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# Probabilistic Fracture Mechanics Analysis of CRDM Inspection Alternatives at Point Beach Unit 1

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## 1.0 INTRODUCTION

NMC experienced some limitations in inspection coverage in implementing RPV top head inspections during the Fall 2002 refueling outage (RFO) at Point Beach Unit 1. The steep curvature of the head at the outer row of CRDM nozzles resulted in an inability to obtain complete coverage with the UT blade probe used to perform nozzle inspections between the thermal sleeves and nozzles. In some nozzles, thermal sleeves were removed to allow full access to the tube material for inspection with a rotating UT probe instead of the blade probe. Removal and eventual re-welding of thermal sleeves is a time consuming and dose intensive operation. In some outer row nozzles, for which the blade probe could access at least 50% of the nozzle circumference for inspection, NRC agreement to not remove the thermal sleeves was obtained.

Subsequent to the RFO, it was discovered that there had been some slippage of the rotating probe UT system, such that 100% coverage was not achieved, even for the nozzles in which thermal sleeves were removed. It is conservatively estimated in this report that only 82% of the total nozzle circumferential lengths were completely inspected in the Fall 2002 inspections.

Although the UT blade probe has been improved, and subsequent inspections of the Point Beach Unit 2 CRDM nozzles achieved full coverage without removal of sleeves, it is anticipated that unit-specific differences may result in a repeat of the inability to achieve full inspection coverage in the upcoming Spring 2004 inspections of Point Beach Unit 1. Because of the high dose nature of the thermal sleeve removal and re-welding process (> 3 REM/nozzle in the Fall 2002 inspections), NMC has authorized this analysis to determine the expected safety impact of not removing thermal sleeves, and thus performing less than 100% inspections, should that eventuality arise. This option would require relaxation to NRC Order EA-03-09 [1].

The analysis utilizes a probabilistic fracture mechanics (PFM) tool developed over the past two years by the PWR Materials Reliability Program (MRP) [2]. The PFM tool incorporates the following major elements:

- computation of applied stress intensity factors for circumferential cracks in nozzles of various angles in the head as a function of crack length,
- determination of critical circumferential flaw sizes for nozzle failure,
- an empirical (Weibull) analysis of the probability of nozzle cracking or leakage as a function of operating time and temperature of the RPV head,
- statistical analysis of PWSCC crack growth rates in the PWR primary water environment as a function of applied stress intensity factor and service temperature, and
- determination of the effects of inspections (inspection type, frequency, coverage and effectiveness),

to compute plant specific probabilities of nozzle leakage and failure (i.e. nozzle ejection from the head) as a function of operating time and head temperature under various head inspection scenarios.

The MRP tool (*MRPERCRD*) has been applied to the Point Beach Unit 1 head inspections considering plant specific parameters such as head geometry, number of nozzles, head temperature, plant operating time and various levels of inspection coverage, to determine

**whether a significant improvement in plant safety (in terms of probability of nozzle leakage or failure) would be achieved by increased levels of nozzle inspection coverage.**

## 2.0 OVERVIEW OF MRP PFM TOOL

Figure 2-1 presents a flow chart of the probabilistic fracture mechanics methodology developed for the MRP [2]. The methodology has been implemented in the computer program *MRPERCRD*. The methodology implements a time-dependent Monte Carlo analysis scheme which predicts the probability of leakage and nozzle ejection versus time for a specific set of top head parameters. Deterministic parameters specific to the top head being analyzed include number of nozzles, the angle of each nozzle with respect to the head, nozzle diameter and wall thickness, number of heats of nozzle material, and identification of which nozzles are from which heat. Another plant-specific input consists of K-matrices for each of several nozzle angles. These are matrices of stress intensity factor versus crack length for several characteristic nozzle angles (usually four) into which the nozzles are lumped based on their angle. The K-matrices are obtained from deterministic fracture mechanics analyses of the specific head geometry and may include stress intensity factor data for ranges of nozzle yield strengths and nozzle-to-vessel interference fits, for cracks centered at both the uphill and downhill sides of the nozzles.

Statistical parameters (random variables) utilized in the Monte Carlo analysis include:

- head operating temperature
- yield strengths for each heat of nozzle material
- nozzle interferences (or gaps)
- number of assumed cracks per nozzle (for NDE detection)
- initial crack size (for NDE detection)
- distribution of crack locations (uphill or downhill)
- Weibull distribution of time to leakage or cracking (dependent on plant operating time and head temperature)
- stress corrosion crack growth law
- correlation factor between time to crack initiation and crack growth, and
- critical crack size for each characteristic nozzle angle.

The statistical parameters are input as distribution type (normal, triangular, log –normal, log-triangular, Poisson, Weibull, etc.), mean and standard deviation or range. As illustrated in Figure 2-1, the analysis algorithm consists of two nested Monte Carlo simulation loops, which step through time for each nozzle in a head, and then for the total number of head simulations specified. For each nozzle simulation, a time to leakage (or cracking) is predicted based on the Weibull distribution. When leakage is predicted, a circumferential through-wall crack equal to 30° of nozzle circumference is conservatively assumed to exist. The assumed circumferential crack is then grown based on the nozzle-specific stress intensity factor and a stress corrosion crack growth law obtained from random sampling of the statistical crack growth law distribution. The crack growth analysis for each nozzle continues until either the end of the evaluation period, or until the crack length reaches the critical flaw size for that nozzle (established based on random sampling of the critical crack size distribution). The analysis is repeated for each nozzle in the head, and then for the total number of top head simulations specified by the user. The software records the total number of top heads predicted to experience at least one nozzle leak or failure as a function of operating time, as well as the total number of nozzles with predicted leaks or failures versus time. The probability of a nozzle leak or failure at a given time is the ratio of the number of top heads predicted to have leaks or failures divided by the total number of top heads simulated.

