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August 26, 2004

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10 CFR 2.390

Docket Nos: 50-315
50-316

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Mail Stop O-P1-17
Washington, DC 20555-0001

Donald C. Cook Nuclear Plant Units 1 and 2
TRANSMITTAL OF NON-PROPRIETARY VERSION OF
WESTINGHOUSE WCAP 14907

References:

1) Letter from M. W. Rencheck, Indiana Michigan Power Company, to Document Control Desk, U. S. Nuclear Regulatory Commission, "Response to Request for Additional Information Regarding Unit 2 Control Rod Drive Mechanism Vessel Head Penetration Justification for Safe Operation Until January 19, 2002," C1101-13, dated November 28, 2001.

2) Letter from J. P. Gebbie, Indiana Michigan Power Company, to Document Control Desk, U. S. Nuclear Regulatory Commission, "Updated Affidavits for Withholding Proprietary Information," AEP:NRC:3279, dated June 20, 2003.

This letter transmits a non-proprietary version of a Westinghouse Electric Corporation report regarding control rod drive mechanism vessel head penetrations.

Reference 1 transmitted a Westinghouse Electric Corporation report, WCAP 14907, "Probabilistic Evaluation of Reactor Vessel Closure Head Penetration Integrity for the Donald C. Cook Units 1 and 2," Revision 1, dated November 2001. The WCAP contained information proprietary to Westinghouse. Accordingly, Reference 1 also transmitted an affidavit requesting that the proprietary information in the WCAP be withheld from public disclosure pursuant to 10 CFR 2.790 (which has since been replaced by 10 CFR 2.390). Reference 2 transmitted an updated affidavit for withholding WCAP 14907, Revision 1, from public disclosure. The attachment to this letter provides a non-proprietary version of the WCAP, designated as

A001

WCAP 14907-NP, Revision 2, dated August 2004, which may be made available for public disclosure.

There are no new regulatory commitments contained in this letter. Should you have any questions, please contact Mr. Michael K. Scarpello, Supervisor of Licensing, at (269) 697-5020.

Sincerely,

John A. Zwolinski,
Safety Assurance Director

JW/rdw

Attachment: WCAP-14907-NP, Revision 2, "Probabilistic Evaluation of Reactor Vessel Closure Head Penetration Integrity for the Donald C. Cook Units 1 and 2," dated August 2004.

c: J. L. Caldwell, NRC Region III
K. D. Curry, Ft. Wayne AEP, w/o attachment
Director, Office of Nuclear Reactor Regulation
J. T. King, MPSC, w/o attachment
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ATTACHMENT TO AEP:NRC:4239

WCAP-14907-NP, REVISION 2, "PROBABILISTIC EVALUATION OF REACTOR VESSEL CLOSURE HEAD PENETRATION INTEGRITY FOR THE DONALD C. COOK UNITS 1 AND 2," DATED AUGUST 2004.

NON-PROPRIETARY

Westinghouse Non-Proprietary Class 3

WCAP-14907-NP
Revision 2 (Revision 1 was never issued)

August-2004

Probabilistsic Evaluation of Reactor Vessel Closure Head Penetration Integrity for the Donald C. Cook Units 1 and 2

Westinghouse

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-14907-NP
Revision 2

Probabilistic Evaluation of Reactor Vessel Closure Head Penetration Integrity for the Donald C. Cook Units 1 and 2

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WCAP-NP-titlepg-080304

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EXECUTIVE SUMMARY

This report is intended for use in response to NRC Generic Letter 97-01. Cracking in Alloy 600 reactor vessel head penetrations is a relatively new issue to the nuclear industry. The issue was first brought to the world's 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 power plant in France. Since then a significant number of studies and research programs have been funded by the industry to determine the causes of the problem and develop strategies for repair and management.

Through these programs and subsequent studies it was concluded that reactor pressure vessel head CRDM penetration cracking at Bugey Unit 3 is induced by is a thermally activated stress corrosion mechanism operative in primary water environments, more commonly known as primary water stress corrosion cracking (PWSCC). Based on conservative evaluation results, the NRC and industry concluded that PWSCC cracks were most likely to initiate from the inside surface of the penetrations, in the axial orientation, and would take at least six years to propagate through the wall under the 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. Therefore this issue is an economic one, and does not constitute a serious challenge to plant safety.

External circumferential cracking is less probable. It may occur only in the presence of an above the 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 wastage of the alloy steel RV head is possible. Conservative evaluations estimate that it would take longer than six years after a through-wall crack occurs before the code structural integrity margin for the RV head would be impacted by corrosion. It was concluded that periodic visual inspection of the RV head in accordance with Generic Letter 88-05 is adequate to maintain plant safety, and sufficient to detect leakage prior to significant penetration cracking and vessel head corrosion.

Worldwide, approximately 5,200 Alloy 600 RV head penetrations have been inspected since the first cracking was observed in 1991. Approximately 2 percent of these penetrations are reported to be cracked. Most of the cracks were observed in French RV head penetrations. If the French inspection records are removed from the inspected population, the percentage of head penetrations with indications is only about 0.5 percent. Only one plant worldwide has experienced PWSCC head penetration through-wall leakage, and this was from a single penetration.

Specialized NDE methods have been developed and verified using mock-ups to ensure accurate inspections. Flaws were introduced into the mock-up penetrations by artificial means. The ability of these NDE methods to detect and size the potential PWSCC indications in the vessel head penetrations was demonstrated. Flaw acceptance criteria were established by the industry, and approved by the NRC staff.

The Westinghouse Owners Group has developed methods to evaluate the PWSCC susceptibility and the probability of a penetration initiating a crack, or a leak, as a function of plant operation time. This information has been used to evaluate the need for inspection of the reactor vessel head penetrations or other appropriate actions.

Through participation in WOG and U.S. industry programs, Indiana/Michigan Power Company has taken a proactive approach to address the cracking issue in RV head penetrations. This approach is based on the conclusion that the issue is not an immediate safety concern, because (1) the PWSCC process is slow; (2) the allowable or critical flaw size is large; (3) leak-before-break (LBB) will occur to allow safe shutdown of a plant and (4) at least six additional years of operation with a penetration leak is required before ASME Code structural margins are challenged.

This report contains the specific results for the Donald C. Cook Units 1 and 2 Plants, and these results are being incorporated into an integrated response to the Generic Letter 97-01, which is being prepared in cooperation with the Nuclear Energy Institute. This response was transmitted to the NRC in the Fall of 1997.

1.0 INTRODUCTION

1.1 SUMMARY OF THE SAFETY EVALUATIONS

The purpose of this section is to review the significance of cracking in pressurized water reactor (PWR) vessel head penetrations and to describe the management of the issue in response to the recently released NRC Generic Letter 97-01. This report covers the following areas: worldwide PWSCC history in head penetrations; safety evaluation conclusions reached by WOG and industry and approved by the NRC relative to PWSCC; and a number of supporting tasks performed by Westinghouse for the WOG concerning this issue. The latest findings on this subject are summarized, along with response to specific questions in Generic Letter 97-01.

In February of 1993, Westinghouse and the Westinghouse Owners Group performed an assessment of the continued safe operation of Westinghouse designed NSSS plants in light of the cracking that had been reported in French supplied and operated plant reactor vessel head penetrations.

Westinghouse reviewed the available metallographic and fractographic data from the French plant and concurred with the EdF conclusion that the mechanism of degradation of the Bugey 3 reactor vessel penetration was due to primary water stress corrosion cracking.

The Westinghouse safety evaluation [1] provided the following elements:

1. *A summary of the vessel head penetration stress analyses that focuses on the nature and orientation of cracking that may occur in the Alloy 600 penetration material.* The Westinghouse evaluation concluded that the penetration residual stress induced by welding into the reactor vessel head was the initiating source promoting crack initiation and growth in a susceptible microstructure.

2. *A summary of the crack propagation analysis along with the basis of the prediction methodology.* As indicated in Section 2 of this report, continued crack growth testing has confirmed the initial expectations. The analysis also predicted that cracking would be axial and any cracks formed would be limited in extent by the penetration stress field distribution. The crack lengths predicted were found to be much smaller than the length of cracking required for any instability. The existence of circumferential cracking is unlikely due to the nature of stress distribution in the penetrations (i.e., hoop stress dominates the stress field).

3. *A description of an assessment of the Westinghouse Owners Group vessels with respect to crack indications reported at Ringhals, Beznau, and various EdF plants.* Important parameters applicable for crack initiation (i.e., time, temperature, stress, and material) were compared to those of Ringhals, Beznau and EdF plants. A comparison of susceptibility predictions suggested that the WOG vessels were generally less susceptible than Ringhals. However, several vessels were found to be more susceptible. Since this initial evaluation, three of these vessels were inspected for penetration cracking. One vessel head was found with cracking in a single penetration and no cracking was found in the penetrations of the other two plants. The level and depth of cracking was found to be covered by the Westinghouse Safety Evaluation.

4. *A penetration leakage assessment summarizing leak rate vs. crack size.* Expectations from this evaluation were that (a) leakage would be detected well before cracks extended to their critical flaw size (through-wall, and 8.5-20 inches long) and (b) Boron deposits would be significant enough from small flaws to be readily visible during a Generic Letter 88-05 walkdown.

5. *A vessel head wastage and structural evaluation.* The evaluation showed that the loss of approximately 1.0 in^3 of vessel head material per year could be expected if cracks initiated and propagated through wall, however, vessel structural margins would be maintained for at least six additional years following the through wall leak.

1.2 HISTORICAL BACKGROUND

In 1991, during a hydrotest of the reactor coolant system at the Bugey Unit 3 power plant in France, a leak from the reactor vessel head was detected by acoustic monitoring [2]. Subsequent investigation, by visual examination and destructive testing, revealed that the leak came from a through wall flaw in one of the head penetrations. Further inspections on this and many other plants in France led to the discovery of flaws in the head penetrations of several plants. Examinations confirmed that the problem was directly related to Primary Water Stress Corrosion Cracking (PWSCC).

EdF conducted additional CRDM (Control Rod Drive Mechanism) penetration inspections at its nuclear plants, using eddy current techniques for indication detection and ultrasonic methods for defect size determination. Inspection results and metallurgical examinations confirmed PWSCC in CRDM penetrations at several other EdF plants. This was a concern to the French regulatory authorities as well as to the other PWR owners and regulatory authorities around the world.

These incidents are similar in nature to what occurred to other Alloy 600 tubular parts used in the Reactor Coolant System (RCS). Over the past few years, cracks in Alloy 600 pressurizer heater sleeve penetrations and instrumentation nozzles [3, 4] have been reported at non-Westinghouse supplied domestic and French PWR plants. In February 1990 the USNRC issued information Notice 90-10 on this issue [5]. The Notice informed PWR utilities of a number of incidences of PWSCC of Alloy 600 in applications other than steam generator tubing and suggested that utilities review their Alloy 600 applications and implement an augmented inspection program as necessary. In 1990, EPRI issued a report [4] which suggested that utilities should identify locations where Alloy 600 is used on the primary side, review the material and fabrication records to assess material susceptibility to PWSCC in terms of microstructure, stress, and environment, and implement an inspection program to detect leakage or cracking with the view of replacing susceptible components, as appropriate.

The Westinghouse Owners Group (WOG) and Westinghouse initiated and helped to lead a joint industry owners group under NUMARC, now the Nuclear Energy Institute (NEI), beginning in 1992. The group consists of all owners of Pressurizer Water Reactors in the USA along with EPRI. This group shared technical information and developed consistent safety evaluations and evaluation procedures for flaws that may be found during inspections. The group also worked with EPRI to develop inspection performance demonstrations for the head penetration inspections. The group demonstrated to the US Nuclear Regulatory Commission that cracking on the head penetrations was not an immediate safety issue. The NRC concurred with the

Westinghouse conclusion, stating that vessel head penetration cracking is not an immediate safety issue [6].

1.3 INSPECTIONS PERFORMED TO DATE

In 1994, two WOG/Westinghouse PWR plants in the US (Point Beach Unit 1 and D. C. Cook Unit 2) voluntarily performed inspections of the CRDM penetrations. The results showed that there were no indications found in Point Beach Unit 1. Three indications were found in a single penetration at D.C. Cook Unit 2. These were significant cracks but considerably smaller than the NRC approved acceptance limit.

In Spring of 1996, D. C. Cook Unit 2 re-inspected some of their penetrations that had been previously inspected and confirmed the same indications reported earlier. No new indications were found and the existing indication was successfully repaired. Meanwhile, North Anna Unit 1 inspected 20 out of the total complement of 65 penetrations. No indications were found.

A large number of inspections have been performed on Westinghouse supplied reactor vessel head penetrations throughout the world, and this section will document those inspections, and the findings to date.

ASME Code Section XI inspections (VT-3) have been performed for a number years on the head penetration to reactor vessel partial penetration weld, and the weld between the head penetration tube and the control rod drive mechanism (CRDM). While these inspections do not cover the Alloy 600 inside diameter surface region of the head penetration directly, they do provide surveillance information on the head penetration region, and must be performed on every penetration once every ten years. To date no indications have been reported.

A second series of inspections which have been carried out regularly since 1988 involves visual surveillance of the head for boron deposits which would be evidence of leaks, following NRC Generic Letter 88-05. Some boron deposits have been found by this surveillance, but the sources of the leakage were not from cracked head penetrations. Generally these leaks have been associated with mechanical seals or canopy seals on the vessel head.

Westinghouse supplied NSSS plants in Spain, Sweden, Switzerland, Belgium, Brazil, and Korea have conducted NDE inspections on Reactor Vessel Head Penetrations. By the beginning of 1996, some 5200 penetrations had been inspected worldwide. The results are summarized in Table 1-1. On average, indications were found in approximately 2% of the penetrations that were inspected. Based on Table 1-1, it appears that the rate of indications at U.S. plants is significantly less than that of the French plants. The operating time for the plants of US manufacture where the inspections have been performed has in most cases been much longer than for the French plants. Of all these inspections, only one penetration was found to have through-wall cracking: the Bugey plant where cracking was first identified.

It will be of interest to examine the history of inspections of the plants of Westinghouse design worldwide, as well as the plants of Westinghouse design with US fabrication. A relatively large number of these plants have been inspected, and very few indications have been found. Outside of France, a total of 39 plants of Westinghouse design have been inspected. Of approximately 1900 penetrations inspected, only 10 were reported to be cracked, amounting to a less than 0.6 percentage. Of the 39 plants, 9 were manufactured in the USA, and for these plants approximately 310 penetrations were inspected with only one reported to be cracked. Thus, for Westinghouse plants manufactured in the USA, only 0.3 percent of the penetrations have been found to be cracked.

Root cause evaluations concluded that the cracks were caused by PWSCC of the Alloy 600 material. Electricite de France (EdF) and Westinghouse concluded that the following factors contributed to the Bugey Unit 3 PWSCC.

- Susceptible microstructure produced during manufacturing
- Surface finish on the inside diameter surface of the penetration
- Stresses induced during welding, which caused ovalization of the penetration

TABLE 1-1
WORLDWIDE VESSEL HEAD PENETRATION PWSCC INSPECTION RESULTS*

Country	Number of Plants Inspected	Total No. of Penetrations in the plants	Number of Penetrations Inspected	Penetrations With Indications	Rate of Indication Detected**
France	47	3225	3213	105	3.3%
Sweden	3	195	190	7	3.7%
Switzerland	2	72	72	2	2.8%
Japan	17	960	834	0	0
Belgium	7	435	435	0	0
Spain	5	325	102	0	0
Brazil	1	40	40	0	0
South Africa	1	63	63	0	0
South Korea	1	65	65	0	0
United States	5	314	217	1***	0.5%
Total:	89	5694	5231	115	2.0%

* Based on data available as of January 1996 (Europe) and July 1996 (U.S.).

** Ratio of number of penetrations with indications detected to number of penetrations inspected.

*** Oconee indications were not counted as cracks, because they had no measurable depth. Eddy current reinspection after one cycle did not indicate any growth

1.4 WOG AND NUCLEAR INDUSTRY PROGRAMS SUMMARY

A number of WOG programs were initiated to investigate the reactor vessel head penetration PWSCC issue. The key programs are summarized in Table 1-2. Additionally, selected utility programs have been responsible for the resolution of IGA due to sulfur species, and penetration attachment weld cracking. Domestically, the Babcock and Wilcox Owners Group (BWOG), Combustion Engineering Owners Group (CEOG), Westinghouse Owners Group (WOG) and the Electric Power Research Institute (EPRI) agreed to combine their efforts as part of the Nuclear Energy Institute's (NEI) Alloy 600 CRDM Head Penetration Cracking Task Force. The purpose of the task force was to evaluate the issue and to recommend appropriate generic actions. Through this effort, the Owners Groups (OGs) and EPRI have conducted the following tasks:

- Performed safety analyses of vessel head penetration cracking
- Standardized flaw evaluation methods
- Developed flaw acceptance criteria
- Developed inspection methodologies to size indications in head penetrations
- Evaluated remedial measures and created probabilistic and economic decision making tools
- Evaluated leakage effects on the vessel head low alloy steel shell

In addition, WOG has developed penetration repair techniques, plant inspection guidelines, and evaluated available leakage detection devices.

The NRC has evaluated the safety analyses and concluded that PWSCC of Alloy 600 head penetration is not an immediate safety concern [6].

Under the programs, research on PWSCC was conducted domestically and overseas, for example, as shown in Refs. 3, 7, 8, 9 and 10. The studies focused on material aspects and mechanics. Material aspects, thermomechanical processing effects, material properties, residual stresses, and microstructure were studied. A model of PWSCC susceptibility and cracking probability was developed [10].

Finite element analyses were performed to determine stresses in the penetrations. The finite element analyses performed included simulation of the whole spectrum of the mechanical fabrication sequences experienced by the RV head penetrations, such as the welding process, hydrotest, straightening and service loads. The finite element simulations allowed the determination of the applied as well as the residual stresses in the penetrations under any given specific geometrical, material, welding, temperature, and loading conditions. Based on the stress data, PWSCC initiation, crack propagation, and final failure were then evaluated. The analysis also furnished results for the time period required for the PWSCC to penetrate through the wall thickness of the penetration and the critical crack size above which instability would occur. Initial crack growth behavior was assumed to be represented by the model developed by P. Scott [11].

Confirmatory crack growth laboratory testing was immediately begun to verify that this initial assessment was correct. The integrity model was structured to be applicable to all penetrations regardless of product form or vessel fabricator. Subsequent testing to obtain comparison data in this area was initiated in 1996. The crack growth test results and preliminary crack initiation test results are discussed in Sections 2 and 3.

