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Component Evaluation for Intersystem Loss-of-Coolant Accidents in Advanced Light Water Reactors

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ABSTRACT

Using the methodology outlined in NUREG/CR-5603 this report evaluates (on a probabilistic basis) design rules for components in ALWRs that could be subjected to intersystem loss-of-coolant accidents (ISLOCAs). The methodology is intended for piping elements, flange connections, on-line pumps and valves, and heat exchangers. The NRC has directed that the design rules be evaluated for BWR pressures of 7.04 MPa (1025 psig), PWR pressures of 15.4 MPa (2235 psig), and 177°C (350°F), and has established a goal of 90% probability that system rupture will not occur during an ISLOCA event. The results of the calculations in this report show that components designed for a pressure of 0.4 of the reactor coolant system operating pressure will satisfy the NRC survival goal in most cases. Specific recommendations for component strengths for BWR and PWR applications are made in the report. A peer review panel of nationally recognized experts was selected to review and critique the initial results of this program.

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EXECUTIVE SUMMARY

Low-pressure piping systems that branch to the reactor coolant systems (RCSs) of light water reactors (LWRs) are normally protected by multiple valves from the reactor coolant. Failure or misalignment of these isolation valves leads to an intersystem (sometimes called interfacing system) loss-of-coolant accident (ISLOCA), and to the potential leak or rupture of low-pressure systems.

SECY-90-016 (NRC, 1990) and the associated Staff Requirements Memorandum from the Nuclear Regulatory Commission (NRC) Commissioners require evolutionary advanced light water reactor (ALWR) plant designers to include ISLOCA in the design basis; this requirement has been extended to passive plant designers as well. However, the NRC did not initially provide design stress allowables or uniform criteria for ISLOCA design. Subsequently, it was decided to use Service Level A design stresses and a fraction of the RCS design pressure to achieve an acceptable overall system failure probability.

Four ALWRs are presently under review by the NRC staff: ABWR, SBWR, AP600, and System 80+. The piping systems of these plants that may be affected by ISLOCAs include, for example, the residual heat removal system, the safety injection system, the makeup and purification system, and other low-pressure lines that branch to the RCS. While the chief safety concern deals with low-pressure lines that bypass containment, piping that remains entirely within the containment is of concern as well.

To date, no full ISLOCAs have occurred in U.S. nuclear plants, though there have been several instances of leakage past valves from the RCS to connecting systems. These instances have been benign and correctable by the plant staff. The total ISLOCA core damage frequency for existing LWRs was estimated to be in the range of 2×10^{-6} events per reactor per year. Thus, it is a low-probability event. Since the maintenance procedures and operator training on ALWRs are expected to be similar to that at present LWRs, the

ISLOCA probability for ALWRs is expected to be in the same range as for current LWRs.

The NRC has established an objective that evolutionary ALWRs (and by extension, passive ALWRs) provide some protection against ISLOCA sequences. The NRC position is that ISLOCA, for purposes of design, can be treated as a severe accident with a very low frequency of occurrence, thereby allowing relatively high conditional failure probabilities given an ISLOCA. The present NRC *goal* (but not a requirement) is to ensure that each connecting system (including piping, flanges, valves, etc.) has at least a 90% chance of surviving an ISLOCA event.

A comprehensive research program to investigate ISLOCAs was carried out in a previous research program at the Idaho National Engineering Laboratory (INEL). Part of that overall program concentrated on the failure probabilities of mechanical components in currently operating LWRs. That portion of the program is documented in NUREG/CR-5603 and NUREG/CR-5862. The purpose of this report is to use the methodology outlined in NUREG/CR-5603 to evaluate design rules for ISLOCA systems in ALWRs on a probabilistic basis. The methodology is intended for piping elements, flange connections, on-line pumps and valves, heat exchangers, and tanks. The NRC has directed that the design rules be evaluated for BWR pressures of 1025 psig, PWR pressures of 2235 psig, and 350°F. The goal of this report is to demonstrate that each type of component in the system achieves a 98% survival confidence, so that the overall system survival confidence would be in the range of 90%.

The basic methodology is to compute failure stresses that can be used with an ISLOCA survival curve to calculate the probability of component survival at a given system pressure. The curves were developed by estimating the median and the uncertainty of the failure stress, and are material and temperature dependent. For other components (e.g., flanges), the methodology is

based on limiting the leak rate for gasketed connections below the makeup capability of the plant.

The methodology assumes that the only cause of failure is overpressure, and includes the effect of the other stresses in determining the failure stresses and the uncertainty. The hoop stress caused by the pressure loading is set equal to a failure stress. However, this failure stress is reduced from the median ultimate tensile strength by a factor of 0.9 for carbon steel and 0.85 for stainless steel to account for the difference in gage length and for the effect of triaxial stresses, part of which arise from stresses other than pressure stresses. Moreover, a wide uncertainty has been assigned by selecting the 99.9% survival confidence as the median yield stress. This accounts for the probability of a large crack existing in the material, and also provides margin for the additional stresses such as thermal and dead-weight stresses present in the pipe. Thus, the design stresses based on high confidences of survival are much closer to the yield stress than to the median ultimate tensile stress.

Available yield stress and ultimate tensile strength data were used in an attempt to better define the material properties that were used in NUREG/CR-5603. The comparison of the NUREG/CR-5603 values to the material property data obtained from alternate sources indicate that the NUREG/CR-5603 values are conservative or representative for most types of materials. However, there are two cases where the NUREG/CR-5603 values appear to be nonconservative. These are for Type 316 stainless steel and SA-516 Grade 70 carbon steel. Alternate curves were developed and used in this report for stainless steels and SA-516 Grade 70 carbon steel.

A pressure ratio of 0.4 (the design pressure divided by the RCS operating pressure) was investigated. The conclusions are that this pressure ratio is a suitable design value for most cases. Based on the calculations in this report, the recommended sizes for components in ALWR systems to be designed for ISLOCA conditions are as follows:

- Pipe and pipe fittings

BWR—STD for all materials

PWR—STD up to 10 in. for all materials

SA-106 Grade B—12 in., STD; 14, 16, 20 in., Sch. 40; 18 in., XS

Type 316—12 in., Sch. 40.; 14 to 20 in., Sch. 60

Type 304—12 and 14 in., XS; 16 to 20 in., Sch. 60

- Flanges

BWR—Class 300

PWR—Class 600

Bolts—High strength with 40 ksi preload

- Valves

BWR—Class 300

PWR—Class 600

- Pumps

Design for 0.4 pressure ratio

Seals—Need not design for ISLOCA but allow minimal leakage

- Heat exchangers

Cylindrical shell—Design for pressure ratio of 0.40 (SA-516 Grade 70 carbon steel), 0.45 (Type 304 stainless steel)

Heads—Design for 0.4 pressure ratio

Tubes and tubesheets—Design to TEMA standards (except 20 gage for 1-in. and 18 gage for 1-1/4-in. PWR tubes).

These recommendations will satisfy the goal of 90% confidence that gross leakage will not occur to the system during an ISLOCA, but the scope of this project did not include any evaluations to assure that components such as pumps and valves will remain operable during, or fit for service after, an ISLOCA event.

An expert peer review panel reviewed the methodology. Their report is included as Attachment 1 to this report.

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I express appreciation to Dr. John O'Brien, NRC Program Manager, for his guidance and support. D. F. Landers, E. C. Rodabaugh, and D. A. Wesley served on the peer review panel and offered many helpful suggestions and comments. W. J. Galyean and D. L. Kelly of the INEL staff assisted with details of a previous INEL study on ISLOCA. G. M. Wilkowski of Battelle Columbus Laboratories and A. L. Hiser of the NRC helped to identify material property data sources. D. R. Pack provided editorial assistance in preparing the manuscript.

ACRONYMS

ABWR	advanced boiling water reactor	ORNL	Oak Ridge National Laboratory
ALWR	advanced light water reactor	PWR	pressurized water reactor
BWR	boiling water reactor	RCS	reactor coolant system
GE	General Electric	RHR	residual heat removal
GLP	gross leak pressure	SBWR	simplified boiling water reactor
INEL	Idaho National Engineering Laboratory	SR	stress relieved
ISLOCA	intersystem loss-of-coolant accident	STD	standard schedule pipe
LWR	light water reactor	UTS	ultimate tensile strength
NPS	nominal pipe size	XS	extra-strong schedule pipe
NRC	Nuclear Regulatory Commission	XXS	double extra-strong schedule pipe

NOMENCLATURE

a,b,c,d	curve fit constants	S	ASME Code design stress limit
A	pump scroll dimension	S _f	flange size
A _b	individual bolt area	S _u	ASME Code ultimate tensile strength
A _g	gasket area	S _y	ASME Code yield stress
A _p	pressure area	t	wall thickness
D	inside diameter	T	temperature
E	elastic modulus	U _g	factor for change in gasket load with pressure
f _L	flange and ring contact factor	x	value from normal probability tables for given survival probability
ΔG _L	change in gasket load	α	Weibull distribution parameter
JR	joint relaxation	β	logarithmic uncertainty
K _g	gasket initial stiffness	β _{bp}	bolt preload uncertainty
K _{gr}	gasket unloading/reloading stiffness	β _{jr}	joint relaxation uncertainty
L	hemispherical head crown radius	δ _{gi}	initial gasket deflection
m	mean of probability distribution	δ _{gr}	relaxed gasket deflection
M	median of probability distribution	ε	strain
N _b	number of bolts	ε _f	strain at σ _f
p	primary system design pressure	θ	Weibull distribution parameter
P	pressure	σ	stress
P _{cr}	critical buckling pressure	σ _{bp}	bolt preload stress
ΔP	change in system pressure	σ _c	failure stress at survival confidence c
r	inside radius	σ _f	failure stress
r _n	knuckle radius of torispherical head	σ _{gi}	initial gasket stress (psi)
R	correction factor for plastic strain	σ _{gr}	relaxed gasket stress (psi)
R _o	outside radius	σ _{sc}	σ _c corrected for plastic strain
s	standard deviation of probability distribution	σ _y	yield stress

Component Evaluation for ISLOCAs in ALWRS

1. INTRODUCTION

Low-pressure piping systems that branch to the reactor coolant systems (RCSs) of light water reactors (LWRs) are normally protected by multiple valves from the reactor coolant. Failure or misalignment of these isolation valves leads to an intersystem (sometimes called interfacing system) loss-of-coolant accident (ISLOCA), and to the potential leak or rupture of low-pressure systems.

SECY-90-016 (NRC, 1990) and the associated Staff Requirements Memorandum from the Nuclear Regulatory Commission (NRC) Commissioners require evolutionary advanced light water reactor (ALWR) plant designers to include ISLOCAs in the design basis; this requirement has been extended to passive plant designers as well. However, the NRC did not initially provide design stress allowables or uniform criteria for ISLOCA design. Subsequently, it was decided to use Service Level A design stresses and a fraction of the RCS design pressure to achieve an acceptable overall system failure probability. The purpose of this report is to evaluate design rules for ISLOCAs on a probabilistic basis.

1.1 Background

Four ALWRs are presently under review by the NRC staff: ABWR, SBWR, AP600, and System 80+. The piping systems of these plants that may be affected by ISLOCAs include, for example, the residual heat removal system, the safety injection system, the makeup and purification system, and other low-pressure lines that branch to the RCS. While the chief safety concern deals with low-pressure lines that bypass containment, piping that remains entirely within the containment is of concern as well.

To date, no full ISLOCAs have occurred in U.S. nuclear plants, though there have been several instances of leakage past valves from the RCS to connecting systems. These instances have

been benign and correctable by the plant staff. The total ISLOCA core damage frequency for existing LWRs was estimated to be in the range of 2×10^{-6} events per reactor per year (Galyean et al., 1993). Thus, it is a low-probability event. Since the maintenance procedures and operator training^a on ALWRs are expected to be similar to that at present LWRs, the ISLOCA probability for ALWRs is expected to be in the same range as for current LWRs.

The NRC has established an objective that evolutionary ALWRs (and by extension, passive ALWRs) provide some protection against ISLOCA sequences. The NRC position is that an ISLOCA, for purposes of design, can be treated as a severe accident with a very low frequency of occurrence, thereby allowing relatively high conditional failure probabilities given an ISLOCA. The present NRC *goal* (but not a requirement) is to ensure that each connecting system (including piping, flanges, valves, etc.) has at least a 90% chance of surviving an ISLOCA event.

It appears that European nuclear safety authorities are considering similar actions. The French and Germans released their safety goals in *Common Safety Approach for Future Pressurized Water Reactors*, in which they state that "containment bypass is to be practically eliminated by such measures as adequate piping design pressure" (*Inside NRC*, 1993).

1.2 INEL ISLOCA Research Programs

A comprehensive research program to investigate ISLOCAs was carried out at the Idaho National Engineering Laboratory (INEL). The results are summarized by Galyean et al. (1993). A part of that overall program concentrated on the

a. Plant personnel actions are the leading cause of ISLOCAs.

Introduction

failure probabilities of mechanical components in currently operating LWRs, which is documented in NUREG/CR-5603 (Wesley et al., 1990) and NUREG/CR-5862 (Wesley, 1992).

The purpose of the current program is to use the methodology outlined in NUREG/CR-5603 to evaluate design rules for ISLOCA systems in ALWRs on a probabilistic basis. Design of systems for ISLOCA pressures of 40% of the primary system operating pressure was the base case evaluated. The methodology is intended to

include piping elements, flange connections, on-line pumps and valves, heat exchangers, and tanks. The NRC has directed that the design rules be evaluated for BWR pressures of 1025 psig, PWR pressures of 2235 psig, and 350°F. A peer review panel of nationally recognized experts was selected to review and critique the initial results of this program. Their conclusions are included as Attachment 1 of this report. The author has addressed their comments in the body of this report.

2. METHODOLOGY DEVELOPMENT

A methodology for evaluating probabilistic pressure capacities for selected components in systems potentially susceptible to ISLOCA events was developed and reported in NUREG/CR-5603 (Wesley et al., 1990). For some components (e.g., pipes, tanks) the methodology for evaluating design rules is based on an allowable stress concept. The basic methodology is to compute failure stresses that can be used with an ISLOCA survival curve to calculate the probability of component survival at a given system pressure. The curves were developed by estimating the median and the uncertainty of the failure stress, and are material and temperature dependent. For other components (e.g., flanges), the methodology is based on limiting the leak rate for gasketed connections below the makeup capability of the plant (a 200-gpm leak rate will be assumed). In the methodology described below, the original NUREG/CR-5603 methodology has been slightly modified in places by the author based on his own and the peer review panel's recommendations, but remains basically the same as described in NUREG/CR-5603.

2.1 Methodology Outline for Allowable Stresses

The major steps and assumptions associated with the allowable stress methodology are as follows:

Step 1. Determine the stress induced in the pipe during ISLOCA conditions.

- The ISLOCA failure mode is assumed to be from a statically applied pressure alone (this assumption is discussed in Section 2.1.1).
- The stress in the pipe wall can be calculated using the equation for hoop stress (pr/t).

Step 2. Estimate the median failure stress.

- The median ultimate tensile strength of the piping materials can be obtained using material property data.

- The median value can be reduced to account for triaxial stresses and the differences in the gage length of the tensile specimens and the actual piping.
- A further reduction can be applied to account for the increase in pipe diameter caused by the plastic strain in the pipe wall.

Step 3. Estimate the uncertainty of the failure stress.

- The failure stress curve is assumed to have a lognormal distribution.
- The uncertainty of the failure stress curve can be estimated by assuming that the failure probability at the yield stress is 10^{-3} (or some smaller value) to account for cracking (original or induced).
- Attention can be given to the manufacturer's tolerance and the corrosion allowance.

The following sections discuss these assumptions.

2.1.1 Failure Mode Assumption. To establish design rules based on the failure probability of piping during an ISLOCA event, it is desirable to have a simple, general methodology that will apply to all ALWR piping systems rather than factor in the specific operating stresses for each individual design. However, the magnitudes of piping stresses (other than the ISLOCA pressure stress that can be assumed to be the full primary system pressure) are design-specific, small compared to the ISLOCA pressure stresses, and depend on the plant conditions at the time of the ISLOCA event. Thermal and deadweight stresses will be present to some degree, while there is a very low probability that seismic or water hammer stresses will occur during the ISLOCA event. These stresses represent only a portion of the overall design stresses (they do not include the pressure stress), which have already been limited according to ASME Code rules for A through D Service Levels, and these stresses would not

increase significantly during the ISLOCA event as does the pressure stress.

The methodology simply assumes that the only cause of failure is overpressure, and includes the effect of the other stresses in the determination of the failure stresses and the uncertainty, as follows. The hoop stress caused by the pressure loading is set equal to a failure stress. However, this failure stress will be reduced from the median ultimate tensile strength (Section 2.1.2). Moreover, a wide uncertainty has been assigned by selecting the 99.9% survival confidence as the median yield stress. This accounts for the probability of a large crack existing in the material, and also provides margin for the additional stresses such as thermal and deadweight stresses present in the pipe. Thus, as shown in later sections, the design stresses based on high confidences of survival are much closer to the yield stress than to the median ultimate tensile stress.

2.1.2 Ultimate Tensile Strength Curve. In NUREG/CR-5603, the median^b ultimate tensile strengths for carbon and stainless steels were obtained from the open literature (Harvey, 1985; Weiss and Sessler, 1963). (Section 3 evaluates NUREG/CR-5603 material properties). The median ultimate tensile strength values were reduced by factors of 0.85 for stainless steel and 0.9 for carbon steel to account for the following differences between the specimens from which the strength data were generated and nuclear piping:

1. The material property data were based on testing uniaxial tensile specimens, whereas a state of triaxial stress will exist in the actual piping (however, only two of the three stress components are significant)
2. The uniaxial tensile specimen gage length was very small compared to that of the actual piping, which is assumed to be the pipe circumference.

These reduction factors were based on Manjoine's (1975) work. Wesley (1990) esti-

b. The median is the stress at which the failure probability is 50%.

imated that the reduction factor is 1.73 for pressure alone and 2 when bending is included. A further reduction of the order of 1.5 to 2 was estimated for the gage length effect. By multiplying the means of the two ranges (1.865×1.75), the estimated reduction factor is 3.264. Figures 1 and 2 show engineering stress-strain curves for stainless and carbon steels, respectively (Boyer, 1987). (However, these curves were not used in NUREG/CR-5603 to arrive at the 0.85 and 0.9 stress reduction factors). The strains (room temperature) at the ultimate tensile strengths are 0.575 and 0.183 in./in., respectively. Applying the mean reduction factors results in estimated failure strains of 0.177 and 0.056 in./in. The stresses at these strains are 63 and 55 ksi, which are 78 and 86% of the ultimate tensile strength and approximately equal to NUREG/CR-5603 values of 0.85 and 0.90. As further verification of the appropriateness of the NUREG/CR-5603 stress reduction values, Chu et al. (1989) reported that General Electric conducted burst tests on seamless A106 carbon steel pipes and found that "the average burst hoop stress of unflawed pipe specimens was found to be at approximately 90% of the ultimate stress independent of the pipe size." Unfortunately, there were no corresponding data for stainless steel. Appendix B of the peer review panel report (Attachment 1 of this report) estimates that the evaluating criteria may underestimate the median burst pressure by about 30%.

After stress reduction factors are applied, the resulting stress is called the median failure stress (σ_f). The lognormal curve results in the following equation for the failure stress (σ_c) at a given percent confidence of survival c:

$$\sigma_c = \sigma_f e^{-\beta x} \quad (1)$$

The logarithmic uncertainty of the failure stress (β) is determined by using the following values of σ_c and x:

$$\sigma_c = \sigma_y$$

$$x = \text{the value from the normal probability tables for a survival probability of } 10^{-3} \text{ (that is, 3.09)}$$

Figure 1. Engineering stress-strain curve for stainless steel (data from Boyer, 1987).

and solving Equation 1 for β . A sensitivity study also was conducted for a survival probability of 10^{-4} at σ_y . Table 1 lists the resulting probability curve parameters for Type 304 stainless and SA-106 Grade B carbon steel pipe failure stresses at several temperatures (using NUREG/CR-5603 and NUREG/CR-5862 material property values),

where

- β = logarithmic uncertainty
- ϵ_f = strain at σ_f
- σ_c = failure stress at survival confidence c

σ_f = failure stress

σ_y = yield stress.

Plots of the resulting failure curves can be made by using the values of the lognormal distribution parameters from Table 1 and the assumed probabilities of failure at the yield stress of 10^{-3} and 10^{-4} . As an example, the lognormal curves at 400°F for Type 304 stainless and SA-106 Grade B carbon steel are plotted in Figures 3 and 4 for yield-stress failure probabilities of 10^{-3} and 10^{-4} . These curves may be considered reasonable for failure stresses of the order of plus

Figure 2. Engineering stress-strain curve for carbon steel (data from Boyer, 1987).

one standard deviation and below; consequently, they have been truncated at $+1\beta$. At failure stresses in the high end of the distribution, some upper bound cutoff is required. Although flaws can reduce the failure stress significantly below the median value, the absence of flaws cannot strengthen the material such that the upper bound is greater than the failure stress of unflawed material. Since we will be working with the high confidence of survival area at the low end of the curve, selection of an upper bound cutoff is unnecessary.

2.1.3 Survival Curve. Once the failure probability curves have been determined, the survival probability (which is 1 minus the failure probability) for any stress can be determined and corrected for the expansion caused by plastic stress.

This correction is applied because the hoop stress in the piping is computed based on the original surface area that the pressure acts upon on the inside wall of the pipe. However, the pipe radius expands as the pressure causes plastic deformation in the wall; consequently, the surface area on which the pressure acts increases with strain [the increased radius is $r(1 + \epsilon)$]. To apply such a correction for the plastic strain, we assume that the stress-strain relation is bilinear with the break point at the yield stress σ_y .^c Then the strain ϵ_f

c. Actually, the stress-strain curve is not linear between the yield strength and the ultimate tensile strength, as seen in Figures 1 and 2. A straight line between the two points results in a higher strain and, therefore, a lower allowable stress than would the actual curve; thus, the assumption is slightly conservative.

Table 1. Failure stress probability curve parameters with failure probability of 10^{-3} and 10^{-4} at yield stress.

Type 304 stainless steel pipe					
Temperature (°F)	σ_f (ksi)	ϵ_f (in./in.)	σ_y (ksi)	β (10^{-3})	β (10^{-4})
Room temperature	73.1	0.283	37	0.22	0.18
400	62.9	0.179	23	0.33	0.27
600	59.5	0.165	19.5	0.36	0.30
800	55.7	0.161	16.5	0.39	0.32
Type 304 stainless steel plate					
Temperature (°F)	σ_f (ksi)	ϵ_f (in./in.)	σ_y (ksi)	β (10^{-3})	β (10^{-4})
Room temperature	67	0.20	37	0.19	0.16
400	57.9	0.13	23	0.30	0.25
600	54.6	0.12	19.5	0.33	0.28
800	51.2	0.11	16.5	0.37	0.30
Type 316 stainless steel					
Temperature (°F)	σ_f (ksi)	ϵ_f (in./in.)	σ_y (ksi)	β (10^{-3})	β (10^{-4})
Room temperature	73.5	0.162	42	0.18	0.15
400	69.3	0.152	35	0.22	0.18
600	65.9	0.151	31	0.24	0.20
800	62.1	0.147	28	0.26	0.21
SA-106 Grade B carbon steel					
Temperature (°F)	σ_f (ksi)	ϵ_f (in./in.)	σ_y (ksi)	β (10^{-3})	β (10^{-4})
Room temperature	61.2	0.119	36	0.17	0.14
400	64.8	0.083	31	0.24	0.20
600	62.1	0.109	27	0.27	0.22
800	49.5	0.163	24	0.23	0.19

Figure 3. Assumed ultimate tensile strength distribution for Type 304 stainless steel (a) 10^{-3} (b) 10^{-4} probability of failure at yield stress.

Figure 4. Assumed ultimate tensile strength distribution for SA-106 Grade B carbon steel (a) 10^{-3} (b) 10^{-4} probability of failure at yield stress.

corresponding to the median (50% confidence) failure stress (σ_f) can be adjusted by the following ratio to estimate the corresponding strain at the failure stress (σ_c):

$$R = \frac{\sigma_c - \sigma_y}{\sigma_f - \sigma_y} \quad (2)$$

where σ_y , σ_f , and σ_c are defined above.

The corrected value of σ_c^d is calculated by dividing σ_c by $(1 + R\epsilon_f)$.

$$\sigma_{sc} = \frac{\sigma_f e^{-\beta x}}{(1 + R\epsilon_f)} \quad (3)$$

where

d. It would be more logical to apply the correction for plastic strain as a multiplier to r in the pr/t stress calculations, but, in practice, when performing sensitivity studies using several pr/t values, it is easier to apply the correction only once to the allowable stress, and, thereby, not have to perform the correction for each pr/t that is calculated.

σ_{sc} = σ_c corrected for plastic strain

$R\epsilon_f$ = strain at σ_c .

Hoop stress (pr/t) versus temperature curves for several survival probabilities are plotted in Figures 5 through 7. The ASME Section III Classes 2 and 3 Levels 2.5A and D stress limits (for an ABWR pressure of 1025 psig and no corrosion allowance) also are included, with the hoop stress computed as follows:

$$\frac{pr}{t} = S - 0.6 p \quad (4)$$

where

p = primary system design pressure

r = inside radius

t = wall thickness

S = ASME Code design stress limit.

