Technical Letter Report

TLR-RES/DE/REB-2023-11

FAVOR v20.1
Testing and Verification and Validation Report

Date Prepared:

February 2021

Date Published:

December 2023

Prepared in response to Subtask 1.5 of task order 31310020D0005 / 31310020F0103 entitled FAVOR, REAP, and RPV Analysis by:

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Revision History

Revision	Date	Comments
0	12/08/2023	Original

Approvals

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Acronyms and Abbreviations

This section provides abbreviations and acronyms specific to this plan and software project.

AFF	As-Found Flaw
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
CM	Configuration Management
CMMP	Configuration Management & Maintenance Plan
COTS	Commercial Off-The-Shelf
JIRA	Software Work Management and Issue Management Tool
NDE	Non-Destructive Examination
NRC	United States Nuclear Regulatory Commission
NQA-1	Nuclear Quality Assurance - 1
PFM	Probabilistic Fracture Mechanics
PM	Project Manager
PMP	Project Management Plan
PWR	Pressurized Water Reactor
QA	Quality Assurance
SDD	Software Design Document
SOW	Statement of Work
SQA	Software Quality Assurance
SQAP	Software Quality Assurance Plan

SQE	Software Quality Engineer
SRD	Software Requirements Document
STP	Software Test Plan
STRR	Software Test Results Report
SVVP	Software Verification and Validation Plan
SVVR	Software Verification and Validation Report
TWCF	Through-Wall Cracking Frequency, which is calculated as a product of the CPF and a matrix defining the sequence (or event) frequency of the loading transients. Calculating a mean TWCF for RPVs subjected to pressure and temperature curves requires a statistical representation of the possible transients and their frequencies of occurrence.
V&V	Verification and Validation

Definitions

This section provides definitions specific to this plan and software project.

Assessment	A review, evaluation, inspection, test, check, surveillance, or audit to determine and document whether items, processes, systems, or services meet specified requirements and perform effectively. (NQA-1-2017)
Acceptance Testing	The process of exercising or evaluating a system or system component by manual or automated means to ensure that it satisfies the specific requirements and to identify differences between expected and actual results in the operating environment. (NQA-1)
Baseline	A specification or product that has been formally reviewed and agreed upon, that thereafter serves as the basis for use and further development, and that can be changed only by using an approved control process. (NQA-1)
Configuration Item	A collection of hardware or software elements treated as unit for the purpose of configuration control. (NQA-1)
Configuration Management (Software)	The process of identifying and defining the configuration items in a system (i.e. software and hardware), controlling the release and change of those items throughout the system's life cycle, and recording and reporting the status of configuration items and change requests. (NQA-1)
Contractor	The organization or organizations contracted by the NRC to work on the FAVOR project.
Error	A condition deviating from an established baseline, including deviations from the current approved computer program and its baseline requirements. (NQA-1)
Graded Approach	The process of ensuring that the level of analysis, documentation, and actions used to comply with a requirement is commensurate with: 1) relative importance to safety, safeguards, and security, 2) magnitude of any hazard involved, 3) the life-cycle stage of a facility or item, 4) programmatic mission of a facility, 5) characteristics of a facility or item, 6) relative importance of radiological and non-radiological hazards, and 7) any other relevant factors (NQA-1)

Independent Reviews/Testing	Person sufficiently independent with respect to the material/product they are reviewing/testing; they did not perform the work they are reviewing or testing. Staff also possess enough subject matter expertise to adequately review/test/evaluate.
Module	A program unit that is discrete and identifiable with respect to compiling; combining with other units, and loading; a logically separable part of a program that can be verified independently and performs a specific limited function, such as modeling physical phenomena, handling user input, output, data storage, etc.; contained, cohesive parts that can be combined to create the final product.
Operating Environment	A collection of software, firmware, and hardware elements that provide for the execution of computer programs. (NQA-1)
Regression Testing	Selective re-testing of a system or component to verify that modifications have not caused unintended effects and that the system or component still complies with its specified requirements.
Software Design Document	A document that describes the design of a system or component. Typical contents include system or component architecture, control logic, data structures, input/output formats, interface descriptions, theoretical bases, embodied mathematical models, control flow, and subroutines used in the software, and the allowed or prescribed ranges for data inputs and outputs in a manner that can be implemented. Currently described in the FAVOR Theory Manual [1].
Software Design Verification	The process of determining if the product of the software design activity fulfills the software design requirements. (NQA-1)
Software Requirements Document	Documentation of the essential requirements (functional performance, design constraints, and attributes (including acceptance criteria)) of the software and its external interfaces.
Software Verification and Validation Plan (SVVP)	A comprehensive, project-level plan which is a roadmap document that describes the elements, processes, and sequence of actions to ensure that the software properly fulfills its intended use as identified in the Software Requirements Document and Software Design Description Document. These actions may include peer reviews, audits, walkthroughs, analyses, architecture evaluations, simulations, testing, and demonstrations.
Test Case	A set of test inputs, execution conditions, and expected results developed for an objective, such as to exercise a program path or to verify compliance with a specific requirement. (NQA-1)

Test Plan	A document that describes the approach to be followed for testing a system or component. Typical contents identify items to be tested, tasks to be performed, and responsibilities for the testing activities. (NQA-1)
Validation	The process of evaluating software to determine whether it satisfies specified requirements, by comparing code predictions to experimental data or independent benchmark standards. Specifically, per the IEEE Std 730™-2014 standard (Reference [2]), the process of providing evidence that the system, software, or hardware and its associated products satisfy requirements allocated to it **at the end of each life cycle activity**, solve the right problem (e.g., correctly model physical laws and use the proper system assumptions), and satisfy intended use and user needs.
Verification	Mathematical proof of the correctness of algorithms, by confirming that code subroutines and functions produce the expected numerical output as the software goes **through each life cycle activity**. As Noted in IEEE Std 730™-2014 standard (Reference [2]), "Verified" designates the corresponding status. In design and development, verification includes examining the result of a given activity to determine conformity with the stated requirement for that activity. A system may be verified to meet the stated requirements yet be unsuitable for operation by the actual users.
Unit Test	Process or code developed to test the numeric accuracy and functionality of new or modified subroutines and functions.
Unit Test Suite	Set of unit tests created while developing and maintaining FAVOR.
Verification Test Suite	Set of input files that exercise all the code options, used to verify that code changes do not negatively impact code performance, and that results are as expected.
Validation Test Suite	Set of input files used to validate the codes' predictions against experimental measurements, to quantify the accuracy, bias, and uncertainty of code predictions.

1 Purpose & Scope

The purpose is to document the Verification and Validation (V&V) plan, the V&V results, sub tier software test plans, and the test plan results. The FAVOR V&V Plan and its sub-task Test Plan describes the approach to be followed for testing the modifications made to the FAVOR code, in particular the FAVPFM module, to provide the ability to specify as-found flaws from in-service reactor vessel inspection results.

With respect to the FAVOR Software V&V plan (see Appendix B), a typical plan includes a comprehensive, project-level plan which is a roadmap document that describes the elements, processes, and sequence of actions to ensure that the software properly fulfills its intended use as identified in the Software Requirements Document and Software Design Description Document. These actions may include peer reviews, audits, walkthroughs, analyses, architecture evaluations, simulations, testing, and demonstrations. For the activities planned for v20.1, simple peer reviews and analyses will be performed due to the type of modification and impact on the current v16.1 capabilities. For v20.1, verification involved the use of mathematical proof of the correctness of algorithms, by confirming that the relevant FAVOR code subroutines and functions produce the expected numerical output. Numerical output should be either identical or close (i.e., within 1% of the original v16.1 results unless there is a change to a more accurate method/model), because the main FAVPFM thermal hydraulic and fracture mechanic modeling, algorithms, and functions are not changing: only the flaw distribution input is changed in FAVOR v20.1. Since no new models, functions, or algorithms are being used as a basis for calculating CPI or CPF, or other critical key outputs, validation was simply that the code still produces identical results to v16.1, which was validated in the past against benchmarks to ABAQUS and experimental data (see Reference [3]).

The resulting test plans from the V&V plan contain the items to be tested, the tasks to be performed, and a description of the responsibilities for the testing activities. The test plan also provides the set of test inputs, execution conditions, and expected results to test the specific requirements stated in the FAVOR Software Requirements and Design Document (SRD and SDD) (Reference [4]). Due to the type and risk impact of the modifications identified in the SRD and SDD (Reference [4]), much of the testing described herein is regression testing, which is selective re-testing of the FAVPFM module to verify that modifications have not caused unintended effects and that FAVPFM still is consistent with the algorithms and methods as described in the FAVOR Theory Manual (Reference [1]). A number of unit/integral tests were also performed to ensure the numeric accuracy and functionality of the new and modified subroutines and functions. The software design document section within the FAVOR v20.1 SRD and SDD document (Reference [4]) lists all the modified subroutines and functions.

Although this specific work was not done under a qualified SQA program, this document is intended to meet the content and intent of such a program. Consistent with the FAVOR Software Quality Assurance Plan (Reference [5]) , unit testing is performed on new subroutines/functions that are added to ensure that information is properly calculated. The Software developer and/or software tester designs an appropriate unit test and documents the results of the testing for inclusion in the V&V section of the technical basis document. Any modification made to existing subroutines shall require the developer or tester to ensure that the existing unit tests are adequate and, if not, to develop additional unit tests corresponding to the modifications made.

Unit testing shall be performed to ensure the following:

- The numerical problem is being solved correctly (i.e., numerical verification),
- The code is continuous within the range of possible input conditions, and
- All new functionality is working properly.

All the existing unit tests must be run and documented in Software Test Reports to be included as appendices before releasing the FAVLoad, FAVPFM, and/or FAVPost changes. Representative unit tests shall be added to the existing unit test suite for continued use.

2 Reference Documents

The following documents were utilized to develop the test plans and results in this document:

[1] P. T. Williams, T. L. Dickson, B. R. Bass and H. B. Klasky, "ORNL/LTR-2016/309: Fracture Analysis of Vessels – Oak Ridge FAVOR, v16.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations (ML16273A033)," Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, August 2016.

[2] IEEE Computer Society, "IEEE Standard for Software Quality," The Institute of Electrical and Electronics Engineers, Inc., New York, NY, 2014.

[3] A. Ayszel, T. L. Dickson, M. Smith and P. Raynaud, "TLR-RE/DE/CIB-2020-002: Assessment of V&V Efforts of Fracture Analysis of Vessels – Oak Ridge (FAVOR) Software Product – Version 16.1 (ML20017A170)," U.S. Nuclear REgulatory Commission, Washington, DC, USA, 2020.

[4] T. Dickson, A. Dyszel, M. Smith and P. Raynaud, "Fracture Analysis of Vessels – Oak Ridge (FAVOR) for v20.1 Pre-Release - Software Requirements and Design Document," U.S. Nuclear Regulatory Commission, Washington, DC, 2020.

[5] A. Dyszel and P. A. C. Raynaud, "FAVOR Software Quality Assurance Plan (SQAP)," U.S. Nuclear Regulatory Commission, Washington, DC, 2020.

3 Roles & Responsibilities

The organizational structure and responsibility assignments shall be such that:

- Software development and maintenance is well planned, verified, and documented under quality assurance procedures.
- Quality is achieved and maintained by those who have been assigned responsibility for performing work, and
- Quality achievement is verified by those not directly responsible for performing the work.

The responsibilities are laid out in the FAVOR Software Quality Assurance Plan (Reference [5]) and not repeated herein. Overall, code development is performed by the NRC and/or the Contractor. The NRC is responsible for high level oversight and direction and assigns work based on staffing resources and knowledge.

A summary of the project team responsibilities is shown in Table 3-1, and a list of key documents that the project team creates during the life cycle of FAVOR development is shown in Table 3-2. This report focuses on the four green highlighted documents shown in these tables.

***Table 3-1: Functional Responsibility Matrix*[1]**

P=Prepare/Perform A=Approve I=Input R=Review S=Surveillance OD=Own & Distribute **Documents/Actions**	NRC PM	Contractor PM	Code Custodian	Records Custodian	Software Developer	Software Tester	SQE[2]	QA Manager[2]
FAVOR Software QA Plan (SQAP)	I, R, A	I, A	I	I, OD	I, R	I, R	P, R[4]	I, R, A
Configuration Mgmt. Plan and Procedures (CMMP)	I, R, A	I, A	I	I, OD	I, R		P, R[4]	I, R, A
Software Requirements Document (SRD)	I, R, A	I, R	P, I, R[4]	OD	P, I, R[4]		I, R[4]	S
Software Design Document (SDD)	I, R	I, R, A	I, OD		P			
Source Codes	I, R	I, R, A	I, OD		P			
Acceptance test input files	I, R	I, R, A	I, OD		I, R	P		
Unit & Integral Test Plans[3] (STPs)		A	I, R[4]		I, R	P		
V&V Plan (SVVP)	I, R, A	I, R, A	R[4]	OD	I, R	P	I, R[4]	R, A
Unit & Integral Tests and Results Reports[2] (STRRs)		R, A	I, R[4]	OD	I, R	P		
V&V Tests and Results Reports (SVVR)	R, A	I, R, A	R[4]	OD	I, R	P	S	S

[1] Note that this document does not meet the full requirements of this matrix as the document was not developed under a fully qualified Software QA program.
[2] Positions in the Quality Assurance Organization of the Contractor. These positions can be filled by one person, depending on the organization and simplicity of the code change.
[3] Per NUREG/BR-0167, these are classified as informal.
[4] Independent Technical Review

P=Prepare/Perform A=Approve I=Input R=Review S=Surveillance OD=Own & Distribute **Documents/Actions**	NRC PM	Contractor PM	Code Custodian	Records Custodian	Software Developer	Software Tester	SQE [2]	QA Manager [2]
Technical Reviews (e.g., assessments/surveillances)	P, I	P					S	S
Software Changes	R, A	I, R	I, R [4]		P			
Change Documents (Appendices D – L)	R, A	I, R	P, I, R [4]	OD	P		I	S
User Input Guide, Theory Manual	I, R, A	I, R	P, I, R [4]	OD	P, I, R [4]		S	S
Maintaining Problem Reporting, Corrective Action, & Change Control	R, A	R	P	OD	I		S	S
QA Records	A	I, R	R [4]	OD			S	S

Table 3-2: Key Process Documents/Outputs

Process Document/Output
Software Quality Assurance Plan (SQAP)
Configuration Management and Maintenance Plan (CMMP)
Software Requirements Document (SRD)
Software Verification & Validation Plan (SVVP)
Software Verification & Validation Report (SVVR)
Software Design Document (SDD) – may be a part of the FAVOR Theory Manual
Software Test Plan(s) (STPs)
Software Test Results Report(s) (STRRs)
JIRA Testing Issues
Implementation Documentation 1. FAVLoad, FAVPFM, FAVPost source code and executables
2. User's Manual
3. FAVOR Theory Manual
4. Acceptance Test Problems

4 FAVOR V&V Plan and FAVOR Test Plan for FAVPFM v20.1

The FAVOR SRD and SDD for v20.1 (Reference [4]) describes in detail the affected subroutines and new subroutines used in the software modification to read in as-found flaw input to FAVPFM. Table 4-1 provides a listing of the software requirements, which provide a basis for the number and type of tests to be performed. That is, all requirements must be verified to be implemented correctly. Details of the FAVOR version 20.1 Incremental Verification and Validation Plan are in Appendix B. The details of the v20.1 FAVPFM Software Test Plan are in Appendix C.

