{x} = \dfrac{\sum_{i=1}^{n} x_i}{n}$

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

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

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

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

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

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

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

FAVPOST.OUT

```
              ************************************************
              *                                              *
              *               WELCOME TO FAVOR-EP              *
              *                                              *
              *   FRACTURE ANALYSIS OF VESSELS: OAK RIDGE    *
              *                 VERSION 05.1                 *
              *                                              *
              *     FAVPOST MODULE: POSTPROCESSOR MODULE     *
              *  COMBINES TRANSIENT INITIAITING FREQUENCIES  *
              *        WITH RESULTS OF PFM ANALYSIS          *
              *                                              *
              *     PROBLEMS OR QUESTIONS REGARDING FAVOR-EP    *
              *             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: 21-Mar-2005  TIME: 06:45:37

               Begin echo of FAVPost-EP input data deck         06:45:37   21-Mar-2005

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-EP, v05.1                     *
    5    ********************************************************************************
    6    *  ====================                                                        *
    7    *     Record CNTL                                                              *
    8    *  ====================                                                        *
    9    *------------------------------------------------------------------------------*
   10    *  NTRAN = NUMBER OF T-H TRANSIENTS                                            *
   11    *------------------------------------------------------------------------------*
   12    ********************************************************************************
   13    CNTL  NTRAN=4
   14    ********************************************************************************
   15    *  ====================                                                        *
   16    *     Record ITRN                                                              *
   17    *  ====================                                                        *
   18    *------------------------------------------------------------------------------*
   19    *  ITRAN = PFM TRANSIENT NUMBER                                                *
   20    *  ITRAN = TRANSIENT NUMBER                                                    *
   21    *  NHIST = NUMBER OF DATA PAIRS IN DISCRETE FREQUENCY DISTRIBUTION             *
   22    *  ISEQ  = THERMAL-HYDRAULIC SEQUENCE NUMBER                                   *
   23    *------------------------------------------------------------------------------*
   24    ********************************************************************************
   25    ITRN ITRAN=1  NHIST=20    ISEQ=7
   26    ********************************************************************************
   27    *------------------------------
   28    * freq[events/year] Density [%]
   29    *------------------------------
   30         2.11E-07          0.50
   31         3.01E-07          0.50
   32         5.19E-07          1.50
   33         7.92E-07          2.50
   34         1.32E-06          5.00
   35         2.43E-06         10.00
   36         3.08E-06          5.00
   37         3.79E-06          5.00
   38         5.55E-06         10.00
   39         7.90E-06         10.00
   40         1.12E-05         10.00
   41         1.64E-05         10.00
   42         2.03E-05          5.00
```

FAVPOST.OUT (continued)

```
  146         4.26E-06         5.00
  147         5.30E-06         5.00
  148         8.53E-06        10.00
  149         1.29E-05         5.00
  150         1.96E-05         2.50
  151         2.90E-05         1.50
  152         3.56E-05         0.50
  153         8.62E-05         0.50
no./col. 1.......10........20........30........40........50........60........70........80

               End echo of FAVPost-EP input data deck          06:45:37   21-Mar-2005


              FAVPOST INPUT  FILE NAME                  = FAVPost-EP.in
              FAVPFM-EP  OUTPUT FILE CONTAINING PFMI ARRAY = INITIATE_10K.DAT
              FAVPFM-EP  OUTPUT FILE CONTAINING PFMF ARRAY = FAILURE_10K.DAT
              FAVPOST OUTPUT FILE NAME                  = FAVPost-EP_10K.out



                 **********************************
                 * NUMBER OF SIMULATIONS =  10000 *
                 **********************************

___________________________________________________________________________________________________
                 CONDITIONAL PROBABILITY                     CONDITIONAL PROBABILITY
                 OF INITIATION CPI=P(I|E)                     OF FAILURE CPF=P(F|E)
TRANSIENT   MEAN          95th %        99th %        MEAN          95th %        99th %    RATIO
 NUMBER      CPI            CPI           CPI          CPF            CPF           CPF   CPFmn/CPImn
        |---------------------------------------|  |---------------------------------------|
    7    3.9283E-03    7.5304E-03    4.1253E-02    8.2565E-05    1.9989E-04    1.3063E-03  0.0210
    9    6.0780E-03    1.1806E-02    5.6460E-02    1.5202E-04    3.2178E-04    2.6620E-03  0.0250
   56    2.3219E-03    4.8027E-03    2.7047E-02    8.9945E-05    1.8779E-04    1.4445E-03  0.0387
   97    2.1333E-04    2.9780E-04    3.9905E-03    1.8994E-04    2.5810E-04    3.6871E-03  0.8904
___________________________________________________________________________________________________

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

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

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

                      0.0000E+00          0.0300        0.0300
                      9.5574E-07         94.9600       94.9900
                      2.8672E-06          2.8300       97.8200
                      4.7787E-06          0.9600       98.7800
                      6.6902E-06          0.3500       99.1300
                      8.6017E-06          0.2300       99.3600
                      1.0513E-05          0.1200       99.4800
                      1.2425E-05          0.1300       99.6100
                      1.4336E-05          0.0500       99.6600
                      1.6248E-05          0.0800       99.7400
                      1.8159E-05          0.0300       99.7700
                      2.0071E-05          0.0200       99.7900
                      2.1982E-05          0.0300       99.8200
                      2.3894E-05          0.0300       99.8500
                      2.5805E-05          0.0100       99.8600
                      2.9628E-05          0.0200       99.8800
                      3.1540E-05          0.0100       99.8900
                      3.5362E-05          0.0100       99.9000
                      3.9185E-05          0.0100       99.9100
                      4.4920E-05          0.0100       99.9200
                      5.0654E-05          0.0200       99.9400
                      5.2566E-05          0.0100       99.9500
                      6.7858E-05          0.0100       99.9600
                      7.3592E-05          0.0100       99.9700
                      7.7415E-05          0.0100       99.9800
                      9.6530E-05          0.0100       99.9900
                      1.1182E-04          0.0100      100.0000

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

                      Minimum                            = 0.0000E+00
                      Maximum                            = 1.1115E-04
                      Range                              = 1.1115E-04

                      Number of Simulations              =  10000
```