TABLE 1-2 SUMMARY OF KEY TASKS PERFORMED BY WOG		
Item	Task Description	Status
1	Root Cause of Cracking	C
2	Key Material & Operation Parameters	C
3	Elastic Finite Element Analysis: Residual/Operational	C
4	Elastic/Plastic Finite Element Analysis: Residual/Operational; 3 Locations	C
5	Crack Propagation/Acceptable Flaw Size Analysis	C
6	Penetration Leakage & Vessel Head Wastage Assessment	C
7	Safety Evaluation	C
8	Plant Screening/Susceptibility Criteria	C
9	Material Microstructure Characteristics	C
10	Leakage Detection Methods Survey	C
11	Evaluation of PWSCC Mitigation Methods	O
12	Grinding Effect on Residual Stresses	C
13	Development/Evaluation of Repaired Configurations	C
14	OD Crack Assessment	C
15	Crack Growth Data and Testing	O
16	Inspection Timing and Economic Decision Tools	C
17	Penetration Attachment Weld Safety Evaluation Report	C
18	Crack Initiation Characterization Studies	O
19	Residual Stress Measurements	C
20	Development of PWSCC Susceptibility Ranking Models	C

Key: C = Complete O = Ongoing.

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 the NRC submittals made in 1992 and 1993. The goal of this section of the report 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 Alloy 600 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 prediction 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 [11]. His model was based on a study of results obtained by McIlree and Smialowska [12] 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 11 contains an error, in that no correction for cold work was applied to the McIlree/Smialowska data. The revision of the Peter Scott model is presented below.

An equation was fitted to the data of Reference 12 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 330°C:

$$\frac{da}{dt} = 2.8 \times 10^{-11} \, (K-9)^{1.16} \ \mathrm{m/sec} \quad 1$$

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 [11] in his paper was to correct these results for the effects of cold work. Based on work by Cassagne and Gelpi [13], 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 was discussed. The revised crack growth model for 330°C then becomes:

$$\frac{da}{dt} = 2.8 \times 10^{-12} \, (K-9)^{1.16} \ \mathrm{m/sec} \quad 2$$

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. 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 [14], who went back to the original data base, and had a smaller correction for cold work. His equation was of a slightly different form:

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

Where A = -25.942

B = 3.595

C = the threshold for cracking

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 [15].

The final verification of Peter Scott's model will come from actual data from head penetration materials in service, as will be discussed in detail 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 growth 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 are 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 penetration materials.

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 stress intensity factor variation 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 although there is a wide scatter band in the figure. 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 obtained to-date are shown in

Figure 2-2. Sufficient results are available to report preliminary findings. The tests were performed with an applied stress intensity factor of 23 Ksi $\sqrt{in}$ 1 (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 H_2. 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 within 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 that 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 [16], 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 modified Scott model in the safety evaluations and other evaluations of head penetration integrity 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 $MPa[m]^{0.5}$

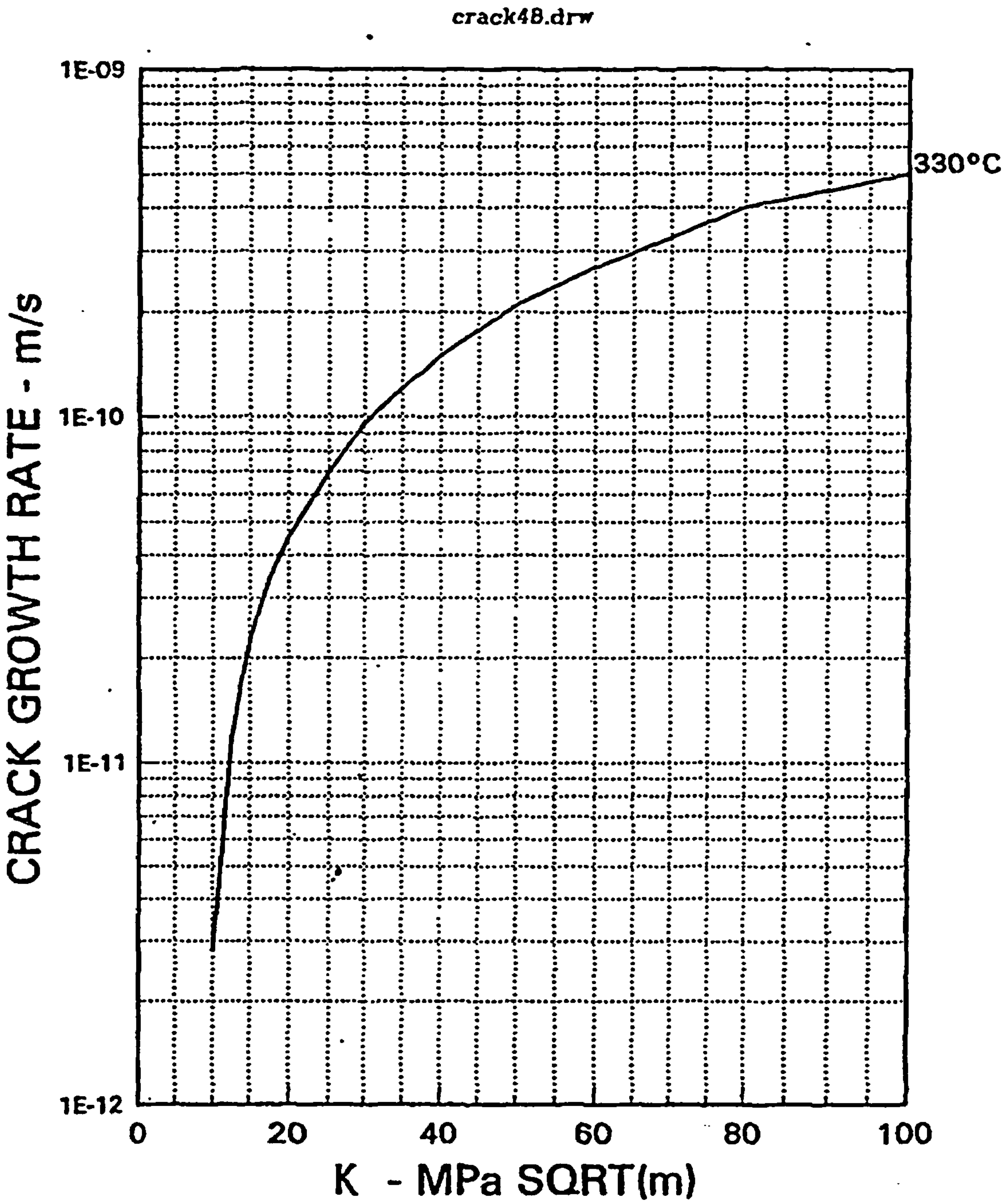

Figure 2-1 Scott Model for PWSCC of Alloy 600 at 330°C, as modified from Reference 11

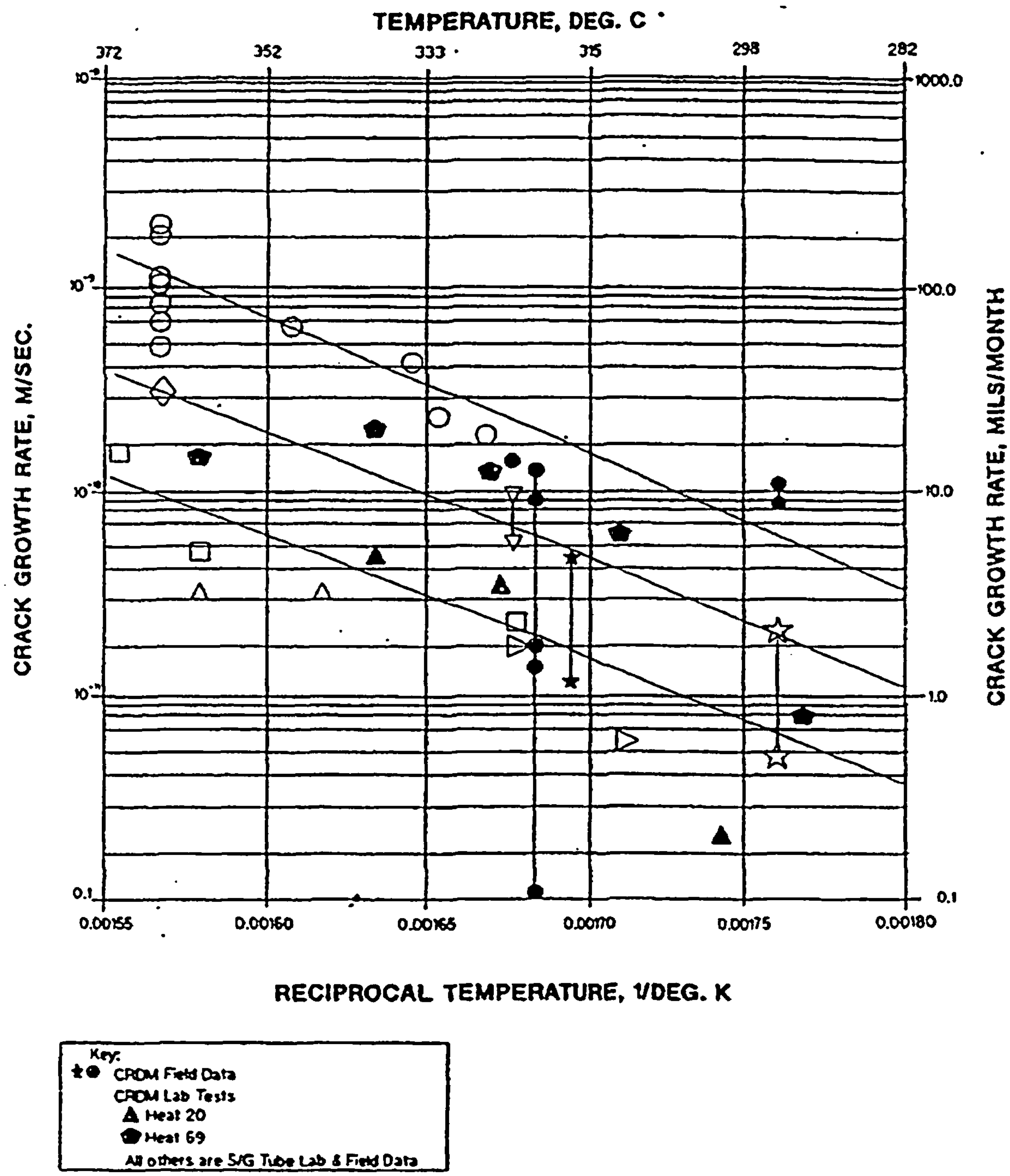

Figure 2-2 Comparison of Temperature Effects Results with Other Laboratory and Field Data

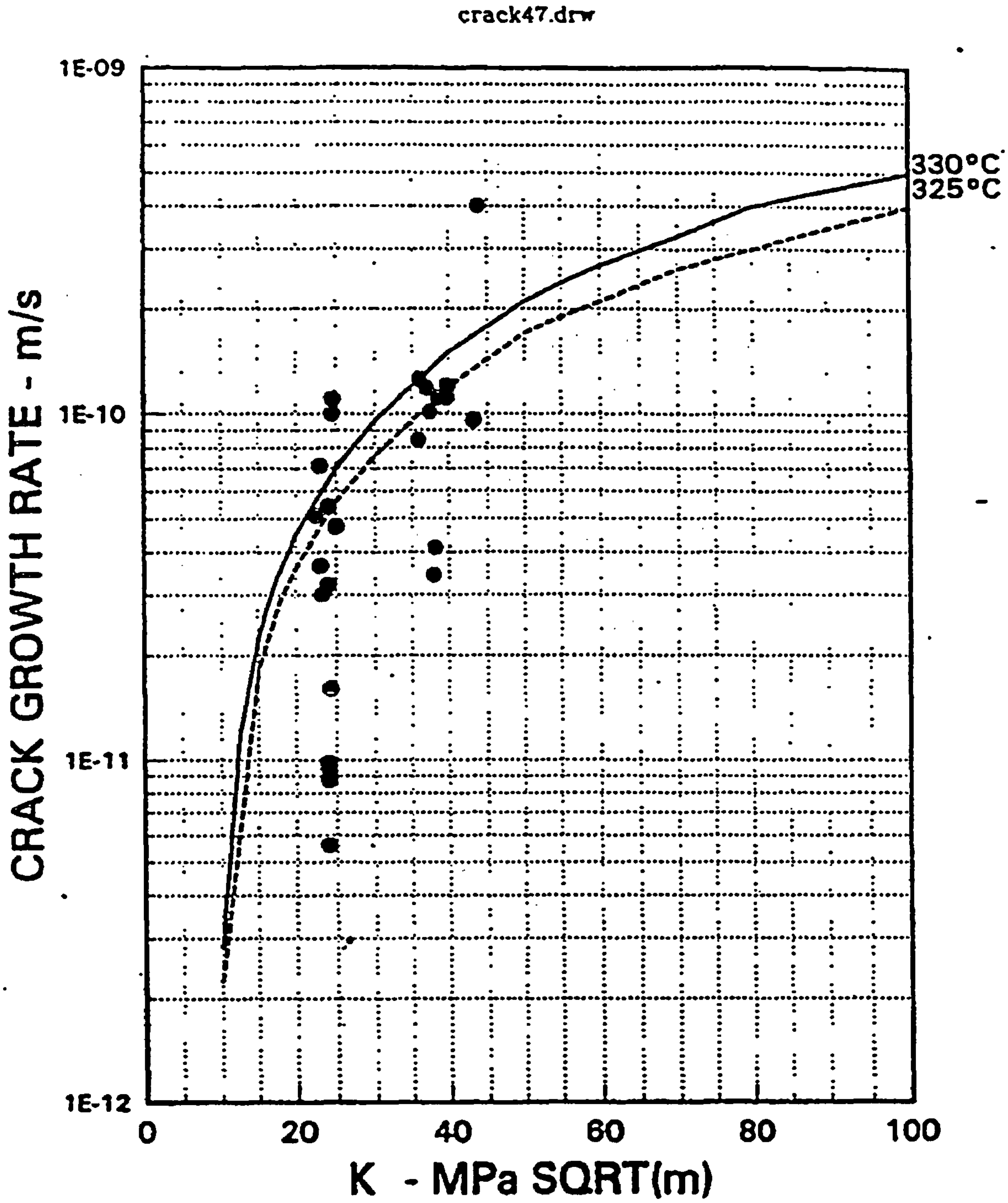

Figure 2-3 **Summary of Available Westinghouse Laboratory Data for Alloy 600 Head Penetrations at 325°C**

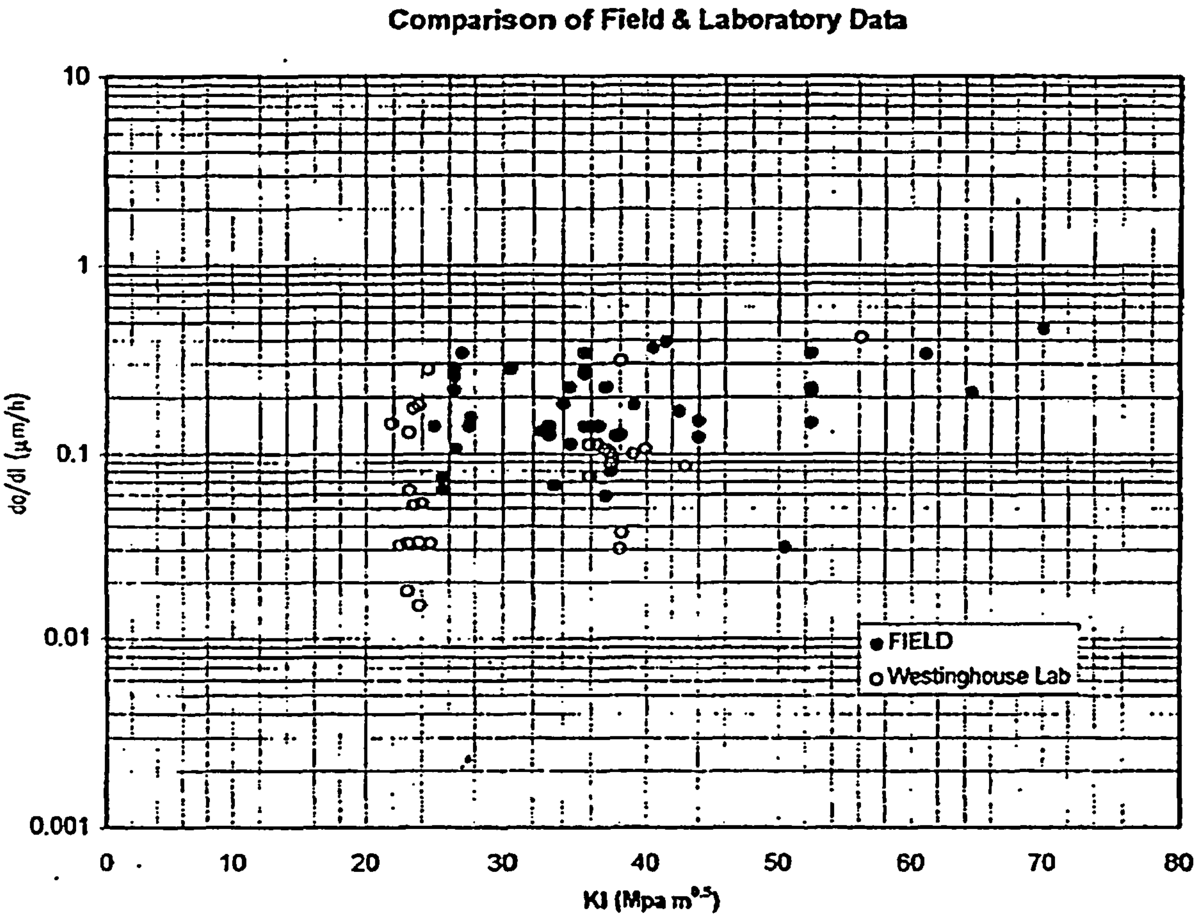

Figure 2-4 Comparison of French Field Data and Westinghouse Laboratory Data (W results reduced to 290°C using Q = 130 KJ/mole) [16]

3.0 WESTINGHOUSE CRACK INITIATION MODEL DEVELOPMENT AND CRACK INITIATION TESTING

3.1 CRACK INITIATION MODEL

Westinghouse advanced an Alloy 600 PWSCC initiation model for primary components in Pressurized Water Reactors [10]. Briefly, the model incorporates three contributing factors for the prediction of crack initiation time; namely, material condition, stress, and temperature. These are discussed below.