Overall, to ensure backward capability to v16.1, the following tests were performed comparing the output of v20.1 to that of v16.1:

- Use of IPFLAW values of 1, 2, and 3 using VFLAW based flaw files
- Flaws in only weld
- Flaws in only plate
- Internal surface breaking flaws and embedded flaws
- Transient stack reversal
- Axial flaws
- Circumferential flaws

For the as-found flaw option (IPFLAW=4), testing involved verifying that PFM solutions of FAVPFM v20.1 yield consistent results when compared to those generated by FAVPFM v16.1 for IPFLAW=1. The full set of verifications includes:

(1) Verification of v20.1 PFM solutions for embedded flaw for IPFLAW=4,

a. Axial flaw in plate,

b. Axial flaw in weld,

c. Circumferential flaw in plate, and

d. Circumferential flaw in weld.

(2) Verification of 20.1 PFM solutions for Internal Surface Breaking (ISB) flaws for IPFLAW=1 and 4,

a. Axial flaw in weld with aspect ratios 2, 6, 10, and infinite,

b. Axial flaw in plate with aspect ratios 2, 6, 10, and infinite,

c. Circumferential flaw in weld with aspect ratios 2, 6, 10, and infinite, and

d. Circumferential flaw in plate with aspect ratios 2, 6, 10, and infinite.

(3) Verification of v20.1 PFM solutions for generalized case – combination of flaw types, orientations, and geometries for IPFLAW=4,

(4) Verification of v20.1 PFM solutions for generalized case – different ordering of flaws,

(5) Verification of v20.1 PFM solutions for embedded flaws for IPFLAW=2,

(6) Verification of v20.1 PFM solutions for embedded flaws for IPFLAW=3, and

(7) Verification of v20.1 input filter.

Note that since the FAVLoad and the FAVPost modules were not changed, testing focused on the FAVPFM module. Since FAVPFM output impacts FAVPost input, testing also focused on ensuring that the CPI and CPF history output files are not adversely impacted by the change.

Table 4-1: Software Verification Against Software Requirements Summary

Software Requirement[5]	Affected FAVPFM[5] Subroutine(s) / Function(s)	Appendix D Test Case(s) to Verify Implementation
Input Requirement 1 – Additional option to v16.1 abilities.	FAVPFM16_1, FILE_INIT, RD17, RDFOUND, FLWDIS, PFM, ACCOUNT, REPORT, FLAW, PROP, get_Kapplied, BANNER, KEMB	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Input Requirement 2 – Use IPFLAW to activate as-found flaw.	FAVPFM16_1, FILE_INIT	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Input Requirement 3 – Allow the use of both VFLAW and as-found flaw input.	FAVPFM16_1, FILE_INIT, FLWDIS	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8, Sections D.5 and D.6
Input Requirement 4 – Use IPFLAW=4 to prompt user for as-found flaw file.	FAVPFM16_1, FILE_INIT	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Input Requirement 5 – As-found flaw input file specifications.	RDFOUND	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Input Requirement 6 - Free format input and require 201 as first record.	RDFOUND	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 1 – Read in as-found input file.	FAVPFM16_1, FILE_INIT, RDFOUND	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 2 – Filter potential user errors in input file.	FAVPFM16_1, RDFOUND, RD17	Section D.7
Functional Requirement 3 – Use existing FAVOR PFM Monte Carlo loop structure.	PFM	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 4 – For each RPV trial, include all user specified as-found flaws.	PFM	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 5 – Prior to entering PFM loop, calculate crack tip temperature and applied stress intensity factor for all user specified flaws.	FAVPFM16_1, TMPTIP, AMNKSE, AMNK99, KEMB	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 6 – Use existing cubic spline methodology for the as-found flaw specification to determine temperature and applied KI.	FAVPFM16_1, TMPTIP, PFM	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8

[5] Based on Table 7-1 of FAVOR v20.1 SRD and SDD document (Reference [4]).

Software Requirement[5]	Affected FAVPFM[5] Subroutine(s) / Function(s)	Appendix D Test Case(s) to Verify Implementation
Functional Requirement 7 – Minimize modifications to FAVLoad and FAVPFM.	NA[6]	No changes made to FAVLoad and FAVPFM. Also no changes to CPI and CPF history files.
Functional Requirement 8 – Calculate the appropriate RT_{NDT} for as-found flaw input.	PFM	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 9 – Assign the appropriate KI time history during the PFM analysis.	FAVPFM16_1, TMPTIP, AMNKSE, AMNK99, KEMB. PFM	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 10 – Use consistent methodology as v16.1 for flaw propagation.	ACCOUNT, FLWDIS, FLAW,PROP, get Kapplied	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Functional Requirement 11 – Maintain security controls for source and code executable.	NA[7]	Not Required.
Output Requirement 1 – Provide error messages in output.	RDFOUND, RD17	Section D.7
Output Requirement 2 – Provide CPI and CPF values for specified as-found flaws.	PFM, ACCOUNT, REPORT	Table D - 1, Table D - 2, Figure D - 7, Figure D - 8
Output Requirement 3 – Provide sorted list of significant flaws (i.e., CPI values > 0.01%).	REPORT	PFM output files for cases supporting Figure D - 7 and Figure D - 8
Output Requirement 4 – Update RTNDT.out file with more descriptive output.	PFM	RTNDT.out files for cases supporting Figure D - 7 and Figure D - 8
Performance Requirement 1 – Limit run times and file sizes to be less than a 100% increase from those of v16.1 of FAVPFM.	RDFOUND, MINZ, MCASE1, MCASE2, MCASE3, MCASE4, MCASE5, AMNKSE, AMNK99, TMPTIP, KEMB, CLCHK	No noticeable degradation other than IPFLAW=3 option due to use of more accurate cubic spline fit for temperature versus linear interpolation.

A list of key inputs to FAVOR, the important functions and algorithms used in FAVOR, and the FAVOR outputs used in critical decisions is shown in Table 4-2. Some key calculated outputs of FAVOR are K_I (applied stress-intensity factor) time history, through-wall temperature time history, and RT_{NDT} (Reference Nil-Ductility

[6] No changes were made to FAVLoad nor FAVPFM to incorporate the as-found flaw input capability.

[7] The FAVOR Configuration Management Plan describes a GitHub platform which is protected by unauthorized use and modification to the source code

Transition Temperature) at the crack tip. These FAVOR outputs are further used in determining flaw propagation and determining CPI (Conditional Probability of crack Initiation) and CPF (Conditional Probability of Failure).

The intent of the as-found flaw modification is to not impact the fundamental models and algorithms in the existing FAVOR theory manual (Reference [1]) listed in Table 4-2 , but to use them in the same fashion as a VFLAW based approach. The current FAVOR models and algorithms have been tested and validated against ABAQUS and used widely in the industry (Reference [3]). As the design intent was to maintaining consistency with the existing models and algorithms, the testing focused on ensuring consistent results to v16.1 of FAVOR.

The metrics of interest in the various tests are based on the critical outputs from FAVOR, particularly those of FAVPFM. Critical outputs from FAVOR, which were previously benchmarked, are identified in a recent assessment of past software quality assurance activities on FAVOR code modifications (See Reference [3]) and are reproduced below. Those characteristics highlighted in yellow in Table 4-2 are potentially impacted by the v20.1 code modifications. Testing therefore focused on verifying that the following outputs had values consistent with those of v16.1:

- Temperature as a function of time throughout vessel wall location,
- Stress as a function of time throughout vessel wall (circumferential and axial),
- K_I as a function of time throughout vessel wall,
- Probability distributions of crack initiation and vessel failure (i.e., CPI and CPF),
- Crack initiation frequency per reactor operating year, and
- Through-wall crack frequency per reactor operating year.

The last two will were logically proven by confirming that the CPI and CPF history files that are input to FAVPost did not change.

Table 4-2: FAVOR Critical Inputs, Functions, and Outputs

Type	Description
Key Inputs	• Thermo-Mechanical Material Properties for clad and base metal of the RPV (i.e., thermal conductivity, specific heat, density, Young's Elastic Modulus, thermal expansion coefficient, Poisson's ratio) • RPV geometry • Thermal Hydraulic boundary conditions (from RELAP or similar Transient T-H code) • Fast Neutron fluence maps (entered as f_o on Embrittlement Data, described below) • Flaw densities, size, and location (plates, welds, and forgings)[8] • Embrittlement Data (i.e., Cu, Ni, P, Mn, f_o, RT_{NDT0}) • Transient Initiating Frequency distributions (from PRA) • Probability distributions (aleatory and epistemic)

Important Functions and Algorithms	• FAVLoad Deterministic analyses
	    ○ Thermal analysis
	    ○ Stress analysis
	    ○ Linear-Elastic Fracture Mechanics (LEFM)
	    ○ Handling of residual stresses in welds
	    ○ Handling of crack-face pressure for surface breaking flaws
	• Calculation of Nil-Ductility Transition Temperature, RT_{NDT}
	• Radiation embrittlement correlations
	• Fast neutron fluence attenuation and sampling
	• Handling of K_{IC} and K_{Ia} Databases and calculations of K_{IC} and K_{Ia}
	• Sampling of RT_{NDT} and RT_{Arrest}
	• Sampling of Material Chemistry
	• Flaw characterizations and uncertainty
	• FAVPFM algorithms and models
	    ○ Warm prestressing logic
	    ○ Truncation for probability distributions
	    ○ Conditional Probability of Initiation (CPI) and Failure (CPF)
	    ○ Post initiation of flaw geometries and orientation
	    ○ Ductile tearing models
	    ○ Initiation-Growth-Arrest (IGA) model
	• FAVPost algorithm using FAVPFM distributions of conditional probabilities of initiation and failure with input transient initiating frequencies to create fracture and failure frequencies

Critical Outputs	• Temperature as a function of time throughout vessel wall location • Stress as a function of time throughout vessel wall (circumferential and axial) • K_I as a function of time throughout vessel wall • Probability distributions of crack initiation and vessel failure • Crack initiation frequency per reactor operating year • Through-wall crack frequency per reactor operating year

[8] Highlighted characteristics are being impacted by this Software Requirements and Software Design

5 Summary of FAVOR V&V and Test Results for v20.1 FAVPFM

The FAVOR V&V and tests for v20.1 FAVPFM were performed to meet both the FAVOR version 20.1 Incremental Verification and Validation Plan in Appendix B and the v20.1 FAVPFM Software Test Plan in Appendix C. As noted in the SVVP, because FAVOR has been previously verified and validated (see Reference [3]), and the modification to FAVPFM only is to add an additional method to enter flaw data (i.e., as-found flaw input), an incremental V&V approach is being used to test v20.1 FAVPFM.

The V&V results, which would normally be in a separate software verification and validation report (SVVR), are summarized in this section. Appendix D provides a detailed discussion of the verification results, which ensures that the software fulfills specified requirements as defined in the FAVOR Software Requirements and Design Document (Reference [4]). Verification is based on documentation that provides a traceable record of the software design requirements and development. Table 4-1 provides the record of the software requirements against the test activities and results of that testing.

As stated in the SVVP and the STP in Section 4, testing was simply focused on: 1) ensuring that backward capability exists for the new version of the program and 2) ensuring that cases for the as-found flaw input generate results consistent with those expected from the use of the current functions and algorithms in FAVPFM.

The following statements can be made regarding how the test cases were run consistent with the V&V plan and STP:

- Regarding method for verification, v20.1 FAVPFM was run against v16.1 of FAVPFM using standard comparative techniques to verify v20.1 of FAVPFM.
- Verification testing took place on the current version of Microsoft Windows 10.
- Acceptance criteria were established and defined as producing either identical results or if justified, results within 5% of the base v16.1 FAVPFM case.
- The testing covered the software life cycle phases of Requirements, Design, and Implementation.
- Test Phases consisting of acceptance test planning, integration test execution, acceptance test execution, and SVVR generation were not completed for v20.1.

The details of the testing are in the software test result report (STRR) as presented in Appendix D. The overall results of the testing are that (1) backward capability exists for v20.1 FAVPFM and that (2) cases for the as-found flaw input generate results consistent with those expected from the use of the current functions and algorithms in v16.1 FAVPFM. Note that v16.1 FAVLoad and v16.1 FAVPost required no change to implement the software requirements and design. Table 4-1 along with the tables and figures within Appendix D provide the documentation showing that the overall testing objectives have been met. A summary of the Appendix D results is provided below.

5.1 Verification of v20.1 PFM solutions for embedded flaw for IPFLAW=4

Table 5-1: Summary of V&V tests for as-found embedded flaws

Flaw Type	Depth	Flaw Orientation	Material	Xinner	Aspect Ratio	Transient	Figure	Acceptance Criteria Met (Y/N)
embedded	range	axial	weld	0.3	6.0	LOCA	Figure D - 1	Y
embedded	range	axial	plate	0.3	6.0	LOCA	Figure D - 2	Y
embedded	range	circ	weld	0.3	6.0	REPR	Figure D - 3	Y
embedded	range	circ	Plate	0.3	6.0	REPR	Figure D - 4	Y

All cases met the acceptance criteria.

5.2 Verification of v20.1 PFM solutions for Internal Surface Breaking (ISB) flaws for IPFLAW=1 and 4

Table 5-2: Summary of V&V tests for internal surface breaking flaws

Flaw Type	Depth	Orientation	Material	Aspect Ratio	Transient	Tables	Acceptance Criteria Met (Y/N)
ISB	range	axial	Weld	Infinite, 10, 6, & 2	LOCA	Table D - 4 Table D - 6 Table D - 8	Y
ISB	range	axial	Plate	Infinite, 10, 6, & 2	LOCA	Table D - 3 Table D - 5 Table D - 7	Y
ISB	range	circ	Weld	Infinite, 10, 6, & 2	LOCA	Table D - 4 Table D - 6 Table D - 8	Y
ISB	range	circ	Plate	Infinite, 10, 6, & 2	LOCA	Table D - 3 Table D - 5 Table D - 7	Y

All cases met the acceptance criteria.

5.3 Verification of v20.1 PFM Solutions for Generalized Case – Combination of Flaw Types, Orientations, and Geometries for IPFLAW=4

<u>The PFM solutions are identical for the first RPV trial</u>; however, are slightly different for subsequent RPV trials. This is due to the fact that the sequence of random numbers is not maintained after the first RPV trial between the two code versions. However, Figure D - 7 (se section D.3) shows that, with enough trials, the converged solutions of mean value of CPI and CPF are very close for the two codes; <u>therefore, the goal of</u>

mutual validation and backward compatibility is achieved. It is also important to note that the same allocation of flaws by category, orientation, and material (weld or plate) for various cases were obtained by both codes.

