Technical Basis for
RPV Upper Head Penetration Inspection Plan

Revision 0
June 20, 2002

Prepared for:
MRP PWR Alloy 600 Assessment Committee

Prepared by:
Peter C. Riccardella and Nathaniel G. Cofie
Structural Integrity Associates, Inc.

SUMMARY

This document presents the technical basis for a risk-informed inspection plan for Pressurized Water Reactor Vessel top heads to address Alloy 600 nozzle and associated weld metal cracking concerns.

Probabilistic Fracture Mechanics (PFM) analyses are described that predict the probability of leakage and failure versus plant operating time for various input parameters that bound the operating characteristics of the US PWR fleet. These include various head operating temperatures, inspection types (visual or non-visual NDE) and inspection intervals. The PFM algorithm includes an experience-based time to leakage correlation based on a Weibull model of plant inspections to date, fracture mechanics analyses of various nozzle configurations containing axial and circumferential cracks, and a statistical representation of crack growth rate data for Alloy 600. The model is benchmarked against the group of plants exhibiting the most severe cracking found to date in the industry (Babcock and Wilcox designed plants) and it produces results that are in agreement with experience to date at these plants. Its application to other plant designs, which have exhibited less severe cracking, is therefore conservative.

The benchmarked PFM model is then used to define susceptibility categories that are designed to keep the worst-case probability of nozzle failure within NRC Regulatory Guide 1.174 guidance for change in core damage frequency. This NRC guidance specifies an acceptable change in core damage frequency (1×10^{-6} per plant year) for changes in plant design parameters, technical specifications, etc. Therefore, the inspection plan is designed to limit the change in any plant's core damage frequency associated with RPV head penetration cracking to less than 1×10^{-6} per plant year. Since the probability of core damage given a nozzle failure (assuming that failure leads to ejection of the nozzle from the head) has been estimated to be 1×10^{-3}, and the probability of nozzle cracking resulting in nozzle ejection is maintained, by implementation of the inspection plan, to be no greater than 1×10^{-3}, the resulting

incremental change in core damage frequency under the plan is 1×10^{-6} (i.e., 1×10^{-3} times 1×10^{-3} equals 1×10^{-6}) per plant year. A comparison of the PFM results with those from deterministic analyses indicates that the risk-based inspection criteria are conservative.

The inspection plan is also designed to maintain the probability of nozzle leakage at an acceptably low level, to preclude head wastage problems. The technical basis for the inspection plan with respect to preventing reactor vessel head wastage is described in a separate document.

PROBABILISTIC FRACTURE MECHANICS

Development is underway of a generic Probabilistic Fracture Mechanics (PFM) methodology for Control Rod Drive Mechanism (CRDM) top head penetrations. The methodology has been fully developed for the most critical reactor type (Babcock & Wilcox designed plants) with respect to top head nozzle cracking based on field inspection results to date. Elements of the methodology include:

- Experience-based time to leakage computations that use a Weibull model of plant inspections to date.
- Fracture mechanics analyses of various nozzle configurations containing axial and circumferential cracks.
- Statistical crack growth rate (CGR) data for Alloy 600 material developed by the Materials Reliability Program (MRP) Expert Panel [1].
- A Monte-Carlo simulation algorithm to determine the probability of leakage versus time and the probability of nozzle ejection (Net Section Collapse or NSC) versus time for various sets of input parameters, including head operating temperature, inspection type (visual or NDE) and inspection intervals.

Details of this methodology are contained in Ref. [2].

The PFM methodology provides a means of evaluating various top head inspection options to determine their relative contributions to safe plant operation.

<u>Assumptions</u>

Several key assumptions are necessary to perform a CRDM PFM analysis with the MRP PFM methodology. These include Weibull parameters for time to leakage, CGR distribution type, correlation factors between time to leakage and crack growth rate, and probabilities of detection (PODs) for the various inspection types. Other required input includes number of CRDM nozzles and heats of nozzle material per head, nozzle angles, yield strengths, and nozzle-to-head shrink-fit conditions. Although this latter group is generally known for each specific plant, assumptions must be made on these parameters as well in order to conduct analyses that simulate the U.S. PWR fleet as a whole. For purposes of this analysis, reasonable values of these parameters were selected that are representative of B&W-designed plants, as summarized in Table 1. These are considered to be a conservative representation of U.S. PWRs as a whole, since the B&W plants have been seen to lead the U.S. fleet in terms of severity of cracking and leakage (7 out of 7 plants found to have leaking nozzles, several of which contained circumferential cracks). However, before proceeding with production analyses, these assumptions were benchmarked against actual performance of the B&W plants.

Table 1
Parameters Assumed for PFM Analysis

Weibull Parameters	Alpha	3
	Beta	15 ± 6 (Triang.)
CGR Distribution	Exponent	1.16
	Alpha (heat-to-heat)	-15.25 ± 2.212 (Log-Triang.)
	Alpha (within heat)	0 ± 1.6 (Log-Triang.)
Correlation Factors	Heat-to-Heat	0.8
	Within Heat	0.8
# Nozzles	69	
# Heats	3	
Nozzle Yield Strength	Normal	44.5 ksi; STD=1.5 ksi
Interference Fit	Normal	0.0003”; STD=0.0014”

Benchmarking of PFM Assumptions

The benchmark analysis results obtained with this particular set of assumptions for a B&W plant design are shown in Figure 1. This figure shows the cumulative probability of leakage, large circumferential cracking, and nozzle net section collapse (NSC) versus time for a plant analyzed with the assumptions listed in Table 1, operated at a 602°F head temperature (the approximate average head temperature for all B&W plants, which ranged from 601°F to 605°F). The results indicate a high probability of leakage (> 90%), and a moderate probability (~ 12%) of a large circumferential crack at 20.1 EFPY. These results are in agreement with experience, since all of the B&W plants experienced at least one leaking nozzle at about 20 EFPY, and one out of seven experienced a large circumferential crack. Thus, the above parameters are considered reasonable and conservative for evaluation of an inspection plan for the entire U.S. PWR fleet, since they are benchmarked against the worst performing group of plants in the fleet.

One final requirement for the evaluation is to specify limits on probability of leakage and net section collapse. Using the NRC guidance for risk-informed decisions [3], a value of 1×10^{-6} has been selected as an acceptable change in core damage frequency per year associated with the nozzle cracking issue. That is, an inspection program will be considered acceptable if it keeps the incremental core damage frequency associated with the CRDM nozzle cracking issue less than this limit for any plant in the fleet. Since the conditional core damage frequency given nozzle ejection (i.e. NSC) has been estimated at approximately 1×10^{-3}, it is assumed for purposes of this analysis that a plant enters the high-risk category when the probability of a nozzle NSC equals 1 x 10^{-3} per year. It will be seen that this limit also corresponds to a cumulative probability of leakage of ~75% if no inspections are performed up to that point.

To further reduce risk, a second, moderate-risk category is defined as the point when a plant enters a region where either the probability of nozzle NSC equals 1 x 10^{-4} per year or the cumulative probability of leakage reaches 20%.

