



# DRAFT REGULATORY GUIDE

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## DRAFT REGULATORY GUIDE DG-1299

(Proposed New Regulatory Guide)

# REGULATORY GUIDANCE ON THE ALTERNATE PRESSURIZED THERMAL SHOCK RULE

## A. INTRODUCTION

### Purpose

This guide describes a method that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable to permit use of the alternate fracture toughness requirements for protection against pressurized thermal shock (PTS) events for pressurized-water reactor (PWR) reactor pressure vessels (RPVs) in Title 10 of the *Code of Federal Regulations*, Part 50, “Domestic Licensing of Production and Utilization Facilities” (Ref. 1), Section 50.61a, “Alternate Fracture Toughness Requirements for Protection against Pressurized Thermal Shock Events” (10 CFR 50.61a).

This guide applies to each holder of an operating license for a pressurized-water nuclear power reactor whose construction permit was issued before February 3, 2010, and whose RPV was designed and fabricated to the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code), 1998 edition or earlier (Ref. 2).

### Applicable Rules and Regulations

- 10 CFR 50.61a provides alternate fracture toughness requirements for protection against PTS events for PWR RPVs to the requirements in 10 CFR 50.61, “Fracture Toughness Requirements for Protection against Pressurized Thermal Shock Events”.

### Related Guidance

- Regulatory Guide 1.190, “Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence,” (Ref. 3).

### Purpose of Regulatory Guides

The NRC issues regulatory guides to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency’s regulations, to explain techniques that

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This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received final staff review or approval and does not represent an official NRC final staff position. Public comments are being solicited on this draft guide and its associated regulatory analysis. Comments should be accompanied by appropriate supporting data. Comments may be submitted through the Federal-rulemaking Web site, <http://www.regulations.gov>, by searching for Docket ID: NRC-2014-0137. Alternatively, comments may be submitted to the Rules, Announcements, and Directives Branch, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001. Comments must be submitted by the date indicated in the *Federal Register* notice.

Electronic copies of this draft regulatory guide, previous versions of this guide, and other recently issued guides are available through the NRC’s public Web site under the Regulatory Guides document collection of the NRC Library at <http://www.nrc.gov/reading-rm/doc-collections/reg-guides/>. The draft regulatory guide is also available through the NRC’s Agencywide Documents Access and Management System (ADAMS) at <http://www.nrc.gov/reading-rm/adams.html>, under Accession No. ML14056A011. The regulatory analysis may be found in ADAMS under Accession No. ML14056A013.

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the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations, and compliance with them is not required.

### **Paperwork Reduction Act**

This regulatory guide contains information collection requirements covered by 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities,” that the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number. This regulatory guide is a rule as designated in the Congressional Review Act (5 U.S.C. 801-808). However, OMB has not found it to be a major rule as designated in the Congressional Review Act.

## **B. DISCUSSION**

### **Reason for Issuance**

This guide is being issued to describe a method that the staff of the NRC considers acceptable to meet the alternate fracture toughness requirements for protection against pressurized thermal shock (PTS) events for pressurized-water reactor (PWR) reactor pressure vessels (RPVs) in 10 CFR 50.61a, “Alternate Fracture Toughness Requirements for Protection against Pressurized Thermal Shock Events.” The alternate PTS requirements are based on updated analysis methods, and are desirable because the previous requirements in 10 CFR 50.61, “Fracture Toughness Requirements for Protection against Pressurized Thermal Shock Events,” are based on overly conservative probabilistic fracture mechanics (PFM) analyses.

### **Background**

The RPV in a nuclear power plant is exposed to neutron radiation during normal operation. Over time, the RPV steel becomes progressively embrittled in the region adjacent to the core. If an RPV had a pre-existing flaw of critical size and certain severe system transients occurred, this flaw could propagate rapidly through the RPV, resulting in a through-wall crack. The severe transients of concern, known as PTS events, are characterized by rapid cooling (i.e., thermal shock) of the internal RPV surface that may be combined with repressurization. The simultaneous occurrence of critical-size flaws, embrittled steel, and a severe PTS transient is a low probability event.

The NRC established the requirements for fracture toughness in 10 CFR 50.61 and many operating plants were licensed to meet these requirements. However, after additional information became available, it was recognized that the initial requirements established in 10 CFR 50.61 were based on overly conservative assumptions. In the *Federal Register* dated January 4, 2010 (Ref. 4), the NRC amended its regulations to provide alternate fracture toughness requirements for protection against PTS events for PWR RPVs. The alternate requirements contained in 10 CFR 50.61a maintain adequate safety while reducing regulatory burden for a PWR licensee who expects to exceed the requirements contained in 10 CFR 50.61 before the expiration of its license. A PWR licensee may choose to apply the provisions of 10 CFR 50.61a as a voluntary alternative to complying with the requirements of 10 CFR 50.61.

The “Alternate PTS Rule” contained in 10 CFR 50.61a is revised PTS screening criteria in the form of an embrittlement reference temperature,  $RT_{MAX-X}$ , which characterizes the RPV material’s resistance to fracture initiating from flaws based on more comprehensive analysis methods.

This document contains four regulatory positions that provide guidance concerning methods that the NRC staff considers acceptable for meeting the various criteria within the Alternate PTS Rule. These four regulatory positions are described below:

1. *Criteria relating to the date of construction and design requirements:* The Alternate PTS Rule is applicable to PWR licensees whose construction permits were issued before February 3, 2010, and whose RPVs were designed and fabricated in accordance with Section III of the ASME Code, 1998 Edition or earlier. The purpose of this applicability restriction is that the structural and thermal hydraulic analyses that established the basis for the Alternate PTS Rule embrittlement limits only represented plants constructed before this date. Licensees whose construction permits were issued after February 3, 2010, or with reactor vessels that were not designed and fabricated to the 1998 Edition or earlier of the ASME code must apply for and receive a specific exemption via 10 CFR 50.12 in order to utilize the alternate 10 CFR 50.61a criteria. Such applicants for an exemption should demonstrate that the risk-significant factors controlling PTS are adequately addressed by the technical basis calculations developed in support of the Alternate PTS Rule. Position 1 of this document identifies factors to be considered in such an evaluation.
2. *Criteria relating to the evaluation of plant-specific surveillance data:* The Alternate PTS Rule includes three statistical tests that should be performed on RPV surveillance data to determine whether the surveillance data are sufficiently close to the predictions of the embrittlement trend curve (ETC) used in 10 CFR 50.61a such that the predicted values based on the ETC are valid for use. Position 2 of this document provides guidance by which licensees can assess plant-specific data to the 10 CFR 50.61a ETC using statistical tests.
3. *Criteria relating to ISI data and NDE requirements:* The Alternate PTS Rule describes a number of tests and conditions on the collection and analysis of inservice inspection (ISI) data and requirements for nondestructive examination (NDE) that are intended to provide reasonable assurance that the distribution of flaws assumed to exist in the PFM calculations that provided the basis for the fracture resistance limits defined in 10 CFR 50.61a (defined in terms of  $RT_{MAX-X}$  values) provide an appropriate, or bounding, model of the population of flaws in the RPV of interest. Position 3 of this document provides guidance by which licensees can satisfy these criteria.
4. *Criteria relating to alternate limits on embrittlement.* The Alternate PTS Rule provides embrittlement criteria in the form of  $RT_{MAX-X}$  limits, as specified in Table 1 of 10 CFR 50.61a. Position 4 of this document describes an alternate procedure by which licensees can assess their plant-specific through-wall cracking frequency (TWCF) for cases where the  $RT_{MAX-X}$  limits are not met.