This test used a set of flaws that are not expected to actually be found in an RPV, but rather to illustrate the ability of the AFF option FAVOR 20.1 to properly analyze a very general combination of flaws. Also, the number and type of flaws resulted in relatively quick convergence of PFM solutions, which was desirable for the purposes of V&V testing.

5.4 Verification of v20.1 PFM Solutions for Generalized Case – Different Ordering of Flaws

A PFM analysis was executed using an AFF file containing a stack of 5254 flaw characterizations in original and reverse order. Figure D - 8 (see section D.4) shows that the PFM solutions are nearly identical regardless of the order in which flaws are specified – providing assurance that the PFM solutions have little dependence on the ordering of flaws and thereby meeting the acceptance criteria.

The allocation of CPI and CPF to the stack of AFF flaws also had negligible differences between cases for original and reverse ordering.

5.5 Verification of v20.1 PFM Solutions for Embedded Flaws for IPFLAW=2

The IPFLAW=2 option places all surface breaking flaws on the external surface of the RPV and embedded flaws distributed uniformly thru the outer 3/8 of the RPV thickness. This option of FAVOR was designed primarily to perform fracture analyses of heat-up transients where the larger axial and hoop tensile stresses occur in the outer part of the RPV wall.

The testing documented in section D.5illustrates that v20.1 FAVPFM generates nearly identical solutions (for embedded flaws, external surface breaking flaws, and generalized combinations of flaw types) as the v16.1 FAVPFM. The largest difference observed was <1% and the difference is most likely due to the improved cubic spline interpolations scheme used in determining the crack tip temperature for embedded flaws. Since the cubic spline is a better fit than linear interpolation, the v20.1 FAVPFM should provide more accurate solutions.

5.6 Verification of v20.1 PFM solutions for embedded flaws for IPFLAW=3

The IPFLAW=3 option places surface breaking flaws on both the internal and external surfaces and places embedded flaws uniformly distributed throughout the thickness of the base ferritic material. This option was designed for leak test transients which exhibit both a heat-up phase and a cooldown phase.

The testing documented in section D.6 illustrates that v20.1 FAVPFM generates nearly identical solutions (for embedded flaws, external surface breaking flaws, and generalized combinations of flaw types) as the v16.1 FAVPFM. For the same reason as for IPFLAW=2, slight differences were noticed due to the use of the cubic spline fit for crack tip temperature for embedded flaws. Most differences were zero with a few differences well within 5%, with the maximum being 3%.

5.7 Verification of v20.1 FAVPFM Input Filter

To test the ability of v20.1 FAVPFM to identify user input errors for the as-found flaw files, an as-found flaw input file with 15 identified errors was created to test each input parameter (IKIND, NSUBR, IORNT, DEPTH, ASPECT RATIO, and flaw ID). Error messages were appropriately printed to both the output file (Fortran unit 29) and as-found echo file (Fortran unit 31), thus confirming the error checking capability in v20.1. In addition, all the erroneous entries were identified, and explanations were made available to the user in both the output file and echo file.

5.8 Conclusion

In summary, the testing based on the STP and SVVP meets the two overall objectives: 1) ensuring that backward capability exists for the new version of the program and 2) ensuring that cases for the as-found flaw input generate results consistent with those expected from the use of the current functions and algorithms in FAVPFM.

Appendix A Software Quality Assurance Forms

The following quality assurance forms should be used to assess the V&V of version 20.1 of FAVOR.

A.1 Software Verification and Validation Plan Criteria

FAVOR Software Quality Assurance	Software Verification and Validation Plan Criteria	FAVOR-SQA-4

Document Name: ______________________________ **Document Number:** __________

Author: ______________________________ **Document Version:** __________

Technical Reviewer: ______________________________

Prior to approval of the Software Verification and Validation Plan (SVVP), all items shall be appropriately addressed so that "**Yes**" or "**N/A**" may be checked.

Methods: Are the methods to be used to perform the verification of each work product defined?	☐ **Yes**	☐ **N/A**
Environment: Has the environment to be used for the verification of each work product been specified?	☐ **Yes**	☐ **N/A**
Acceptance Criteria: Has criteria been developed that align with each work product, requirements, methods, and characteristics of the verification environment and provide traceability to previous work products?	☐ **Yes**	☐ **N/A**
Requirements Phase V&V Does the SVVP specify requirements for a software requirements traceability analysis, software requirements evaluation, software requirements interface analysis, and system test plan?	☐ **Yes**	☐ **N/A**
Design Phase V&V Does the SVVP specify requirements for a software design traceability analysis, software design evaluation, software design interface analysis, unit test plan, integration test plan, unit test design, and integration test design?	☐ **Yes**	☐ **N/A**
Implementation Phase V&V Does the SVVP specify requirements for a source code traceability analysis, source code evaluation, source code interface analysis, source code documentation analysis, unit test cases, integration test cases, unit test procedures, integration test procedures, and unit test execution?	☐ **Yes**	☐ **N/A**
Test Phase V&V Does the SVVP specify requirements for acceptance test procedures, integration test execution, acceptance test execution, and SVVR generation?	☐ **Yes**	☐ **N/A**

Key for check boxes above:

Check **Yes** for each item reviewed and found acceptable. Check **N/A** for items which are not applicable.

A.2 Software Test Plan Criteria

FAVOR Software Quality Assurance	Software Test Plan Criteria	FAVOR-SQA-8

Document Name: ______________________________ Document Number: __________

Author: ____________________________________ Document Version: __________

Technical Reviewer: ___________________________

Prior to approval of the software test plan (STP), all items shall be appropriately addressed so that "**Yes**" or "**N/A**" may be checked.

Required Tests, Test Sequences, and Staging Does the STP identify required tests, appropriate sequence, verification methods, and the stages at which testing is required and acceptance criteria to ensure the final software satisfies the requirements of the software requirements document (SRD)? Check "Yes" if peer review is identified to fulfill the validation requirements.	☐ **Yes**	☐ **N/A**
Required Ranges of Input Parameters and Assumptions Are acceptable ranges of inputs specified to assure the software performs within its defined capabilities and limitations during testing?	☐ **Yes**	☐ **N/A**
Do the test cases demonstrate that the code adequately performs all intended functions and produces valid results for problems encompassing the range of permitted usage?	☐ **Yes**	☐ **N/A**
Does user interface testing exercise the success and failure paths for each input and provide the appropriate look of the output?	☐ **Yes**	☐ **N/A**
Test Case Criteria Are the criteria for establishing test cases defined?	☐ **Yes**	☐ **N/A**
Requirements for Testing Logic Branches and Failure Paths Does the STP specify requirements for testing logic branches to ensure proper flow?	☐ **Yes**	☐ **N/A**
Does the STP specify requirements for testing failure paths to ensure there are no abnormal terminations?	☐ **Yes**	☐ **N/A**
Requirements for Hardware Integration Are all hardware interfaces identified with necessary testing to assure functionality?	☐ **Yes**	☐ **N/A**

Requirements for COTS Software Providing Necessary Functionality Is all commercial off-the-shelf (COTS) software that provides necessary functionality to the code identified and the associated critical characteristics and their capabilities and limitations for the intended use identified with necessary testing to assure functionality?	☐ **Yes**	☐ **N/A**
Anticipated Output Values Does the STP identify expected values that the code should produce and test the boundary of anticipated values to ensure that out of range values are properly handled?	☐ **Yes**	☐ **N/A**
Acceptance Criteria Does the STP identify acceptance criteria that are traceable to requirements specified in the SRD?	☐ **Yes**	☐ **N/A**
Test Result Validation Methods Check one or more, where applicable, as based on code functionality: The test results will be compared to the following:		
• Hand Calculations	☐ **Yes**	☐ **N/A**
• Manual Inspection	☐ **Yes**	☐ **N/A**
• Calculations using comparable proven problems	☐ **Yes**	☐ **N/A**
• Empirical data and information form confirmed published data and correlation and/or technical literature (e.g., Oak Ridge HSST tests)	☐ **Yes**	☐ **N/A**
• Other validated software of similar purpose (e.g., ABAQUS)	☐ **Yes**	☐ **N/A**
• Other independent software of similar purpose (e.g., ABAQUS)	☐ **Yes**	☐ **N/A**
A documented peer review will be performed.	☐ **Yes**	☐ **N/A**

Key for check boxes above:

Check **Yes** for each item reviewed and found acceptable. Check **N/A** for items which are not applicable.

A.3 Software Test Results Report Criteria

FAVOR Software Quality Assurance	Software Test Results Report Criteria	FAVOR-SQA-9

Document Name: ______________________________ **Document Number:** __________

Author: ______________________________ **Document Version:** __________

Technical Reviewer: ______________________________

Prior to approval of the software test results report (STRR), all items shall be appropriately addressed so that "**Yes**" or "**N/A**" may be checked.

Test Report Contents		
Does the STRR contain a summary of test results compared to expected results from the software test plan (STP) captured in the software test log?	☐ **Yes**	☐ **N/A**
Do test results meet the acceptance criteria identified in the software requirements description and STP?	☐ **Yes**	☐ **N/A**
Are test cases and test results documented in sufficient detail so they can be repeated?	☐ **Yes**	☐ **N/A**
Does the STRR contain a summary of anomalies including status, disposition, and resolutions?	☐ **Yes**	☐ **N/A**
Is the STRR written in a manner that can be understood by an independent, technically competent individual?	☐ **Yes**	☐ **N/A**

Key for check boxes above:

Check **Yes** for each item reviewed and found acceptable. Check **N/A** for items which are not applicable.

A.4 Software Verification and Validation Report Criteria

FAVOR Software Quality Assurance	Software Verification and Validation Report Criteria	FAVOR-SQA-10

Document Name: ______________________________ **Document Number:** __________

Author: ______________________________ **Document Version:** __________

Technical Reviewer: ______________________________

Prior to approval of the Software Verification and Validation Report (SVVR), all items shall be appropriately addressed so that "**Yes**" or "**N/A**" may be checked.

Does the SVVR contain a summary of the V&V activities for lifecycle phase that aligns to the Software Verification and Validation Plan?		
• Requirements Phase V&V	☐ **Yes**	☐ **N/A**
• Design Phase V&V	☐ **Yes**	☐ **N/A**
• Implementation Phase V&V	☐ **Yes**	☐ **N/A**
• Test Phase V&V	☐ **Yes**	☐ **N/A**
Does the SVVR contain a summary of task results compared to expected results captured in module STRRs?	☐ **Yes**	☐ **N/A**
Do V&V activities meet the acceptance criteria identified in the SVVP allowable or prescribed ranges for inputs and outputs specified?	☐ **Yes**	☐ **N/A**
Are V&V activities documented in sufficient detail so they can be repeated?	☐ **Yes**	☐ **N/A**
Does the SVVR contain a summary of anomalies including status, disposition, and resolutions?	☐ **Yes**	☐ **N/A**
Does the SVVR contain an assessment of overall software quality?	☐ **Yes**	☐ **N/A**
Does the SVVR contain lessons learned and best practices (to include deficiencies in the V&V process)?	☐ **Yes**	☐ **N/A**
Does the SVVR contain recommendations for software acceptance?	☐ **Yes**	☐ **N/A**
Is the SVVR written in a manner that can be understood by an independent, technically competent individual?	☐ **Yes**	☐ **N/A**

Key for check boxes above:

Check **Yes** for each item reviewed and found acceptable. Check **N/A** for items which are not applicable.

Appendix B FAVOR version 20.1 Incremental Verification and Validation Plan

As FAVOR has been previously verified and validated, and the modification to FAVPFM only is to add an additional method to enter flaw data (i.e., as-found flaw input), an incremental V&V approach is being used to establish the plan. This V&V plan defines the test cases, acceptance criteria, procedures for reporting and resolving reviewer concerns and discrepancies identified during the validation testing, and version control to be used for the FAVOR software. The guide in section A.1 provides a means to establish the SVVP.

The purpose of verification is to ensure that the software fulfills specified requirements as defined in the FAVOR Software Requirements and Design Document (Reference [4]). Verification is based on documentation that provides a traceable record of the software design requirements and development. The software development objectives must be sufficient to be understood by knowledgeable persons other than the originator. If it is determined that an accurate translation of these objectives has been performed, then that step has been verified. Verification activities do not replace industry practices, compliance with industry standards, or design guidelines.

Since FAVOR has been extensively validated in the past (see Reference [3]), the purpose of validation herein is to provide overall assurance that the main functions and algorithms correctly calculate the key outputs and are unaffected. The following key functions and algorithm should not be affected, unless noted:

- Thermal analysis
- Stress analysis
- Linear-Elastic Fracture Mechanics (LEFM)
- Handling of residual stresses in welds
- Handling of crack-face pressure for surface breaking flaws
- Calculation of Nil-Ductility Transition Temperature, RT_{NDT}
- Radiation embrittlement correlations
- Fast neutron fluence attenuation and sampling
- Handling of KIc and KIa Databases and calculations of KIc and KIa
- Sampling of RT_{NDT} and RT_{Arrest}
- Sampling of Material Chemistry
- Flaw characterizations and uncertainty: the as-found flaw input bypasses the VFLAW based methodology and therefore the VFLAW methodology will not be used when IPFLAW is set to 4, as designed. However, the algorithms used for the VFLAW based approach should not be affected.

- Warm prestressing logic
- Truncation for probability distributions
- Conditional Probability of Initiation (CPI) and Failure (CPF)
- Post initiation of flaw geometries and orientation
- Ductile tearing models
- Initiation-Growth-Arrest (IGA) model
- FAVPost algorithm using FAVPFM distributions of conditional probabilities of initiation and failure with input transient initiating frequencies to create fracture and failure frequencies

The following FAVOR critical outputs should also not be affected:

- Temperature as a function of time throughout vessel wall location
- Stress as a function of time throughout vessel wall (circumferential and axial)
- KI as a function of time throughout vessel wall
- Probability distributions of crack initiation and vessel failure
- Crack initiation frequency per reactor operating year
- Through-wall crack frequency per reactor operating year

Based on the above, the SVVP is simply focused on: 1) ensuring that backward capability exists for the new version of the program and 2) ensuring that cases for the as-found flaw input generate results consistent with those expected from the use of the current functions and algorithms stated above.

The following statements can be made regarding the section A.1 guide on criteria for a SVVP.

- Regarding method for verification, v20.1 FAVPFM was run against v16.1 of FAVPFM using standard comparative techniques to verify v20.1 of FAVPFM.
- The operating environment that verification will take place is on Microsoft Windows 10 or later.
- Acceptance criteria were established and defined as producing either identical results or if justified, results within 5% of the base v16.1 FAVPFM case.
- This SVVP covers the software life cycle phases of Requirements, Design, and Implementation phases. Test Phases consisting of acceptance test planning, integration test execution, acceptance test execution, and SVVR generation were not completed for v20.1.

The V&V results, which would normally be in a separate software verification and validation report (SVVR), are reported in Section 5. The software test plan (STP) used to support the V&V plan and report is presented in Appendix C and the software test result report (STRR) is presented in Appendix D.

Appendix C v20.1 FAVPFM Software Test Plan

The software testing strategy is to meet the following objectives in the Software V&V plan:

(1) Verify FAVOR 20.1 PFM solutions has backward compatibility with FAVOR 16.1 for options IPFLAW=1, 2, and 3.