Material Condition and Microstructure

As reported by several authors [17, 18, 19, 20, and 21], the Alloy 600 microstructure is a function of the thermomechanical history of the material heat as well as its carbon content. Alloy 600 material heats subjected to mill annealing at low temperatures, i.e., 926°C or less, exhibit a fine grained microstructure with heavy transgranular carbide precipitation and little or no carbides precipitate on the grain boundaries. Such a microstructure is reported to be more susceptible to PWSCC. On the other hand, a high temperature mill-anneal (>1000°C) tends to put more carbon into solution, increases grain size, produces grain boundary chromium carbide precipitation and renders the material more resistant to resist PWSCC. Norring, et. al. [22], did not find a correlation between the total content of carbon and the crack initiation time, but they observed good correlation between the amount of grain boundary carbides and crack initiation time. The fact that grain boundary precipitation is beneficial to PWSCC has been reported by many researchers [23]. Norring, et. al., [22], showed that the crack initiation time varied directly (linearly) with grain boundary carbides. Their data suggested that when the grain boundary carbide coverage is increased by a factor of 3, the crack initiation time also increased by a similar factor (from 4,000 hours to 12,000 hours). Bandy and Van Rooyen [24], pointed out that in addition to grain boundary carbide coverage, other features relating to processing history variables such as carbon concentration gradients, substructural features, grain size distribution, cold work, intragranular carbide distribution and the grain boundary segregates all play an important role in the cracking behavior of the Alloy 600 material.

When considering the influence of microstructure on the PWSCC susceptibility for the purpose of the current evaluation, to enable comparison of heats fabricated at different vendor shops, the thermomechanical processing history effect is separated from the grain boundary carbide coverage effects. In general, the influence of the grain boundary carbides is known and the coverage (G) can be easily measured directly from the microstructure. The influence of other structural features due to processing history cannot be assessed directly. These processing effects are represented in the current treatment by a single parameter (A) characteristic of the fabrication shop (vendor). This approach provides a means of comparing the PWSCC susceptibilities of Alloy 600 material heats from different vendor shops although they may contain similar grain boundary carbide contents.

Influence of Stress

Steady state tensile stress in the component, either due to residual and/or applied loads, has a strong influence on the PWSCC.

Bandy and Van Rooyen [24], reported that the time to failure varied inversely as the fourth power of applied stress in both annealed and coldworked specimens. They also reported data to support that coldwork reduces the resistance to PWSCC. The effective stress at a given Alloy 600 location is a function of the fabrication steps and their sequence, the yield stress of the material, and the service stress. In general, the local residual stresses resulting from fabrication can play a more significant role than the service stresses themselves.

Temperature Effects

Several investigators [17, 24], examined the role of temperature on PWSCC. It is well *established from these results that the crack initiation time decreases exponentially with* temperature and that they are related through an Arrhenius equation expressed as a function of the activation energy of the process. The experimental results confirm that Alloy 600 PWSCC is a thermally activated process and the activation energy for the process varies approximately between 50 to 55 kcal per mole. An activation energy value of 55 kcal/mole is consistently applied throughout the current assessments, for crack initiation. A different value, 32.4 applies for crack growth as was discussed in Section 2.

3.2 THE WESTINGHOUSE CRACK INITIATION MODEL

Consistent with the contributing factors discussed above, the crack initiation time (t_i) or the rate of crack initiation ($1/t_i$) is proportional:

$$1/t_i \ \alpha \ (\text{Stress})^n$$

$$\alpha \ e^{-Q/RT}$$

α inverse of the grain boundary carbide coverage factor, (1/G)

so that $$1/t_i \ \alpha \ \frac{\sigma^n \ e^{-Q/RT}}{G}$$

Since the nature of the vendor thermomechanical processing is also a significant contributing factor, one can say that for a given fabrication process

$$1/t_i = A \ \frac{\sigma^n \ e^{-Q/RT}}{G} \tag{3-1}$$

The proportionality constant "A" can be chosen to represent the processing conditions representative of a given manufacturing process or manufacturer, and could include parameters such as yield strength as part of the expression.

"A" can be assessed for a given heat by substituting the parameters of a service component with a known cracking history for the heat of material. "A" will then represent the processing condition (or the vendor) by the definition we have just established.

The parameters in the above rate equation (3-1) are described below:

A is a constant, relating to the processing, and fabrication conditions of the material

G is the grain boundary carbide coverage factor

Φ is the effective tensile stress (resulting from applied and residual stresses)

n is the stress exponent having a value ranging from 3.5 to 4.5 for Alloy 600 in primary water

Q is the activation energy for the crack initiation process and has an approximate value of 55 kcal/mole

R is the gas constant (1.987 cal/mole degrees K)

T is the absolute temperature in degrees K, and

t_i is the time to initiate cracking.

3.3 CRACK INITIATION TESTING

Westinghouse currently has an ongoing autoclave test program to establish the PWSCC crack initiation behavior of archive Alloy 600 RV head penetration material heats from a variety of fabricators representative of microstructures of RV head penetrations that are currently in service. The objectives of the Program are:

- **To determine the effect of penetration microstructure and material type (vendor) on the relative susceptibility to cracking.**
- **To define a material index (A) to assist in plant maintenance planning.**

The program is sponsored by EPRI and the CE, W, and B&W owners groups. The accelerated testing is conducted under dense steam with hydrogen at 400°C and utilizes full size ring samples fabricated from RV head penetration tubing from different vendor shops. A listing of vendor shops representing the ring samples employed in the testing is provided in Table 3-1. To provide reference benchmarking, samples from steam generator rolled transition tubing and

Alloy 690 penetration material are also included in the test matrix. Penetration material specimens with known crack growth behavior measurements from previous test programs are included for comparison with other data.

This environment has been shown to provide adequate acceleration (up to 500x) to provide results within the test period. This will be verified using the specimens from heats that have been tested previously. Test samples under the doped steam test will be inspected at 25, 50, 100, 200, 400, 800, 1400 and 2000 hours. Inspection will include visual, metallographic and destructive examinations.

The ID surfaces of the ring samples are strained by controlled cyclic ovalization to simulate the residual hoop stresses in the plant. The stresses are quantified based on the ovalization. The final cycle of ovalization is calibrated to induce a 2mm difference in measured inside diameter. This corresponds to the upper 95% of the measured ovality in the outermost penetrations in service. The cyclic straining procedure of the full ring samples is illustrated by the loading curve shown in Figure 3-1.

The testing is conducted under two phases. The first phase involves a cumulative exposure of up to 800 hours in six exposure intervals. Periodic inspections are performed at 25, 50, 100, 200, 400 and 800 cumulative hours of exposure. The second phase testing involves the exposure of specimens for a cumulative exposure of up to 2000 hours with an interim inspection at 1400 hours. Currently, with the Phase I testing completed, the preliminary test results indicate clear trends in the initiation behavior. Out of the six heats of material tested, two of the heats consistently showed higher susceptibility to cracking; the worst heat being the heat that also showed the highest crack growth rate under the crack growth test program discussed in Section 2. Further useful trends in cracking behavior are expected at the end of the 2000 hours exposure. The overall results of the program are expected to provide useful information for plant maintenance planning.

TABLE 3-1 MATERIAL HEATS EMPLOYED IN THE ALLOY 600 RVHP CRACK INITIATION TESTS				
S No.	Heat No.	Supplier	Fabricator	As Pred. Size
1	93510	B&W	B&W	½" (6 pcs)
2	93510-R	B&W	B&W	½" (6 pcs)
3	91069	B&W	B&W	½" (6 pcs)
4	93511	B&W	B&W	½" (6 pcs)
5	WF675	B&W	Creusot Loire	3-5/8" (1 pc)
6	WF151	Sizewell	Creusot Loire	3-½" (1 pc)
7	M-7817-1 (EO-6943#2)	CE	Standard Steel	4-1/8" (1 pc)
8	R13-4 (NX64209)	CE	Huntington	4-1/8" (1 pc)
9	NX8101-75		Huntington	6" (1 pc)
10	NX34C3-68		Huntington	6" (1 pc)
11	R177	Vattenfall	Sandvik	6" (1 pc)

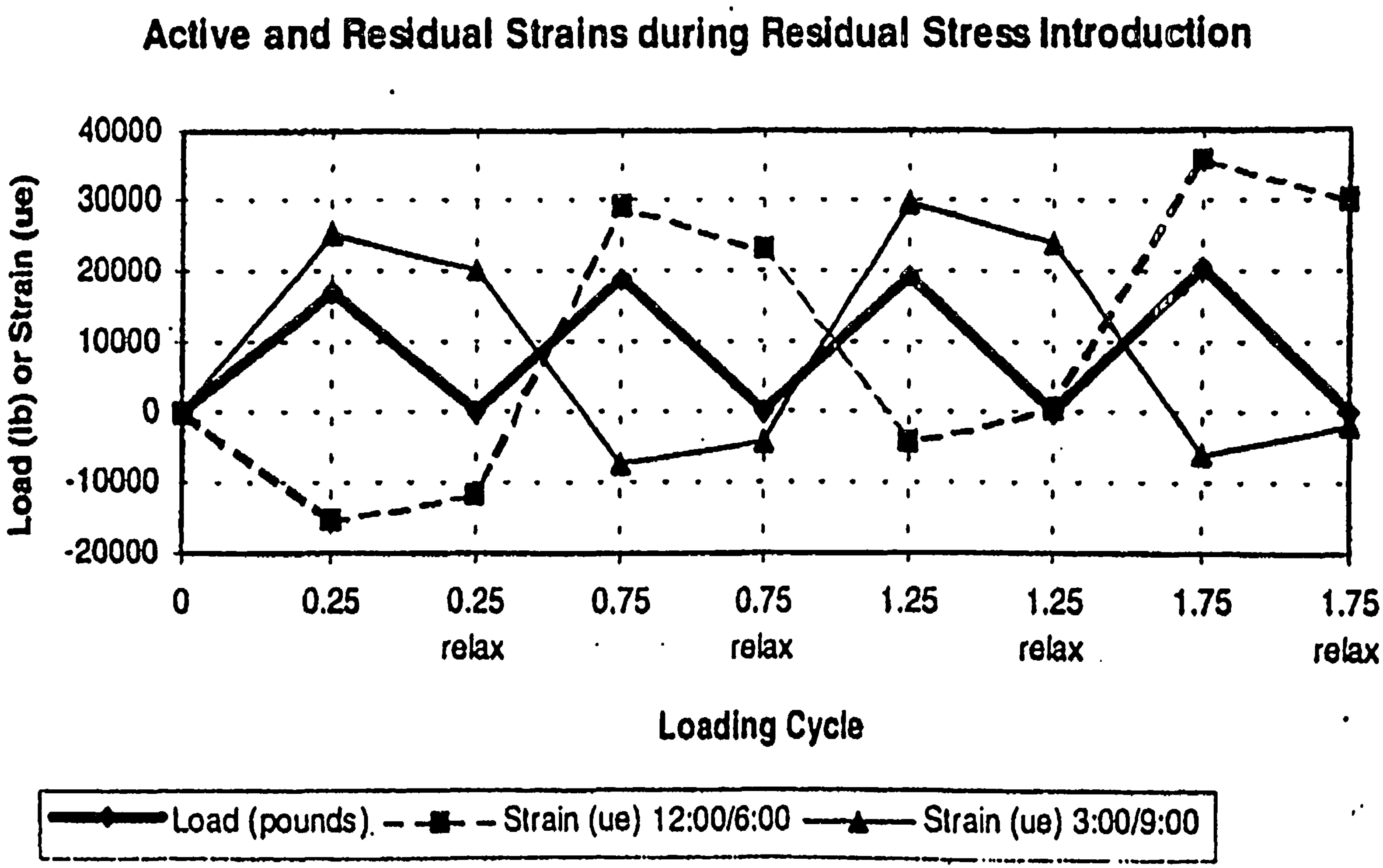

Figure 3-1 Residual Stresses and Strains Induced During Controlled Cyclic Ovalization of RV Penetration Ring Samples

4.0 TECHNICAL DESCRIPTION OF PROBABILISTIC MODELS

To calculate the probability of failure of the Alloy 600 vessel head penetration as a function of operating time t, $Pr(t \leq t_f)$, 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 head penetration nozzles are based upon the probabilistic and 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 4-1),

2. Crack growth rates agree with measured field data (see Figures 2-3 and 2-4).

Recent improvements have also been made to the model in order to maximize its use for individual plant predictions. Among the changes were:

1. The model accepts measured microstructure (replication) and also has the capability to ignore its effects, if desired.

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

3. Statistically based Bayesean updating of probabilities due to initial inspection results has been added (e.g. the lack of any indications at any given plant),

4. The uncertainty on crack growth rate after initiation has been updated to reflect the findings observed in the recent Westinghouse test data and the recent in-reactor measurement data to be published by EdF [16] (see Figure 4-2),

5. All models have been independently reviewed by APTECH Engineering (Begley and Woodman)[25], and an improved model was developed for the effect of monotonic yield strength on time to initiation, and

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

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

$$t_f = t_i + (a_f - a_0) / da/dt \qquad (4\text{-}1)$$

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 (4-1), 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 axial cracks in the penetration that are deeper than the structural limit of 75% of the penetration wall thickness (w), it would be specified as:

$$a_f = 0.75\,w \qquad (4\text{-}2)$$

The time to PWSCC crack initiation, t_i in hours, consistent with the previous equation 3.1 by RAO [10] and is defined by:

$$t_i = \frac{C_1 + (1 + C_2 P_{GBC})}{\sigma^{n_1} \cdot S_y^{\,n_2}} \exp\left(\frac{Q_1}{RT}\right) \qquad (4\text{-}3)$$

C_1 = a log-normal distribution on the initiation coefficient, which was based upon the data of Hall and others [26] for forged Alloy 600 pressurizer nozzles, with only the uncertainty based upon the data of Gold and others [27],

C_2 = coefficient for the effect of grain boundary carbide coverage, which is based upon the data of Norring and others [22],

σ = the maximum residual and operating stress level derived from the detailed elastic-plastic finite-element analysis from the WOG study of Ball and others [28] as shown in Figure 4-1, with its normally distributed uncertainty being derived from the variation in ovality from Duran and others [29] (see Figure 4-3), which is a trigonometric function of the penetration diameter and setup angle (local angle between the head and longitudinal axis of penetration).

S_y = yield strength of the penetration material,

$n_1 n_2$ = exponents on stress and yield strength, respectively ($n_1 = 4$, $n_2 = 2.5$)

Q_1 = the activation energy for crack initiation, which is normally distributed,

R = universal gas constant, and

T = the penetration absolute temperature, which is uniformly distributed based upon the calculated variation of the nominal head operating temperature.

Equation 4-3 is equivalent to the initiation equation by Rao [10] as listed in Section 3.2, where $G/A = C_1 + (1 + C_2 P_{GBC})/S_y^{\,n_2}$.

Either data from field replication [30] or the correlation model by RAO [31] can be used to determine the percent grain boundary carbide coverage, P_{GBC} in equation (4-3). The model [31] 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 4-4, applies equally well to both the predicted and measured values.

The hours at temperature per operating cycle (year), which is normally distributed, is used to check if crack initiation has occurred. Once the crack has initiated, it is assumed to have a depth of a_0 and its growth rate, da/dt, 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 [32], as discussed in Section 2. The crack growth model is:

$$\frac{da}{dt} = C_3 (K_I - K_{TH})^{1.16} \exp\left(\frac{Q_2}{RT}\right) \quad (4\text{-}4)$$

C_3 = a log-normally distributed crack growth rate coefficient (see Figure 4-2),

K_I = 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 the following form of the Raju and Newman equations [33]:

$$K_I = 0.982 + 1.006\ (a\ /\ w)^2 s(\pi\ a)^{0.5} \quad (4\text{-}5)$$

Q_2 = activation energy for PWSCC crack growth, which is also normally distributed, and

K_{TH} = threshold stress intensity factor for crack growth

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. Monte Carlo simulation is an analytical method that provides a histogram of failures with time in a given number of trials (simulated life tests). The area under the simulated histogram increases with time due to PWSCC. The ratio of this area to the total number of trials is approximately equal to the probability of failure at any given time. In each trial, the values of the specified set of random variables is selected according to the specified distribution. A mechanistic analysis is performed using these values to calculate if the penetration will fail at any time during its lifetime (e.g. 60 years). This process is repeated many times (e.g. 6000) until a sufficient number of failures is achieved (e.g. 10 per year) to define a meaningful histogram, which is an approximation of the lower tail of the true statistical distribution in time to failure (see Figure 4-5). The shape of the distribution depends upon the input median values and specified distributions of the random variables. It is not forced to be an assumed type of distribution (e.g. Weibull) as is done for other non-mechanistic probabilistic methods. For the worst penetration in one plant, the mean time to failure was greater than 160 years but its uncertainty was so large that the normalized area under the histogram (estimated probability) at 60 years was 8 percent.

To apply the Monte Carlo simulation method for vessel head penetration nozzle (VHPN) failure, the existing PROF (probability of failure) object library in the Westinghouse Structural Reliability and Risk Assessment (SRRA) software system was combined with the PWSCC structural reliability models described previously. This system provides 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.

As reported previously [34], the Westinghouse SRRA Software System has been verified by hand calculation for simple models and alternative methods for more complex models. Recently the application of this same Westinghouse SRRA 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 [35] and other independent NRC contractors. Table 4-1 provides a summary of the wide range of parameters that were considered in this comprehensive benchmarking study that compared the Westinghouse calculated probabilities from the analysis (labeled SRRA) with those from the pc-PRAISE program [36]. As shown in Figure 4-6, 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.

In addition, the VHPNPROF Program calculated probabilities of getting a given crack depth due to PWSCC were compared for four plants where sufficient head penetration information and inspection results were available. The four plants are identified in Table 4-2 along with the values of the key input parameters and calculated failure probabilities. Table 4-2 also shows the agreement between the latest available inspection results and VHPNPROF predicted failure trends due to PWSCC.

TABLE 4-1 PARAMETERS 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 value of stress range and high value of frequency) for small pipe, Thermal Fatigue (high value of stress range and low value of frequency) for large pipe.

TABLE 4-2
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	51.2	51.2
Percent GBC	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 Reported Indications from ISI	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 individual penetration.