The Level D limit allows a factor of 2 increase in pressure over the normal primary system operating pressure, so piping designed for 50% of the

Figure 5. Comparisons of allowable stress limits for Type 304 stainless steel pipe: ASME Code Levels 2.5 A and D and probability-based confidence limits (10^{-3} probability of failure at yield stress).

Figure 6. Comparisons of allowable stress limits for Type 304 stainless steel pipe: ASME Code Levels 2.5A and D and probability-based confidence limits (10^{-4} probability of failure at yield stress).

Figure 7. Comparisons of allowable stress limits for SA-106 Grade B carbon steel pipe: ASME Code Levels 2.5A and D and probability-based confidence limits (10^{-3} probability of failure at yield stress).

expected ISLOCA pressure would meet the Level D stress limit. The Level D limit provides about a 98% confidence of survival at 350°F for Type 304 stainless steel with an assumed 10^{-3} failure probability at yield stress (Figure 5).

Piping designed for 40% of the primary system operating pressure would meet a 2.5 Level A stress limit. The 2.5 Level A confidence level is about 90%. The Level D confidence level at 350°F would increase to greater than 99% for an assumed 10^{-4} failure probability at yield stress (Figure 6), while the 2.5 Level A confidence level is about 93%. Both the Level D and 2.5 Level A limits provide greater than 99% confidence of survival at 350°F for carbon steel with an assumed 10^{-3} failure probability at yield stress (Figure 7).

2.2 Methodology for Leak Rate Assumptions

For nonmetallic components such as gaskets and seals (where leakage will occur before rupture), the basic assumption will be to limit the leakage to a small amount that is within the capability of the plant's coolant makeup system. The details for affected components such as flanges are included in Section 4.

A related question that is not within the scope of the present study, but which is planned to be addressed later, is whether small lines under a certain diameter (as yet to be determined) that branch from the main system, may be excluded from consideration because the leakage from a ruptured line in the system will be within the capacity of the plant's coolant makeup system.

2.3 Investigations of Other Possible Assumptions

A number of assumptions were made in the previous section to obtain survival probability curves. Two alternatives were investigated to determine how different assumptions would affect the results. The first was to use another probability distribution for the failure stress

curve, and the second was to use a different assumption for the failure strength uncertainty.

2.3.1 Weibull Distribution Assumption.

The lognormal distribution represents a distribution that is appropriate when the variable is the product of a number of factors. Other probability distributions (such as Weibull or beta distributions) also could be used. Consequently, the lognormal distribution and the Weibull distribution, a distribution that was conceived for failure data, were compared. The Weibull probability distribution function is defined as

$$f(x; \theta, \alpha) = \frac{\alpha}{\theta^\alpha} x^{\alpha-1} e^{-\left(\frac{x}{\theta}\right)^\alpha} \text{ for } x > 0 \quad (5)$$

and the corresponding cumulative density function is

$$F(x; \theta, \alpha) = 1 - e^{-\left(\frac{x}{\theta}\right)^\alpha} \text{ for } x > 0 \quad (6)$$

We can solve for θ and α by choosing the 50% confidence level as the median of the ultimate tensile strength data corrected for the effects of triaxial stress and gage length (σ_f), and the 99.9% confidence level as σ_y . For SA-106 Grade B carbon steel at 400°F ($\sigma_f = 64.8$ ksi, $\sigma_y = 31$ ksi), the Weibull parameters are $\theta = 67.5$ and $\alpha = 8.87$.

The Weibull distribution is plotted versus the comparable lognormal curve (uncorrected for strain) in Figure 8. Next, the 90%, 97%, and 99% survival probability stresses for the Weibull and lognormal distributions were computed, including the adjustment to correct for the increased pipe diameter caused by plastic strain. The results are presented in the Table 2.

The Weibull distribution results in about a 3 to 4 ksi increase in allowable stress levels over the lognormal curve. Thus, the lognormal curve provides more conservative stress values than does the Weibull curve.

2.3.2 Alternate Uncertainty Assumption.

Figures 5 and 7 show that using the failure assumptions in Section 2.1, carbon steel has a higher probability of survival than does stainless steel. This does not mean, however, that carbon

Figure 8. Comparison of lognormal and Weibull representations of the ultimate failure stress for SA-106 Grade B carbon steel at 400°F.

Table 2. Comparison of allowable stresses computed using Weibull and lognormal distributions.

Survival confidence (%)	Weibull distribution		Lognormal distribution	
	Stress from curve (ksi)	Corrected stress (ksi)	Stress from curve (ksi)	Corrected stress (ksi)
90	52.4	49.8	47.6	45.8
97	45.6	44.9	41.3	40.2
99	40.2	39.3	37.1	36.5

steel is a preferred material; the higher failure probability for carbon steel is a result of the ratios of the yield and ultimate strengths of carbon and stainless steels, and the basis that is used in the ASME Boiler and Pressure Vessel Code for selecting allowable stresses. The ASME Code uses the lesser of one-fourth of the ultimate tensile strength or two-thirds of the yield stress as the allowable stress for Class 2 piping.

Table 3 shows that the allowable stress is based on one-fourth of the tensile strength for SA-106

Grade B carbon steel, but on two-thirds of the yield stress for Type 304 stainless steel at 400°F (ASME, 1992a).^e For carbon steel, the ratio of the yield to the design stress is 2, while the ratio is only 1.5 for stainless steel. Thus, the 99% survival confidence stress (the yield stress) is twice the design stress (the Level D limit) for carbon

e. S is used throughout the text to indicate ASME Code stresses (e.g., S_y is the Code yield stress and S_u is the Code ultimate tensile strength), whereas σ is used in the text to denote computed stresses.

Table 3. Computation of ASME Code allowable stress for SA-106 Grade B carbon steel and Type 304 stainless steel.

	Carbon steel (ksi)	Stainless steel (ksi)
S_u	60.0	64.4
$1/4 S_u$	15.0	16.1
S_y	30.0	20.7
$2/3 S_y$	20.0	13.8
S	15.0	13.8

steel, but twice the design stress for stainless steel is greater than the yield stress, so the survival confidence at the Level D limit is less than 99%.

Brookhaven National Laboratory has attempted to define the failure uncertainty by assigning the average ultimate tensile strength as the 99% failure limit to the failure curve, and 90% of the average ultimate tensile strength as the median of the curve (Chu, 1989). The basis for the 90% value as the median of the curve was from the GE pipe burst test results previously mentioned in which the hoop stress at burst was 90% of the ultimate tensile strength. The resulting failure probability at the yield stress ranged from 2×10^{-3} to 8×10^{-3} , which is about the same order of magnitude as the failure probability of 1×10^{-3} assumed in NUREG/CR-5603. While the Brookhaven study has a defensible basis for the median and upper confidence level, the lower confidence level was not based on anything physical and did not take into account the possibility of cracking but was decided by the parameters of the upper portion of the curve. Yet the lower region of the curve is of interest since we need to determine stress limits for high probabilities of survival.

The difficulties in establishing the lower survival confidence limit in the Brookhaven and

NUREG/CR-5603 studies show that there is no straightforward way to define the lower limit, as pointed out in the peer review panel report (Attachment 1). We have no data for overpressure failures of nuclear piping that has been designed to ASME Code stress limits. However, we do know that for piping designed to ASME Code requirements, there have been no overpressure failures (excluding piping thinned by erosion/corrosion), so the failure probability must be "low." If we assign various failure probabilities to represent this "low" number at the Level A design stress and the failure stress in Table 1 as the median stress, the survival probabilities at 2.5 times the Level A stress for 350°F are as shown in Figure 9. Using this argument, the lower confidence limit is now based on something physical for which we have data, namely the design stress value for which we have experience at operating pressures. However, we have no operating data at higher pressures, nor do we have any precise knowledge of the magnitude of the failure probability at the design stress.

Based on operating experience of LWRs worldwide, the failure probability at the design stress is estimated to be less than 10^{-4} events per reactor per year, so the survival confidence from Figure 9 at 2.5 times the Level A stress is about 92% or greater. The survival confidences in Figure 9 are approximately the same for carbon and stainless steels; whereas, using the assumption of 10^{-3} failure probability of failure at the yield stress, the survival confidence is substantially greater for carbon than for stainless steels.

The alternate method of developing an uncertainty for the failure curves leads to basically the same conclusion as does the method in NUREG/CR-5603, that is, the minimum survival confidence at 2.5 times the Level A design stress is greater than 90%. This argument is based on actual operating data, and shows a better balance between the carbon and stainless steel survival probabilities than does the NUREG/CR-5603 method.

Figure 9. Survival confidences at 2.5 times the Level A stress for various probabilities of failure at the Level A stress.

3. MATERIAL PROPERTIES

In NUREG/CR-5603, the median ultimate tensile strengths for carbon and stainless steels were obtained from Harvey (1985) and Weiss and Sessler (1963). In a September 1992 presentation by the author to the ASME Subgroup on Design in New York, the question was asked whether the NUREG/CR-5603 data had been compared to the data used in generating the ASME Code material property values. In response, material property data were obtained from alternate sources and compared to the NUREG/CR-5603 data. The ASME staff stated that the original data are found in some old ASTM publications, designated DS5 (stainless steel) and DS11 (carbon steel) and their supplements (Simmons and Van Echo, 1965; Simmons and Cross, 1952 and 1955; Smith, 1969 and 1972). The data in the five ASTM publications are carefully referenced (in almost all cases) to the source, the product form (bar, plate, pipe/tube, etc.), and the test temperature. Individual data points (as opposed to averages) are tabulated. Therefore, these publications make excellent sources to which the NUREG/CR-5603 median values can be compared.

Data from several other sources also were used to supplement the ASME/ASTM data, where applicable. Dr. Gery Wilkowski of Battelle Columbus Laboratories was particularly helpful in identifying material property data sources.

From discussions with ALWR vendors and a review of the materials in operating plants, the following materials are believed to be those that will likely be used in systems subject to ISLOCA in ALWRs:

- Type 304 stainless steel pipe (wrought and cast) and plate
- Type 316 stainless steel pipe (wrought and cast)
- SA-106 Grade B carbon steel pipe
- SA-516 Grade 70 carbon steel plate.

The median ultimate tensile strengths and the yield stresses of the alternate data can be compared directly with the NUREG/CR-5603 values, though in some cases the mean (m) and the standard deviation (s) need to be converted to the lognormal uncertainty (β) and the median (M), using the following formulas:

$$M = e^{\ln(m) - \frac{\beta^2}{2}} = m e^{-\frac{\beta^2}{2}} \quad (7)$$

$$\beta = \sqrt{\ln\left[\left(\frac{s}{m}\right)^2 + 1\right]} \quad (8)$$

Some further adjustments need to be made for the survival confidences. To obtain the survival confidences for the alternate data, the median failure stresses [σ_u (data) $\times$ 0.85 (stainless steel) and 0.9 (carbon steel)] were adjusted by dividing by the $1 + R \epsilon_f$ factor to account for the increased diameter caused by the plastic strain. To obtain ϵ_f for the alternate data, the corresponding strains from NUREG/CR-5603 were multiplied by the ratio of the differences in median failure and yield stresses of the alternate data and the NUREG/CR-5603 values.

3.1 Wrought Type 304 Stainless Steel

Wrought Type 304 stainless steel data are available in two product forms applicable to systems to be designed for ISLOCA: pipe and plate.

3.1.1 Pipe. The oldest Type 304 stainless steel data sets are from Simmons and Cross (1952). This ASTM special publication had two supplements (Simmons and Van Echo, 1965; Smith, 1969). The 1952 data series contain values for three forms of 18-8 steel (although Type 304 stainless steel is not specially referred to in this reference, its composition is 18Cr-8Ni): bar stock, sheet, and other (cast). There is no specific mention of the wrought pipe/tube product form. Supplement 1, published in 1965, specifically lists wrought Type 304 stainless steel as a separate product form, whereas Supplement 2, published in 1969, lists Type 304-304H pipe/tube as a separate product form. Other sources of data are

Hiser (1989), Wilkowski et al. (1989), Hays et al. (1986), Kanninen (1982), and Yagawa et al. (1984).

The ultimate tensile strength (UTS) and yield stress data are plotted in Figures 10 and 11 with the NUREG/CR-5603 values. Since the ASME/ASTM 1969 supplement does not present the data sources, some of the data in the two supplements may be duplicated. For the range of temperatures at which we are interested for ISLOCA (350 to 550°F), the NUREG/CR-5603 median values are slightly higher than the ASTM data for the ultimate tensile strength, but slightly lower than the ASTM data for the yield stress. To obtain best-estimate values for the material parameters, least-squares curve fits were calculated from the material property data and are shown in Figures 12 and 13. The curve fits are of the form:

$$\sigma = a + bT + cT^2 + dT^3 \quad (9)$$

where T is the temperature and a through d are constants (shown in Table 4).

What is really important is how the confidence level stresses compare. Table 5 compares the 90, 97, and 99% NUREG/CR-5603 confidence levels for a 10^{-3} probability of failure at the yield stress to the other data at 350 and 500°F. The NUREG/CR-5603 confidence levels are within 1 ksi of the confidence levels calculated using the other data, except for the 90% confidence level at 350°F, where the NUREG/CR-5603 values are about 2.5 ksi nonconservative.

Table 6 summarizes the confidence levels assuming a 10^{-4} probability of failure at the yield stress. At this failure probability, the NUREG/CR-5603 values are within about 1 ksi of the survival probabilities calculated using the other data at 500°F, and about 1 to 3 ksi nonconservative with respect to the other data at 350°F. The overall conclusion is that the survival confidences calculated using the NUREG/CR-5603 and other data differ by, at most, about 6%.

Figure 10. Ultimate tensile strength data for wrought Type 304 stainless steel pipe.

Figure 11. Yield stress data for wrought Type 304 stainless steel pipe.

Figure 12. Ultimate tensile strength curve fit for wrought Type 304 stainless steel pipe.

Figure 13. Yield stress curve fit for wrought Type 304 stainless steel pipe.

Table 4. Curve fit constants for Type 304 wrought stainless steel.

Pipe	a	b	c	d
S_y	42.94	-0.08229	0.000110	-5.1×10^{-8}
S_u	96.0938	-0.1593	0.000260	-1.4×10^{-7}

Plate	a	b	c	d
S_y	42.82	-0.07195	9.02×10^{-5}	-4.3×10^{-8}
S_u	98.32	-0.1720	0.000279	-1.5×10^{-7}

Table 5. Comparison of survival confidence stress values for wrought Type 304 stainless steel pipe (10^{-3} probability of failure at yield stress).

Survival confidence (%)	Stress (ksi)			
	Temperature = 500°F		Temperature = 350°F	
	NUREG/CR-5603	Other data	NUREG/CR-5603	Other data
99	26.71	27.79	30.72	30.15
97	30.55	31.01	34.44	33.22
90	36.45	35.83	40.00	37.73

Table 6. Comparison of survival confidence stress values for wrought Type 304 stainless steel pipe (10^{-4} probability of failure at yield stress).

Survival confidence (%)	Stress (ksi)			
	Temperature = 500°F		Temperature = 350°F	
	NUREG/CR-5603	Other data	NUREG/CR-5603	Other data
99	30.35	30.61	33.99	32.84
97	33.69	33.49	37.31	35.55
90	38.85	37.72	42.16	39.47

3.1.2 Plate. The ASTM data by Simmons and Van Echo (1965) and Smith (1969), and other data from Wilkowski et al. (1989) and Kanninen et al. (1976 and 1982) contain a few material property values for Type 304 stainless steel plate. Figures 14 and 15 show the NUREG/CR-5603 Type 304 stainless steel values plotted with the data points for Type 304 plate material from other sources. From inspection, some of the data from the two ASME/ASTM sources may be dupli-

cated. The NUREG/CR-5603 ultimate tensile strength values trend higher than the other data, whereas the NUREG/CR-5603 yield stress values trend lower than the other data points.

Table 4 lists the Equation 9 curve fit coefficients and Figures 16 and 17 show the curve fits. The curve coefficients for the pipe and plate forms do not differ greatly. Table 7 compares the survival confidences at 350°F.

Figure 14. Comparison of ultimate tensile strength data for wrought Type 304 stainless steel plate.

Figure 15. Comparison of yield stress data for wrought Type 304 stainless steel plate.

Figure 16. Curve fit for wrought Type 304 stainless steel plate ultimate tensile strength data.

Figure 17. Curve fit for wrought Type 304 stainless steel plate yield stress data.

Table 7. Comparison of survival confidence stress values for Type 304 stainless steel plate at 350°F (10^{-3} and 10^{-4} probabilities of failure at yield stress).

Survival confidence (%)	Stress (ksi)			
	10^{-3} failure probability at σ_y		10^{-4} failure probability at σ_y	
	NUREG/CR-5603	Curve fit	NUREG/CR-5603	Curve fit
99	30.32	31.49	32.02	34.15
97	33.76	34.52	35.19	36.82
90	38.90	38.97	39.92	40.69

The NUREG/CR-5603 survival confidences are within 2 ksi of the corresponding survival confidences calculated from the other data. NUREG/CR-5603 recommends lower failure stress values for vessels than for piping; consequently, the survival confidence levels for the NUREG/CR-5603 values in Table 7 are lower than those in Tables 5 and 6.

3.2 Cast Type 304 Stainless Steel

Most of the data in the ASTM reports are for wrought stainless steel. The 1969 report deliberately excludes data for cast stainless steel, whereas the 1952 and 1965 reports contain only a

few points for cast material at several temperatures. The data in the 1965 report are for cast stainless steel pipe that had been bored and cold expanded. Figures 18 and 19 plot this data with data from Brown (1992) [which were obtained from Allegheny Ludlum (1958)], Hiser (1988), and Chopra et al. (1991). The overall conclusions are that the NUREG/CR-5603 ultimate tensile strength values trend higher than the other data, and that the NUREG/CR-5603 yield stress values are approximately the same as the additional data.

Table 8 lists the Equation 9 curve fit coefficients, and Figures 20 and 21 show the curve fits. The curve coefficients for the cast and wrought forms do not differ greatly. Table 9 compares the survival confidences at 350°F. The NUREG/CR-5603 survival confidences are within 0 to 3 ksi of the curve fit values obtained from the other data. The ASTM (1952) data were from tests of cast cylinders and cast keel blocks (navy pattern). The ASTM (1965) data were from tests of material that was cast, rough-turned and bored, cold expanded, and annealed. Based on the

graphs in Figures 18 through 21 and the survival confidences in Table 9, it appears that the NUREG/CR-5603 values are representative for cast Type 304 stainless steel.

3.3 Type 316 Stainless Steel

The Type 316 stainless steel data in NUREG/CR-5603 were taken from the 1963 version of the *Aerospace Structural Metals Handbook* (Brown, 1992). These data were in turn taken from tests conducted by the Timken Roller Bearing Company (1962). Unfortunately, there were no data reported between room temperature and 1000°F, so essentially a straight-line curve was fit between the room temperature and the 1000°F data in the *Aerospace Structural Metals Handbook*. From review of the same data reported in Simmons and Van Echo (1965), the type of stainless steel tested was wrought, 6-5/8-in. diameter by 1-5/16-in. wall, seamless, rotary-pierced, inside-and-outside-surfaces-machined material.

Figure 18. Comparison of ultimate tensile strength data for cast Type 304 stainless steel.

Figure 19. Comparison of yield stress data for cast Type 304 stainless steel.

Table 8. Curve fit constants for Type 304 cast stainless steel pipe.

	a	b	c	d
S_y	41.94	-0.07655	0.000109	-6.0×10^{-8}
S_u	93.67	-0.165	0.000278	-1.6×10^{-7}

There are far less available data for Type 316 stainless steel than for Type 304 stainless steel. A comparison of the wrought and cast properties of Type 304 stainless steel pipe show that the cast yield and ultimate tensile strength values are less than the wrought values by 5.3 and 3.3%, respectively. From plots of the corresponding values for Type 316 stainless steel, it appears that there also is not a great difference between the wrought and cast values; therefore, no differentiation will be made between the forms of Type 316 stainless steel.

The NUREG/CR-5603 Type 316 stainless steel ultimate tensile strength and the yield strength data are plotted with wrought and cast

Type 316 from Simmons and Van Echo (1965), Smith (1969), and CF8M (the cast form of Type 316 stainless steel) from Bamford and Swamy (1984), Chopra et al. (1991), Hiser (1988), Wilkowski et al. (1989), and Wilkowski (1984) in Figures 22 and 23. The other data are clearly lower than the NUREG/CR-5603 values in the ISLOCA temperature range. The shape of the Type 316 stainless steel data curve follows the general trend for stainless steels (e.g., Type 304) in the room temperature to 1000°F range.

Table 10 lists Equation 9 curve fit coefficients, and Figures 24 and 25 show the curve fits. Table 11 presents the survival confidences for the Type 316 data. The curve fit values are about

Figure 20. Curve fit for cast Type 304 stainless steel ultimate tensile strength data.

Figure 21. Curve fit for cast Type 304 stainless steel yield stress data.

Table 9. Comparison of survival confidence stress values for cast Type 304 stainless steel pipe at 350°F (10^{-3} and 10^{-4} probabilities of failure at yield stress).

Survival confidence (%)	Stress (ksi)			
	10^{-3} failure probability at σ_y		10^{-4} failure probability at σ_y	
	NUREG/CR-5603	Curve fit	NUREG/CR-5603	Curve fit
99	30.72	30.25	33.99	32.71
97	34.44	33.05	37.31	35.18
90	40.00	37.16	42.16	38.73

Figure 22. Comparison of ultimate tensile strength data for Type 316 stainless steel.

7 to 10 ksi lower than the NUREG/CR-5603 values. This is mainly a result of the yield stress from the curve fit being 27.4 ksi at 350°F, compared to the NUREG/CR-5603 value of 36.1. Therefore, it appears that the NUREG/CR-5603 values are nonconservative for Type 316 stainless steel.

Figures 26 and 27 compare the curves fits for the three forms of Type 304 stainless steel with

the curve fit for Type 316 stainless steel. The material property values appear about the same in the region of interest (350 to 550°F).

The best-estimate ultimate tensile strength value at 350°F from the curve fit of the available data is 65.8 ksi, whereas the ASME Code values for cast and wrought Type 316 stainless steel are

Figure 23. Comparison of yield stress data for Type 316 stainless steel.

Table 10. Curve fit constants for Type 316 stainless steel.

	a	b	c	d
S_y	43.47	-0.07495	0.000088	-3.5×10^{-8}
S_u	91.58	-0.152	0.000274	-1.5×10^{-7}

67.75 and 72.6 ksi, respectively. The ASME ultimate tensile strength values also are not supported by the data in Simmons and Van Echo (1965).

3.4 SA-106 Grade B Carbon Steel

NUREG/CR-2137 (Rodabaugh and Desai, 1980) presents data for carbon steel at room temperature. Although there are no elevated temperature data, the report does have the advantage that a relatively large number of data are presented for

each material, and, thus, the shape of the probability distribution can be estimated. However, there are insufficient data samples to produce an extremely smooth curve. Figures 28 and 29 plot the ultimate tensile strength and yield stress normal and lognormal distributions for SA-106 Grade B carbon steel with the distribution of the 102 data points in NUREG/CR-2137. Equations 10 and 11 are the forms of the normal and lognormal distribution functions used, respectively. The traces of the normal and lognormal distributions are very similar, and both fit the data reasonably well.

Figure 24. Curve fit for Type 316 stainless steel ultimate tensile strength data.

Figure 25. Curve fit for Type 316 stainless steel yield stress data.

Table 11. Comparison of survival confidence stress values for Type 316 stainless steel at 350°F (10⁻³ and 10⁻⁴ probabilities of failure at yield stress).

Survival confidence (%)	Stress (ksi)			
	10 ⁻³ failure probability at σ_y		10 ⁻⁴ failure probability at σ_y	
	NUREG/CR-5603	Curve fit	NUREG/CR-5603	Curve fit
99	40.94	31.00	43.63	33.52
97	43.99	33.87	46.26	36.03
90	48.36	38.03	49.95	39.63

Figure 26. Curve fit comparison of Types 304 and 316 stainless steel ultimate tensile strength data.

$$f(\text{sigms}) = \frac{1}{s\sqrt{2\pi}} e^{-\frac{(\sigma-m)^2}{2s^2}} \quad (10)$$

$$f(\sigma) = \frac{1}{\sigma\beta\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{1}{\beta}\ln\left(\frac{\sigma}{M}\right)\right]^2} \quad (11)$$

The NUREG/CR-5603 ultimate tensile strength of 68 ksi at room temperature is very close to the median in Figure 28, but the NUREG/CR-5603 yield stress of 36 ksi is located on the extreme lower tail of the curve in Figure 29. Thus, we would expect that the stress values for high survival confidences based on the NUREG/CR-5603 values would be conservative.

Simmons and Cross (1955) have a few data points at several temperatures for SA-106 Grade B carbon steel. There are three data points at each temperature for the as-rolled material and an additional three values where the material had been stress relieved for 2 hours at 1150°F. The ASTM Standards (1982) state that "... A-106 Grade B material shall be killed steel; pipe sizes of NPS 2 and over shall be furnished hot finished (cold-drawn pipe may be furnished if agreed upon between the manufacturer and purchaser); hot-finished pipe need not be heat treated, but cold-drawn pipe shall be heat treated at a temperature

Figure 27. Curve fit comparison of Types 304 and 316 stainless steel yield stress data.

Figure 28. Normal and lognormal representations of SA-106 Grade B carbon steel ultimate tensile strength data from NUREG/CR-2137 (room temperature).