(2) Verify that PFM solutions of FAVOR 20.1 for the as-found flaw (AFF) option (IPFLAW=4) yield consistent results when compared to those generated by the 16.1 FAVPFM module for IPFLAW=1.

Satisfying the first condition above was relatively simple to verify and simply involved running both codes using the identical three input flaw files. Identical probabilistic fracture mechanics (PFM) solutions were obtained, as should be the case. This confirmed that the changes made to FAVPFM 16.1 to add the AFF option did not change PFM results for options IPFLAW=1,2, and 3.

Satisfying the second condition was more complex because in some cases FAVPFM 16.1 had to be slightly modified to perform verification testing.

Using section A.2 as a guide, a series of tests involving IPFLAW settings, flaw types, and embrittlement map complexity provided a means to confidently test and ultimately verify and validate the use of v20.1. Here is a summary of the various tests:

(1) **Verification of v20.1 PFM solutions for embedded flaw for IPFLAW=4,**

   a. **Axial flaw in plate,**

   b. **Axial flaw in weld,**

   c. **Circumferential flaw in plate, and**

   d. **Circumferential flaw in weld.**

(2) **Verification of 20.1 PFM solutions for Internal Surface Breaking (ISB) flaws for IPFLAW=1 and 4,**

   a. **Axial flaw in weld with aspect ratios 2, 6, 10, and infinite,**

   b. **Axial flaw in plate with aspect ratios 2, 6, 10, and infinite,**

   (Note that for a. and b. above, FAVPFM v16.1 will need to be slightly modified to allow for axial orientation for ISB type flaws. Currently FAVPFM v16.1 PFM solutions use only circumferential flaws for ISB type flaws.)

   c. **Circumferential flaw in weld with aspect ratios 2, 6, 10, and infinite, and**

   d. **Circumferential flaw in plate with aspect ratios 2, 6, 10, and infinite.**

(3) **Verification of v20.1 PFM solutions for generalized case – combination of flaw types, orientations, and geometries for IPFLAW=4,**

(4) **Verification of v20.1 PFM solutions for generalized case – different ordering of flaws,**

(5) **Verification of v20.1 PFM solutions for embedded flaws for IPFLAW=2,**

(6) **Verification of v20.1 PFM solutions for embedded flaws for IPFLAW=3, and**

(7) **Verification of v20.1 input filter.**

Using section A.2, “Software Test Plan Criteria”, the following statements can be made:

- Testing was done prior to release of v20.1 of FAVPFM.
- Acceptance criteria were defined as producing either identical results, or if justified, results within 3% of the base v16.1 FAVPFM case.
- Full range of IPFLAW was tested. This is the key input variable that was modified.
- Test cases exercise those potentially impacted routines specified in the SRD and SDD (Reference [4]) and Table 4-1. If run satisfactorily, the test cases demonstrate that the code adequately performs all intended functions and produces valid results for problems encompassing the range of permitted IPFLAW values.
- The identified test cases exercise different logic branches (e.g., use of weld, plate, axial flaw, circumferential flaw, aspect ratio, internal surface breaking, embedded, varying number of flaws, etc.) to ensure proper flow through the whole FAVPFM module.
- Test cases check for different potential failure paths due to user input error on the as-found flaw input file.
- Test cases exercise FAVLoad interface and FAVPost interface. FAVPFM requires the FAVLoad generated output file, and therefore interface issues will surface when running v20.1 of FAVPFM. In addition, FAVPost uses the CPI and CPF history files from FAVPFM. If test cases produce identical results for these files, FAVPost interface is unaffected.
- Test cases require no commercial off-the-shelf (COTS) software other than MS Excel and MS Word to report results from the testing.

Appendix D FAVPFM Software Test Results

D.1 Verification of v20.1 PFM solutions for embedded flaw for IPFLAW=4

Testing was performed incrementally, i.e., the simplest case being a single flaw in a single beltline region subjected to a single transient. Table D - 1 provides details of testing for individual embedded flaws (in a single region subjected to a single transient) and specifies the Figures in this document that illustrate the results of the testing that provide the desired verification. All cases in Table D – 1 met the acceptance criteria.

Figure D - 1 illustrates the verification of PFM solutions (CPI_{mean} and CPF_{mean}) for a single axially oriented embedded flaw geometry (aspect ratio = 6, inner crack tip located 0.3 inches from the wetted inner surface) subjected to a specified transient as a function of flaw depth. The embrittlement model consists of a single subregion that is weld material. Since the flaw resides in weld material, the load would include the thru-wall weld residual stress.

Figure D - 2 is similar to Figure D - 1 except the flaw is in plate material and therefore the load does not include the thru-wall weld residual stress. In Figure D - 3, the flaw is circumferentially oriented and is in weld material. In Figure D - 4, the flaw is circumferentially oriented and is in plate material.

Figure D - 3 and Figure D - 4 are similar to Figure D - 1 and Figure D - 2 except the embedded flaws are circumferentially oriented.

In a traditional FAVPFM analysis of embedded flaws in v16.1 (and earlier versions), each embedded flaw in a PFM analysis has 3 geometrical variables that are sampled: (1) depth, (2) aspect ratio, and (3) thru-wall location of crack tip nearest the RPV wetted inner surface. Therefore, to mimic the AFF option, the FAVPFM v16.1 source code had to be modified to execute each of the analyses in Figure D - 1 through Figure D - 4, where the geometry of a specific flaw remains the same for all flaws and RPV trials.

The tests for the individual embedded flaws were the simplest initial tests. The testing then increased in complexity to more general cases: multiple embedded flaws, embrittlement maps consisting of multiple beltline regions, and multiple transients. The results of these many tests were successful and could be easily reproduced; however, they are not included here for the sake of brevity.

Table D - 1: Data for Verification of PFM solutions for Embedded Flaws

Flaw Type	Depth	Flaw Orientation	Material	Xinner	Aspect Ratio	Transient	Figure	Acceptance Criteria Met (Y/N)
embedded	range	axial	weld	0.3	6.0	LOCA	Figure D - 1	Y
embedded	range	axial	plate	0.3	6.0	LOCA	Figure D - 2	Y
embedded	range	circ	weld	0.3	6.0	REPR	Figure D - 3	Y
embedded	range	circ	Plate	0.3	6.0	REPR	Figure D - 4	Y

Notes: LOCA is Loss of Coolant Accident and REPR is Re-Pressurization Transient

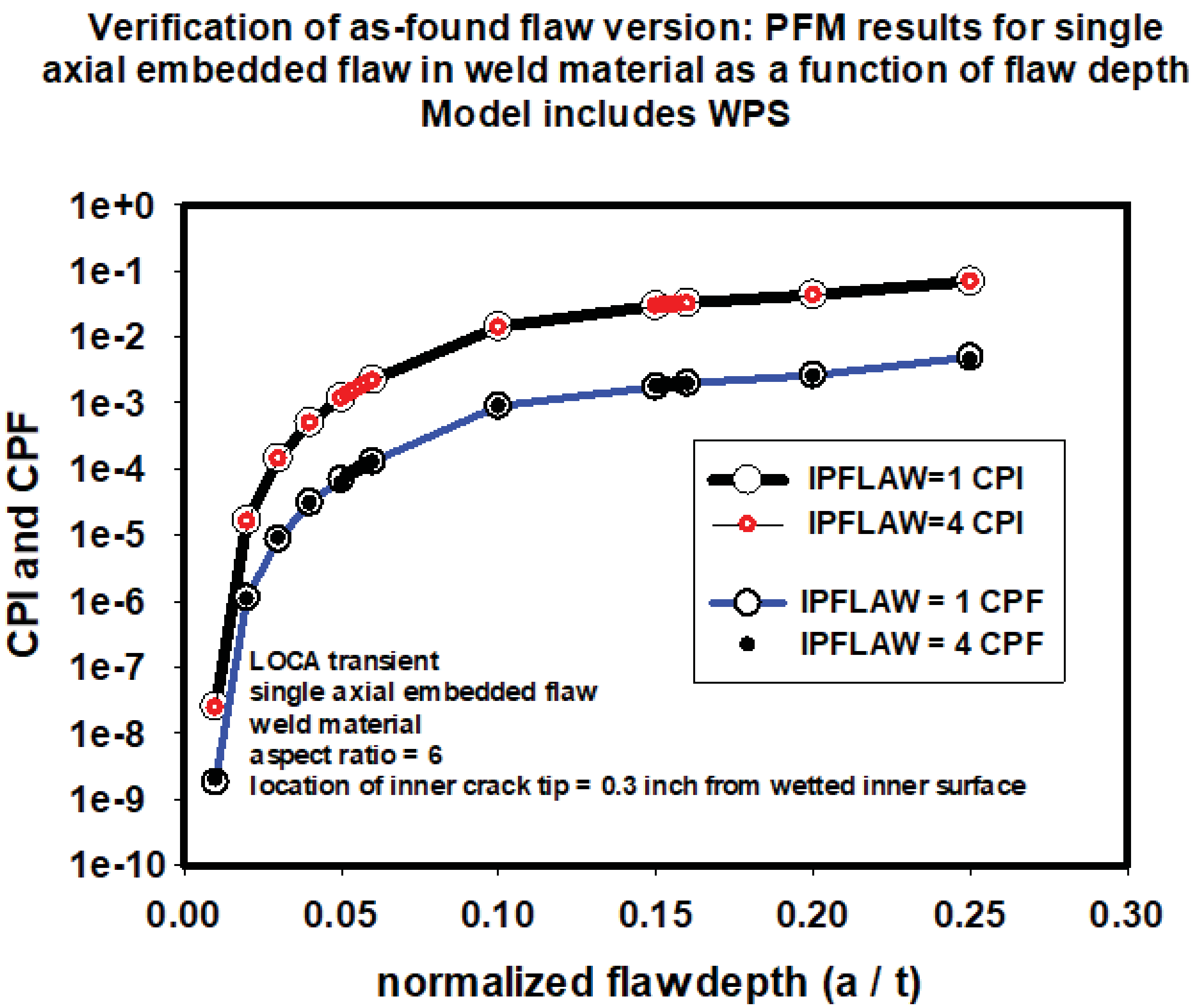

Figure D - 1: Verification of AFF PFM Solutions vs FAVOR 16.1 for Single Embedded Flaw Geometry in Weld Material

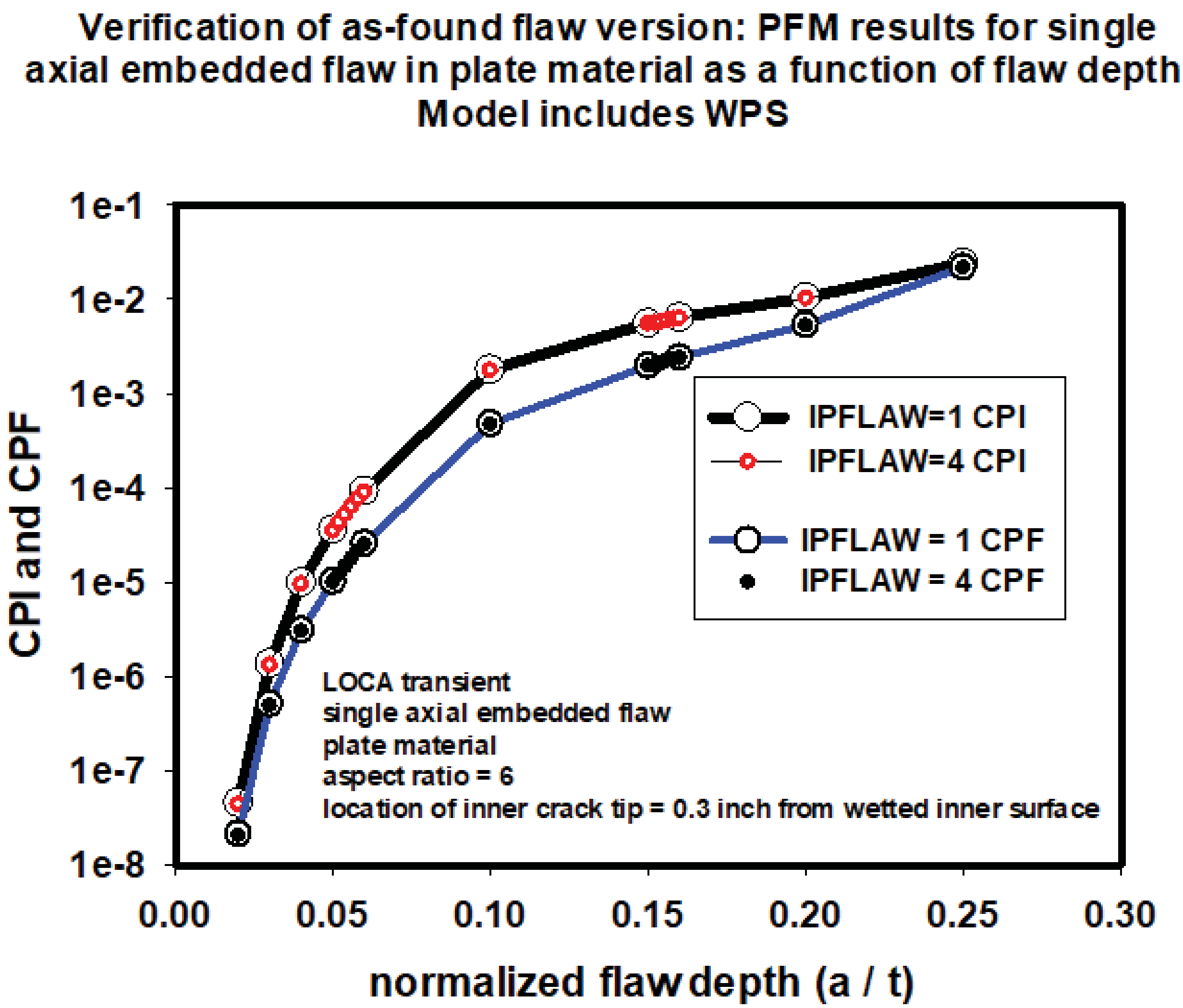

Figure D - 2: Verification of AFF PFM solutions vs FAVOR 16.1 for Single Axial Embedded Flaw Geometry in Plate Material