A correlation factor between crack initiation and crack growth is included as a user input, which allows one to simulate an inter-relationship between the time to initiation and the crack growth rate for each nozzle. A high negative correlation factor (-0.9 or -1) implies that a material heat that tends to be bad from the perspective of crack initiation (i.e. leaks early in life) would also have a high crack growth rate. A correlation factor of 0 implies no correlation.

The program also permits the user to specify inspections performed at various times within the analysis interval. Either visual inspections (for leakage) or non-destructive examinations (for cracking) or combinations thereof may be specified. The user also specifies inspection coverage (% of nozzles inspected) and reliability for each inspection (probability of detecting a leak if it exists in a visual examination or probability of detection versus crack depth for a non-destructive examination). When inspections are performed, cracks in nozzles that are predicted to be detected are removed from the simulation, and are no longer considered threats to grow to leakage or failure. One can thus perform multiple analyses, with and without various forms of inspection, at various intervals, to compare the probabilities of leakage and failure, and thus evaluate the effectiveness of different inspection options.

Figure 2-2 illustrates the probability of detection (POD) curve used for top head ultrasonic inspections, and a comparison to vendor demonstration programs on cracked nozzles. The POD curve, obtained from Ref. [3], indicates a very low probability of detection for very small cracks, for which the two NDE vendors missed about half of the cracks in the demonstration samples. As the crack depths get larger (greater than 0.15") however, the vendors detected all cracks in the samples. For this crack size, the POD curve predicts about a 75% probability of detection. The POD curve continues to increase with increasing crack depth, approaching a maximum POD of 95% for crack depths of 0.35", about half of the typical CRDM nozzle wall thickness. (The program assumes at least 5% chance of missing a crack no matter how deep.)

The *MRPERCRD* methodology has been benchmarked and calibrated with respect to field inspection results, both in terms of predicted nozzle leakage and the occurrence of circumferential cracks. Figure 2-3 presents a comparison of *MRPERCRD* predictions with plants that have observed leakage or significant cracking in CRDM nozzles. The data points represent the time to first leakage or cracking distribution for the fourteen U.S. plants that have experienced leaking or cracking. The solid curve represents the *MRPERCRD* Monte Carlo prediction of time to first leakage for the base case parameters. The horizontal scale on this plot is EFPYs at 600°F, or EDYs, which is consistent with the plant data since they too are normalized to 600°F (EDYs). The agreement is quite good. The dashed curve in Figure 2-3 is the leakage prediction corresponding to a set of benchmarked parameters developed from the circumferential crack comparison (see discussion below). It is seen that switching from base case to benchmarked parameters doesn't have a strong effect on the leakage predictions, so the dashed curve is a little more conservative, but still in reasonable agreement with the field leakage data.

Table 2-1 contains data from the eleven nozzles in U.S. plants that were found to have circumferential cracking, sorted in order of increasing crack length. The nozzles were sorted into bins of 30° crack length increments, and the bins were summed as shown in column 4 of the table. There were 11 total cracks of length greater than 30°, seven of length greater than 60°, and so on, down to two of length greater than 150°.

Table 2-1. Benchmarking of PFM Model with Respect to Nozzles with Circumferential Cracks

| **Plant Data** | | | | | ***MRPERCRD* Results** | | | |
|---|---|---|---|---|---|---|---|---|
| Circ. Crack Lengths (°) | # Nozzles | Cumulative # of nozzles w/Crack Length Greater Than: | | Frequency (881 Inspected) | Base Case | Correlation Factor =-1 | Conservative θ and Corr. Factor = -1 | Ultimate Sensitivity Case |
| 30-60 | 4 | 30 | 11 | $1.25 \times 10^{-2}$ | $2.24 \times 10^{-2}$ | $2.24 \times 10^{-2}$ | $3.17 \times 10^{-2}$ | $1.01 \times 10^{-1}$ |
| 60-90 | 1 | 60 | 7 | $7.95 \times 10^{-3}$ | $2.94 \times 10^{-3}$ | $3.94 \times 10^{-3}$ | $6.40 \times 10^{-3}$ | $9.19 \times 10^{-3}$ |
| 90-120 | 3 | 90 | 6 | $6.81 \times 10^{-3}$ | $1.62 \times 10^{-3}$ | $2.30 \times 10^{-3}$ | $3.87 \times 10^{-3}$ | $5.14 \times 10^{-3}$ |
| 120-150 | 1 | 120 | 3 | $3.41 \times 10^{-3}$ | $1.19 \times 10^{-3}$ | $1.66 \times 10^{-3}$ | $2.81 \times 10^{-3}$ | $3.49 \times 10^{-3}$ |
| 150-180 | 2 | 150 | 2 | $2.27 \times 10^{-3}$ | $8.98 \times 10^{-4}$ | $1.36 \times 10^{-3}$ | $2.25 \times 10^{-3}$ | $2.74 \times 10^{-3}$ |
| | | Predicted Collapse: | 0.5 | $5.68 \times 10^{-4}$ | $3.97 \times 10^{-4}$ | $6.54 \times 10^{-4}$ | $1.09 \times 10^{-3}$ | $1.23 \times 10^{-3}$ |