PFM Results

Definition of Risk Categories

The results of the aforementioned PFM analyses are summarized in Figures 2 and 3. Referring to Figure 3, it is seen that the NSC curves intersect the 1 x 10^{-3} per year limit (upper dashed line) at decreasing times as the temperature increases from 560°F to the maximum of 605°F. These intersection points have been translated to a locus of EFPY versus temperature (upper red, chain-link curve) in Figure 4. Similar loci have been constructed from intersections with the lower dashed line in Figure 3 (probability of NSC = 1 x 10^{-4} per year) and from the intersections of the probability of leakage curves with the two dashed lines in Figure 2 (20% and 75% cumulative leakage probability). The lower NSC limit (1 x 10^{-4}) is shown as the brown chain-link curve in Figure 4. The leakage limits are shown by the two solid curves in Figure 4 (blue for 75% and orange for 20%). It is seen that there is reasonable correspondence between the two sets of curves. That is, both the upper and lower leakage and NSC curves lie close to one another, such that a single set of limits will address both risks. Plants that plot above and to the right of the upper two curves are considered to be in a high-risk category, since their probability of NSC would exceed 1 x 10^{-3} per year, and they would also have a 75% cumulative probability of leakage. Plants that plot between the upper and lower sets of curves are considered to be in a moderate risk category, since their probability of NSC would exceed 1 x 10^{-4} per year, and they would have a 20% cumulative probability of leakage. Plants that plot below and to the left of the bottom set of curves are considered to be at low-risk with respect to the CRDM nozzle cracking issue.

Also shown in Figure 4 are data points corresponding to plant inspections, along with the current head operating temperatures at each plant and an estimate of EFPY at the times of inspection. The red triangles represent the nine plants in which leakage has been detected (seven B&W plants and two Westinghouse plants). The yellow-filled squares represent the plants in which cracking (but no leakage) has been detected. The solid blue, diamond-shaped data-points represent plants that have performed visual examinations with no leakage detected, and the solid blue squares represent plants that have performed non-destructive examinations with no indications of cracking. Note that in some cases, multiple inspections have been performed at a given plant. These are identified in Figure 4 by vertical lines connecting the data-points for that plant.

It can be seen from these data that the proposed risk-based categorization curves line up well with plant inspection results to date. All of the inspections that resulted in either leakage or cracking lie in the moderate or high-risk regions, and all except one of the plants with leaks lie on or above the high-risk curve. The plant with large circumferential cracks (Oconee-3) was well into the high-risk region at the time the cracks were observed. Also shown are data-points corresponding to planned future inspections (Fall 2002 or Spring 2003). It is seen from these data that all plants in the high-risk region and the large majority of the plants in the moderate-risk region have been inspected at least once.

Finally, the curves and data-points from Figure 4 are re-plotted in Figure 5, along with several light-blue curves that represent various numbers of Effective Degradation Years (EDYs, or equivalent EFPYs at 600 F). EDYs are computed in accordance with the following activation energy equation (from Ref. 4):

$$EDY_{600°\mathrm{F}} = \sum_{j=1}^{n} \left\{ \Delta EFPY_j \exp\left[-\frac{Q_i}{R}\left(\frac{1}{T_{head,j}} - \frac{1}{T_{ref}} \right) \right] \right\} \quad [1]$$

where:

$EDY_{600°\mathrm{F}}$	=	total effective degradation years through February 2001, normalized to a reference temperature of 600°F
Q_i	=	activation energy for crack initiation (50 kcal/mole)
R	=	universal gas constant (1.103×10^{-3} kcal/mol-°R)
$T_{head,j}$	=	100% power head temp. during time period j (°R = °F + 459.67)
T_{ref}	=	arbitrary reference temperature (600°F = 1059.67°R)
n	=	number of different head temperatures during plant history

It is seen from Figure 5 that the risk categories defined above correspond to the following limits in terms of EDYs:

Low-Risk: $0 < \mathrm{EDYs} < 10$
Moderate-Risk: $10 \le \mathrm{EDYs} < 18$
High-Risk: $18 \le \mathrm{EDYs}$

Inspection Interval Sensitivity Studies

PFM analysis was also used to perform sensitivity studies of the effects of various inspection intervals for plants in the moderate and high-risk categories. These studies were all performed at an assumed head operating temperature of 600°F, so they yield results directly in EDYs, which can be translated to other operating temperatures via the above activation energy equation.

One additional assumption needed for the inspection interval studies is probability of detection (POD) for the two inspection types, bare metal visual (BMV) and non-destructive examination (NDE). For BMV, it was assumed that, if a penetration is leaking when the initial visual inspection is performed, there is a 60% probability that the leakage will be detected. For subsequent visual examinations of a penetration that was previously inspected but leakage was missed, the 60% POD is multiplied by a factor of 0.2, yielding a POD of 12% for repeat inspections. These conservatively low PODs, account for a combination of effects including tight shrink fit conditions, difficult accessibility for inspections and human error. For NDE, a previously developed curve for "Full-V" ultrasonic inspection of reactor vessels was obtained from Ref. 5, and then multiplied by a factor of 0.8. The resulting curve of POD versus crack depth, shown in Figure 6, is also considered to be conservative for the types of NDE currently being performed on CRDM nozzles.

Figure 7 illustrates the effect of BMV at various intervals, beginning when a plant first enters the High Risk category (18 EFPYs at 600°F = 18 EDYs). BMVs every 4 EDY, 2 EDY and at each refueling outage (RFO) were evaluated. It is seen that in all cases, the yearly probability of NSC, which is just approaching 1×10^{-3} at the time of initial inspection, is approximately halved immediately following the inspection. The curves for 2 and 4 EDY intervals increase after that, however, and after some period of time are predicted to again exceed the 1×10^{-3} limit. Inspection each RFO, on the other hand, reduces the probability of net section collapse below the 1×10^{-3} limit throughout the time period analyzed.

Figure 8 presents similar results for NDE beginning when a plant first enters the high-risk category, considering inspection intervals of 4 and 8 EDY. It is seen that, for the POD assumed, NDE at 4 EDY intervals is even more effective than BMV each RFO at reducing the probability of NSC to an acceptable level, and keeping it there indefinitely. NDE at 8 EDY intervals is less effective, and does allow the probability to re-approach 1×10^{-3} between inspections.

Finally, Figure 9 illustrates that the recommended inspections for plants in the Moderate category (BMV at 2 EDY or NDE at 4 EDY intervals) are more than adequate to maintain the probabilities of NSC at acceptable levels for the time period until the plants reach the high risk category. These inspections provide an extra measure of assurance, which would not be required just based on the PFM analysis by itself, to keep the probability of NSC of the entire PWR fleet at an extremely low level.

DETERMINISTIC CRACK GROWTH ANALYSIS

A deterministic crack growth evaluation has also been performed to determine the time it will take for an assumed initial circumferential flaw to reach the ASME Code Section XI allowable through-wall length. Inputs into this deterministic analysis include crack growth law, stress intensity factor versus flaw length distribution and assumed initial flaw size. Each of these inputs is described in the following paragraphs.

<u>Crack Growth Law for Alloy 600</u>

Reference 1 provides the MRP recommended curve to be used to evaluate growth of SCC flaws in Alloy 600 materials, such as RHV nozzle and is given by:

$$\dot{a} = \exp\left[-\frac{Q_g}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]\alpha\left(K - K_{th}\right)^{\beta} \tag{2}$$

where:

$\dot{a}$ = crack growth rate at temperature T in m/s (or in/yr)

Q_g = thermal activation energy for crack growth

= 130 kJ/mole (31.0 kcal/mole)

R = universal gas constant

= 8.314 x 10^{-3} kJ/mole·K (1.103□10^{-3} kcal/mole·°R)

T = absolute operating temperature at location of crack, K (or °R)

T_{ref} = absolute reference temperature used to normalize data

= 598.15 K (1076.67°R)

α = crack growth amplitude

= 2.89 x 10^{-12} at 325°C for $\dot{a}$ in units of m/s and K in units of MPa$\sqrt{\text{m}}$ (4.00 x 10^{-3} at 617°F for $\dot{a}$ in units of in/yr and K in units of ksi$\sqrt{\text{in}}$)

K = crack tip stress intensity factor, MPa$\sqrt{\text{m}}$ (or ksi$\sqrt{\text{in}}$)

K_{th} = crack tip stress intensity factor threshold

= 9 MPa$\sqrt{\text{m}}$ (8.19 ksi$\sqrt{\text{in}}$)

β = exponent

= 1.16

This curve represents the 75th percentile level of the CGR data contained in Reference 1. Furthermore, for deterministic analysis, the MRP recommends a factor of two be applied to the above crack growth law. The MRP equation, including the factor of two can be written in a simpler form, as:

$$\frac{da}{dt} = C(K - 8.19)^{1.16} \quad in/hr \tag{3}$$

where:

K is the stress intensity factor ($ksi\sqrt{in}$)

C is a parameter which is a function of temperature and whose values are indicated in Table 2.