FAVPOST.OUT (continued)

```
***********************************************************
*      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          2.9500        2.9500
          3.5989E-08         93.8700       96.8200
          1.0797E-07          1.2800       98.1000
          1.7994E-07          0.5400       98.6400
          2.5192E-07          0.3900       99.0300
          3.2390E-07          0.1300       99.1600
          3.9588E-07          0.1200       99.2800
          4.6785E-07          0.1000       99.3800
          5.3983E-07          0.0600       99.4400
          6.1181E-07          0.1100       99.5500
          6.8379E-07          0.0300       99.5800
          7.5576E-07          0.0500       99.6300
          8.2774E-07          0.0300       99.6600
          8.9972E-07          0.0500       99.7100
          9.7170E-07          0.0200       99.7300
          1.0437E-06          0.0100       99.7400
          1.1157E-06          0.0400       99.7800
          1.1876E-06          0.0200       99.8000
          1.2596E-06          0.0200       99.8200
          1.4755E-06          0.0200       99.8400
          1.5475E-06          0.0100       99.8500
          1.6195E-06          0.0200       99.8700
          1.6915E-06          0.0200       99.8900
          1.8354E-06          0.0100       99.9000
          2.1953E-06          0.0100       99.9100
          2.6992E-06          0.0100       99.9200
          2.9871E-06          0.0100       99.9300
          3.0590E-06          0.0100       99.9400
          3.5629E-06          0.0100       99.9500
          3.6349E-06          0.0100       99.9600
          4.2827E-06          0.0100       99.9700
          5.1464E-06          0.0100       99.9800
          6.8019E-06          0.0100       99.9900
          7.1618E-06          0.0100      100.0000


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

          Minimum                           = 0.0000E+00
          Maximum                           = 7.1258E-06
          Range                             = 7.1258E-06

          Number of Simulations             =  10000

          5th Percentile                    = 4.5694E-15
          Median                            = 1.8520E-10
          95.0th Percentile                 = 3.5989E-08
          99.0th Percentile                 = 2.4638E-07
          99.9th Percentile                 = 1.8354E-06

          Mean                              = 1.6871E-08
          Standard Deviation                = 1.6101E-07
          Standard Error                    = 1.6101E-09
          Variance (unbiased)               = 2.5926E-14
          Variance (biased)                 = 2.5923E-14
          Moment Coeff. of Skewness         = 2.7002E+01
          Pearson's 2nd Coeff. of Skewness  =-9.2878E-01
          Kurtosis                          = 9.4951E+02
```

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    170.68   2.30         0.33          0.88     0.17     1.05
   2    170.68   2.30         0.19          0.49     0.09     0.57
   3    157.95   3.70         2.87         18.44     2.39    20.83
   4    157.95   3.70         4.08         26.94     3.90    30.84
   5     95.38  19.31        88.95          3.11     0.01     3.12
   6    225.73  13.15         0.10          0.85     0.09     0.94
   7    204.02  13.15         0.01          0.06     0.01     0.07
   8    260.85  21.20         3.03         36.10     2.94    39.05
   9    230.85  21.20         0.45          3.21     0.32     3.53

        TOTALS 100.01       100.00         90.08     9.92   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    170.68   2.30         0.00          0.00     0.00     0.00
   2    170.68   2.30         0.00          0.00     0.00     0.00
   3    157.95   3.70         0.00          0.00     0.00     0.00
   4    157.95   3.70         0.00          0.00     0.00     0.00
   5     95.38  19.31         0.00          0.00     0.00     0.00
   6    225.73  13.15         2.99          2.25     0.35     2.60
   7    204.02  13.15         0.01          0.06     0.01     0.07
   8    260.85  21.20        80.44         84.17     9.24    93.41
   9    230.85  21.20        16.56          3.60     0.32     3.93

        TOTALS 100.01       100.00         90.08     9.92   100.00
```

FAVPOST.OUT (continued)

```
***********************************************************
 *    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 1    CAT 2    CAT 3    CAT 1    CAT 2  CAT 3
  (in)     flaws    flaws    flaws    flaws    flaws  flaws

  0.080     0.00     1.58     0.00     0.00     0.33     0.00
  0.161     0.00    36.42     0.00     0.00    17.57     0.00
  0.241     0.00    20.37     0.00     0.00    11.15     0.00
  0.321     0.00    10.82     0.00     0.00     7.90     0.00
  0.402     0.00     9.19     0.00     0.00     5.31     0.00
  0.482     0.00     4.62     0.00     0.00     5.55     0.00
  0.563     0.00     2.06     0.00     0.00     4.99     0.00
  0.643     0.00     4.34     0.00     0.00     1.40     0.00
  0.723     0.00     1.54     0.00     0.00     0.99     0.00
  0.804     0.00     2.07     0.00     0.00     0.30     0.00
  0.884     0.00     0.29     0.00     0.00     0.15     0.00
  0.964     0.00     1.17     0.00     0.00     0.23     0.00
  1.045     0.00     0.55     0.00     0.00     0.10     0.00
  1.125     0.00     0.18     0.00     0.00     0.03     0.00
  1.205     0.00     0.98     0.00     0.00     0.15     0.00
  1.286     0.00     0.11     0.00     0.00     0.06     0.00
  1.366     0.00     0.00     0.00     0.00     0.00     0.04
  1.446     0.00     0.00     0.00     0.00     0.00     0.00
  1.527     0.00     0.00     0.00     0.00     0.04     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     0.14     0.00     0.00     0.11     0.00
  1.929     0.00     0.00     0.00     0.00     0.00     0.00

 TOTALS     0.00    96.42     0.00     0.00    56.36     0.06


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

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

  0.080     0.00     0.02     0.00     0.00     0.29     0.00
  0.161     0.00     0.67     0.00     0.00     8.20     0.00
  0.241     0.00     1.05     0.00     0.00    12.49     0.00
  0.321     0.00     1.02     0.00     0.00    13.61     0.00
  0.402     0.00     0.83     0.00     0.00     8.98     0.00