Further details and the technical background associated with the guidance provided in this document may be found in NUREG-2163, “Technical Basis for Regulatory Guidance on the Alternative PTS Rule, (10 CFR 50.61a)” (Ref. 5).

### **Harmonization with International Standards**

The NRC staff reviewed guidance from the International Atomic Energy Agency and did not identify any standards that provided useful guidance to NRC staff, applicants, or licensees.

## Documents Discussed in Staff Regulatory Guidance

This regulatory guide endorses, in part, the use of one or more codes or standards developed by external organizations, and other third-party guidance documents. These codes, standards and third-party guidance documents may contain references to other codes, standards or third-party guidance documents (“secondary references”). If a secondary reference has itself been incorporated by reference into NRC regulations as a requirement, then licensees and applicants must comply with that standard as set forth in the regulation. If the secondary reference has been endorsed in a regulatory guide as an acceptable approach for meeting an NRC requirement, then the standard constitutes a method acceptable to the NRC staff for meeting that regulatory requirement as described in the specific regulatory guide. If the secondary reference has neither been incorporated by reference into NRC regulations nor endorsed in a regulatory guide, then the secondary reference is neither a legally-binding requirement nor a “generic” NRC-approved acceptable approach for meeting an NRC requirement. However, licensees and applicants may consider and use the information in the secondary reference, if appropriately justified, consistent with current regulatory practice, and consistent with applicable NRC requirements.

### C. STAFF REGULATORY GUIDANCE

#### 1. Criteria Relating to the Date of Construction and Design Requirements

10 CFR 50.61a(b) states that the Alternate PTS Rule applies to holders of an operating license for a PWR whose construction permit was issued before February 3, 2010, and whose reactor vessel was designed and fabricated to the ASME Boiler and Pressure Code, 1998 Edition or earlier. If a licensee does not fit within this category (e.g., a licensee whose construction permit was issued after February 3, 2010), the provisions of 10 CFR 50.61a may not be used unless the licensee applies for and obtains a specific exemption under 10 CFR 50.12 from the 10 CFR 50.61a(b) prohibition. The criteria for obtaining such an exemption are listed in 10 CFR 50.12(a): the exemption must be authorized by law, must not present an undue risk to the public health and safety, must be consistent with the common defense and security, and special circumstances must be present. When addressing these exemption criteria, the licensee should demonstrate that the risk-significant factors controlling PTS for the plant in question are adequately addressed by the technical basis calculations that were performed to develop 10 CFR 50.61a. Factors to be considered in this evaluation should include the following:

- The event sequences, which may lead to over-cooling of the RPV.
- The thermal-hydraulic response of the nuclear steam supply system (NSSS) in response to such sequences.
- Characteristics of the RPV design (e.g., vessel diameter, vessel wall thickness, operating pressure) that influence the stresses that develop in the beltline region of the vessel in response to the event sequences.
  - Note: As indicated in Section 1.2 of NUREG-2163, the “reactor vessel beltline” is defined as those reactor vessel shell materials with projected neutron fluence values equal to or greater than  $1 \times 10^{17}$  n/cm<sup>2</sup> at the end of the design life. Fluence values should be determined in accordance with methodology consistent with that specified in Regulatory Guide 1.190, “Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence,” March 2001, or using methods otherwise acceptable to the staff.
- Characteristics of the RPV material and its embrittlement behavior.

The technical details of how these factors were considered in the development of the Alternate PTS Rule are contained in NUREG-1806, "Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10 CFR 50.61)" (Ref. 6).

## 2. Criteria Relating to the Evaluation of Plant-Specific Surveillance Data

This regulatory position describes a procedure by which licensees can assess their plant-specific material surveillance data using the three statistical tests required by Paragraph (f)(6) of 10 CFR 50.61a. If the criteria for all three statistical tests are satisfied for all beltline materials, then the  $RT_{MAX-X}$  screening criteria in Table 1 of 10 CFR 50.61a can be used without modification. Conversely, if any of the criteria from the three statistical tests required by 10 CFR 50.61a are not satisfied for any beltline material, then additional action is required to justify the use of the  $RT_{MAX-X}$  screening criteria in Table 1 of 10 CFR 50.61a as required by Paragraph (f)(6)(vi) of 10 CFR 50.61a.

To use this procedure the following equations are needed. Equation numbers identical to those in Paragraph (g) of 10 CFR 50.61a are used for consistency. Equation (5) is the embrittlement trend curve (ETC).

$$\Delta T_{30} = MD + CRP \quad (5)$$

$$MD = A \times (1 - 0.001718 \times T_C) \times (1 + 6.13 \times P \times Mn^{2.471}) \times \phi_e^{0.5} \quad (6)$$

$$\text{where: } A = \begin{cases} 1.140 \times 10^{-7} & \text{for forgings} \\ 1.561 \times 10^{-7} & \text{for plates} \\ 1.417 \times 10^{-7} & \text{for welds} \end{cases}$$

$$CRP = B \times (1 + 3.77 \times Ni^{1.191}) \times f(Cu_e, P) \times g(Cu_e, Ni, \phi_e) \quad (7)$$

$$\text{where: } B = \begin{cases} 102.3 & \text{for forgings} \\ 102.5 & \text{for plates in non - Combustion Engineering manufactured vessels} \\ 135.2 & \text{for plates in Combustion Engineering manufactured vessels} \\ 155.0 & \text{for welds} \end{cases}$$

$$Cu_e = \begin{cases} 0 & \text{for } Cu \leq 0.072 \text{ wt\%} \\ MIN[Cu, MAX(Cu_e)] & \text{for } Cu > 0.072 \text{ wt\%} \end{cases}$$

$$MAX(Cu_e) = \begin{cases} 0.243 & \text{for Linde 80 welds} \\ 0.301 & \text{for all other materials} \end{cases}$$

$$f(Cu_e, P) = \begin{cases} 0 & \text{for } Cu \leq 0.072 \\ [Cu_e - 0.072]^{0.668} & \text{for } Cu > 0.072 \text{ and } P \leq 0.008 \\ [Cu_e - 0.072 + 1.359 \times (P - 0.008)]^{0.668} & \text{for } Cu > 0.072 \text{ and } P > 0.008 \end{cases}$$

$$g(Cu_e, Ni, \phi_e) = 0.5 + (0.5 \times \tanh \left\{ \frac{[\log_{10}(\phi_e) + (1.1390 \times Cu_e) - (0.448 \times Ni) - 18.120]}{0.629} \right\})$$

$$\phi_e = \begin{cases} \phi & \text{for } \phi \geq 4.39 \times 10^{10} \text{ n/cm}^2/\text{sec} \\ \phi \times \left( \frac{4.39 \times 10^{10}}{\phi} \right)^{0.2595} & \text{for } \phi < 4.39 \times 10^{10} \text{ n/cm}^2/\text{sec} \end{cases}$$

The variables in these equations and their units are shown in Table 1.