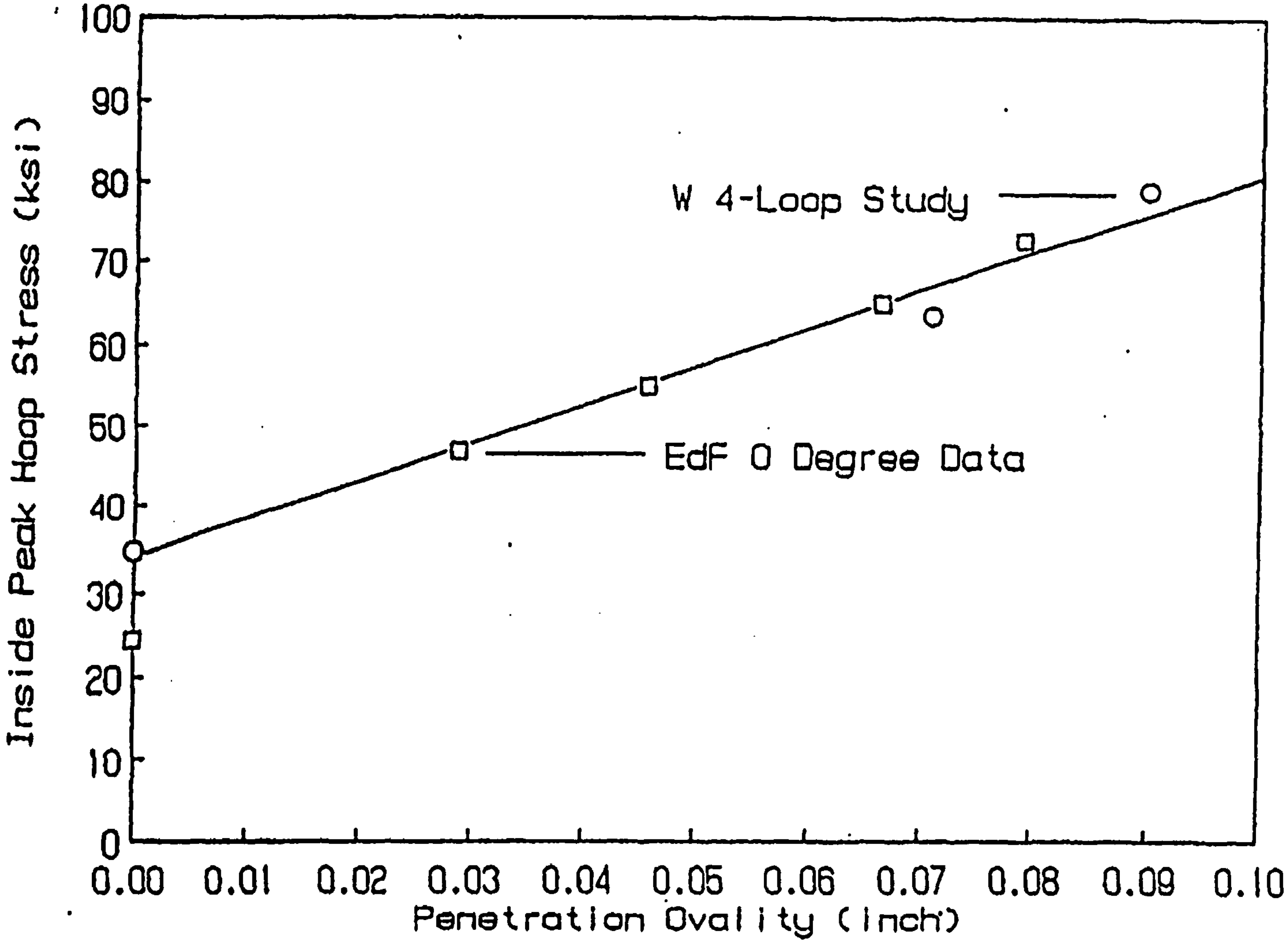

Figure 4-1 Vessel Head Penetration Stresses from WOG 4-Loop Plant Study [28]

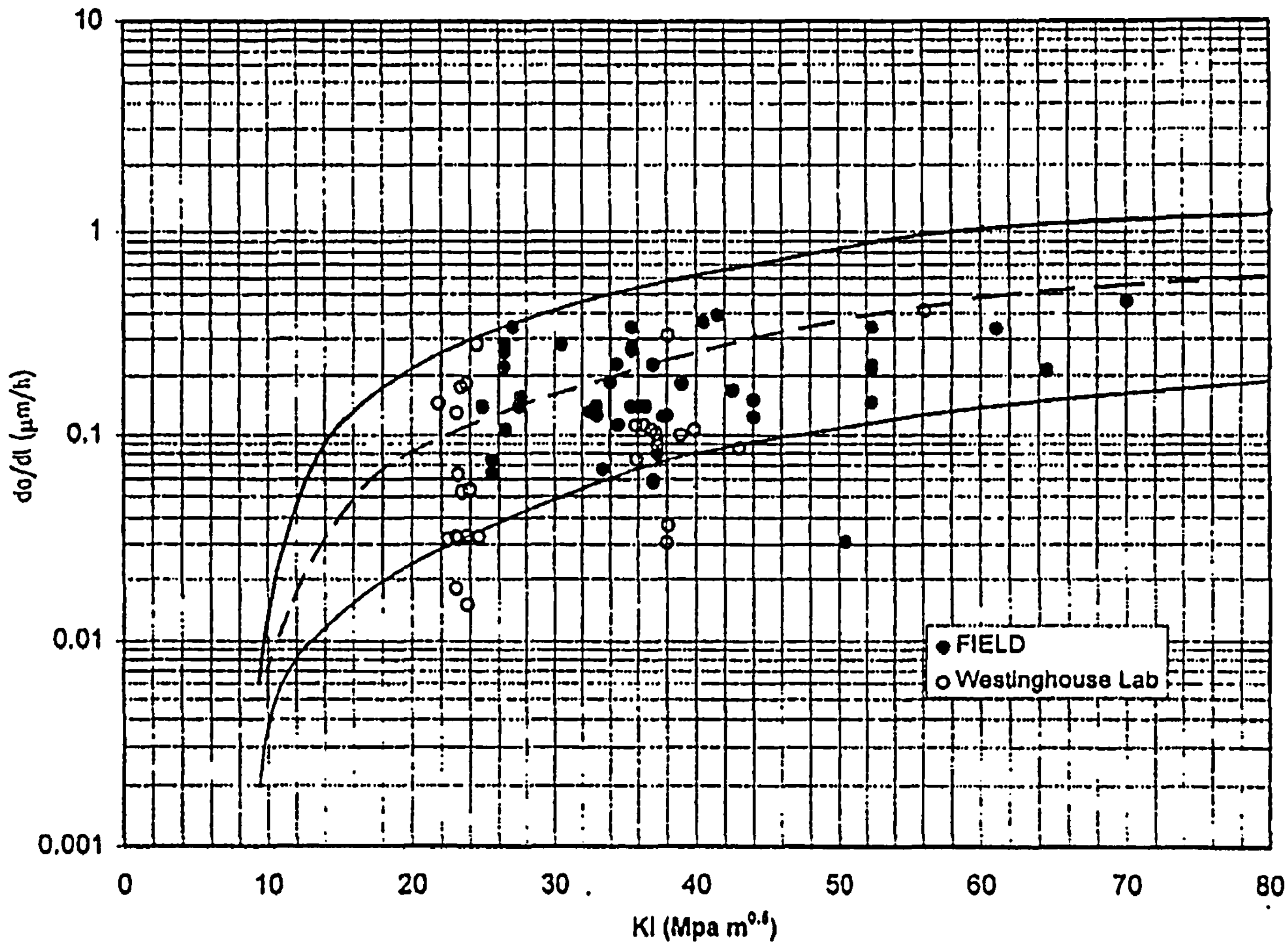

Figure 4-2 Comparison of Recent Alloy 600 Data with the Crack Growth Rate Model

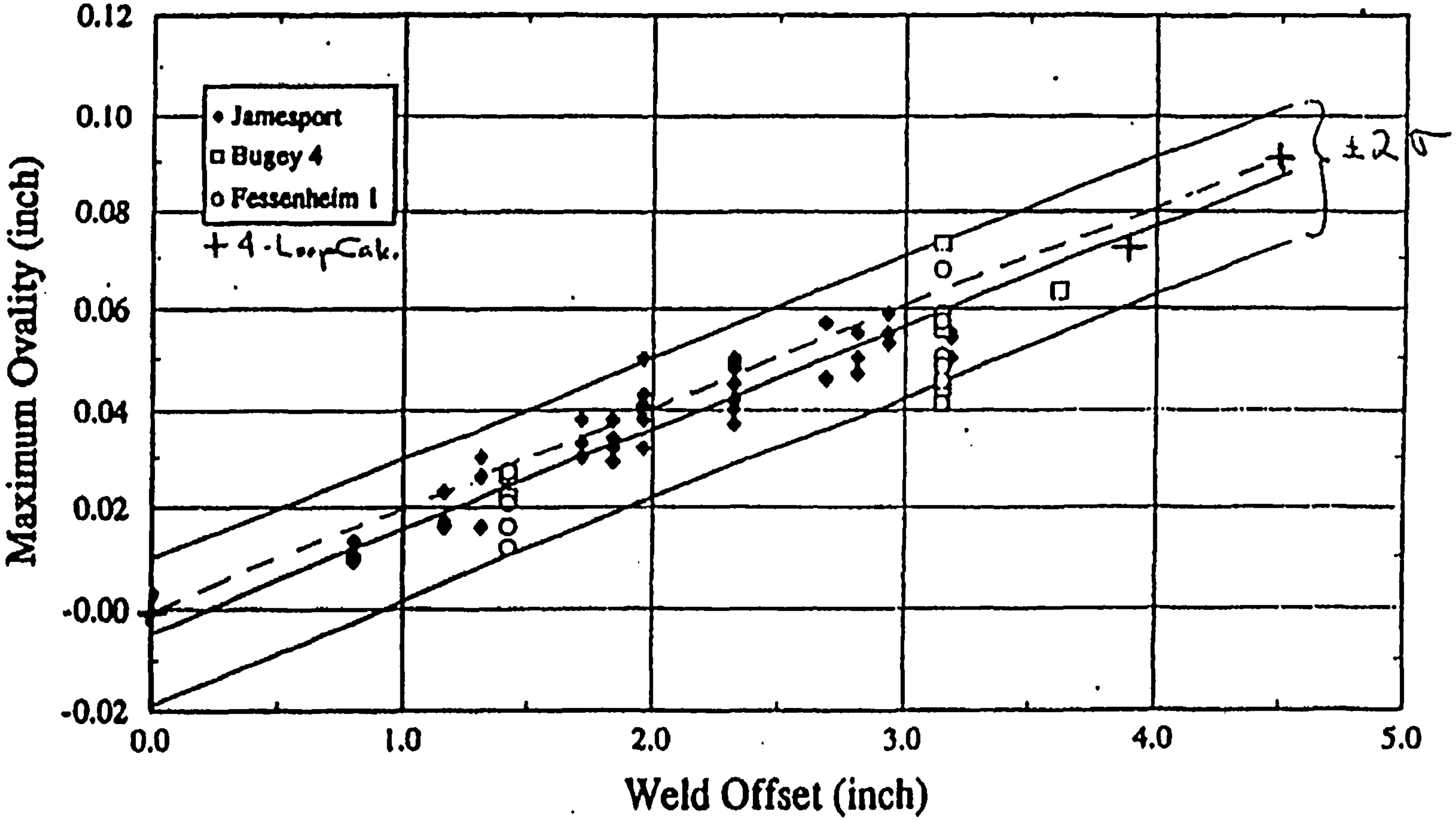

Figure 4-3 Measured Vessel Head Penetration Ovality Data and Regression Results [29]

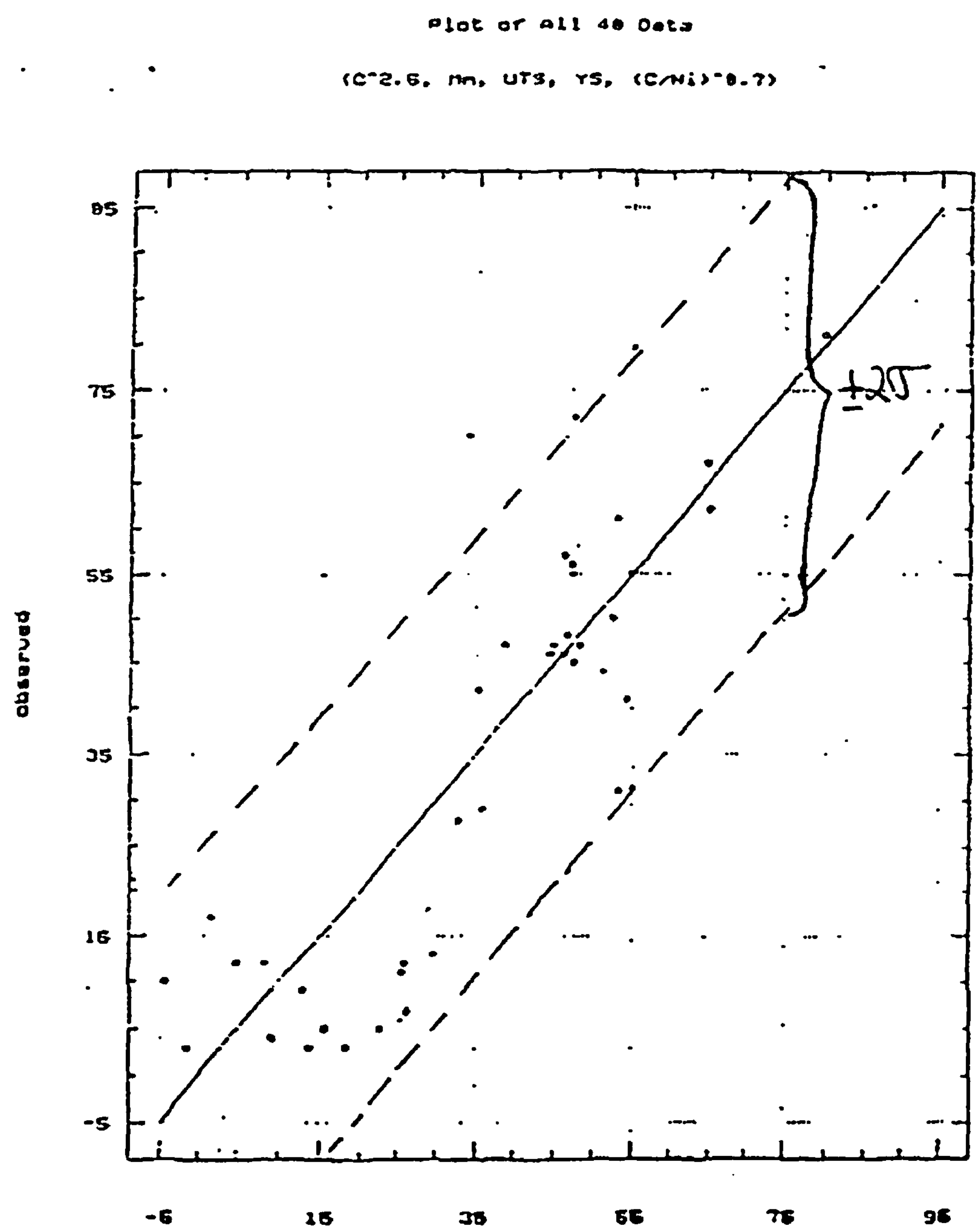

Figure 4-4 Curve Fit of Alloy 600 Grain Boundary Carbide Coverage Results [31]

