Westinghouse Non-Proprietary Class 3

Probabilistic and Economic Evaluation of Reactor Vessel Closure Head Penetration Integrity for Virgil C. Summer Nuclear Plant

WCAP - 14955
Revision 1

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1.0 INTRODUCTION - SUMMARY OF SAFETY CASE

Primary Water Stress Corrosion Cracking (PWSCC) in Alloy 600 reactor vessel head penetrations is a relatively new issue in the nuclear industry. The issue was first brought to attention in 1991 when, after 10 years of operation, a leak was detected during a hydrotest of the reactor coolant system at the Bugey Unit 3 plant in France. Since that time a significant number of research programs have been funded by the industry to determine the causes of the problem and develop strategies for repair and management. Through these studies is was concluded that the reactor vessel head penetration cracking is a thermally activated stress corrosion process in primary water environments. The process is a slow one that causes no immediate safety concern. Based on conservative evaluation results, the NRC and industry concluded that cracks were most likely to initiate from the inside surface of the penetrations, in the axial direction, and would take at least six years to propagate through the wall under typical plant operating conditions. Fracture mechanics evaluations have determined that the crack is non critical until its axial length reaches 8.5 inches to 20 inches, depending on plant design.

External circumferential cracking is less probable. It may occur only in the presence of an above the attachment weld through-wall crack, with active leakage. Assuming coolant is present on the outer diameter of the penetration, one conservative analysis estimated that it would take more than 90 years before penetration failure would occur. In the presence of reactor coolant, corrosion of the alloy steel reactor vessel head is possible. Conservative evaluations estimate that it would take longer than six years after a through-wall crack occurs before the ASME Code structural integrity margin for the reactor vessel head would be impacted by corrosion. It was concluded that periodic visual inspection of the reactor vessel head in accordance with Generic Letter 88-05 is adequate and sufficient to detect leakage prior to significant cracking and vessel head corrosion.

Based on the above, evaluations using 10CFR50.59 requirements concluded that head penetration cracking is not an unreviewed safety question.

On April 1, 1997 the NRC issued Generic Letter 97-01, "Degradation of Control Rod Drive Mechanism Nozzle and Other Vessel Closure Penetrations". The purpose of the letter is to request licensees to describe, in writing, their program for ensuring timely inspection of vessel closure head penetrations. This description is to include programs/plans to deal with PWSCC of vessel head penetrations and to perform an assessment of any resin bed ingress into the RCS.

The purpose of this report is to provide South Carolina Electric and Gas with an analytical basis for developing a response to Generic Letter 97-01 relative to PWSCC of the vessel head penetrations.

2.0 DEVELOPMENT OF A CRACK GROWTH RATE MODEL FOR ALLOY 600 HEAD PENETRATIONS

Crack growth rate testing has been underway since 1992 to characterize the behavior of head penetration materials. The modified Scott model, as described below was initially used for safety evaluation calculations in submittals made in 1992 and 1993. The goal of this work is to review the applicability of that model in light of the past five years of testing, during which over forty specimens have been tested representing 15 heats of material. The original basis of the model will be reviewed, followed by all the available laboratory results, and finally a treatment of the available field results.

The effort to develop a reliable crack growth rate model for Alloy 600 began in the Spring of 1992, when the Westinghouse, Combustion Engineering, and Babcock and Wilcox Owners Groups were developing a safety case to support continued operation of plants. At the time there was no available crack growth rate data for head penetration materials, and only a few publications existed on growth rates of Alloy 600 in any product form.

The best available publication was found to be that of Peter Scott of Framatome, who had developed a growth rate model for PWR steam generator materials [1]. His model was based on a study of results obtained by McIlree and Smialowska [2] who had tested short steam generator tubes which had been flattened into thin compact specimens. His model is shown in Figure 2-1. Upon study of his paper there were several ambiguities, and several phone conversations were held to clarify his conclusions. These discussions indicated that reference 1 contains an error, in that no correction for cold work was applied to the McIlree/Smialowska data. The correct development is given below.

An equation was fitted to the data of reference [2] for the results obtained in water chemistries that fell within the standard specification for PWR primary coolant. Results for chemistries outside the specification were not used. The following equation was fitted to the data for a temperature of 330EC:

$$\frac{da}{dt} = 2.8 \times 10^{-11} (K-9)^{1.16} \text{ m/sec}$$

where K is in $MPa[m]^{0.5}$. This equation implies a threshold for cracking susceptibility, $K_{iscc} = 9\ MPa[m]^{0.5}$. Correction factors for other temperatures are shown in Table 2-1.

The next step described by Scott in his paper was to correct these results for the effects of cold work. Based on work by Cassagne and Gelpi [3], he concluded that dividing the above equation by a factor of 10 would be appropriate to account for the effects of cold work. This step was inadvertently omitted from Scott's paper, even though it is discussed. The crack growth model for 330°C then becomes:

$$\frac{da}{dt} = 2.8 \times 10^{-12} (K-9)^{1.16} \text{ m/sec}$$

This equation was verified by Scott in a phone call in July 1992.

Scott further corrected this model for the effects of temperature, but his correction was not used in the model employed here. Instead, an independent temperature correction was developed based on service experience. This correction uses an activation energy of 32.4 kCal/mole, which gives a smaller temperature correction than that used by Scott (44 kcal/mole), and will be discussed in more detail below.

Scott's crack growth model for 330°C was independently obtained by B. Woodman of ABB-CE [4], who went back to the original data base, and did not account for cold work. His equation was of a slightly different form:

$$\frac{da}{dt} = 0.2 \exp [A + B \ln \{\ln (K - Q)\}]$$

Where $A = -25.942$

$B = 3.595$

$Q = 0$

This equation is nearly identical with Peter Scott's original model uncorrected for cold work. This work provided an independent verification of Scott's work. A further verification of the modified Scott model used here was provided by some operational crack growth rates collected by Hunt, et al [5].

The final proof of the usefulness of Peter Scott's model will come from actual data from head penetration materials in service, as will be discussed further below. To date 15 heats have been tested in carefully controlled PWR environment. One heat did not crack, and of the fourteen heats where cracking was observed, the growth rates observed in twelve were bounded by the Scott model. Two heats cracked at a faster rate, and the explanation for this behavior is being investigated.

A compilation was made of the laboratory data obtained to date in the Westinghouse laboratory tests at 325°C, and the results appear in Figure 2-3. Notice that much of the data is far below the Scott model, and a few data points are above the model. These results represent 14 heats of head penetrations.

The effect of temperature on crack growth rate was first studied by compiling all the available crack growth rate data, for both laboratory and field cracking of Alloy 600. This information is summarized in Figure 2-2, where the open symbols are for steam generator tube materials, and the solid symbols are for head penetration materials. The results are presented in a simple format, with crack growth plotted as a function of temperature. The effect of different applied stress intensity factor values has been ignored in this presentation, and this doubtless adds to the scatter in the data. The remarkable result is a consistent temperature effect over a temperature range from 288°C to 370°C, more than covering the temperature range of PWR plant operation. The work done originally in 1992 results in a calculated activation energy of 32.4 Kcal/mole, which has been used to adjust the base crack growth law to account for different operating temperatures.

A series of crack growth tests is in progress under carefully controlled conditions to study the temperature effect for head penetration materials, and the results are shown in Figure 2-3. Sufficient results are available to report preliminary findings. The tests were performed with an applied stress intensity factor of 23 Ksi $\sqrt{in}$ (25.3 MPa$[m]^{0.5}$), periodic unload/reload parameters of a hold time of one hour and a water chemistry of 1200 ppm B + 2 ppm Li + 25 cc/kg Hz. The results are consistent with the previous steam generator and head penetration material work. In the case of heat 69, the three results in the middle of the temperature range, 309°C, 327°C and 341°C have the same trend as the scatter band, almost exactly, while the high temperature and low temperature results are both lower than would be predicted by the activation energy, as shown in Figure 2-2. The results for heat 20 show a similar behavior, with the results at 325°C and 340°C also with the scatter band and nearly parallel to the heat 69 specimens, but at a lower crack growth rate, as shown in Figure 2-2.

The effects of several different water chemistries have been investigated in a closely controlled series of tests, on two different heats of archive material. Results showed there is no measurable effect of Boron and Lithium on crack growth.

The key test of the laboratory crack growth data is its comparison to field data. Crack growth from actual head penetrations has been plotted on Figure 2-2 as solid points. The solid circles are from Swedish and French plants and the solid stars are from a US plant.

Figure 2-4 shows a summary of the inservice cracking experience in the head penetrations of French plants, prepared by Amzallag [6], compared with the Westinghouse laboratory data, corrected for temperature. This figure shows excellent agreement between lab and field data, further supporting the applicability of the lab data.

Therefore it can be seen that the laboratory data is well represented by the Scott model corrected for temperature using an activation energy of 32.4 kcal/mole. Also the laboratory results are consistent with the crack growth rates measured on actual installed penetrations. Therefore the use of the Scott model in the safety evaluations is still justifiable, in light of both laboratory and field data obtained to date.

TABLE 2-1
TEMPERATURE CORRECTION FACTORS FOR CRACK GROWTH: ALLOY 600

Temperature	Correction Factor (CF)	Coefficient (Co)
330C	1.0	2.8×10^{-12}
325	0.798	2.23×10^{-12}
320	0.634	1.78×10^{-12}
310	0.396	1.11×10^{-12}
300	0.243	7.14×10^{-13}
290	0.147	4.12×10^{-13}