Figure 29. Normal and lognormal representations of SA-106 Grade B carbon steel yield stress data from NUREG/CR-2137 (room temperature).

of 1200°F or higher.” From this specification, we infer that most material would be hot-rolled, not stress-relieved. The major difference in Grades A, B, and C is the specified carbon contents, which are 0.25, 0.30, and 0.35%, respectively. Battelle Columbus Laboratories (Wilkowski et al., 1989) present data for SA-106 Grade B carbon steel pipe at three temperatures.

The data are plotted in Figures 30 and 31 (the legend SR is for the stress-relieved material). There is considerable scatter in the data, but this is to be expected from Figures 28 and 29. The room temperature data in Figures 30 and 31 lie within the bands of the data in Figures 28 and 29. The NUREG/CR-5603 values appear to be representative or conservative overall (however, when compared to the ASME/ASTM stress-relieved material property data, the NUREG/CR-5603 data are not conservative). Although NUREG/CR-5603 does not present a value at 200°F, data from all forms of carbon steel in Simmons and Cross (1955) show a dip in the curve at this tem-

perature; consequently, this should be taken into account when choosing representative values in the room temperature to 400°F range.

Figures 30 and 31 demonstrate that, except for the few points for stress-relieved material, the NUREG/CR-5603 values are conservative compared to the ASTM data. We do not need to calculate survival confidences since both the NUREG/CR-5603 ultimate tensile strengths and the yield stresses are lower than the median data from other sources, and there are insufficient data to attempt to fit a curve through the data.

3.5 SA-516 Grade 70 Carbon Steel

While NUREG/CR-5603 and the ASME Code use SA-516 Grade 70 in the context of a plate material for tanks and vessels, it is also a piping material. For example, the fittings of the main coolant piping of currently operating B&W

Figure 30. Ultimate tensile strength data for SA-106 Grade B carbon steel.

Figure 31. Yield stress data for SA-106 Grade B carbon steel.

Material Properties

plants, and both the piping and the fittings of currently operating Combustion Engineering plants are made of SA-516 Grade 70 material. The Grade 70 indicates that the minimum ultimate tensile strength is 70 ksi. The carbon content is specified as 0.27 to 0.31%, the minimum yield strength as 38 ksi, and the ultimate tensile strength as 70 to 90 ksi.

There is not a great deal of data on the properties of this material. The Nuclear Systems Materials Handbook (ORNL, 1988) gives equations for typical strengths of two product forms of SA-516 Grade 70 carbon steel. For normalized and tempered material,

$$\begin{aligned}\sigma_u = & 66.104 + 0.083002 T \\ & - 1.2010 \times 10^{-4} T^2 \\ & + 1.4249 \times 10^{-8} T^3 \quad (12)\end{aligned}$$

Figure 32. Ultimate tensile strength data for SA-516 Grade 70 carbon steel.

$$\begin{aligned}\sigma_y = & 43.340 - 0.016623 T \\ & - 3.8182 \times 10^{-6} T^2 \quad (13)\end{aligned}$$

where the temperature (T) is in °F, and the stress is in ksi.

Figures 32 and 33 plot comparative data from Rodabaugh and Desai (1980), Wilkowski (1989), and ORNL (1988) Equations (12 and 13) with the ASME Code ultimate tensile strength and yield stress values. The NUREG/CR-5603 values are greater than the values from the alternate sources, with the exception of the Rodabaugh and Desai yield strength value (which is an average of 52 samples) at room temperature. Some of the alternate data even lie below the ASME Code curve.

We can conclude that the NUREG/CR-5603 values appear nonconservative and would result in lower survival confidence stresses than those that would be calculated using the alternate data. From observation of the data in Figures 32 and 33, the best approximation might be to use the ORNL data curves.

Figure 33. Yield stress data for SA-516 Grade 70 carbon steel.

3.6 Summary

The comparison of the NUREG/CR-5603 values to the material property data obtained from alternate sources indicates that the NUREG/CR-5603 values are conservative and/or representative for most types of materials. However, there are two cases where the NUREG/CR-5603

values appear to be nonconservative. These are for Type 316 stainless steel and SA-516 Grade 70 carbon steel. Alternate material property data were used in Section 4 of this report for all materials except SA-106 Grade B carbon steel, for which the NUREG/CR-5603 values were used. Tables of the survival confidences for best-estimate values are presented in Attachment 2.

4. COMPONENT EVALUATIONS

To achieve the goal of 90% system survival confidence in the event of an ISLOCA, each of the components in the system (piping, flanges, pumps, valves, heat exchangers) must have a survival confidence such that the product of the confidences equals 90%. If the survival confidence goal for each of these five components is set for 98%, then the overall system survival confidence will be about 90%.

In Section 2, the methodology of NUREG/CR-5603 defined the uncertainty in the failure stress by assigning a failure probability at the yield stress. Since the probability of failure at the yield stress is essentially zero for unflawed material, this methodology assumes that a large flaw exists in the material in a small percentage of cases. The probability of a large flaw existing increases with the amount of material, such as the length of piping or the number of welds in a component. However, this was not taken into account in NUREG/CR-5603. Although it is not based on failure probabilities, the ASME Code follows this same logic in that the same design allowable stresses are applied regardless of the size of a component or the number of welds.

In this section, the NUREG/CR-5603 methodology is applied to the components that make up the systems that will be designed for ISLOCA. Specifically, the survival confidences for components designed to 40% of the operating pressure at 350°F are calculated. Corrosion allowances are included, where applicable, but manufacturing tolerances are not included.

4.1 Piping

Calculations were performed to estimate the percent survival probability of various sizes (2- to 20-in. nominal diameter) of carbon and stainless steel pipes. A design temperature of 350°F and design pressures of 410 (BWRs) and 894 (PWRs) psig (40% of the operating pressures of 1025 and 2235 psig for current plants) were used. The minimum wall thickness for each pipe size was calculated using Equation (3) of ASME Code (ASME,

1992b) Section III NC-3641.1 and corrosion allowance values of 0.120 and 0.004 in. (BWRs) and 0.060 and 0.003 in. (PWRs) for carbon and stainless steel pipe, respectively. Based on the value of the calculated minimum wall thickness, the next higher standard pipe schedule was identified.

Three survival confidences were calculated:

1. The confidence based on the wall thickness from the ASME Code minimum wall thickness calculations.
2. The confidence based on the wall thickness of the lowest standard pipe schedule with a wall thickness greater than the calculated thickness in (1).
3. If the survival confidence in (2) was less than 99.0%, the calculations were repeated for the next larger (higher) pipe schedule.

In the design of actual piping systems, piping with *minimum* wall thicknesses will not generally be used, but rather *standard* pipe schedules. Therefore, standard pipe schedules were selected from B36 [ASME (1985a, 1985b)] using the following approach. B36.10 lists a number of thicknesses for each nominal size pipe. However, only those designed by a Schedule number (for example, 20, 30, 40, etc.) or by standard (STD), extra-strong (XS), or double extra-strong (XXS) designations have been chosen for the tables. For carbon steel, the approach uses the minimum thickness standard schedule from B36.10 that is greater than the minimum calculated thickness. B36.19 lists pipe schedules for stainless steels where the schedule designation is followed by an "S." For stainless steel, the approach uses standard schedules from B36.19. However, B36.19 lists no 40S or 80S schedules above 12-in. nominal diameter, so B36.10 schedules are used for these larger sizes.

The calculations are summarized in Tables 12 through 17 for Types 304 and 316 stainless and

Table 12. Survival confidences for Type 304 stainless steel BWR pipe.

Nominal Diameter (in.)	Actual Diameter (in.)	Corrosion Allowance (in.)	Design Pressure (psi)	Calculated Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Standard Pipe Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Next Larger Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)
20	20.000	0.004	410	0.2518	40.36	90.1	STD	0.375	26.60	99.8				
18	18.000	0.004	410	0.2298	40.36	90.1	10	0.250	36.48	91.6	20	0.312	26.93	99.5
16	16.000	0.004	410	0.2020	40.36	90.1	10	0.250	32.31	97.7	20	0.312	26.60	99.9
14	14.000	0.004	410	0.1773	40.36	90.1	10	0.250	28.14	98.6				
12	12.750	0.004	410	0.1618	40.36	90.1	10S	0.180	36.10	92.4	STD	0.375	16.59	99.9
10	10.750	0.004	410	0.1370	40.36	90.1	10S	0.185	33.19	96.9	STD	0.365	14.24	99.9
8	8.625	0.004	410	0.1107	40.36	90.1	10S	0.148	29.67	99.2				
6	6.625	0.004	410	0.0960	40.36	90.1	5S	0.109	31.31	96.4				
4	4.500	0.004	410	0.0567	40.36	90.1	5S	0.083	28.17	99.6				
3	3.500	0.004	410	0.0473	40.36	90.1	5S	0.083	21.68	99.9				
2	2.375	0.004	410	0.0334	40.36	90.1	5S	0.065	16.93	99.9				
20	20.000	0.004					STD	0.375	26.60	99.8				
18	18.000	0.004					STD	0.375	23.84	99.9				
16	16.000	0.004					STD	0.375	21.06	99.9				
14	14.000	0.004					STD	0.375	18.31	99.9				
12	12.750	0.004					STD	0.375	16.59	99.9				
10	10.750	0.004					STD	0.365	14.24	99.9				
8	8.625	0.004					STD	0.322	12.88	99.9				
6	6.625	0.004					STD	0.280	11.28	99.9				
4	4.500	0.004					STD	0.237	8.67	99.9				
3	3.500	0.004					STD	0.216	7.44	99.9				
2	2.375	0.004					STD	0.184	7.09	99.9				

Table 13. Survival confidences for Type 316 stainless steel BWR pipe.

Nominal Diameter (in.)	Actual Diameter (in.)	Corrosion Allowance (in.)	Design Pressure (psi)	Calculated Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Standard Pipe Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Next Larger Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)
20	20.000	0.004	410	0.2267	45.01	<77.5	10	0.250	40.64	94.9	STD	0.375	26.60	99.9
18	18.000	0.004	410	0.2044	45.01	<77.5	10	0.250	36.48	94.2	20	0.312	26.93	99.6
16	16.000	0.004	410	0.1821	45.01	<77.5	10	0.250	32.31	96.5				
14	14.000	0.004	410	0.1598	45.01	<77.5	10	0.250	28.14	99.7				
12	12.750	0.004	410	0.1458	45.01	<77.5	5S	0.185	39.58	87.9	10S	0.180	36.10	94.7
10	10.750	0.004	410	0.1237	45.01	<77.5	5S	0.134	41.36	82.6	10S	0.165	33.19	97.9
8	8.625	0.004	410	0.1000	45.01	<77.5	5S	0.109	41.07	83.7	10S	0.148	29.67	99.5
6	6.625	0.004	410	0.0778	45.01	<77.5	5S	0.109	31.31	96.0				
4	4.500	0.004	410	0.0541	45.01	<77.5	5S	0.083	28.17	99.7				
3	3.500	0.004	410	0.0430	45.01	<77.5	5S	0.083	21.68	99.9				
2	2.375	0.004	410	0.0304	45.01	<77.5	5S	0.065	16.93	99.9				
20	20.000	0.004					STD	0.375	26.60	99.9				
18	18.000	0.004					STD	0.375	23.84	99.9				
16	16.000	0.004					STD	0.375	21.06	99.9				
14	14.000	0.004					STD	0.375	18.31	99.9				
12	12.750	0.004					STD	0.375	16.59	99.9				
10	10.750	0.004					STD	0.365	14.24	99.9				
8	8.625	0.004					STD	0.322	12.88	99.9				
6	6.625	0.004					STD	0.280	11.28	99.9				
4	4.500	0.004					STD	0.237	8.67	99.9				
3	3.500	0.004					STD	0.216	7.44	99.9				
2	2.375	0.004					STD	0.184	7.09	99.9				

SA-106 Grade B carbon steel pipes. The curve fit material values from Section 3 were used for stainless steel, and the NUREG/CR-5603 values were used for carbon steel. The cast Type 304 stainless steel parameters were used since they resulted in slightly more conservative survival confidences than did the wrought parameters. Survival confidences and stresses are presented in tables in Attachment 2. No manufacturing tolerances are included in these calculations. Otherwise, they represent conservative survival confidences in that no pressure resistance is allowed for the material within the corrosion allowance.

Tables 12 through 14 show that for BWRs, STD pipe schedules will give greater than 98% survival confidence for all three materials. Using 40% of the operating pressure as the design pressure would result in 5S piping being chosen for piping up to 12 in. for Type 316 stainless steel, and up to 6-in. piping being chosen for Type 304 stainless steel. STD piping would be chosen for all carbon steel piping except for sizes 8 to 12 in., for which less than STD schedules would give 99.8% survival confidences.

Tables 15 through 17 show that for PWRs, XS pipe schedules will give greater than 98%

Component Evaluations

Table 14. Survival confidences for SA-106 Grade B carbon steel BWR pipe.

Nominal Diameter (in.)	Actual Diameter (in.)	Corrosion Allowance (in.)	Design Pressure (psi)	Calculated Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Standard Pipe Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)
20	20.000	0.12	410	0.3804	36.86	94.1	30	0.500	28.98	99.9
18	18.000	0.12	410	0.3633	36.86	94.1	STD	0.375	38.18	99.9
16	16.000	0.12	410	0.3363	36.86	94.1	STD	0.375	31.13	99.9
14	14.000	0.12	410	0.3093	36.86	94.1	20	0.312	36.34	99.9
12	12.750	0.12	410	0.2924	36.86	94.1	30	0.330	30.08	99.9
10	10.750	0.12	410	0.2653	36.86	94.1	30	0.307	28.44	99.9
8	8.625	0.12	410	0.2386	36.86	94.1	20	0.250	32.98	99.9
6	6.625	0.12	410	0.2066	36.86	94.1	STD	0.280	20.20	99.9
4	4.500	0.12	410	0.1806	36.86	94.1	STD	0.237	18.89	99.9
3	3.500	0.12	410	0.1673	36.86	94.1	STD	0.218	17.88	99.9
2	2.375	0.12	410	0.1521	36.86	94.1	STD	0.184	34.77	99.9
20	20.000	0.12					STD	0.375	39.17	99.1
18	18.000	0.12					STD	0.375	38.18	99.5
16	16.000	0.12					STD	0.375	31.13	99.9
14	14.000	0.12					STD	0.375	27.11	99.9
12	12.750	0.12					STD	0.375	24.60	99.9
10	10.750	0.12					STD	0.385	21.48	99.9
8	8.625	0.12					STD	0.322	20.86	99.9
6	6.625	0.12					STD	0.280	20.20	99.9
4	4.500	0.12					STD	0.237	18.89	99.9
3	3.500	0.12					STD	0.218	17.88	99.9
2	2.375	0.12					STD	0.184	34.77	99.9

Table 15. Survival confidences for Type 304 stainless steel PWR pipe.

Nominal Diameter (in.)	Actual Diameter (in.)	Corrosion Allowance (in.)	Design Pressure (psi)	Calculated Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Standard Pipe Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Next Larger Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)
30	30.000	0.009	894	0.8092	36.86	82.7	---	0.812	36.21	84.1	---	0.875	36.21	82.1
20	20.000	0.009	894	0.5395	36.86	82.7	40	0.594	35.58	83.4	60	0.812	28.39	99.9
18	18.000	0.009	894	0.4831	36.86	82.7	X5	0.500	36.24	87.1	40	0.662	33.75	99.2
16	16.000	0.009	894	0.4398	36.86	82.7	X5	0.500	33.74	98.2	60	0.668	23.15	99.9
12	12.750	0.009	894	0.3431	36.86	82.7	STD	0.375	36.07	82.4	40	0.408	33.12	99.9
10	10.750	0.009	894	0.2898	36.86	82.7	30	0.307	37.28	88.7	STD	0.368	30.86	98.7
8	8.625	0.009	894	0.2331	36.86	82.7	20	0.250	36.79	90.9	30	0.277	32.84	97.1
6	6.625	0.009	894	0.1797	36.86	82.7	STD	0.280	24.48	99.9				
4	4.500	0.009	894	0.1290	36.86	82.7	STD	0.237	18.26	99.9				
3	3.500	0.009	894	0.0984	36.86	82.7	10S	0.120	31.19	96.5	STD	0.216	18.13	99.9
2	2.375	0.009	894	0.0684	36.86	82.7	10S	0.109	22.80	99.9				
30	30.000	0.009					X5	0.500	66.22	<77.5				
20	20.000	0.009					X5	0.500	42.73	<77.5				
18	18.000	0.009					X5	0.500	36.24	87.1				
16	16.000	0.009					X5	0.500	33.74	98.2				
12	12.750	0.009					X5	0.500	28.43	99.9				
10	10.750	0.009					X5	0.500	21.94	99.9				
8	8.625	0.009					X5	0.500	17.16	99.9				
6	6.625	0.009					X5	0.432	15.02	99.9				
4	4.500	0.009					X5	0.337	12.82	99.9				
3	3.500	0.009					X5	0.300	10.93	99.9				
2	2.375	0.009					X5	0.218	10.11	99.9				
30	30.000	0.009					---	0.838	33.82	96.4				
20	20.000	0.009					---	1.000	31.39	96.4				
18	18.000	0.009					60	0.812	28.39	99.9				
16	16.000	0.009					60	0.750	24.88	99.9				
12	12.750	0.009					60	0.592	29.75	99.2				
10	10.750	0.009					X5	0.500	26.43	99.9				
8	8.625	0.009					STD	0.365	30.85	98.7				
6	6.625	0.009					STD	0.322	27.88	98.7				
4	4.500	0.009					STD	0.280	24.48	99.9				
3	3.500	0.009					STD	0.237	19.26	99.9				
2	2.375	0.009					STD	0.216	18.13	99.9				

survival confidence for all three materials, with the exception of the larger sizes. Schedule 60 is needed for all sizes greater than 18 in. for carbon and Type 316 stainless steel, and for sizes greater than 16 in. for Type 304 stainless steel.

Pipe fittings purchased to the requirements of ANSI B16.9 and analyzed to the requirements of the ASME Code are assumed to be of equal strength to the same schedule of straight pipe.

Table 16. Survival confidences for Type 316 stainless steel PWR pipe.

Nominal Diameter (in.)	Actual Diameter (in.)	Corrosion Allowance (in.)	Design Pressure (psi)	Calculated Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Standard Pipe Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Next Larger Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)
20	20.000	0.003	884	0.4834	44.28	<77.5	XS	0.600	48.75	<77.5	40	0.588	38.88	94.7
18	18.000	0.003	884	0.4354	44.28	<77.5	30	0.497	44.11	<77.5	XS	0.500	38.84	88.5
16	16.000	0.003	884	0.3874	44.28	<77.5	XS	0.500	33.74	97.1	80	0.488	35.18	98.9
14	14.000	0.003	884	0.3393	44.28	<77.5	STD	0.378	38.82	85.1	40	0.438	33.73	87.1
12	12.750	0.003	884	0.3093	44.28	<77.5	STD	0.378	36.07	94.0	40	0.408	35.12	87.7
10	10.750	0.003	884	0.2812	44.28	<77.5	30	0.307	37.28	91.7	40S	0.388	30.98	98.0
8	8.625	0.003	884	0.2102	44.28	<77.5	20	0.280	38.79	82.7	40S	0.322	27.98	98.8
6	6.625	0.003	884	0.1821	44.28	<77.5	STD	0.280	24.49	98.9				
4	4.500	0.003	884	0.1111	44.28	<77.5	10S	0.120	40.75	82.0	40S	0.237	18.28	98.9
3	3.500	0.003	884	0.0871	44.28	<77.5	10S	0.120	31.19	98.9				
2	2.375	0.003	884	0.0601	44.28	<77.5	5S	0.088	40.87	82.8	10S	0.108	22.80	98.9
20	20.000	0.003					XS	0.600	48.75	<77.5				
18	18.000	0.003					XS	0.500	38.84	88.5				
16	16.000	0.003					XS	0.500	33.74	97.1				
14	14.000	0.003					XS	0.500	29.84	98.8				
12	12.750	0.003					XS	0.500	28.43	98.9				
10	10.750	0.003					XS	0.500	21.94	98.9				
8	8.625	0.003					XS	0.500	17.16	98.9				
6	6.625	0.003					XS	0.432	18.02	98.9				
4	4.500	0.003					XS	0.337	12.82	98.9				
3	3.500	0.003					XS	0.300	10.83	98.9				
2	2.375	0.003					XS	0.218	10.11	98.9				
20	20.000	0.003					60	0.612	25.38	98.9				
18	18.000	0.003					60	0.750	24.66	98.9				
16	16.000	0.003					60	0.656	25.15	98.9				
14	14.000	0.003					60	0.593	24.28	98.9				
12	12.750	0.003					40	0.408	33.12	97.7				
10	10.750	0.003					STD	0.388	30.98	98.0				
8	8.625	0.003					STD	0.322	27.98	98.8				
6	6.625	0.003					STD	0.280	24.49	98.9				
4	4.500	0.003					STD	0.237	18.28	98.9				
3	3.500	0.003					STD	0.218	18.13	98.9				
2	2.375	0.003					STD	0.154	18.34	98.9				

Table 17. Survival confidences for SA-106 Grade B carbon steel PWR pipe.

Nominal Diameter (in.)	Actual Diameter (in.)	Corrosion Allowance (in.)	Design Pressure (psi)	Calculated Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)	Standard Pipe Schedule	Wall Thickness (in.)	Hoop stress (ksi)	Survival Confidence (%)
20	20.000	0.06	884	0.8421	36.16	99.4	60	0.812	27.49	99.9
18	18.000	0.06	884	0.5839	36.16	99.4	60	0.750	28.92	99.9
16	16.000	0.06	884	0.5257	36.16	99.4	60	0.656	27.77	99.9
14	14.000	0.06	884	0.4675	36.16	99.4	XS	0.500	33.32	99.9
12	12.750	0.06	884	0.4311	36.16	99.4	XS	0.500	30.15	99.9
10	10.750	0.06	884	0.3729	36.16	99.4	XS	0.500	25.07	99.9
8	8.625	0.06	884	0.3110	36.16	99.4	STD	0.322	34.55	98.8
6	6.625	0.06	884	0.2528	36.16	99.4	STD	0.280	31.42	98.9
4	4.500	0.06	884	0.1910	36.16	99.4	STD	0.237	26.18	99.9
3	3.500	0.06	884	0.1619	36.16	99.4	STD	0.218	22.84	99.9
2	2.375	0.06	884	0.1291	36.16	99.4	STD	0.154	26.00	99.9
20	20.000	0.06					XS	0.500	48.58	91.8
18	18.000	0.06					XS	0.500	43.48	97.7
16	16.000	0.06					XS	0.500	38.40	98.9
14	14.000	0.06					XS	0.500	33.32	99.9
12	12.750	0.06					XS	0.500	30.15	99.9
10	10.750	0.06					XS	0.500	25.07	99.9
8	8.625	0.06					XS	0.500	19.67	98.9
6	6.625	0.06					XS	0.432	17.67	98.9
4	4.500	0.06					XS	0.337	15.92	98.9
3	3.500	0.06					XS	0.300	14.08	98.9
2	2.375	0.06					XS	0.218	14.58	98.9
20	20.000	0.06					40	0.593	39.70	98.7
18	18.000	0.06					XS	0.500	43.48	97.7
16	16.000	0.06					XS (40)	0.500	38.40	98.5
14	14.000	0.06					40	0.438	38.15	98.8
12	12.750	0.06					STD	0.375	43.00	98.7
10	10.750	0.06					STD	0.365	37.15	98.9
8	8.625	0.06					STD	0.322	34.55	98.9
6	6.625	0.06					STD	0.280	31.42	98.9
4	4.500	0.06					STD	0.237	26.18	98.9
3	3.500	0.06					STD	0.218	22.84	98.9
2	2.375	0.06					STD	0.154	26.00	98.9

4.2 Flanges

There are several styles of flange and gasket designs. The style analyzed in NUREG/CR-5603 and typical of those used in nuclear power plants is shown in Figure 34. The two flange sections are attached by a bolted joint and gasket connection. The figure shows a "raised-face" flanged joint, where the gasket is placed between the raised faces, and the bolts are torqued to a given preload. As the flange faces are drawn together, the gasket is compressed. The combined load of the bolts is equal to the load in the gasket. The gasket deflection (that is, the reduction in its thickness) equals the gasket stress (load per unit area) divided by the gasket stiffness.

The gasket shown in Figure 34 is metallic and spiral-wound with an outer compression ring, called Style CG. (Other styles may have no compression ring, an inner compression ring, or both outer and inner compression rings). The compression ring is made of solid metal and has three pur-

poses: to center the gasket within the bolt ring, to prevent gasket blowout, and to act as a compression stop. The centering is accomplished by making the outer diameter of the ring equal to the bolt circle less one bolt diameter. Once the gasket has been compressed sufficiently for the flange face to contact the compression ring (0.050 in. in NUREG/CR-5603), the gasket can be compressed no further, and the flange faces and compression ring lock. Any further increase in the joint preload is carried almost entirely by the compression ring, so that the stress in the gasket remains very nearly constant once contact takes place.

The gasket is made by spirally winding a corrugated metal strip (with a filler material such as asbestos) over a mandrel, whose outer diameter is the desired inner diameter of the gasket. Because of its construction and materials, the gasket relaxes under load over time, such that its stress (and, therefore, the load) gradually lowers. For the case where the flange faces do not initially contact the compression ring, the bolt load must

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Figure 34. Raised-face flange with Style CG gasket.

also reduce when the gasket load relaxes; consequently, the flange faces are drawn closer together, and the gasket deflection (compression) increases. For the case where the flange faces come in contact with the compression ring *during the gasket relaxation*, the gasket load will transfer to the compression ring after contact, and the gasket deflection will remain very nearly constant thereafter. NUREG/CR-5603 assumes that the outer 1/8 in. of the gasket is ineffective in sealing, so the "effective" gasket outside diameter (OD), that is, the actual OD less 1/8 in., is used to compute the gasket area.