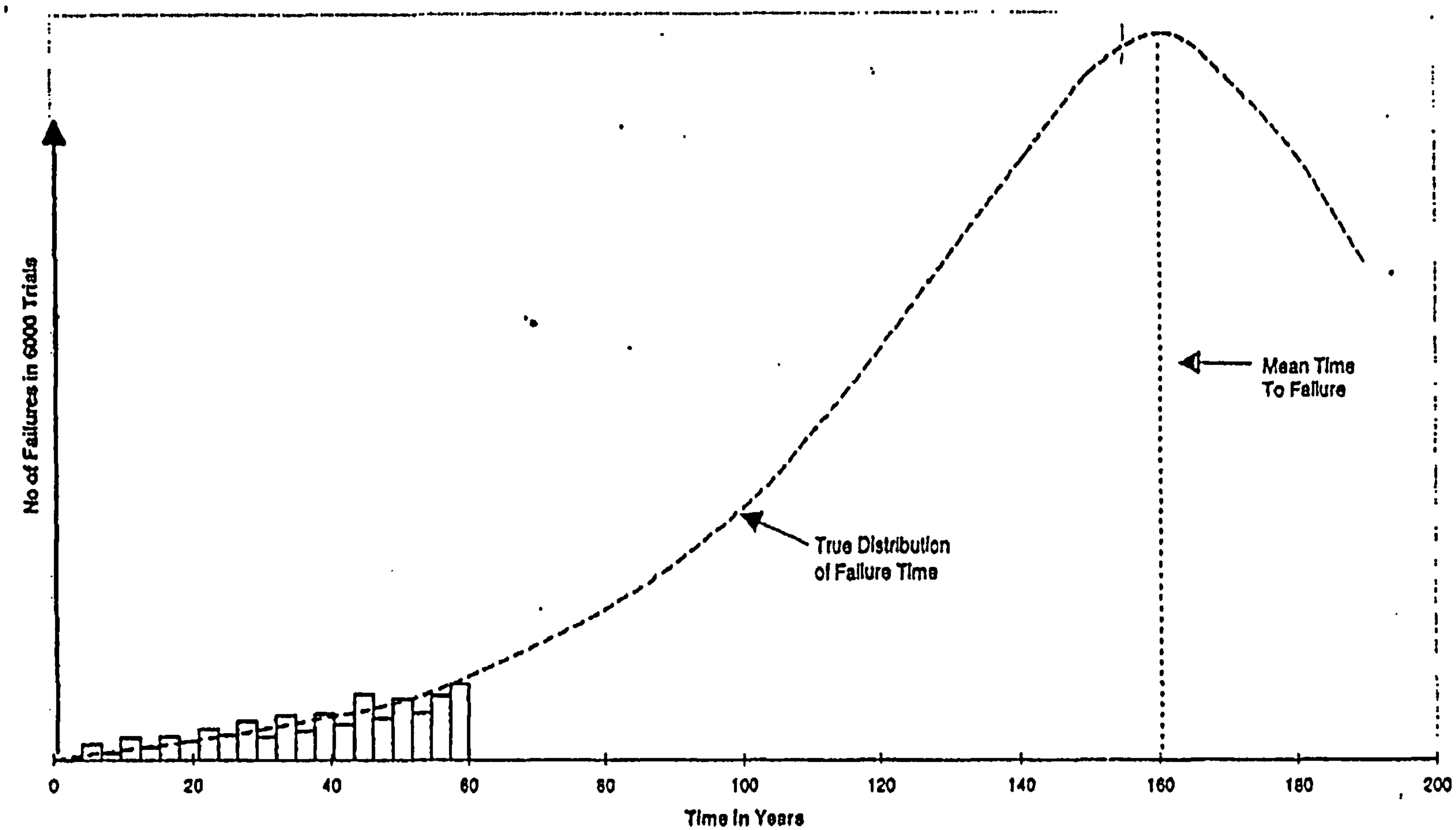

Figure 4-5 Histogram of Failures from Monte-Carlo Simulation

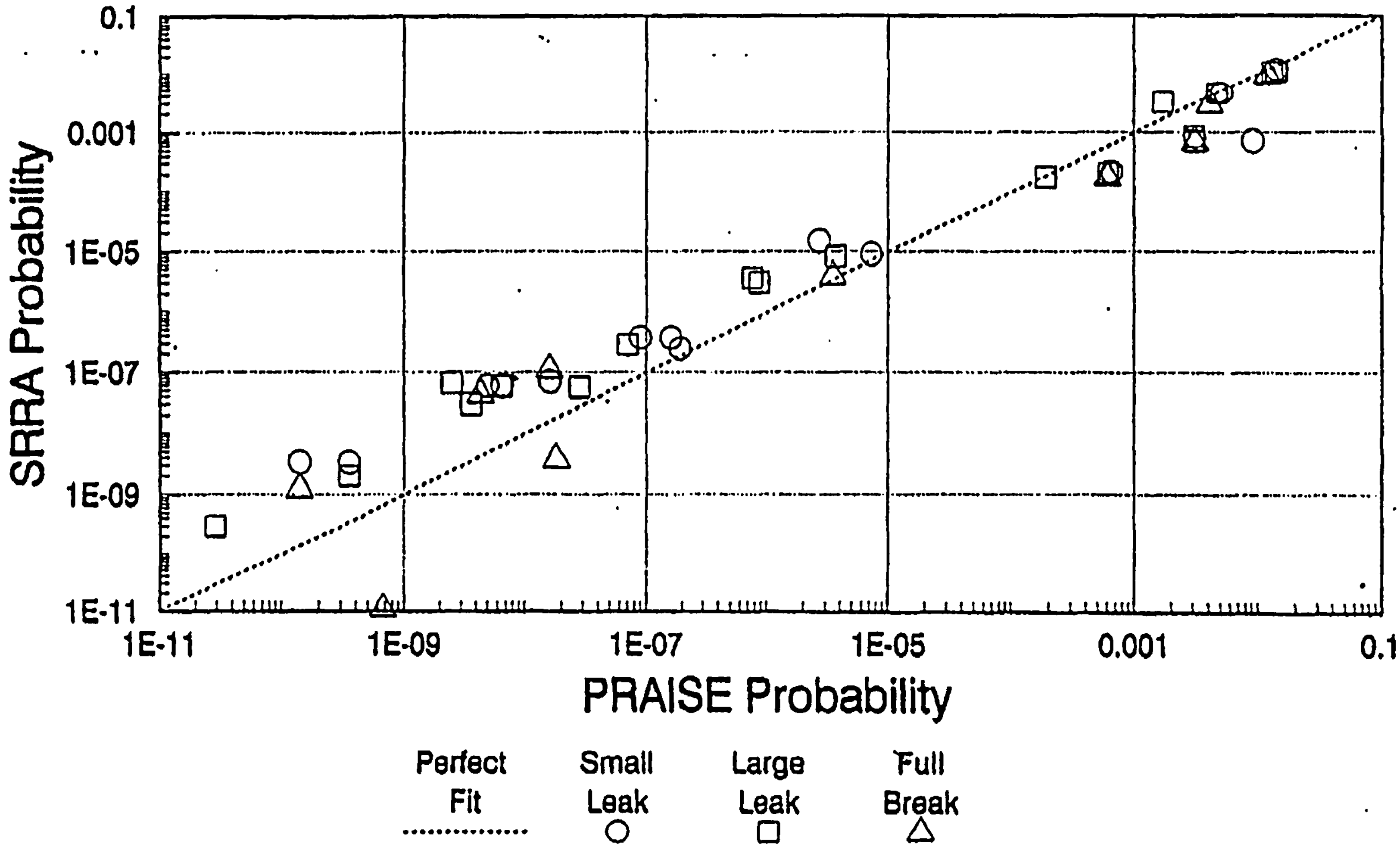

Figure 4-6 Comparison of Calculated Piping Probabilities

5.0 INPUT AND RESULTS OF PROBABILISTIC ANALYSIS

The Donald C. Cook Units 1 and 2 reactor vessels and closure heads were manufactured for Westinghouse by Combustion Engineering for Unit 1 and Chicago Bridge and Iron for Unit 2. The closure head contains 79 head penetrations for Unit 1 and 78 penetrations for Unit 2 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. These penetrations are utilized for a number of purposes. These purposes are typically for Control Rod Drive Mechanisms (CRDM), capped latch housings (CLH), part length mechanisms (P/L), thermocouple column locations (TCC), and spare penetrations. In addition to the standard head penetrations, the head also contains a vent pipe typically fabricated from Alloy 600 which is a different geometry and is not addressed in this report.

A review of the fabrication records indicates that the closure head penetrations were fabricated from 5 different heats for Unit 1 and 7 different heats for Unit 2 of Alloy 600 material. Table 5-1 provides a summary of the material heats. These heats of material were supplied by Huntington for Unit 1 and Westinghouse for Unit 2.

For plants which have operated at more than one temperature, the evaluation was somewhat more complicated, as described below. Analyses were run for each of the temperatures of operation, and the results were combined. Let us consider as an example a plant which has operated at three temperatures, T_1, T_2 and T_3, for the following times:

Time at temperature T_1 = 3 years
Time at temperature T_2 = 5 years
Time at temperature T_3 = now and for the foreseeable future

Having completed analyses for each of the three temperatures, we now have the probability of failure (0.75 T flaw) as a function of time for all three temperatures. Starting with the run for T_1, we find the probability of failure after 3 years, P_3. Now, looking at the analysis for T_2, we find a value as close to P_3 as possible. Using P_3 as the starting point, we continue counting years in the T_2 run, for five more years. At the end of five years, we now have a new probability of failure corresponding to eight years service = P_8. Now to complete the analysis we look at the analysis for T_3, and find a probability close to P_8, which now becomes the starting point for the rest of the analysis. Looking at Appendix A, you will see the years marked off for each of the temperatures of operation.

Table 5-2 provides the input values to the probabilistic analysis and Table 5-3 provides the results of the analysis in terms of the probability of failure (%) after 10, 20, 30, 40, 50, and 60 years of operation. Penetrations were grouped into cases. Each case was selected because the failure probability with time for the penetrations in the group is the same. 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 A. 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:

$$P_{ONE} = 1 - \Pi_N (1 - p_i)^{ni} \tag{5-1}$$

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:

$$E(N_F) = \Sigma_N \, ni \, p_i \tag{5-2}$$

For a better understanding of some of these probabilistic parameters, consider the analogy of rolling a number of dice. For this analogy, failure is defined to rolling the number 6. For each six-sided die, the probability of failure is 1 in 6 or 16.7%. If six dice are rolled (or one die six times), the expected number of failures would be 1 (6 x 1/6). If this is repeated many times, say 6000 rolls, 1000 failures would be expected or an average failure probability of 1000/6000 or 16.7%. For 60 head penetrations with an average failure probability of 1.67% (1/60), one penetration would therefore be expected to have a failure. In other words, the expected number of failures is one.

Using the dice rolling analogy, consider the probability of at least one failure. The first time the die is rolled, the probability of failure (getting a 6) is 16.7%. If a 6 was not rolled the first time, then the probability of failure on the second roll should be higher than 1/6. Conversely, the probability of failure on the second roll would be lower than 1/6 if a failure occurred on the first roll. If there were no failures on the first 5 rolls of the dice, then the probability of failure on the sixth roll should be high (65.5% per equation 5-1) since it is expected from the law of averages to get one failure for every six rolls. For 60 head penetrations all with a failure probability of 1.67% (1/60), then the probability of the 60th failing given that the first 59 didn't fail would be 63.5%. In other words, there would be a 63.5% probability of at least one (or only one) failure in 60 penetrations (given 59 non-failures). This approach was used to determine the entries in Table 5-4, as a function of time. The probabilities of individual penetrations failing are given in Table 5-3.

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

The detailed input and calculated results for the head penetration nozzle probabilistic analysis are given in the VHPNPROF output print files, some of which are reproduced 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. Here, 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 supplemental information on the effect of the first inservice inspection.

Figure 5-1 shows the failure probability with time for each of the penetrations in the group most likely to fail, and the average failure probability with time for all penetration nozzles on the vessel head. Also shown in Figure 5-1 is the probability of at least one failed penetration in all the vessel head penetrations. For reference, [ ] 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 [ ] and the probability of at least one failure is [ ] for all 78 penetration nozzles in D.C. Cook 2.

TABLE 5-1
D. C. COOK UNIT 1
HEAD PENETRATION ALLOY 600 HEAT NUMBERS

Row	Penetration No.	Heat Number	Material Supplier
0	1	NX7926	HUNTINGTON
1	2	NX7280	HUNTINGTON
	3	NX7280	HUNTINGTON
	4	NX7280	HUNTINGTON
	5	NX7280	HUNTINGTON
2	6	NX7280	HUNTINGTON
	7	NX7280	HUNTINGTON
	8	NX7280	HUNTINGTON
	9	NX7280	HUNTINGTON
3	10	NX7280	HUNTINGTON
	11	NX7280	HUNTINGTON
	12	NX8069	HUNTINGTON
	13	NX7280	HUNTINGTON
4	14	NX7280	HUNTINGTON
	15	NX8069	HUNTINGTON
	16	NX8069	HUNTINGTON
	17	NX8069	HUNTINGTON
	18	NX8069	HUNTINGTON
	19	NX8069	HUNTINGTON
	20	NX8069	HUNTINGTON
	21	NX8069	HUNTINGTON
5	22	NX8251	HUNTINGTON
	23	NX7280	HUNTINGTON
	24	NX7280	HUNTINGTON
	25	NX7280	HUNTINGTON
6	26	NX7280	HUNTINGTON
	27	NX7280	HUNTINGTON
	28	NX7280	HUNTINGTON
	29	NX7280	HUNTINGTON
7	30	NX7280	HUNTINGTON
	31	NX7280	HUNTINGTON
	32	NX7280	HUNTINGTON
	33	NX7280	HUNTINGTON
	34	NX7280	HUNTINGTON.
	35	NX7280	HUNTINGTON
	36	NX7280	HUNTINGTON
	37	NX7280	HUNTINGTON

TABLE 5-1 (Continued) D. C. COOK UNIT 1			
Row	**Penetration No.**	**Heat Number**	**Material Supplier**
8	38	NX8069	HUNTINGTON
	39	NX8069	HUNTINGTON
	40	NX8069	HUNTINGTON
	41	NX7926	HUNTINGTON
	42	NX7926	HUNTINGTON
	43	NX7926	HUNTINGTON
	44	NX7926	HUNTINGTON
	45	NX7926	HUNTINGTON
9	46	NX7926	HUNTINGTON
	47	NX7926	HUNTINGTON
	48	NX7926	HUNTINGTON
	49	NX7926	HUNTINGTON
10	50	NX7280	HUNTINGTON
	51	NX7280	HUNTINGTON
	52	NX7280	HUNTINGTON
	53	NX7926	HUNTINGTON
	54	NX7926	HUNTINGTON
	55	NX7926	HUNTINGTON
	56	NX7926	HUNTINGTON
	57	NX7926	HUNTINGTON
11	58	NX7280	HUNTINGTON
	59	NX7280	HUNTINGTON
	60	NX8251	HUNTINGTON
	61	NX7280	HUNTINGTON
12	62	NX7760	HUNTINGTON
	63	NX8069	HUNTINGTON
	64	NX8069	HUNTINGTON
	65	NX8069	HUNTINGTON
	66	NX8069	HUNTINGTON
	67	NX8069	HUNTINGTON
	68	NX8069	HUNTINGTON
	69	NX8069	HUNTINGTON
13	70	NX8069	HUNTINGTON
	71	NX8069	HUNTINGTON
	72	NX8069	HUNTINGTON
	73	NX8069	HUNTINGTON
14	74	NX8069	HUNTINGTON
	75	NX8069	HUNTINGTON

TABLE 5-1 (Continued) D. C. COOK UNIT 1			
Row	**Penetration No.**	**Heat Number**	**Material Supplier**
	76	NX8069	HUNTINGTON
	77	NX8069	HUNTINGTON
	78	NX8069	HUNTINGTON
	79	NX8069	HUNTINGTON

TABLE 5-1
D. C. COOK UNIT 2
HEAD PENETRATION ALLOY 600 HEAT NUMBERS

Row	Penetration No.	Heat Number	Material Supplier
0	1	NX0223-23	WESTINGHOUSE
1	2	NX0230-34	WESTINGHOUSE
	3	NX0230-34	WESTINGHOUSE
	4	NX0230-35	WESTINGHOUSE
	5	NX0230-35	WESTINGHOUSE
2	6	NX0219-9	WESTINGHOUSE
	7	NX0216-2	WESTINGHOUSE
	8	NX0230-35	WESTINGHOUSE
	9	NX0233-52	WESTINGHOUSE
3	10	NX0216-1	WESTINGHOUSE
	11	NX0216-6	WESTINGHOUSE
	12	NX0216-7	WESTINGHOUSE
	13	NX0230-36	WESTINGHOUSE
4	14	NX0218-15	WESTINGHOUSE
	15	NX0233-49A	WESTINGHOUSE
	16	NX0218-17	WESTINGHOUSE
	17	NX0215-24	WESTINGHOUSE
5	18	NX0233-44	WESTINGHOUSE
	19	NX0233-45	WESTINGHOUSE
	20	NX0233-46	WESTINGHOUSE
	21	NX0233-47	WESTINGHOUSE
6	22	NX0218-15	WESTINGHOUSE
	23	NX0216-3	WESTINGHOUSE
	24	NX0216-4	WESTINGHOUSE
	25	NX0215-27	WESTINGHOUSE
	26	NX0215-27	WESTINGHOUSE
	27	NX0230-37	WESTINGHOUSE
	28	NX0230-38	WESTINGHOUSE
	29	NX0233-48	WESTINGHOUSE
7	30	NX0233-46	WESTINGHOUSE
	31	NX0218-16	WESTINGHOUSE
	32	NX0215-24	WESTINGHOUSE
	33	NX0218-17	WESTINGHOUSE
	34	NX0233-44	WESTINGHOUSE
	35	NX0233-45	WESTINGHOUSE
	36	NX0233-46	WESTINGHOUSE
	37	NX0233-47	WESTINGHOUSE

TABLE 5-1 (Continued) D. C. COOK UNIT 2			
Row	**Penetration No.**	**Heat Number**	**Material Supplier**
8	38	NX0216-1	WESTINGHOUSE
	39	NX0216-6	WESTINGHOUSE
	40	NX0216-7	WESTINGHOUSE
	41	NX0216-7	WESTINGHOUSE
9	42	NX0216-2	WESTINGHOUSE
	43	NX0230-38	WESTINGHOUSE
	44	NX0216-4	WESTINGHOUSE
	45	NX0230-32	WESTINGHOUSE
	46	NX0230-37	WESTINGHOUSE
	47	NX0230-38	WESTINGHOUSE
	48	NX0230-40	WESTINGHOUSE
	49	NX0233-52	WESTINGHOUSE
10	50	NX0218-13	WESTINGHOUSE
	51	NX0218-17	WESTINGHOUSE
	52	NX0219-12	WESTINGHOUSE
	53	NX0230-32	WESTINGHOUSE
11	54	NX0219-10	WESTINGHOUSE
	55	NX0219-10	WESTINGHOUSE
	56	NX0216-2	WESTINGHOUSE
	57	NX0219-11	WESTINGHOUSE
	58	NX0233-56	WESTINGHOUSE
	59	NX0219-12	WESTINGHOUSE
	60	NX0233-52	WESTINGHOUSE
	61	NX0218-57	WESTINGHOUSE
12	62	NX0223-21	WESTINGHOUSE
	63	NX0230-59	WESTINGHOUSE
	64	NX0215-24	WESTINGHOUSE
	65	NX0230-59	WESTINGHOUSE
13	66	NX0223-21	WESTINGHOUSE
	67	NX0223-23	WESTINGHOUSE
	68	NX0223-23	WESTINGHOUSE
	69	NX0230-37	WESTINGHOUSE
	70	NX0230-35	WESTINGHOUSE
	71	NX0230-34	WESTINGHOUSE
	72	NX0218-16	WESTINGHOUSE
	73	NX0230-40	WESTINGHOUSE
14	74	NX0215-27	WESTINGHOUSE
	75	NX0233-44	WESTINGHOUSE

TABLE 5-1 (Continued) D. C. COOK UNIT 2			
Row	**Penetration No.**	**Heat Number**	**Material Supplier**
	76	NX0216-3	WESTINGHOUSE
	77	NX0216-4	WESTINGHOUSE
	78	NX0216-6	WESTINGHOUSE

CB&I drawing 68-3262-R14, Revision 6 was used as the basis for determining which Alloy 600 heat of material applies to each penetration number. However, during the evaluation, it was noted that there were several inconsistencies between the drawing and the material certifications relative to the heat and slab numbers of the Alloy 600 materials. The penetration numbers which had inconsistencies are penetrations 16, 23, 66, and 76. The shipping documentation was reviewed and this documentation provided the resolution of these inconsistencies. These inconsistencies and the resolution are described below.

1. Penetration 16 - Drawing 68-3262-R14 indicates the heat of material and slab number for this penetration is NX0216-17. A review of the CMTR for heat NX0216 shows that there is not a slab 17 associated with this heat of material. The shipping documentation indicates that the heat of material associated with this penetration number is NX0218-17. Therefore, NX0218-17 is used in the analysis.

2. Penetration 23 - Drawing 68-3262-R14 indicates the heat of material for this penetration is NX0216 without a slab number. The shipping documentation indicates that the heat of material associated with this penetration number is NX0216-3. Therefore, NX0216-3 is used in the analysis.

3. Penetration 66 - Drawing 68-3262-R14 indicates the heat of material and slab number for this penetration is NX0233-21. A review of the CMTR for heat NX0233 shows that there is not a slab 21 associated with this heat of material. The shipping documentation indicates that the heat of material associated with this penetration number is NX0223-21. Therefore, NX0223-21 is used in the analysis.

4. Penetration 76 - Drawing 68-3262-R14 indicates the heat of material for this penetration is NX0216 without a slab number. The shipping documentation indicates that the heat of material associated with this penetration number is NX0216-3. Therefore, NX0216-3 is used in the analysis.

The CMTRs for heat number NX0233 reports two different values for the Yield and Ultimate strength. These different values are associated with the different slabs of the material. The CB&I drawing 68-3262-R14 documentation indicates that the yield strength for penetration 75 should be the lower value (44 ksi); however, other inconsistencies, as described above, have been observed in the documentation. An evaluation was therefore performed to identify which value of the yield strength should be used in the probabilistic analysis and the results are presented below.

1. Using the current probabilistic model, the probability of cracking calculated using a 44 ksi yield strength would only be two-thirds that for North Anna where no cracking was detected. Also, for a 44 ksi yield strength, the probability in cracked penetration 75 is less than one-third the calculated probability in 3 outer row penetrations (76, 77, & 78) that did not crack.