$$\frac{da}{dt} = Co\,(K - 9)^{1.16}\ m/s$$

where K is in $MPa[m]^{0.5}$

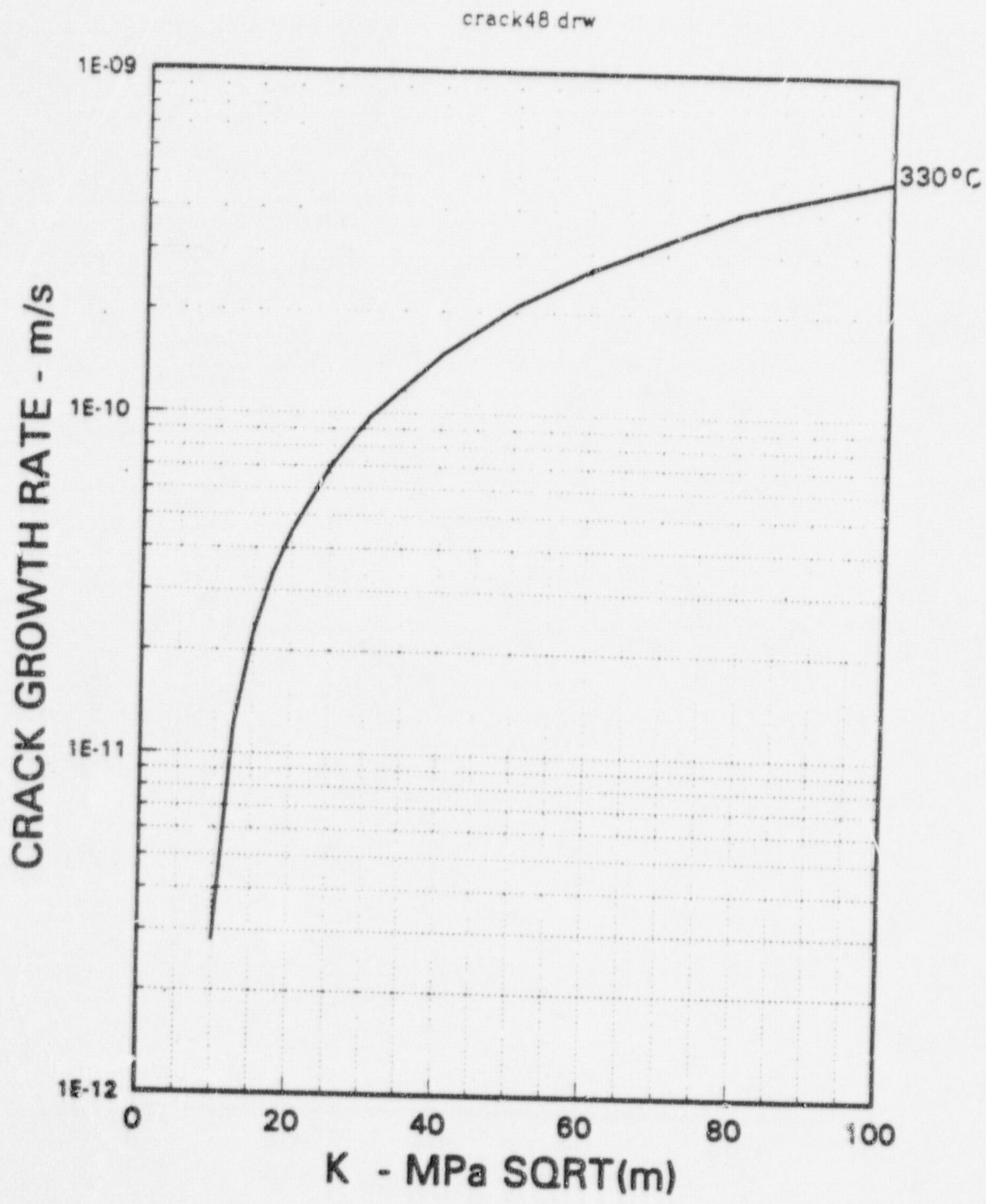


Figure 2-1 Scott Model for PWSCC of Alloy 600 at 330°C, as modified from reference [1]

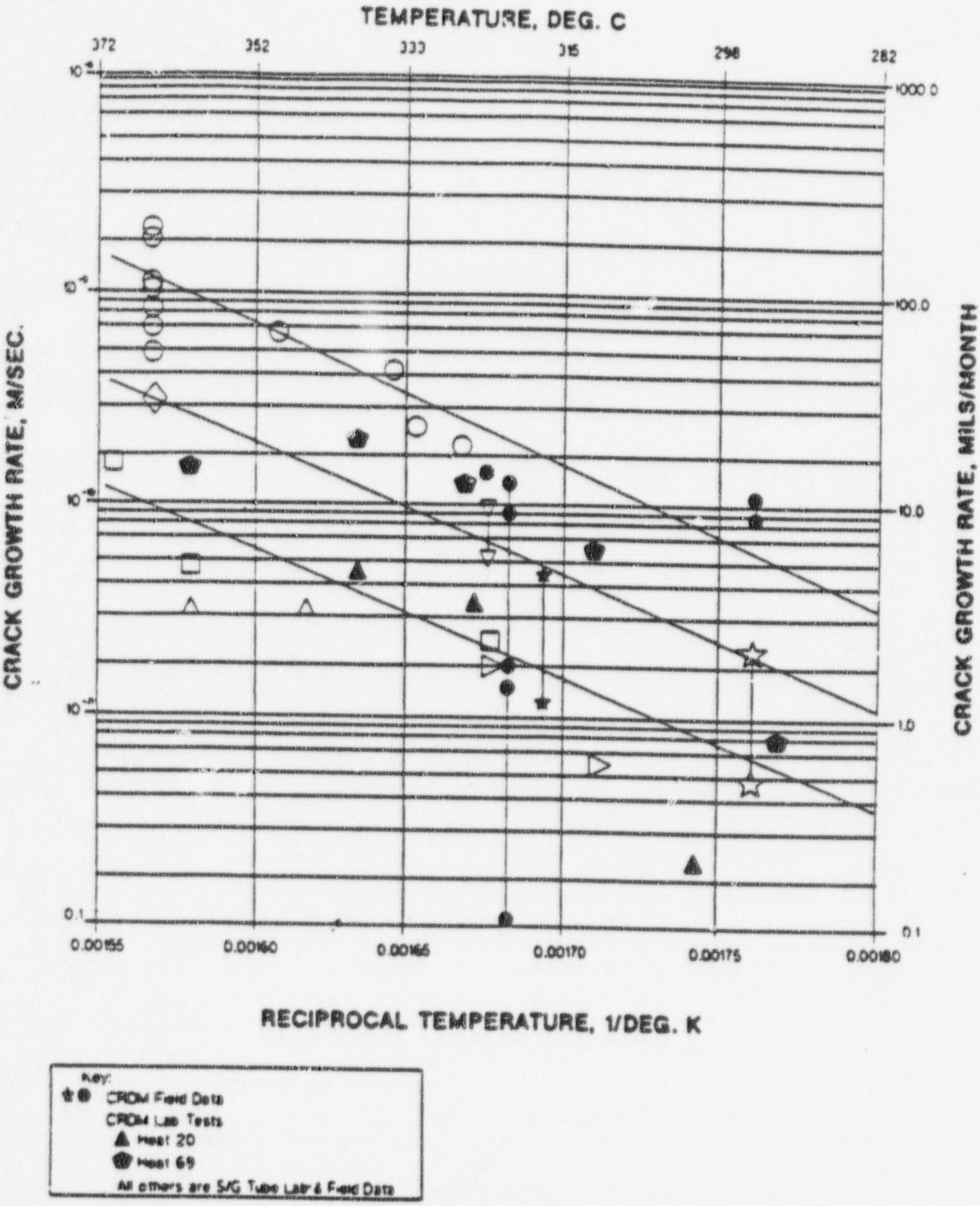


Figure 2-2 Comparison of Temperature Effects Results with Other Laboratory and Field Data

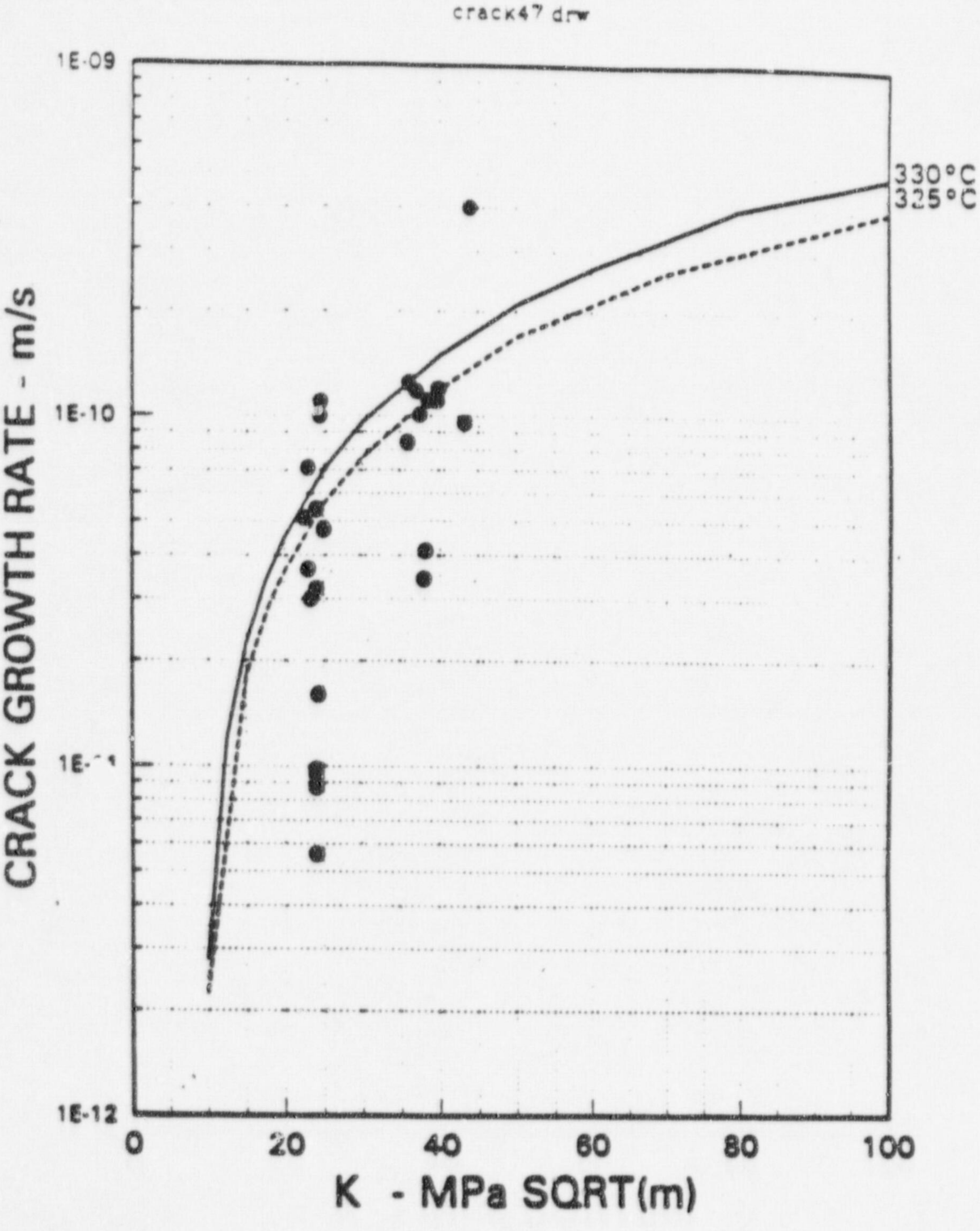


Figure 2-3 Summary of Available Westinghouse Laboratory Data for Alloy 600 Head Penetrations at 325°C