In the past, the nomenclature for flanges was their pressure ratings, for example, 150 lb, 300 lb, etc. However, flanges are now designated as Class 150, Class 300, etc., since there are different pressure ratings, depending on the material of construction, for each class and temperature.

4.2.1 ASME Flange Sizes. Flange sizes based on temperature and pressure are listed in Table 2 of ASME/ANSI B16.5 (ASME, 1988). The pressure ratings at 400°F for carbon and stainless steels are reproduced in Table 18. At 40% of the

ABWR pressure (410 psig), Class 300 flanges would be chosen. At 40% of PWR pressures (894 psig), Class 600 flanges would be chosen with the exception of the 1.2 material in Table 18, where a Class 400 flange would be used.

4.2.2 Methodology to Determine the GLP.

The methodology used in this report is from NUREG/CR-5603, but since NUREG/CR-5862 is more recent and contains supplementary information, it also has been used. The more precise calculational method outlined in NUREG/CR-5603 is followed. Although NUREG/CR-5603 includes a methodology for leak rate calculations where gross leakage is taking place (since this is needed to evaluate operating plants), the best approach at the design stage is to size the flange and prescribe bolt preloads so that no gross leakage is allowed. In flange terminology, this means that the "gross leak pressure (GLP)," where the internal fluid pressure equals the gasket stress, is not exceeded for the desired confidence level. Thus, the leak rate calculations of NUREG/CR-5603 are not included in this report. To ensure that gross leakage does not take place during an ISLOCA event, it is recommended that high

Table 18. B16.5 flange pressure ratings (psi).

Class	Carbon steel				Stainless steel		
	1.1	1.2	1.3	1.4	304	316	304L
150	200	200	200	200	180	195	160
300	635	705	620	530	470	515	415
400	845	940	825	705	630	685	550
600	1270	1410	1235	1060	940	1030	825

Number	Composition	Forgings	Castings
1.1	C-Mn-Si	A105, A 350 Grade LF2	A 216 Grade WCB
1.2	C-21 Ni to 31Ni	A 350 Grade LF3	A 216 Grade WCC, A 352 Grades LCC, LC2, LC3
1.3	C-21 Ni to 31Ni	—	A 352, Grade LCB
1.4	C	—	A 350 Grade LF1

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strength bolts be used in flanges, so that the bolt yield stress is not exceeded during boltup. The calculations performed for flanges in this report assume that SA-193-B7 high-strength bolts (yield stress = 111,700 psi; $E = 29.32 \times 10^6$ psi) preloaded to 40,000 psi initial stress, will be used.

When the flange bolts are preloaded, the gasket undergoes an initial compressive stress, which afterwards relaxes (a 25% relaxation in stress is assumed to be the median stress reduction). As internal pressure is applied to the flange, the pressure load is statically balanced by changes in the gasket and bolt stresses. The gasket compression is reduced as internal pressure is applied to the piping system containing the flange, and the bolt stresses may or may not increase, depending on the geometry of the flange (which controls the rotation of the flange).

The gasket deflections, both before and after relaxation, must be calculated to determine if the flanges and compression ring lock. Locking limits the gasket deflection (compression) where the flange face and compression ring come into contact (lock) to 0.050 in. (the value used in NUREG/CR-5603).

4.2.2.1. Median GLP. The initial and relaxed deflections and stresses, assuming linear behavior of both the gasket and the flange assembly, are calculated using the following equations:

$$\delta_{gi} = \frac{\sigma_{bp} A_b N_b}{K_g A_g} \leq 0.050 \text{ in.} \quad (14)$$

$$\sigma_{gi} = \delta_{gi} K_g \quad (15)$$

$$\delta_{gr} = \delta_{gi} + f_L \frac{JR \sigma_{gi}}{100 K_{gr}} \leq 0.050 \text{ in.} \quad (16)$$

$$\sigma_{gr} = \sigma_{gi} \left(1 - \frac{JR}{100} \right) \quad (17)$$

where

δ_{gi} = initial gasket deflection (in.)

δ_{gr} = relaxed gasket deflection (in.)

σ_{gi} = initial gasket stress (psi)

σ_{gr} = relaxed gasket stress (psi)

σ_{bp} = bolt preload stress (psi)

A_b = area of each bolt (in.²)

A_g = gasket area (in.²)

f_L = 0 if flange and ring contact ($\delta_{gi} = 0.050$ in.)

= 1 otherwise

N_b = number of bolts

JR = joint relaxation (%)

K_g = gasket initial stiffness (psi/in.)

K_{gr} = gasket unloading/reloading stiffness (1,000,000 psi/in.).

If the gasket deflection does not reach 0.050 in., the flanges/rings do not lock.

The median gross leak pressure is defined as the pressure at which the flange internal fluid pressure equals the stress in the gasket. The gross leak pressure (GLP) can be calculated with the aid of Figure 3-1 of NUREG/CR-5603, which is reproduced here as Figure 35. The figure shows the ratio of the change in the gasket load to the total pressure load. For example, the pressure load goes totally into unloading the gasket with no change in the bolt load for Class 150 flanges of sizes 12 in. or greater, while part of the pressure load goes into unloading the gasket, and the remaining fraction of the load goes into lengthening the bolts for smaller flanges. The curves in Figure 35 are approximated by

$$\frac{-\Delta G_L}{\Delta P A_p} = 0.0547 S_f + 0.376 \quad (S_f < 12 \text{ in.}) \quad (18)$$

where

ΔG_L = change in gasket load (lb)

Figure 35. Fraction of pressure load transferred to gasket (Figure 3-1 of NUREG/CR-5603).

ΔP = change in system pressure (psi)

A_p = pressure area (in.²)

S_f = flange size (in.)

$$U_g(600) = 0.0547 S_f + 0.0727 \quad (S_f < 18 \text{ in.})$$

$$= 1 \quad (S_f \geq 18 \text{ in.})$$

the median GLP can be calculated by the following equation:

and defining U_g (Class rating) as

$$U_g(150) = 0.0547 S_f + 0.376 \quad (S_f < 12 \text{ in.})$$

$$= 1 \quad (S_f \geq 12 \text{ in.})$$

$$U_g(300) = 0.0547 S_f + 0.214 \quad (S_f < 16 \text{ in.})$$

$$= 1 \quad (S_f \geq 16 \text{ in.})$$

$$GLP = P_{LO} + \frac{\sigma_{gr} - P_{LO}}{1 + U_g \frac{A_p}{A_g}} \quad (19)$$

where P_{LO} , the pressure at which the flange/ring locking load is overcome, is defined by the difference in the total bolt preload and the gasket load (after relaxation):

$$P_{LO} = \frac{\sigma_{bp}A_bN_b - \sigma_{gr}A_g}{A_p} \quad (20)$$

Although NUREG/CR-5603 does not address the question, it would appear that the flexibility of the flange would affect unloading of the locking ring nearly identically to unloading the gasket, and, thus, the Figure 35 curves also would be applicable to unloading the locking ring. In this case, the right-hand side of Equation 20 should be divided by the factor U_g .

4.2.2.2 Uncertainty. The assumptions based on the NUREG/CR-5603 methodology described above include two major uncertainties, those for the joint relaxation and the bolt torque/initial preload; however, other parameters for which there are uncertainties have not been included, for example,

- Gasket stiffness
- Gasket area
- Bolt stiffness (length, area, elastic modulus)
- Bolt area
- Pressure area
- Initial flange/compression ring separation
- Figure 35 unloading curves.

In order to determine a 99% confidence GLP, we need an estimate of the uncertainty. The uncertainties in the GLP are

- Whether the flange and compression ring will lock
- The bolt preload
- The percent joint relaxation
- How much of the change in pressure load is shared by the gasket and the bolts (the value of U_g).

However, if we assume there is sufficient preload with high-strength bolts such that the flange is securely locked to the compression ring, most of the uncertainties no longer affect the GLP. The loss of gasket load caused by relaxation is simply transferred to the locking ring, so the only important variable is the bolt preload to be overcome.

Yahr (1985) estimates the range of the accuracy of bolt preloading from $\pm 15\%$, with a digital torque wrench and no operator error, to $\pm 30\%$ for a bar torque wrench under field conditions with a variability in friction. Using these percentages as the 99% confidence (2.33β) value, the resulting β values are 0.060 and 0.123 (the 0.07 value used in NUREG/CR-5603 is within this range.) A β_{bp} of 0.0915, the midpoint of the Yahr range, will be used as the 99% confidence level for bolt preload, since this is slightly more conservative than the NUREG/CR-5603 value of 0.07.

A joint relaxation of 25% as the median, and 0 and 50% as the $\pm 3\beta$ uncertainties will be used. The β_{jr} for joint relaxation is computed using the GLP at 0%, 25%, and 50% joint relaxation. In most cases, this uncertainty will be zero, since the loss of load from relaxation in the gasket will be simply transferred to the locking ring. The overall β is computed from the square root of the sum of the squares of β_{bp} and β_{jr} .

4.2.3 Flange Size and Bolt Preload Verification Calculations. In Section 4.2.1., we determined that for a pressure ratio of 0.4, the designer would typically select a Class 300 flange for the ABWR, and a Class 600 flange for PWRs. Calculations were performed to determine if these size flanges with a bolt preload of 40,000 psi are adequate so that the design pressure (1025 psig for ABWRs and 2235 psig for PWRs) will not exceed the GLP with a 99% confidence.

Tables 19 and 20 summarize the calculations for GLP for Class 300 flanges subject to BWR conditions and Class 600 flanges subject to PWR conditions, respectively. High-strength bolts preloads of 40,000 psi and a 0.050-in. gasket/compression ring gap were used. The flange

Table 19. BWR flange calculations for 40,000 psi bolt preload.

Flange size (in.)	Number of bolts	Bolt area (in. ²)	Pressure area (in. ²)	Gasket area (in. ²)	Gasket stiffness (psi/in.)	Gasket stress @ 0% (psi)	Gasket stress @ 25% (psi)	Gasket stress @ 50% (psi)
1-1/2	4	0.334	3.547	1.865	431263	21563	16172	10782
2	8	0.2256	5.940	2.356	456480	22824	17118	11412
2-1/2	8	0.334	8.296	2.749	586094	29305	21979	14652
3	8	0.334	12.566	4.234	380537	19027	14270	9513
4	8	0.334	19.635	6.332	254429	12721	9541	6361
6	12	0.3340	40.579	11.275	198477	9924	7443	4962
8	12	0.4612	66.303	16.221	206600	10330	7748	5165
10	16	0.6051	100.518	19.768	297242	14862	11147	7431
12	16	0.7627	140.501	27.489	282457	14123	10592	7061
14	20	0.7627	167.990	29.943	323574	16179	12134	8089
16	20	0.9684	217.077	40.939	302348	15117	11338	7559
18	24	0.9684	274.294	59.824	237965	11898	8924	5949
20	24	0.9684	336.146	65.911	216007	10800	8100	5400
24	24	1.4041	481.107	86.161	240258	12013	9010	6006

Flange size (in.)	Liftoff pressure @ 0% (psi)	Liftoff pressure @ 25% (psi)	Liftoff pressure @ 50% (psi)	GLP @ 0% (psi)	GLP @ 25% (psi)	GLP @ 50% (psi)	β_{jr}	β	99% Conf. GLP (psi)
1-1/2	17416	30665	43914	20364	16172	10782	0.1060	0.1400	11677
2	9586	16586	23585	16879	16879	11412	0.0652	0.1124	12997
2-1/2	14828	26172	37516	23624	21979	14652	0.0796	0.1213	16576
3	5540	9779	14018	11895	11895	9513	0.0372	0.0988	9453
4	3098	5468	7837	7207	7207	6361	0.0208	0.0938	5794
6	2201	3472	4744	4818	4818	4818	0.0000	0.0915	3894
8	1246	2215	3185	3725	3725	3725	0.0000	0.0915	3011
10	1222	2182	3142	4023	4023	4023	0.0000	0.0915	3252
12	817	1611	2404	3259	3259	3259	0.0000	0.0915	2634
14	764	1500	2235	3136	3136	3136	0.0000	0.0915	2535
16	718	1431	2143	3003	3003	3003	0.0000	0.0915	2427
18	794	1443	2092	2782	2782	2782	0.0000	0.0915	2249
20	648	1177	1707	2312	2312	2312	0.0000	0.0915	1369
24	650	1188	1726	2376	2376	2376	0.0000	0.0915	1921

Table 20. PWR flange calculations for 40,000 psi bolt preload.

Flange size (in.)	Number of bolts	Bolt area (in. ²)	Gasket area (in. ²)	Pressure area (in. ²)	Gasket stiffness (psi/in.)	Gasket stress @ 0% (psi)	Gasket stress @ 25% (psi)	Gasket stress @ 50% (psi)
1-1/2	4	0.3340	1.865	3.547	431263	21563	16172	10782
2	8	0.2256	2.356	5.940	513540	25677	19258	12839
2-1/2	8	0.3340	2.749	8.296	659356	32968	24726	16484
3	8	0.3340	4.234	12.566	428104	21405	16054	10703
4	8	0.4612	8.247	17.721	306184	15309	11482	7655
6	12	0.6051	14.726	37.122	322554	16128	12096	8064
8	12	0.7627	20.654	61.863	317137	15857	11893	7928
10	16	0.9684	28.459	91.830	391842	19592	14694	9796
12	20	0.9684	37.797	130.192	368413	18421	13815	9210
14	20	1.1538	38.448	159.485	411247	20562	15422	10281
16	20	1.4041	50.621	207.395	383376	19169	14377	9584
18	20	1.7723	65.299	268.803	385943	19297	14473	9649
20	24	1.7723	71.975	330.064	420175	21009	15757	10504
24	24	2.4107	86.161	481.107	481250	24063	18047	12031

Flange size (in.)	Liftoff pressure @ 0% (psi)	Liftoff pressure @ 25% (psi)	Liftoff pressure @ 50% (psi)	GLP @ 0% (psi)	GLP @ 25% (psi)	GLP @ 50% (psi)	β_{jr}	β	99% Conf. GLP (psi)
1-1/2	51264	90264	129264	21563	16172	10782	0.1155	0.1474	11479
2	10810	24794	38778	20999	19258	12839	0.0820	0.1229	14471
2-1/2	26952	64518	102084	31885	24726	16484	0.1100	0.1431	17728
3	5462	13076	20690	14825	14825	10703	0.0543	0.1064	11575
4	4130	10240	16350	11004	11004	7655	0.0605	0.1097	8526
6	3558	7547	11537	9810	9810	8064	0.0327	0.0972	7825
8	1223	3816	6410	7010	7010	7010	0.0000	0.0915	5666
10	1093	3543	5992	7260	7260	7260	0.0000	0.0915	5868
12	827	2660	4494	5837	5837	5837	0.0000	0.0915	4718
14	991	2468	3946	5361	5361	5361	0.0000	0.0915	4333
16	778	2012	3246	4544	4544	4544	0.0000	0.0915	3673
18	587	1759	2931	4244	4244	4244	0.0000	0.0915	3430
20	574	1719	2864	4232	4232	4232	0.0000	0.0915	3421
24	501	1578	2656	4080	4080	4080	0.0000	0.0915	3289

parameters were obtained from NUREG/CR-5603. Calculations were carried out for 0% gasket relaxation, 25% gasket relaxation (the median case), and 50% gasket relaxation. The deflections were calculated using Equations 14 and 16, and the gasket stresses were calculated using Equations 15 and 17. In all cases, the calculated initial deflections exceeded 0.050 in., so this value was used as the gasket deflection. The contact (liftoff) pressures that must be overcome before the gasket starts to unload were calculated using Equation 20, and are listed in the first three columns of the lower half of the tables. The GLPs were calculated using Equation 19. The uncertainty (β) was calculated from the square root of the sum of the squares of the bolt preload uncertainty (0.0915) and β_{jr} .

Table 19 shows that for initial bolt preload stresses of 40,000, all sizes of Class 300 flanges can be pressurized to the ABWR pressure of 1025 psig without exceeding the 99% confidence GLP. Section 3.2.1 of NUREG/CR-5603 states that a bolt preload of 30,000 psi represents a -3β lower bound for Class 300 and 600 flanges. A calculation using a 30,000 psi bolt preload for the 20-in. flange (which has the lowest GLP in Table 19) shows that the 99% confidence GLP was 1440 psi.

Table 20 shows that for initial bolt preload stresses of 40,000, all sizes of Class 600 flanges can be pressurized to the PWR pressure of 2235 psig without exceeding the 99% confidence GLP. A calculation using a 30,000 psi bolt preload for the 24-in. flange (which has the lowest GLP in Table 20) shows that the 99% confidence GLP was 2446 psi.

4.3 Valves

Unlike piping and flanges, which more or less have standard designs, there are many different styles of valves, each of which has unique features based on the valve's function. Since for ISLOCA design we are only interested in the valve's pressure-retaining capabilities, the internals of valves are not examined in this report.

As discussed in NUREG/CR-5603, there are three areas of the valve where leakage may occur: the valve body (and bonnet), bolted connections, and packing. These areas are shown in Figure 36 (the packing is interior to the valve and cannot be seen, so only the general location is given). Figure 37 shows a typical bolted connection with a grooved flange face and gasket. The type gasket in the figure might represent a style R spiral-wound gasket, which has no compression ring. The packing is compressed tightly around the valve stem where it exits the bonnet, as shown in Figure 38.

Valve Body: Table 21 lists the pressure ratings for valves from B16.34. The Class and pressure ratings are identical to those for flanges. Section III (NC-3521) of the ASME Code states that the valve section modulus and metal area shall not be less than 110% of the comparable piping parameters. Table NC-3521-1 of ASME Code

Figure 36. Bolted bonnet valve.

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Figure 37. Valve bolted connection.

Section III allows a 1.1 factor on design pressure for Service Level B. From this we can conclude that the walls of the valve will be at least as thick as the walls of the attached piping, so the survival confidences of the valve body will be at least as great as that of the attached piping. As pointed out in the peer review panel report in Attachment 2,

Figure 38. Packing on gate valve.

the Class 300 and 600 valves will be hydrostatically pressure tested to (or very nearly to) the ISLOCA pressure.

Table 21. B16.34 valve pressure ratings (psig) at 400°F.

Class	Carbon steel				Stainless steel		
	1.1	1.2	1.3	1.4	304	316	304L
150	200	200	200	200	180	195	160
300	635	705	620	530	470	515	415
400	845	940	825	705	630	685	550
600	1270	1410	1235	1060	940	1030	825

Number	Composition	Forgings	Castings
1.1	Carbon C-Mn-Si	A105, A 350 Grade LF2	A 216 Grade WCB
1.2	Carbon 2-1/2 Ni	-----	A 216 Grade WCC A 352 Grade LC2
	3-1/2 Ni	A 350 Grade LF3	A 352 Grade LC3
1.3	Carbon	-----	A 352 Grade LCB
	2-1/2 Ni	-----	-----
	3-1/2 Ni	-----	-----
1.4	Carbon	A 350 Grade LF1	-----

Bolted Connections: The recommendations for Class sizes and bolt preloads made for flanges also are applicable for valve bolted connections.

Packing: The packing leakage is expected to be minimal, since the leak area through any degraded areas of the packing material would be small.

4.4 Pumps

In contrast to piping and flanges, which more or less have standard designs, there are many different types of pumps, each of which has unique features. Since for ISLOCA design we are only interested in the pump's pressure-retaining capabilities, the pump internals are not examined in this report.

There are three general areas of the pump where the loss of the pressure-retaining boundary may take place: the casing, bolted connections, and seals.

Casing: The casing thickness in NC-3441 of ASME Code Section III for types A and C centrifugal pumps is

$$t = \frac{PA}{S} \quad (\text{Type A}) \quad (21)$$

$$t = \frac{PA}{2S} \quad (\text{Type C}) \quad (22)$$

where

P = design pressure (psig)

A = scroll dimension (see Figures 39 and 40)

S = allowable stress.

The piping connected to the pump is designed to a minimum wall thickness proportional to the radius of the pipe. The type A pump casing is designed to a minimum wall thickness proportional to A in Figure 39, while the Type C pump is designed to a minimum wall thickness proportional to 0.5A in Figure 40. Since from Figures 39

Figure 39. Type A pump.

T93 1285

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Figure 40. Type C pump.

and 40 the pipe radius is less than dimension A in Figure 39 or $0.5A$ in Figure 40, the pump casing will be thicker than the adjacent pipe. Therefore, the pressure stresses in the pump casing should be less than in the adjoining piping, and the survival confidence of the pump casing will be greater than that of the adjacent piping.

Bolted Connections: The recommendations for Class sizes and bolt preloads made for flanges also are applicable for pump bolted connections.

Seals: Seals are judged to be have the highest potential for leakage of the pump subcomponents. In fact, Generic Issue 23, Reactor Coolant Pump Seal Failure, was developed to evaluate such an issue (Ruger and Lucas, 1989).

NUREG/CR-5603 recommends that a nominal leak rate of 100 to 200 mg/sec be assumed as the pump seal leakage rate under ISLOCA conditions. Since 200 mg/s is much less than 1 gpm, a leak rate of this magnitude would have a negligible affect on the total RCS fluid inventory.

Westinghouse Electric Corporation (1993) has stated that the RHR pump seal is the only AP600 component connected to the RCS not designed to have an ultimate rupture strength equal to the normal RCS operating pressure. They report that the rupture pressure of the seals with the RHR pumps operating is 670 to 700 psig, and that a seal designed to withstand full RCS pressure will likely experience abnormally fast wear during normal operation.

Based on the minimal leakage expected through the pump mechanical seals during an ISLOCA event, it appears that the Westinghouse proposal of allowing the mechanical seals to fail, but to minimize and control the leakage, is a satisfactory approach.

4.5 Heat Exchangers

Heat exchangers can be designed using either the shell or the tube side as the boundary for the hotter coolant. Figure 41 shows a PWR residual heat removal (RHR) system heat exchanger, which is a tube-side heat exchanger; that is, the

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Figure 41. PWR RHR heat exchanger.

hotter coolant flows within the tubes while the external cooling water flows exterior to the tubes but within the shell. The tubes and tubesheet separate the hotter and cooler fluids. The tubesheet is located between two bolted flanges and sealed from the flanges by gaskets on the tubesheet top and bottom; however, there are several varieties of flange and tubesheet design [TEMA (1982)]. The primary water inlet and outlet connections, the lower head, the tubesheet, and the tubes would be designed for ISLOCA pressures.

The RHR heat exchangers on BWR plants are shell-side (Public Service Electric & Gas), with the external cooling water flowing inside the tubes and the hotter RHR coolant flowing inside the shell and external to the tubes. The design pressure is 450 psig and the design temperature is 470°F for both the tube- and the shell-side of the Hope Creek RHR heat exchangers.

Thus, the design of tube-side heat exchangers for ISLOCA pressures requires analysis for pressure within the tubes but not within the cylindrical shell or the upper head, while for shell-side heat exchangers the cylindrical shell and the upper head are analyzed for the ISLOCA design pressure, as well as pressure external to the tubes.

Although the ASME Code has design rules for component stress allowables, it is not detailed enough to deal with all the special features of heat exchanger design. A universally accepted code that provides minimum standards for heat exchanger design is the TEMA Standard (1982). This standard was originally designed to supplement Section VIII, Division 1, of the ASME Code. A good discussion of the rules of various heat exchanger design and construction codes can be found in Schlünder (1989).

4.5.1 Heads and Shells. The design of heat exchanger vessels with hemispherical, torispherical, and 2:1 ellipsoidal heads were investigated for ISLOCA conditions. The methodology used in this section is from NUREG/CR-5603, but since NUREG/CR-5862 is more recent and contains supplementary information, it also has been used.

4.5.1.1 ASME Code Design Thicknesses.

Cylindrical shells: The design thickness of a cylindrical shell from Section III, NC-3324.3(c) is

$$t = \frac{P R_o}{S + 0.4P} = \frac{P (r + t)}{S + 0.4P}$$

$$= \frac{P r}{S - 0.6P} \quad (23)$$

and the t/r ratio is

$$\frac{t}{r} = \frac{P}{S - 0.6P} \quad (24)$$

where

- R_o = outside radius = $r + t$ (in.)
- r = inside radius
- t = wall thickness (in.)
- P = design pressure (psig)
- S = ASME Code allowable stress.

Ellipsoidal heads: The design thickness of a 2:1 ellipsoidal head from NC-3324.6 of Section III of the ASME Code is calculated by

$$t = \frac{P D}{2S - 0.2P} \quad (25)$$

The thickness-to-inside-radius ratio is

$$\frac{t}{r} = \frac{P}{S - 0.1P} \quad (26)$$

where

- t = wall thickness (in.)
- P = design pressure (psi)
- D = inside diameter (in.)
- r = inside radius (in.)

S = ASME Section III, Appendix I allowable stress (psi).