The group of plants containing these circumferential cracks had an average age of 19.75 EDYs at the time of inspection (very close to 20 EDYs). A total of 881 nozzles in plants of this age have been inspected. Thus 881 was used as a denominator to compute frequency of occurrence of circumferential cracks exceeding the various crack lengths in column 5 of Table 2-1. Finally, columns 6-9 of the table present *MRPERCRD* predictions of cumulative probabilities of cracking at twenty years, computed on a per nozzle (rather than a per head) basis. It is seen from these results that, except for the probability of a 30° crack, the base case consistently under predicts the probabilities of large circumferential cracks by about a factor of 2 to 4. The remaining columns contain *MRPERCRD* analysis results with increasingly conservative input parameters. The first step was to change the crack growth to initiation correlation factor to -1.0. This increased the circumferential crack probabilities somewhat, but they still under-predict the cumulative distribution from the plant data. In the next column, a combination of correlation factor =-1 plus a more conservative Weibull θ distribution was assumed (triangular with θ-mean = 15.2, ±6.5). This gave the best general comparison of circumferential crack probabilities, over-predicting at some crack lengths, under-predicting at others, and agreeing almost exactly at the largest crack length (>150°). This case was therefore designated as the "benchmarked" parameters, and that column of Table 2-1 is highlighted. These benchmarked parameters were used for the plant specific evaluation of Point Beach Unit 1, discussed in the following section.