 TOTALS     0.00     3.58     0.00     0.00    43.58     0.00

               DATE: 21-Mar-2005  TIME: 06:45:41
```

3. Example Case

The example case included on the distribution CD was developed for the RPV beltline description shown in Fig. 18. Partial input listings for the three FAVOR-EP modules are given on the following pages. The complete output listings are included on the distribution CD.

Example Case FAVLoad-EP input file (partial listing)

```
********************************************************************************
*      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY            *
********************************************************************************
*                EXAMPLE INPUT DATASET FOR FAVLoad-EP, v05.1               [UNITS]*
********************************************************************************
*  ====================                                                         *
*     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
```

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

```
********************************************************************************
*  ====================                                                        *
*     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=468  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
* =====================================
*     TIME [MIN] h[BTU/HR-FT**2-F]
* =====================================
          0.00   4216.86
          0.50   2063.75
          1.00    748.74
          1.50    552.12
          2.00    582.22
          2.50    907.80
          3.00   1365.43
          3.50   1297.57
          4.00    665.04
          4.50    601.89
          5.00    630.19
          5.50    533.59
          6.00    443.70
          6.50    493.02
          7.00    369.04
          7.50    327.64
          8.00    392.38
          8.50    370.52
```

Example Case FAVPFM-EP input file (partial listing)

```
**********************************************************************************************************
*              ALL RECORDS WITH AN ASTERISK(*) IN COLUMN 1 ARE COMMENT ONLY                              *
**********************************************************************************************************
*                         EXAMPLE INPUT DATASET FOR FAVPFM-EP, v05.1                                 [UNITS]*
**********************************************************************************************************
*  ====================                                                                                  *
*  Control Record CNT1                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
*  NSIM           = NUMBER OF RPV SIMULATIONS                                                        [-] *
*--------------------------------------------------------------------------------------------------------*
*  IGATR          = NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                         [-] *
*--------------------------------------------------------------------------------------------------------*
*  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                   [-] *
*  WPS_OPTION     = 1        INCLUDE WARM-PRESTRESSING IN ANALYSIS                                   [-] *
*--------------------------------------------------------------------------------------------------------*
*  PC3_OPTION     = 0 DO NOT PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                 [-] *
*  PC3_OPTION     = 1        PERFORM FRACTURE ANALYSIS OF CATEGORY 3 FLAWS IN PLATES                 [-] *
*--------------------------------------------------------------------------------------------------------*
*  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.     *
*                                                                                                        *
*  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=10000    IGATR=100    WPS_OPTION=0    PC3_OPTION=0    CHILD_OPTION=1   RESTART_OPTION=0
**********************************************************************************************************
*  ====================                                                                                  *
*  Control Record CNT2                                                                                   *
*  ====================                                                                                  *
*--------------------------------------------------------------------------------------------------------*
* IRTNDT     = 992 ==> USE RG 1.99, REV 2,  FOR ESTIMATING RADIATION-INDUCED SHIFT IN RTNDT              *
* IRTNDT     = 993 ==> USE E900 CORRELATION FOR ESTIMATING RADIATION-INDUCED SHIFT IN RTNDT              *
*--------------------------------------------------------------------------------------------------------*
* TC         = INITIAL RPV COOLANT TEMPERATURE (applicable only when IRTNDT=993)                     [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                       [-] *
*--------------------------------------------------------------------------------------------------------*
**********************************************************************************************************
CNT2 IRTNDT=993 TC=550 EFPY=32  IDT_OPTION=1  IDT_INI=1
**********************************************************************************************************
*  ====================                                                                                  *
*  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=1  FAILCR=0.9
**********************************************************************************************************
```

Example Case FAVPFM-EP input file (continued)

```
**********************************************************************************************************
*  ====================                                                                                  *
*      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=0.056 SIGFLC=0.118
**********************************************************************************************************
*  ====================                                                                                  *
*      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-EP 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                                                                                 *
*  ===============================                                                                       *
*  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=4  KFLAW=3003   FLAW_LOG_OPTION=1
**********************************************************************************************************
*  ====================                                                                                  *
*     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                                                [-] *
*--------------------------------------------------------------------------------------------------------*
```

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