Table 2
Value of Parameter C for Deterministic Analysis as a Function of Temperature

Temperature (ºF)	C
580	3.604×10^{-7}
590	4.665×10^{-7}
600	6.008×10^{-7}
602	6.316×10^{-7}
605	6.806×10^{-7}

<u>Stress Intensity Factor Distribution</u>

In previous work done to support the MRP risk assessment, the stress intensity factor (K) for circumferential flaws of two plant types was determined. This information is shown in Tables 3 and 4. As can be seen from these tables, K is a strong function of the nozzle angle. For this deterministic evaluation, the most conservative nozzle angle location (38º for the B&W-type plants and 43.5º for the Westinghouse-type plant) is used. It can be seen further from these tables that K is also dependent on whether the crack is in the uphill or downhill direction. The uphill direction, being the most conservative distribution of the two, is used in this deterministic evaluation for B&W plants. For Westinghouse plants, the conservative downhill distribution is used. Although generic analyses have not yet been performed for Combustion Engineering designed plants, the stress intensity factors in Tables 3 and 4 are considered to be representative of the bounding CEDM nozzles in this plant design.

Table 3
Typical Stress Intensity Factor Distribution for B&W-Type Plant

Nozzle Angle	Circumferential Crack Length		Stress Intensity Factor (ksi*(in)$^{1/2}$)	
	Degrees	Inches	Uphill	Downhill
0°	30	0.9664	20.8	N/A
	70	2.2550	18.8	N/A
	160	5.1540	20.3	N/A
	180	5.3140	0.64	N/A
	220	6.4950	0.63	N/A
	260	7.6760	0.63	N/A
	300	8.8570	0.62	N/A
18°	30	1.0170	27.2	27.2
	70	2.3730	24.0	24.0
	160	5.4240	24.5	24.5
	180	5.5920	23.4	1.0
	220	6.8350	23.8	2.4
	260	8.0770	26.9	6.0
	300	9.3200	26.5	11.5
26°	30	1.0830	29.7	29.7
	70	2.5260	26.1	26.1
	160	5.7750	26.5	26.5
	180	5.9530	28.4	0.4
	220	7.2760	23.2	1.7
	260	8.5990	23.6	7.5
	300	9.9220	24.9	16.6
38°	30	1.2380	34.4	34.4
	70	2.8830	27.1	27.1
	160	6.6020	29.2	29.2
	180	6.8060	37.7	4.5
	220	8.3190	31.2	6.7
	260	9.8310	26.6	12.7
	300	11.3440	29.9	25.9

Table 4
Typical Stress Intensity Factor Distribution for Westinghouse-Type Plant

Nozzle Angle	Circumferential Crack Length		Stress Intensity Factor (ksi*(in)$^{1/2}$)	
	Degrees	Inches	Uphill	Downhill
0°	30	0.9653	20.8	N/A
	70	2.2525	18.8	N/A
	160	5.1487	20.3	N/A
	180	5.3014	0.64	N/A
	220	6.4790	0.63	N/A
	260	7.6576	0.63	N/A
	300	8.8357	0.62	N/A
13.6°	30	0.9793	27.2	27.2
	70	2.2851	24.0	24.0
	160	5.2232	24.5	24.5
	180	5.3782	6.9	28.3
	220	6.5733	10.1	29.7
	260	7.7684	12.4	29.8
	300	8.9636	16.7	28.7
30°	30	1.0413	29.7	29.7
	70	2.4299	26.1	26.1
	160	5.5541	26.5	26.5
	180	5.7188	6.9	37.2
	220	6.9897	8.0	39.8
	260	8.2605	11.7	41.3
	300	9.5314	18.5	41.0
43.5°	30	1.1554	34.4	34.4
	70	2.6959	27.1	27.1
	160	6.1622	29.2	29.2
	180	6.3449	14.8	47.2
	220	7.7549	13.5	51.9
	260	9.1649	16.7	58.1
	300	10.5749	23.8	63.7

Initial Flaw Size and Allowable Flaw Size

The initial flaw size for this evaluation is assumed to be a through-wall circumferential flaw that is 30 degrees of the circumference, corresponding to the first crack length for which a K value is provided in Tables 3 and 4. This assumed initial crack length is very conservative and should provide a conservative estimate of time to reach allowable flaw size.

From Reference 4, the allowable flaw size based on a safety factor of 3, consistent with ASME Code Section XI, is about 300º of the circumference. This allowable flaw size is used in the evaluation.

Crack Growth Evaluation and Results

The evaluation is performed separately for the two plant types. The temperatures, as shown in Table 2, were considered in the crack growth evaluation using the input parameters discussed above. The results of the evaluation are shown in Figures 10 and 11, and are summarized in Table 5.

It can be seen that in the worst case corresponding to a temperature of 605ºF, the time for an initial 30º flaw to reach the allowable flaw size is 24.3 EFPY for B&W plant-type, and 16.8 EFPY for the Westinghouse plant-type. For reference, the time to reach Oconee Unit 3 type flaw (165º) is also noted. For a B&W plant at 605ºF, it takes 13.4 EFPY to reach this flaw size, while for a Westinghouse-type plant, it takes 12.5 years.

Table 5
Summary of Deterministic Crack Growth Results

Temperature (ºF)	Time for Initial Flaw Size of 30º Circumference to Grow to 165º and Allowable Flaw Size of 300º (EFPY)			
	B&W-Type Plants		Westinghouse-Type Plant	
	165º	300º	165º	300º
580	25.3	>40	23.7	31.7
590	19.6	35.3	18.3	24.6
600	15.2	27.3	14.2	19.1
602	14.4	26.0	13.5	18.2
605	13.4	24.3	12.5	16.8

Referring to Figure 12, the deterministic crack growth times reported in Table 5 for the Westinghouse-type plant were added to the lower, 20% probability of leakage curve in Figure 4. This equates to the amount of time, conservatively, that a crack would require to grow from the initial assumed size at leakage (30°) to the allowable flaw size of 300°. It is seen that these times exceed the high-risk curve from the risk-based analysis, indicating that the risk-based limits are conservative with respect to deterministic crack growth analysis.