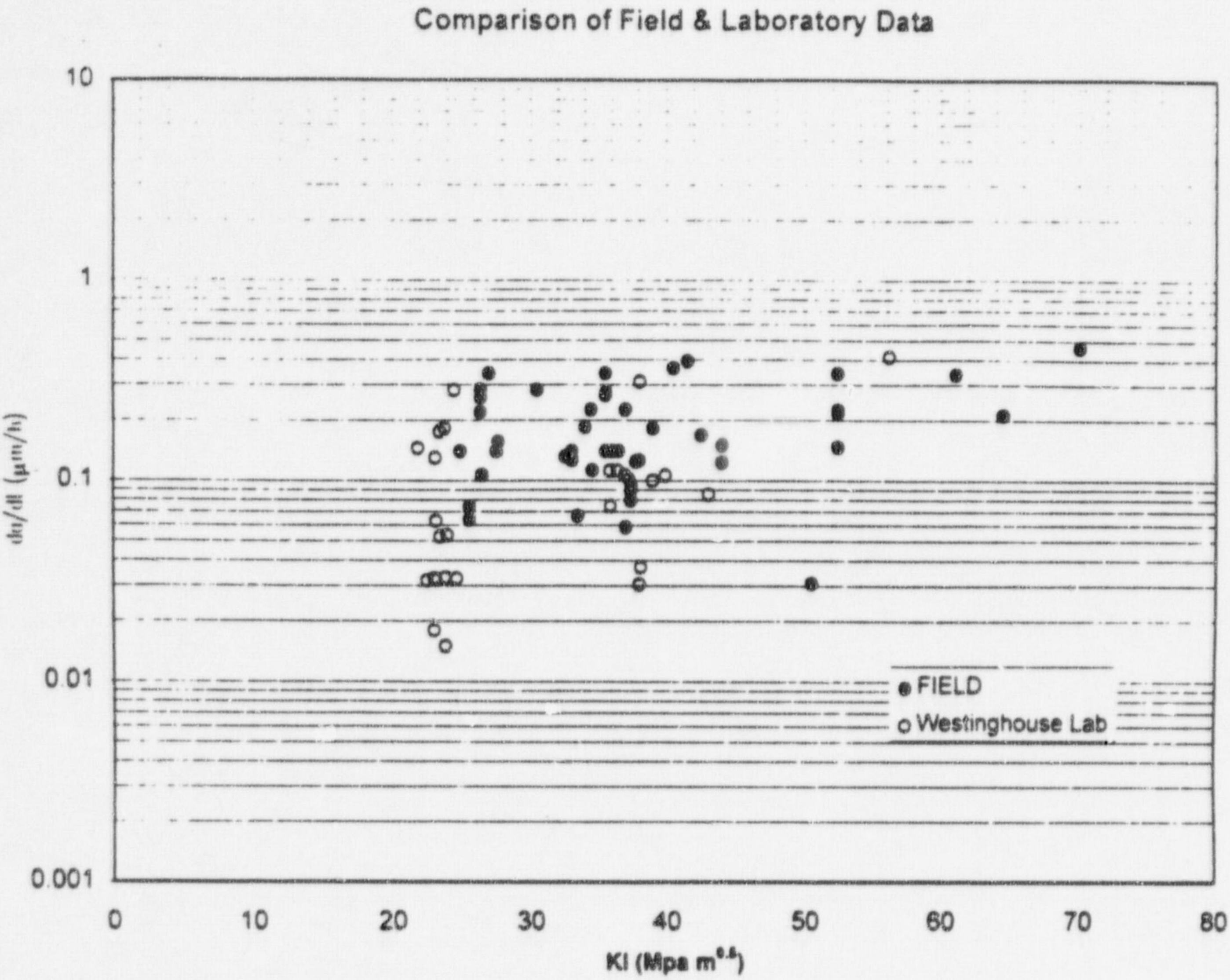


Figure 2-4 Comparison of French Field Data and Westinghouse Laboratory Data (W results reduced to 290°C using Q = 130 KJ/mole) [6]

3.0 TECHNICAL DESCRIPTION OF PROBABILISTIC AND ECONOMIC DECISION MODELS

The following two sections of this report describe the models and software for calculating the probability of failure with time and performing the economic decision analysis. The input to these models and the calculated results are described in Section 4 of this report.

3.1 PROBABILISTIC MODEL

To calculate the probability of failure of the Alloy 600 vessel head penetration as a function of operating time t, $Pr(t \leq t_i)$, structural reliability models were used with Monte-Carlo simulation methods. This section describes these structural reliability models and their basis for the primary failure mode of crack initiation and growth due to primary water stress corrosion cracking (PWSCC). The models used for the evaluation of the V.C. Summer vessel head penetration nozzles are based upon the economic decision tools developed previously for the Westinghouse Owners Group (WOG). The capabilities of this software have already been verified in the following ways:

1. Calculated stresses compare well with measured stresses (see Figure 3-1),

2. A wide range (both high and low values) of calculated probabilities are consistent with plant observations as discussed below.

   The model predictions have been used to justify the scope for the second inspection performed at D. C. Cook Unit 2, when the cracked penetration was successfully repaired. The model accepts measured microstructure (replication) and has capability to ignore its effects, if desired.

Recent improvements have also been made by Westinghouse to the software models in order to maximize their utility for individual plant predictions. Among the changes were:

1. Improved the relationship of initiation time to material microstructural effects and yield strength to more closely match the observations from the recent inspection at North Anna Unit 1,

2. Added statistically based Bayesean updating of probabilities due to initial inspection results (e.g. the lack of any indications at any given plant),

3. Updated the uncertainty on crack growth rate after initiation to reflect that observed in the recent Westinghouse test data and the recent in-reactor measurement data to be published by EdF (see Figure 3-2) and

4. All models have been independently reviewed by APTECH Engineering (Begley and Woodman), including an improved model for the effect of monotonic yield strength on time to initiation.

The most important parameter for estimating the failure probability is the time to failure, t_f in hours. It is defined as follows:

$$t_f = t_i + (a_f - a_0) / da/dt \qquad (3\text{-}1)$$

where:

t_i	=	time to initiation in hours,
a_f	=	failure crack depth in inches,
a_0	=	crack depth at initiation in inches and
da/dt	=	crack growth rate in inch/hour.

In equation (3-1), both the crack depths at failure and initiation may be specified as a fraction of the penetration wall thickness, w. The failure depth a_f depends upon the failure mode being calculated. Since the failure mode of concern is cracks in the penetration that are deeper than the structural limit of 75% of the penetration wall thickness w, it would be specified as:

$$a_f = 0.75\ w \qquad (3\text{-}2)$$

The time to PWSCC crack initiation, t_i in hours, is defined by a model that includes the following terms and their uncertainties:

a. a log-normal distribution on an initiation coefficient, which was based upon the data of Hall and others [8] for forged Alloy 600 pressurizer nozzles, with only the uncertainty based upon the data of Gold and others [9],

b. a grain boundary coverage factor, which is based upon the data of Norring and others [10],

c. the residual and operating stress level derived from the detailed elastic-plastic finite-element analysis from the WOG study of Ball and others [11] as shown in Figure 3-1. Its normally distributed uncertainty was derived from the variation in ovality from Duran and others [12] (see Figure 3-3), which is a trigonometric function of the penetration diameter and setup angle (local angle between the head and longitudinal axis of penetration).

d. an initiation activation energy, which is also normally distributed,

e. the penetration material temperature, which is uniformly distributed based upon the calculated variation of the nominal head operating temperature, and

f. the hours at temperature per operating cycle (year), which is normally distributed.

Either replication data can be used or a model can be used for grain boundary carbide coverage. The model [7] is a statistical correlation of measured values with the following materials certification parameters:

- Carbon content,
- Nickel content,
- Manganese content,
- Ultimate tensile strength and
- Yield strength.

The uncertainty on this model, which is as shown in Figure 3-4, applies equally well to both the predicted and measured values.

Once the crack has initiated, it is assumed to have a depth of a_0 and its growth rate, da/dt in inches per hour, is calculated by the Peter Scott model, which matches the latest Westinghouse and EdF data and the previous data given in the WOG report on the industry Alloy 600 PWSCC growth rate testing results [13], and discussed in Section 2. The key parameters in the model are:

a. a log-normally distributed crack growth rate coefficient (see Figure 3-2),

b. the stress intensity factor conservatively calculated assuming a constant stress through the penetration wall for an axial flaw at the inside surface with a length 6 times its depth using a simplification of the Raju and Newman equations for pressure vessel evaluation [14], and

c. an activation energy for PWSCC crack growth, which is also normally distributed.

To calculate the effects of an in-service inspection (ISI) for the economic decision analysis of Section 3.2, the structural reliability ISI model uses a simple but conservative assumption that the probability of detection is directly proportional to the ratio of the depth of the crack to the wall thickness (e.g. 50% detection probability for a crack depth of 50% of the wall. No credit is given for previous inspections so that the effect of the first inspection can be calculated for each year of operation.

The probability of failure of the Alloy 600 vessel head penetration as a function of operating time t, $Pr(t \leq t_i)$, is calculated directly for each set of input values using Monte-Carlo simulation. To apply the simulation method for vessel head penetration nozzle (VHPN) failure, the existing Westinghouse PROF (probability of failure) Software System (object library) was combined with the PWSCC structural reliability models described previously. The Westinghouse PROF library provided standard input and output, including plotting, and probabilistic analysis capabilities (e.g. random number generation, importance sampling). The result was program VHPNPROF for calculation of head penetration failure probability with time.

The Westinghouse PROF Software Library has been verified by hand calculation for simple models and alternative methods for more complex models. Recently the application of this same Westinghouse PROF methodology to the WOG sponsored pilot program for piping risk based inspection has been extensively reviewed and verified by the ASME Research Task Force on RBI Guidelines [15] and other independent NRC contractors. Table 3-1 provides a summary of the wide range of parameters that were considered in this comprehensive benchmarking study that compared the Westinghouse PROF calculated probabilities with those from the pc-PRAISE program [16]. As shown in Figure 3-5, the comparison of calculated probabilities after 40 years of operation is excellent for both small and large leaks and full breaks, including those reduced due to taking credit for leak detection.

To verify the proper operation of the VHPNPROF Program in predicting the probability of getting a given crack depth due to PWSCC, calculated results were compared for four plants where sufficient head penetration information and inspection results were available. The four plants are identified in Table 3-2 along with the values of the key input parameters and calculated failure probabilities. For comparison, the latest available inspection results are also provided. Table 3-2 shows acceptable agreement between the observed plant and VHPNPROF calculated failure trends due to PWSCC.

The input and output parameters for the VHPNPROF program runs for the 65 V.C Summer head penetration nozzles are provided in Appendix A and discussed in Section 4.1.

TABLE 3-1
PA· AMETERS USED FOR THE PC PRAISE BENCHMARKING STUDY

Type of Parameter	Low Value	High Value
Pipe Material	Ferritic	Stainless Steel
Pipe Geometry	6.625" O.D. 0.562" Wall	29.0" O.D. 2.5" Wall
Failure Modes	Small Leak, Through-Wall Crack	Full Break, Unstable Fracture
Last Pass Weld Inspection	No X-Ray	Radiographic
Pressure Loading	1000 psi	2235 psi
Low-Cycle Loading	25 ksi Range 10 cycles/year	50 ksi Range 20 cycles/year
High-Cycle* Loading	1 ksi Range 0.1 cycles/min.	20 ksi Range 1.0 cycles/sec.
Design Limiting Stress	15 ksi	30 ksi
Disabling Leak Rate	50 gpm	500 gpm
Detectable Leak Rate	None	3 gpm

* Note: Mechanical Vibration (low stress range and high frequency) for small pipe,
Thermal Fatigue (high stress range and low frequency) for large pipe.