Table 1. Variables, Symbols, and Units used in Eqs. (5) – (7).

Variable	Symbol	Units
Transition temperature shift	$\Delta T_{30}$	$^{\circ}\text{F}$
Neutron Fluence (E > 1 MeV)	$\phi$	n/cm <sup>2</sup>
Effective Neutron Fluence (E > 1 MeV)*	$\phi_e$	n/cm <sup>2</sup>
Neutron Flux (E > 1 MeV)	$\phi$	n/cm <sup>2</sup> /sec
Irradiation Temperature	$T_C$	$^{\circ}\text{F}$
Copper content	$Cu$	weight %
Effective Copper content	$Cu_e$	weight %
Nickel content	$Ni$	weight %
Manganese content	$Mn$	weight %
Phosphorus content	$P$	weight %

**Step 1: Assess the Availability of Surveillance Data and Collect Information to Support the Statistical Analysis**

Paragraph (f)(6)(i) of 10 CFR 50.61a requires that the licensee assess the suitability of its surveillance data. Licensees who utilize this guidance should assess its surveillance data as follows:

- (a) For each shell material in the RPV beltline region, identify all surveillance data from the plant being assessed and from any other reactor that is operating, or has previously operated, under a license issued by the NRC that is of the same heat of material.
- (b) Count the number of values of shift produced by irradiation in the Charpy V-notch (CVN) transition temperature at the 30 ft-lb energy level,  $\Delta T_{30}$ , for each beltline material identified in Step 1(a). When counting data for individual plates and forgings,  $\Delta T_{30}$  obtained for different notch orientations should be treated as part of the same data set.

- i. If there are fewer than three  $\Delta T_{30}$  values measured at three different fluence values for a material, then no surveillance tests are required for that material. The remaining steps of this procedure may be ignored and the ETC in 10 CFR 50.61a (Equation (5)) may be used.
  - ii. If there are three or more  $\Delta T_{30}$  values measured at three different fluence values for a material, then statistical surveillance tests are required for this material. The remaining steps of this procedure should be followed.
- (c) For all materials remaining after Step (1)(b)(ii), assemble the following information:
- heat identification
  - plant identification
  - capsule identification
  - product form
  - notch orientation
  - the unirradiated reference temperature,  $RT_{NDT(U)}$
  - $\Delta T_{30}$
  - Charpy-V notch energy data used to estimate  $\Delta T_{30}$
  - fluence
  - operating time
  - cold leg temperature under normal full-power operating conditions ( $T_c$ )
    - Note:  $T_c$  (°F) is determined as the time-weighted average coolant temperature of the reactor coolant system cool leg covering the time period from the start of full power operation through the end of licensed operation.
  - copper (Cu) content
  - nickel (Ni) content
  - phosphorus (P) content
  - manganese (Mn) content
  - citation

The values of Cu, Ni, P, and Mn must represent the best estimate values for the material (10 CFR 50.61a(f)(3)). For a plate or forging, the best estimate value is normally the mean of the measured values for that plate or forging. For a weld, the best estimate value is normally the mean of the measured values for a weld deposit made using the same weld wire heat number as the critical vessel weld. If these values are not available, either the upper limiting values given in the material specifications to which the vessel material was fabricated, or conservative estimates (i.e., mean plus one standard deviation) based on generic data should be used.

## Step 2: Perform Statistical Assessments of the Surveillance Data

For each material remaining after Step (1)(b)(ii), determine if each of the following three statistical tests are met:

### (a) Mean Test

Paragraph (f)(6)(ii) of 10 CFR 50.61a requires that the licensee perform a statistical mean test. Licensees utilizing this guidance should perform the statistical mean test as follows:

- i. Determine the mean deviation from the data from the ETC using the following equation for each surveillance datum identified in Step 1:

$$r = \Delta T_{30(\text{Measured})} - \Delta T_{30(\text{predicted})} \quad (8)$$

where the measured  $\Delta T_{30}$  represents the shift in CVN transition temperature at the 30 ft-lb energy level produced by irradiation for each datum identified in Step 1, and the predicted  $\Delta T_{30}$  is estimated using Equation (5) and the best-estimate composition and exposure values for the plant from which the companion measured  $\Delta T_{30}$  value was obtained.

- ii. Estimate the mean residual ( $r_{\text{mean}}$ ):

$$r_{\text{mean}} = \frac{1}{n} \sum_{i=1}^n \{r_i\} \quad (9)$$

where  $n$  is the number of data points in the specific data set,

- iii. Estimate the maximum credible heat-average residual ( $r_{\text{max}}$ ):

$$r_{\text{max}} = \frac{2.33\sigma}{n^{0.5}} \quad (10)$$

where  $\sigma$  is from Table 2.

- iv. If  $r_{\text{mean}}$  exceeds  $r_{\text{max}}$ , then the mean test is not satisfied; in this case proceed to Step 2(d). If  $r_{\text{mean}}$  is less than or equal to  $r_{\text{max}}$  then the mean test is satisfied; in this case proceed to Step 2(b).

Table 2. Standard Deviation of Residuals about Eq. (5).

Product Form	Standard Deviation (°F)	
	Cu ≤ 0.072 wt %	Cu > 0.072 wt %
Weld	18.6	26.4
Plate		21.2 <sup>(a)</sup>
Forging		19.6

a. Includes the standard reference materials.

### (b) Slope Test

Paragraph (f)(6)(iii) of 10 CFR 50.61a requires that the licensee perform a statistical slope test. Licensees who utilize this guidance should perform the statistical slope test as follows:

- i. Using the method of least squares, estimate the slope of the ETC model residuals (i.e., the  $r$  values, from Eq. (8)) plotted as a function of the base 10 logarithm of neutron fluence for the specific data set. Also estimate the standard-error of the estimated value of slope,  $se(m)$ .
- ii. Estimate the T-statistic for  $m$  as follows:

$$T_{\text{SURV}} = \frac{m}{se(m)} \quad (11)$$



- iii. Determine the critical value of T ( $T_{CRIT}$ ) from the rightmost column in Table 3. For surveillance data sets with greater than 15 data points, the  $T_{MAX}$  value should be calculated using Student's T distribution with a significance level ( $\alpha$ ) of 1 percent for a one-tailed test.
- iv. If  $T_{SURV}$  exceeds  $T_{CRIT}$ , then the slope test is not satisfied; in this case proceed to Step 2(d). If  $T_{SURV}$  is less than or equal to  $T_{CRIT}$  then the slope test is satisfied; in this case proceed to Step 2(c).