REFERENCES

1. MRP-55, “Crack Growth Rates for Evaluating Primary Water Stress Corrosion (PWSCC) of Thick-Wall Alloy 600 Material” (Draft), Materials Reliability Program (MRP), February 6, 2002.
2. S.S. Tang and P. C. Riccardella, “M R P E R C R D Evaluation of Reliability for Control Rod Drive Nozzles in Vessel Top Head” Materials Reliability Program, Structural Integrity Report (Draft), January 2002.
3. NRC Reg. Guide 1.174. “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Current Licensing Basis,” U.S. Nuclear Regulatory Commission, January 1998.
4. PWR Materials Reliability Report, “Interim Alloy 600 Safety Assessments for US PWR Plants (MRP-44), Part 2: Reactor Vessel Top Head Penetrations,” EPRI Report No. TP-1001491, Part 2, May 2001
5. Dimitrijevic, V. and Ammirato, F., “Use of Nondestructive Evaluation Data to Improve Analysis of Reactor Pressure Vessel Integrity, “ EPRI Report TR-102074, Yankee Atomic Electric Co. March 1993

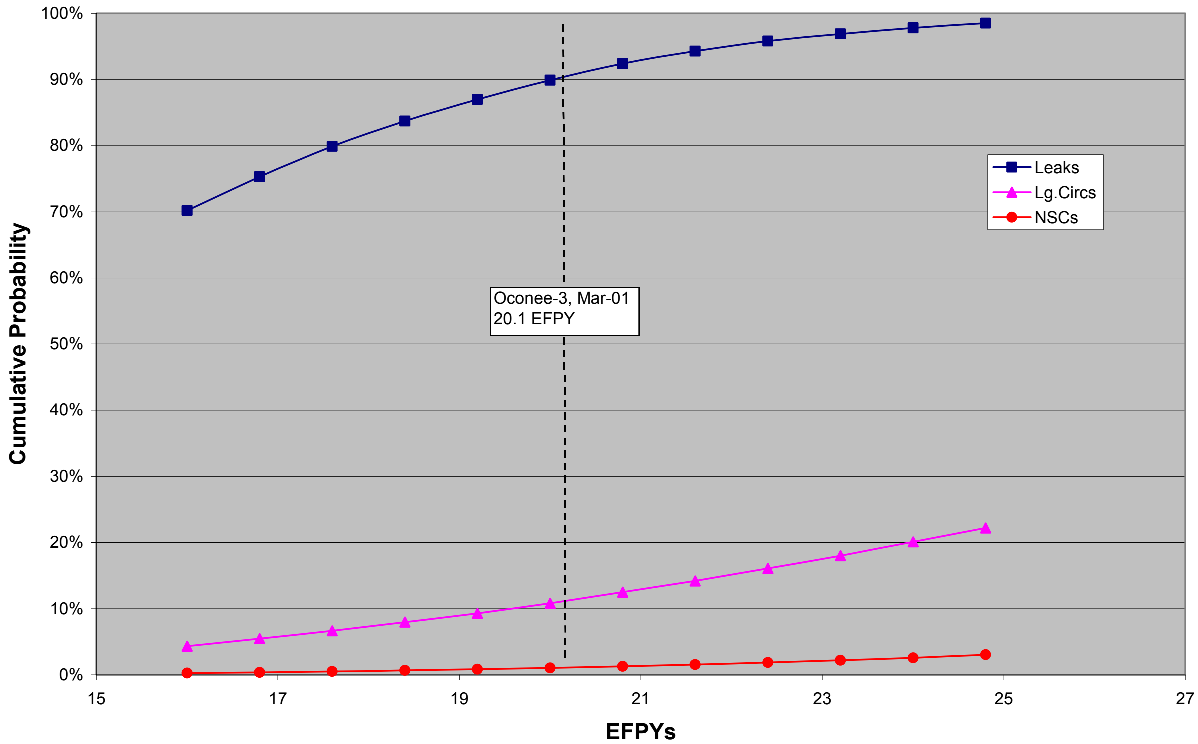

Figure 1. Results of PFM Calibration Analysis at 602°F Showing Comparison to Oconee-3 Inspection Results

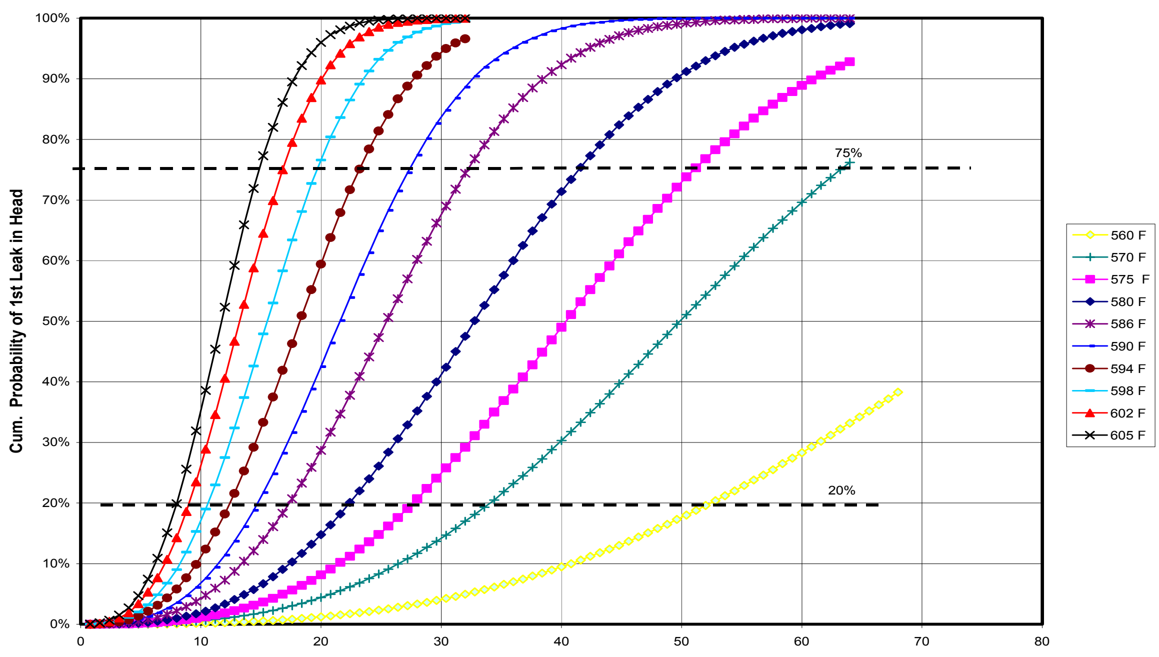

Figure 2. Cumulative Probability of Leakage versus Time for Various Head Temperatures