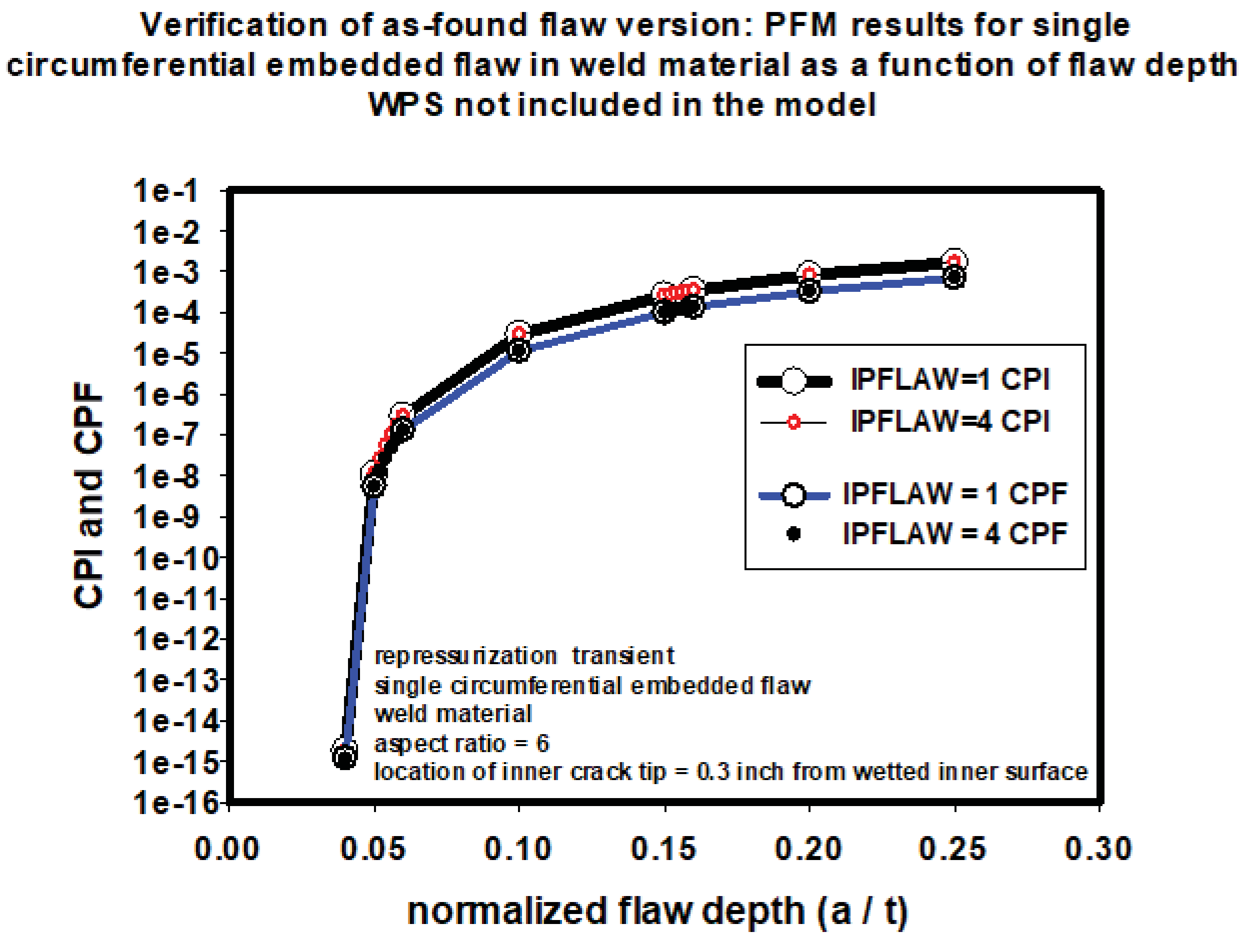

Figure D - 3: Verification of AFF PFM Solutions vs FAVOR 16.1 for Single Circumferential Embedded Flaw Geometry in Weld Material

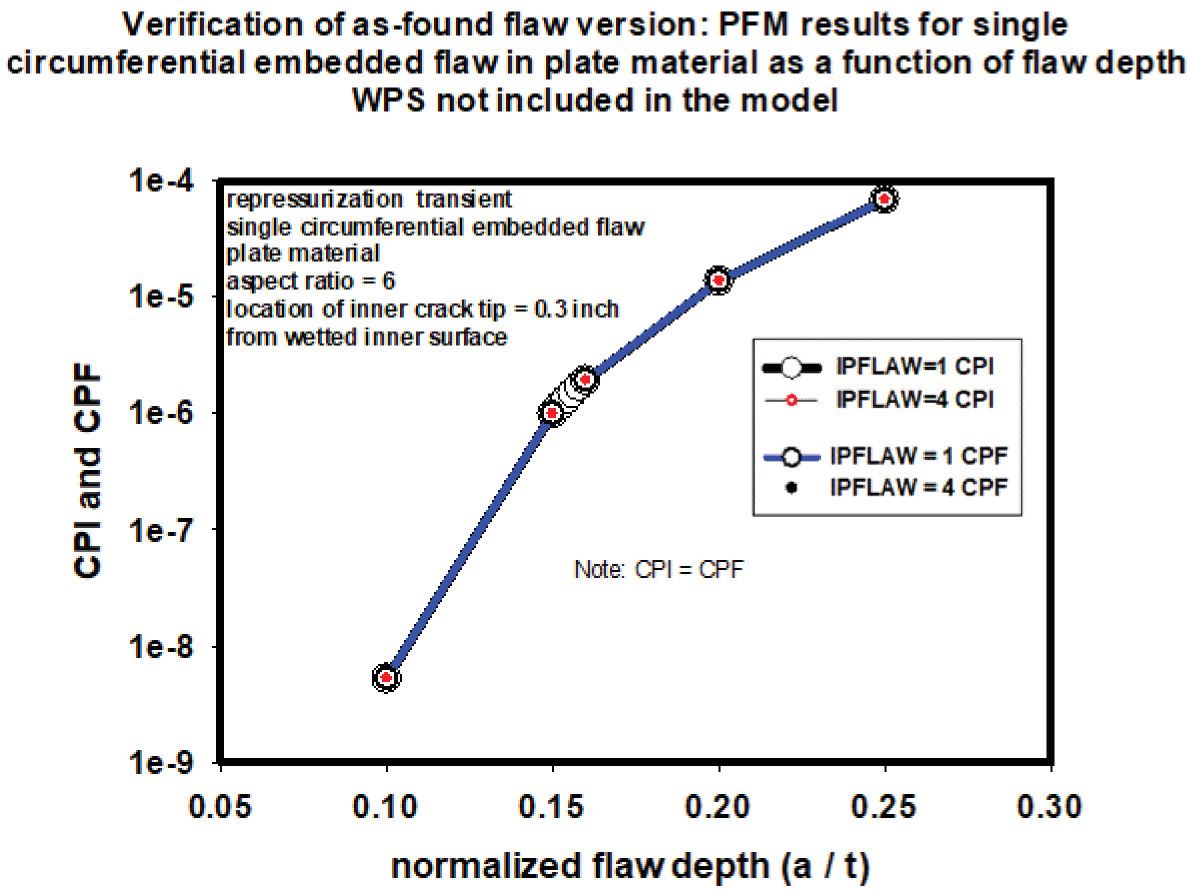

Figure D - 4: Verification of AFF PFM solutions vs FAVOR 16.1 for Single Circumferential Embedded Flaw Geometry in Plate Material

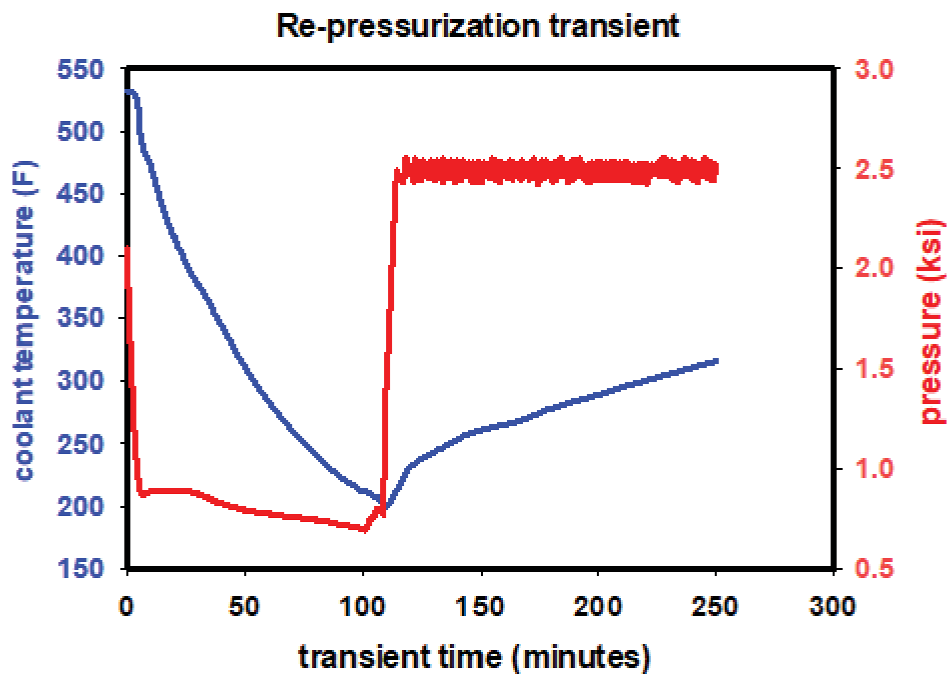

Figure D - 5: Re-Pressurization Transient Used in Verification of PFM Solutions

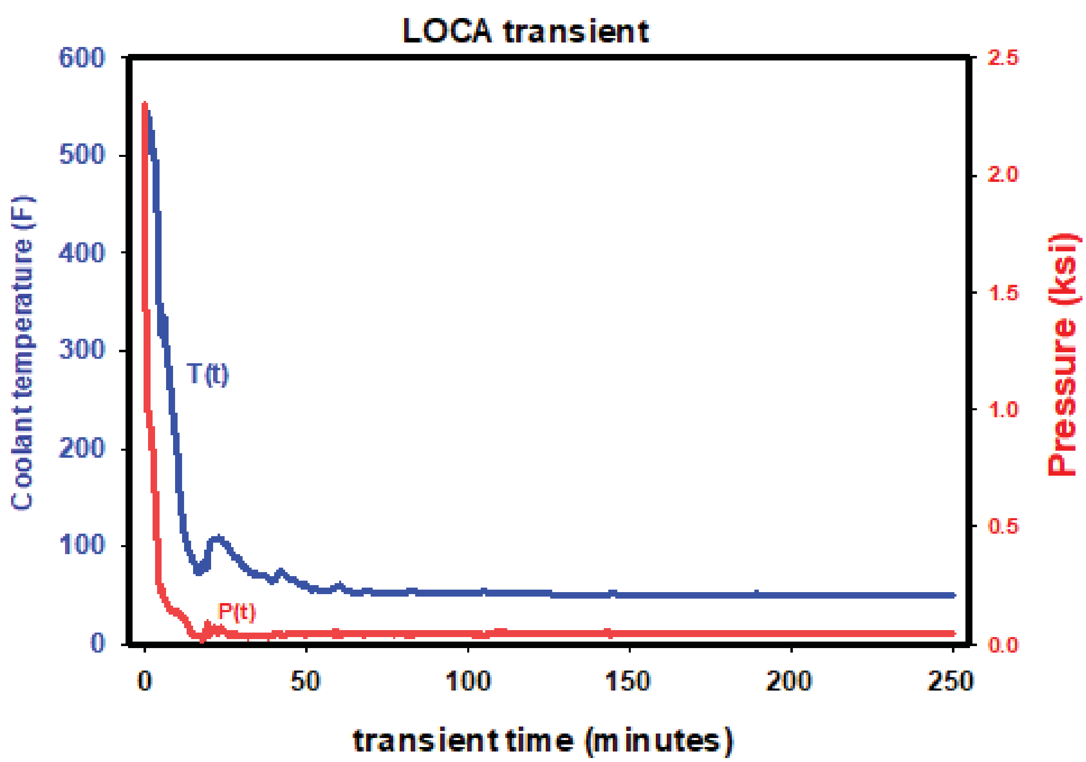

Figure D - 6: LOCA Transient Used in Verification of PFM Solutions - No WPS

D.2 Verification of v20.1 PFM solutions for Internal Surface Breaking (ISB) flaws for IPFLAW=1 and 4

Table D - 2 provides a summary of the v20.1 PFM solutions for internal surface breaking flaws. The table references Table D - 3 through Table D - 8 that contain the results of verification testing (of FAVOR v20.1) for Internal Surface Breaking (ISB) flaws. Table D - 3 provides the verification of PFM solutions for a single ISB flaw, with a depth of 0.08t, residing in a plate region as a function of aspect ratio, and orientation. Table D - 3 consists of 4 sub-tables: one for each of the aspect ratios 2, 6, 10 and infinite, with each sub-table containing 5 cases for each aspect ratio. As shown in Table D – 2 all cases met the acceptance criteria.

The first and second cases are for verification of axially oriented ISB flaws. The 1st case is the FAVPFM v16.1 PFM solution for axially oriented ISB flaws generated using the usual 3 flaw files based on VFLAW methodology. FAVPFM v16.1 had to be modified such that ISB flaws would be axially oriented rather than the normal rule of making all ISB flaws circumferentially oriented. The second case is the FAVOR v20.1 PFM solution for axial flaws when the as-found flaw (AFF) option has been activated (IPFLAW=4).

Cases 3-5 are for the verification of circumferentially oriented ISB flaws. Case 3 is the FAVOR v20.1 AFF solution for a circumferentially oriented flaw (IPFLAW=4). Case 4 is the FAVOR 20.1 version PFM solution for a circumferentially oriented flaw (IPFLAW=1) generated using the usual three flaw files based on VFLAW methodology.

Case 5 is the FAVOR 16.1 version PFM solution for a circumferentially oriented flaw (IPFLAW=1) generated using the usual three flaw files. All flaw files had to be specifically designed to have the correct flaw depth and aspect ratio.

These 5 cases have met the acceptance criteria for all aspect ratios and provide verification of (1) backward compatibility for PFM solutions generated by FAVOR v20.1 (for both IPFLAW=1 and IPFLAW=4) with those generated by FAVOR v16.1 and (2) consistency of PFM solutions generated by v20.1 between IPFLAW=1 and 4.

Table D - 4 is identical to Table D - 3 except it is for weld material and therefore the load includes the thru wall weld residual stress. Table D - 5 and Table D - 6 are identical to Table D - 3 and Table D - 4 except a normalized flaw depth of 0.15t was used in the generation of these results. Table D - 7 and Table D - 8 are also identical to Table D - 3 and Table D - 4 except a normalized flaw depth of 0.25t was used in the generation of these results.

A LOCA transient was used in these verification exercises. Warm pre-stress was not included in the model. The Eason 2006 embrittlement correlation was used. Each PFM analysis was executed for 1000 RPV trials. The computer codes, input datasets, and output datasets used to generate these tables are available in the controlled test directory.

The tests for the individual embedded flaws were the simplest initial tests. The testing then increased in complexity to more general cases: multiple ISB flaws, embrittlement maps consisting of multiple beltline regions, and multiple transients. The results of these many tests were successful and could be easily reproduced; however, they are not included here for the sake of brevity.