Torispherical heads: The design thickness of a torispherical head with a hemispherical crown and a knuckle radius that is 6% of the crown radius (NC-3324.8 of Section III of the ASME Code) is calculated by

$$t = \frac{0.885 P L}{S - 0.1P} \quad (27)$$

where

t = wall thickness (in.)
P = design pressure (psi)
L = hemispherical crown radius (in.)
S = ASME Section III, Appendix I allowable stress (psi)

and the thickness to hemispherical crown radius ratio is

$$\frac{t}{L} = \frac{0.885 P}{S - 0.1P} \quad (28)$$

To provide an example with representative numbers, we can use the dimensions in Figure NC-3324.2-1 of Section III. In this Figure, $L/r = 1.5 \div 1.75/2 = 1.714$. Then the previous equation becomes

$$\frac{t}{r} = \frac{1.517 P}{S - 0.1P} \quad (29)$$

Hemispherical heads: The design thickness of a hemispherical head with $t/r < 0.356$ (NC-3324.7 of Section III of the ASME Code) is calculated by

$$t = \frac{P L}{2S - 0.2P} \quad (30)$$

where

t = wall thickness (in.)

P = design pressure (in.)

L = hemispherical radius (r in NUREG/CR-5603 terminology) (in.)

S = ASME Section III, Appendix I allowable stress (psi)

and the thickness to hemispherical crown radius ratio is

$$\frac{t}{r} = \frac{P}{2(S - 0.1P)} \quad (31)$$

4.5.1.2 Cylindrical Shells. Table 22 lists the thickness-to-radius ratios for Type 304 stainless steel cylindrical shells at 350°F at various design pressure to operating pressure ratios. Hoop stresses were calculated the same as for piping for BWR and PWR conditions. Survival confidences were calculated using the Tables in Appendix B for plate material.

The hoop stresses and the survival confidences at 10^{-3} and 10^{-4} failure probability at yield stress are listed in Table 22. Survival probabilities at a pressure ratio of 0.4 (410 psi for BWRs, 894 psi for PWRs) are about 85 to 90%. A pressure ratio of about 0.48 to 0.49 is needed to achieve a survival confidence of 98% (at 10^{-3} failure probability at yield stress), and about 0.45 at 10^{-4} failure probability at yield stress. Since there is less metal in heat exchangers than in pipes, a 10^{-4} failure probability at yield stress would seem appropriate for the shells. However, like pipes, the shells would be made of plate that would probably be chosen to the nearest 1/8 in. Table 23 shows that for cylindrical shells designed for BWR conditions and constructed of plates where the thickness is divisible by 1/8 in., six of the ten example thickness survival confidences are greater than 98%.

Similar calculations for SA-516 Grade 70 carbon steel shells show that the survival confidences were greater than 99% for both BWR and PWR conditions.

4.5.1.3 Hemispherical Heads. Comparing Equations 24 and 30, the thickness for the head

Table 22. Survival confidences for Type 304 stainless steel cylindrical shells at 350°F.

Pressure ratio	BWR				PWR			
	t/r	Hoop stress (psi)	Survival conf. (10 ⁻³ @ σ_y) (%)	Survival conf. (10 ⁻⁴ @ σ_y) (%)	t/r	Hoop stress (psi)	Survival conf. (10 ⁻³ @ σ_y) (%)	Survival conf. (10 ⁻⁴ @ σ_y) (%)
0.40	0.02538	40385	86.5	90.8	0.05635	39659	88.4	92.5
0.41	0.02603	39385	89.0	93.0	0.05781	38659	90.7	94.4
0.42	0.02667	38433	91.2	94.8	0.05927	37707	92.6	96.7
0.43	0.02732	37525	92.9	96.2	0.06074	36799	94.1	97.1
0.44	0.02796	36658	94.4	97.2	0.06220	35932	95.4	97.8
0.45	0.02861	35829	95.5	98.0	0.06367	35103	96.4	98.5
0.46	0.02925	35037	96.5	98.5	0.06514	34311	97.2	98.9
0.47	0.02990	34279	97.2	98.9	0.06661	33553	97.8	99.2
0.48	0.03055	33552	97.8	99.2	0.06809	32826	98.3	99.5
0.49	0.03120	32854	98.3	99.5	0.06956	32128	98.7	99.6
0.50	0.03185	32185	98.7	99.7	0.07104	31459	99.0	99.7

Table 23. Survival confidences for Type 304 stainless steel shells at BWR conditions constructed of plates of thicknesses divisible by 1/8 in.

Radius (in.)	ASME t (in.)	Rounded t (in.)	t/r	Hoop stress (psi)	Survival confidence (10 ⁻³ @ σ_y) (%)	Survival confidence (10 ⁻⁴ @ σ_y) (%)
6	0.1523	0.250	0.04167	24600	99.9	99.9
8	0.2030	0.250	0.03125	32800	98.3	99.5
10	0.2538	0.375	0.03750	27333	99.9	99.9
12	0.3046	0.375	0.03125	32800	98.3	99.5
14	0.3553	0.375	0.02679	38267	91.5	95.1
16	0.4061	0.500	0.03125	32800	98.3	99.5
18	0.4568	0.500	0.02778	36900	94.0	96.9
20	0.5076	0.625	0.03125	32800	98.3	99.5
22	0.5584	0.625	0.02841	36080	95.2	97.7
24	0.6091	0.625	0.02604	39360	89.1	93.1

needs to be only about half of that of the cylindrical shell ($P \ll S$). Therefore for cylindrical shells and heads of nearly equal thickness, failure is controlled by burst of the cylindrical shell.

4.5.1.4 Torispherical Heads. NUREG/CR-5603 discusses two failure modes for dished heads: plastic collapse and knuckle buckling. For dished heads with low r/t ratios, Galletly and Aylward (1979) determined that head failure will occur because of plastic collapse rather than knuckle buckling. Galletly has defined plastic collapse as the pressure where the deflection of the crown is twice the deflection that occurs at a pressure when the material yields. This is the approach used in Appendix II (II-1430) of Section III of the ASME Code. Formulas for head collapse are also found in Langer (1964) and Shield and Drucker (1961), as mentioned in Attachment 1. However, plastic collapse by itself does not represent a failure of the head where coolant would be released, only that a certain strain level has been reached, or a lower-bound plastic hinge will form. Bennett (1987) has tested torispherical heads modeling nuclear reactor containments, and found that failure occurs first by the occurrence of knuckling buckling, and later at a higher pressure 2.4 to 3.7 times the buckling pressure. No mention is made of plastic collapse. Therefore, for design considerations for ISLOCA, plastic collapse will not be considered as a credible failure mode.

The r/t ratios for vessels designed to ISLOCA pressures are lower (less than 100) than would normally be the case in existing LWRs, that is, the vessels would be thicker. Consequently, the r/t ratios are lower than those used by researchers such as Radhamoham and Galletly (1979), where the r/t ratios were of the order of 600 to 1500, and Bennett (1987) where the r/t ratios were of the order of 700 to 900. In Attachment 2, Rodabaugh states that low design pressures for vessels designed to ISLOCA pressures using formulas in NUREG/CR-5603 (from Galletly) or in Langer result either from using the formulas outside their intended r/t range, or from the conservatism in collapse criteria. The author believes that the latter reason causes the extreme conservatism. The

Shield and Drucker (1961) r/t ratios go as low as 71.

Vessels designed for the higher ISLOCA pressures should be more immune to collapse. As Shield and Drucker state, "A thin-walled sharply curved knuckle region is far weaker than the main part of the spherical cap or the cylindrical portion of the vessel. On the other hand, if the torus wall is not so thin compared with the knuckle radius, the knuckle region is stiff and strong and acts somewhat like a stiffening ring at the junction of a spherical cap and cylinder. The ASME Code... apparently contains the implicit assumption that ordinarily the resistance to inward motion of the knuckle region is adequately high. Although true for vessels designed to carry large pressure, the assumption is not valid for many storage vessels and other low-pressure containers."

NUREG/CR-5603 recommends increasing the analytically computed pressures by a factor of 1.78 (based on limited experimental data) to determine the expected mean capacities. Bennett (1987) reports a rupture pressure of 2.7 to 3.4 times the buckling pressure calculated using the BOSOR-5 Code. The NUREG/CR-5603 approach was followed in this report.

Bennett (1987) states that based on his experiments, "no truly conservative, and accurate equation has been found to predict the results of these fabricated shell experiments at this time. ... For margin-to-buckling studies, where actual containment geometry is known, a BOSOR-5 analysis or the Galletly formula using the 'worst meridian' will provide a good estimate of the buckling pressure." Consequently, the calculations in this report use the Galletly equations.

The Galletly equation for buckling of a torispherical head is

$$P_{cr} = \frac{285\sigma_y \left(1 - \frac{125}{E} \left(\frac{r}{D}\right)^{0.84}\right)}{\left(\frac{D}{t}\right)^{1.53} \left(\frac{L}{D}\right)^{1.1}}$$

where

σ_y = yield stress

Component Evaluations

E = elastic modulus

r_n = knuckle (torus) radius

D = cylinder diameter

t = head thickness

L = crown (hemispherical) radius.

To provide an example with representative numbers, we can use the dimensions in Figure NC-3324.2-1 of Section III, where $L/D = 1.5 \div 1.75/2 \div 2 = 0.857$, and a knuckle radius of 0.06 of the crown radius. The results (using $\beta = 0.224$ for stainless steel and 0.245 for carbon steel) are shown in Table 24. The 99% buckling pressures are all above the ISLOCA pressure, even without applying the 1.78 factor to compute the failure pressure.

4.5.1.5 Ellipsoidal Heads. The formula for knuckle buckling from Galletly and Aylward (1979) is

$$P_{cr} = \frac{10.4 S_y}{\left(\frac{D}{t}\right)^{1.25}} \text{ for } 600 < \frac{D}{t} < 1500 \quad (32)$$

Calculational results are shown in Table 25. The buckling pressures p_{cr} were multiplied by 1.78 to obtain the estimated failure pressure, and from these the 99% survival confidence pressures were calculated. These all were above the ISLOCA pressures. However, it is assumed in NUREG/CR-5603 that in 20% of buckling cases, a crack will develop at P_{cr} . For the case with the least margin, Type 304 stainless steel at BWR conditions, the survival confidence at 1025 psi is 73.6%. If failure occurs during 20% of the 26.4% of the cases where buckling occurs at 1025 psig, then failure (rupture) will occur only 5.3% of the time, and the overall survival confidence is 94.7%. For the three other cases, the survival confidence is greater than 98%. Since there will be some margin based on fabricating the head from plate that is made in 1/8-in. increments, the confidence will no doubt be greater than 98% for actual heads.

Table 24. Knuckle buckling pressures for torispherical heads at 350°F.

	Type 304 plate		SA-516 Grade 70	
	BWR	PWR	BWR	PWR
t/r	0.03802	0.08315	0.03562	0.07789
r/D	0.07	0.07	0.07	0.07
D/t	52.6	24.05	56114	25.68
L/D	0.86	0.86	0.86	0.86
r/L	0.06	0.06	0.06	0.06
S_y (psi)	26,830	26,830	37,990	37,990
E (psi)	26,800,000	26,800,000	28,000,000	28,000,000
P_{cr} (psi)	1925	6373	2342	7751
99% buckling confidence (psi)	1143	3784	1391	4603

Table 25. Survival confidences for ellipsoidal heads at 350°F.

	Type 304 plate		SA 516 Grade 70	
	BWR	PWR	BWR	PWR
t/r	0.02506	0.05481	0.02348	0.05135
D/t	79.80	36.49	85.17	38.95
P _{cr} (psi)	1169	3111	1527	4060
1.78 P _{cr} (psi)	2082	5538	2718	7228
99% survival confidence (psi)	1237	3289	1614	4292

4.5.2 Tubes. Heat exchanger tubes have the same basic geometry as pipes, that is, long circular cylinders. The requirements of pipe design are solely to sustain the internal pressure without degrading over time, and if a pipe is selected whose walls are thicker than the minimum required for the design pressure, the only drawback is the added weight and cost. However, the thermal designer desires that heat exchanger tubes be sufficiently thin to maximize heat transfer between the fluids on either side of the tubes. Thus, we might not expect large wall thickness increases over the minimum required thickness in order to reach a standard schedule as we did in the case of pipes. Furthermore, the thermal designer does not want the added thickness associated with the corrosion allowance of carbon steel tubes, so stainless steel will be assumed as the tube material for ISLOCA design.

Tubes are generally specified with a minimum thickness, and the manufacturer typically makes them slightly thicker than the minimum so that if the manufacturing process diverges slightly from the prescribed settings and the walls deviate slightly thinner, no tubes will have to be scrapped. Consequently, while the tubes may be slightly thicker than required, it appears valid for ISLOCA design purposes to assume that they will be the minimum required thickness.

The survival confidences for heat exchanger tubes can be calculated the same as for pipes.

Using the methodology for piping, the minimum survival confidences for heat exchanger tubes subject to internal pressure designed to 40% primary coolant pressure at 350°F are 90% for Type 304 stainless steel. However, if the minimum tube thicknesses specified in the TEMA standards are used, the minimum survival confidences for tubes up to 2 in. (under internal pressure) are higher, as shown in Tables 26 and 27. A corrosion allowance of 0.004 in. for BWRs and 0.003 in. for PWRs was used. Tubes with wall thicknesses made according to TEMA standards would have greater than 99.9% survival confidence at BWR pressures, and also for PWR pressures, with the exception of 1- and 1-1/4-in. tubes. The 1-in., 20-gage tube has a survival confidence of 97.4%, but the 1-1/4-in., 20-gage tube has only an 88.2% survival confidence. A 1-1/4-in., 18-gage tube has a survival confidence of greater than 99%.

4.5.3 Tubesheets. Since tubesheets are basically flat plates, their primary failure modes would be from shear or bending, not from bursting, as in the case of piping. The bending and shear stresses are related to the tube hole pattern, and, therefore, are tubesheet dependent. Formulas (both bending and shear) for the minimum design thickness of tubesheets, based on the type of construction, are given in the TEMA standards.

The major concern with tubesheets is leakage at flanged joints. The recommendations on Class

Table 26. Survival confidences for Type 304 BWR heat exchanger tubes subject to internal pressure designed to TEMA standards.

Diameter (in.)	Gage	Thickness (in.)	Hoop stress (psi)	Survival confidence (%)
1/4	27	0.016	9652	99.9
3/8	24	0.022	9652	99.9
1/2	22	0.028	9652	99.9
5/8	20	0.035	9473	99.9
3/4	20	0.035	11374	99.9
1	20	0.035	11507	99.9
1-1/4	20	0.035	19640	99.9
1-1/2	16	0.065	11577	99.9
2	14	0.083	11950	99.9

Table 27. Survival confidences for Type 304 PWR heat exchanger tubes subject to internal pressure designed to TEMA standards.

Diameter (in.)	Gage	Thickness (in.)	Hoop stress (psi)	Survival confidence (%)
1/4	27	0.016	19255	99.9
3/8	24	0.022	19820	99.9
1/2	22	0.028	20115	99.9
5/8	20	0.035	19940	99.9
3/4	20	0.035	23956	99.9
1	20	0.035	32687	97.5
1-1/4	20	0.035	41417	79.7
1-1/4	18	0.049	28132	99.6
1-1/2	16	0.065	24801	99.9
2	14	0.083	25703	99.9

sizes and bolt preloads made for flanges also are applicable for tubesheet flanges.

4.6 Tanks

In most if not all cases, it will probably prove impractical to design large tanks for ISLOCA pressures. Should there be cases in which tanks

are designed for ISLOCA conditions, the formulas and method for vessels in Section 4.5 can be used. These show that for the cylindrical portion of the shell, a pressure ratio of between 0.45 and 0.50 is required to meet ISLOCA confidence limits for Type 304 stainless steel. A pressure ratio of 0.40 will provide 99% survival confidence for SA-516 Grade 70 carbon steel.

5. CONCLUSIONS AND RECOMMENDATIONS

The NUREG/CR-5603 methodology for system rupture survival during an ISLOCA event has been applied to ALWR plants. Conditions of 350°F and BWR pressures of 1025 psig and PWR pressures of 2235 psig were used. This report presents criteria such that each of the types of components in the system will achieve about a 98% survival confidence, so that the overall system survival confidence will be about 90%.

The confidence limits were determined by developing stress failure curves that used a failure stress, defined as 0.9 and 0.85 times the median ultimate tensile strength for carbon and stainless steel, respectively, as the median failure stress. The uncertainty was determined by selecting the 0.001 confidence failure stress as the median yield stress. This assumption in establishing the uncertainty is based on the probability of a large crack existing in the metal, either induced during manufacture or in operation, and is the source of several comments in the peer review panel report. There does not appear to be a straightforward way to establish the uncertainty. An alternate approach considers the operating experience in nuclear components that have been designed and operated according to the ASME Code. The alternate method of developing an uncertainty for the failure curves leads to basically the same conclusion as does the method in NUREG/CR-5603, that is, the minimum system survival confidence at 2.5 times the Level A design stress is greater than 90%. This argument is based on actual operating data, and shows a better balance between the carbon and stainless steel survival probabilities than does the NUREG/CR-5603 method.

Available yield stress and ultimate tensile strength data were used to better define the material properties than the values used in NUREG/CR-5603. It is concluded that the NUREG/CR-5603 values are representative for SA-106 Grade B carbon steel, but alternate curves were developed and used in this report for stainless steels and SA-516 Grade 70 carbon steel.

A pressure ratio of 0.4 (the design pressure divided by the operating pressure) was investi-

gated. The conclusions are that this pressure ratio is a suitable value for most cases. The recommended sizes for components are as follows:

- Pipe and pipe fittings
BWR—STD for all materials
PWR—STD up to 10 in. for all materials
SA-106 Grade B—12 in., STD; 14, 16, 20 in., Sch. 40; 18 in., XS
Type 316—12 in., Sch. 40.; 14 to 20 in., Sch. 60
Type 304—12 and 14 in., XS; 16 to 20 in., Sch. 60
- Flanges
BWR—Class 300
PWR—Class 600
Bolts—High strength with 40 ksi preload
- Valves
BWR—Class 300
PWR—Class 600
- Pumps
Design for 0.4 pressure ratio
Seals—Need not design for ISLOCA but allow minimal leakage
- Heat exchangers
Cylindrical shell—Design for pressure ratio of 0.40 (SA-516 Grade 70 carbon steel), 0.45 (Type 304 stainless steel)^f
Heads—Design for 0.4 pressure ratio
Tubes and tubesheets—Design to TEMA standards except 20 gage for 1-in. and 18 gage for 1-1/4-in. tubes PWR.

These recommendations will satisfy the goal of 90% confidence that gross leakage will not occur to the system during an ISLOCA, but the scope of this project did not include any evaluations to assure that components such as pumps and valves will remain operable during, or fit for service after, an ISLOCA event.

f. Based on 10^{-4} survival confidence at yield stress.

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Peer Review Panel Report
The ALWR ISLOCA Evaluation Criteria

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July 19, 1993

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1.0 INTRODUCTION

The United States Nuclear Regulatory Commission staff (NRC) recommended to the Commissioners that future evolutionary Advanced Light Water Reactor (ALWR) designs reduce the possibility of a loss-of-coolant accident outside containment (ISLOCA) by designing, to the extent practicable, all systems and subsystems connected to the reactor coolant system (RCS) to an ultimate rupture strength at least equal to the full RCS pressure. The Division of Engineering, Office of Nuclear Regulatory Research (RES), working with Idaho Nuclear Engineering Laboratory (INEL), has developed evaluation criteria for addressing this issue and established a peer review panel to obtain third party input on the INEL assumptions, results and conclusions. This report provides the results of the review conducted by the peer review panel.

2.0 BACKGROUND

The basic goal of the NRC was to have ALWR design agents evaluate systems connected to the RCS to demonstrate that the probability of failure (burst or gross leak), is not more than 0.10. This could be accomplished by assigning this failure probability as a goal and allowing each applicant to submit, for review, their method of compliance. However, in the spirit of standardization and in order to reduce the cost and time that would be required for the review process, NRC RES has developed a draft evaluation criteria that provides guidance to applicants on acceptable - to - NRC methods for satisfying the failure probability goal. This draft evaluation criteria is contained in NUREG/CR-5862, NUREG/CR-5603 and six INEL letter reports (References 1 through 7). These documents provide the basis for the review conducted by the peer review panel and the comments and conclusions contained in this report.

3.0 BASIS FOR REVIEW

Dr. John O'Brien, NRC RES provided specific ground rules to the peer review panel with respect to our efforts. These are provided below:

3.1 ISLOCA Pressures

- (a) 1025 psi for Boiling Water Reactors (BWR)
- (b) 2235 psi for Pressurized Water Reactors (PWR)

3.2 ISLOCA Temperatures

- (a) 350°F for both BWR and PWR

3.3 Gross Leak Rate

- (a) Approximately 200 gallons per minute, anything less than 200 GPM is not a concern.

3.4 Minimum Thickness (t_m) Assumptions

- (a) Corrosion allowance is not included
- (b) Manufacturing tolerances are not considered

4.0 EVALUATION CRITERIA

The NRC RES evaluation criteria provided in Reference 2, is quite simple and can be summarized as follows:

Systems containing components (piping, pumps, valves, tanks, heat exchangers, etc.) subjected to the ISLOCA event satisfy the goal of having a failure probability of 0.10 or less if the component wall thickness, using ASME Section III Code Class 2 allowable stress, is based on a design pressure equal to 0.4 times the ISLOCA pressure (410 psi for BWR and 894 psi for PWR).

This simple evaluation criteria is based on the reports reviewed by the peer review panel which contain a significant amount of background documentation.

5.0 PEER REVIEW PANEL COMMENTS

Following are the comments of the peer review panel.

5.1 General Comments

- (1) It is difficult to follow the overall approach utilized since details for understanding one document are provided in another without reference.
- (2) The goal, as stated above, is related to system failure probabilities, however, the evaluation addresses components. One can deduce that it may be necessary to have a component probability of failure of 0.01 in order to satisfy the system goal of 0.1. If this is the case, it should be explicitly defined and the correlation explained.
- (3) The evaluation criteria as expressed in Section 4.0 above is exclusive of the amount of piping or number of components. Based on this, a system with 20 feet of pipe, 1 valve and 4 pipe fittings is as acceptable as a system with 200 feet of pipe, 3 valves and 20 pipe fittings. Engineering judgement (and PRA) would suggest this is not true. The reports should address this issue and based on further peer review comments, a case may be made that sufficient conservatism exists to cover such anomalies. The same anomaly applies to tanks or vessels, size and the number of welds do not change the failure probability.

5.2 Specific Comments on Technical Approach

- (1) While Reference 1 does not say so, the results in the section on Pipe are based on Beta established by assuming

that $Pr(f)$ at $S_y = 0.001$ as described in Reference 2. This, of course, is a very significant assumption and the choice of 0.001 is not adequately explained or defended.

From the data provided in Table 3 of Reference 7, it is apparent that the probability of having A106-B material with UTS equal to S_y is essentially zero. Thus, it follows that assuming that $Pr(f)$ at $S_y = 0.001$ implies the presence of some sort of defect in the pipe. From Appendix A of this report, the following specific example is taken. For a straight pipe with a radius of 10 inches and a wall thickness of 0.3 inches an axial crack 1/3 through wall (0.1 inch) must be longer than 8.7 inches for failure to occur when the pressure hoop stress equals S_y .

What is the probability of cracks of the length/depth indicated above being detected by the inspection requirements of Subsection NC and the In-Service inspection requirements of Section XI of the Code? If that question could be answered, a rational basis for the selection of $Pr(f)$ at S_y would emerge. In addition there is the concern of seamless versus longitudinally welded pipe. The $Pr(f)$ has been assumed the same for both. Existing experience gained from examination requirements of Section XI indicates little difference should exist. In fact, Section XI has eliminated longitudinal welds from the ISI program except adjacent to butt welds. Finally, the potential of erosion/corrosion effects on carbon steel generate another concern. One can conclude that the selection of S_y for determining $Pr(f)$ includes a number of assumptions and variables and the amount of conservatism inherent in that selection is not apparent.

- (2) Based on the calculations provided in Appendix B of this report, the evaluation criteria can be considered to underestimate the median burst pressure by about 30 percent. However, based on comparison with limited testing of SA-106 Grade B pipe performed by General Electric, the evaluation criteria could be considered appropriate.
- (3) There are a number of other variables that are mentioned without assigning any value to them other than for gage length and triaxial stress effects. For these variables, cumulative reduction factors of 10 to 15 percent have been applied to the failure stress. There is some question as to whether or not triaxial stress effects is a variable of concern. Other variables that are not assigned separate reduction factors but are considered as uncertainties used to reduce the failure stress are the existence of large cracks, additional stresses (deadweight and thermal), modeling uncertainties and erosion/corrosion. In addition, the source for material properties used in the evaluation criteria is conservative by 1000 to 7000 psi as compared to ASTM or Battelle data.
- (4) Another issue not discussed is pipe fittings. The position of the peer review panel is that fittings purchased to the requirements of ANSI B16.9 may be taken as equal to that of the designated matching straight pipe if the following is satisfied:
 - (a) Purchase orders for ANSI B16.9 fittings shall require evidence from the vendor that paragraph 2.2 of B16.9, as modified by footnote (1) to Table NC-3132-1 of Section III, has been complied with.

Attachment 1

- (5) Although, the peer review panel has a number of questions and concerns on straight pipe we recommend the following lower bound on acceptable pipe wall thickness:

- (a) Standard weight for BWR
- (b) Extra strong for PWR

5.3 Comments on NUREG/CR-5862 (Reference 1)

The following comments are provided using Reference 1 Table of Contents but, as can be seen, are applicable to many of the INEL documents related to the evaluation criteria.