TABLE 3-2
COMPARISON OF VHPNPROF CALCULATED PROBABILITIES WITH PLANT OBSERVATIONS

Parameters	Almaraz 1	D. C. Cook 2	Ringhals 2	North Anna 1
Hours of Operation	85,400	87,000	108,400	91,000
Setup Angle (°)	42.6	50.5	38.6	*
Temperature (°F)	604.3	598.5	605.6	600.0
Yield Strength (ksi)	37.5	58.0	51.2	51.2
Percent GBCC	57.0	44.3	3.0	2.0
Flaw Depth/Wall	0.10	0.43	0.25	0.10
Initiation Probability	1.1%	41.4%	37.6%	15.3%
Failure Probability**	1.1%	38.1%	34.6%	15.3%
Penetrations With Indications	0	1	3 (2 with scratches)	0

* Calculations performed at an equivalent setup angle for the 2nd highest stress location that could be inspected.

** Defined here as the probability of reaching the specified flaw depth for the limiting penetration.

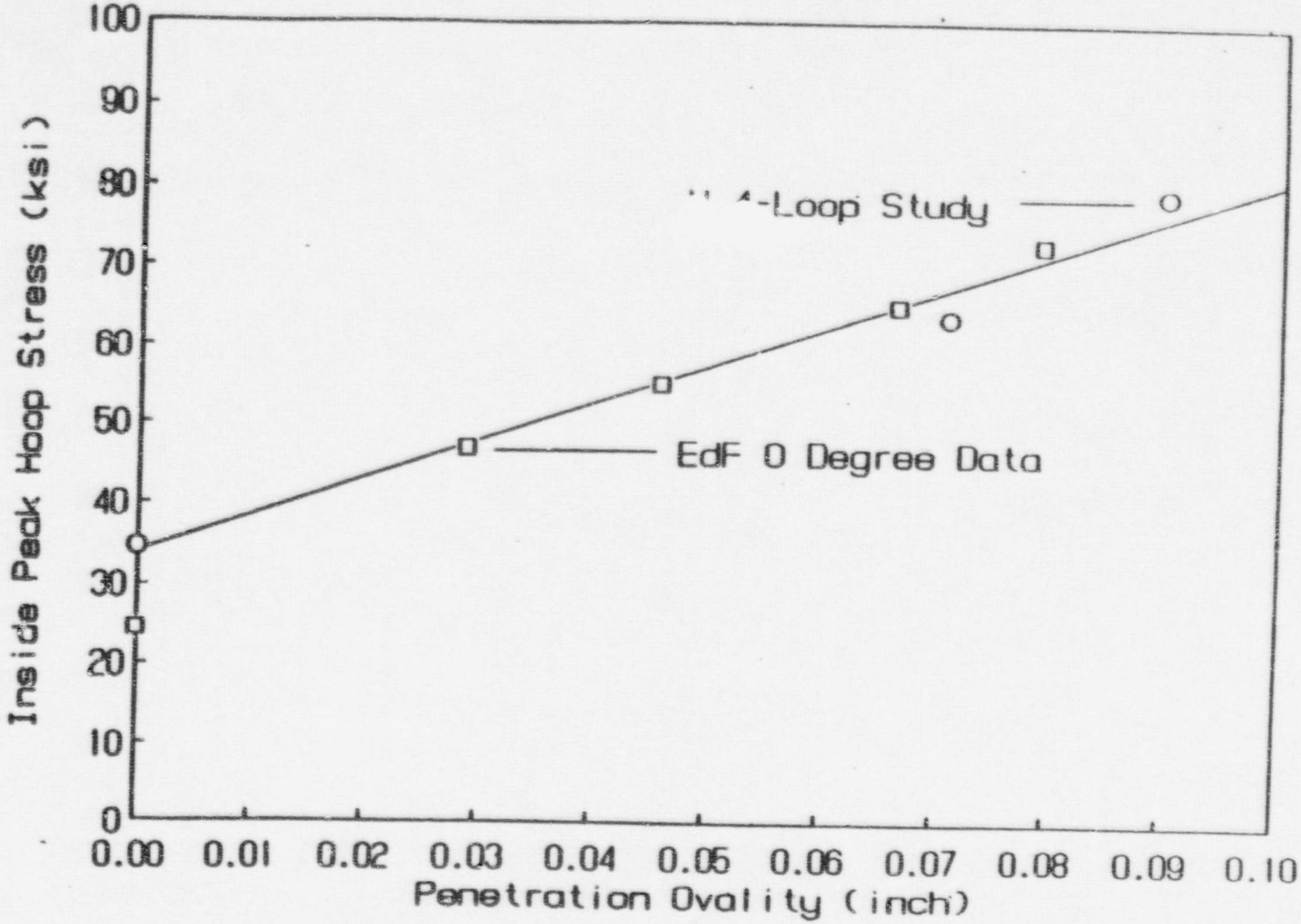


Figure 3-1 Vessel Head Penetration Stresses from WOG 4-Loop Plant Study [11]