```
************************************************************************************************************
*  ====================                                                                                    *
*      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-EP transient stack                                              [-]
*
*   ISEQ   = Thermal Hydraulic trasient sequence number                                                [-] *
*   TSTART = starting time for FAVPFM-EP analysis                                                       [MIN]
*
*   TEND   = ending time for FAVPFM-EP 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
************************************************************************************************************
*  ====================                                                                                    *
*     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
************************************************************************************************************
*                       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) heat estimate copper content                                                               [wt% Cu] *
*----------------------------------------------------------------------------------------------------------*
*  (7) heat estimate nickel content                                                               [wt% Ni] *
*----------------------------------------------------------------------------------------------------------*
*  (8) heat estimate phosphorus content                                                           [wt%  P] *
*----------------------------------------------------------------------------------------------------------*
*  (9) 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=993 then set B = 206)                                                     [-] *
*      Not CE = 2 (if IRTNDT=993 then set B = 156)                                                     [-] *
*      where CE is a Combustion Engineering vessel                                                         *
*----------------------------------------------------------------------------------------------------------*
* (10) copper saturation flag = 0 for plates and forgings                                              [-] *
*                             = 1 for Linde 80 and Linde 91 weld fluxes                                    *
*                             = 2 for all other weld fluxes                                                *
*       N.B.: maximum value of copper content (copper saturation)                                          *
*             = 0.25 for Linde 80 and = 0.305 for all others                                               *
*----------------------------------------------------------------------------------------------------------*
* (11) unirradiated best estimate (mean) for RTNDT0                                                    [F] *
*----------------------------------------------------------------------------------------------------------*
* (12) unirradiated standard deviation for RTNDT0                                                      [F] *
*----------------------------------------------------------------------------------------------------------*
* (13) PF flag      Product Form         CF Override                                                       *
*      -------      ------------         ------------                                                      *
*      = 11            weld                  no                                                        [-] *
*      = 12            weld                  yes                                                       [-] *
*      = 21            plate                 no                                                        [-] *
*      = 22            plate                 yes                                                       [-] *
*      = 31           forging                NA                                                        [-] *
*----------------------------------------------------------------------------------------------------------*
* (14) standard deviation for DRTNDT correlation                                                       [F] *
*----------------------------------------------------------------------------------------------------------*
* (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                                                                       [-] *
```

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

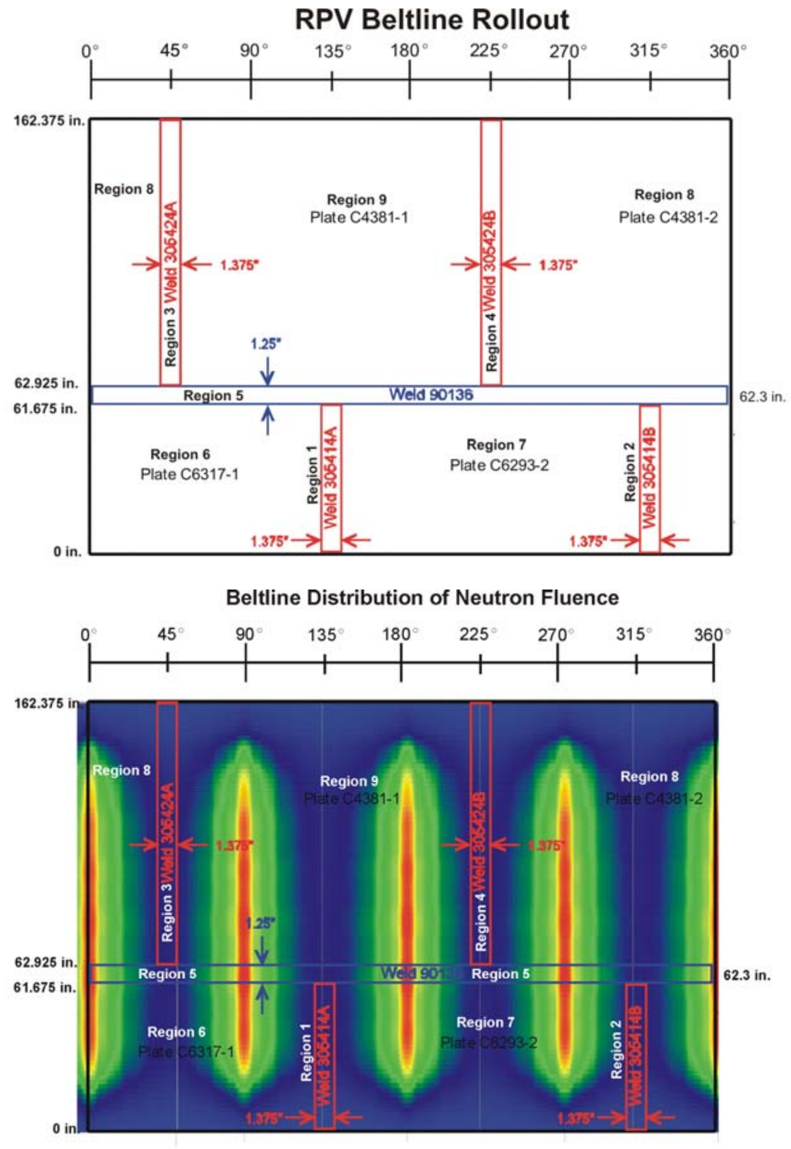
```
*==========================================================================================================*
*    Notes:                                                                                                *
*                                                                                                          *
*    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   17  : only applies to weld subregions. For plates set to 0.                                *
*    6. Field   19  : applicable only if IRTNDT=992 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  2  2  -56.0 17.00 11 23.6  1.0000  1.2000  9.4500  1  0    98
00002 03594 03662  1 0.1173 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.1996  9.4469  1  0    98
00003 03595 03663  1 0.1682 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.3996 18.8969  1  0    98
00004 03596 03664  1 0.2317 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2047 17.3622  1  0    98
00005 03597 03665  1 0.3100 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.3996 18.8969  1  0    98
00006 03598 03666  1 0.4193 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.3760 18.7109  1  0    98
00007 03599 03667  1 0.5191 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.6043 12.6341  1  0    98
00008 03600 03668  1 0.6065 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.2500  9.8438  1  0    98
00009 03601 03669  1 0.7145 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.5728 12.3861  1  0    98
00010 03602 03670  1 0.8412 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8720 14.7424  1  0    98
00011 03603 03671  1 0.9584 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00012 03604 03672  1 1.0646 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00013 03605 03673  1 1.1577 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00014 03606 03674  1 1.2384 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00015 03607 03675  1 1.3065 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00016 03608 03676  1 1.3636 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00017 03609 03677  1 1.4095 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00018 03610 03678  1 1.4452 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00019 03611 03679  1 1.4712 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00020 03612 03680  1 1.4879 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00021 03613 03681  1 1.4961 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00022 03614 03682  1 1.4961 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00023 03615 03683  1 1.4895 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00024 03616 03684  1 1.4790 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00025 03617 03685  1 1.4718 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00026 03618 03686  1 1.4803 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.3012 10.2468  1  0    98