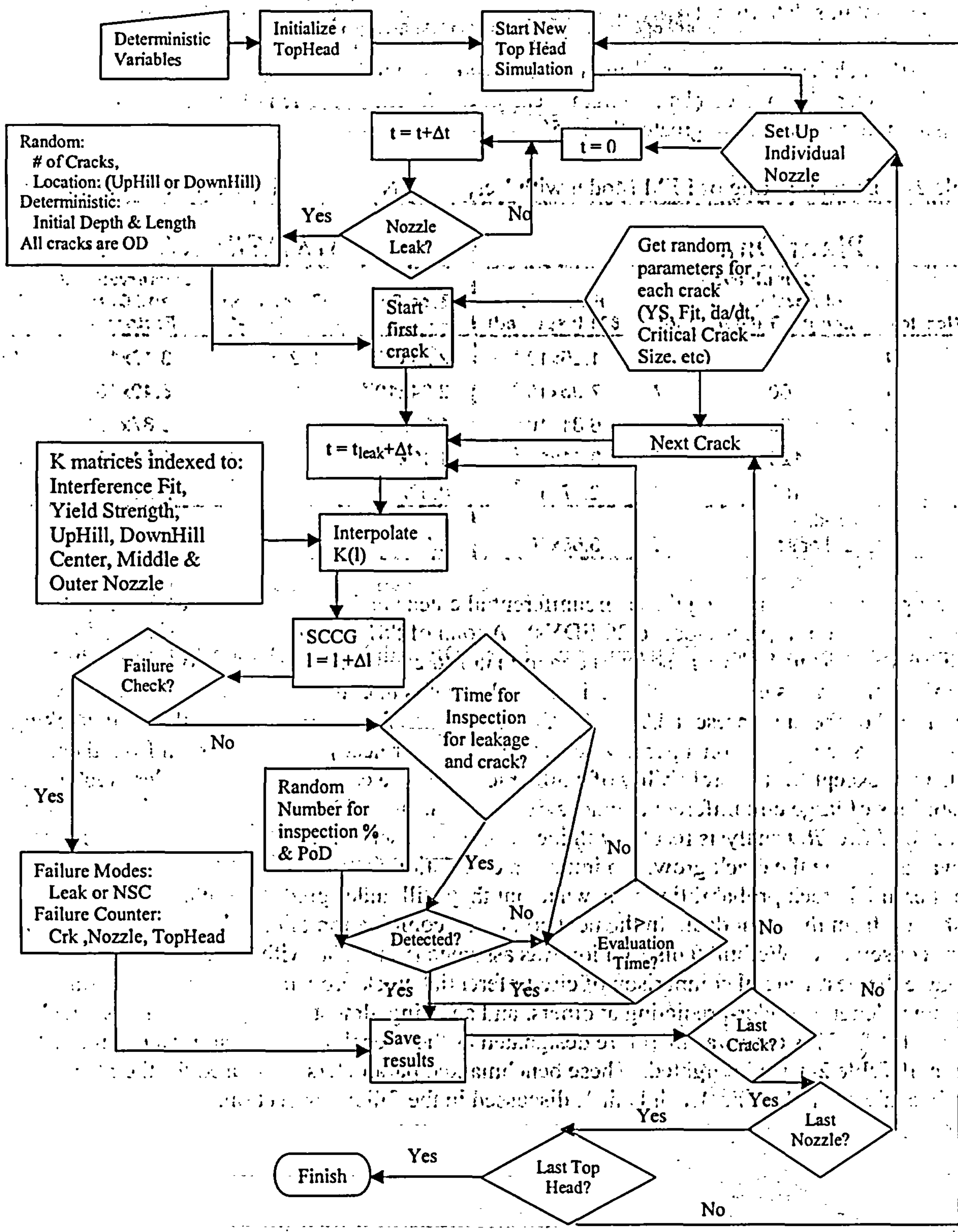


Figure 2-1. Flow Chart of PFM Methodology

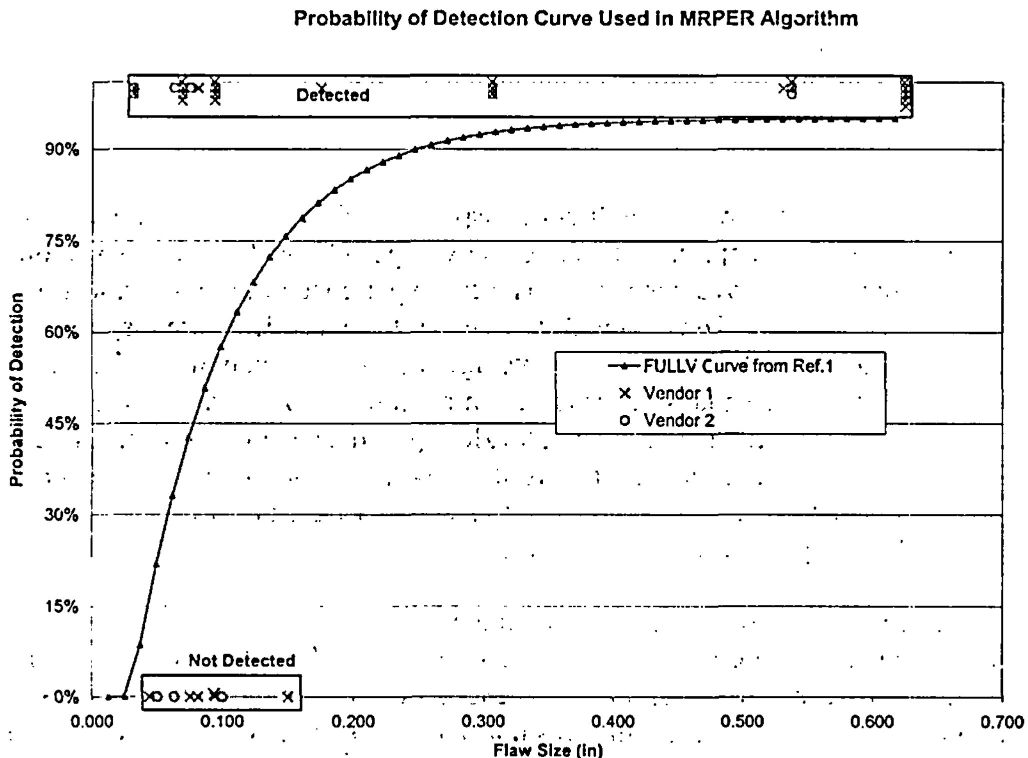


Figure 2-2. Comparison of POD curve used for NDE with Vendor Demonstration Programs

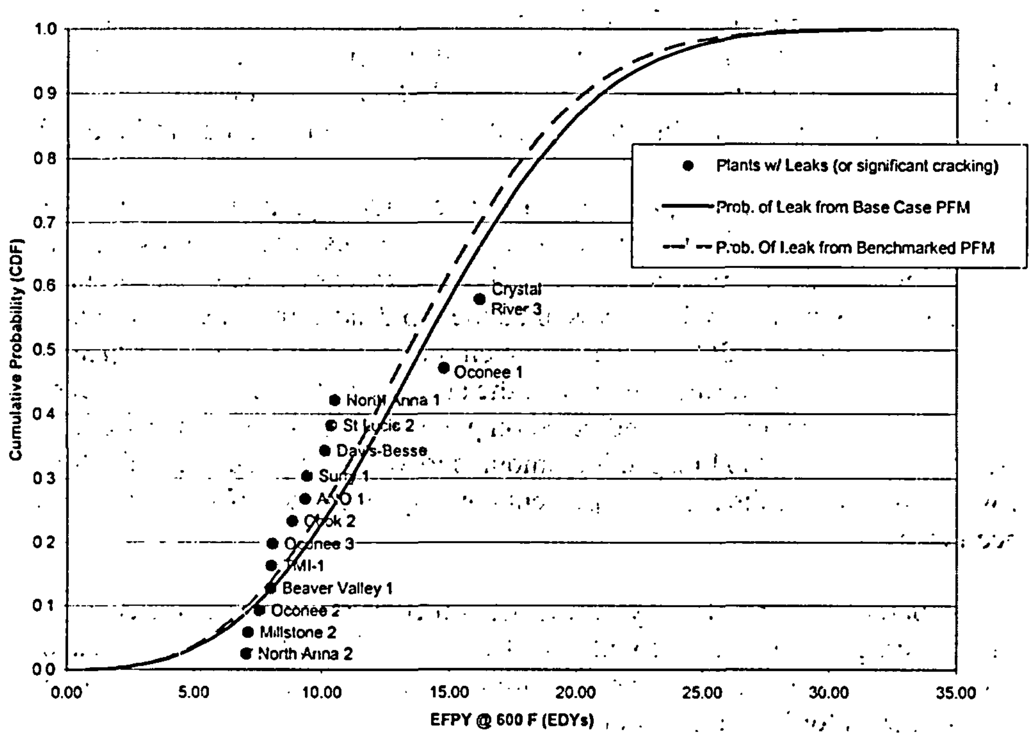


Figure 2-3. Benchmarking of PFM Model with respect to Plants with Nozzle Leaks or Cracking

# 3.0 APPLICATION TO POINT BEACH UNIT 1

## 3.1 Inspection Coverage Assumptions

Nozzle by nozzle inspection results from the Fall 2002 inspection of the Point Beach Unit 1 top head were reviewed to estimate the approximate percent coverage achieved in that inspection (see Appendix A). The majority of coverage problems were experienced in the outermost row of nozzles with thermal sleeves (nozzles 26 through 33). Four of these nozzles were inspected with the blade probe, achieving less than full inspection coverage (but greater than 50%). Three of the nozzles in this group required thermal sleeves to be removed for inspection with the rotating probe, and the stall problem was then encountered. Nozzle 1 (top dead center) also required thermal sleeve removal, but didn't experience stall problems with the rotating probe. Several other nozzles that did not have thermal sleeves present to start with were also inspected with the rotating probe, five of which experienced stall problems.