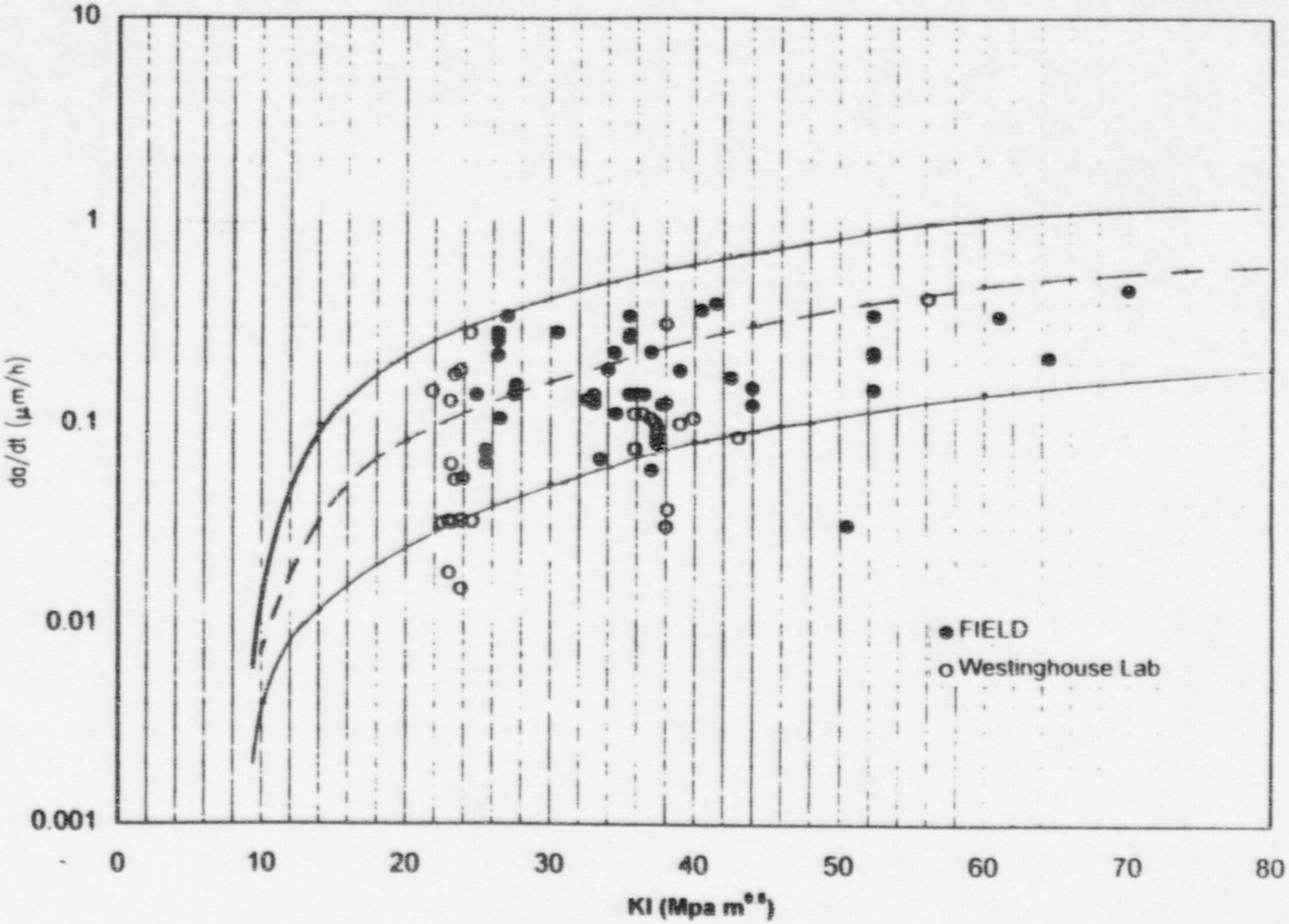


Figure 3-2 Comparison of Recent Alloy 600 Data with the Crack Growth Rate Model

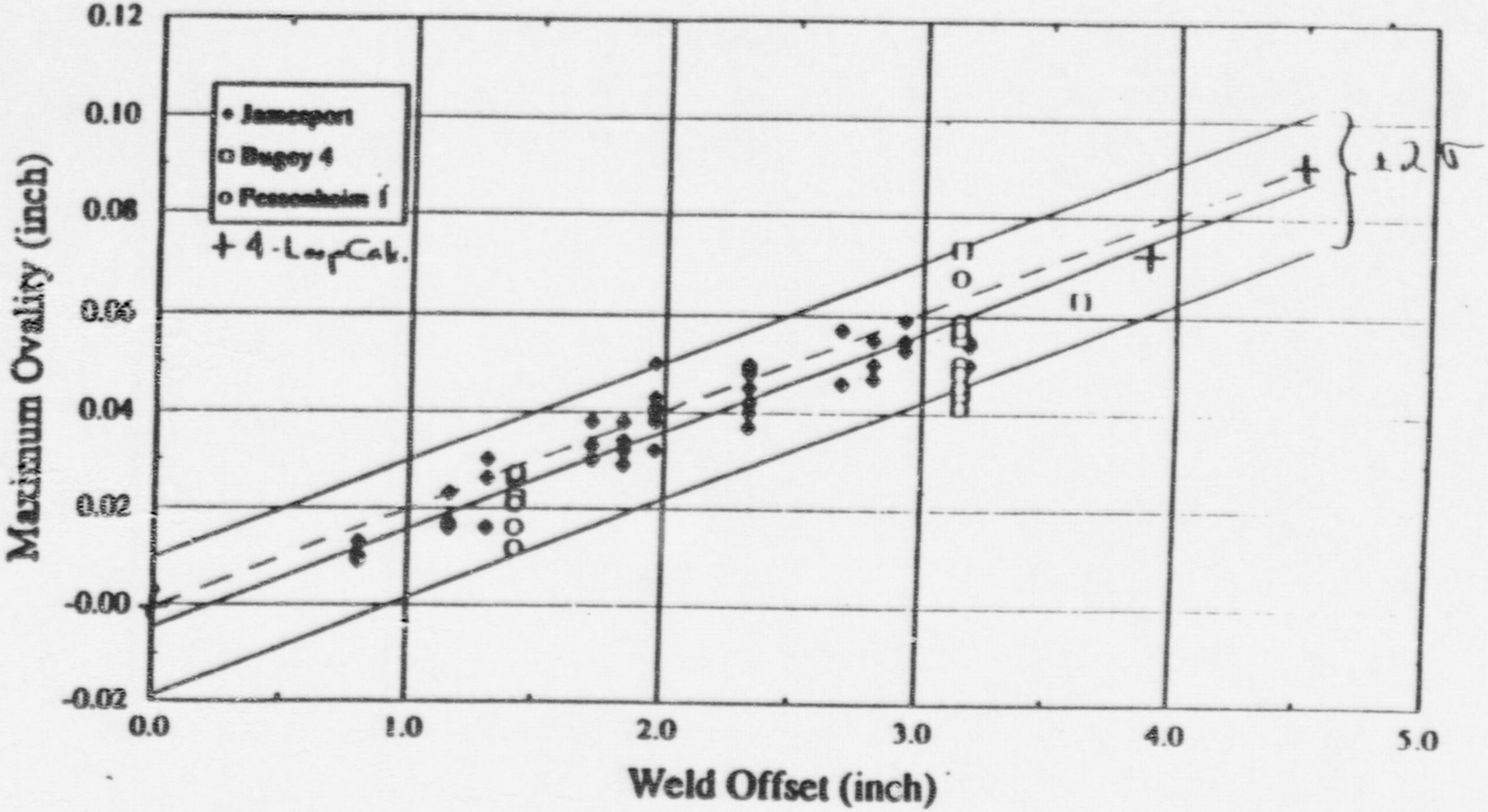


Figure 3-3 Measured Vessel Head Penetration Ovality Data and Regression Results [12]

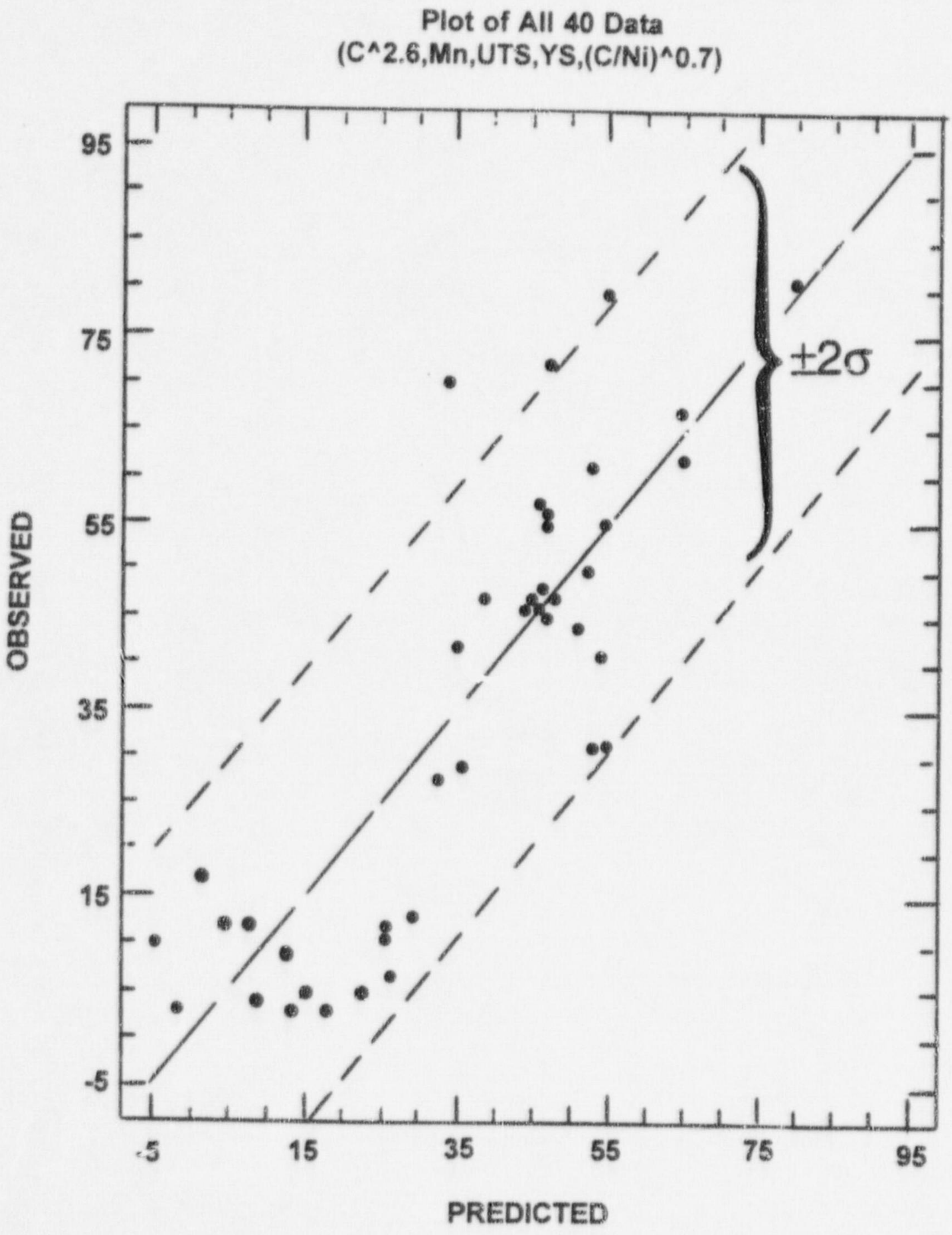


Figure 3-4 Curve Fit of Alloy 600 Grain Boundary Carbide Coverage Results [7]

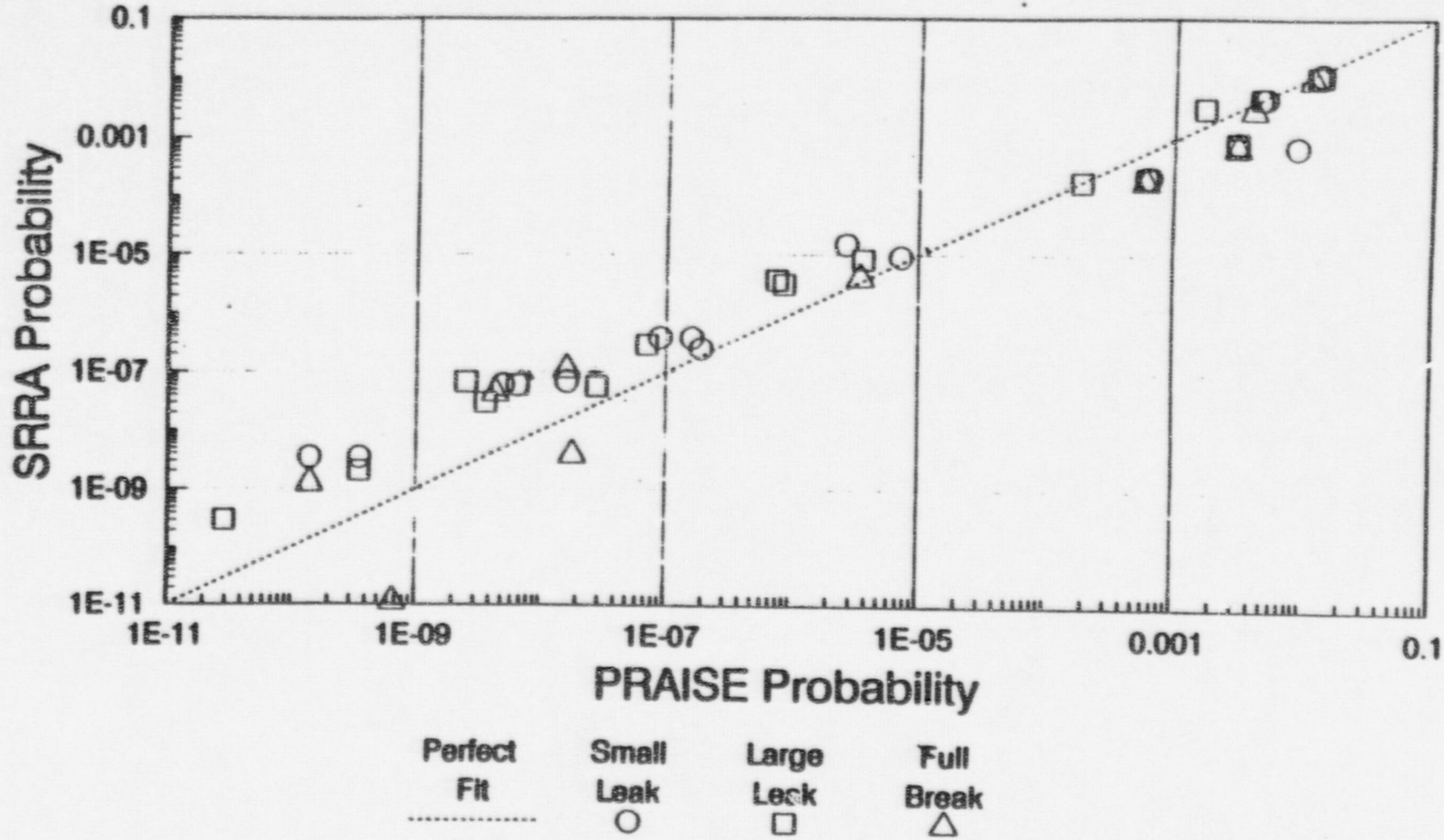


Figure 3-5 Comparison of Calculated Piping Probabilities

3.2 ECONOMIC DECISION ANALYSIS MODELS

The basis for the economic decision analysis model is the Influence Diagram for Plant Life Extension (PLEX) shown in Figure 3-6. The relationships shown by the dashed lines are not included since VHPN cracking due to PWSCC is not a safety issue. The component mitigative strategy in this case is the first inspection of the outer three rows of vessel head penetration nozzles and repair of those with detectable cracks. The probability of failure, which is a crack depth 75% of wall, and probability of inspection detection (1-PND) for each year of operation and group of penetrations come from the output files for the VHPNPROF analysis runs. The effectiveness of this mitigative strategy on future failure costs can also be calculated directly using this same information instead of being estimated as is done in other decision analysis models.

The output files for the V. C. Summer vessel head penetration nozzle decision analyses are included in Appendix B. The first page of the output file summarizes the input, which is described in Section 4.2. The next two pages are the results of model calculations, which can be described as follows for each column heading on each page.

CYCLE: Number of operating cycle (year) when values of the parameters below are calculated.

MAX-PROB: This is the maximum failure probability calculated by VHPNPROF for all the penetration nozzles.

PROB-ONE: This is supplementary information about the probability that at least one of the head penetration nozzles will fail.

AVG-PROB: This is the average failure probability, which is the expected number of failures that is used to calculate the failure cost divided by the number of head penetration nozzles.

NPVFC-50: The Net Present Value of the median (50% probability) failure cost, which is the product of the expected number of failures and the median cost per penetration nozzle failure.

NPVFC-05: 5% Lower confidence bound on the NPV of the failure costs.