- (1) Introduction - Discussion related to some of the variables in Section 5.2 are applicable here.
- (2) Section 2, Tanks and Heat Exchangers -
 - (a) 1st Paragraph - Certainly one would expect large tanks and some heat exchangers to have lower capacities than pipe, valves or flanges. However, small tanks and heat exchanger tubes should have capacities similar to piping and may have higher capacities than longitudinally welded pipe.
 - (b) 2nd Paragraph - Although higher nozzle loading may occur as a result of increased temperature it should be recognized that the load of concern, thermal expansion, is truly secondary in nature and small deformations relieve the condition. The vessel rules, for conservatism, classify thermal expansion stresses

in the nozzle as a primary stresses. These loadings should not result in any greater uncertainty in the tank nozzle than they do in the attached pipe.

- (c) Section 2.1 - See comment (b) above on nozzle loads.
- (d) Section 2.2 - The approach used on torispherical heads is much too conservative. Appendix C of this report provides detail comments and some comparisons between this work and Reference 9. Although the discussion in Appendix C begins with the results presented in Reference 4, the real concern is with the applicability of Equation (2-2) in this section of the NUREG report. For example, Table 22 of Reference 4 indicates a collapse pressure of 443 psi for the BWR whose ISLOCA pressure (sort of design pressure since the sizing of the vessel is based on this pressure) is 410 psi. Since the relief valve setting would be 1.1 times design pressure ($1.1 \times 410 = 451$ psi) the median collapse pressure of 443 psi would be exceeded. Also, hydrostatically testing the vessel at 1.5 times design pressure ($1.5 \times 410 = 615$ psi) approaches the median collapse pressure at room temperature of 644 psi. The collapse pressures cited in Table 2 are too conservative and, as noted by one member of the peer review panel, $P_0 = 443$ psi is incredible.
- (e) Section 3 - See comments in Section 5.2 (1), 5.2 (2), Appendix A and Appendix B.

- (f) Section 4 - The work in this section is to a large degree superseded by Reference 5. The position of the peer review panel is that ANSI B16.5 flanges be used as follows:

300 Class or higher - BWR

600 Class or higher - PWR

This is essentially in agreement with Reference 5 except we do not share the bolt pre-load concern expressed therein.

- (g) Section 5 - The work in this section is superseded by Reference 6 and the peer review panel agrees with these conclusions although for different reasons. ANSI B16.34 valves should be used as follows:

300 Class or higher - BWR

600 Class or higher - PWR

This is based on the fact that each valve body is hydrostatically tested to the following pressures:

<u>Class</u>	<u>Material Group</u>	<u>Test Pressure (PSI)</u>	<u>Primary Coolant Pressure (PSI)</u>	<u>ISLOCA Evaluation Pressure (PSI)</u>
300	1.1	1110	1025	410
300	2.1	1080	1025	410
600	1.1	2220	2235	894
600	2.1	2160	2235	894

- (h) Section 6 - Evaluation criteria is not provided. Reference 6 also addresses pumps but the discussion is limited to centrifugal pumps and little guidance is given. The basic conclusion of Reference 6 is that the basic pressure design using evaluation criteria pressures would result in wall thicknesses greater than that for the attached pipe and therefore pump casings are acceptable.

Since close tolerances are required between the casing and the impeller for efficient operation the casings are normally stiffer (thicker) than required for pressure stress. Experience with detailed pump analysis indicates the most highly stressed locations are at the cutwater tip in Type A pumps and in the splitter in Type C pumps neither of which would result in pressure boundary failure. The peer review panel feels that designing centrifugal pump casings to the evaluation criteria pressures is acceptable. However, as Reference 6 points out, seal leakage will occur. ALWR designs must accommodate such leakage to assure that gross leak rate criteria are complied with. With respect to positive - displacement pumps, experience and judgement indicates that these type pumps would have a higher survival rate than centrifugal pumps. One member of the peer review panel suggests shop hydrotesting of all pumps to the RCS pressure. This obviously would demonstrate acceptability.

The general consensus of the panel is that designing to 0.4 time the ISLOCA pressure for pumps should be as acceptable an approach as it is for straight pipe.

6.0 SUMMARY

The peer review panel is satisfied with the general approach to addressing ISLOCA presented in Reference 1 through 7. However, a number of areas addressed in the body of these reports require better explanation and/or justification. Also the evaluation criteria for torispherical heads, as addressed in References 1 and 3, is much too conservative and requires a significant amount of additional work.

In addition, the peer review panel has evaluated components not specifically addressed or, in our opinion, inadequately addressed by the reference documents and we are of the opinion that piping systems having components that meet the following minimum have $P_r(n_f) \geq 0.9$.

<u>COMPONENT</u>	<u>BWR</u>	<u>PWR</u>
Pipe and B16.9 Fittings	Standard Weight	Extra Strong
B16.5 Flanged Joints	300 Class	600 Class
B16.34 Valves	300 Class	600 Class
Pumps, Evaluate for (1)	410 PSI	894 PSI

(1) Assure Seal Leakage Satisfies Gross Leak Rate.

One further point not addressed in Reference 1 through 7 is that of component operability. It is the opinion of the peer review panel that the evaluation criteria proposed does not assure the operability of components such as pumps and valves. This is no doubt obvious to all and is not a concern, but it should be addressed in the INEL work.

7.0 REFERENCES

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2. A. G. Ware, and D. A. Wesley, *Probabilistic Based Design Rules for Intersystem LOCAS in ABW Piping*," no publishing date.
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6. A. G. Ware, *Pumps, Valve and Heat Exchanger Tube and Tubesheet Evaluation for ISLOCA Design Using NUREG/CR-5603 Methodology*, INEL Letter Report, April 1993.
7. A. G. Ware, *Comparison of NUREG/CR-5603 and Alternate Materials Data for Stainless and Carbon Steels*, INEL Letter Report, March 1993.
8. D. A. Wesley, T. R. Kipp, D. K. Nakaki, and H. Hadidi-Tamjed, *Pressure - Dependent Fragilities for Piping Components*, NUREG/CR-5603.

Attachment 1

7.0 **REFERENCES** (Cont'd)

9. Welding Research Council Bulletin No. 95 dated April 1964, "PVRC Interpretive Report of Pressure Vessel Research, Section 1 - Design Considerations", B. F. Langer.

APPENDIX A

Significance of $P_r(f) = 0.001$ at S_y

by

E. C. Rodabaugh

While NUREG/CR-5862 does not say so, its results in the section on "Pipe" are based on Beta established by assuming that $Pr(f)$ at $S_y = 0.001$. This, of course, is a very significant assumption in calculating $Pr(nf)$. Reference 2 describes how the Beta's are derived; i.e., by assuming that $Pr(f)$ at $S_y = 0.001$. But, to me, the choice of 0.001 is not adequately explained or defended.

Figure 5 of Reference 2 was included as an indication of the sensitivity of the screening method to the selection of $Pr(f)$ at S_y . However, the "90%" line is not correctly shown. The attached Table A shows the results of my sensitivity study for both $Pr(f)$ at $S_y = 0.01$ and 0.0001.

Table A, for $Pr(nf) = 0.99$, indicates that the screening method is sensitive by about 30 or 40% at 400F. This, I think, is not highly significant relative to the overall precision of the screening method.

By looking at Table 3 of Reference 7, it is apparent that the probability of having A106-B material with UTS equal to S_y is essentially zero. Thus, it follows that assuming that $Pr(f)$ at $S_y = 0.001$ implies the presence of some sort of defect in the pipe.

First, I'll point out that pipe to A106-B must be shop hydrotested to a pressure of $0.6 \cdot (2 \cdot S_y \cdot t / D)$. Such shop tests are NOT sufficient to eliminate pipe with a defect such that it would fail when subjected to a pressure, $P = S_y \cdot t / r$.

What size of defect would cause the pipe to fail at $P = S_y \cdot t / r$? Some indication of the size of axial defect can be obtained from ASME Section XI, H-5420. I used the equation with $(SF) = 1$ and with S_f (=flow stress) = $(S_u + S_y) / 2 = (61.2 + 36) / 2 = 48.6$ ksi. These are from Reference 2 for A106B at 100F. The crack sizes are:

Attachment 1

t/a	L/r for	
	t/r = 0.03	t/r = 0.06
4	infinity	infinity
3	0.87	1.23
2	0.32	0.45

The values of $t/r = 0.03$ and 0.06 are representative of pipe wall thicknesses per NC-3600 for $P_d = 410$ and 894 , respectively. The results indicate that a crack that is $1/4$ through wall will not fail at $P = S_y * t/r$. A crack that is $1/3$ or $1/2$ through wall will fail only if the crack length exceeds the L/r indicated; L = crack length.

As a specific example, consider a pipe with $r = 10$ inch, $t = 0.03 * 10 = 0.3$ inch. A crack of depth 0.10 inch must be longer than $0.87 * 10 = 8.7$ inch for failure to occur at $P = S_y * t/r$.

An obvious question is: What is the probability of cracks of the length/depth indicated above being detected by the inspection requirements of Subsection NC of the Code? If that question could be answered, a rational basis for the selection of $Pr(f)$ at S_y would emerge.

There is a conceptual problem for me in that A106-B is seamless pipe; Type 304 may be seamless or longitudinally welded. Conceptually, if I thought $Pr(f)$ at $S_y = 0.001$ was appropriate for longitudinally welded pipe, I would tend use something like $Pr(f)$ at $S_y = 0.0001$ for seamless pipe.

But, there are other considerations related to in-service inspection and the potential of corrosion/erosion of carbon steel pipe. There is a lot buried in the selection of $Pr(f)$ at S_y .

TABLE A

SENSITIVITY TO ASSUMED $Pr(f)$ at S_y
"PROBABILISTIC BASED DESIGN RULES FOR INTERSYSTEM LOCAS IN
ABWR PIPING", WARE AND WESLEY, NOT DATED, RECEIVED FROM INEL 5/6/93

Temp M't'l For $C = Pr(S)$ as indicated, the Ratios of the Stresses at assumed $Pr(f)$ at S_y of 0.01 or 0.0001 to Stresses for assumed $Pr(f)$ at $S_y = 0.001$ are:

		$C = 0.99$		$C = 0.97$		$C = 0.090$	
		0.01	0.0001	0.01	0.0001	0.01	0.0001
100	A106-B	0.90	1.05	0.92	1.04	0.95	1.03
400	A106-B	0.85	1.09	0.88	1.07	0.91	1.05
600	A106-B	0.83	1.09	0.86	1.08	0.90	1.05
100	TP 304	0.89	1.06	0.91	1.05	0.94	1.03
400	TP 304	0.80	1.11	0.84	1.09	0.89	1.06
600	TP 304	0.78	1.13	0.82	1.10	0.88	1.07

C = confidence of survival; for $C = 0.50$, ratios are all 1.00; i.e., the choice of $Pr(f)$ at S_y does not change the median stresses.

APPENDIX B

**Conservatism of the Median Burst
Pressure for Straight Pipe**

by

E. C. Rodabaugh

The screening method calculates the burst pressure by the equation:

$$P(3) = 2*S(3)*t/D_i \quad (A)$$

where $P(3)$ is the burst pressure, $S(3)$ is the stress by Eq. (3) of Reference 1. For A106-B at 100F, the median of $S(3)$ is 54.7 ksi.

There are sufficient burst test data on straight pipe to assert that the median burst pressure of a 4*diameter length of A106-B pipe at room temperature is given by the equation:

$$P_b = 2*S_u*t/D_m$$

where P_b = median burst pressure, 4*diameter length

S_u = median UTS of A106 Grade B material

D_m = mean pipe diameter

At room temperature, I think $S_u = 72$ ksi is a good median estimate. Then, ignoring the difference between D_i and D_m :

$$P(3)/P_b = 54.7/72 = 0.76$$

Thus, in my opinion, the "method" is conservative by a factor of about 0.76 for the specific case of A106-B at 100F.

There are very few burst tests on straight pipe made of austenitic stainless steel; e.g., Type 304. However, those few tests plus theory (Langer, Reference 9) indicate that Eq. (B) should be multiplied by about 0.85 for estimating the median burst pressure of pipe made of 304 material. At room temperature, 304 material, I think $S_u = 85$ ksi is a reasonable median estimate. Then, ignoring the difference between D_i and D_m :

$$P(3)/P_b = 57.0/(85*0.85) = 0.79$$

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Attachment 1

I am not aware of any burst tests of straight pipe (without intentional defects) at elevated temperatures.

Langer (Reference 9) gives the equation:

$$P_b = S_u * F * \ln W \quad (C)$$

where P_b = burst pressure of a cylindrical shell (straight pipe)

S_u = engineering UTS of pipe material

$F = [0.250 / (e + 0.227)] * [2.7183 / e] e$

e = true strain at maximum load in pipe material tensile test

W = pipe outside diameter divided by pipe inside diameter

Noting that $\ln W$ is essentially equal to $2t/D_m$, Eq. (C) can be written as:

$$P_b = 2 * S_u * t / D_m * F \quad (D)$$

The factor F depends on e ; e is not a pipe material specification property. To determine e , a tensile stress-strain curve out to the maximum load is needed. If appropriate values of e could be established, then Eq. (D) could be used to help access the median burst pressure of straight pipe at elevated temperatures. To really tie things down, it would be nice to have some burst tests on "not-intentionally-flawed" straight pipe at elevated temperatures.

In summary, the screening method under estimates the median burst pressure of a 4*diameter length of straight pipe at 100F by a factor of around 0.77; i.e., the median burst pressure is about 30% higher than estimated by the screening method.

The 4*diameter length qualification comes from typical burst test specimens. The test pipe is generally about four diameters in length,

closed at each end with (often) 2:1 ellipsoidal heads. Rupture usually starts at the axial center of the pipe. (2:1 ellipsoidal heads, of the same thickness as the pipe, do NOT break). The important aspect is that the tests are NOT tests of, say, a mile long straight pipe. If they were, then I suspect that the median failure pressure would be significantly lower than given in Eq. (B). This, of course, is related to my Comment in Section 5.1(3) of this report.

APPENDIX C

Torispherical Heads

by

E. C. Rodabaugh

Table 22 of Reference 4 is for torispherical heads with $L/r = 1.714$, $rt/L = 0.06$. These particular parameters are within the scope of NC-3324.8 and thus (t/r) 's shown in Table 22 constitute valid applications of NC-3324.8.

Table 22, 400F, P_o , ABWR, shows $P_o = 443$ psi. This for a design pressure of 410 psi! This indicates that, if the relief valve is set at $1.1*P_d$, the median "collapse pressure" will be exceeded. Also, if the vessel is hydrotested to $1.5*P_d$, there is a good chance that "collapse" will occur in the test. I view $P_o = 443$ psi as being incredible.

P_o comes from Eq. (2-2) of NUREG/CR-5862. Eq. (2-2) is based on ranges of parameters:

$$\begin{aligned} 250 < r/t < 750 \\ 1.5 < L/r < 3 \\ 0.12 < rt/r < 0.36 \\ 20 \text{ ksi} < S_y < 75 \text{ ksi} \end{aligned}$$

Noting the (t/r) 's in Table 22 (r/t ranging from 12 to 30), it is apparent that Eq. (2-2) is being used way outside its intended range of application; i.e., $r/t > 250$. I think this is the reason for the "incredible" P_o 's shown in Table 22.

Langer (Reference 9), under the heading "stability under internal pressure", gives Eq. (1.3-3). He credits Eq. (1.3-3) to Shields and Drucker and intimates that is based on "limit analysis". Langer does not cite the range of applicability of Eq. (1.3-3); probably the Shields and Drucker paper does. However, if the range of applicability is found, it should be noted that a limit pressure, as determined by a limit analysis, may be a small fraction of the rupture pressure; e.g., $1/2$ or $1/4$.

Attachment 1

The attached Table X shows comparisons between Eqs. (2-2) and (1.3-3).

The first line of Table X is a torispherical head with $L = r$ and $rt = .06*L$; which, of course, is exactly a hemispherical head. I included it to show what happens when Eqs. (2-2) and (1.3-3) are used outside their range of applicability. The gross yield and burst pressure of the head (assuming the attached cylindrical shell does not yield or burst first) are:

$$P_y = 2*S_y*t/r = 2*23000*2.245/100 = 1033 \text{ psi}$$

$$P_u = 2*S_u*t/r = 2*54600*2.245/100 = 2452 \text{ psi}$$

The (median) burst pressure of 2452 psi is a rather far cry from the 210 psi from Eq. (2-2) or the 545 psi from Eq. (1.3-3). Of course, I am mis-using Eq. (2-2) both with respect to r/t and L/r . I suspect that I am similarly mis-using Eq. (1.3-3).

Table X shows a line for $L/r = 1.25$; I doubt if $L/r = 1.25$ is used very much. L/r between 1.5 and 2.0 are, I think, more in the range of typical torispherical heads with $r/t = 0.06*L$. Table X stops at $L/r = 2.00$ because that is the largest L/r covered by the Code; see NC-3324.5(d).

I think that Eq. (2-2) of NUREG/CR-5862 should be reviewed to see what relevance, if any, it has to pressure boundary failure of heads with r/t around 20. It may also be desirable to review the Drucker and Shield paper, referenced by Langer, to see what it is based on. If (as I suspect) both Eqs. (2-2) and (1.3-3) are relevant only to heads with $r/t < 250$, it may be desirable to run some appropriate analyses of heads with $r/t = 20$.

TABLE X

**Torispherical Heads with $L/rt = 0.06$, P_d = Design Pressure
Vessel Radius = $r = 100$ inch
304 material at 400F**

<u>L</u> <u>in.</u> <u>(a)</u>	<u>rt</u> <u>in.</u> <u>(b)</u>	<u>Pd = 410 psi</u>			<u>Pd = 894 psi</u>		
		<u>t</u> <u>in.</u> <u>(c)</u>	<u>P1</u> <u>psi</u> <u>(d)</u>	<u>P2</u> <u>psi</u> <u>(e)</u>	<u>t</u> <u>in.</u> <u>(c)</u>	<u>P1</u> <u>psi</u> <u>(d)</u>	<u>P2</u> <u>psi</u> <u>(e)</u>
100	6	2.245	210	545	4.911	494	1996
100	---	1.267	113	228	2.775	265	765
125	7.5	2.807	284	561	6.139	666	2017
150	9.0	3.368	362	577	7.366	850	2038
175	105.	3.930	445	593	8.594	1045	2058
200	12.0	4.491	533	609	9.822	1250	2080

(a) L = inside crown radius

(b) rt = torus radius

(c) Except for second line, $t = 0.885 \cdot P_d \cdot L / (S - 0.1P_d)$
Second line, $t = P_d \cdot L / (2 \cdot S - 0.2 \cdot P)$
 S = Code allowable stress for 304 at 400F, = 16200 psi

(d) NUREG/CR-5862 Eq. (2-2)
 $S_y = 23000$ psi, $e_y = 0.00087$, $R_s = L$

(e) Langer (WRC Bulletin 95) Eq. (1.3-3)
 $S_y = 23000$ psi

APPENDIX D

Comments on ALWR ISLOCA

Evaluation Criteria

by

D. A. Wesley

**COMMENTS ON
ALWR ISLOCA EVALUATION CRITERIA**

By:

D.A. WESLEY

INTRODUCTION

The ALWR ISLOCA evaluation criteria developed by A.G. Ware of INEL EG&G Idaho were based on methods developed for evaluation of existing reactors subject to ISLOCA conditions (References 1 and 2). These methods were developed to provide realistic pressure capacities for a number of components including pipe, tanks and vessels, valves, flanges and pumps. The methods were developed to provide capacities using simple analysis techniques and avoided thermal analysis of pipe lines, fracture mechanics analysis, and other analysis which might be required in a rigorous design verification. The methods developed for evaluation of existing plants included provision for possible undetected partial through wall cracks in pipe and vessels, as well as expected variability in material properties (including variation at temperatures above the system design temperature), uncertainty in strain at initiation of plastic instability, variability in initial bolt loads for a specified bolt torque, and analytical modeling uncertainty, as well as other possible sources of variability. The resulting expected leak (or burst) pressures were therefore described in probabilistic terms suitable for a probabilistic risk assessment (PRA).

Subsequent to the development of the methodology described in References 1 and 2, a considerable amount of review of the methodology and extension of these methods to the evaluation of ALWR ISLOCA conditions (References 3-8) has been completed. I believe the resulting evaluation criteria are appropriate for evaluation of ALWR ISLOCA conditions. Although based on probabilistic values, the criteria which have been presented require an absolute minimum of analysis, are easy to apply in conjunction with more rigorous design criteria, and most important, do not constrain the designer to exceed existing design conditions to implement ISLOCA modifications for those requirements which he can defend as impractical.

Attachment 1

Although many of the methods and parameters used in References 1 and 2 are open to discussion, the overall capacities developed using these methods and material properties are considered to be representative. The decision by the USNRC staff to limit evaluation of ALWR ISLOCA conditions to 350°F and their finding that designing to 40% of reactor coolant pressure is adequate reduces the effects of the use somewhat different material properties or different assumed variabilities associated with a given leak or burst pressure, and makes fine tuning of the evaluation criteria less critical.

MATERIALS

The materials evaluated in References 1 and 2 were limited to those most frequently encountered in the few existing plants evaluated for ISLOCA to date. It is my understanding that ALWR will likely include similar materials. However if materials with significantly different properties, particularly brittle materials or materials other than carbon or stainless steels, are used in ALWR design, some re-evaluation of the methods as well as material properties used in the current evaluation criteria would be required.

Cast Type 316 stainless steel was not explicitly considered in References 1 and 2. The evaluation conducted by INEL (Reference 6) points out that the cast Type 316 exhibits lower strength than wrought Type 316 and hence use of the Reference 1 and 2 material properties is unconservative. I agree with this conclusion. Similarly, only hot rolled SA-106 Grade B pipe was considered in References 1 and 2. Both yield and ultimate strengths for stress relieved material are less than corresponding hot rolled values over the temperature range of interest. One way to assure the applicability and limitations of the materials and their conditions used in the ALWR ISLOCA evaluation criteria is to require the designer to either note the use of the same material in his design or provide necessary adjustments in capacities to account for variations in his material conditions.

PIPE AND VESSELS

The pressure capacity of pipes and vessels in References 1 and 2 as well as subsequent INEL work is assessed based on the onset of plastic instability in the controlling membrane stress. Simplified methods for thin walled vessels which accounted for biaxial strains, strain concentrations, and variations in the material

yield and ultimate strengths and stress strain relationships were used. Comparisons with limited experimental burst test data shows good correlation using this approach. From Reference 9 for instance, test results of Type 304 stainless steel cylinders with wall ratios ($W = D_o/D_i$) in the 1.2 to 1.3 range (i.e., pipe schedule 140 to 160 range) show maximum internal pressure capacities in the range of 11,000 to over 13,000 psig. Similar values are calculated using the Reference 1 and 2 methods as shown in Tables 3-1 and 2-18 of References 1 and 2 respectively. Similar correlation was seen with published data on SA 106 Grade B pipe. Thus, I believe the median capacities for burst of pipe and vessels as given in the proposed ALWR evaluation criteria are realistic.

The variabilities developed in References 1 and 2 and subsequently used in establishing the ALWR evaluation criteria included not only the variabilities associated with the materials such as variability in the yield and ultimate strengths and uncertainty in the stress-strain relation, but also some provision for uncertainty in the condition of the system being evaluated. For instance ISLOCA conditions can result in temperatures well above the design temperature of many systems under consideration. Such temperatures may result in high bending moments in the pipe, high nozzle loads in vessels, etc., in addition to the pressure induced hoop stress in the pipe or vessel. Undetected flaws may also exist in the system. In order to account for such possibilities, it was judged that a probability of failure of 10^{-3} at hoop yield stress would provide a reasonable estimate of overall variability. This approach eliminates the necessity of conducting thermal stress analysis of the cold lines for ISLOCA and provides a simple approach for including a great many unknowns. However, to my knowledge, there is no database to support a number of 10^{-3} . Consequently, a parameter study using a 10^{-4} probability of failure at yield was conducted by INEL and the results are compared in the 10^{-3} INEL results.

Failure of a cylinder at a nominal hoop stress equal to yield may be implied to correspond to the existence of a partial through wall crack. For a typical wall thickness cylinder of materials under consideration here, this implies a partial through wall axial crack of the order of 3/4 of the wall thickness and several inches long. Similar results exist for a partial circumferential crack although the critical size of such cracks is much more sensitive to pipe bending moments and orientation. Clearly, such cracks should be detectable using either fabrication inspection or ISI techniques. Thus, the variability associated with assuming a 10^{-3}

or 10^{-4} probability may be overly conservative. However, lacking a database which would deny the existence of significant flaws and in the absence of thermal stress analysis of lines and nozzle loads, I, believe the evaluation criteria developed by INEL using the above variabilities provide a reasonable approach for evaluation of ALWRs.

The above methodology together with the NRC specified requirements for evaluation pressures, temperatures, and survival confidences leads to requirements for schedule 40 pipe for BWRS and schedule 60 or 80 for some of the larger diameter PWR piping depending on material. I believe these are prudent design conditions and should not impose undue costs on the design.

For vessels and tanks, cost penalties are expected particularly for the larger diameter vessels. Plastic collapse pressures for torispherical heads is lower than for semispherical heads which may force a greater use of semispherical heads compared to the normally less expensive torispherical. Clearly, for tanks such as flat bottomed atmospheric tanks, compliance with ISLOCA conditions will be impractical in my opinion.