2. Using a 58 ksi yield strength the calculated probability is comparable to that for Ringhals Unit 2 where cracking was observed. Also, for a 58 ksi yield strength, the calculated probability (~1/3) in cracked penetration 75 is approximately the same as that for the three other outer row penetrations (76, 77, & 78) that did not crack.

Considering the above observations, a yield strength value of 58 ksi was used in the probabilistic analysis for penetration 75.

TABLE 5-2 D. C. COOK UNIT 1 INPUT VALUES FOR PROBABILISTIC ANALYSIS					
Case	Pen. No.	Temp.(1)	Set-up Angle (°)	Y.S. (ksi)	GBC (%)(2)
1	74 thru 79	591.5°F	48.8	58.5	61.5
2	70 thru 73	for 96,800 hrs	44.3	58.5	61.5
3	63 thru 69		38.6	58.5	61.5
4	62	575.0°F	38.6	38.0	36.2
5	60	for 22,300 hrs	36.3	35.0	48.2
6	58, 59, 61		36.3	40.5	42.1
7	53 thru 57	578.0°F	35.1	35.5	62.3
8	50 thru 52	thereafter	35.1	40.5	42.1
9	46 thru 49		34.0	35.5	62.3
10	38 thru 40		30.2	58.5	61.5
11	41 thru 45		30.2	35.5	62.3
12	30 thru 37		26.2	40.5	42.1
13	26 thru 29		24.8	40.5	42.1
14	22		23.3	35.0	48.2
15	23 thru 25		23.3	40.5	42.1
16	15 thru 21		18.2	58.5	61.5
17	14		18.2	40.5	42.1
18	12		16.2	58.5	61.5
19	10, 11, 13		16.2	40.5	42.1
20	6 thru 9		11.4	40.5	42.1
21*	2 thru 5		8.0	40.5	42.1

(1) Mean upper head temperature based on Westinghouse calculations

(2) Grain boundary carbide coverage

* This case also used to bound penetration 1

TABLE 5-2 D. C. COOK UNIT 2 INPUT VALUES FOR PROBABILISTIC ANALYSIS					
Case	Pen. No.	Temp.(1)	Set-up Angle (°)	Y.S. (ksi)	GBC (%)(2)
1	75	595.5°F	50.6	58.0	44.3
2	76 thru 78	for 29,800	50.6	57.0	39.9
3	74		50.6	51.0	40.1
4	69 thru 71, 73	600.7°F	47.0	58.0	45.6
5	66 thru 68	thereafter	47.0	63.0	54.1
6	72		47.0	51.0	56.1
7	63, 65		45.8	56.0	47.7
8	62		45.8	63.0	54.1
9	64		45.8	51.0	40.1
10	58		39.9	58.0	44.3
11	60		39.9	44.0	30.3
12	54, 55, 57, 59		39.9	41.0	30.6
13	61		39.9	51.0	56.1
14	56		39.9	57.0	39.9
15	53		37.5	58.0	45.6
16	52		37.5	41.0	30.6
17	50, 51		37.5	51.0	56.1
18	49		36.3	44.0	30.3
19	43, 45 thru 48		36.3	58.0	45.6
20	42, 44		36.3	57.0	39.9
21	38 thru 41		35.0	57.0	39.9
22	30, 34 thru 37		31.1	44.0	30.3
23	31, 33		31.1	51.0	56.1
24	32		31.1	51.0	40.1
25	29		27.0	44.0	30.3
26	27, 28		27.0	58.0	45.6
27	22		27.0	51.0	56.1
28	23, 24		27.0	57.0	39.9
29	25, 26		27.0	51.0	40.1
30	18 thru 21		25.5	44.0	30.3
31	15		23.9	44.0	30.3
32	14, 16		23.9	51.0	56.1
33	17		23.9	51.0	40.1

TABLE 5-2 (Continued) D. C. COOK UNIT 2 INPUT VALUES FOR PROBABILISTIC ANALYSIS					
Case	Pen. No.	Temp.(1)	Set-up Angle (°)	Y.S. (ksi)	GBC (%)(2)
34	13		18.7	58.0	45.6
35	10 thru 12		18.7	57.0	39.9
36	9		16.7	44.0	30.3
37	8		16.7	58.0	45.6
38	6		16.7	41.0	30.6
39	7		16.7	57.0	39.9
40	2 thru 5		11.7	58.0	45.6
41	1		0	63.0	54.1

(1) Mean upper head temperature based on Westinghouse calculations

(2) Grain boundary carbide coverage

TABLE 5-3
D. C. COOK UNIT 1
RESULTS OF PROBABILISTIC ANALYSIS FOR INDIVIDUAL PENETRATIONS
(PROBABILITY OF FLAW WITH DEPTH = 0.75T, IN PERCENT)

Case	Pen. No.	10 Years	20 Years	30 Years	40 Years	50 Years	60 Years
1	74 thru 79	7.0	21.8	35.7	47.3	56.9	>58.0
2	70 thru 73	2.4	12.7	21.6	32.2	40.6	>42.0
3	63 thru 69	1.0	4.2	9.6	16.8	23.0	>24.0
4	62	0.1	0.4	1.1	2.3	4.2	>4.4
5	60	~0	0.1	0.2	0.5	1.0	>1.0
6	58, 59, 61	~0	0.3	0.9	1.9	3.4	>3.6
7	53 thru 57	~0	~0	0.1	0.2	0.5	>0.5
8	50 thru 52	~0	0.2	0.7	1.5	2.8	>2.9
9	46 thru 49	~0	~0	0.1	0.2	0.3	>0.4
10	38 thru 40	0.1	0.9	2.5	4.7	7.9	>8.0
11	41 thru 45	~0	~0	~0	0.1	0.2	>0.2
12	30 thru 37	~0	~0	0.1	0.2	0.5	>0.5
13	26 thru 29	~0	~0	0.1	0.2	0.4	>0.4
14	22	~0	~0	~0	~0	~0	>0
15	23 thru 25	~0	~0	~0	0.1	0.2	>0.2
16	15 thru 21	~0	0.1	0.2	0.5	1.0	>1.0
17	14	~0	~0	~0	~0	0.1	>0.1
18	12	~0	~0	0.1	0.3	0.8	>0.8
19	10, 11, 13	~0	~0	~0	~0	~0	>0
20	6 thru 9	~0	~0	~0	~0	~0	>0
21	2 thru 5	~0	~0	~0	~0	~0	>0

TABLE 5-3
D. C. COOK UNIT 2
RESULTS OF PROBABILISTIC ANALYSIS FOR INDIVIDUAL PENETRATIONS
(PROBABILITY OF FLAW WITH DEPTH = 0.75T, IN PERCENT)

Case	Pen. No.	10 Years	20 Years	30 Years	40 Years	50 Years	60 Years
1	75	31.2	67.2	87.6	93.8	96.1	97.9
2	76 thru 78	31.5	67.5	87.8	93.6	96.1	97.9
3	74	20.2	53.0	76.2	88.1	93.2	95.2
4	69 thru 71, 73	18.0	51.8	74.4	87.0	92.6	94.8
5	66 thru 68	22.8	57.7	78.8	90.9	94.1	96.2
6	72	7.2	32.4	52.1	66.7	78.7	86.8
7	63, 65	13.0	42.5	62.9	78.1	87.6	92.7
8	62	19.4	52.9	75.4	87.5	93.0	94.8
9	64	9.4	35.1	55.8	71.6	82.1	89.3
10	58	5.8	28.6	47.9	63.2	75.5	83.6
11	60	1.6	12.2	25.4	38.3	49.3	58.7
12	54,55,57,59	1.1	8.3	19.3	30.5	41.4	49.6
13	61	1.6	14.3	28.7	41.9	53.0	62.6
14	56	6.2	28.7	48.0	63.3	75.9	84.0
15	53	3.7	22.0	40.0	53.7	66.3	76.2
16	52	0.8	5.2	14.8	24.9	34.9	43.0
17	50, 51	1.2	9.3	21.4	34.1	44.7	53.2
18	49	0.9	6.8	17.3	28.4	37.9	47.3
19	43, 45 thru 48	2.5	19.7	35.8	50.5	62.3	71.6
20	42, 44	2.6	20.3	36.5	50.9	63.4	73.3
21	38 thru 41	2.1	17.2	34.0	47.5	58.3	67.6
22	30, 34 thru 37	0.2	2.3	8.3	16.8	24.7	32.0
23	31, 33	0.2	2.9	9.3	18.8	27.0	35.1
24	32	0.7	5.3	14.3	24.5	34.7	43.4
25	29	0.1	1.3	4.3	8.8	15.9	21.9
26	27, 28	0.8	5.3	14.3	24.4	34.6	43.1
27	22	0.1	1.4	5.0	10.3	18.0	24.1
28	23, 24	0.7	5.7	14.8	25.2	35.4	44.1
29	25, 26	0.2	2.2	7.7	16.2	24.0	31.3
30	18 thru 21	0.1	0.9	3.3	7.5	13.1	19.0

TABLE 5-3 (Continued)
D. C. COOK UNIT 2
RESULTS OF PROBABILISTIC ANALYSIS FOR INDIVIDUAL PENETRATIONS
(PROBABILITY OF FLAW WITH DEPTH = 0.75T, IN PERCENT)

Case	Pen. No.	10 Years	20 Years	30 Years	40 Years	50 Years	60 Years
31	15	0.1	0.7	2.5	6.0	10.1	15.7
32	14, 16	0.1	0.8	3.0	6.8	11.6	17.7
33	17	0.1	1.3	4.9	10.0	17.2	23.5
34	13	0.1	1.1	4.2	8.6	14.6	21.4
35	10 thru 12	0.1	1.2	4.4	9.0	15.7	21.8
36	9	~0	0.1	0.8	1.8	3.7	5.9
37	8	0.1	0.8	2.9	6.8	11.4	17.2
38	6	~0	0.1	0.3	1.0	2.3	3.7
39	7	0.1	0.9	3.3	7.1	12.1	18.3
40	2 thru 5	~0	0.2	1.1	3.1	5.7	8.9
41	1	~0	~0	0.1	0.3	0.8	1.6

TABLE 5-4 D. C. COOK UNIT 1 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.)
45.5	90.7	98.9	99.9	100.0	100.0

TABLE 5-4 D. C. COOK UNIT 2 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.)
99.0	100.0	100.0	100.0	100.0	100.0

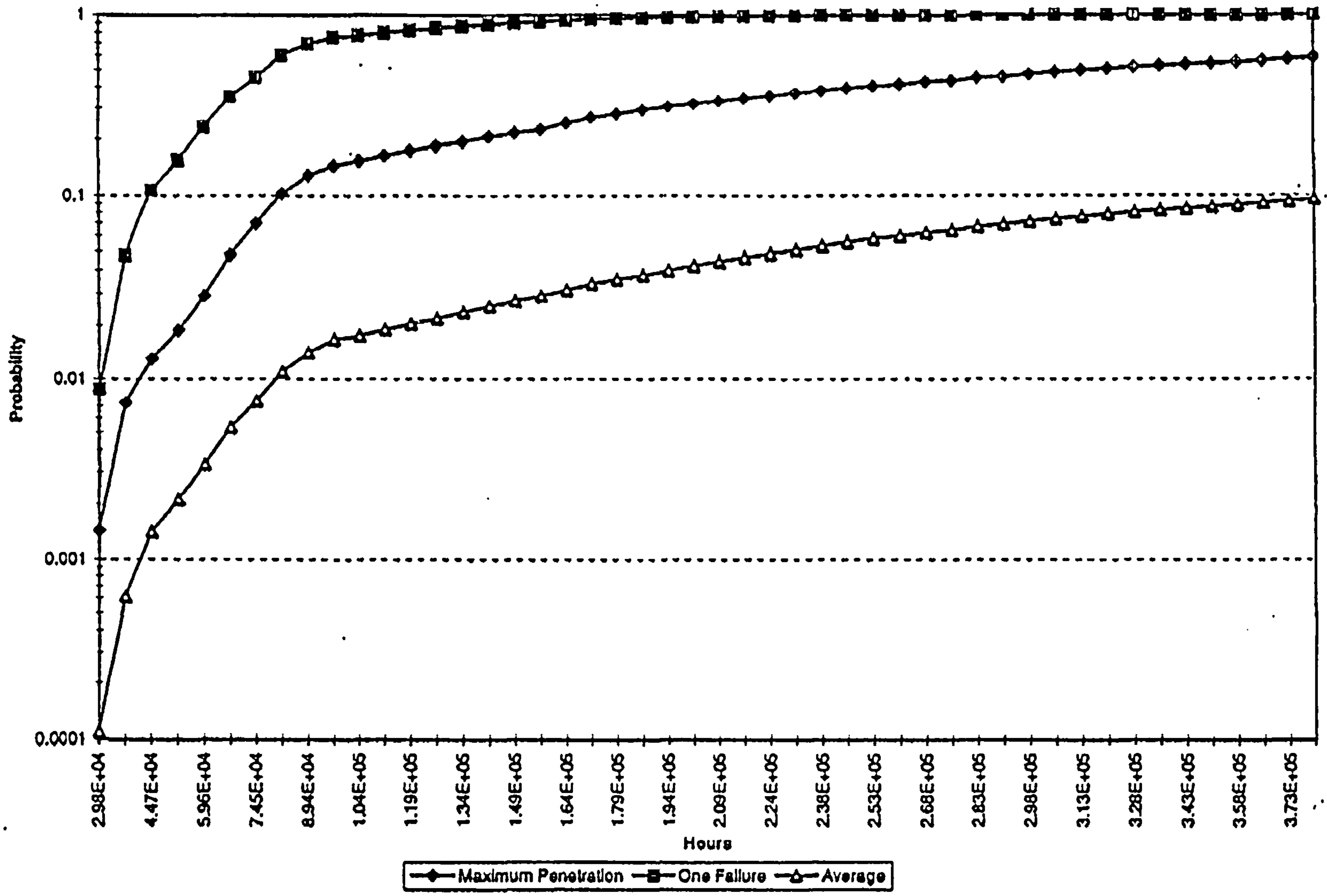

Figure 5-1 Failure Probability vs. Time: D. C. Cook Unit 1

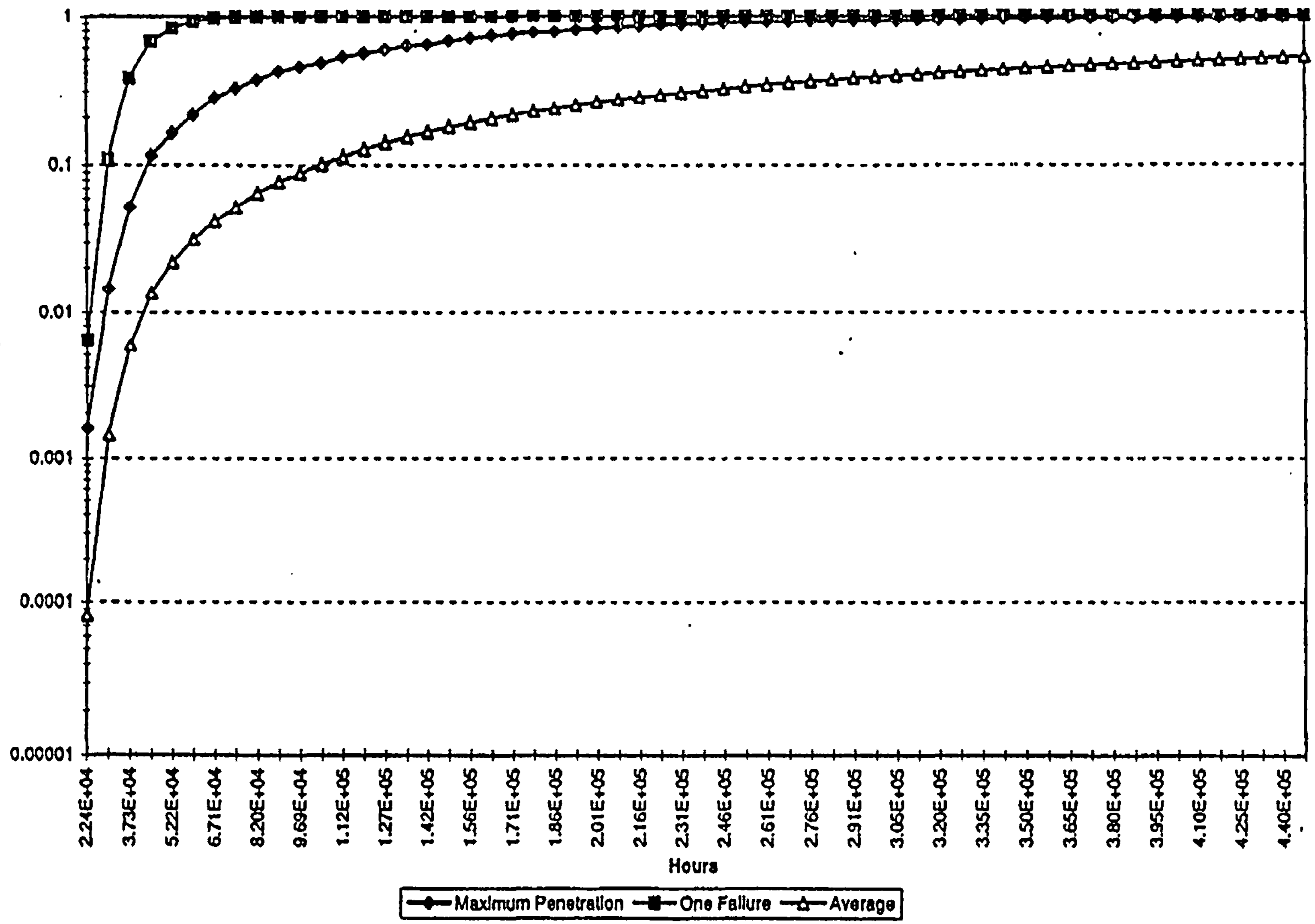

Figure 5-2 Failure Probability vs. Time: D. C. Cook Unit 2

6.0 SUMMARY

A detailed evaluation of the reactor vessel closure head penetrations has been completed for the Donald C. Cook Units 1 and 2 plants. One of the two degradation mechanisms covered by Generic Letter 97-01 has been addressed: Primary water stress corrosion cracking (PWSCC). Stress corrosion cracking due to resin intrusions is covered separately.

An in-depth probabilistic assessment has been completed for all of the reactor vessel closure head penetrations. These methods have been verified by comparison with actual inspection results, as shown in Table 4-2, and discussed in Section 4.

The results of the assessment show that the mean time to failure (defined as crack depth = 75% of wall thickness) for the worst penetration is [ ] years for Unit 1. For Unit 2 this value is [ ] years. This corresponds to the year at which there is a 50 percent probability of failure for the worst penetration, which is another way of looking at the results.