Table D - 2: Verification of v20.1 PFM Solutions for ISB flaws for IPFLAW=4

Flaw Type	Depth	Orientation	Material	Aspect Ratio	Transient	Tables	Acceptance Criteria Met (Y/N)
ISB	range	axial	Weld	Infinite	LOCA	Table D - 4 Table D - 6 Table D - 8	Y
ISB	range	axial	Weld	10	LOCA		Y
ISB	range	axial	Weld	6	LOCA		Y
ISB	range	axial	Weld	2	LOCA		Y
ISB	range	axial	Plate	Infinite	LOCA	Table D - 3 Table D - 5 Table D - 7	Y
ISB	range	axial	Plate	10	LOCA		Y
ISB	range	axial	Plate	6	LOCA		Y
ISB	range	axial	plate	2	LOCA		Y
ISB	range	circ	Weld	Infinite	LOCA	Table D - 4 Table D - 6 Table D - 8	Y
ISB	range	circ	Weld	10	LOCA		Y
ISB	range	circ	Weld	6	LOCA		Y
ISB	range	circ	Weld	2	LOCA		Y
ISB	range	circ	Plate	Infinite	LOCA	Table D - 3 Table D - 5 Table D - 7	Y
ISB	range	circ	Plate	10	LOCA		Y
ISB	range	circ	Plate	6	LOCA		Y
ISB	range	circ	plate	2	LOCA		Y

Table D - 3: Verification of PFM Solutions for Single ISB flaw in Plate Subregion as a Function of Aspect Ratio, and Orientation, Flaw Depth = 0.08t

Aspect Ratio = Infinite - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	Plate	Infinite	axial	104.29	3.218e-2	1.578e-3	128.8
2	20.1AFF	4	0.08t	Plate	Infinite	axial	104.29	3.218e-2	1.578e-3	128.8
3	20.1AFF	4	0.08t	Plate	Infinite	circ	104.29	3.686e-3	6.164e-6	128.8
4	20.1	1	0.08t	Plate	Infinite	circ	104.29	3.686e-3	6.164e-6	128.8
5	16.1	1	0.08t	Plate	Infinite	circ	104.29	3.686e-3	6.164e-6	128.8
Aspect Ratio = 10 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	Plate	10	axial	104.29	7.550e-4	3.848e-4	128.8
2	20.1AFF	4	0.08t	Plate	10	axial	104.29	7.550e-4	3.848e-4	128.8
3	20.1AFF	4	0.08t	Plate	10	circ	104.29	7.450e-4	1.211e-6	128.8
4	20.1	1	0.08t	Plate	10	circ	104.29	7.450e-4	1.211e-6	128.8
5	16.1	1	0.08t	Plate	10	circ	104.29	7.450e-4	1.211e-6	128.8
Aspect Ratio = 6 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	Plate	6	axial	104.29	4.057e-4	2.080e-4	128.8
2	20.1AFF	4	0.08t	Plate	6	axial	104.29	4.057e-4	2.080e-4	128.8
3	20.1AFF	4	0.08t	Plate	6	circ	104.29	4.006e-4	6.243e-7	128.8
4	20.1	1	0.08t	Plate	6	circ	104.29	4.006e-4	6.243e-7	128.8
5	16.1	1	0.08t	Plate	6	circ	104.29	4.006e-4	6.243e-7	128.8
Aspect Ratio = 2 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	Plate	2	axial	104.29	3.322e-6	1.545e-6	128.8
2	20.1AFF	4	0.08t	Plate	2	axial	104.29	3.322e-6	1.545e-6	128.8
3	20.1AFF	4	0.08t	Plate	2	circ	104.29	3.357e-6	9.145e-10	128.8
4	20.1	1	0.08t	Plate	2	circ	104.29	3.357e-6	9.145e-10	128.8
5	16.1	1	0.08t	Plate	2	circ	104.29	3.357e-6	9.145e-10	128.8

Table D - 4: Verification of PFM Solutions for Single ISB flaw in Weld Subregion as a Function of Aspect Ratio, and Orientation, Flaw Depth = 0.08t

Aspect Ratio = Infinite - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	weld	Infinite	axial	145.23	1.132e-1	3.129e-2	190.6
2	20.1	4	0.08t	weld	Infinite	axial	145.23	1.132e-1	3.129e-2	190.6
3	20.1	4	0.08t	weld	Infinite	circ	145.23	1.220e-1	8.148e-4	190.6
4	20.1	1	0.08t	weld	Infinite	circ	145.23	1.220e-1	8.148e-4	190.6
5	16.1	1	0.08t	weld	Infinite	circ	145.23	1.220e-1	8.148e-4	190.6
Aspect Ratio = 10 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	weld	10	axial	145.23	5.358e-2	1.474e-2	190.6
2	20.1	4	0.08t	weld	10	axial	145.23	5.358e-2	1.474e-2	190.6
3	20.1	4	0.08t	weld	10	circ	145.23	5.350e-2	3.419e-4	190.6
4	20.1	1	0.08t	weld	10	circ	145.23	5.350e-2	3.419e-4	190.6
5	16.1	1	0.08t	weld	10	circ	145.23	5.350e-2	3.419e-4	190.6
Aspect Ratio = 6 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	weld	6	axial	145.23	3.483e-2	1.054e-2	190.6
2	20.1	4	0.08t	weld	6	axial	145.23	3.483e-2	1.054e-2	190.6
3	20.1	4	0.08t	weld	6	circ	145.23	3.480e-2	2.539e-4	190.6
4	20.1	1	0.08t	weld	6	circ	145.23	3.480e-2	2.539e-4	190.6
5	16.1	1	0.08t	weld	6	circ	145.23	3.480e-2	2.539e-4	190.6
Aspect Ratio = 2 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.08t	weld	2	axial	145.23	2.800e-3	7.254e-4	190.6
2	20.1	4	0.08t	weld	2	axial	145.23	2.800e-3	7.260e-4	190.6
3	20.1	4	0.08t	weld	2	circ	145.23	2.811e-3	1.897e-5	190.6
4	20.1	1	0.08t	weld	2	circ	145.23	2.811e-3	1.897e-5	190.6
5	16.1	1	0.08t	weld	2	circ	145.23	2.811e-3	1.897e-5	190.6

Table D - 5: Verification of PFM Solutions for Single ISB Flaw in Plate Subregion as a Function of Aspect Ratio, and Orientation, Flaw Depth = 0.15t

Aspect Ratio = Infinite - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	Plate	Infinite	axial	100.94	3.793e-3	2.761e-3	128.8
2	20.1AFF	4	0.15t	Plate	Infinite	axial	100.94	3.793e-3	2.761e-3	128.8
3	20.1AFF	4	0.15t	Plate	Infinite	circ	100.94	2.997e-3	1.284e-5	128.8
4	20.1	1	0.15t	Plate	Infinite	circ	100.94	2.997e-3	1.284e-5	128.8
5	16.1	1	0.15t	Plate	Infinite	circ	100.94	2.997e-3	1.284e-5	128.8
Aspect Ratio = 10 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	Plate	10	axial	100.94	6.994e-4.	5.205e-4	128.8
2	20.1AFF	4	0.15t	Plate	10	axial	100.94	6.994e-4.	5.205e-4	128.8
3	20.1AFF	4	0.15t	Plate	10	circ	100.94	6.987e-4	3.058e-6	128.8
4	20.1	1	0.15t	Plate	10	circ	100.94	6.987e-4	3.058e-6	128.8
5	16.1	1	0.15t	Plate	10	circ	100.94	6.987e-4	3.058e-6	128.8
Aspect Ratio = 6 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	Plate	6	axial	100.94	2.969e-4	2.217e-4	128.8
2	20.1AFF	4	0.15t	Plate	6	axial	100.94	2.969e-4	2.217e-4	128.8
3	20.1AFF	4	0.15t	Plate	6	circ	100.94	2.992e-4	1.283e-6	128.8
4	20.1	1	0.15t	Plate	6	circ	100.94	2.992e-4	1.283e-6	128.8
5	16.1	1	0.15t	Plate	6	circ	100.94	2.992e-4	1.283e-6	128.8
Aspect Ratio = 2 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	Plate	2	axial	100.94	1.313e-6	8.779e-7	128.8
2	20.1AFF	4	0.15t	Plate	2	axial	100.94	1.313e-6	8.779e-7	128.8
3	20.1AFF	4	0.15t	Plate	2	circ	100.94	1.411e-6	6.277e-10	128.8
4	20.1	1	0.15t	Plate	2	circ	100.94	1.411e-6	6.277e-10	128.8
5	16.1	1	0.15t	Plate	2	circ	100.94	1.411e-6	6.277e-10	128.8

Table D - 6: Verification of PFM Solutions for Single ISB Flaw in Weld Subregion as a Function of Aspect Ratio, and Orientation, Flaw Depth = 0.15t

Aspect Ratio = Infinite - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	weld	Infinite	axial	142.29	1.344e-1	4.747e-2	190.6
2	20.1	4	0.15t	weld	Infinite	axial	142.29	1.344e-1	4.747e-2	190.6
3	20.1	4	0.15t	weld	Infinite	circ	142.29	1.210e-1	8.879e-4	190.6
4	20.1	1	0.15t	weld	Infinite	circ	142.29	1.210e-1	8.879e-4	190.6
5	16.1	1	0.15t	weld	Infinite	circ	142.29	1.210e-1	8.879e-4	190.6
Aspect Ratio = 10 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	weld	10	axial	142.29	5.858e-2	2.008e-2	190.6
2	20.1	4	0.15t	weld	10	axial	142.29	5.858e-2	2.008e-2	190.6
3	20.1	4	0.15t	weld	10	circ	142.29	5.858e-2	3.969e-4	190.6
4	20.1	1	0.15t	weld	10	circ	142.29	5.858e-2	3.969e-4	190.6
5	16.1	1	0.15t	weld	10	circ	142.29	5.858e-2	3.969e-4	190.6
Aspect Ratio = 6 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	weld	6	axial	142.29	3.757e-2	1.269e-2	190.6
2	20.1	4	0.15t	weld	6	axial	142.29	3.757e-2	1.269e-2	190.6
3	20.1	4	0.15t	weld	6	circ	142.29	3.799e-2	2.438e-4	190.6
4	20.1	1	0.15t	weld	6	circ	142.29	3.799e-2	2.438e-4	190.6
5	16.1	1	0.15t	weld	6	circ	142.29	3.799e-2	2.438e-4	190.6
Aspect Ratio = 2 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.15t	weld	2	axial	142.29	1.998e-3	6.188e-4	190.6
2	20.1	4	0.15t	weld	2	axial	142.29	1.998e-3	6.188e-4	190.6
3	20.1	4	0.15t	weld	2	circ	142.29	2.079e-3	1.072e-5	190.6
4	20.1	1	0.15t	weld	2	circ	142.29	2.079e-3	1.072e-5	190.6
5	16.1	1	0.15t	weld	2	circ	142.29	2.079e-3	1.072e-5	190.6

Table D - 7: Verification of PFM Solutions for Single ISB Flaw in Plate Subregion as a Function of Aspect Ratio, and Orientation, Flaw Depth = 0.25t

Aspect Ratio = Infinite - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	Plate	Infinite	axial	96.31	3.037e-3	2.925e-3	128.8
2	20.1AFF	4	0.25t	Plate	Infinite	axial	96.31	3.037e-3	2.925e-3	128.8
3	20.1AFF	4	0.25t	Plate	Infinite	circ	96.31	1.269e-3	3.180e-5	128.8
4	20.1	1	0.25t	Plate	Infinite	circ	96.31	1.269e-3	3.180e-5	128.8
5	16.1	1	0.25t	Plate	Infinite	circ	96.31	1.269e-3	3.180e-5	128.8
Aspect Ratio = 10 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	Plate	10	axial	96.31	2.082e-4	2.018e-4	128.8
2	20.1AFF	4	0.25t	Plate	10	axial	96.31	2.082e-4	2.018e-4	128.8
3	20.1AFF	4	0.25t	Plate	10	circ	96.31	2.243e-4	5.706e-6	128.8
4	20.1	1	0.25t	Plate	10	circ	96.31	2.243e-4	5.706e-6	128.8
5	16.1	1	0.25t	Plate	10	circ	96.31	2.243e-4	5.706e-6	128.8
Aspect Ratio = 6 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	Plate	6	axial	96.31	4.697e-5	4.560e-5	128.8
2	20.1AFF	4	0.25t	Plate	6	axial	96.31	4.697e-5	4.560e-5	128.8
3	20.1AFF	4	0.25t	Plate	6	circ	96.31	5.037e-5	1.229e-6	128.8
4	20.1	1	0.25t	Plate	6	circ	96.31	5.037e-5	1.229e-6	128.8
5	16.1	1	0.25t	Plate	6	circ	96.31	5.037e-5	1.229e-6	128.8
Aspect Ratio = 2 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	Plate	2	axial	96.31	7.616e-9	7.615e-9	128.8
2	20.1AFF	4	0.25t	Plate	2	axial	96.31	7.616e-9	7.615e-9	128.8
3	20.1AFF	4	0.25t	Plate	2	circ	96.31	1.041e-8	3.345e-10	128.8
4	20.1	1	0.25t	Plate	2	circ	96.31	1.041e-8	3.345e-10	128.8
5	16.1	1	0.25t	Plate	2	circ	96.31	1.041e-8	3.345e-10	128.8

Table D - 8: Verification of PFM Solutions for Single ISB Flaw in Weld Subregion as a Function of Aspect Ratio, and Orientation, Flaw Depth = 0.25t

Aspect Ratio = Infinite - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	weld	Infinite	axial	138.17	1.163e-1	5.567e-2	190.6
2	20.1	4	0.25t	weld	Infinite	axial	138.17	1.163e-1	5.566e-2	190.6
3	20.1	4	0.25t	weld	Infinite	circ	138.17	7.666e-2	1.228e-3	190.6
4	20.1	1	0.25t	weld	Infinite	circ	138.17	7.666e-2	1.228e-3	190.6
5	16.1	1	0.25t	weld	Infinite	circ	138.17	7.666e-2	1.228e-3	190.6
Aspect Ratio = 10 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	weld	10	axial	138.17	2.925e-2	1.342e-2	190.6
2	20.1	4	0.25t	weld	10	axial	138.17	2.925e-2	1.342e-2	190.6
3	20.1	4	0.25t	weld	10	circ	138.17	3.076e-2	4.567e-4	190.6
4	20.1	1	0.25t	weld	10	circ	138.17	3.076e-2	4.567e-4	190.6
5	16.1	1	0.25t	weld	10	circ	138.17	3.076e-2	4.567e-4	190.6
Aspect Ratio = 6 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	weld	6	axial	138.17	1.271e-2	5.721e-3	190.6
2	20.1	4	0.25t	weld	6	axial	138.17	1.271e-2	5.721e-3	190.6
3	20.1	4	0.25t	weld	6	circ	138.17	1.337e-2	1.864e-4	190.6
4	20.1	1	0.25t	weld	6	circ	138.17	1.337e-2	1.864e-4	190.6
5	16.1	1	0.25t	weld	6	circ	138.17	1.337e-2	1.864e-4	190.6
Aspect Ratio = 2 - Acceptance Criteria met: Identical results for axial and circ flaws										
Case	**Code**	**IPFLAW**	**Depth**	**Material**	**Aspect**	**Orient**	**RTavg**	**CPI_{mean}**	**CPF_{mean}**	**RTmax**
1	16.1ax	1	0.25t	weld	2	axial	138.17	1.227e-4	5.147e-5	190.6
2	20.1	4	0.25t	weld	2	axial	138.17	1.227e-4	5.147e-5	190.6
3	20.1	4	0.25t	weld	2	circ	138.17	1.400e-4	1.612e-6	190.6
4	20.1	1	0.25t	weld	2	circ	138.17	1.400e-4	1.612e-6	190.6
5	16.1	1	0.25t	weld	2	circ	138.17	1.400e-4	1.612e-6	190.6

D.3 Verification of v20.1 PFM Solutions for Generalized Case – Combination of Flaw Types, Orientations, and Geometries for IPFLAW=4

When IPFLAW=1, 2, or 3, v16.1 and v20.1 of FAVPFM determine the flaw characteristics (type, category, depth, aspect ratio, subregion, and orientation) for each flaw by application of the usual sampling method(s), i.e., creation and application of probability distribution functions (PDFs) and cumulative probability distribution functions (CDFs) using data from the 3 VLFAW based flaw files (surface flaw distribution, weld embedded flaw distribution, and plate embedded flaw distribution). Therefore, the flaw distribution will be different for each RPV trial.

v16.1 of FAVPFM was modified such that the characteristics of each flaw in the first RPV trial were saved internally such as to be applied for all subsequent RPV trials. Therefore, the characteristics of flaw number n would be identical for each RPV trial. In theory, this should be identical to the same PFM analysis performed by the as-found flaw (AFF) option of v20.1 FAVPFM (IPFLAW=4), assuming that the as-found flaw specification matches the distribution sampled at the first RPV trial using IPFLAW=1.