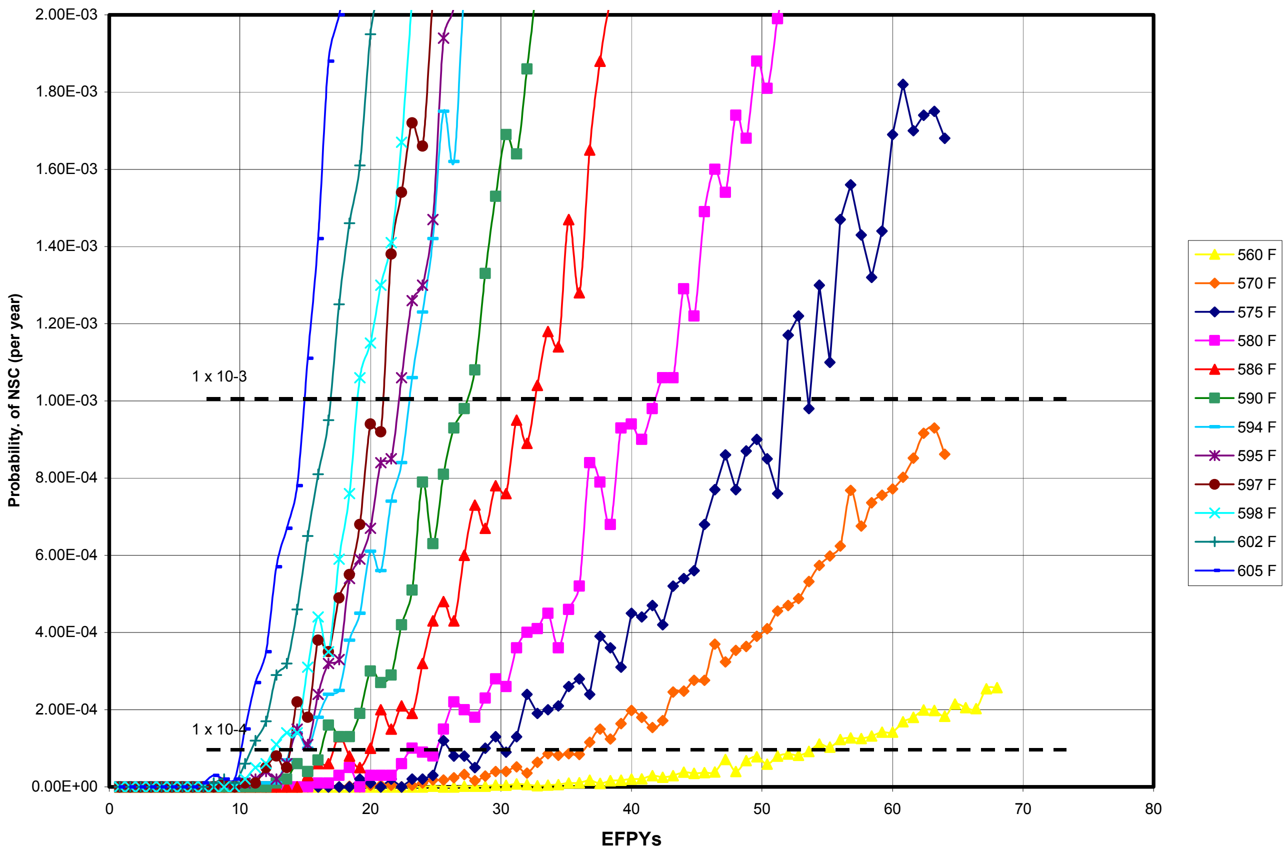

Figure 3. Probability Density (per year) of Net Section Collapse versus Time for Various Head Temperatures

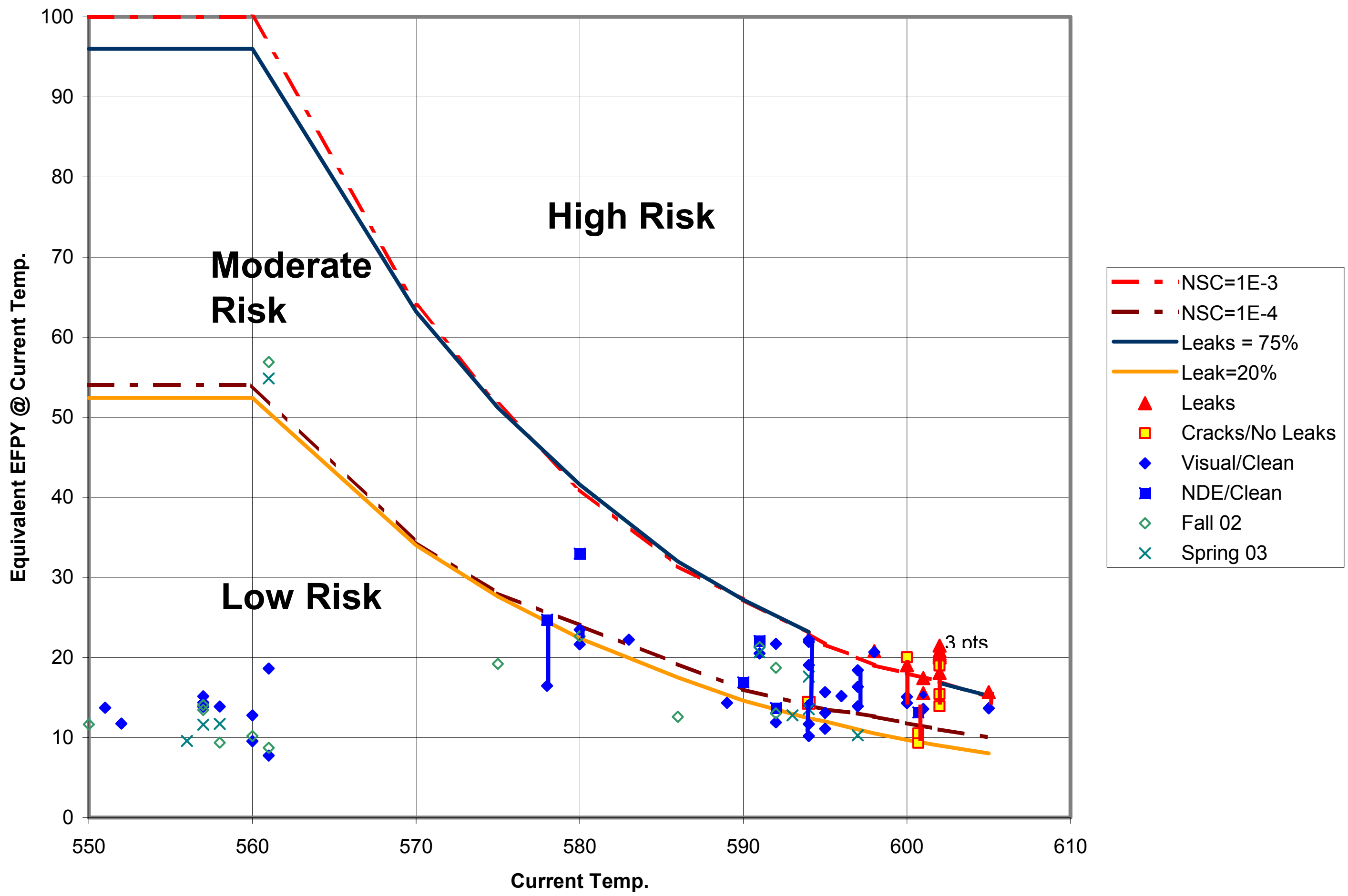

Figure 4. Definition of Low, Moderate, and High Risk Time-Temperature Regimes Based on PFM Results. Plant Inspection Results Also Indicated

Notes Regarding Plant Data in Figure:

1. Vertical lines connecting the data points for a given plant indicate multiple inspections at that plant.
2. For plants that have operated at more than one head temperature, the EFPYs have been normalized to the current temperature (per Equation 1), and the data points have been plotted at that temperature.