Table 3.  $\alpha = 1\%$  Student's-T Values.

Number of $\Delta T_{30}$ Values, n	n-2	One-Tailed $T_{CRIT}$ (1%, n-2)
3	1	31.82
4	2	6.96
5	3	4.54
6	4	3.75
7	5	3.36
8	6	3.14
9	7	3.00
10	8	2.90
11	9	2.82
12	10	2.76
13	11	2.72
14	12	2.68
15	13	2.65

**(c) Outlier Test**

Paragraph (f)(6)(iv) of 10 CFR 50.61a requires that the licensee perform a statistical outlier test. Licensees who utilize this guidance should perform the statistical outlier test as follows:

- i. Estimate the normalized residual, r, for each or the n observations in the  $\Delta T_{30}$  dataset:

$$r^* = \frac{r}{\sigma} \tag{12}$$

where r is defined using Equation (8) and  $\sigma$  is from Table 2.

- ii. Find the largest and second largest  $r^*$  values; designate these  $r^*_1$  and  $r^*_2$ , respectively.

Find the limit values of  $r_{LIMIT(1)}$  and  $r_{LIMIT(2)}$  corresponding to the dataset size n in

iii. Table 4.

iv. If  $r^*_1 \leq r_{LIMIT(1)}$  and  $r^*_2 \leq r_{LIMIT(2)}$  then the dataset satisfies the outlier test; otherwise it does not. In either case proceed to Step 2(d).

Table 4.  $\alpha = 1\%$  Threshold Value for the Outlier Test.

<b>n</b>	<b>r<sub>LIMIT(2)</sub></b>	<b>r<sub>LIMIT(1)</sub></b>
3	1.55	2.71
4	1.73	2.81
5	1.84	2.88
6	1.93	2.93
7	2.00	2.98
8	2.05	3.02
9	2.11	3.06
10	2.16	3.09
11	2.19	3.12
12	2.23	3.14
13	2.26	3.17
14	2.29	3.19
15	2.32	3.21
17	2.37	3.24
26	2.53	3.36
64	2.83	3.62

**(d) Outcome of Step 2**

- i. Assessment: If all surveillance materials meeting the data quantity requirements of Step (1)(b)(ii) satisfy all three statistical surveillance tests of Steps (2)(a), (2)(b), and (2)(c), then the  $RT_{MAX-X}$  screening criteria in Table 1 of 10 CFR 50.61a can be used without modification. The values of  $\Delta T_{30}$  used in estimating the  $RT_{MAX-X}$  values should be based on the ETC defined by Equation (5) using best-estimate input values for the plant and plant materials being assessed, and should not be modified based on surveillance data. In the event that any of the statistical tests in Steps (2)(a), (2)(b), and (2)(c) are not satisfied, 10 CFR 50.61a stipulates that:

... the licensee shall review the data base for that heat in detail, including all parameters used in [the ETC] and the data used to determine the baseline Charpy V-notch curve for the material in an unirradiated condition. The licensee shall submit an evaluation of the surveillance data to the NRC and shall propose  $\Delta T_{30}$  and  $RT_{MAX-X}$  values, considering their plant-specific surveillance data, to be used for evaluation relative to the acceptance criteria of this rule. These evaluations must be submitted for review and approval by the Director in the form of a license amendment...

The following guidance provides information for these additional evaluations.

- ii. Factors to Consider When the Step 2 Statistical Test are not Satisfied: When any of the statistical tests are not satisfied, values of  $\Delta T_{30}$  predicted using Equation (5) may under-estimate the embrittlement magnitude. Therefore, review of the data for that heat, including all parameters used in Equation (5) and the data used to determine the CVN curve for the material in the unirradiated condition, should be performed. The most appropriate approach may not be a heat-specific adjustment of the ETC predictions in all cases. For example, statistically significant differences may indicate situations where the available data (i.e., the measured  $\Delta T_{30}$  values and/or the composition and exposure values associated with the measured  $\Delta T_{30}$  values) may not be accurate, thereby making adjustment of the ETC predictions to match these data unnecessary. Assessment of the data should consider, but not be limited to, the following factors:

- RT<sub>NDT(U)</sub> value: A records investigation of the RT<sub>NDT(U)</sub> value, and/or the performance of additional testing of archival material, may provide a more accurate estimate of RT<sub>NDT(U)</sub>, which may explain the reason for not satisfying the mean and/or outlier tests.
  - Irradiated T<sub>30</sub> values: While most CVN energy vs. temperature curves (from which T<sub>30</sub> values are estimated) are based on ≈8 to 12 individual measurements, some data sets are more limited, which can lead to increased uncertainty in the values of T<sub>30</sub>. In the event that any of the statistical tests are not satisfied, a review of the individual CVN energy vs. temperature curves may help reveal the cause.
  - Composition and exposure variables: The input variables to Equation (5) are subject to variability and are often based on limited data. However, the predictions of Equation (5) are very sensitive to the value of the input variables, particularly Cu content, fluence, temperature, and Ni content. If a sensitivity analysis reveals that small variations of the values input to Equation (5) explain the cause of not satisfying the statistical tests, this might indicate that more refined information concerning input values (e.g., additional measurements) are necessary, and may form the basis for proposing ΔT<sub>30</sub> and RT<sub>MAX-X</sub> values considering the plant-specific surveillance data. Specific limits are not provided; these should be justified on a case-specific basis.
  - Notch orientation: The T<sub>30</sub> values for plate and forging materials are sensitive to the orientation of the notch in the CVN specimens relative to the primary working directions of the plate or forging materials. Differences in notch orientation between the unirradiated T<sub>30</sub> values and the T<sub>30</sub> values for all of the irradiated specimens could help to explain why the mean test is not satisfied. Similarly, differences in notch orientations between the unirradiated T<sub>30</sub> values and the T<sub>30</sub> values for the irradiated specimens in a single capsule could help to explain why the outlier is not satisfied. In these situations, the outcome of a records search or metallurgical investigation of the tested specimens may provide part of the basis for proposing ΔT<sub>30</sub> and RT<sub>MAX-X</sub> values considering the plant-specific surveillance data.
  - Comparative trends analysis: In addition to CVN specimens, surveillance capsules also contain tensile specimens. Like ΔT<sub>30</sub>, the increase in yield strength with irradiation (ΔYS) also follows predictable trends. If ΔYS data for a particular material that failed the statistical tests follow the trends exhibited by ΔYS data for a similar composition, this information may form part of the basis for proposing ΔT<sub>30</sub> and RT<sub>MAX-X</sub> values considering the plant-specific surveillance data.
- iii. Specific Procedures: In the event that the evaluation of factors described in Step 2(d)(ii) do not explain or rationalize the cause of the statistical tests not being satisfied, adjustment of the ETC predictions based on plant specific data should be considered. Three situations exist for which a specific procedure may be used, as follows:
1. Mean Test Failure: One procedure for adjusting ETC predictions to account for a failure of the mean test is illustrated on the left side of Figure 1. This procedure is as follows:
    - a. Calculate the value *ADJ* as follows:

$$ADJ = r_{mean} - r_{max}$$

- b. Adjust the prediction of Equation (5) as follows:

$$\Delta T_{30(ADJ)} = MD + CRP + ADJ$$

- c. Use the value  $\Delta T_{30(ADJ)}$  in place of the predicted  $\Delta T_{30}$  in all calculations required by the Alternate PTS Rule for the materials that do not satisfy the mean statistical test.
2. Slope Test Failure: One procedure for adjusting ETC predictions to account for a failure of the slope test is to adjust the ETC predictions (Eq. (5)) from the Alternate PTS Rule based on the greater increase of embrittlement with fluence suggested by the plant-specific data. The specific procedure used should be technically justified and documented.
3. Outlier Test Failure (Not Satisfied at Low Fluence): The right side of Figure 1 illustrates a situation where a  $\Delta T_{30}$  value measured at low fluence is responsible for not satisfying the outlier test. Such a situation is not considered relevant to a PTS evaluation, and may therefore be ignored, provided that both of the following conditions are satisfied:
- The fluence of the datum that caused the outlier test failure ( $\phi_{t_{LOW}}$ ) is less than 10 percent of the fluence at which the PTS evaluation is being performed ( $\phi_{t_{EVAL}}$ ), and
  - After elimination of the datum measured at ( $\phi_{t_{LOW}}$ ), the entry conditions for the surveillance tests are still met (i.e., at least three datum measured at three different fluence values remain) and all three statistical tests are satisfied with the reduced data set.

Other approaches to assessment of surveillance data where all surveillance measurements are bounded are subject to review and approval by the NRC.

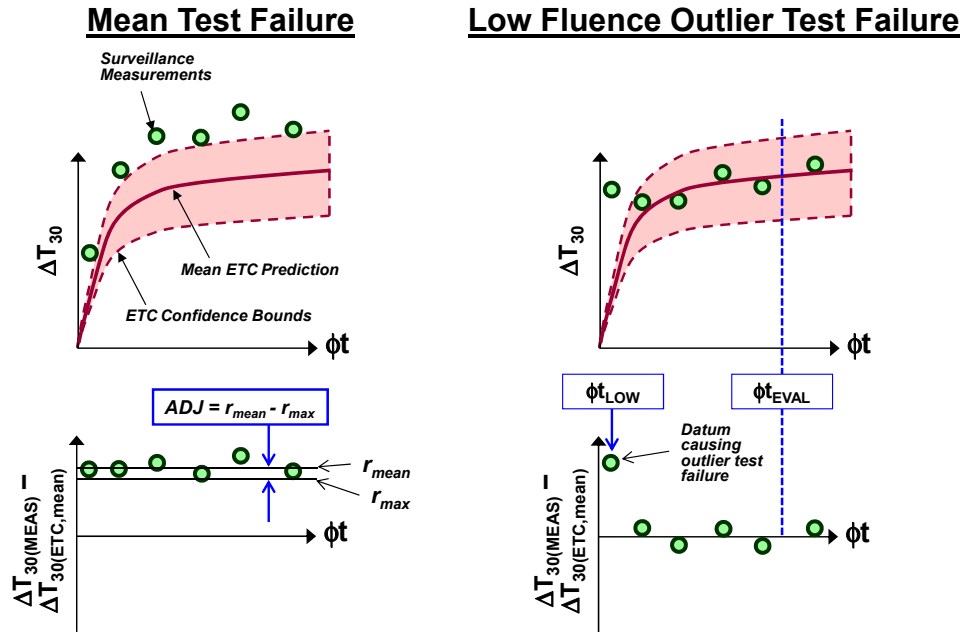


Figure 1. Specific Procedures to Address Unsatisfactory Mean Statistical Test (left) or Low Fluence Outlier Statistical Test (right)

### 3. Criteria Relating to ISI Data and NDE Requirements

Figure 2 illustrates the procedure in 50.61a for examination and flaw detection requirements. Compliance with Tables 2 and 3 of 10 CFR 50.61a demonstrates that the flaw distribution in the RPV is adequately represented by the flaw distribution assumed in the PFM calculations that established the technical basis for the  $RT_{\text{MAX-X}}$  limits in Table 1 of 10 CFR 50.61a. The steps in the flowchart of Figure 2 are as follows:

Step A: All plant-specific recordable flaw data (see Figure 3) should be collected for the inner three-eighths of the wall thickness ( $3/8t$ ) for the base material and weld metal examination volumes within the RPV beltline region using procedures, equipment and personnel, as required in ASME Code, Section XI (Ref. 7), Mandatory Appendix VIII, Supplements 4 and 6, using UT volumetric examinations.

- Note: Any flaws that are detected within the ultrasonic transducer scan paths, but are located outside of the required ASME Code, Section XI, examination volume, should also be included in the flaw table evaluation.

Step B: The plant-specific flaw data from Step A should be evaluated for axial flaw surface connection. Any flaws with a through-wall extent greater than or equal to 0.075 inch, axially oriented and located at the clad-to-base metal interface, should be verified to not be connected to the RPV inner surface using surface examination techniques capable of detecting and characterizing service-induced cracking of the RPV cladding. Eddy current and visual examinations methods are acceptable to the staff for detection of cladding cracks. An appropriate quality standard shall be implemented to ensure these examinations are effective at identification of surface cracking as required by 10 CFR 50 Appendix B, Criterion IX "Control of Special Processes," which requires in part, that measures shall be established to assure that special

processes, including nondestructive testing, are controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements. Appropriate quality standards for implementation of surface examinations are identified in the ASME Code Section XI “Rules for Inservice Inspection of Nuclear Power Plant Components” and/or Section V “Nondestructive Examination.”

Step C: If the results of Step B are acceptable, the plant-specific flaw data should be evaluated for acceptability in accordance with ASME Code, Section XI, Table IWB-3510-1 flaw acceptance standards.

Step D: If the results of Step C are satisfactory, or (if applicable) the results of Step F are acceptable, the plant-specific flaw data should be compared to Tables 2 and 3 of 10 CFR 50.61a. A specific example of how this step may be performed, including how the plant-specific flaw data is categorized into weld or plate flaws, is shown in Section 6.3 of NUREG-2163.

Step E: If the results of Step B indicate that any axial flaws with through-wall extents greater than 0.075 inch are connected to the RPV inner surface, or (if applicable) the results of Step “F” are not acceptable, other plant-specific assessment is required and the provisions of 10 CFR 50.61a may not be used.