The capacity of dished heads is based on analytical results from Galletly (References 10-13) using the computer program BOSOR 5 (Reference 14). Plastic collapse was defined as corresponding to deformations equal to twice the elastic deformation. Also, the results were quite sensitive to analytical modeling assumptions such as flow laws. Although the analytical results were adjusted to correlate more closely with limited experimental data, some additional analytical studies may be warranted, particularly for thicker heads and possibly using different analytical codes and assumptions. Such investigations may show the existing methods to be conservative.

From the limited number of evaluations of heat exchangers subjected to ISLOCA conditions which I have conducted, the tubes have normally not been the controlling element, either for tube side pressure (tube burst) or for shell side pressure (tube collapse). Rather, the shell or channel burst or tube sheet gasket leak has normally controlled the capacity. Hopefully this would indicate that the heat transfer characteristics of ALWR heat exchangers will not be significantly affected by ISLOCA considerations.

The ISLOCA evaluation of bolted flanges and bolted valve bonnets is similar and is based on PVRC gasket test data. The INEL recommendation differ in methodology only in using a larger coefficient of variation ($COV = 0.15$) for bolt preload for a given bolt-torque based on recommendations from Yahr (Reference 15) compared to a $COV = 0.07$ based on Shigley's machine design which was used in References 1 and 2. The 0.15 provides a more conservative evaluation and I have no basis to judge one value more accurate than the other.

The INEL recommendations lead to Class 300 flanges for BWR and Class 600 flanges for PWR ISLOCA evaluation. This recommendation is based on maintaining ISLOCA evaluation pressures below the Gross Leak Pressure (GLP) of the gasketed flange.. I believe it is sound practice to eliminate Class 150 flanges, particularly with SA193 Grade B8 or equivalent bolts, in applications subject to ISLOCA conditions and I support this recommendation.

PUMPS

Pump designs vary significantly for various applications and different vendors. Pump casings designed using normal design requirements would normally have wall thicknesses resulting in lower stresses than attached piping and hence a lower probability of rupture. However, an ISLOCA evaluation does not constitute the design criteria and while schedule 40 or higher pipe and Class 300 flanges or higher are included in the ISLOCA evaluation criteria for pipe, there is nothing that requires the pump designer to think in similar terms. Thus, the design criteria might permit the pump designer to come up with a casing thickness corresponding to Schedule 10S piping and Class 150 flanges rather than the heavier components recommended for ISLOCA.

One possibility might be to have the pump vendor hydrotest the casing (not necessarily the seals) to ISLOCA pressure. However, in order to assure himself that he would not induce inelastic stresses which would result in a permanently deformed case, the pumps designer would probably end up with the ISLOCA pressure and temperature as the design condition with associated cost.

Noting that permanent deformation in the installed condition is acceptable from a safety consideration (although pump replacement could be required) analysis of the pump casing for ISLOCA evaluation is likely to be preferable to testing. In this case, limits on inelastic strains may be desirable as part of the ISLOCA evaluation criteria.

Bolted pump casing flanges using spiral wound gaskets can be evaluated using the same methodology as bolted pipe flanges, valve bonnets, and heat exchanger tube sheets. Some pump flanges are sealed using elastomeric seals such as silicone rubber or ethylene propylene O-rings. Leakage of this type of seal can be evaluated using simple techniques provided the residual set (and possibly increased temperature accident set) of the O-rings is included in the bolted flange opening clearance. It is my understanding designing pumps seals to withstand ISLOCA conditions would result in increased seal wear. Typically, the pumps under consideration would not be expected to have to operate during an ISLOCA event, and I would expect the amount of non-operating seal leakage during an ISLOCA would be acceptable in most instances. It is my understanding that it is the NRC staff position that consideration of ISLOCA should not result in changes to the design that could degrade normal operating performance, and I strongly support this position.

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Survival Confidence Tables

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Wrought Type 304 stainless steel				66.35 median UTS					0.195 median failure strain			
2	350F				55.40 median failure stress					64.58 NUREG/CR-5603 failure stress			
3	1.0E-03 failure probability				25.44 median yield stress					25.12 NUREG/CR-5603 yield stress			
4					0.258 beta					0.153 adjusted failure strain			
5													
6	survival		adjusted		survival			adjusted		survival			adjusted
7	confidence	x	stress	stress	confidence	x	stress	stress		confidence	x	stress	stress
8	0.9999	3.71902											
9	0.999	3.09023	25.44000	25.44000	0.924	1.43250	38.99313	36.54836		0.849	1.03215	43.22951	39.74031
10	0.998	2.87816	26.88854	26.88043	0.923	1.42554	38.06311	36.60210		0.848	1.02789	43.27698	39.77538
11	0.997	2.74778	27.78634	27.46824	0.922	1.41885	39.13251	36.65537		0.847	1.02365	43.32427	39.81031
12	0.996	2.65207	28.47997	28.05898	0.921	1.41183	39.20132	36.70815		0.846	1.01943	43.37140	39.84510
13	0.995	2.57583	29.04487	28.53714	0.920	1.40507	39.26965	36.76052		0.845	1.01622	43.41847	39.87982
14	0.994	2.51214	29.52537	28.94180	0.919	1.39838	39.33739	36.81241		0.844	1.01303	43.46538	39.91441
15	0.993	2.45726	29.94578	29.29431	0.918	1.39174	39.40474	36.86397		0.843	1.00986	43.51208	39.94885
16	0.992	2.40892	30.32102	29.60778	0.917	1.38517	39.47149	36.91504		0.842	1.00671	43.55862	39.98315
17	0.991	2.36562	30.68114	29.89089	0.916	1.37866	39.53774	36.96570		0.841	0.99958	43.60499	40.01731
18	0.990	2.32635	30.97290	30.14959	0.915	1.37220	39.60360	37.01802		0.840	0.99448	43.65130	40.05141
19	0.989	2.29037	31.26133	30.38824	0.914	1.36581	39.66885	37.06585		0.839	0.98936	43.69743	40.08538
20	0.988	2.25713	31.53018	30.61010	0.913	1.35946	39.73379	37.11541		0.838	0.98627	43.74349	40.11925
21	0.987	2.22621	31.78234	30.81767	0.912	1.35317	39.79823	37.16457		0.837	0.98220	43.78938	40.15300
22	0.986	2.19729	32.02001	31.01285	0.911	1.34684	39.86216	37.21330		0.836	0.97815	43.83510	40.18680
23	0.985	2.17009	32.24517	31.19735	0.910	1.34076	39.92567	37.26169		0.835	0.97411	43.88074	40.22014
24	0.984	2.14441	32.45820	31.37238	0.909	1.33462	39.98888	37.30981		0.834	0.97009	43.92621	40.25353
25	0.983	2.12007	32.66338	31.53898	0.908	1.32854	40.05156	37.35751		0.833	0.96609	43.97150	40.28678
26	0.982	2.09693	32.85867	31.69805	0.907	1.32251	40.11383	37.40487		0.832	0.96210	44.01672	40.31997
27	0.981	2.07485	33.04811	31.85045	0.906	1.31652	40.17578	37.45196		0.831	0.95812	44.06187	40.35310
28	0.980	2.05378	33.22823	31.99864	0.905	1.31058	40.23730	37.49870		0.830	0.95418	44.10685	40.38607
29	0.979	2.03352	33.39985	32.13731	0.904	1.30469	40.29840	37.54509		0.829	0.95022	44.15184	40.41891
30	0.978	2.01409	33.56745	32.27289	0.903	1.29884	40.35918	37.59121		0.828	0.94629	44.19636	40.45167
31	0.977	1.99539	33.72955	32.40381	0.902	1.29303	40.41963	37.63706		0.827	0.94238	44.24090	40.48430
32	0.976	1.97737	33.88650	32.53038	0.901	1.28727	40.47966	37.68255		0.826	0.93848	44.28538	40.51685
33	0.975	1.95998	34.03883	32.65305	0.900	1.28155	40.53935	37.72777		0.825	0.93458	44.32989	40.54943
34	0.974	1.94313	34.18673	32.77198	0.899	1.27587	40.59872	37.77272		0.824	0.93072	44.37400	40.58199
35	0.973	1.92684	34.33050	32.88743	0.898	1.27024	40.65784	37.81731		0.823	0.92686	44.41814	40.61398
36	0.972	1.91104	34.47052	32.99972	0.897	1.26464	40.71634	37.86171		0.822	0.92301	44.46222	40.64619
37	0.971	1.89570	34.60702	33.10904	0.896	1.25908	40.77470	37.90583		0.821	0.91918	44.50611	40.67826
38	0.970	1.88079	34.74020	33.21557	0.895	1.25357	40.83262	37.94959		0.820	0.91537	44.54982	40.71018
39	0.969	1.86630	34.87012	33.31938	0.894	1.24806	40.89041	37.99322		0.819	0.91156	44.59357	40.74212
40	0.968	1.85218	34.99720	33.42076	0.893	1.24264	40.94776	38.03650		0.818	0.90777	44.63713	40.77391
41	0.967	1.83842	35.12148	33.51980	0.892	1.23723	41.00487	38.07958		0.817	0.90399	44.68062	40.80563
42	0.966	1.82501	35.24302	33.61856	0.891	1.23188	41.06184	38.12238		0.816	0.90023	44.72392	40.83721
43	0.965	1.81191	35.36216	33.71129	0.890	1.22653	41.11806	38.16490		0.815	0.89647	44.76726	40.86880
44	0.964	1.79912	35.47887	33.80399	0.889	1.22123	41.17424	38.20721		0.814	0.89273	44.81041	40.90025
45	0.963	1.78681	35.59339	33.89486	0.888	1.21596	41.23017	38.24932		0.813	0.88901	44.85338	40.93154
46	0.962	1.77438	35.70571	33.98388	0.887	1.21072	41.28587	38.29122		0.812	0.88529	44.89638	40.96285
47	0.961	1.76241	35.81599	34.07118	0.886	1.20553	41.34111	38.33276		0.811	0.88159	44.93920	40.99401
48	0.960	1.75089	35.92429	34.15884	0.885	1.20036	41.39621	38.37417		0.810	0.87790	44.98184	41.02510
49	0.959	1.73920	36.03079	34.24099	0.884	1.19522	41.45108	38.41538		0.809	0.87422	45.02480	41.05613
50	0.958	1.72793	36.13555	34.32368	0.883	1.19012	41.50555	38.45630		0.808	0.87055	45.06719	41.08709
51	0.957	1.71680	36.23847	34.40484	0.882	1.18504	41.55991	38.49709		0.807	0.86689	45.10971	41.11798
52	0.956	1.70604	36.33990	34.48475	0.881	1.18000	41.61390	38.53759		0.806	0.86325	45.15203	41.14873
53	0.955	1.69540	36.43965	34.56328	0.880	1.17499	41.66785	38.57789		0.805	0.85962	45.19427	41.17940
54	0.954	1.68494	36.53798	34.64057	0.879	1.17000	41.72125	38.61808		0.804	0.85600	45.23644	41.21001
55	0.953	1.67466	36.63487	34.71670	0.878	1.16505	41.77449	38.65793		0.803	0.85239	45.27853	41.24055
56	0.952	1.66456	36.73032	34.79181	0.877	1.16012	41.82758	38.69768		0.802	0.84879	45.32054	41.27102
57	0.951	1.65463	36.82440	34.86539	0.876	1.15522	41.88041	38.73721		0.801	0.84520	45.36247	41.30142
58	0.950	1.64485	36.91730	34.93818	0.875	1.15035	41.93299	38.77654		0.800	0.84162	45.40433	41.33175
59	0.949	1.63523	37.00960	35.00960	0.874	1.14551	41.98530	38.81585		0.799	0.83805	45.44611	41.36202
60	0.948	1.62578	37.09930	35.08061	0.873	1.14069	42.03747	38.85463		0.798	0.83450	45.48789	41.39213
61	0.947	1.61644	37.18848	35.15031	0.872	1.13590	42.08938	38.89339		0.797	0.83095	45.52931	41.42226
62	0.946	1.60725	37.27663	35.21914	0.871	1.13113	42.14113	38.93203		0.796	0.82742	45.57073	41.45224
63	0.945	1.59818	37.36374	35.28711	0.870	1.12639	42.19262	38.97045		0.795	0.82390	45.61208	41.48215
64	0.944	1.58927	37.44970	35.35412	0.869	1.12168	42.24385	39.00865		0.794	0.82038	45.65348	41.51207
65	0.943	1.58047	37.53469	35.42034	0.868	1.11699	42.29492	39.04672		0.793	0.81687	45.69476	41.54193
66	0.942	1.57179	37.61872	35.48574	0.867	1.11232	42.34583	39.08486		0.792	0.81338	45.73586	41.57183
67	0.941	1.56322	37.70187	35.55041	0.866	1.10768	42.39648	39.12238		0.791	0.80990	45.77688	41.60128
68	0.940	1.55477	37.78403	35.61427	0.865	1.10306	42.44697	39.15997		0.790	0.80642	45.81794	41.63090
69	0.939	1.54643	37.86530	35.67738	0.864	1.09847	42.49719	39.19734		0.789	0.80296	45.85880	41.66039
70	0.938	1.53820	37.94568	35.73975	0.863	1.09390	42.54726	39.23457		0.788	0.79950	45.89999	41.68990
71	0.937	1.53007	38.02522	35.80144	0.862	1.08935	42.59718	39.27167		0.787	0.79608	45.94039	41.71925
72	0.936	1.52204	38.10396	35.86248	0.861	1.08482	42.64690	39.30863		0.786	0.79262	45.98112	41.74862
73	0.935	1.51410	38.18199	35.92287	0.860	1.08032	42.69637	39.34537		0.785	0.78919	46.02177	41.77792
74	0.934	1.50628	38.25918	35.98260	0.859	1.07584	42.74567	39.38198		0.784	0.78577	46.06233	41.80714
75	0.933	1.49851	38.33564	36.04172	0.858	1.07138	42.79481	39.41844		0.783	0.78237	46.10270	41.83621
76	0.932	1.49085	38.41137	36.10023	0.857	1.06694	42.84379	39.45477		0.782	0.77897	46.14309	41.86530
77	0.931	1.48328	38.48635	36.15812	0.856	1.06252	42.89261	39.49096		0.781	0.77557	46.18353	41.89440
78	0.930	1.47579	38.56068	36.21548	0.855	1.05812	42.94125	39.52702		0.780	0.77219	46.22376	41.92334
79	0.929	1.46836	38.63437	36.27229	0.854	1.05374	42.98973	39.56293		0.779	0.76882	46.26391	41.95222
80	0.928	1.46106	38.70729	36.32848	0.853	1.04939	43.03794	39.59862		0.778	0.76546	46	

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Wrought Type 304 stainless steel				66.35	median UTS				0.195	median failure strain		
2	350F				56.40	median failure stress				64.56	NUREG/CR-5803 failure stress		
3	1.0E-04 failure probability				25.44	median yield stress				25.12	NUREG/CR-5803 yield stress		
4					0.214	beta				0.153	adjusted failure strain		
5													
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	adjusted	stress
8	0.9999	3.71902	25.44000	25.44000									
9	0.999	3.09023	29.10538	28.58821	0.924	1.43250	41.50362	38.45484	0.849	1.03215	45.21733	41.19814	
10	0.998	2.87818	30.45710	29.72115	0.923	1.42554	41.56550	38.50128	0.848	1.02789	45.26858	41.22807	
11	0.997	2.74778	31.31912	30.43598	0.922	1.41865	41.62685	38.54730	0.847	1.02365	45.29968	41.25869	
12	0.996	2.65207	31.96740	30.96968	0.921	1.41183	41.68768	38.59289	0.846	1.01943	45.34062	41.28857	
13	0.995	2.57583	32.49339	31.40028	0.920	1.40507	41.74803	38.63812	0.845	1.01522	45.38150	41.31821	
14	0.994	2.51214	32.93943	31.76374	0.919	1.39838	41.80768	38.68292	0.844	1.01103	45.42222	41.34472	
15	0.993	2.45726	33.32867	32.07967	0.918	1.39174	41.86733	38.72742	0.843	1.00686	45.46278	41.37410	
16	0.992	2.40862	33.67534	32.36005	0.917	1.38517	41.92625	38.77150	0.842	1.00271	45.50319	41.40338	
17	0.991	2.36562	33.98892	32.61288	0.916	1.37866	41.98472	38.81521	0.841	0.99858	45.54343	41.43249	
18	0.990	2.32838	34.27585	32.84356	0.915	1.37220	42.04281	38.85862	0.840	0.99448	45.58362	41.46156	
19	0.989	2.29037	34.54066	33.06607	0.914	1.36581	42.10036	38.90180	0.839	0.99036	45.62384	41.49051	
20	0.988	2.25713	34.78751	33.25338	0.913	1.35946	42.15783	38.94434	0.838	0.98627	45.66360	41.51941	
21	0.987	2.22621	35.01852	33.43778	0.912	1.35317	42.21443	38.98672	0.837	0.98220	45.70341	41.54818	
22	0.986	2.19729	35.23598	33.61086	0.911	1.34694	42.27077	39.02872	0.836	0.97815	45.74305	41.57682	
23	0.985	2.17009	35.44174	33.77451	0.910	1.34078	42.32672	39.07042	0.835	0.97411	45.78262	41.60540	
24	0.984	2.14441	35.63711	33.92951	0.909	1.33462	42.38239	39.11189	0.834	0.97009	45.82204	41.63388	
25	0.983	2.12007	35.82327	34.07694	0.908	1.32854	42.43789	39.15299	0.833	0.96609	45.86129	41.66219	
26	0.982	2.09693	36.00118	34.21758	0.907	1.32251	42.49240	39.19377	0.832	0.96210	45.90047	41.69047	
27	0.981	2.07485	36.17172	34.35221	0.906	1.31652	42.54692	39.23432	0.831	0.95812	45.93960	41.71868	
28	0.980	2.05375	36.33547	34.48125	0.905	1.31058	42.60108	39.27457	0.830	0.95418	45.97856	41.74677	
29	0.979	2.03352	36.49318	34.60534	0.904	1.30469	42.65480	39.31450	0.829	0.95022	46.01735	41.77473	
30	0.978	2.01409	36.64526	34.72485	0.903	1.29884	42.70825	39.35420	0.828	0.94629	46.05608	41.80284	
31	0.977	1.99539	36.79224	34.84018	0.902	1.29303	42.76140	39.39365	0.827	0.94238	46.09464	41.83042	
32	0.976	1.97737	36.93444	34.95161	0.901	1.28727	42.81418	39.43279	0.826	0.93848	46.13314	41.85813	
33	0.975	1.95998	37.07234	35.05953	0.900	1.28155	42.86691	39.47189	0.825	0.93458	46.17187	41.88587	
34	0.974	1.94313	37.20614	35.16410	0.899	1.27587	42.91878	39.51035	0.824	0.93072	46.20984	41.91333	
35	0.973	1.92684	37.33611	35.26558	0.898	1.27024	42.97052	39.54870	0.823	0.92688	46.24804	41.94080	
36	0.972	1.91104	37.46290	35.36418	0.897	1.26464	43.02206	39.58687	0.822	0.92301	46.28617	41.96822	
37	0.971	1.89571	37.58582	35.46014	0.896	1.25906	43.07330	39.62479	0.821	0.91918	46.32413	41.99551	
38	0.970	1.88079	37.70597	35.55361	0.895	1.25357	43.12413	39.66240	0.820	0.91537	46.36193	42.02267	
39	0.969	1.86630	37.82311	35.64463	0.894	1.24808	43.17484	39.69990	0.819	0.91158	46.39975	42.04984	
40	0.968	1.85218	37.93781	35.73350	0.893	1.24264	43.22515	39.73709	0.818	0.90777	46.43741	42.07688	
41	0.967	1.83842	38.04952	35.82027	0.892	1.23723	43.27523	39.77409	0.817	0.90399	46.47500	42.10386	
42	0.966	1.82501	38.15860	35.90500	0.891	1.23186	43.32501	39.81085	0.816	0.90023	46.51243	42.13071	
43	0.965	1.81191	38.26605	35.98791	0.890	1.22653	43.37447	39.84736	0.815	0.89647	46.54988	42.15758	
44	0.964	1.79912	38.37098	36.06901	0.889	1.22123	43.42370	39.88369	0.814	0.89273	46.58718	42.18431	
45	0.963	1.78661	38.47366	36.14848	0.888	1.21598	43.47272	39.91984	0.813	0.88901	46.62427	42.21092	
46	0.962	1.77438	38.57471	36.22630	0.887	1.21072	43.52151	39.95581	0.812	0.88529	46.66141	42.23753	
47	0.961	1.76241	38.67368	36.30259	0.886	1.20553	43.56999	39.99145	0.811	0.88159	46.69839	42.26402	
48	0.960	1.75069	38.77083	36.37740	0.885	1.20036	43.61813	40.02699	0.810	0.87790	46.73529	42.29045	
49	0.959	1.73920	38.86630	36.45067	0.884	1.19522	43.66615	40.06234	0.809	0.87422	46.77212	42.31681	
50	0.958	1.72793	38.96018	36.52304	0.883	1.19012	43.71385	40.09744	0.808	0.87055	46.80888	42.34312	
51	0.957	1.71689	39.05236	36.59385	0.882	1.18504	43.76141	40.13243	0.807	0.86689	46.84556	42.36937	
52	0.956	1.70604	39.14317	36.66354	0.881	1.18000	43.80885	40.16716	0.806	0.86325	46.88208	42.39548	
53	0.955	1.69540	39.23242	36.73199	0.880	1.17499	43.85598	40.20171	0.805	0.85962	46.91852	42.42154	
54	0.954	1.68494	39.32037	36.79937	0.879	1.17000	43.90283	40.23614	0.804	0.85600	46.95490	42.44753	
55	0.953	1.67466	39.40699	36.86569	0.878	1.16505	43.94907	40.27032	0.803	0.85239	46.99119	42.47347	
56	0.952	1.66456	39.49228	36.93094	0.877	1.16012	43.99548	40.30438	0.802	0.84879	47.02742	42.49935	
57	0.951	1.65463	39.57632	36.99517	0.876	1.15522	44.04185	40.33826	0.801	0.84520	47.06358	42.52516	
58	0.950	1.64485	39.65928	37.05853	0.875	1.15035	44.08789	40.37195	0.800	0.84162	47.09966	42.55092	
59	0.949	1.63523	39.74101	37.12092	0.874	1.14551	44.13329	40.40545	0.799	0.83805	47.13566	42.57661	
60	0.948	1.62578	39.82185	37.18243	0.873	1.14069	44.17885	40.43884	0.798	0.83450	47.17150	42.60217	
61	0.947	1.61644	39.90118	37.24303	0.872	1.13590	44.22417	40.47204	0.797	0.83095	47.20736	42.62774	
62	0.946	1.60725	39.97975	37.30287	0.871	1.13113	44.26935	40.50512	0.796	0.82742	47.24304	42.65318	
63	0.945	1.59819	40.05737	37.36183	0.870	1.12639	44.31429	40.53801	0.795	0.82390	47.27865	42.67856	
64	0.944	1.58927	40.13393	37.42015	0.869	1.12168	44.35899	40.57072	0.794	0.82038	47.31429	42.70395	
65	0.943	1.58047	40.20960	37.47788	0.868	1.11699	44.40355	40.60330	0.793	0.81687	47.34985	42.72928	
66	0.942	1.57179	40.28438	37.53444	0.867	1.11232	44.44798	40.63577	0.792	0.81338	47.38524	42.75448	
67	0.941	1.56322	40.35835	37.59058	0.866	1.10768	44.49213	40.66804	0.791	0.80990	47.42055	42.77961	
68	0.940	1.55477	40.43142	37.64599	0.865	1.10306	44.53615	40.70020	0.790	0.80642	47.45569	42.80478	
69	0.939	1.54643	40.50386	37.70074	0.864	1.09847	44.57993	40.73217	0.789	0.80296	47.49105	42.82977	
70	0.938	1.53820	40.57508	37.75483	0.863	1.09390	44.62358	40.76401	0.788	0.79950	47.52624	42.85479	
71	0.937	1.53007	40.64578	37.80832	0.862	1.08935	44.66705	40.79574	0.787	0.79606	47.56125	42.87988	
72	0.936	1.52204	40.71569	37.86121	0.861	1.08482	44.71038	40.82734	0.786	0.79262	47.59629	42.90488	
73	0.935	1.51410	40.78485	37.91357	0.860	1.08032	44.75347	40.85875	0.785	0.78919	47.63125	42.92991	
74	0.934	1.50626	40.85345	37.96532	0.859	1.07584	44.79641	40.89004	0.784	0.78577	47.66613	42.95419	
75	0.933	1.49851	40.92128	38.01652	0.858	1.07138	44.83920	40.92121	0.783	0.78237	47.70083	42.97883	
76	0.932	1.49085	40.98844	38.06719	0.857	1.06694	44.88184	40.95228	0.782	0.77897	47.73556	43.00348	
77	0.931	1.48328	41.05491	38.11731	0.856	1.06252	44.92432	40.98318	0.781	0.77557	47.77032	43.02814	
78	0.930	1.47579	41.12079	38.16695	0.855	1.05812	44.96665	41.01399	0.780	0.77219	47.80489	43.05266	
79	0.929	1.46838	41.18607	38.21612	0.854	1.05374	45.00883	41.04468	0.779	0.76882	47.83939	43.07713	
80	0.928	1.46106	41.25065	38.26473	0.853	1.04939	45.05078	41.07515	0.7				