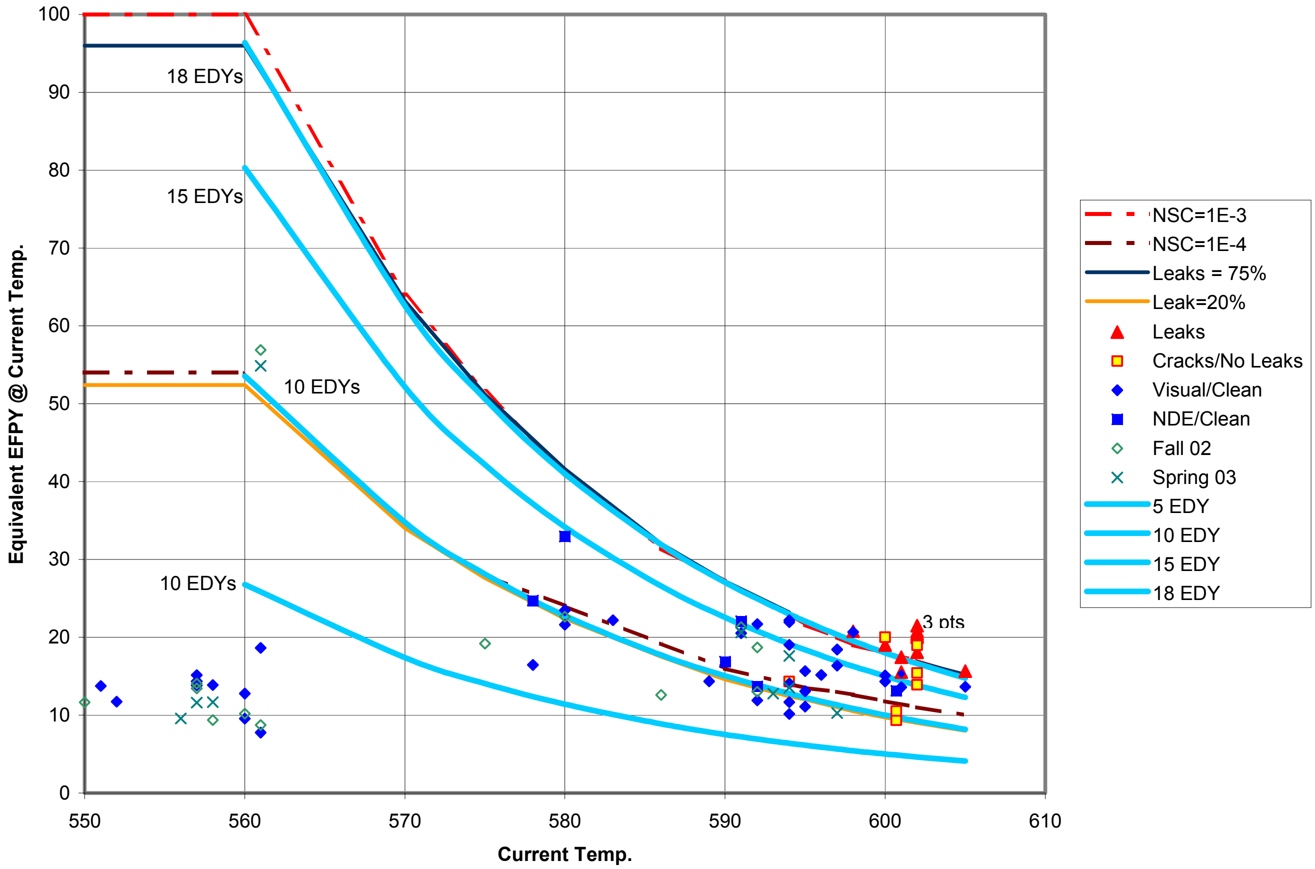

Figure 5. Correspondence of Time-Temperature Regimes Based on PFM Results to Effective Degradation Years