00027 03619 03687  1 1.4840 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  0.7500  5.9062  1  0    98
00028 03620 03688  1 1.4861 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.2067  9.5027  1  0    98
00029 03621 03689  1 1.5108 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2264 17.5327  1  0    98
00030 03622 03690  1 1.5398 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.5059 19.7340  1  0    98
00031 03623 03691  1 1.5611 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0    98
00032 03624 03692  1 1.5718 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0    98
00033 03625 03693  1 1.5738 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0    98
00034 03626 03694  1 1.5640 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.1770  9.2686  1  0    98
************************************************************************************************************
* 1     2     3    4    5     6     7     8     9 10    11   12   13  14     15      16      17   18 19    20
************************************************************************************************************
00035 03661 03593  2 0.0675 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.2000  9.4500  1  0    98
00036 03662 03594  2 0.1173 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.1996  9.4469  1  0    98
00037 03663 03595  2 0.1682 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.3996 18.8969  1  0    98
00038 03664 03596  2 0.2317 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2047 17.3622  1  0    98
00039 03665 03597  2 0.3100 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.3996 18.8969  1  0    98
00040 03666 03598  2 0.4193 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.3760 18.7109  1  0    98
00041 03667 03599  2 0.5191 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.6043 12.6341  1  0    98
00042 03668 03600  2 0.6065 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.2500  9.8438  1  0    98
00043 03669 03601  2 0.7145 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.5728 12.3861  1  0    98
00044 03670 03602  2 0.8412 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8720 14.7424  1  0    98
00045 03671 03603  2 0.9584 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00046 03672 03604  2 1.0646 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00047 03673 03605  2 1.1577 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00048 03674 03606  2 1.2384 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00049 03675 03607  2 1.3065 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00050 03676 03608  2 1.3636 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00051 03677 03609  2 1.4095 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00052 03678 03610  2 1.4452 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00053 03679 03611  2 1.4712 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00054 03680 03612  2 1.4879 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00055 03681 03613  2 1.4961 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00056 03682 03614  2 1.4961 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00057 03683 03615  2 1.4895 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00058 03684 03616  2 1.4790 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00059 03685 03617  2 1.4718 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.8504 14.5719  1  0    98
00060 03686 03618  2 1.4803 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.3012 10.2468  1  0    98
00061 03687 03619  2 1.4840 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  0.7500  5.9062  1  0    98
00062 03688 03620  2 1.4861 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.2067  9.5027  1  0    98
00063 03689 03621  2 1.5108 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2264 17.5327  1  0    98
00064 03690 03622  2 1.5398 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.5059 19.7340  1  0    98
00065 03691 03623  2 1.5611 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0    98
00066 03692 03624  2 1.5718 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0    98
00067 03693 03625  2 1.5738 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0    98
00068 03694 03626  2 1.5640 0.337 0.609 0.012  2  2  -56.0 17.00 11 23.6  1.0000  1.1770  9.2686  1  0    98
************************************************************************************************************
* 1     2     3    4    5     6     7     8     9 10    11   12   13  14     15      16      17   18 19    20
************************************************************************************************************
00069 06483 10882  3 1.5204 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  4.6144 36.3382  1  0   112
00070 06484 10883  3 1.5009 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  2.2244 17.5172  1  0   112
00071 06485 10884  3 1.5023 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.1201  8.8206  1  0   112
00072 06486 10885  3 1.5012 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  0.7500  5.9063  1  0   112
00073 06487 10886  3 1.4961 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.1437  9.0066  1  0   112
00074 06488 10887  3 1.5079 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.9252 15.1609  1  0   112
00075 06489 10888  3 1.5254 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  2.1181 16.6801  1  0   112
00076 06490 10889  3 1.5379 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.9252 15.1609  1  0   112
00077 06491 10890  3 1.5439 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.9173 15.0989  1  0   112
00078 06492 10891  3 1.5424 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  2.1358 16.8196  1  0   112
00079 06493 10892  3 1.5294 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.9331 15.2229  1  0   112
00080 06494 10893  3 1.5145 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.7146 13.5022  1  0   112
00081 06495 10894  3 1.4915 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  2.1024 16.5561  1  0   112
00082 06496 10895  3 1.4738 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.9252 15.1609  1  0   112
00083 06497 10896  3 1.4740 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  1.1614  9.1462  1  0   112
00084 06498 10897  3 1.4718 0.273 0.629 0.013  2  2  -56.0 17.00 11 23.6  1.0000  0.7500  5.9063  1  0   112
```

Example Case FAVPost-EP input file