The flaw characteristics for each of the flaws were also saved to an external file during the PFM analysis of the first flaw such that this file can be used as AFF input file when applying the AFF option of v20.1 FAVPFM. For purposes of documentation, this modified version of FAVPFM v16.1 was called FAV161_MAKEAFF.

The resultant flaw file from this modified version resulted in 5254 flaws, with various combinations of flaw type (embedded and ISB flaws), geometry, orientation, and material (weld and plate).

An additional modified FAVPFM v16.1 was developed called FAV162_MAKEAFF. This version included a change to the interpolation scheme from a linear to cubic spline for determining the crack tip temperature of embedded flaws. FAVPFM v20.1 had already incorporated the cubic spline interpolation scheme and the impact of that change required evaluation.

The PFM solutions are identical for the first RPV trial; however, are slightly different for subsequent RPV trials. This is due to the sequence of random numbers not being maintained after the first RPV trial between the two code versions. It is possible that further time and effort could identify exactly those locations in the code where the random number sequence is disrupted, and adjusted to maintain the one-to-one correspondence of the two PFM solutions for RPV trials > 1.

Figure D - 7 is a graphical illustration of PFM solutions generated by FAV162_MAKEAFF and the AFF option of v20.1 FAVPFM. Figure D - 7 provides illustration that the converged solutions of mean value of CPI and CPF are very close for the two codes; therefore, the goal of mutual validation and backward compatibility is achieved. It is also important to note that the same allocation of flaws by category, orientation, and material (weld or plate) for various cases was obtained by both codes.

The PFM solutions in Figure D - 7 were generated using a simplified embrittlement map consisting of 13 major regions – 7 weld regions and 6 plate regions. This map is a simplified version of the map used for the Palisades PWR. The LOCA transient illustrated in Figure D - 6 was used as the transient. The model included type 1 WPS.

Figure D - 8 is identical to Figure D - 7 except that PFM embrittlement model corresponded to 60 EFPY. It should be noted that this was not in any way intended to be an exercise for set of flaws expected to actually be found in an RPV, but rather to illustrate the ability of the AFF option FAVOR 20.1 to properly analyze a very general combination of flaws. Also, the number and type of flaws provided for relatively quick convergence of PFM solutions, which was desirable for the purposes of V&V testing.

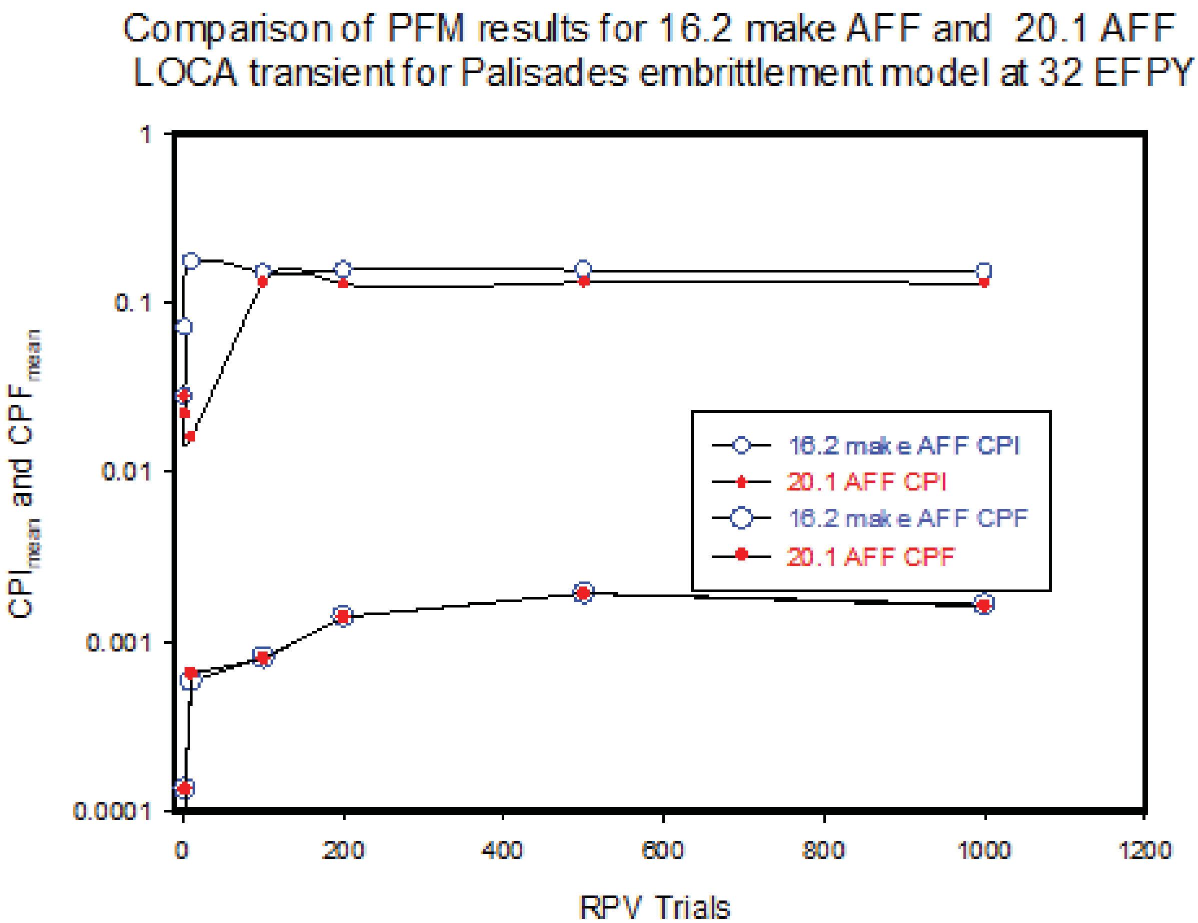

Figure D - 7: Verification of v20.1 AFF Solutions vs FAVOR 16.2 make AFF for Stack of 5254 Flaws – Combination of Flaw Types, Geometries, and Orientations

D.4 Verification of v20.1 PFM Solutions for Generalized Case – Different Ordering of Flaws

A PFM analysis was executed using an AFF file containing the stack of 5254 flaw characterizations in reverse order. Figure D - 8 illustrates the PFM solutions for the original and reverse ordering of flaws. The PFM solutions are nearly identical, thus providing assurance that the PFM solutions have little dependence on the ordering of flaws, and thereby meeting the acceptance criteria.

The allocation of CPI and CPF to the stack of AFF flaws also had negligible differences between cases for original and reverse ordering.

Further informal consistency tests were performed to illustrate that the PFM solutions had no dependencies, including the allocations of CPI and CPF to individual flaws, or the location of a particular transient in an analysis in which there are multiple transients.

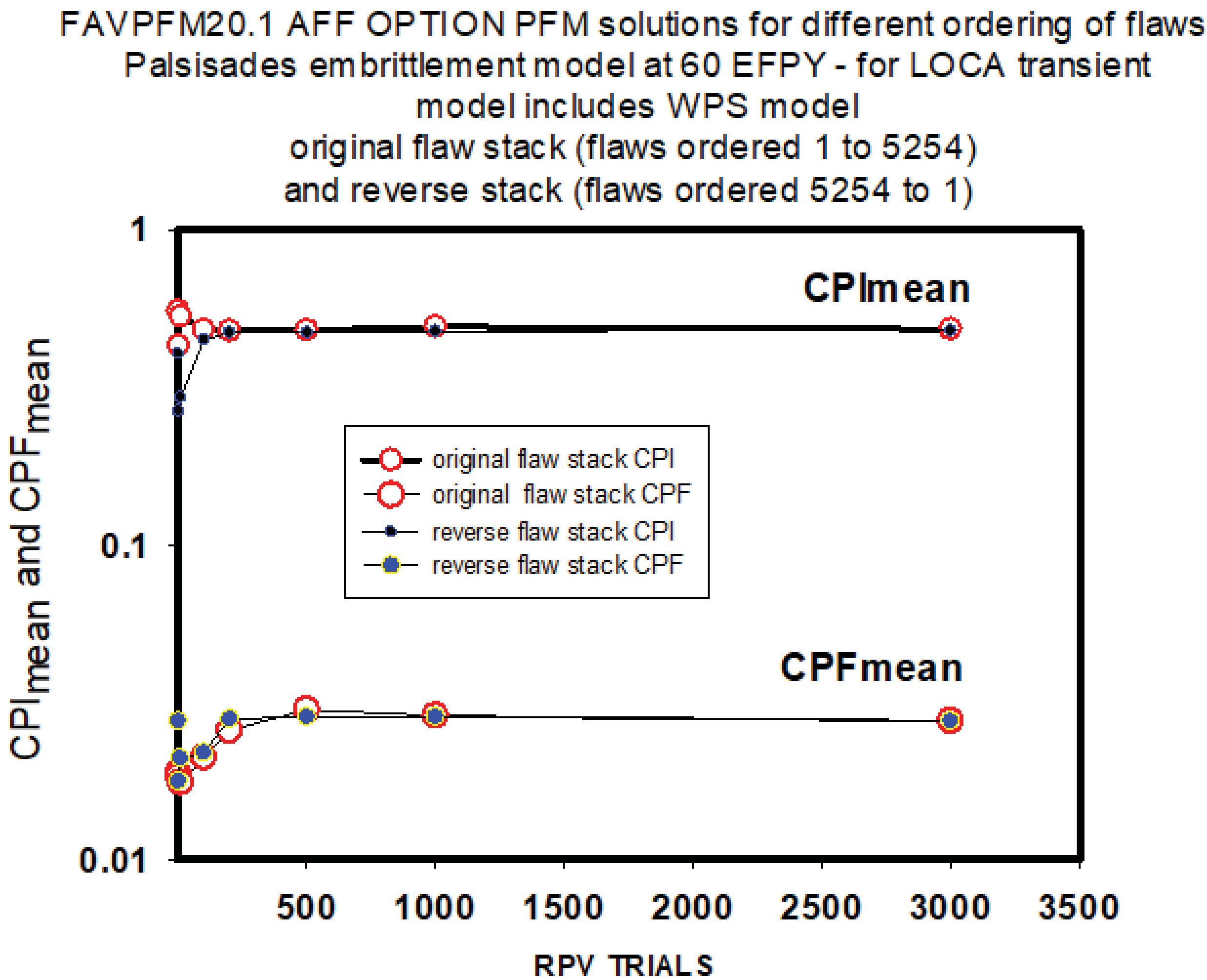

Figure D - 8: Illustration that PFM Converged Solutions for 20.1 (IPFLAW=4) has no Dependency on Ordering of As-Found Flaws

D.5 Verification of v20.1 PFM Solutions for Embedded Flaws for IPFLAW=2

The IPFLAW=2 option places all surface breaking flaws on the external surface of the RPV and embedded flaws distributed uniformly thru the outer 3/8 of the RPV thickness. This option of FAVOR was designed primarily to perform fracture analyses of heat-up transients where the larger axial and hoop tensile stresses occur in the outer part of the RPV wall.

The testing documented in this section illustrates that the v20.1 FAVPFM solutions generate nearly identical solutions (for embedded flaws, external surface breaking flaws, and generalized combinations of flaw types) to the v16.1 FAVPFM. The largest difference observed was <1% and the difference is most likely due to the improved cubic spline interpolations scheme used in determining the crack tip temperature for embedded flaws. Since the cubic spline is a better fit than linear interpolation, the v20.1 FAVPFM should provide more accurate solutions.

For IPFLAW=2, the number and geometry of flaws are characterized by reading three flaw files into FAVPFM: a surface breaking flaw distribution file, a file that numerically characterizes the distribution of embedded flaws in welds, and a file that numerically characterizes the distribution of embedded flaws in plates and forgings.

Table D - 9: Verification of PFM Solutions for Single External Surface Breaking; Flaw depth = 0.25t - Severe Heat-up Transient - with Warm Pre-Stress – Eason 2006 (1000 RPV trials)

Case	Code	IPFLAW	Depth	Aspect	RTavg	CPI_{mean} and CPF_{mean}
1	16.1	2	0.25t	Infinite	123.58	2.858e-2
2	20.1	2	0.25t	Infinite	123.58	2.858e-2
Acceptance Criteria met: Identical results						
3	16.1	2	0.25t	6	123.58	4.649e-3
4	20.1	2	0.25t	6	123.58	4.649e-3

Table D - 10: Verification of PFM Solutions for Embedded Flaws in Plate Material - Severe Heat-up Transient - with Warm Pre-Stress – Eason 2006 (1000 RPV trials)

Case	Code	IPFLAW	Depth	Aspect	RTavg	CPI_{mean} and CPF_{mean}
1	16.1	2	range	range	118.37	7.852E-8
2	20.1	2	range	range	118.37	7.852E-8
Acceptance Criteria met: Identical results						

Table D - 11: Verification of PFM Solutions for Embedded Flaws in Weld Material Severe Heat-up Transient - with Warm Pre-Stress – Eason 2006 (1000 RPV trials)

Case	Code	IPFLAW	Depth	Aspect	RTavg	CPI_{mean} and CPF_{mean}
1	16.1	2	range	range	188.87	1.128e-4
2	20.1	2	range	range	188.87	1.129e-4
Acceptance Criteria met: Essentially Identical results (within roundoff)						

Table D - 12: Verification of PFM Solutions Generalized Flaw Types ESB + Embedded Flaws in Weld Material + Embedded Flaws in Plate Material, Severe Heat-up Transient - with Warm Pre-Stress – Eason 2006, (1000 RPV trials)

Case	Code	IPFLAW	Depth	Aspect	RTavg	CPI_{mean} and CPF_{mean}
1	16.1	2	range	range	149.11	2.825e-2
2	20.1	2	range	range	149.11	2.825e-2
Acceptance Criteria met: Identical results						

D.6 Verification of 20.1 PFM solutions for embedded flaws for IPFLAW=3

The IPFLAW=3 option places surface breaking flaws on both the internal and external surfaces and places embedded flaws uniformly distributed thru the thickness of the base ferritic material. This option was designed for leak test transients which exhibit both a heat-up phase and a cooldown phase.