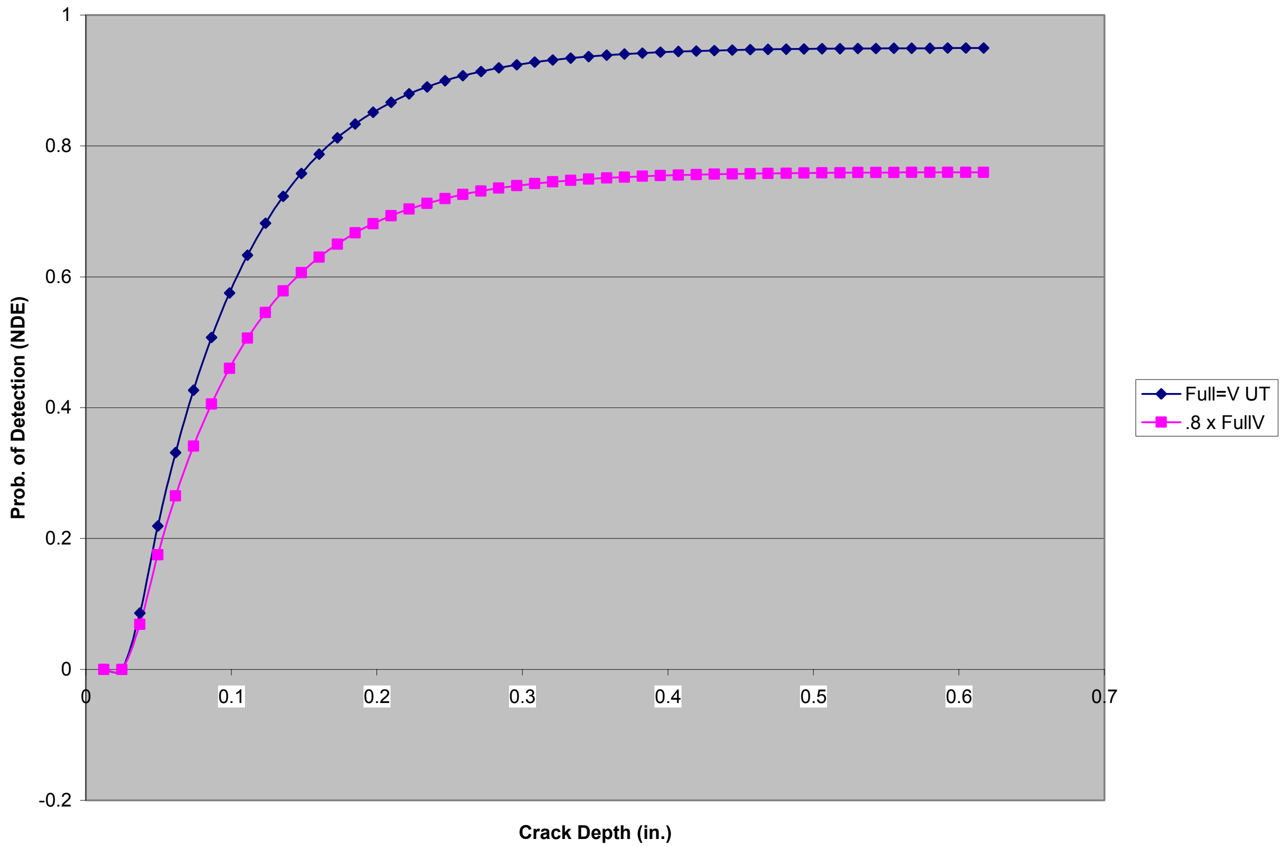

Figure 6 – Probability of Detection Curves for Non-Destructive Examination

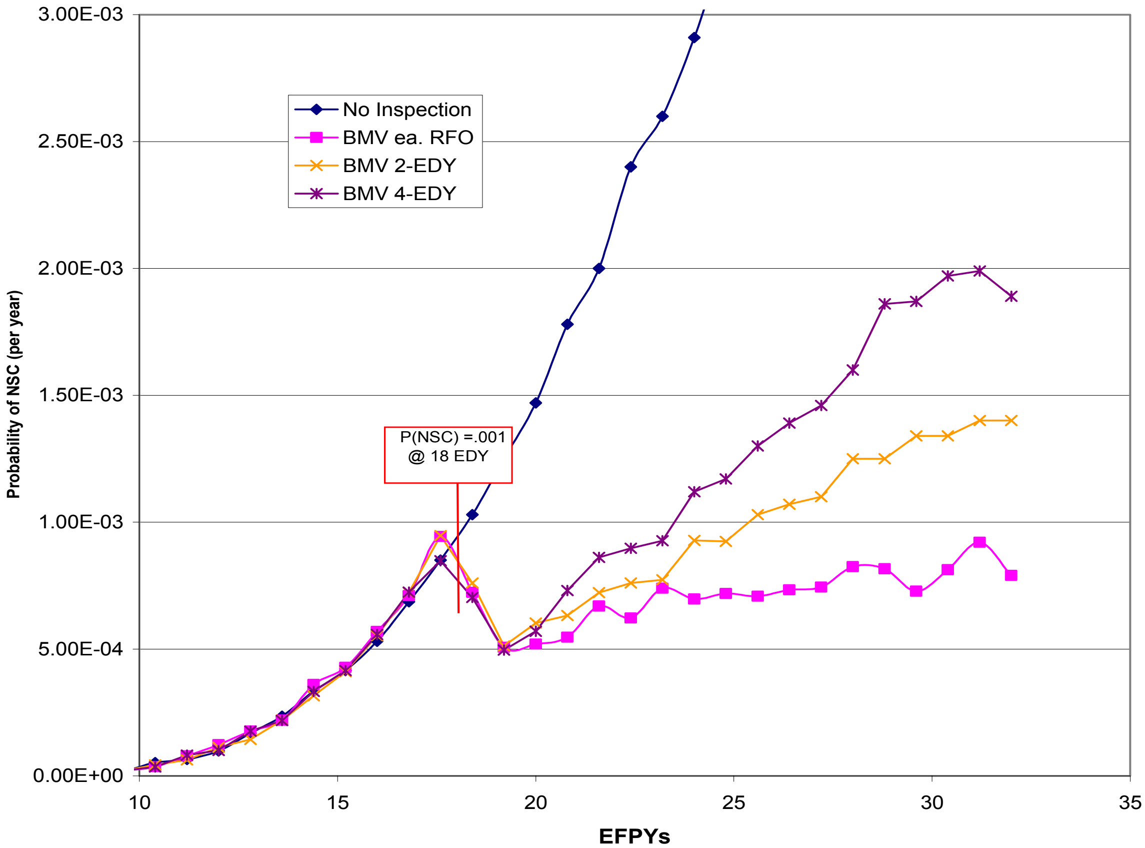

Figure 7 – Effect of Bare Metal Visual Inspection on Net Section Collapse Probability for Plants in the High Risk Inspection Category (Analysis run at 600°F)

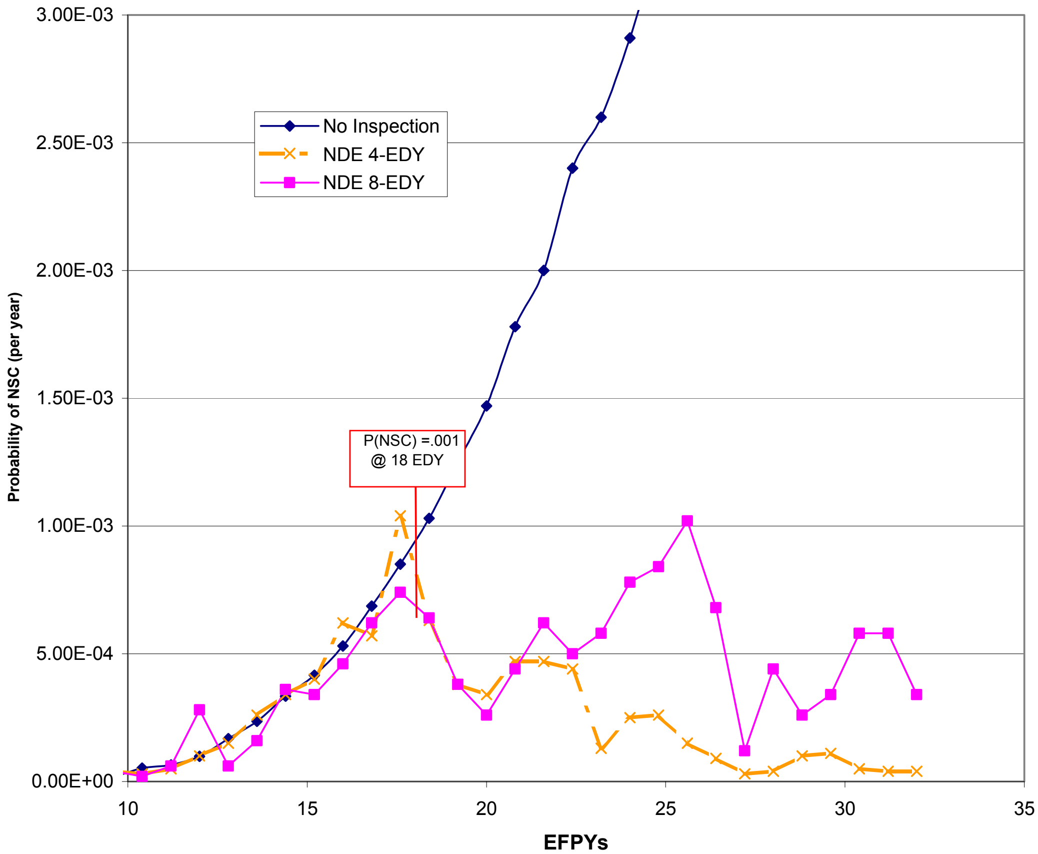

Figure 8 – Effect of Non-Destructive Examination on Net Section Collapse Probability for Plants in the High Risk Inspection Category (Analysis run at 600°F)

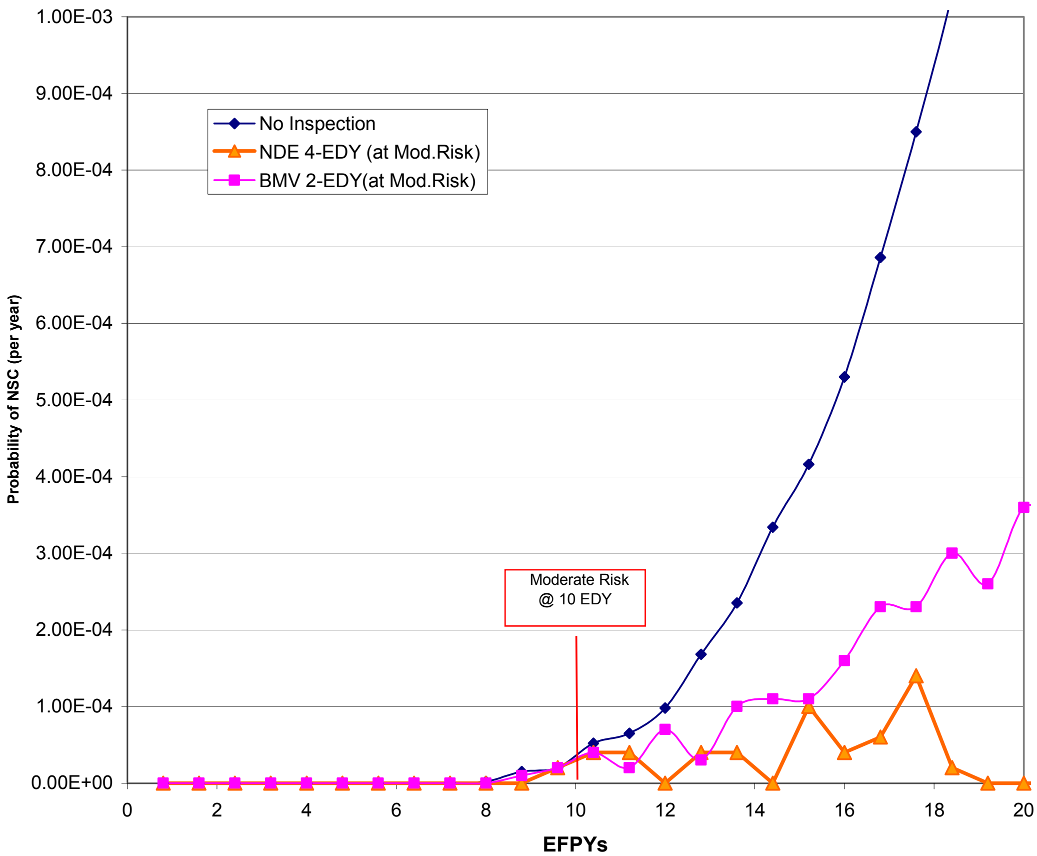

Figure 9 – Effect of Recommended Inspections on Net Section Collapse Probability for Plants in the Moderate Risk Inspection Category (Analysis run at 600°F)