```
********************************************************************************
*      ALL RECORDS WITH AN ASTERISK (*) IN COLUMN 1 ARE COMMENT ONLY           *
********************************************************************************
*                EXAMPLE INPUT DATASET FOR FAVPost-EP, v05.1
*
********************************************************************************
*  ====================                                                        *
*     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
```

Example Case FAVPost-EP 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. 18. 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 19, 20, and 21 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 FAVLoad-EP. Figure 22 shows the initiating-event frequency histograms for the four transients that are used as input to FAVPost-EP for this example.

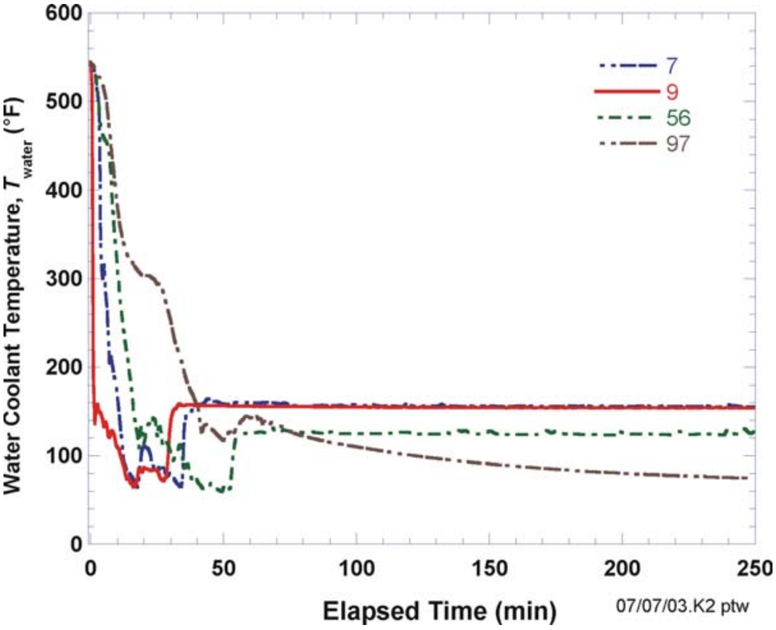


Fig. 19. Time histories of coolant temperature for four PTS transients.

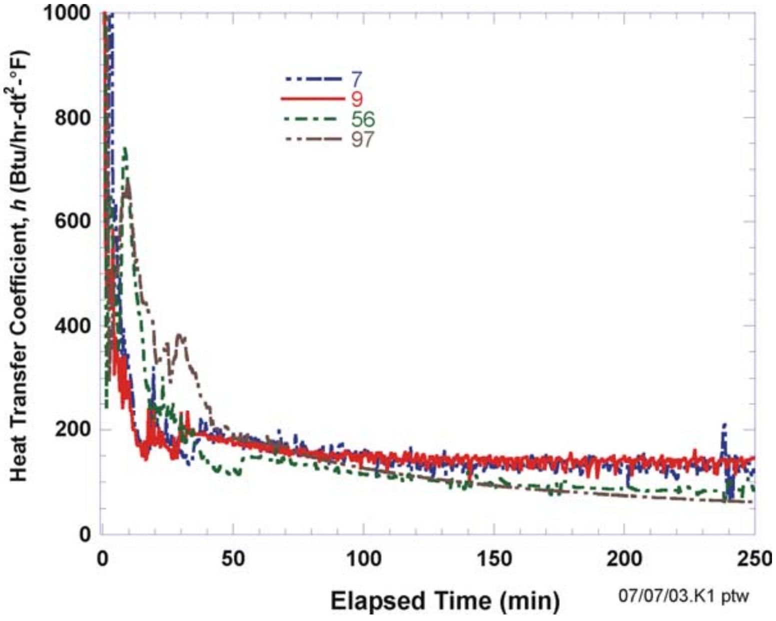


Fig. 20.Time histories of convection heat transfer coefficient four PTS transients.

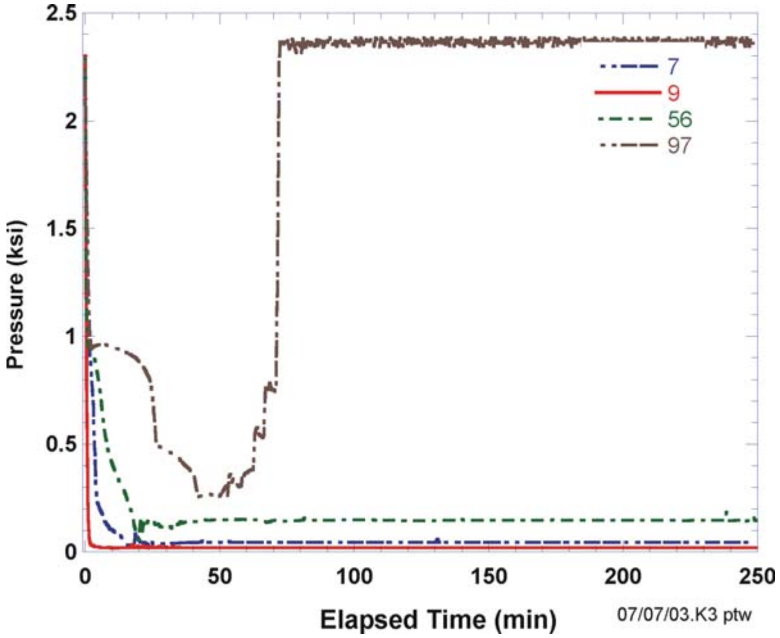


Fig. 21. Time histories for internal pressure for four PTS transients.

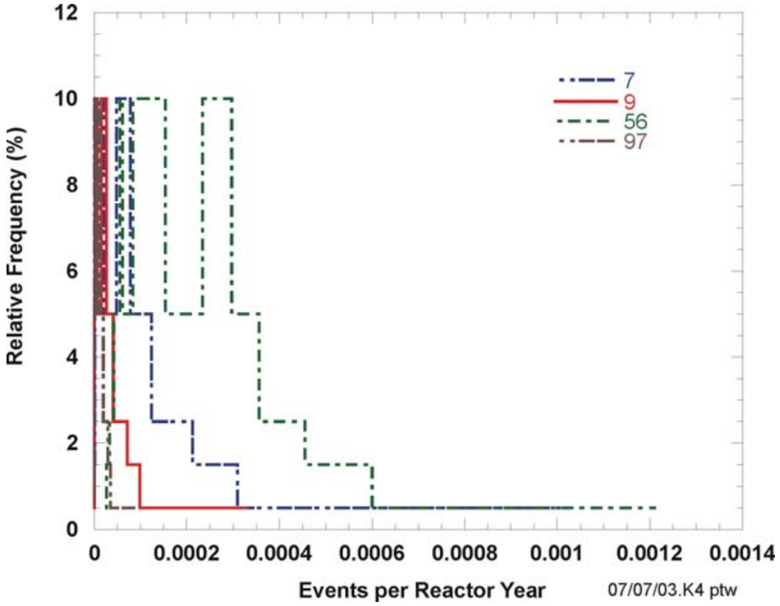


Fig. 22. Initiation event frequency distribution for PTS Transients 7, 9, 56, and 97.

The output files for this case are listed in Section 3 of this report as examples of output files and are included on the distribution CD. The 10,000-vessel simulation example case on the distribution CD required 48,475,720 flaws to be analyzed and took approximately 31 hours on a FAVOR-EP-dedicated Pentium IV computer (Windows XP Professional operating system) with 2048 MB of memory and a clock speed of 1.5 GHz.

4. Summary and Conclusions

The FAVOR-EP, v05.1, 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-EP, v05.1:

- **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,**
- **a new embrittlement correlation,**
- **a new ductile-tearing model simulating stable and unstable ductile fracture,**
- **the ability to handle multiple transients in one execution of FAVOR-EP,**
- **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-EP, v05.1, 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-EP, v05.1 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-EP, v05.1.

5. References

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

2. P. T. Williams, T. L. Dickson, and S. Yin, *Fracture Analysis of Vessels – FAVOR-EP (v05.1) Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations*, NUREG/???? (ORNL/TM-2005/???), Oak Ridge National Laboratory, Oak Ridge, TN, 2005.

3. A. R. Foster and R. L. Wright, Jr., *Basic Nuclear Engineering*, 2nd ed., Allyn and Bacon, Inc., Boston, 1973.

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

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

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

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

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

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

10. R. D. Cheverton and D. G. Ball, *OCA-P, A Deterministic and Probabilistic Fracture Mechanics Code for Application to Pressure Vessels,* NUREG/CR-3618 (ORNL-5991), Oak Ridge National Laboratory, Oak Ridge, TN, May 1984.

11. F. A. Simonen, et al., *VISA-II – A Computer Code for Predicting the Probability of Reactor Pressure Vessel Failure*, NUREG/CR-4486 (PNL-5775), Pacific Northwest Laboratory, Richland, Washington, March 1986.

12. T. L. Dickson and F. A. Simonen, “The Application of Probabilistic Fracture Analysis to Residual Life Evaluation of Embrittled Reactor Vessels,” AD-Vol. 28, Reliability Technology, *American Society of Mechanical Engineers,* (1992) 43-55.

13. B. A. Bishop, T. L. Dickson, and F. A. Simonen, *Benchmarking of Probabilistic Fracture Mechanics Analyses of Reactor Vessels Subjected to Pressurized Thermal Shock (PTS) Loading,* Research Project 2975-5, Final Report, February 1993.