A total of seven transducers were mounted on the rotating probe, and plots of transducer coverage versus azimuthal angle were reviewed [4] to determine which portions of the nozzles were scanned by each transducer. For purposes of this evaluation, it was conservatively assumed that any portion of the nozzle circumference that was not scanned by all seven transducers was un-inspected. The resulting coverage fractions for each nozzle are listed in Appendix A. The total inspection coverage achieved by both the blade probe and rotating probe is summed on page A-3, and amounts to a total of 82% of the circumferential lengths of all nozzles. Finally, in keeping with the assumptions in Ref. [2], NDE of the nozzles (with no weld inspection) was specified as 80% coverage, under the assumption that 20% of the chance of leakage is due to weld cracking. Thus the resulting percent coverage input to *MRPERCRD* for the Fall 2002 inspections was 65%. All inspections applied the FULLV POD curve illustrated in Figure 2-2.

For the upcoming Spring 2004 inspections, assumptions were made regarding which nozzles might encounter inspection coverage limitations if the thermal sleeves are not removed, and what percentage the limitations would be. As seen in Appendix A, it was assumed that all eight nozzles in the outermost row with thermals sleeves, plus the top dead center nozzle, might experience coverage limitations up to 50% of the nozzle circumferences. (Note, if inspection limitations are actually encountered during the outage, the analysis will be redone considering the actual nozzles and coverage levels.) As indicated on page A-3, the sum of the assumed inspection coverage for the Spring 2004 inspection amounts to 90.8%, and applying the 80% factor for lack of weld inspections, the resulting percent coverage input to *MRPERCRD* for the Spring 2004 inspections was 73%.

As a base case for comparison, a second analysis was performed of the theoretical case of complete inspection coverage, in accordance with the NRC Order, in both the Fall 2002 and Spring 2004 inspections. Accounting for no weld examinations, this results in percent coverage input to *MRPERCRD* of 80% for both inspections.

## 3.2 Analyses and Results

A tabulation of the detailed input parameters used in the Point Beach Unit 1 analyses is presented in Table 3-1. The results are presented graphically in Figures 3-1 and 3-2.

Table 3-1. - Detailed *MRPERCRD* Input Parameters for Point Beach Unit 1 Partial Inspection Coverage Analysis

| Item | Variable | Probability Distribution | Mean Value | Standard Deviation | Lower Bound | Upper Bound | Units |
|---|---|---|---|---|---|---|---|
| 1 | **Number of Nozzles in the Top Head** | Constant | 49 | NA | NA | NA | nozzles |
| | Nozzle wall thickness | | 0.625 | | | | inches |
| | Maximum angle for center Nozzle | | 5 | | | | degrees |
| | Maximum angle for middle inner nozzle | | 18 | | | | degrees |
| | Maximum angle for middle outer nozzle | | 30 | | | | degrees |
| | Maximum angle for outer nozzle | | 43.5 | | | | degrees |
| 2 | Number of Heats of Material | Constant | 5 | NA | NA | NA | NA |
| 3 | Reference Temperature for Leakage | Constant | 600 | NA | NA | NA | °F |
| 4 | Reference Temperature for Crack Growth | Constant | 617 | NA | NA | NA | °F |
| 5 | **Inspection Plan** | | NRC Order | Partial Coverage | | | |
| | Number of NDE Inspections | Constant | 2 | 2 | | NA | NA |
| | Percentage of Nozzles Inspected | Constant | 80% | 65%,73% | | | NA |
| | Inspection technique | Constant | FULLV | FULLV | | | NA |
| | Inspection Time 1 | Constant | 177828 | 177828 | | | Hours |
| | Inspection Time 2 | Constant | 190311 | 190311 | | | Hours |
| 6 | Input Nozzle Temperature | Normal | 501.6 | 0.001 | NA | NA | °F |
| 7 | Material Yield Strength | Normal | 60 | 1.5 | NA | NA | KSI |
| | | Normal | 40.5 | 1.5 | NA | NA | KSI |
| | | Normal | 46.5 | 1.5 | NA | NA | KSI |
| | | Normal | 47 | 1.5 | NA | NA | KSI |
| | | Normal | 43 | 1.5 | NA | NA | KSI |
| 8 | **Probability of Leakage** | Weibull | | | | | |
| | Weibull theta | | 15.2 | NA | NA | NA | EDYs |
| | Weibull beta | | 3 | NA | NA | NA | NA |
| | Activation Energy for leakage | | 50 | NA | NA | NA | kcal/mol |
| 9 | Local Variability in Leakage applied to Weibull alpha | Triangle | 0 | NA | -6.5 | 6.5 | EDYs |
| 10 | Constant term in crack growth law | Log Triangle | -15.2485 | NA | -13.035 | -17.461 | NA |
| 11 | Exponential term in crack growth law | Normal | 1.16 | 0 | NA | NA | NA |
| 12 | Local variability in crack growth rate term by material heat | Log Triangle | 0 | NA | -1.6 | 1.6 | NA |
| 13 | Crack growth threshold | Normal | 8.188 | 0.001 | NA | NA | ksi-in^.5 |
| 14 | Crack growth activation energy threshold | Normal | 31.05 | 0.001 | NA | NA | kcal/mol |
| 15 | Correlation coefficient between SCC initiation and SCC crack growth | Constant | -1.0 | NA | NA | NA | NA |
| 16 | Initial shrink fit for the center nozzle | Normal | -0.00032 | 0.00083 | NA | NA | inches |