NPVFC-95: 95% Upper confidence bound on the NPV of the failure costs.

CYISI: Number of operating cycle (year) after which the first In-Service Inspection (ISI) would be performed.

NPV-CISI: This is the NPV of the median inspection cost, which is the number of nozzles in the outer three rows times the average inspection cost per nozzle. Because of the time value of money, the later the inspection is performed, the lower its NPV.

NPV-CREP: This is the NPV of the median repair costs, which is the average repair cost per nozzle times the fraction of inspected nozzles with cracks large enough to lead to failure and to be detected during ISI. The value of this fraction is calculated directly from the VHPNPROF output for the groups of nozzles being inspected.

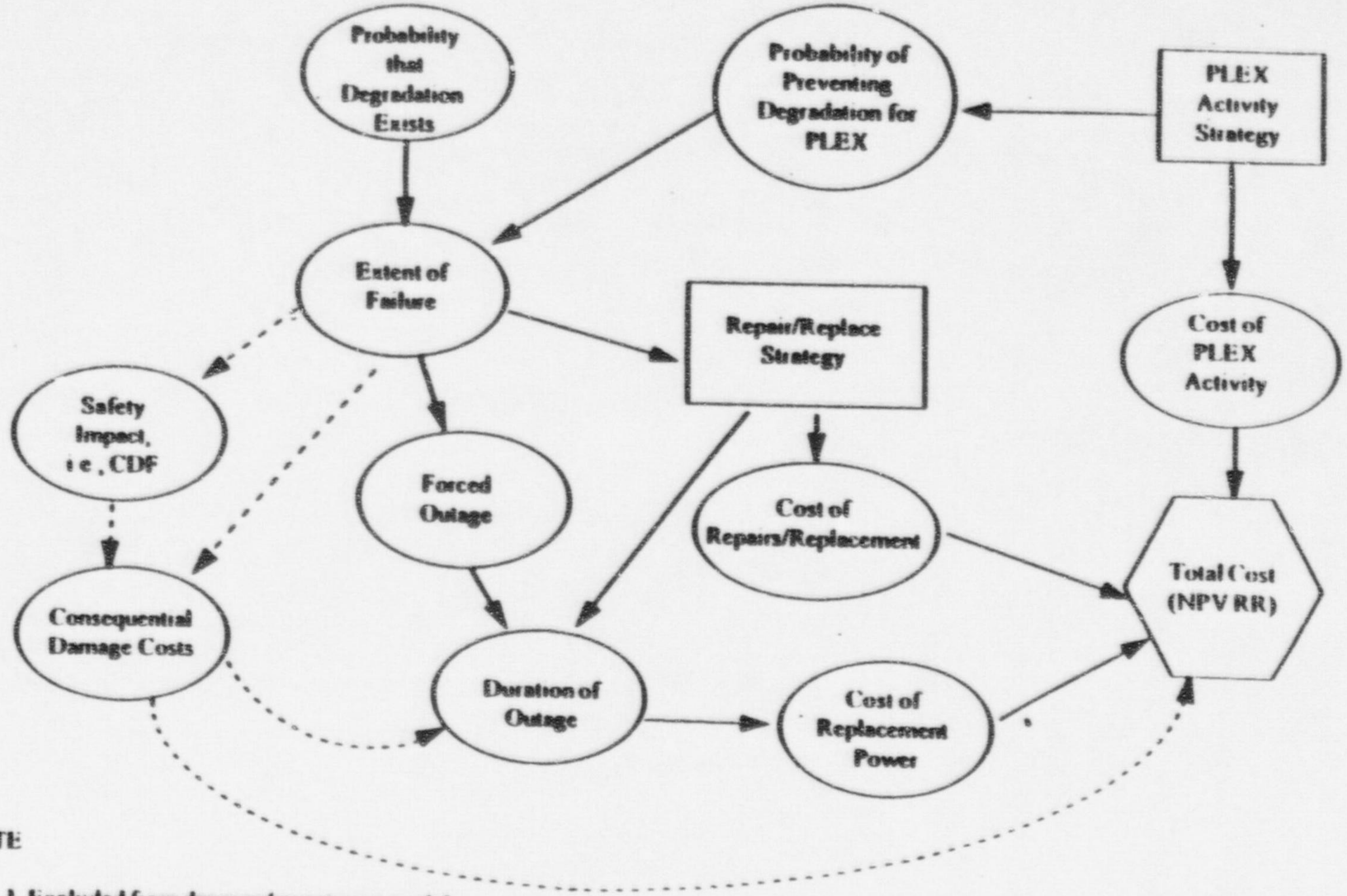
NPV-CBEN: This is the NPV of the median cost benefit of doing the inspection. The benefit is the elimination of the future failure costs for those nozzles that have been repaired. There is no reduction in failure probability and the associated expected failure cost contribution until a partially cracked nozzle is repaired.

NPVTC-50: This is the median NPV of the total cost integrated over a 60-year plant life. It is the sum of the NPV of the failure cost for all nozzles at 60 years and the inspection and repair costs less the NPV of the cost benefit of the repairs. The best economic decision would be to perform the first inspection when the NPV of this cost is a minimum.

NPVTC-05: 5% Lower confidence bound on the NPV of the total cost.

NDUTC-95: 95% Upper confidence bound on the NPV of the total cost.

The input to these models and the output values calculated by the decision analysis program VHPNECON are described in Section 4.2 for the V. C. Summer vessel head penetration nozzles.



NOTE

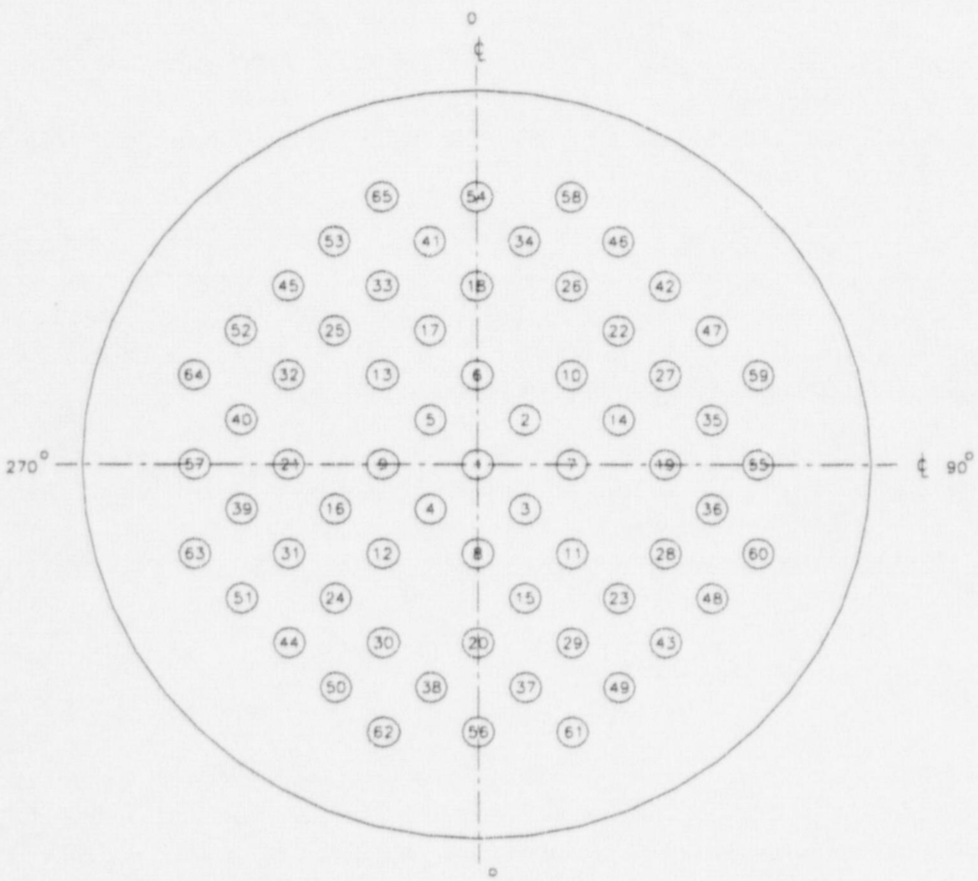
[-----] Excluded from decision/investment model
- safety/impact costs
- consequential damage costs

Figure 3-6 Component Decision/Investment Model Influence Diagram

4.0 RESULTS OF PROBABILISTIC AND ECONOMIC DECISION MODELS

4.1 INPUT AND RESULTS OF PROBABILISTIC ANALYSIS

The V. C. Summer reactor vessel and closure head were manufactured for Westinghouse by the Chicago Bridge and Iron Company. The closure head contains 65 head penetrations fabricated from Alloy 600 tube which are welded to a stainless steel flange. This assembly is then welded to the low alloy steel closure head utilizing a J-groove weld. An outside view of the closure head which shows the penetration numbers is provided in the following sketch. These penetrations are utilized for a number of purposes. These purposes are for Control Rod Drive Mechanisms (CRDM), capped latch housings (CLH), part length mechanisms (P/L), thermocouple column locations (TCC), reactor vessel level instrumentation system connection (RVLIS), and spare penetrations.



A review of the fabrication records for V.C. Summer indicates that the closure head penetrations were fabricated from two different heats of Alloy 600 material. Both of these heats of material were supplied by Babcock and Wilcox and are designated as M6369 and M6370.

Table 4-1 provides a summary of each head penetration and its use and associated heat of material.

Table 4-2 provides the input values to the probabilistic analysis and Table 4-3 provides the results of the analysis in terms of the probability of failure (%) after 10, 20, 30, 40, 50, and 60 years of operation (note that penetrations 1 through 25 are bounded by penetrations 26 through 33 since they utilize the same heats of material and their set-up angle is less than that of penetrations 26 through 33).

The detailed input and calculated results for the V.C. Summer vessel head penetration nozzle probabilistic analysis are given in the VHPNPROF output print files in Appendix A. The first page of each file is a description of the input for each analysis, including the standard uncertainties that were used for the probabilistic analysis. The second page of the output file lists the calculated probabilities.

The first column is the cycle number; the second is the probability of failure during the cycle; the third is the accumulated probability at the end of the cycle. The fourth and fifth columns are the same types of probability as the second and third columns respectively but for an in-service inspection (ISI) each cycle. This is of course an unrealistic assumption, but provides useful information for the economic analysis.

Figure 4-1 shows the increase of the best-estimate crack depth with time for the penetrations with the highest failure probability in some of the outer rows. The shortest mean time to failure (depth of 75% of the wall thickness or approximately 0.5 inch) of [ ]^{a,b} years is for group 1 (penetrations 58 to 65) or case 1 in Appendix A. For the second row in (penetrations 49 to 52), the residual stresses are lower so that the time to crack initiation is longer and the crack growth rate is smaller. In this case, the mean time to failure increases to almost [ ]^{a,b} years. Likewise, for the third and fourth rows in the mean times to failure are approximately [ ]^{a,b} and [ ]^{a,b} years, respectively. Because of the effects of all the uncertainties that are considered in the probabilistic analysis, the uncertainty band on the time to failure is quite wide. Even with a mean time of failure of [ ]^{a,b} years for the case 1 penetrations (58 to 65), there is about an [ ]^{a,b}% probability of failure by year 60 (see Table 4-3). However , as the mean time to failure increases for the inner rows, then the probability of failure at a given time, say 60 years, decreases. For the case 8 penetrations (34 to 38), there is only a [ ]^{a,b}% probability of failure by year 60 because the mean time to failure increased to [ ]^{a,b} years as shown in Figure 4-1.