14. T. L. Dickson and R. D. Cheverton, *Review of Reactor Pressure Vessel Evaluation Report for Yankee Rowe Nuclear Power Station (YAEC No. 1735), Appendix D,* NUREG/CR-5799 (ORNL/TM-11982), Oak Ridge National Laboratory, Oak Ridge, TN, March 1992.

15. B. R. Bass, et al., *International Comparative Assessment Study of Pressurized Thermal Shock in Reactor Pressure Vessels,* NUREG/CR-6651 (ORNL/TM-1999/231), Oak Ridge National Laboratory, Oak Ridge, TN, December 1999.

16. T. L. Dickson, *FAVOR-EP: A Fracture Analysis Code for Nuclear Reactor Pressure Vessels, Release 9401*, ORNL/NRC/LTR/94/1, Oak Ridge National Laboratory, Oak Ridge, TN, 1994.

17. American Society of Mechanical Engineers Boiler and Pressure Vessel Code – Sect. II, Part D: Properties, 1998.

18. L. Stumpfrock, et al., "Brittle Crack Initiation, Propagation and Arrest of Shallow Cracks in a Clad Vessel Under PTS Loading," *NESC II Final Report*, NESCDOC Man (02) 07, EUR 20696 EN, European Commission DG-JRC/IE, Petten, The Netherlands, March 2003.

19. F. N. Fritsch and R. E. Carlson, "Monotone Piecewise Cubic Interpolation," *SIAM J. Numer. Anal.* **17**(2), (1980) 238-246.

20. F. N. Fritsch and J. Butland, "A Method for Constructing Local Monotone Piecewise Cubic Interpolants," *SIAM J. Sci. Stat. Comput.* **5**(2), (1984) 300-304.

21. T. L. Dickson, W. J. McAfee, W. E. Pennell, and P. T. Williams, "Evaluation of Margins in the ASME Rules for Defining the P-T Curve for an RPV," *Proceedings of the Twenty-Sixth Water Reactor Safety Meeting, Vol. 1*, NUREG/CR-0166, Oak Ridge National Laboratory, (1999) 47-72.

6. Appendix A – Summary of RVID2 Data for Use in FAVOR-EP Calculations

Product Form	Heat	Beltline	$\sigma_{flow(u)}$ [ksi]	$RT_{NDT(u)}$ [°F]			Composition[(2)]			USE_0 (ft-lbf)
				$RT_{NDT(u)}$ Method	$RT_{NDT(u)}$ Value	$\sigma_{(u)}$ Value	Cu	Ni	P	
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	90
	C4381-2	INTERMEDIATE SHELL B6607-2	84.3	MTEB 5-2	73	0	0.14	0.62	0.015	84
	C6293-2	LOWER SHELL B7203-2	78.8	MTEB 5-2	20	0	0.14	0.57	0.015	84
	C6317-1	LOWER SHELL B6903-1	72.7	MTEB 5-2	27	0	0.2	0.54	0.01	80
LINDE 1092 WELD	305414	LOWER SHELL AXIAL WELD 20-714	75.3	Generic	-56	17	0.337	0.609	0.012	98
	305424	INTER SHELL AXIAL WELD 19-714	79.9	Generic	-56	17	0.273	0.629	0.013	112
LINDE 0091 WELD	90136	CIRC WELD 11-714	76.1	Generic	-56	17	0.269	0.07	0.013	144
Calvert Cliffs 1, (Designer and Manufacturer: CE) **Coolant Temperature = 545°F, Vessel Thickness = 8 5/8-in.**										
PLATE	B-8489-1	LOWER SHELL D-7207-3	78.8	MTEB 5-2	-20	0	0.11	0.53	0.008	81
	B-8489-2	LOWER SHELL D-7207-2	80.3	MTEB 5-2	-10	0	0.11	0.56	0.009	90
	C-4351-2	INTERMEDIATE SHELL D-7206-1	74.7	MTEB 5-2	20	0	0.11	0.55	0.011	90
	C-4420-1	LOWER SHELL D-7207-1	78.0	MTEB 5-2	10	0	0.13	0.54	0.01	77
	C-4441-1	INTERMEDIATE SHELL D-7206-3	78.5	ASME NB-2331	10	0	0.12	0.64	0.011	112
	C-4441-2	INTERMEDIATE SHELL D-7206-2	82.6	ASME NB-2331	-30	0	0.12	0.64	0.011	81
LINDE 1092 WELD	20291/12008	INTERMEDIATE SHELL AXIAL WELD 2-203	78.8	ASME NB-2331	-50	0	0.22	0.83	0.01	110
	21935	LOWER SHELL AXIAL WELD 3-203A/C	78.6	Generic	-56	17	0.18	0.72	0.015	109
LINDE 0091 WELD	33A277	INT. TO LOWER SHELL CIRC. WELD 9-203	78.6	ASME NB-2331	-80	0	0.24	0.16	0.014	160
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	109
PLATE	C2197-2	INTERMEDIATE SHELL	(4)	B&W Generic	1	26.9	0.15	0.5	0.008	81
	C2800-1	LOWER SHELL	(4)	B&W Generic	1	26.9	0.11	0.63	0.012	81
	C2800-2	LOWER SHELL	69.9	B&W Generic	1	26.9	0.11	0.63	0.012	119
	C3265-1	UPPER SHELL	75.8	B&W Generic	1	26.9	0.1	0.5	0.015	108
	C3278-1	UPPER SHELL	(4)	B&W Generic	1	26.9	0.12	0.6	0.01	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	70
	299L44	INT./UPPER SHL CIRC WELD (OUTSIDE 39%) WF-25	(4)	B&W Generic	-7	20.6	0.34	0.68	(3)	81
	61782	NOZZLE BELT/INT. SHELL CIRC WELD SA-1135	(4)	B&W Generic	-5	19.7	0.23	0.52	0.011	80
	71249	INT./UPPER SHL CIRC WELD (INSIDE 61%) SA-1229	76.4	ASME NB-2331	10	0	0.23	0.59	0.021	67