The probability of a flaw initiating and reaching 75% of the wall thickness in 40 years was calculated for each case analyzed, and appears in Table 5-3. For 60 years, the probability increases, as shown in Figure 5-1 and Table 5-3. The probability of at least one penetration in the entire head cracking to this depth is given in Table 5-4.

7.0 REFERENCES

[1] WCAP-13565, Rev. 1, "Alloy 600 Reactor Vessel Adapter Tube Cracking Safety Evaluation," February 1993 (Proprietary).

[2] F. Heddin and P. Gasquet, "Alloy 600 Reactor Vessel Head Penetration Cracking: An Industrial Challenge," 12th SMIRT Post Conference, August 23-25, 1993, Paris, France.

[3] Rao, G. V., and Wright, D. A., "Evaluation and Resolution of the Primary Water Stress Corrosion Cracking (PWSCC) Incidents of Alloy 600 Primary System Pressure Boundary Penetrations in Pressurized Water Reactors," Proceedings of Fontevraud II Symposium on "Contribution of Materials Investigation to the Resolution of Problems Encountered in PWR Plants," Royal Abbey of Fontevraud, France, September 10-14, 1990.

[4] A. S. O'Neill and J. F. Hall, Combustion Engineering, "Literature Survey of Cracking of Alloy 600 Components in PWR Plants," Report prepared for EPRI, January 1990.

[5] U.S. NRC Information Notice No. 90-10, "Primary Water Stress Corrosion Cracking (PWSCC) of Inconel 600, February 23, 1990.

[6] NRC letter from William T. Russell to William Rasin of NUMARC (now NEI), November 19, 1993.

[7] Pichon, C, Boudot, R., Benhamour, C., and Gelpi, A., "Residual Life Assessment of French PWR Vessel Head Penetrations through Metallurgical Analysis," Service Experience and Reliability Improvement; Nuclear, Fossil, and Petrochemical Plants, PVP Vol. 288, ASME, 1994.

[8] Lagerstrom, J., Wilson, B., Person, B., Bamford, W.H., and Bevilacqua, B, "Experiences with Detection and Disposition of Indications in Head Penetrations of Swedish Plants, "Services Experience and Reliability Improvement; Nuclear, Fossil, and Petrochemical Plants, PVP Vol.288, ASME, 1994, pages 29 to 40.

[9] Bamford, W. H., Fyfitch, S., Cyboron, R. D., Ammirato, F., Schreim, M., and Pathania, R., "An Integrated Industry Approach to the Issue of Head Penetration Cracking for the USA,: Services Experience and Reliability Improvement; Nuclear, Fossil, and Petrochemical Plants, PVP-Vol 288, ASME, 1994, pages 11 to 19.

[10] Rao, G. V., "Methodologies to Assess PWSCC Susceptibility of Primary Alloy 600 Components in PWRs," Proceedings, Sixth International Conference on Environmental Degradation of Materials in Nuclear Power Systems, NACE, August 1993.

[11] Scott, P. M., "An Analysis of Primary Water Stress Corrosion Cracking in PWR Steam Generators," in Proceedings, Specialists Meeting on Operating Experience With Steam Generators, Brussels Belgium, September 1991, pages 5, 6.

[12] Mc Ilree, A. R., Rebak, R. B., Smialowska, S., "Relationship of Stress Intensity to Crack Growth Rate of Alloy 600 in Primary Water," Proceedings International Symposium Fontevraud II, Volume 1, p. 258-267, September 10-14, 1990.

[13] Cassagne, T., Gelpi, A., "Measurements of Crack Propagation Rates on Alloy 600 Tubes in PWR Primary Water," in Proceeding of the 5th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors," August 25-29, 1991, Monterey, California.

[14] Personal Communication, Brian Woodman, Combustion Engineering, October 1993.

[15] Hunt, S. L. and Gorman, J., "Crack Predictions and Acceptance Criteria for Alloy 600 Head Penetrations" in Proceedings of the 1992 EPRI Workshop on PWSCC of Alloy 600 in PWRs, December 1-3, 1992, Orlando Fl (published in 1993).

[16] Personal communication - C. Amzallag to W. Bamford, Feb. 26, 1997.

[17] G. Economy, F. W. Pement, Corrosion/89 Paper 493.

[18] H. Tass et. Al., "Relation Between Microstructural Features and Tube Cracking Observed on Tube Samples of Doel 2 Steam Generator." EPRI Steam Generator Owners Group, SCC Contractors Workshop San Diego, CA, March 1985.

[19] A. A. Stein, "Development of Microstructural Correlation and a Tubing Specification for Alloy 600." Paper presented at EPRI Steam Generator Owner Group SCC Contractors Workshop, San Diego, CA, March 1985.

[20] A. R. McIlree, "Results of Reannealing Studies of Trojan, Doel 2, Ringhals 2 and 3, Ginna and Indian Point 3 Steam Generator Tubing" Paper as in Ref. 18.

[21] G. P. Airey, "Optimization of Metallurgical Variables to Improve Corrosion Resistance of Inconel Alloy 600," Palo Alto, CA, Electric Power Research Institute, EPRI NP 3051, July 1983.

[22] "Intergranular Stress Corrosion Cracking in Steam Generator Tubing, Testing of Alloy 690 and Alloy 600 Tubes," Norring, Engstrom and Norberg, in *Third International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors - Proceedings,* The Metallurgical Society, 1988

[23] Z. Szklarska-Smialowska, "Factors Influencing IGSCC of Alloy 600 in Primary and Secondary Waters of PWR Steam Generators" Proceedings of the 5th International Symposium on "Environmental Degradation of Materials in Nuclear Power Systems ' Water Reactors." Nace Meeting. Edited by D. Cubicciotti, August 1989, p. 6-1.

[24] R. Bandy and D. Van Rooyen, "Stress Corrosion Cracking of Inconel Alloy 600 in High Temperature Water - An Update" Corrosion, Vol. 40, No. 8, page 425 (1984).

[25] Letter, J. A. Begley (APTECH) to B. A. Bishop, "Review of the Westinghouse Structural Reliability, Model for PWSCC of RV Head Penetrations," June 23, 1997.

[26] "Evaluation of Leaking Alloy 600 Nozzles and Remaining Life Prediction for Similar Nozzles in PWR Primary System Application," Hall, Magee, Woodman and Melton, in *Service Experience and Reliability Improvement*, ASME PVP-Vol. 288, 1994

[27] "The Status of Laboratory Evaluations in 400°C Steam of the Stress Corrosion of Alloy 600 Steam Generator Tubing," Gold, Fletcher and Jacko in *Proceedings of 2nd International Topical Meeting on Nuclear Power Plant Thermal Hydraulics and Operations*, 1986

[28] WCAP-13525, Rev. 1, *RV Closure Head Penetration Alloy 600 PWSCC (Phase 2)*, Ball et al., December 1992 **(Class 2)**

[29] WCAP-13493, *Reactor Vessel Closure Head Penetration Key Parameters Comparison*, Duran, Kim and Pezze, September 1992 **(Class 2)**

[30] G. V. Rao, "Development of Surface Replication Technology for the Field Assessment of Alloy 600 Micro-Structures in Primary Loop Penetrations," WCAP-13746, Westinghouse Class 2 Report, June, 1993.

[31] G. V. Rao and T. R. Leax, Microstructural Correlations with Material Certification Data in Several Commercial Heats of Alloy 600 Reactor Vessel Head Penetration Materials - WCAP-13876, Rev. 1, June 1997.

[32] WCAP 13929, Rev. 2, *Crack Growth and Microstructural Characterization of Alloy 600 Head Penetration Materials*, Bamford, Foster and Rao, November 1996 **(Class 2C)**

[33] Newman, J.C. Jr. And Raju, I.S. "Stress Intensity Factors for Internal Surface Cracks in Cylindrical Pressure Vessels" Transactions ASME, Journal of Pressure Vessel Technology, Volume 102, 1980, pp. 342-346.

[34] WCAP-14572, Westinghouse Owners Group Application of Risk-Based Methods to Piping Inservice Inspection Topical Report, pp E-1 to E-6, March 1996 (Class 3).

[35] *Risk-Based Inspection - Development of Guidelines, Volume 1, General Document*, ASME Research Task Force on Risk-Based Inspection Guidelines Report CRTD-Vol. 20-1 (or NUREG/GR-005, Vol. 1), American Society of Mechanical Engineers, 1991

[36] NUREG/CR-5864, *Theoretical and User's Manual for pc-PRAISE, A Probabilistic Fracture Mechanics Computer Code for Piping Reliability Analysis*, Harris and Dedhia, July 1992

Appendix A

Output Files From VHPNPROF for Probabilistic Failure Analysis: D. C. Cook Units 1 and 2 Head Penetration Nozzles

WESTINGHOUSE
ESBU-NSD

VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS
79 Nozzles at D.C. COOK 1_____ Plant on 07-02-97

VHPNECON
06/06/97

a,b

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	E(NUMFS)
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591.5°F

Output Print File VHPNPROF.P01 Opened at 09:05 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	48.8
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 1: RV Head Penetration 74 THRU 79 AEP

a,b

a,b

Output Print File VHPNPROF.P02 Opened at 09:06 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	44.3
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 2: RV Head Penetration 70 THRU 73 AEP

a,b

a,b

Output Print File VHPNPROF.P03 Opened at 10:24 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	38.6
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 3: RV Head Penetration 63 THRU 69 AEP

a,b

a,b

Output Print File VHPNPROF.P04 Opened at 10:25 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	38.0
Penetration Setup Angle (degrees)	38.6
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	36.2
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-NSD

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INPUT VARIABLES FOR CASE 4: RV Head Penetration 62 AEP

a,b

a,b

Output Print File VHPNPROF.P05 Opened at 10:26 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	48.2
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-NSD

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INPUT VARIABLES FOR CASE 5: RV Head Penetration 60 AEP

a,b

a,b

Output Print File VHPNPROF.P06 Opened at 10:26 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 6: RV Head Penetration 58 59 61 AEP

a,b

a,b

Output Print File VHPNPROF.P07 Opened at 10:27 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	35.1
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

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INPUT VARIABLES FOR CASE 7: RV Head Penetration 53 THRU 57 AEP

a,b

a,b

Output Print File VHPNPROF.P08 Opened at 10:28 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	35.1
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 8: RV Head Penetration 50 THRU 52 AEP

a,b

a,b

Output Print File VHPNPROF.P09 Opened at 10:29 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	34.0
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

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INPUT VARIABLES FOR CASE 9: RV Head Penetration 46 THRU 49 AEP

a,b

[a,b]

Output Print File VHPNPROF.P10 Opened at 10:30 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	30.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 10: RV Head Penetration 38 THRU 40 AEP

a,b

a,b

Output Print File VHPNPROF.P11 Opened at 10:31 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	30.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

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INPUT VARIABLES FOR CASE 11: RV Head Penetration 41 THRU 45 AEP

a,b

[redacted] a,b

Output Print File VHPNPROF.P12 Opened at 10:32 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	26.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 12: RV Head Penetration 30 THRU 37 AEP

a,b

a,b

Output Print File VHPNPROF.P13 Opened at 10:33 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	24.8
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 13: RV Head Penetration 26 THRU 29 AEP

a,b

Output Print File VHPNPROF.P14 Opened at 10:33 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.0
Penetration Setup Angle (degrees)	23.3
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	48.2
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-NSD

INPUT VARIABLES FOR CASE 14: RV Head Penetration 22 AEP

a,b

Output Print File VHPNPROF.P15 Opened at 10:35 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	23.3
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 15: RV Head Penetration 23 THRU 25 AEP

a,b

a,b

Output Print File VHPNPROF.P16 Opened at 10:36 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	18.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 16: RV Head Penetration 15 THRU 21 AEP

a,b

a,b

Output Print File VHPNPROF.P17 Opened at 10:37 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	18.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 17: RV Head Penetration 14 AEP

a,b

a,b

Output Print File VHPNPROF.P18 Opened at 10:38 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	16.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 18: RV Head Penetration 12 AEP

a,b

[ ]a,b

Output Print File VHPNPROF.P19 Opened at 10:38 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	16.2
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 19: RV Head Penetration 10 11 13 AEP

a,b

[ ][a,b]

Output Print File VHPNPROF.P20 Opened at 10:39 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	11.4
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 20: RV Head Penetration 6 THRU 9 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P21 Opened at 10:40 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	8.0
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 21: RV Head Penetration 2 THRU 5 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P22 Opened at 10:41 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	0.0
Penetration Temperature (F)	591.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

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INPUT VARIABLES FOR CASE 22: RV Head Penetration 1 AEP

a,b

WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 79 Nozzles at D.C. COOK 1_____ Plant on 07-02-97 06/06/97

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	E(NUMFS)
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575°F

Output Print File VHPNPROF.P01 Opened at 12:39 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	48.8
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 1: RV Head Penetration 74 THRU 79 AEP

a,b

[ ] a,b

Output Print File VHPNPROF.P02 Opened at 12:40 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	44.3
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 2: RV Head Penetration 70 THRU 73 AEP

a,b

a,b

Output Print File VHPNPROF.P03 Opened at 12:40 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	38.6
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 3: RV Head Penetration 63 THRU 69 AEP

a,b

5,6

Output Print File VHPNPROP.P04 Opened at 12:41 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	38.0
Penetration Setup Angle (degrees)	38.6
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	36.2
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 VHPNPROP ESBU-NSD

INPUT VARIABLES FOR CASE 4: RV Head Penetration 62 AEP

a,b

a,b

Output Print File VHPNPROF.P05 Opened at 12:42 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	48.2
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-NSD

INPUT VARIABLES FOR CASE 5: RV Head Penetration 60 AEP

a,b

a,b

Output Print File VHPNPROF.P06 Opened at 12:42 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 6: RV Head Penetration 58 59 61 AEP

a,b

a,b

Output Print File VHPNPROF.P07 Opened at 12:43 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	35.1
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

INPUT VARIABLES FOR CASE 7: RV Head Penetration 53 THRU 57 AEP

a,b

Output Print File VHPNPROF.P08 Opened at 12:44 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	35.1
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 8: RV Head Penetration 50 THRU 52 AEP

a,b

a,b

Output Print File VHPNPROF.P09 Opened at 12:44 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	34.0
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

INPUT VARIABLES FOR CASE 9: RV Head Penetration 46 THRU 49 AEP

a,b

Output Print File VHPNPROF.P10 Opened at 12:45 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	30.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 10: RV Head Penetration 38 THRU 40 AEP

a,b

a,b

Output Print File VHPNPROP.P11 Opened at 12:46 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	30.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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 VHPNPROP ESBU-NSD

INPUT VARIABLES FOR CASE 11: RV Head Penetration 41 THRU 45 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P12 Opened at 12:46 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	26.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 12: RV Head Penetration 30 THRU 37 AEP

a,b

Output Print File VHPNPROF.P13 Opened at 12:47 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	24.8
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 13: RV Head Penetration 26 THRU 29 AEP

a,b

Output Print File VHPNPROF.P14 Opened at 12:47 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.0
Penetration Setup Angle (degrees)	23.3
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	48.2
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-NSD

INPUT VARIABLES FOR CASE 14: RV Head Penetration 22 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROP.P15 Opened at 12:48 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	23.3
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 15: RV Head Penetration 23 THRU 25 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10 FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P16 Opened at 12:54 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	18.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 16: RV Head Penetration 15 THRU 21 AEP

a,b

a,b

Output Print File VHPNPROF.P17 Opened at 12:55 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	18.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 17: RV Head Penetration 14 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P18 Opened at 12:56 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	16.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 18: RV Head Penetration 12 AEP

a,b

[ ] [a,b]

Output Print File VHPNPROF.P19 Opened at 12:57 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	16.2
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 19: RV Head Penetration 10 11 13 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P20 Opened at 12:58 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	11.4
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 20: RV Head Penetration 6 THRU 9 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P21 Opened at 12:58 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	8.0
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 21: RV Head Penetration 2 THRU 5 AEP

a,b

Output Print File VHPNPROF.P22 Opened at 12:59 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	0.0
Penetration Temperature (F)	575.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

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INPUT VARIABLES FOR CASE 22: RV Head Penetration 1 AEP

[ ] c,b

A-75

WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 79 Nozzles at D.C. COOK 1_____ Plant on 07-02-97 06/06/97

a,b

	CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	E(NUMPS)
	6				
	7				
	8				
	9				
	10				
	11				
	12				
	13				
	14				
	15				
	16				
	17				
	18				
	19				
	20				
	21				
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17 -	26				
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20 -	29				
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	31				
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30 -	39				
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	46				
	47				
	48				
40 -	49				
	50				
	51				
	52				
	53				
	54				
	55				
	56				
	57				
	58				
50 -	59				
	60				

578°F

Output Print File VHPNPROF.P01 Opened at 10:53 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	48.8
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 1: RV Head Penetration 74 THRU 79 AEP

a,b

a,b

Output Print File VHPNPROF.P02 Opened at 10:54 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	44.3
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 2: RV Head Penetration 70 THRU 73 AEP

a,b

a,b

Output Print File VHPNPROF.P03 Opened at 10:54 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	38.6
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

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INPUT VARIABLES FOR CASE 3: RV Head Penetration 63 THRU 69 AEP

a,b

a,b

Output Print File VHPNPROF.P04 Opened at 10:55 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	38.0
Penetration Setup Angle (degrees)	38.6
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	36.2
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-NSD

INPUT VARIABLES FOR CASE 4: RV Head Penetration 62 AEP

a,b

a,b

Output Print File VHPNPROF.P05 Opened at 10:56 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	48.2
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-NSD

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INPUT VARIABLES FOR CASE 5: RV Head Penetration 60 AEP

a,b

[ ] a,b

Output Print File VHPNPROP.P06 Opened at 10:56 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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 VHPNPROP ESBU-NSD

INPUT VARIABLES FOR CASE 6: RV Head Penetration 58 59 61 AEP

a,b

[a,b]

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Output Print File VHPNPROF.P07 Opened at 10:57 on 07-01-1997

Limit Depth Fraction of Wall                    0.750
Monotonic Yield Strength (Ksi)                   35.5
Penetration Setup Angle (degrees)                35.1
Penetration Temperature (F)                     578.0
Center Penetration Stress (Ksi)                  34.4
Grain Boundary Carbide Coverage (%)              62.3
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-NSD
==============================================================================
     INPUT VARIABLES FOR CASE  7: RV Head Penetration 53 THRU 57 AEP
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a,b

[ ] a,b

Output Print File VHPNPROF.P08 Opened at 10:58 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	35.1
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 8: RV Head Penetration 50 THRU 52 AEP

a,b

a,b

Output Print File VHPNPROF.P09 Opened at 10:59 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	34.0
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