To calculate the combined effects for all the vessel head penetration nozzle (VHPN) failures (crack depths of 75% of the wall), a second program (VHPNECON) was run. The results of these calculations are given in the VHPNECON output file, which is shown in the first page of Appendix B. The column headings used in the output file and their meaning are described below.

CYCLE: Number of operating cycle (year) when values of the parameters below are calculated. Each cycle has 7446 hours at temperature. For these calculations each cycle was assumed to be one year.

MAX-PROB: This is the maximum failure probability calculated by VHPNPROF for the penetration nozzle most likely to fail.

PROB-ONE: This is the probability that at least one of the head penetration nozzles will fail. It is calculated as follows:

$$P_{ONE} = 1-\Pi_N (1 - p_i)^{ni} \qquad (4\text{-}1)$$

where p_i = failure probability for the ith group

ni = number of penetrations in the ith group

N = number of groups

AVG-PROB: This is the average failure probability, which is the expected number of failures divided by the number of head penetration nozzles.

E(NUMFS): This is the expected value of the number of failures in all the penetrations. It is calculated as follows:

$$E(N_F) = \Sigma_N \, ni \, p_i \qquad (4\text{-}2)$$

Table 4-5 provides the results of the analysis for the probability of at least one penetration failure in the head.

Figure 4-2 shows the failure probability with time for each of the penetrations (58 to 65) in the highest group (1 or case 1 in Table 4-2 and Appendix A). This figure also shows the increase in the average failure probability with time for all 65 penetration nozzles for the V.C. Summer vessel head. This average probability is 1/65th of the expected number of failures used in the economic decision analysis of Section 4.2. For reference, [ ]^{a,b}% is the calculated failure (75% wall depth) probability in the worst penetration in D.C. Cook Unit 2 when a crack depth of 43% of the wall thickness was found after 87,000 hours of operation. The corresponding average failure probability is [ ]^{a,b}% and the probability of at least one failure is [ ]^{a,b}% for all 78 penetration nozzles in D.C. Cook 2.

4.2 INPUT AND RESULTS OF ECONOMIC DECISION ANALYSIS

The output files for the economic decision analysis on when to perform the first inspection of the outer three rows of vessel head penetration nozzles in V. C. Summer is listed in Appendix B. The first page of the output is a summary of the input to the VHPNECON Program.

The reference year for the net present value calculation was set to cycle (year) 14 based upon the total hours of operation at temperature to date and an average 7,446 hours per cycle used in the VHPNPROF analyses. The interest rate of 5% is based upon an assumed discount rate of 9% less an assumed 4% escalation rate.

The range of costs for failure inspection and repair were calculated using the same method to combine uncertainties as was used for the simple WOG cost model. The cost calculations for the V. C. Summer decision analysis are summarized in Table 4-4. The cost of inspection would include eddy-current inspection of all the sleeved and unsleeved penetrations in the outer three rows and a ultrasonic inspection of one flaw in one penetration. The repair costs are based upon excavation of one flaw in one penetration.

The failure costs are based upon excavation of one deep flaw and weld overlay repair for one penetration only. Also included are the additional industry/NRC interaction costs and ALARA penalty costs from the simple cost model developed for WOG. Not included in the failure costs were the follow-on inspection costs for the repaired nozzle. Replacement power costs for extension of critical path time or unexpected shutdown due to leakage of a nozzle were not included in the subtotal of the failure costs in Table 4-4. This cost penalty at an assumed [ ][d] per day significantly increases the total failure cost in Table 4-4 as well as the cost avoidance benefit of the penetration nozzle inspection and repairs.

Figure 4-3 shows the 5, 50 (median value) and 95% confidence bounds on the NPV of the minimum total costs of failure through 60 years including the NPV of the inspection and repair costs at the time (cycle) for the first inspection. The minimum failure costs do not include the high downtime replacement power penalty costs. As can be seen, the minimum NPV cost would occur for no inspection at all (cycle 59). Because of the low failure cost for the low failure probabilities of the V. C. Summer vessel head penetration nozzles, the expected benefit of repairing the detected cracked penetrations never offsets the inspection and repair costs.

However, the benefits of the first inspection and repair of detected cracks are increased significantly when the total failure cost includes the replacement power costs for an unplanned repair of failed penetration nozzle. Figure 4-4 shows the 5, 50 (median value) and 95% confidence bounds on the NPV of the maximum total costs of failure through 60 years, where the maximum total failure costs include the replacement power penalty costs. For this maximum cost case, the minimum NPV cost would occur for inspection at end of cycle [ ][a,b] (calendar year [ ][a,b]).

TABLE 4-1
HEAD PENETRATION USES AND ALLOY 600 HEAT NUMBER

Row	Penetration No.	Use	Thermal Sleeve	Heat Number
0	1	P/L	YES	M6369
1	2	CRDM	YES	M6369
	3	CRDM	YES	M6369
	4	CRDM	YES	M6370
	5	CRDM	YES	M6369
2	6	CRDM	YES	M6369
	7	CRDM	YES	M6369
	8	CRDM	YES	M6370
	9	CRDM	YES	M6369
3	10	CRDM	YES	M6370
	11	CRDM	YES	M6370
	12	CRDM	YES	M6370
	13	CRDM	YES	M6370
4	14	SPARE	NO	M6370
	15	SPARE	NO	M6369
	16	RVLIS	NO	M6369
	17	SPARE	NO	M6369
5	18	P/L	YES	M6370
	19	P/L	YES	M6370
	20	P/L	YES	M6369
	21	P/L	YES	M6370
6	22	CRDM	YES	M6369
	23	CRDM	YES	M6369
	24	CRDM	YES	M6369
	25	CRDM	YES	M6369
7	26	CRDM	YES	M6370
	27	CRDM	YES	M6370
	28	CRDM	YES	M6369
	29	CRDM	YES	M6369
	30	CRDM	YES	M6369
	31	CRDM	YES	M6370
	32	CRDM	YES	M6369
	33	CRDM	YES	M6369

TABLE 4-1 (Continued)

Row	Penetration No.	Use	Thermal Sleeve	Heat Number
8	34	CRDM	YES	M6370
	35	CRDM	YES	M6370
	36	CRDM	YES	M6370
	37	CRDM	YES	M6370
	38	CRDM	YES	M6370
	39	CRDM	YES	M6369
	40	CRDM	YES	M6369
	41	CRDM	YES	M6369
9	42	CRDM	YES	M6370
	43	CRDM	YES	M6370
	44	CRDM	YES	M6369
	45	CRDM	YES	M6369
10	46	CLH	YES	M6369
	47	TCC	NO	M6369
	48	CLH	YES	M6369
	49	TCC	NO	M6370
	50	CLH	YES	M6370
	51	TCC	NO	M6370
	52	CLH	YES	M6370
	53	TCC	NO	M6369
11	54	CRDM	YES	M6369
	55	CRDM	YES	M6369
	56	CRDM	YES	M6369
	57	CRDM	YES	M6369
12	58	CRDM	YES	M6369
	59	CRDM	YES	M6369
	60	CRDM	YES	M6369
	61	CRDM	YES	M6369
	62	CRDM	YES	M6369
	63	CRDM	YES	M6369
	64	CRDM	YES	M6369
	65	CRDM	YES	M6369

TABLE 4-2
INPUT VALUES FOR PROBABILISTIC ANALYSIS

Case	Pen. No.	Temp.	SA	Y.S. (ksi)	GBC (%)
1	58 thru 65	557.3 °F	46.1	40.531	-12.3
2	54 thru 57		43.1	40.531	-12.3
3	49 thru 52		41.6	42.034	-2.1
4	46, 47, 48 & 53		41.6	40.531	-12.3
5	44 & 45		40.1	40.531	-12.3
6	42 & 43		40.1	42.034	-2.1
7	39 thru 41		35.5	40.531	-12.3
8	34 thru 38		35.5	42.034	-2.1
9	28, 29, 30, 32 & 33		30.6	40.531	-12.3
10	26, 27 & 31		30.6	42.034	-2.1

TABLE 4-3
RESULTS OF PROBABILISTIC ANALYSIS
(PROBABILITY OF FAILURE %)

Case	Pen. No.	10 Years	20 Years	30 Years	40 Years	50 Years	60 Yes
1	58 thru 65	~0	0.2	0.9	2.6	4.8	8.1
2	54 thru 57	~0	<0.1	0.4	1.2	2.7	4.5
3	49 thru 52	~0	<0.1	0.3	1.0	2.3	3.8
4	46, 47, 48 & 53	~0	<0.1	0.3	0.9	1.9	3.3
5	44 & 45	~0	<0.1	0.2	0.7	1.4	2.6
6	42 & 43	~0	<0.1	0.2	0.7	1.6	2.8
7	39 thru 41	~0	~0	<0.1	0.2	0.6	1.0
8	34 thru 38	~0	~0	<0.1	0.3	0.6	1.1
9	28, 29, 30, 32 & 33	~0	~0	~0	<0.1	0.2	0.3
10	26, 27 & 31	~0	~0	<0.1	<0.1	0.2	0.4

TABLE 4-4
COST CALCULATIONS FOR V. C. SUMMER VHPN ECONOMIC ANALYSIS

Inspection of Nozzles in Outer Three Rows ($K)					
		High	Median	Variance	d
W Cost Range					
Utility Cost Range					
Total Cost Range					
Total Cost Range/Nozzle					
Repair of 1 Nozzle in Outer Three Rows ($K)					
	Low	High	Median	Variance	d
W Cost Range					
Utility Cost Range					
PCI Cost Range					
Total Cost Range					
Failure of 1 Nozzle Anywhere ($K)					
	Low	High	Median	Variance	d
W Cost Range					
Utility Cost Range					
PCI Cost Range					
NRC/Industry Interaction Costs					
ALARA Penalty					
Subtotal Cost Range					
Down Time Penalty					
Total Cost Range w/DTP					