| Item | Variable | Probability Distribution | Mean Value | Standard Deviation | Lower Bound | Upper Bound | Units |
|---|---|---|---|---|---|---|---|
| 17 | Initial shrink fit for the middle inner nozzle | Normal | -0.00005 | 0.00170 | NA | NA | inches |
| 18 | Initial shrink fit for the middle outer nozzle | Normal | -0.00020 | 0.00158 | NA | NA | inches |
| 19 | Initial shrink fit for the outer nozzle | Normal | -0.00030 | 0.00138 | NA | NA | inches |
| 20 | Number of Cracks per Nozzle | Poisson | 2 | NA | NA | NA | NA |
| 21 | Initial Crack Depth | Normal | 0.05 | 0.01 | NA | NA | inches |
| 22 | $T_{init}$ | Constant | 0.5 | NA | NA | NA | NA |
| 23 | **Critical Crack Length** | | | | | | |
| | Center nozzle | Normal | 10.01 | 0.01 | NA | NA | inches |
| | Middle inner nozzle | Normal | 10.18 | 0.01 | NA | NA | inches |
| | Middle outer nozzle | Normal | 10.92 | 0.01 | NA | NA | inches |
| | Outer nozzle | Normal | 12.24 | 0.01 | NA | NA | inches |
| 24 | Number of equivalent full power hours | Constant | 224694 | NA | NA | NA | Hours |
| 25 | Number of time intervals | Constant | 27 | NA | NA | NA | NA |
| 26 | Number of Monte Carlo Simulations | Constant | 500,000 | NA | NA | NA | NA |

From Figure 3-1, it is seen that the predicted probability of leakage (POL) for Point Beach Unit 1 reached approximately 10% prior to the initial inspections performed in Fall, 2002. Following that inspection, and the subsequent inspections planned for Spring 2004, the POL drops dramatically, to ~1% at the time of head replacement in Fall 2005, under either inspection coverage assumption. The difference between the theoretical case of full nozzle inspections in accordance with the NRC Order and the partial coverage case described above is illustrated by the red and green lines in the figure. Had full coverage been achieved in both inspections, the POL at head replacement would have been 0.8%. With the conservative estimates of partial coverage levels for the Fall 2002 and the Spring 2004 inspections, the resulting probability of leakage at the time of head replacement would be 1.5%.

Similarly, from Figure 2-2, it is seen that the difference in the predicted probability of nozzle ejection is also quite small. Had full coverage been achieved in both inspections, the probability of failure at the time of head replacement would have been $1.8 \times 10^{-4}$. With the conservative estimates of partial coverage levels for the Fall 2002 and the Spring 2004 inspections, the resulting probability of failure at the time of head replacement would be $4.3 \times 10^{-4}$. These differences are considered to be quite small, and clearly not worth the additional man-REM exposure that would be incurred if thermal sleeves are required to be removed to achieve full inspection coverage. The probabilities also remain well below generally accepted limits (POL < 5% and POF < $1 \times 10^{-3}$) after the initial baseline examinations were performed.

One final point should be noted regarding the assumptions made in this PFM analysis. Although the predicted probabilities of leakage and failure are a function of the many input variables assumed in the analysis, the specific set of variables used to compare inspection programs have been benchmarked and calibrated with respect to field experience. Also, changes to these variables would affect the analyses of the full coverage case as well as the partial coverage case in approximately the same manner. Thus the comparison and conclusions of this study are expected to remain the same for realistic ranges of these input variables.