	72445	UPPER/LOWER SHELL CIRC WELD SA-1585	(4)	B&W Generic	-5	19.7	0.22	0.54	0.016	65
	8T1762	LOWER SHELL AXIAL WELDS SA-1430	75.5	B&W Generic	-5	19.7	0.19	0.57	0.017	70
	8T1762	UPPER SHELL AXIAL WELDS SA-1493	(4)	B&W Generic	-5	19.7	0.19	0.57	0.017	70

Product Form	Heat	Beltline	$\sigma_{flow(u)}$ [ksi]	$RT_{NDT(u)}$ [°F]			Composition[(2)]			USE_0 (ft-lbf)
				$RT_{NDT(u)}$ Method	$RT_{NDT(u)}$ Value	$\sigma_{(u)}$ Value	Cu	Ni	P	
	8T1762	LOWER SHELL AXIAL WELDS SA-1426	75.5	B&W Generic	-5	19.7	0.19	0.57	0.017	70
Palisades, (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	87
	B-5294	D-3804-3	(4)	MTEB 5-2	-25	0	0.12	0.55	0.01	73
	C-1279	D-3803-3	(4)	ASME NB-2331	-5	0	0.24	0.5	0.011	102
	C-1279	D-3803-1	74.7	ASME NB-2331	-5	0	0.24	0.51	0.009	102
	C-1308A	D-3804-1	(4)	ASME NB-2331	0	0	0.19	0.48	0.016	72
	C-1308B	D-3804-2	(4)	MTEB 5-2	-30	0	0.19	0.5	0.015	76
LINDE 0124 WELD	27204	CIRC. WELD 9-112	76.9	Generic	-56	17	0.203	1.018	0.013	98
LINDE 1092 WELD	34B009	LOWER SHELL AXIAL WELD 3-112A/C	76.1	Generic	-56	17	0.192	0.98	(3)	111
	W5214	LOWER SHELL AXIAL WELDS 3-112A/C	72.9	Generic	-56	17	0.213	1.01	0.019	118
	W5214	INTERMEDIATE SHELL AXIAL WELDS 2-112 A/C	72.9	Generic	-56	17	0.213	1.01	0.019	118

Notes:

1. Information taken directly from the July 2000 release of the NRCs Reactor Vessel Integrity (RVID2) database.
2. These composition values are as reported in RVID2. In FAVOR-EP calculations these values should be treated as the central tendency of the Cu, Ni, and P 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 values 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 for the unirradiated upper-shelf CVN energy, USE_0, are recorded in RVID2 for these heats.

7. Appendix B – FAVOR-EP 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	(-)

NRC FORM 335
(2-89)
NRCM 1102,
3201,3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if anv.1

NUREG -
ORNL/TM-2005/

2. TITLE AND SUBTITLE

Fracture Analysis of Vessels – Oak Ridge (FAVOR-EP, v05.1):
User's Guide

3. DATE REPORT PUBLISHED

MONTH	YEAR
September	2005

4. FIN OR GRANT NUMBER
Y6533

5. AUTHOR(S)

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

6. TYPE OF REPORT
Final, technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Heavy Section Steel Technology Program
Oak Ridge National Laboratory
P. O. Box 2008, Mail Stop 6085
Oak Ridge, TN 37831-6085

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Engineering Technology
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 2055-0001

10. SUPPLEMENTARY NOTES

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

The current regulations to insure that nuclear reactor pressure vessels (RPVs) maintain their structural integrity when subjected to transients such as pressurized thermal shock (PTS) events were derived from computational models developed in the early-to-mid 1980s. Since that time, advancements and refinements in relevant technologies that impact RPV integrity assessment have led to an effort by the NRC to re-evaluate its PTS regulations. 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). Contributors to the development of these methodologies include the NRC staff, their contractors, and representatives from the nuclear industry. These updated methodologies have been integrated into the Fracture Analysis of Vessels – Oak Ridge (FAVOR-EP, v05.1) computer code developed for the NRC by the Heavy Section Steel Technology (HSST) program at Oak Ridge National Laboratory (ORNL). The FAVOR-EP, v05.1, code represents the baseline NRC-selected applications tool for re-assessing the current PTS regulations. This report provides a user's guide to the computer system requirements, installation, input data-deck preparation, and execution of the FAVOR-EP, v05.1, deterministic and probabilistic fracture mechanics computer code.

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

13. AVAILABILITY STATEMENT
unlimited

14. SECURITY CLASSIFICATION
(This Page)
unclassified
(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)