TABLE 4-5
PROBABILITY (%) OF A FLAW WITH DEPTH = 0.75T IN AT LEAST ONE PENETRATION

10 Years (74500 hrs.)	20 Years (149,000 hrs.)	30 Years (223,500 hrs.)	40 Years (298,000 hrs.)	50 Years (372,500 hrs.)	60 Years (447,000 hrs.)
~ 0	2.1	12.0	33.5	57.0	76.9

a,b

Figure 4-1 Mean Crack Growth for V.C. Summer VHP Nozzles

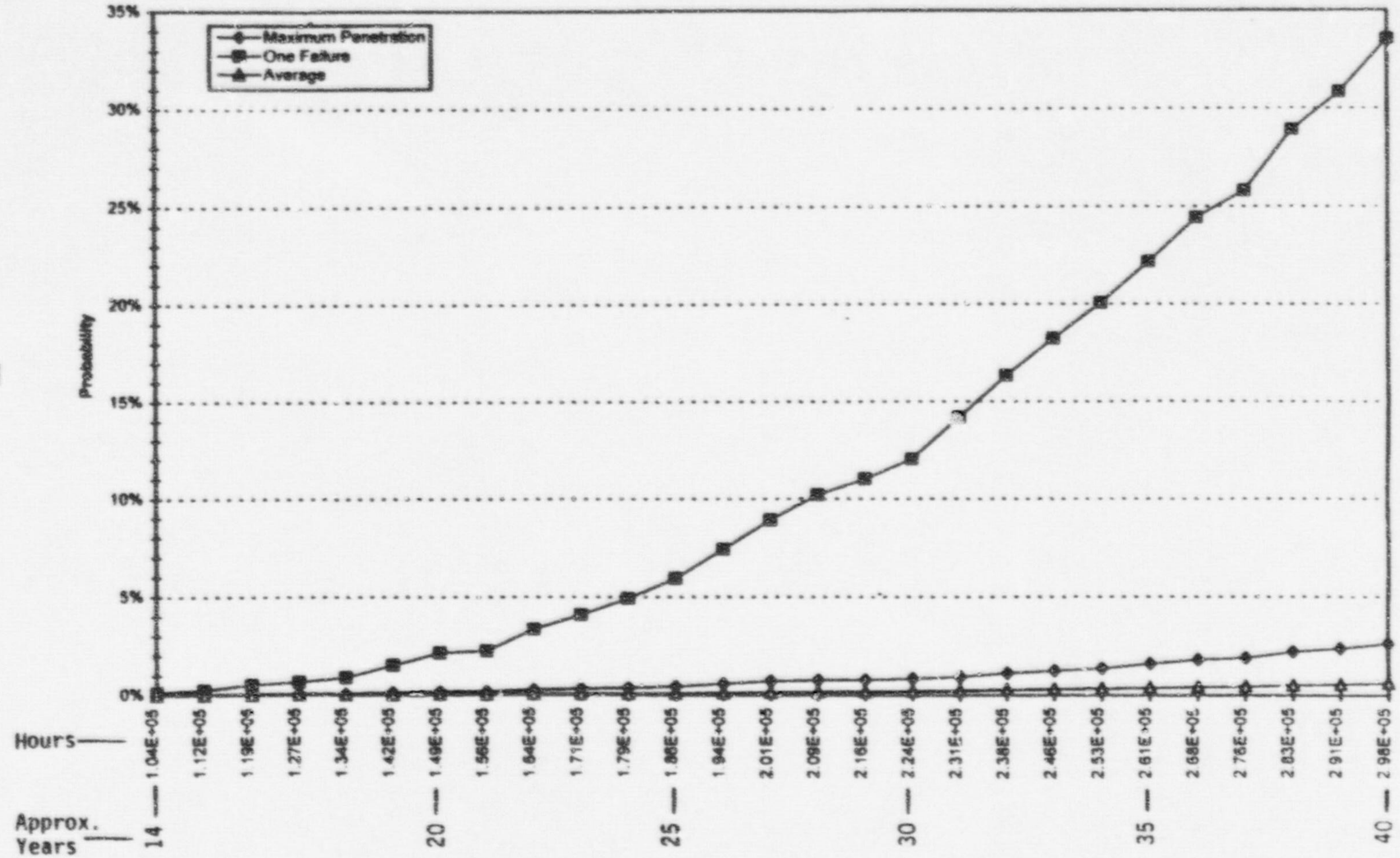


Figure 4-2 Failure Probability for V. C. Summer

a,b

Figure 4-3 Expected Total Costs for No Downtime Penalty

a,b

Figure 4-4 Expected Total Costs with Downtime Penalty

5.0 SUMMARY/CONCLUSIONS

A detailed evaluation of the reactor vessel closure head penetrations has been completed for the Virgil Summer plant. One of the two degradation mechanisms covered by Generic Letter 97-01 has been addressed: Primary water stress corrosion cracking (PWSCC).

An in-depth probabilistic assessment has been completed for all of the reactor vessel closure head penetrations, using state-of-the-art methods which have been independently reviewed. These methods have also been verified by comparison with actual inspection results, as shown in Table 3-2, and discussed in Section 3.

The results of the assessment show that the mean time to failure for the worst penetration is [ ]^{a,b} years, indicating that the V.C. Summer plant is not at risk for this issue. The probability of a flaw initiating and reaching 75% of the wall thickness in 40 years was calculated to be [ ]^{a,b} percent. For 60 years, the probability increases to [ ]^{a,b} percent.

The probabilistic results combined with the economic decision analysis model, and the conclusion reached was that the optimum time (minimum cost) for a head penetration inspection at V.C. Summer would be at [ ]^{a,b} calendar years of service, as shown in Figure 4-4.

6.0 REFERENCES

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Appendix A

Output Files From VHPNPROF for
Probabilistic Failure Analysis
of the V.C. Summer Vessel
Head Penetration Nozzles

WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 65 Nozzles at Virgil C. Summer Plant on 05-31-97 06/06/97

a,b

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	E(NUMFS)
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
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43				
44				
45				
46				
47				
48				
49				
50				
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				

Output Print File VHPNPROF.P01 Opened at 16:44 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	46.1
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-12.3
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 1: RV Head Penetration CGE 58-65

[ ] a,b

a,b

Output Print File VHPNPROF.P02 Opened at 16:51 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	43.1
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-12.3
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

INPUT VARIABLES FOR CASE 2: RV Head Penetration CGE 54-57

[ ] a,b

a,b

Output Print File VHPNPROF.P03 Opened at 17:00 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	42.0
Penetration Setup Angle (degrees)	41.6
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-2.1
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

INPUT VARIABLES FOR CASE 3: RV Head Penetration CGE 49-52

a,b

a,b

Output Print File VHPNPROF.P04 Opened at 17:06 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	41.6
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-12.3
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 4: RV Head Penetration CGE 46; 47; 48; 53

a,b

a,b

Output Print File VHPNPROF.P05 Opened at 17:12 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	40.1
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-12.3
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 5: RV Head Penetration CGE 44 & 45

a,b

a,b

Output Print File VHPNPROF.P06 Opened at 17:17 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	42.0
Penetration Setup Angle (degrees)	40.1
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-2.1
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

INPUT VARIABLES FOR CASE 6: RV Head Penetration CGE 42 & 43

[ ] a,b

a,b

Output Print File VHPNPROF.P07 Opened at 17:22 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	35.5
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-12.3
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 7: RV Head Penetration CGE 39-41

a,b

a,b

Output Print File VHPNPROF.P08 Opened at 17:28 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	42.0
Penetration Setup Angle (degrees)	35.5
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-2.1
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 8: RV Head Penetration CGE 34-38

a,b

[ ]a,b

Output Print File VHPNP'^F.P09 Opened at 17:33 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	30.6
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-12.3
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 9: RV Head Penetration CGE 28;29;30;32;33

a,b

[ ]a,b

Output Print File VHPNPROF.P10 Opened at 17:37 on 05-12-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	42.0
Penetration Setup Angle (degrees)	30.6
Penetration Temperature (F)	557.3
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	-2.1
Months in Operating Cycle	12.0
LOG10 of Years Between ISI	0.00
Wall Fraction for 50% Detection	0.500
Operating Cycles per Year	1.000

STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)

WESTINGHOUSE PROBABILITY OF FAILURE PROGRAM VHPNPROF ESBU-SMPD

==

INPUT VARIABLES FOR CASE 10: RV Head Penetration CGE 26; 27; 31

[ ] a,b

a,b

Appendix B

Output Files From VHPNECON for Economic Decision Analysis of the V.C. Summer Vessel Head Penetration Nozzles

Ref. Year & Interest Rate (%) for NPV Calculations = 1.400E+01 5.000E+00

Min. and Max. Failure Cost per Penetration ($K) = [ ] d

Min. and Max. Inspection Cost per Penetration ($K) =

Min. and Max. Repair Cost per Penetration ($K) =

Reading Probabilities for 8 Nozzles in Group 1 From File: VHPNPROF.001

Reading Probabilities for 4 Nozzles in Group 2 From File: VHPNPROF.002

Reading Probabilities for 4 Nozzles in Group 3 From File: VHPNPROF.003

Reading Probabilities for 4 Nozzles in Group 4 From File: VHPNPROF.004

Reading Probabilities for 2 Nozzles in Group 5 From File: VHPNPROF.005

Reading Probabilities for 2 Nozzles in Group 6 From File: VHPNPROF.006

Reading Probabilities for 3 Nozzles in Group 7 From File: VHPNPROF.007

Reading Probabilities for 5 Nozzles in Group 8 From File: VHPNPROF.008

Reading Probabilities for 5 Nozzles in Group 9 From File: VHPNPROF.009

Reading Probabilities for 28 Nozzles in Group 10 From File: VHPNPROF.010

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	NPVFC-05	NPVFC-50	NPVFC-95
14						
15						
16						
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WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 65 Nozzles at Virgil C. Summer Plant on 06-10-97 06/06/97

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CYISI	NPV-CISI	NPV-CREP	NPV-CBEN	NPVTC-05	NPVTC-50	NPVTC-95
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WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 65 Nozzles at Virgil C. Summer Plant on 06-10-97 06/06/97

Ref. Year & Interest Rate (%) for NPV Calculations = 1.400E+01 5.000E+00

Min. and Max. Failure Cost per Penetration ($K) = [ ]

Min. and Max. Inspection Cost per Penetration ($K) = [ ]

Min. and Max. Repair Cost per Penetration ($K) = [ ] d

Reading Probabilities for 8 Nozzles in Group 1 From File: VHPNPROF.001

Reading Probabilities for 4 Nozzles in Group 2 From File: VHPNPROF.002

Reading Probabilities for 4 Nozzles in Group 3 From File: VHPNPROF.003

Reading Probabilities for 4 Nozzles in Group 4 From File: VHPNPROF.004

Reading Probabilities for 2 Nozzles in Group 5 From File: VHPNPROF.005

Reading Probabilities for 2 Nozzles in Group 6 From File: VHPNPROF.006

Reading Probabilities for 3 Nozzles in Group 7 From File: VHPNPROF.007

Reading Probabilities for 5 Nozzles in Group 8 From File: VHPNPROF.008

Reading Probabilities for 5 Nozzles in Group 9 From File: VHPNPROF.009

Reading Probabilities for 28 Nozzles in Group 10 From File: VHPNPROF.010

WESTINGHOUSE   VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS   VHPNECON
ESBU-NSD   65 Nozzles at Virgil C. Summer Plant on 06-10-97   06/06/97

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	NPVFC-05	NPVFC-50	NPVFC-95
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a,b

CYISI	NPV-CISI	NPV-CREP	NPV-CBEN	NPVTC-05	NPVTC-50	NPVTC-95
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