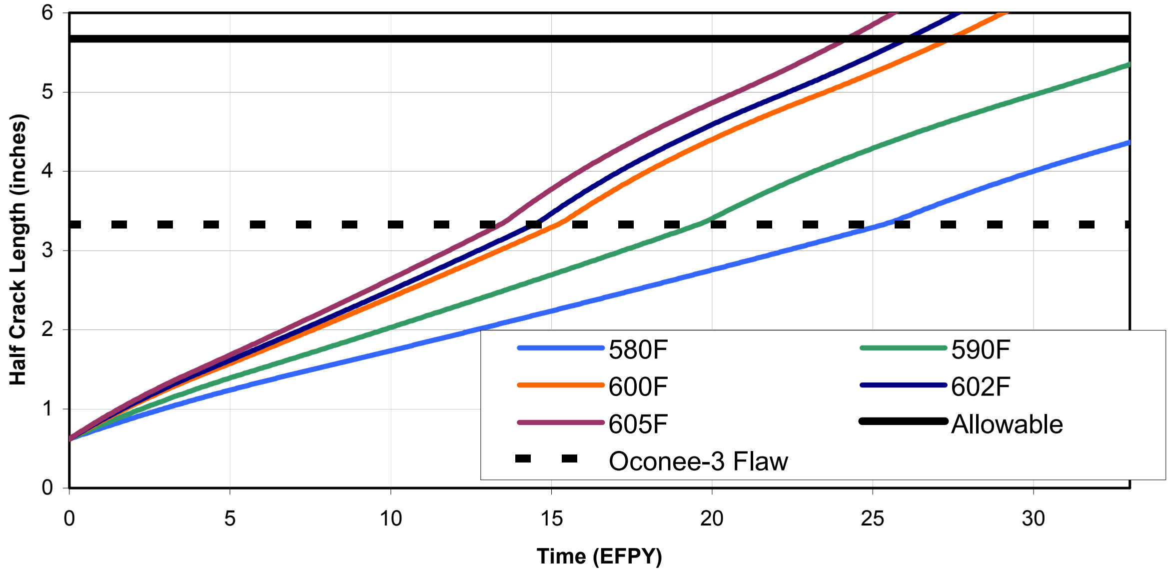

Figure 10 – Results of Deterministic Crack Growth Evaluation for B&W-Type Plant

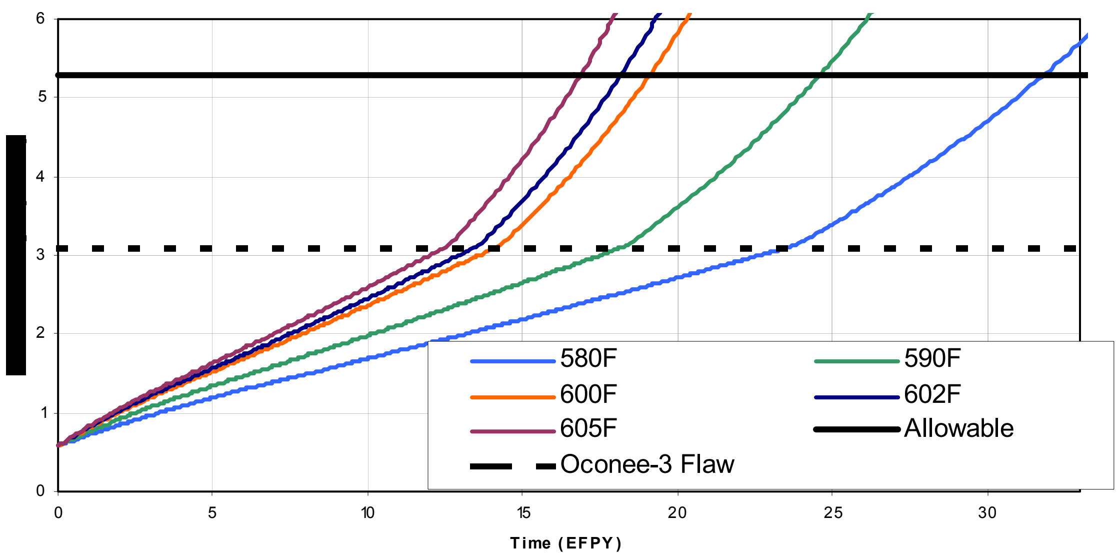

Figure 11 – Results of Deterministic Crack Growth Evaluation for Westinghouse-Type Plant

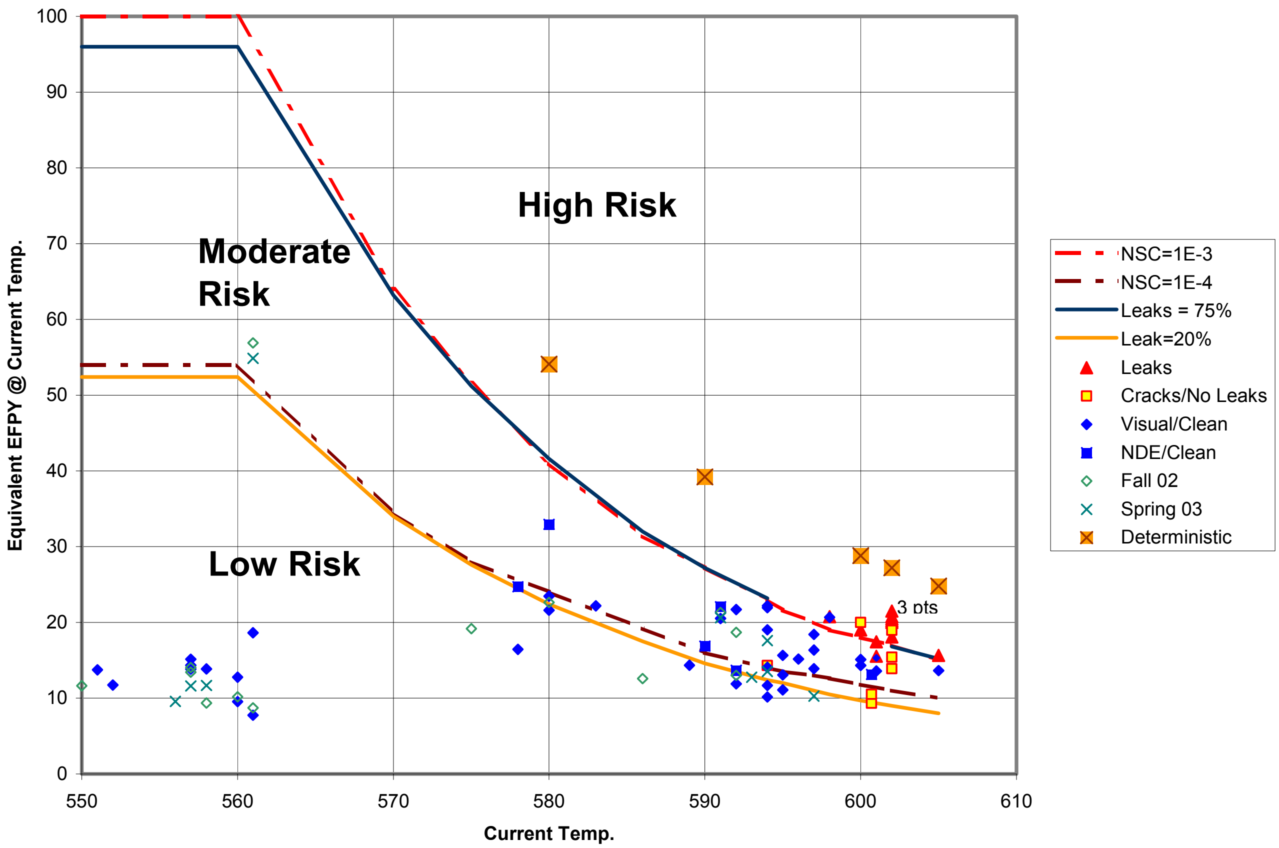

Figure 12 – Deterministic Crack Growth Results for Westinghouse-Type Plant Added to Figure 4, Illustrating Conservatism of Risk-Based Limits