Step F: If the evaluation associated with Step C is not successful (i.e., if any flaws exceed ASME Code, Section XI, Table IWB-3510-1 flaw acceptance standards), the flaws should be evaluated and found to be acceptable in accordance with ASME Code, Section XI flaw evaluation methods, and the flaws should be evaluated for acceptability according to 10 CFR 50.61a (see Step I).

Step G: If the results of Step D are not acceptable, NDE uncertainties may be accounted for in the evaluation. Appendix C of NUREG-2163 describes the development and application of one methodology acceptable to the NRC that accounts for uncertainties in NDE data. This method may be used for the purpose of developing more realistic vessel-specific flaw depth and density distributions for comparison to Tables 2 and 3 of 10 CFR 50.61a, as well as for use in a plant-specific PFM analysis. The methodology considers flaw sizing errors, a flaw detection threshold, probability of detection (POD), and a prior flaw distribution assumption. It uses a Bayesian updating methodology to combine the observed NDE data with the available flaw data and models used as part of the PTS re-evaluation effort. The licensee must submit the adjustments made to the volumetric test data to account for NDE-related uncertainties as described in (c)(2) of 10 CFR 50.61a.

Step H: The revised flaw distribution results of Step G should be used to compare the revised plant-specific flaw data to Tables 2 and 3 of 10 CFR 50.61a.

Step I: If the results of Step H are not acceptable, all flaws should be evaluated for acceptability using one of the following approaches:

1. Preclusion of brittle fracture. Satisfactory demonstration of upper shelf behavior, which precludes brittle fracture, can be based on maintaining temperature above  $RT_{NDT} + 60$  °F using the following steps:
  - i. Compute the irradiated  $RT_{NDT}$  for all flaws as follows:

- Determine the unirradiated value of  $RT_{NDT}$ ,  $RT_{NDT(U)}$ , for the material at each flaw location.
  - Determine the fluence at each flaw location.
  - Compute  $\Delta T_{30}$  for each flaw using Eq. (5) and the fluence at each flaw location.
  - Compute the flaw-specific value of  $RT_{NDT}$  as  $RT_{NDT(U)} + \Delta T_{30}$  for each flaw.
- ii. Assuming a lower bound PTS transient temperature of 75°F, upper shelf behavior is assured if  $RT_{NDT} + 60 \leq 75$  °F. Therefore, the flaw-specific value of  $RT_{NDT}$  should be less than or equal to 15 °F.
- iii. The evaluation associated with Step I is acceptable if the flaw-specific value of  $RT_{NDT}$  is less than or equal to 15°F for all flaws.
2. Calculate the plant-specific TWCF using a plant-specific PFM analysis. A plant-specific PFM analysis to calculate TWCF is complex, and there are many variations of inputs possible for such an analysis. Therefore, specific guidance for plant-specific PFM analysis to calculate TWCF is not included in this regulatory guide. General considerations to include in a plant-specific PFM analysis are provided in Section 6.2.2 of NUREG-2163. A discussion of the methodology that was used in performing TWCF calculations for PTS may be found in NUREG-1806, NUREG-1807 (Ref. 8), and NUREG/CR-6854 (Ref. 9). The steps associated with conducting a plant-specific PFM calculation are as follows:
- i. Perform a Bayesian update of the flaw distribution:
- Apply the procedures of Appendix C of NUREG-2163 and obtain revised flaw depth and flaw density parameters (similar to those shown in Table 11 of NUREG-2163).
- ii. Calculate the TWCF using a PFM computer code (e.g., ORNL/TM-2012/566, Fracture Analysis of Vessels - Oak Ridge (FAVOR) (Ref. 10)):
- Run the generalized procedure for generating flaw-related inputs for the FAVOR Code described in NUREG/CR-6817 (Ref. 11) using the revised flaw depth and flaw density parameters.
  - Develop necessary plant-specific inputs using the guidance in NUREG-1806, NUREG-1807, and NUREG/CR-6854.
  - Run a plant-specific PFM analysis.
  - Calculate the TWCF.
- iii. Compare the plant-specific TWCF to the TWCF limit specified in 10 CFR 50.61a:



- The evaluation associated with Step I is acceptable if the calculated TWCF is less than or equal to the  $1 \times 10^{-6}$  events per reactor year limit specified in 10 CFR 50.61a.

Step J: If the results of Step I are not acceptable, the licensee should perform a plant-specific assessment for PTS and submit the assessment to the Director of the Office of Nuclear Reactor Regulation for review and approval as required by 10 CFR 50.61a(d)(4).

Step K: If the results of Step D or (if applicable) Step H or (if applicable) Step I are satisfactory, the screening criteria contained in Table 1 of 10 CFR 50.61a may be applied to the plant in question. As required by 10 CFR 50.61a(c), the plant-specific assessment, including explicit details and results, must be submitted to the Director of the Office of Nuclear Reactor Regulation for review and approval in the form of a license amendment at least 3 years before  $RT_{MAX-X}$  is projected to exceed the Alternate PTS Rule screening criteria.