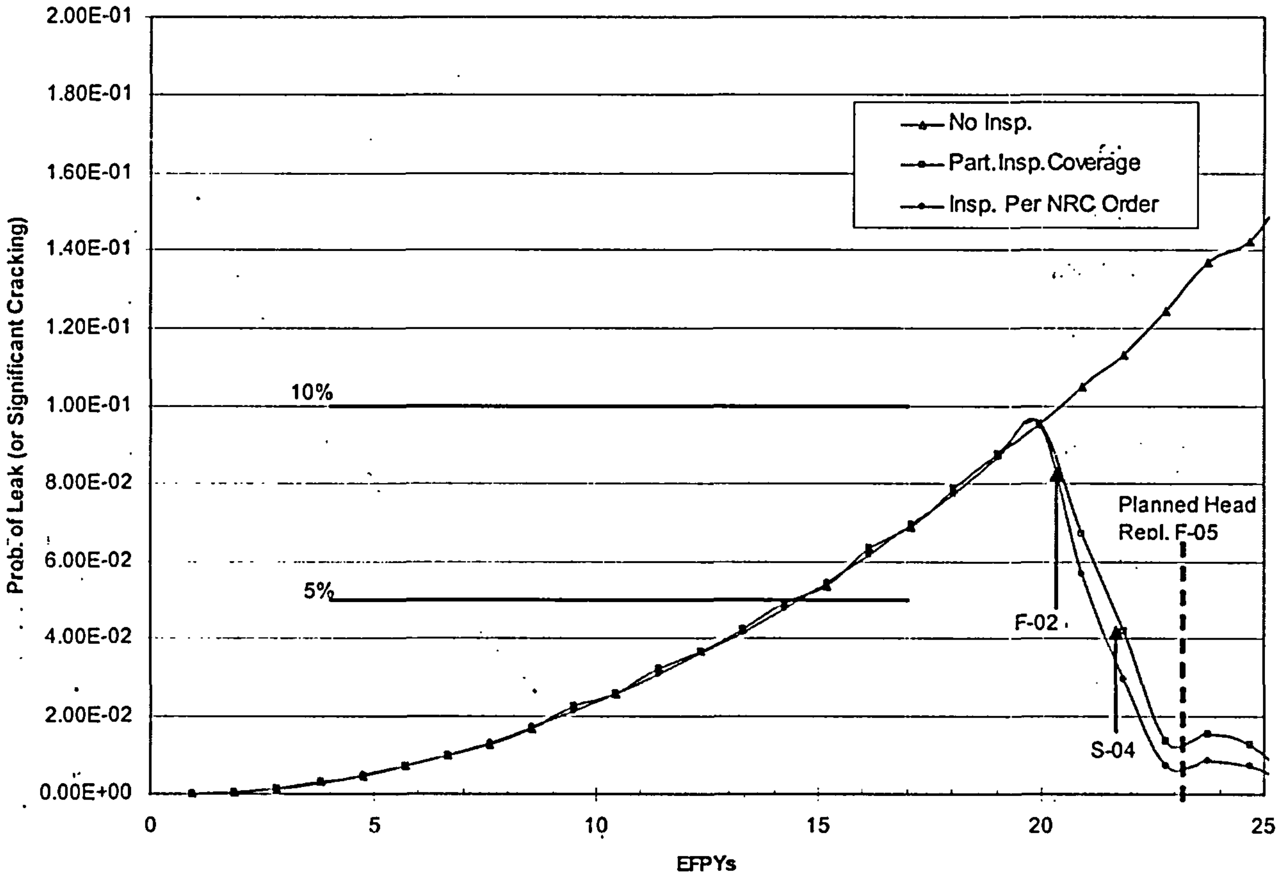


Figure 3-1. Comparison of Probability of Leakage for Point Beach Unit 1 Top Head Inspections under Full and Partial Inspection Coverage Assumptions

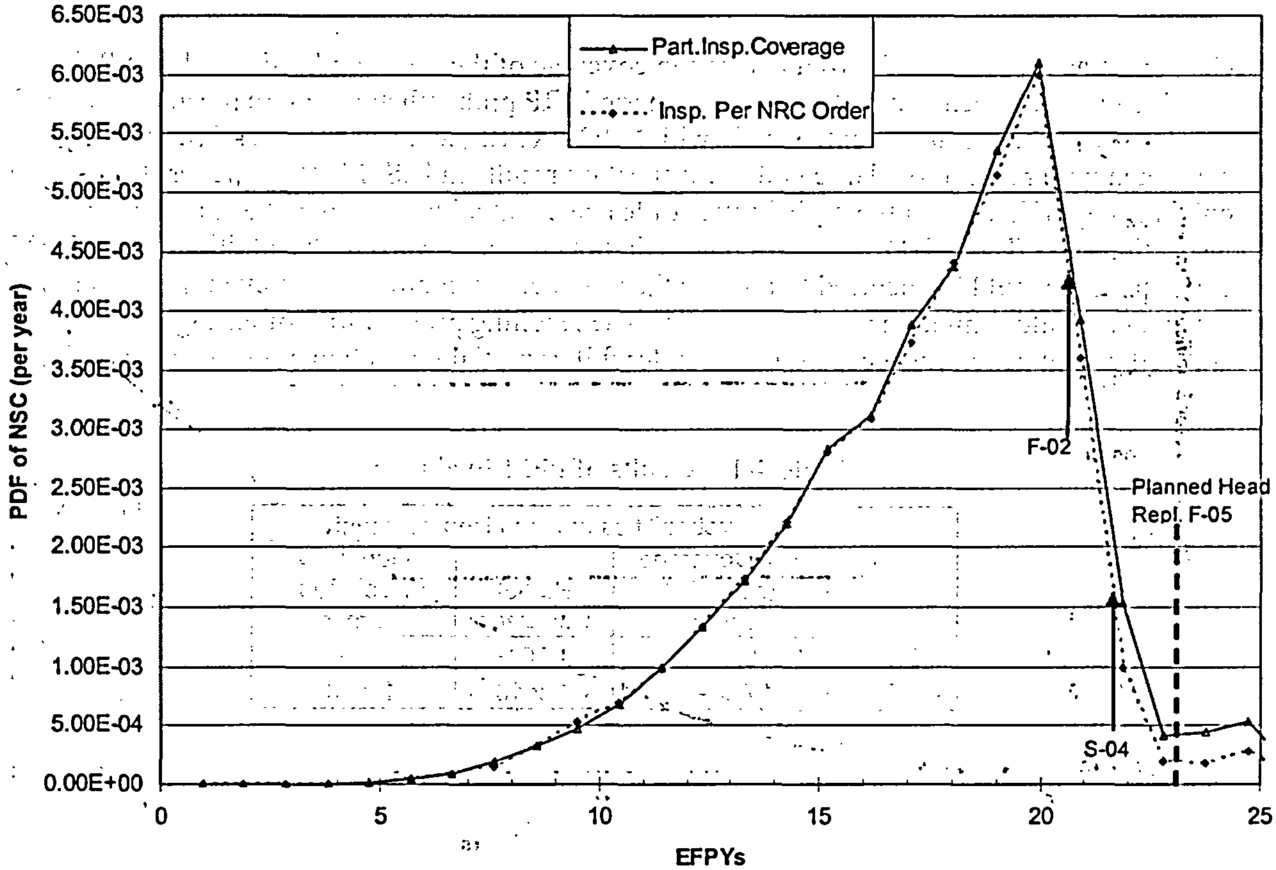


Figure 3-2. Comparison of Probability of Leakage for Point Beach Unit 1 Top Head Inspections under Full and Partial Inspection Coverage Assumptions