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INPUT VARIABLES FOR CASE 9: RV Head Penetration 46 THRU 49 AEP

a,b

Output Print File VHPNPROF.P10 Opened at 10:59 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	30.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 10: RV Head Penetration 38 THRU 40 AEP

a,b

[ ]a,b

Output Print File VHPNPROF.P11 Opened at 11:00 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	30.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

INPUT VARIABLES FOR CASE 11: RV Head Penetration 41 THRU 45 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P12 Opened at 11:00 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	26.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

==

INPUT VARIABLES FOR CASE 12: RV Head Penetration 30 THRU 37 AEP

a,b

[ ]a,b

Output Print File VHPNPROF.P13 Opened at 11:01 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	24.8
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

==

INPUT VARIABLES FOR CASE 13: RV Head Penetration 26 THRU 29 AEP

a,b

Output Print File VHPNPROP.P14 Opened at 11:02 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.0
Penetration Setup Angle (degrees)	23.3
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	48.2
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-NSD

-INPUT VARIABLES FOR CASE 14: RV Head Penetration 22 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROP.P15 Opened at 11:03 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	23.3
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 15: RV Head Penetration 23THRU 25 AEP

a,b

Output Print File VHPNPROF.P16 Opened at 11:03 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	18.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD
==
INPUT VARIABLES FOR CASE 16: RV Head Penetration 15 THRU 21 AEP

a,b

a,b

Output Print File VHPNPROF.P17 Opened at 11:04 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	18.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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 VHPNPROP ESBU-NSD

INPUT VARIABLES FOR CASE 17: RV Head Penetration 14 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P18 Opened at 11:05 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.5
Penetration Setup Angle (degrees)	16.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	61.5
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-NSD

INPUT VARIABLES FOR CASE 18: RV Head Penetration 12 AEP

a,b

[a,b]

Output Print File VHPNPROF.P19 Opened at 11:05 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	16.2
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 19: RV Head Penetration 10 11 13 AEP

a,b

Output Print File VHPNPROF.P20 Opened at 11:06 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	11.4
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

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INPUT VARIABLES FOR CASE 20: RV Head Penetration 6 THRU 9 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P21 Opened at 11:07 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	40.5
Penetration Setup Angle (degrees)	8.0
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	42.1
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-NSD

INPUT VARIABLES FOR CASE 21: RV Head Penetration 2 THRU 5 AEP

a,b

WARNING: PROBABILITIES CALCULATED FOR LESS THAN 10
FAILURES CAN HAVE VERY HIGH UNCERTAINTIES

Output Print File VHPNPROF.P22 Opened at 11:13 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	35.5
Penetration Setup Angle (degrees)	0.0
Penetration Temperature (F)	578.0
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	62.3
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-NSD

INPUT VARIABLES FOR CASE 22: RV Head Penetration 1 AEP

a,b

WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 78 Nozzles at D.C. COOK 2_____ Plant on 07-02-97 06/06/97

a,b

595.5°F

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	E(NUMFS)
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59				
60				

Output Print File VHPNPROF.P01 Opened at 15:13 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	50.6
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	44.3
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-NSD

INPUT VARIABLES FOR CASE 1: RV Head Penetration 75 AMP

a,b

a,b

Output Print File VHPNPROF.P02 Opened at 15:14 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	50.6
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 2: RV Head Penetration 76 THRU 78 AMP

a,b

a,b

Output Print File VHPNPROF.P03 Opened at 15:14 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	50.6
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 3: RV Head Penetration 74 AMP

a,b

a,b

Output Print File VHPNPROF.P04 Opened at 15:15 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	47.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 4: RV Head Penetration 69 THRU 71 & 73 AMP

a,b

a,b

Output Print File VHPNPROF.P05 Opened at 15:15 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	63.0
Penetration Setup Angle (degrees)	47.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	54.1
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-NSD

INPUT VARIABLES FOR CASE 5: RV Head Penetration 66 THRU 68 AMP

a,b

ab

Output Print File VHPNPROF.P06 Opened at 15:16 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	47.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

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INPUT VARIABLES FOR CASE 6: RV Head Penetration 72 AMP

[ ]

a,b

a,b

Output Print File VHPNPROF.P07 Opened at 15:17 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	56.0
Penetration Setup Angle (degrees)	45.8
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	47.7
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-NSD

INPUT VARIABLES FOR CASE 7: RV Head Penetration 63 65 AMP

a,b

a,b

Output Print File VHPNPROF.P08 Opened at 15:17 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	63.0
Penetration Setup Angle (degrees)	45.8
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	54.1
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 VHPNPROP ESBU-NSD

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INPUT VARIABLES FOR CASE 8: RV Head Penetration 62 AMP

a,b

a,b

Output Print File VHPNPROF.P09 Opened at 15:18 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	45.8
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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-INPUT VARIABLES FOR CASE 9: RV Head Penetration 64 AMP

a,b

a,b

Output Print File VHPNPROF.P10 Opened at 15:18 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	44.3
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-NSD

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INPUT VARIABLES FOR CASE 10: RV Head Penetration 58 AMP

a,b

a,b

Output Print File VHPNPROF.P11 Opened at 15:19 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 11: RV Head Penetration 60 AMP

a,b

a,b

Output Print File VHPNPROF.P12 Opened at 15:19 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	41.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.6
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-NSD

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INPUT VARIABLES FOR CASE 12: RV Head Penetration 54 55 57 59 AMP

a,b

a,b

Output Print File VHPNPROF.P13 Opened at 15:20 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

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INPUT VARIABLES FOR CASE 13: RV Head Penetration 61 AMP

a,b

a,b

Output Print File VHPNPROF.P14 Opened at 15:21 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

INPUT VARIABLES FOR CASE 14: RV Head Penetration 56 AMP

a,b

a,b

Output Print File VHPNPROF.P15 Opened at 15:21 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	37.5
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

INPUT VARIABLES FOR CASE 15: RV Head Penetration 53 AMP

a,b

a,b

Output Print File VHPNPROF.P16 Opened at 15:22 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	41.0
Penetration Setup Angle (degrees)	37.5
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.6
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-NSD

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INPUT VARIABLES FOR CASE 16: RV Head Penetration 52 AMP

a,b

[redacted] a,b

Output Print File VHPNPROF.P17 Opened at 15:22 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	37.5
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

INPUT VARIABLES FOR CASE 17: RV Head Penetration 50 51 AMP

a,b

a,b

Output Print File VHPNPROF.P18 Opened at 15:23 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

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INPUT VARIABLES FOR CASE 18: RV Head Penetration \49 AMP

a,b

a,b

Output Print File VHPNPROF.P19 Opened at 15:24 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 19: RV Head Penetration 43 45 THRU 48 AMP

a,b

a,b

Output Print File VHPNPROF.P20 Opened at 15:25 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 20: RV Head Penetration 42 44 AMP

a,b

a,b

Output Print File VHPNPROF.P21 Opened at 15:26 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	35.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

==

INPUT VARIABLES FOR CASE 21: RV Head Penetration 38 THRU 41 AMP

a,b

ab

Output Print File VHPNPROF.P22 Opened at 15:26 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	31.1
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 22: RV Head Penetration 30 34 THRU 37 AMP

[ ] ab

a,b

Output Print File VHPNPROF.P23 Opened at 15:27 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	31.1
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

INPUT VARIABLES FOR CASE 23: RV Head Penetration 31 33 AMP

a,b

a,b

Output Print File VHPNPROF.P24 Opened at 15:27 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	31.1
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

INPUT VARIABLES FOR CASE 24: RV Head Penetration 32 AMP

a,c

a,b

Output Print File VHPNPROP.P25 Opened at 15:28 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 25: RV Head Penetration 29 AMP

a,b

[ ]a,b

Output Print File VHPNPROF.P26 Opened at 15:29 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 26: RV Head Penetration 27 28 AMP

a,b

a,b

Output Print File VHPNPROF.P27 Opened at 15:29 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

INPUT VARIABLES FOR CASE 27: RV Head Penetration 22 AMP

[ ] a,b

a,b

Output Print File VHPNPROF.P28 Opened at 15:30 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 28: RV Head Penetration 23 24 AMP

a,b

a,b

Output Print File VHPNPROF.P29 Opened at 15:30 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 29: RV Head Penetration 25 26 AMP

a,b

a,b

Output Print File VHPNPROF.P30 Opened at 15:31 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	25.5
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

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INPUT VARIABLES FOR CASE 30: RV Head Penetration 18 THRU 21 AMP

[ ] a,b

a,b

Output Print File VHPNPROF.P31 Opened at 15:31 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	23.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 31: RV Head Penetration 15 AMP

a,b

a,b

Output Print File VHPNPROF.P32 Opened at 15:32 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	23.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

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INPUT VARIABLES FOR CASE 32: RV Head Penetration 14 16 AMP

a,b

a,b

Output Print File VHPNPROF.P33 Opened at 15:32 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	23.9
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

INPUT VARIABLES FOR CASE 33: RV Head Penetration 17 AMP

a,b

a,b

Output Print File VHPNPROF.P34 Opened at 15:33 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	18.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 34: RV Head Penetration 13 AHP

a,b

a,b

Output Print File VHPNPROF.P35 Opened at 15:34 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	18.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 35: RV Head Penetration 10 THRU 12 AMP

a,b

a,b

Output Print File VHPNPROF.P36 Opened at 15:35 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 36: RV Head Penetration 9 AMP

a,b

a,b

Output Print File VHPNPROF.P37 Opened at 15:35 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

INPUT VARIABLES FOR CASE 37: RV Head Penetration 8 AMP

a,b

a,b

Output Print File VHPNPROF.P38 Opened at 15:42 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	41.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.6
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-NSD

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INPUT VARIABLES FOR CASE 38: RV Head Penetration 6 AMP

a,b

[ ]a,b

Output Print File VHPNPROF.P39 Opened at 15:43 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 39: RV Head Penetration 7 AMP

a,b

[ ] a,b

Output Print File VHPNPROF.P40 Opened at 15:44 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	11.7
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

INPUT VARIABLES FOR CASE 40: RV Head Penetration 2 THRU 5 AMP

a,b

a,b

Output Print File VHPNPROF.P41 Opened at 15:44 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	63.0
Penetration Setup Angle (degrees)	0.0
Penetration Temperature (F)	595.5
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	54.1
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-NSD

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INPUT VARIABLES FOR CASE 41: RV Head Penetration 1 AMP

a,b

a,b

WESTINGHOUSE VESSEL HEAD PEN. NOZZLE ECONOMIC DECISION ANALYSIS VHPNECON
ESBU-NSD 78 Nozzles at D.C. COOK 2_____ Plant on 07-02-97 06/06/97

a,b

600.7°F

CYCLE	MAX-PROB	PROB-ONE	AVG-PROB	E(NUMFS)
3				
4				
5				
6				
7				
8				
9				
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11				
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13				
14				
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16				
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56				
57				
58				
59				
60				

Output Print File VHPNPROF.P01 Opened at 13:42 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	50.6
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	44.3
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-NSD

INPUT VARIABLES FOR CASE 1: RV Head Penetration 75 AMP

a,b

Output Print File VHPNPROF.P02 Opened at 13:43 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	50.6
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 2: RV Head Penetration 76 THRU 78 AMP

a,b

a,b

a,b

Output Print File VHPNPROF.P03 Opened at 13:44 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	50.6
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 3: RV Head Penetration 74 AMP

a,b

a,b

Output Print File VHPNPROF.P04 Opened at 13:44 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	47.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 4: RV Head Penetration 69 THRU 71 & 73

a,b

a,b

Output Print File VHPNPROF.P05 Opened at 13:45 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	63.0
Penetration Setup Angle (degrees)	47.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	54.1
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-NSD

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INPUT VARIABLES FOR CASE 5: RV Head Penetration 66 THRU 68 AMP

a,b

a,b

Output Print File VHPNPROF.P06 Opened at 13:47 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	47.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

INPUT VARIABLES FOR CASE 6: RV Head Penetration 72 AMP

a,b

a,b

Output Print File VHPNPROF.P07 Opened at 13:48 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	56.0
Penetration Setup Angle (degrees)	45.8
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	47.7
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-NSD

INPUT VARIABLES FOR CASE 7: RV Head Penetration 63 65 AMP

a,b

a,b

Output Print File VHPNPROF.P08 Opened at 13:50 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	63.0
Penetration Setup Angle (degrees)	45.8
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	54.1
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-NSD

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INPUT VARIABLES FOR CASE 8: RV Head Penetration 62 AMP

a,b

a,b

Output Print File VHPNPROF.P09 Opened at 13:54 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	45.8
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 9: RV Head Penetration 64 AMP

a,b

a,b

Output Print File VHPNPROF.P10 Opened at 13:55 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	44.3
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-NSD

INPUT VARIABLES FOR CASE 10: RV HEAD PENETRATION 58 AMP

a,b

a,b

Output Print File VHPNPROP.P11 Opened at 14:00 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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 VHPNPROP ESBU-NSD

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INPUT VARIABLES FOR CASE 11: RV Head Penetration 60 AMP

a,b

a,b

Output Print File VHPNPROF.P12 Opened at 14:01 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	41.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.6
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-NSD

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INPUT VARIABLES FOR CASE 12: RV Head Penetration 54 55 57 59 AMP

[ ] a,b

a,b

Output Print File VHPNPROF.P13 Opened at 14:02 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

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INPUT VARIABLES FOR CASE 13: RV Head Penetration 61 AMP

a,b

a,b

Output Print File VHPNPROF.P14 Opened at 14:03 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	39.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 14: RV Head Penetration 56 AMP

a,b

a,b

Output Print File VHPNPROP.P15 Opened at 14:04 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	37.5
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 15: RV Head Penetration 53 AMP

a,b

a,b

Output Print File VHPNPROF.P16 Opened at 14:04 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	41.0
Penetration Setup Angle (degrees)	37.5
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.6
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-NSD

INPUT VARIABLES FOR CASE 16: RV Head Penetration 52 AMP

[ ]a,b

a,b

Output Print File VHPNPROF.P17 Opened at 14:05 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	37.5
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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 VHPNPROP ESBU-NSD

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INPUT VARIABLES FOR CASE 17: RV Head Penetration 50 51 AMP

a,b

a,b

Output Print File VHPNPROF.P18 Opened at 14:06 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 18: RV Head Penetration 49 AMP

a,b

a,b

Output Print File VHPNPROF.P19 Opened at 14:09 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

INPUT VARIABLES FOR CASE 19: RV Head Penetration 43 45 THRU 48 AMP

a,b

a,b

Output Print File VHPNPROF.P20 Opened at 14:10 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	36.3
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 20: RV Head Penetration 42 44 AMP

[ ] a,b

9b

Output Print File VHPNPROF.P21 Opened at 14:11 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	35.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 21: RV Head Penetration 38 THRU 41 AMP

a,b

a,b

Output Print File VHPNPROF.P22 Opened at 14:12 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	31.1
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 22: RV Head Penetration 30 34 THRU 37 AMP

[ ] a,b

a,b

Output Print File VHPNPROF.P23 Opened at 14:13 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	31.1
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

INPUT VARIABLES FOR CASE 23: RV Head Penetration 31 33 AMP

a,b

a,b

Output Print File VHPNPROF.P24 Opened at 14:14 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	31.1
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 24: RV Head Penetration 32 AMP

a,b

a,b

Output Print File VHPNPROF.P25 Opened at 14:15 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

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INPUT VARIABLES FOR CASE 25: RV Head Penetration 29 AMP

a,b

a,b

Output Print File VHPNPROF.P26 Opened at 14:15 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

INPUT VARIABLES FOR CASE 26: RV Head Penetration 27 28 AMP

a,b

a,b

Output Print File VHPNPROP.P27 Opened at 14:16 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

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INPUT VARIABLES FOR CASE 27: RV Head Penetration 22 AMP

a,b

a,b

Output Print File VHPNPROF.P28 Opened at 14:17 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

INPUT VARIABLES FOR CASE 28: RV Head Penetration 23 24 AMP

[ ] a,b

a,b

Output Print File VHPNPROF.P29 Opened at 14:17 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	27.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 29: RV Head Penetration 25 26 AMP

a,b

a,b

Output Print File VHPNPROF.P30 Opened at 14:18 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	25.5
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

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INPUT VARIABLES FOR CASE 30: RV Head Penetration 18 THRU 21 AMP

a,b

a,b

Output Print File VHPNPROF.P31 Opened at 14:20 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	23.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

INPUT VARIABLES FOR CASE 31: RV Head Penetration 15 AMP

a,b

a,b

Output Print File VHPNPROF.P32 Opened at 14:24 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	23.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	56.1
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-NSD

INPUT VARIABLES FOR CASE 32: RV Head Penetration 14 16 AMP

a,b

a,b

Output Print File VHPNPROF.P33 Opened at 14:24 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	51.0
Penetration Setup Angle (degrees)	23.9
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	40.1
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-NSD

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INPUT VARIABLES FOR CASE 33: RV Head Penetration 17 AMP

a,b

a,b

Output Print File VHPNPROF.P34 Opened at 14:25 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	18.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 34: RV Head Penetration 13 AMP

a,b

A-261

a,b

Output Print File VHPNPROF.P35 Opened at 14:26 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	18.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 35: RV Head Penetration 10 THRU 12 AMP

a,b

a,b

Output Print File VHPNPROF.P36 Opened at 14:27 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	44.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.3
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-NSD

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INPUT VARIABLES FOR CASE 36: RV Head Penetration 9 AMP

a,b

a,b

Output Print File VHPNPROF.P37 Opened at 14:28 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

INPUT VARIABLES FOR CASE 37: RV Head Penetration 8 AMP

a,b

a,b

Output Print File VHPNPROF.P38 Opened at 14:29 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	41.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	30.6
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-NSD

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INPUT VARIABLES FOR CASE 38: RV Head Penetration 6 AMP

a,b

a,b

Output Print File VHPNPROF.P39 Opened at 14:29 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	57.0
Penetration Setup Angle (degrees)	16.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	39.9
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-NSD

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INPUT VARIABLES FOR CASE 39: RV Head Penetration 7 AMP

a,b

a,b

Output Print File VHPNPROF.P40 Opened at 14:30 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	58.0
Penetration Setup Angle (degrees)	11.7
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	45.6
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-NSD

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INPUT VARIABLES FOR CASE 40: RV Head Penetration 2 THRU 5 AMP

a,b

a,b

Output Print File VHPNPROF.P41 Opened at 14:31 on 07-01-1997

Limit Depth Fraction of Wall	0.750
Monotonic Yield Strength (Ksi)	63.0
Penetration Setup Angle (degrees)	0.0
Penetration Temperature (F)	600.7
Center Penetration Stress (Ksi)	34.4
Grain Boundary Carbide Coverage (%)	54.1
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-NSD

INPUT VARIABLES FOR CASE 41: RV Head Penetration 1 AMP

a,b

[ ][a,b]