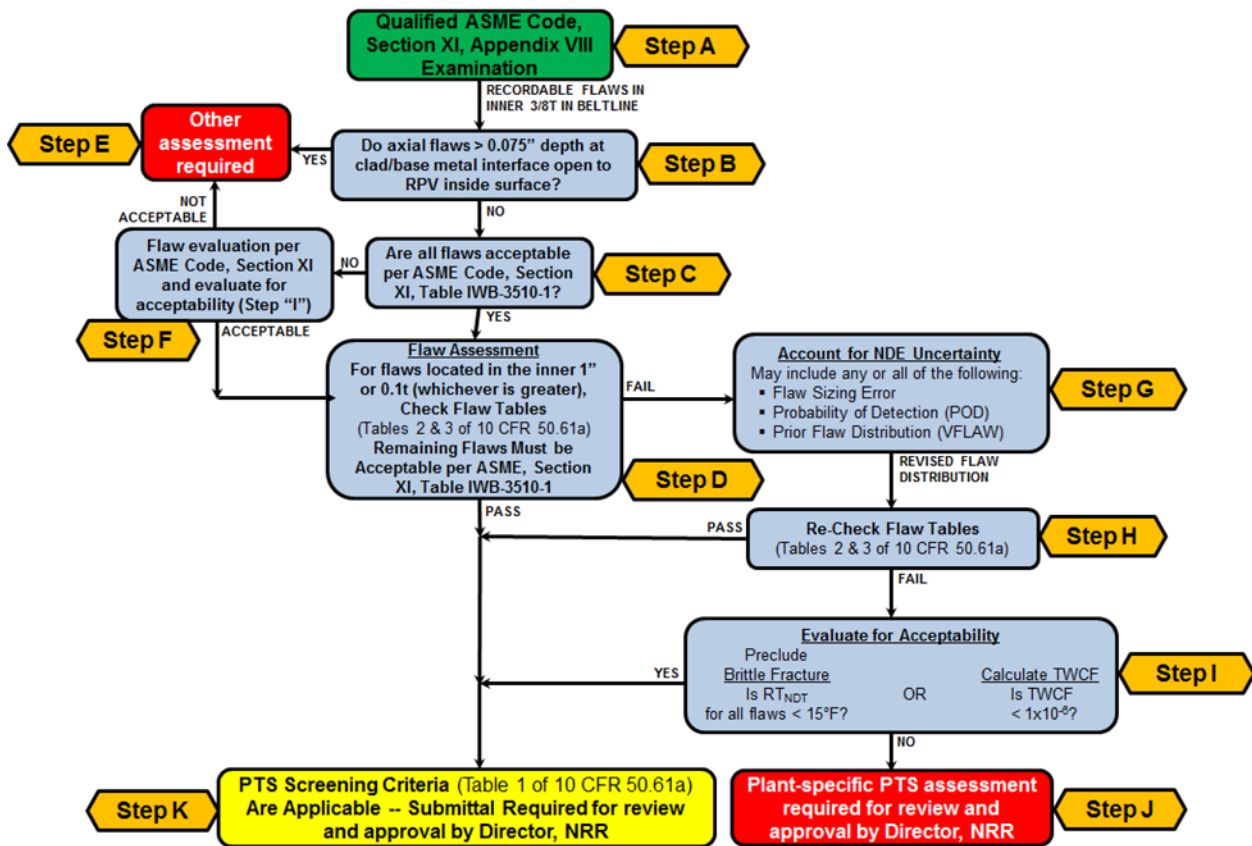


Figure 2. Flow Diagram with Guidance for Meeting the Requirements of the Alternate PTS Rule

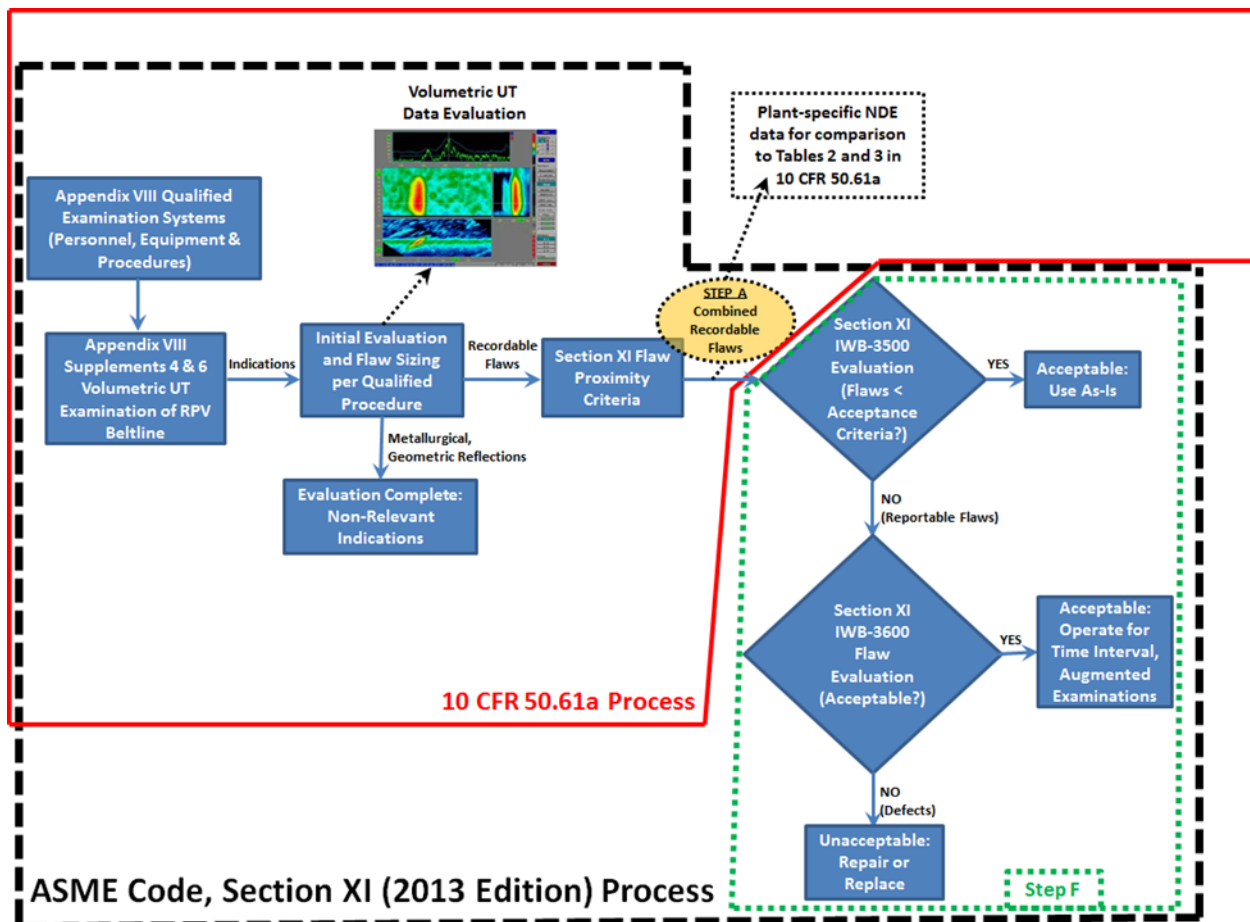


Figure 3. ASME Code, Section XI Examination and Flaw Evaluation Process and Identification of Flaws for Comparison to Alternate PTS Rule

#### 4. Criteria Relating to Alternate Limits on Embrittlement

This regulatory position describes an alternate procedure by which licensees can assess their plant-specific TWCF for cases where embrittlement criteria are not met, as allowed by Paragraph (c)(3) of 10 CFR 50.61a (i.e., the  $RT_{MAX-X}$  limits of Table 1 of 10 CFR 50.61a are not satisfied). This position fulfills the requirements in Paragraphs (d)(3) through (d)(6) of 10 CFR 50.61a, and includes calculation of a plant-specific TWCF value to provide an alternate demonstration that the limits of Table 1 of 10 CFR 50.61a are satisfied. One method to make such a demonstration is using the methods and formulae provided in Section 3.5.1, Step 4, of NUREG-1874 (Ref. 12). Satisfactory demonstration for this position includes the following steps:

- Step 1. Establish the plant characterization parameters (e.g., copper, fluence).
- Step 2. Estimate values of  $RT_{MAX-X}$  using the values of the characterization parameters from Step 1 and the formulae given in Section 3.5.1 of NUREG-1874.
- Step 3. Estimate the 95<sup>th</sup> percentile TWCF value,  $TWCF_{95-XX}$ , for each of the axial weld flaw, plate flaw, circumferential weld flaw, and forging flaw populations using the  $RT_{MAX-X}$  values from Step 2 and the formulae given in Section 3.5.1 of NUREG-1874.