# 4.0 CONCLUSIONS

Conservative evaluation of partial inspection coverage of the RPV top head nozzles at Point Beach Unit 1 has been conducted using a generic MRP probabilistic fracture mechanics tool [2]. The tool has been discussed extensively with NRC / ACRS, and has been benchmarked and calibrated with respect to a large body of inspection results in U.S. PWRs. The results indicate only a small difference in the probabilities of leakage and failure compared to full coverage inspections (see Table 4-1). The differences do not appear to warrant the additional man-REM exposure that would be incurred to remove thermal sleeves in order to achieve full inspection coverage, should limitations be encountered. The resulting probabilities of leakage and failure are well within generally accepted limits under full or partial inspection coverage assumptions.

Table 4-1. Results of PFM Evaluation

| | Probabilities at Head Replacement | | |
|---|---|---|---|
| | Full Coverage (per NRC Order) | Partial Coverage | Generally Accepted Limits |
| POL | 0.80% | 1.50% | 5% |
| POF | $1.8 \times 10^{-4}$ | $4.3 \times 10^{-4}$ | $1 \times 10^{-3}$ |

## 5.0 REFERENCES


1. U.S. NRC Order EA-03-009, "Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors", issued on February 11, 2003

2. Materials Reliability Program, "Probabilistic Fracture Mechanics Analysis of PWR Reactor Pressure Vessel Top Head Nozzle Cracking," MRP-105, March 2004. EPRI Proprietary.

3. 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

4. Framatome NCR #6028873, Rev. 1, and Disposition, 9/21/2003.

APPENDIX A

POINT BEACH UNIT 1
RPV TOP HEAD NOZZLE INSPECTION COVERAGE

| Nozzle | Angle | Fall 2002 (actual) | | | Spring 2004 (assumed) |
|---|---|---|---|---|---|
| 1 | 0 | 1 | Rotating | Removed TS & Re-welded | 0.5 |
| 2 | 19.5 | 1 | Blade | | 1 |
| 3 | 19.5 | 1 | Blade | | 1 |
| 4 | 19.5 | 1 | Blade | | 1 |
| 5 | 19.5 | 1 | Blade | | 1 |
| 6 | 13.6 | 1 | Rotating | | 1 |
| 7 | 13.6 | 1 | Rotating | | 1 |
| 8 | 13.6 | 0.375 | Rotating | Stall | 1 |
| 9 | 13.6 | 1 | Rotating | | 1 |
| 10 | 28.1 | 1 | Blade | | 1 |
| 11 | 28.1 | 1 | Blade | | 1 |
| 12 | 28.1 | 1 | Blade | | 1 |
| 13 | 28.1 | 1 | Blade | | 1 |
| 14 | 31.8 | 1 | Blade | | 1 |
| 15 | 31.8 | 1 | Blade | | 1 |
| 16 | 31.8 | 1 | Blade | | 1 |
| 17 | 31.8 | 1 | Blade | | 1 |
| 18 | 30 | 1 | Blade | | 1 |
| 19 | 30 | 1 | Blade | | 1 |
| 20 | 30 | 1 | Blade | | 1 |
| 21 | 30 | 1 | Blade | | 1 |
| 22 | 31.8 | 1 | Blade | | 1 |
| 23 | 31.8 | 1 | Blade | | 1 |
| 24 | 31.8 | 1 | Blade | | 1 |
| 25 | 31.8 | 1 | Blade | | 1 |
| 26 | 37 | 0.78 | Blade | | 0.5 |
| 27 | 37 | 0.66 | Blade | | 0.5 |
| 28 | 37 | 0.52 | Blade | | 0.5 |
| 29 | 37 | 1 | Blade | | 0.5 |
| 30 | 37 | 0.5 | Blade | | 0.5 |
| 31 | 37 | 0.42 | Rotating | Removed TS & Re-welded, Stall | 0.5 |
| 32 | 37 | 0.25 | Rotating | Removed TS & Re-welded, Stall | 0.5 |
| 33 | 37 | 0.17 | Rotating | Removed TS & Re-welded, Stall | 0.5 |
| 34 | 43.5 | 1 | Rotating | | 1 |
| 35 | 43.5 | 1 | Rotating | | 1 |
| 36 | 43.5 | 0.24 | Rotating | Stall | 1 |
| 37 | 43.5 | 0.17 | Rotating | Stall | 1 |
| 38 | 9.7 | 1 | Blade | | 1 |
| 39 | 9.7 | 1 | Blade | | 1 |
| 40 | 9.7 | 1 | Blade | | 1 |
| 41 | 9.7 | 1 | Blade | | 1 |
| 42 | 22 | 0.49 | Rotating | Stall | 1 |
| 43 | 22 | 1 | Rotating | | 1 |
| 44 | 22 | 0.39 | Rotating | Stall | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 45 | 22 | 0.44 | Rotating | Stall | | 1 |
| 46 | 22 | 0.25 | Rotating | Stall | | 1 |
| 47 | 22 | 0.33 | Rotating | Stall | | 1 |
| 48 | 22 | 1 | Rotating | | | 1 |
| 49 | 22 | 1 | Rotating | | | 1 |
| Totals | 49 | 0.816 | 49 | | 12 | 0.908 |
| 0.8 Factor for no weld insp. | | 0.653 | | | | 0.727 |