The testing documented in this section illustrates that v20.1 FAVPFM generates nearly identical solutions (for embedded flaws, external surface breaking flaws, and generalized combinations of flaw types) to v16.1 FAVPFM. As for IPFLAW=2, slight differences are noticed due to the use of the cubic spline fit for crack tip temperature for embedded flaws. Most differences were zero with a few differences well within 5%, with the maximum being 3%.

For this test, the FAVLoad output file contained 2 transients: a cooldown transient with a late re-pressurization and a heat-up transient. The number and geometry of flaws are characterized by reading three flaw files into FAVPFM: a surface breaking flaw distribution file, a file that numerically characterizes the distribution of embedded flaws in welds, and a file that numerically characterizes the distribution of embedded flaws in plates and forgings.

Table D - 13: Verification of v20.1 PFM Solutions for IPFLAW=3 - ISB and ESB Surface Breaking Flaws only - Cooldown and Severe Heat-up Transient, Model Includes Warm Pre-Stress and Eason 2006

Case	Code	IPFLAW	Depth	Aspect	RTavg	RPV trials	CPI_{mean}	CPF_{mean}
Transient 1 – cooldown								
1	16.1	3	0.23t	range	16.10	10000	5.056e-7	0.000e-0
2	20.1	3	0.23t	range	16.10	10000	5.056e-7	0.000e-0
Transient 2 – heatup								
1	161	3	range	range	16.10	10000	4.515e-5	3.515e-5
2	20.1	3	range	range	16.10	10000	4.515e-5	3.515e-5
Acceptance Criteria met: Identical results								

Table D - 14: Verification of v20.1 PFM Solutions for IPFLAW=3 – Embedded Flaws – Weld Material only – Cooldown and Severe Heat-up Transient, Model Includes Warm Pre-Stress and Eason 2006

Case	Code	IPFLAW	Depth	Aspect	RTavg	RPV trials	CPI_{mean}	CPF_{mean}
Transient 1 – cooldown								
1	16.1	3	range	range	45.83	100	5.163e-5	4.980e-5
2	20.1	3	range	range	45.83	100	5.143e-5	4.962e-5
Transient 2 – heatup								
1	16.1	3	range	range	45.83	100	0.000e-0	0.000e-0
2	20.1	3	range	range	45.83	100	0.000e-0	0.000e-0
Acceptance Criteria met: Essentially Identical results (well within 1%)								

Table D - 15: Verification of v20.1 PFM solutions for IPFLAW=3 – Embedded Flaws – Weld Material only – Cooldown and Severe Heat-up Transient, Modified Weld Embedded Flaw File (Relative to Table D.6 - 2) to have Non-Zero PFM Solutions - Model Includes Warm Pre-Stress and Eason 2006

Case	Code	IPFLAW	Depth	Aspect	RTavg	RPV trials	CPI_{mean}	CPF_{mean}
Transient 1 – cooldown								
1	16.1	3	range	range	41.01	100	4.528e-1	4.443e-1
2	20.1	3	range	range	41.01	100	4.516e-1	4.443e-1
Transient 2 – heatup								
1	16.1	3	range	range	41.01	100	3.939e-3	3.743e-3
2	20.1	3	range	range	41.01	100	3.939e-3	3.743e-3
Acceptance Criteria met: Essentially Identical results (well within 1%)								

Table D - 16: Verification of v20.1 PFM solutions for IPFLAW=3 – Embedded Flaws – Plate Material only – Cooldown and Severe Heat-up Transient, Model Includes Warm Pre-Stress and Eason 2006

Case	Code	IPFLAW	Depth	Aspect	RTavg	RPV trials	CPI_{mean}	CPF_{mean}
Transient 1 – cooldown								
1	161	3	range	range	15.90	100	4.765e-8	4.765e-8
2	20.1	3	range	range	15.90	100	4.762e-8	4.762e-8
Transient 2 – heatup								
1	16.1	3	range	range	15.90	100	0.000e-0	0.000e-0
2	20.1	3	range	range	15.90	100	0.000e-0	0.000e-0
Acceptance Criteria met: Essentially Identical results (well within 1%)								

Table D - 17: Verification of v20.1 PFM solutions for IPFLAW=3 – Embedded Flaws – Plate Material only – Cooldown and Severe Heat-up Transient, Modified Plate Embedded Flaw File (Relative to Table D.6 – 4) to have Non-Zero PFM Solutions

Case	Code	IPFLAW	Depth	Aspect	RTavg	RPV trials	CPI_{mean}	CPF_{mean}
Transient 1 – cooldown								
1	16.1	3	range	range	14.28	100	7.849e-3	7.849e-3
2	20.1	3	range	range	14.28	100	7.691e-3	7.691e-3
Transient 2 – heatup								
1	16.1	3	range	range	14.28	100	1.487e-7	1.487e-7
2	20.1	3	range	range	14.28	100	1.487e-7	1.487e-7
Acceptance Criteria met: Essentially Identical results (well within 5%)								

Table D - 18: Verification of v20.1 PFM Solutions for IPFLAW=3 – Generalized Case: Surface breaking + Weld Embedded + Plate Embedded, Severe Heat-up Transient - with Warm Pre-Stress – Eason 2006 (100 RPV trials)

Case	**Code**	**IPFLAW**	**Depth**	**Aspect**	**RTavg**	**RPV trials**	**CPI_{mean}**	**CPF_{mean}**
Transient 1 – cooldown								
1	16.1	3	range	range	27.64	100	1.168e-4	1.150e-4
2	20.1	3	range	range	27.64	100	1.150e-4	1.131e-4
Transient 2 – heatup								
1	16.1	3	range	range	27.64	100	4.349e-6	3.912e-6
2	20.1	3	range	range	27.64	100	4.349e-6	3.912e-6
Acceptance Criteria met: Essentially Identical results (within 2%)								

D.7 Verification of v20.1 FAVPFM Input Filter

To test the ability of v20.1 FAVPFM to identify user input errors for the as-found flaw files, an as-found flaw input file with identified errors in all of the following categories was created:

1. IKIND must be 1 or 2 (1=Internal surface-breaking or 2=embedded). Specified IKIND value of 3 for flaw ID 33.
2. NSUBR must not be greater than the number of subregions. (NUSBR=subregion number where flaw resides). Specified NSUBR value of 14 for flaw ID 13 and 28 for flaw ID 21, where 13 subregions are only allowed.
3. IORNT must be 1 or 2 (1=axial or 2=circumferential). Specified IORNT value of 3 for flaw ID 50 and value of 0 for flaw ID 51ZERO.
4. For internal-surface breaking flaws (IKIND=1), 0 ≤ DEPTH ≤ 0.5*wall thickness. Specified DEPTH value of 5.312 for ISB flaw ID 29. This is greater than maximum allowable 4.375 in, which is 50% of total wall thickness.
5. For embedded flaws (IKIND=2), CLTH < DEPTH ≤ (0.9*wall thickness – XINNER), where CLTH is the clad thickness and XINNER is radial location of crack tip from inner surface. Also, XINNER (xinner + depth) < 0.90 * thick. Specified DEPTH value of 5.312 for embedded flaw ID 42 with xinner equal to 3.3 in. DEPTH is greater than maximum allowable 4.575 in., and XINNER is greater than 4.575.
6. Aspect ratio for IKIND = 1 (Internal surface-breaking), must be 2, 6, 10, or 99. Specified aspect ratio value of 7 for flaw ID 1XBDDF, 100 for flaw ID 8ABCD, and 1 for flaw ID 7.
7. Aspect ratio for IKIND = 2 (Embedded), must be 1 ≤ aspect ≤ 20. Specified aspect ratio value of 25 for embedded flaw ID 242xy.
8. Duplicate FLAWIDs now allowed. Specified flaw ID 242xy three times.

Error messages are printed to both the output file (Fortran unit 29) and as-found echo file (Fortran unit 31). This section provides the input file and excerpts of the output file obtained when testing the above user entry errors. Results of the test showed that all of the above errors were identified and reported to the user in both the output file and echo file.

Table D - 19: As-Found Flaw Test Input File for Filtering User Entry Errors

```
no./col.
1.......10........20........30........40........50........60........70........80........90.......
100
 1 201
 2 1XBDDFEG 1 1 1 .3125 7 0.3
 3 8ABCD 1 2 1 .3125 100 0.3
 4 7 1 3 1 .3125 1 0.3
 5 3 1 4 1 .3125 6 0.3
 6 4 1 5 1 .3125 6 0.3
 7 242xy 1 6 1 .3125 6 0.3
 8 5 1 7 1 .3125 6 0.3
 9 6 1 8 1 .3125 6 0.3
 10 9 1 9 1 .3125 6 0.3
 11 10 1 10 1 .3125 6 0.3
 12 11 1 11 1 .3125 6 0.3
 13 12 1 12 1 .3125 6 0.3
 14 13 1 14 1 .3125 6 0.3
 15 14 2 1 1 .3125 1 0.3
 16 25 2 2 1 .3125 19.5 0.3
 17 242xy 2 3 1 .3125 25.0 0.3
 18 17 2 4 1 .3125 6 0.3
 19 23 2 5 1 .3125 6 0.3
 20 19 2 6 1 .3125 6 0.3
 21 22 2 7 1 .3125 6 0.3
 22 21 2 28 1 .3125 6 0.3
 23 15 2 9 1 .3125 6 0.3
 24 16 2 10 1 .3125 6 0.3
 25 18 2 11 1 .3125 6 0.3
 26 20 2 12 1 .3125 6 0.3
 27 26 2 13 1 .3125 6 0.3
 28 27ABCD     1       1       2       0.25    6       0.3
 29 28  1      2       2       0.3125  6       0.3
 30 29  1      3       2       5.3125  6       0.3
 31 30  1      4       2       0.3125  6       0.3
 32 31  1      5       2       0.3125  6       0.3
 33 242xy      1       6       2       0.3125  6       0.3
 34 33  3      7       2       0.3125  6       0.3
 35 34  1      8       2       0.3125  6       0.3
 36 35  1      9       2       0.3125  6       0.3
 37 36  1      10      2       0.3125  6       0.3
 38 37  1      11      2       0.3125  6       0.3
 39 38  1      12      2       0.3125  6       0.3
 40 39  1      13      2       0.3125  6       0.3
 41 40CLAD     2       1       2       0.25    6       0.3
 42 41  2      2       2       5.3125  6       0.3
 43 42  2      3       2       5.3125  6       3.3
 44 43  2      4       2       0.3125  6       0.3
 45 44  2      5       2       0.3125  6       0.3
 46 45  2      6       2       0.3125  6       0.3
 47 46  2      7       2       0.3125  6       0.3
 48 47  2      8       2       0.3125  6       0.3
 49 48  2      9       2       0.3125  6       0.3
 50 49  2      10      2       0.3125  6       0.3
 51 50  2      11      3       0.3125  6       0.3
 52 51ZERO     2       12      0       0.3125  6       0.3
 53 52  2      13      2       0.3125  6       0.3
```

Table D - 20: As-Found Flaw Test Output Echo for Filtering User Entry Errors

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

Flaw Flaw Depth Crack tip Aspect Flaw Sub
ID# KIND (inch) (inch) ratio ORNT region
1XBDDF 1 0.312 0.312 7 1 1

Aspect ratio must be 2,6,10, or 99 for flaw ID 1XBDDF

8ABCD 1 0.312 0.312 100 1 2

Aspect ratio must be 2,6,10, or 99 for flaw ID 8ABCD

7 1 0.312 0.312 1 1 3

Aspect ratio must be 2,6,10, or 99 for flaw ID 7

3 1 0.312 0.312 6 1 4
4 1 0.312 0.312 6 1 5
242xy 1 0.312 0.312 6 1 6
5 1 0.312 0.312 6 1 7
6 1 0.312 0.312 6 1 8
9 1 0.312 0.312 6 1 9
10 1 0.312 0.312 6 1 10
11 1 0.312 0.312 6 1 11
12 1 0.312 0.312 6 1 12
13 1 0.312 0.312 6 1 14

For flaw ID 13 subregion number 14
is greater than total number of subregions 13

14 2 0.312 0.300 1 1 1
25 2 0.312 0.300 19 1 2
242xy 2 0.312 0.300 25 1 3

Aspect ratio for embedded flaw with flaw ID 242xy must be 1 < AR < 20

17 2 0.312 0.300 6 1 4
23 2 0.312 0.300 6 1 5
19 2 0.312 0.300 6 1 6
22 2 0.312 0.300 6 1 7
21 2 0.312 0.300 6 1 28

For flaw ID 21 subregion number 28
is greater than total number of subregions 13

15 2 0.312 0.300 6 1 9
16 2 0.312 0.300 6 1 10
18 2 0.312 0.300 6 1 11
20 2 0.312 0.300 6 1 12
26 2 0.312 0.300 6 1 13
27ABCD 1 0.250 0.250 6 2 1
28 1 0.312 0.312 6 2 2
29 1 5.312 5.312 6 2 3

ISB flaw depth for flaw ID 29 is 5.312
This is greater than maximum allowable 4.375
which is 50% of total wall thickness

30 1 0.312 0.312 6 2 4
31 1 0.312 0.312 6 2 5
242xy 1 0.312 0.312 6 2 6
33 3 0.312 0.300 6 2 7

IKIND for flaw ID 33 must be 1 or 2
```

Table D - 21: As-Found Flaw Test Output Echo for Filtering User Entry Errors – (Continued)

```
34 1 0.312 0.312 6 2 8
35 1 0.312 0.312 6 2 9
36 1 0.312 0.312 6 2 10
37 1 0.312 0.312 6 2 11
38 1 0.312 0.312 6 2 12
39 1 0.312 0.312 6 2 13
40CLAD 2 0.250 0.300 6 2 1
41 2 5.312 0.300 6 2 2
42 2 5.312 3.300 6 2 3

Embedded flaw depth for flaw ID 42 is 5.312
This is greater than maximum allowable 4.575


xinner for flaw ID 42 is 3.300
This is greater than maximum allowable 2.562

43 2 0.312 0.300 6 2 4
44 2 0.312 0.300 6 2 5
45 2 0.312 0.300 6 2 6
46 2 0.312 0.300 6 2 7
47 2 0.312 0.300 6 2 8
48 2 0.312 0.300 6 2 9
49 2 0.312 0.300 6 2 10
50 2 0.312 0.300 6 3 11

Orientation for flaw ID 50 must be 1 or 2

51ZERO 2 0.312 0.300 6 0 12

Orientation for flaw ID 51ZERO must be 1 or 2

52 2 0.312 0.300 6 2 13

Flaw ID 242xy has duplicate

Flaw ID 242xy has duplicate

Flaw ID 242xy has duplicate

15 Incidents of errors in AFF data
Correct errors and try again
```