- Step 4. Estimate the total 95<sup>th</sup> percentile TWCF, TWCF<sub>95-TOTAL</sub>, for the vessel using the formulae given in Section 3.5.1 of NUREG-1874.

The results of this approach are acceptable if the plant-specific value of TWCF<sub>95-TOTAL</sub> is less than or equal to  $1 \times 10^{-6}$  events per reactor year.

## D. IMPLEMENTATION

The purpose of this section is to provide information on how applicants and licensees<sup>1</sup> may use this guide and information regarding the NRC's plans for using this regulatory guide. In addition, it describes how the NRC staff complies with the Backfit Rule (10 CFR 50.109) and any applicable finality provisions in 10 CFR Part 52.

### Use by Licensees

Licensees may voluntarily<sup>2</sup> use the guidance in this document to demonstrate compliance with the underlying NRC regulations. Methods or solutions that differ from those described in this regulatory guide may be deemed acceptable if they provide sufficient basis and information for the NRC staff to verify that the proposed alternative demonstrates compliance with the appropriate NRC regulations.

Licensees may use the information in this regulatory guide for actions that do not require NRC review and approval such as changes to a facility design under 10 CFR 50.59, "Changes, Tests, and Experiments," that do not require prior NRC review and approval. Licensees may use the information in this regulatory guide or applicable parts to resolve regulatory or inspection issues.

### Use by NRC Staff

During regulatory discussions on plant-specific operational issues, the staff may discuss with licensees various actions consistent with staff positions in this regulatory guide, as one acceptable means of meeting the underlying NRC regulatory requirement. Such discussions would not ordinarily be considered backfitting even if prior versions of this regulatory guide are part of the licensing basis of the facility. However, unless this regulatory guide is part of the licensing basis for a facility, the staff may not represent to the licensee that the licensee's failure to comply with the positions in this regulatory guide constitutes a violation.

If an existing licensee voluntarily seeks a license amendment or change and (1) the NRC staff's consideration of the request involves a regulatory issue directly relevant to this new or revised regulatory guide and (2) the specific subject matter of this regulatory guide is an essential consideration in the staff's determination of the acceptability of the licensee's request, then the staff may request that the licensee either follow the guidance in this regulatory guide or provide an equivalent alternative process that demonstrates compliance with the underlying NRC regulatory requirements. This is not considered backfitting as defined in 10 CFR 50.109(a)(1) or a violation of any of the issue finality provisions in 10 CFR Part 52.

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<sup>1</sup> In this section, "licensees" refers to licensees of nuclear power plants under 10 CFR Parts 50 and 52; and the term "applicants," refers to applicants for licenses and permits for (or relating to) nuclear power plants under 10 CFR Parts 50 and 52, and applicants for standard design approvals and standard design certifications under 10 CFR Part 52.

<sup>2</sup> In this section, "voluntary" and "voluntarily" means that the licensee is seeking the action of its own accord, without the force of a legally binding requirement or an NRC representation of further licensing or enforcement action.

The NRC staff does not intend or approve any imposition or backfitting of the guidance in this regulatory guide. The NRC staff does not expect any existing licensee to use or commit to using the guidance in this regulatory guide, unless the licensee makes a change to its licensing basis. The NRC staff does not expect or plan to request licensees to voluntarily adopt this regulatory guide to resolve a generic regulatory issue. The NRC staff does not expect or plan to initiate NRC regulatory action that would require the use of this regulatory guide. Examples of such unplanned NRC regulatory actions include issuance of an order requiring the use of the regulatory guide, requests for information under 10 CFR 50.54(f) as to whether a licensee intends to commit to use of this regulatory guide, generic communication, or issuance of a rule requiring the use of this regulatory guide without further backfit consideration.

If a licensee believes that the NRC is either using this regulatory guide or requesting or requiring the licensee to implement the methods or processes in this regulatory guide in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfit appeal with the NRC in accordance with the guidance in NUREG-1409 and NRC Management Directive 8.4.

## REFERENCES

1. *U.S. Code of Federal Regulations (CFR) Title 10 “Energy”, Part 50, “Domestic Licensing of Production and Utilization Facilities,”* U.S. Nuclear Regulatory Commission, Washington, DC.<sup>3</sup>
2. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, Section III, “Rules for Construction of Nuclear Facility Components,” New York, NY, 1998 Edition or earlier.<sup>4</sup>
3. Regulatory Guide 1.190, “Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence,” U.S. Nuclear Regulatory Commission, Washington, DC, March 2001.
4. Nuclear Regulatory Commission (NRC), “Alternate Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events”, *Federal Register*, Vol. 75 p.13 (75 FR 13). Washington, DC. January 4, 2010.
5. NUREG-2163 (Draft), “Technical Basis for Regulatory Guidance on the Alternative PTS Rule (10 CFR 50.61a),” U.S. Nuclear Regulatory Commission, Washington, DC, November 2014.<sup>5</sup>
6. NUREG-1806, “Technical Basis for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10 CFR 50.61): Summary Report,” U.S. Nuclear Regulatory Commission, Washington, DC, August 2007.
7. ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” New York, NY, 2013 Edition.<sup>4</sup>
8. NUREG-1807, “Probabilistic Fracture Mechanics – Models, Parameters, Uncertainty Treatment Used in FAVOR Version 04.1,” U.S. Nuclear Regulatory Commission, Washington, DC, June 2007.
9. NUREG/CR-6854, ORNL/TM-2004/244, “Fracture Analysis of Vessels – Oak Ridge FAVOR, v04.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations,” U.S. Nuclear Regulatory Commission, Washington, DC, August 2007.
10. ORNL/TM-2012/566, “Fracture Analysis of Vessels – Oak Ridge FAVOR, v12.1, Computer Code: User’s Guide,” Oak Ridge National Laboratory, Oak Ridge, TN, November 2012.<sup>6</sup>

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<sup>3</sup> Publicly available NRC published documents are available electronically through the NRC Library on the NRC’s public Web site at: <http://www.nrc.gov/reading-rm/doc-collections/>. The documents can also be viewed on-line or printed for a fee in the NRC’s Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone 301-415-4737 or (800) 397-4209; fax (301) 415-3548; and e-mail [pdr.resource@nrc.gov](mailto:pdr.resource@nrc.gov).

<sup>4</sup> Copies may be purchased from the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990; phone (212) 591-8500; fax (212) 591-8501; [www.asme.org](http://www.asme.org).

<sup>5</sup> Available in Agencywide Documents Access and Management System (ADAMS) at Accession No. ML15058A677.

<sup>6</sup> Available in ADAMS at Accession No. ML13008A016.

11. NUREG/CR-6817, PNNL-14268, "A Generalized Procedure for Generating Flaw-Related Inputs for the FAVOR Code," U. S. Nuclear Regulatory Commission, Washington, DC, March 2004.
12. NUREG-1874, "Recommended Screening Limits for Pressurized Thermal Shock (PTS)," U. S. Nuclear Regulatory Commission, Washington, DC, March 2010.