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Wrought Type 304 stainless steel				64.4	median UTS				0.171	median failure strain		
2	500F				54.74	median failure stress				81	NUREG/CR-5603 failure stress		
3	1.0E-03 failure probability				22.94	median yield stress				21.1	NUREG/CR-5603 yield stress		
4					0.281	beta				0.136	adjusted failure strain		
5													
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902											
9	0.999	3.09023	22.94000	22.94000	0.924	1.43250	36.57748	34.55771	0.849	1.03215	40.93998	38.00794	
10	0.998	2.87816	24.35088	24.20480	0.923	1.42554	36.64920	34.61541	0.848	1.02789	40.99909	38.04610	
11	0.997	2.74778	25.26098	25.01219	0.922	1.41865	36.72033	34.67282	0.847	1.02365	41.03803	38.08411	
12	0.996	2.65207	25.95067	25.62010	0.921	1.41183	36.79088	34.72632	0.846	1.01943	41.08680	38.12198	
13	0.995	2.57583	26.51351	26.11358	0.920	1.40507	36.86095	34.78580	0.845	1.01522	41.13551	38.15978	
14	0.994	2.51214	26.99305	26.53218	0.919	1.39838	36.93041	34.84136	0.844	1.01103	41.18405	38.19744	
15	0.993	2.45726	27.41321	26.89756	0.918	1.39174	36.99949	34.89679	0.843	1.00686	41.23241	38.23494	
16	0.992	2.40892	27.78870	27.22301	0.917	1.38517	37.06797	34.95170	0.842	1.00271	41.28080	38.27230	
17	0.991	2.36562	28.12942	27.51742	0.916	1.37866	37.13595	35.00618	0.841	0.99856	41.32861	38.30950	
18	0.990	2.32635	28.44203	27.76882	0.915	1.37220	37.20352	35.06031	0.840	0.99448	41.37656	38.34684	
19	0.989	2.29037	28.73151	28.03664	0.914	1.36581	37.27049	35.11392	0.839	0.99038	41.42433	38.38363	
20	0.988	2.25713	29.00155	28.26722	0.913	1.35946	37.33716	35.16726	0.838	0.98627	41.47204	38.42056	
21	0.987	2.22621	29.25503	28.48412	0.912	1.35317	37.40331	35.22017	0.837	0.98220	41.51957	38.45734	
22	0.986	2.19729	29.49411	28.68829	0.911	1.34694	37.46895	35.27263	0.836	0.97815	41.56682	38.49396	
23	0.985	2.17009	29.72076	28.88145	0.910	1.34078	37.53418	35.32474	0.835	0.97411	41.61421	38.53052	
24	0.984	2.14441	29.93634	29.06485	0.909	1.33462	37.59910	35.37657	0.834	0.97009	41.66132	38.56693	
25	0.983	2.12007	30.14212	29.23690	0.908	1.32854	37.66349	35.42796	0.833	0.96609	41.70825	38.60319	
26	0.982	2.09693	30.33906	29.40657	0.907	1.32251	37.72748	35.47898	0.832	0.96210	41.75511	38.63938	
27	0.981	2.07485	30.52818	29.56665	0.906	1.31652	37.79112	35.52973	0.831	0.95812	41.80191	38.67580	
28	0.980	2.05375	30.71000	29.72032	0.905	1.31058	37.85435	35.58011	0.830	0.95416	41.84852	38.71148	
29	0.979	2.03352	30.88535	29.86829	0.904	1.30469	37.91715	35.63013	0.829	0.95022	41.89495	38.74730	
30	0.978	2.01409	31.05471	30.01100	0.903	1.29884	37.97963	35.67988	0.828	0.94629	41.94131	38.78305	
31	0.977	1.99539	31.21857	30.14890	0.902	1.29303	38.04178	35.72931	0.827	0.94238	41.98749	38.81865	
32	0.976	1.97737	31.37730	30.28230	0.901	1.28727	38.10350	35.77839	0.826	0.93848	42.03361	38.85419	
33	0.975	1.95996	31.53142	30.41166	0.900	1.28155	38.16489	35.82718	0.825	0.93458	42.07977	38.88974	
34	0.974	1.94313	31.68113	30.53715	0.899	1.27587	38.22595	35.87599	0.824	0.93072	42.12551	38.92486	
35	0.973	1.92684	31.82671	30.65903	0.898	1.27024	38.28657	35.92382	0.823	0.92688	42.17129	38.96020	
36	0.972	1.91104	31.96855	30.77785	0.897	1.26464	38.34696	35.97175	0.822	0.92301	42.21701	38.99538	
37	0.971	1.89570	32.10687	30.89318	0.896	1.25908	38.40701	36.01938	0.821	0.91918	42.26254	39.03040	
38	0.970	1.88079	32.24188	31.00583	0.895	1.25357	38.46661	36.06684	0.820	0.91537	42.30789	39.06526	
39	0.969	1.86630	32.37363	31.11583	0.894	1.24808	38.52609	36.11378	0.819	0.91156	42.35328	39.10015	
40	0.968	1.85218	32.50254	31.22295	0.893	1.24264	38.58512	36.16054	0.818	0.90777	42.39848	39.13488	
41	0.967	1.83842	32.62865	31.32783	0.892	1.23723	38.64392	36.20709	0.817	0.90399	42.44361	39.16955	
42	0.966	1.82501	32.75203	31.43033	0.891	1.23186	38.70237	36.25334	0.816	0.90023	42.48854	39.20405	
43	0.965	1.81191	32.87300	31.53074	0.890	1.22653	38.76047	36.29930	0.815	0.89647	42.53353	39.23858	
44	0.964	1.79912	32.99155	31.62903	0.889	1.22123	38.81832	36.34505	0.814	0.89273	42.57832	39.27295	
45	0.963	1.78661	33.10791	31.72542	0.888	1.21596	38.87594	36.39058	0.813	0.88901	42.62292	39.30715	
46	0.962	1.77438	33.22206	31.81989	0.887	1.21072	38.93332	36.43590	0.812	0.88529	42.66757	39.34139	
47	0.961	1.76241	33.33417	31.91258	0.886	1.20553	38.99023	36.48083	0.811	0.88159	42.71203	39.37548	
48	0.960	1.75069	33.44430	32.00355	0.885	1.20036	39.04700	36.52564	0.810	0.87790	42.75641	39.40946	
49	0.959	1.73920	33.55263	32.09296	0.884	1.19522	39.10353	36.57022	0.809	0.87422	42.80071	39.44339	
50	0.958	1.72793	33.65922	32.18085	0.883	1.19012	39.15969	36.61451	0.808	0.87055	42.84494	39.47728	
51	0.957	1.71689	33.76397	32.26714	0.882	1.18504	39.21572	36.65867	0.807	0.86689	42.88910	39.51108	
52	0.956	1.70604	33.86723	32.35214	0.881	1.18000	39.27139	36.70252	0.806	0.86326	42.93306	39.54489	
53	0.955	1.69540	33.96879	32.43568	0.880	1.17499	39.32690	36.74615	0.805	0.85962	42.97684	39.57825	
54	0.954	1.68494	34.06894	32.51798	0.879	1.17000	39.38207	36.78965	0.804	0.85600	43.02075	39.61175	
55	0.953	1.67466	34.16765	32.59903	0.878	1.16505	39.43697	36.83284	0.803	0.85239	43.06448	39.64517	
56	0.952	1.66456	34.26491	32.67883	0.877	1.16012	39.49173	36.87590	0.802	0.84879	43.10813	39.67853	
57	0.951	1.65463	34.36081	32.75745	0.876	1.15522	39.54622	36.91874	0.801	0.84520	43.15171	39.71181	
58	0.950	1.64485	34.45551	32.83503	0.875	1.15035	39.60048	36.96135	0.800	0.84162	43.19521	39.74502	
59	0.949	1.63523	34.54893	32.91150	0.874	1.14551	39.65444	37.00374	0.799	0.83805	43.23863	39.77817	
60	0.948	1.62578	34.64113	32.98691	0.873	1.14069	39.70827	37.04600	0.798	0.83450	43.28185	39.81114	
61	0.947	1.61644	34.73211	33.06128	0.872	1.13590	39.76184	37.08803	0.797	0.83095	43.32512	39.84414	
62	0.946	1.60725	34.82208	33.13474	0.871	1.13113	39.81525	37.12992	0.796	0.82742	43.36818	39.87698	
63	0.945	1.59819	34.91097	33.20729	0.870	1.12639	39.86840	37.17159	0.795	0.82390	43.41117	39.90974	
64	0.944	1.58927	34.99872	33.27886	0.869	1.12168	39.92129	37.21304	0.794	0.82038	43.45420	39.94253	
65	0.943	1.58047	35.08551	33.34959	0.868	1.11699	39.97402	37.25434	0.793	0.81687	43.49714	39.97524	
66	0.942	1.57179	35.17132	33.41947	0.867	1.11232	40.02659	37.29551	0.792	0.81338	43.53999	40.00779	
67	0.941	1.56322	35.25625	33.48859	0.866	1.10768	40.07889	37.33644	0.791	0.80990	43.58255	40.04027	
68	0.940	1.55477	35.34020	33.55686	0.865	1.10306	40.13104	37.37724	0.790	0.80642	43.62526	40.07278	
69	0.939	1.54643	35.42325	33.62436	0.864	1.09847	40.18292	37.41781	0.789	0.80296	43.66778	40.10500	
70	0.938	1.53820	35.50539	33.69107	0.863	1.09390	40.23463	37.45823	0.788	0.79950	43.71030	40.13745	
71	0.937	1.53007	35.58672	33.75708	0.862	1.08935	40.28619	37.49855	0.787	0.79606	43.75284	40.16963	
72	0.936	1.52204	35.66724	33.82239	0.861	1.08482	40.33758	37.53866	0.786	0.79262	43.79502	40.20184	
73	0.935	1.51410	35.74703	33.88708	0.860	1.08032	40.38870	37.57857	0.785	0.78919	43.83732	40.23397	
74	0.934	1.50626	35.82599	33.95103	0.859	1.07584	40.43966	37.61834	0.784	0.78577	43.87953	40.26603	
75	0.933	1.49851	35.90422	34.01435	0.858	1.07138	40.49045	37.65788	0.783	0.78237	43.92154	40.29792	
76	0.932	1.49085	35.98171	34.07704	0.857	1.06694	40.54108	37.69744	0.782	0.77897	43.96359	40.32963	
77	0.931	1.48328	36.05845	34.13908	0.856	1.06252	40.59154	37.73677	0.781	0.77557	44.00568	40.36178	
78	0.930	1.47579	36.13454	34.20057	0.855	1.05812	40.64184	37.77588	0.780	0.77219	44.04756	40.39352	
79	0.929	1.46838	36.20998	34.26148	0.854	1.05374	40.69197	37.81501	0.779	0.76882	44.08936	40.42521	
80	0.928	1.46108	36.28485	34.32174	0.853	1.04939	40.74182	37.85362	0.778	0.76546	44.13		

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Wrought Type 304 stainless steel				64.4 median UTS					0.171 median failure strain			
2	500F				64.74 median failure stress					61 NUREG/CR-5603 failure stress			
3	1.0E-04 failure probability				22.94 median yield stress					21.1 NUREG/CR-5603 yield stress			
4					0.234 beta					0.136 adjusted failure strain			
5													
6	survival		adjusted		survival			adjusted		survival		adjusted	
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902	22.94000	22.94000									
9	0.999	3.09023	26.57366	26.16635	0.924	1.43250	39.15770	36.61294		0.849	1.03215	43.00090	39.59657
10	0.998	2.87818	27.92498	27.34087	0.923	1.42654	39.22148	36.66320		0.848	1.02789	43.04376	39.62933
11	0.997	2.74778	28.78953	28.08544	0.922	1.41865	39.28473	36.71302		0.847	1.02365	43.08646	39.66166
12	0.996	2.65207	29.44117	28.64311	0.921	1.41183	39.34743	36.76239		0.846	1.01943	43.12900	39.69446
13	0.995	2.57583	29.97079	29.09413	0.920	1.40507	39.40969	36.81136		0.845	1.01522	43.17148	39.72691
14	0.994	2.51214	30.42052	29.47555	0.919	1.39836	39.47139	36.85991		0.844	1.01103	43.21380	39.75922
15	0.993	2.45726	30.81345	29.80784	0.918	1.39174	39.53273	36.90813		0.843	1.00686	43.25596	39.79139
16	0.992	2.40992	31.16378	30.10290	0.917	1.38517	39.59351	36.95599		0.842	1.00271	43.29797	39.82343
17	0.991	2.36562	31.48093	30.38929	0.916	1.37866	39.65384	37.00327		0.841	0.99858	43.33980	39.85534
18	0.990	2.32635	31.77136	30.61271	0.915	1.37220	39.71379	37.05033		0.840	0.99446	43.38158	39.88719
19	0.989	2.29037	32.03982	30.83719	0.914	1.36581	39.77318	37.09692		0.839	0.99036	43.42320	39.91891
20	0.988	2.25713	32.28965	31.04582	0.913	1.35948	39.83226	37.14328		0.838	0.98627	43.46475	39.95057
21	0.987	2.22621	32.52418	31.24095	0.912	1.35317	39.89092	37.18924		0.837	0.98220	43.50614	39.98209
22	0.986	2.19729	32.74486	31.42440	0.911	1.34694	39.94908	37.23481		0.836	0.97815	43.54736	40.01348
23	0.985	2.17009	32.95383	31.59777	0.910	1.34076	40.00686	37.28006		0.835	0.97411	43.58852	40.04481
24	0.984	2.14441	33.15233	31.76219	0.909	1.33462	40.06434	37.32508		0.834	0.97009	43.62952	40.07601
25	0.983	2.12007	33.34157	31.91870	0.908	1.32854	40.12135	37.36986		0.833	0.96609	43.67035	40.10707
26	0.982	2.09693	33.52249	32.06809	0.907	1.32251	40.17797	37.41394		0.832	0.96210	43.71112	40.13807
27	0.981	2.07485	33.69603	32.21118	0.906	1.31652	40.23429	37.45798		0.831	0.95812	43.75182	40.16901
28	0.980	2.05375	33.86271	32.34843	0.905	1.31058	40.29021	37.50166		0.830	0.95416	43.79236	40.19981
29	0.979	2.03352	34.02329	32.48047	0.904	1.30469	40.34575	37.54504		0.829	0.95022	43.83273	40.23048
30	0.978	2.01409	34.17824	32.60772	0.903	1.29884	40.40098	37.58818		0.828	0.94629	43.87303	40.26109
31	0.977	1.99539	34.32803	32.73058	0.902	1.29303	40.45591	37.63102		0.827	0.94236	43.91316	40.29156
32	0.976	1.97737	34.47299	32.84935	0.901	1.28727	40.51044	37.67355		0.826	0.93848	43.95323	40.32197
33	0.975	1.95998	34.61383	32.96443	0.900	1.28155	40.56487	37.71563		0.825	0.93458	43.99334	40.35240
34	0.974	1.94313	34.75013	33.07600	0.899	1.27587	40.61859	37.75785		0.824	0.93072	44.03307	40.38253
35	0.973	1.92684	34.88277	33.18429	0.898	1.27024	40.67210	37.79953		0.823	0.92686	44.07283	40.41269
36	0.972	1.91104	35.01189	33.28960	0.897	1.26464	40.72540	37.84104		0.822	0.92301	44.11253	40.44278
37	0.971	1.89570	35.13772	33.39212	0.896	1.25908	40.77838	37.88228		0.821	0.91918	44.15206	40.47273
38	0.970	1.88079	35.26045	33.49201	0.895	1.25357	40.83096	37.92318		0.820	0.91537	44.19142	40.50255
39	0.969	1.86630	35.38014	33.58933	0.894	1.24808	40.88342	37.96367		0.819	0.91156	44.23061	40.53238
40	0.968	1.85218	35.49716	33.68438	0.893	1.24264	40.93546	38.00443		0.818	0.90777	44.27003	40.56207
41	0.967	1.83842	35.61156	33.77723	0.892	1.23723	40.98726	38.04470		0.817	0.90399	44.30918	40.59170
42	0.966	1.82501	35.72342	33.86793	0.891	1.23186	41.03879	38.08470		0.816	0.90023	44.34818	40.62119
43	0.965	1.81191	35.83302	33.95672	0.890	1.22653	41.08997	38.12444		0.815	0.89647	44.38717	40.65070
44	0.964	1.79912	35.94036	34.04359	0.889	1.22123	41.14063	38.16399		0.814	0.89273	44.42603	40.68007
45	0.963	1.78661	36.04566	34.12875	0.888	1.21598	41.19167	38.20335		0.813	0.88901	44.46487	40.70930
46	0.962	1.77438	36.14890	34.21216	0.887	1.21072	41.24217	38.24251		0.812	0.88529	44.50337	40.73854
47	0.961	1.76241	36.25023	34.29397	0.886	1.20553	41.29226	38.28134		0.811	0.88159	44.54189	40.76764
48	0.960	1.75069	36.34972	34.37423	0.885	1.20038	41.34222	38.32004		0.810	0.87790	44.58035	40.79669
49	0.959	1.73920	36.44752	34.45308	0.884	1.19522	41.39194	38.35855		0.809	0.87422	44.61873	40.82566
50	0.958	1.72793	36.54371	34.53053	0.883	1.19012	41.44134	38.39680		0.808	0.87055	44.65704	40.85455
51	0.957	1.71689	36.63818	34.60655	0.882	1.18504	41.49080	38.43482		0.807	0.86689	44.69528	40.88343
52	0.956	1.70604	36.73126	34.68140	0.881	1.18000	41.53953	38.47278		0.806	0.86325	44.73334	40.91215
53	0.955	1.69540	36.82277	34.75494	0.880	1.17499	41.58822	38.51043		0.805	0.85962	44.77133	40.94079
54	0.954	1.68494	36.91295	34.82735	0.879	1.17000	41.63678	38.54797		0.804	0.85600	44.80925	40.96938
55	0.953	1.67466	37.00180	34.89884	0.878	1.16505	41.68501	38.58524		0.803	0.85239	44.84709	40.99790
56	0.952	1.66456	37.08930	34.96880	0.877	1.16012	41.73310	38.62238		0.802	0.84879	44.88486	41.02636
57	0.951	1.65463	37.17553	35.03789	0.876	1.15522	41.78094	38.65932		0.801	0.84520	44.92256	41.05475
58	0.950	1.64485	37.26065	35.10604	0.875	1.15035	41.82856	38.69607		0.800	0.84162	44.96019	41.08309
59	0.949	1.63523	37.34457	35.17319	0.874	1.14551	41.87593	38.73262		0.799	0.83805	44.99774	41.11135
60	0.948	1.62578	37.42736	35.23940	0.873	1.14069	41.92315	38.76905		0.798	0.83450	45.03511	41.13948
61	0.947	1.61644	37.50903	35.30485	0.872	1.13590	41.97014	38.80527		0.797	0.83095	45.07251	41.16762
62	0.946	1.60725	37.58973	35.36909	0.871	1.13113	42.01699	38.84137		0.796	0.82742	45.10974	41.19561
63	0.945	1.59819	37.66945	35.43272	0.870	1.12639	42.06359	38.87727		0.795	0.82390	45.14689	41.22354
64	0.944	1.58927	37.74811	35.49545	0.869	1.12168	42.10994	38.91297		0.794	0.82038	45.18407	41.25149
65	0.943	1.58047	37.82566	35.55743	0.868	1.11699	42.15615	38.94855		0.793	0.81687	45.22117	41.27937
66	0.942	1.57179	37.90273	35.61865	0.867	1.11232	42.20222	38.98400		0.792	0.81338	45.25809	41.30711
67	0.941	1.56322	37.97877	35.67918	0.866	1.10768	42.24804	39.01924		0.791	0.80990	45.29494	41.33478
68	0.940	1.55477	38.05390	35.73895	0.865	1.10308	42.29371	39.05436		0.790	0.80642	45.33181	41.36247
69	0.939	1.54643	38.12819	35.79801	0.864	1.09847	42.33913	39.08928		0.789	0.80296	45.36851	41.39001
70	0.938	1.53820	38.20164	35.85638	0.863	1.09390	42.38440	39.12407		0.788	0.79950	45.40523	41.41757
71	0.937	1.53007	38.27434	35.91411	0.862	1.08935	42.42952	39.15873		0.787	0.79606	45.44178	41.44498
72	0.936	1.52204	38.34626	35.97121	0.861	1.08482	42.47450	39.19326		0.786	0.79262	45.47835	41.47241
73	0.935	1.51410	38.41755	36.02774	0.860	1.08032	42.51922	39.22759		0.785	0.78919	45.51484	41.49977
74	0.934	1.50626	38.48805	36.08363	0.859	1.07584	42.56379	39.26179		0.784	0.78577	45.55128	41.52708
75	0.933	1.49851	38.55787	36.13995	0.858	1.07138	42.60820	39.29586		0.783	0.78237	45.58749	41.55421
76	0.932	1.49085	38.62700	36.19370	0.857	1.06694	42.65247	39.32981		0.782	0.77897	45.62375	41.58137
77	0.931	1.48328	38.69544	36.24786	0.856	1.06252	42.69656	39.36362		0.781	0.77557	45.66004	41.60855
78	0.930	1.47578	38.76328	36.30153	0.855	1.05812	42.74053	39.39730		0.780	0.77219	45.69615	41.63558
79	0.929	1.46838	38.83051	36.35468	0.854	1.05374	42.78433	39.43085		0.779	0.76882	45.73217	41.66254
80	0.928	1.46108	38.89704	36.40724	0.853	1.04939	42.82788	39.46420		0.778	0.		

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Wrought Type 304 stainless steel plate				65.92	median UTS				0.141	median failure strain		
2	350F				58.03	median failure stress				59.28	NUREG/CR-5603 failure stress		
3	1.0E-03 failure probability				26.83	median yield stress				25.12	NUREG/CR-5603 yield stress		
4					0.236	beta				0.120	adjusted failure strain		
5													
6	survival		adjusted		survival			adjusted		survival		adjusted	
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902											
9	0.999	3.06023	26.83000	26.83000	0.924	1.43250	39.82751	37.80485	0.849	1.03215	43.81435	40.95127	
10	0.998	2.87816	26.22073	26.06010	0.923	1.42554	39.89363	37.85782	0.848	1.02789	43.85885	40.98585	
11	0.997	2.74778	26.11130	26.84047	0.922	1.41866	39.95918	37.91032	0.847	1.02365	43.90319	41.02029	
12	0.996	2.65207	26.78290	29.42522	0.921	1.41183	40.02418	37.96235	0.846	1.01943	43.94736	41.05458	
13	0.995	2.57563	30.32894	29.89831	0.920	1.40507	40.08870	38.01397	0.845	1.01522	43.99148	41.08862	
14	0.994	2.51214	30.79276	30.29852	0.919	1.39838	40.15266	38.06512	0.844	1.01103	44.03542	41.12292	
15	0.993	2.45726	31.18811	30.64705	0.918	1.39174	40.21625	38.11594	0.843	1.00686	44.07920	41.15688	
16	0.992	2.40862	31.58957	30.95888	0.917	1.38517	40.27926	38.16626	0.842	1.00271	44.12282	41.19098	
17	0.991	2.36552	31.88690	31.23667	0.916	1.37868	40.34180	38.21621	0.841	0.99858	44.16626	41.22437	
18	0.990	2.32635	32.18670	31.48229	0.915	1.37220	40.40395	38.26582	0.840	0.99448	44.20965	41.25799	
19	0.989	2.29037	32.48388	31.72805	0.914	1.36581	40.46552	38.31493	0.839	0.99038	44.25286	41.29146	
20	0.988	2.25713	32.72203	31.94718	0.913	1.35946	40.52680	38.36379	0.838	0.98627	44.29601	41.32485	
21	0.987	2.22621	32.98402	32.15218	0.912	1.35317	40.58759	38.41224	0.837	0.98220	44.33900	41.35811	
22	0.986	2.19729	33.18198	32.34492	0.911	1.34694	40.64789	38.46027	0.836	0.97815	44.38181	41.39128	
23	0.985	2.17009	33.40783	32.52709	0.910	1.34078	40.70780	38.50797	0.835	0.97411	44.42456	41.42435	
24	0.984	2.14441	33.61299	32.69888	0.909	1.33462	40.76740	38.55541	0.834	0.97009	44.46713	41.45728	
25	0.983	2.12007	33.80842	32.86436	0.908	1.32854	40.82651	38.60243	0.833	0.96609	44.50954	41.49008	
26	0.982	2.09693	33.99537	33.02138	0.907	1.32251	40.88522	38.64910	0.832	0.96210	44.55188	41.52278	
27	0.981	2.07485	34.17471	33.17180	0.906	1.31652	40.94362	38.69582	0.831	0.95812	44.59416	41.55544	
28	0.980	2.05375	34.34698	33.31808	0.905	1.31058	41.00182	38.74159	0.830	0.95416	44.63626	41.58796	
29	0.979	2.03352	34.51298	33.45481	0.904	1.30469	41.05921	38.78732	0.829	0.95022	44.67819	41.62033	
30	0.978	2.01409	34.67313	33.58870	0.903	1.29884	41.11649	38.83278	0.828	0.94629	44.72005	41.65264	
31	0.977	1.99539	34.82798	33.71789	0.902	1.29303	41.17345	38.87797	0.827	0.94236	44.76174	41.68481	
32	0.976	1.97737	34.97786	33.84278	0.901	1.28727	41.23001	38.92281	0.826	0.93848	44.80336	41.71691	
33	0.975	1.95996	35.12328	33.96381	0.900	1.28155	41.28624	38.96739	0.825	0.93458	44.84501	41.74903	
34	0.974	1.94313	35.26443	34.08115	0.899	1.27587	41.34217	39.01189	0.824	0.93072	44.88628	41.78085	
35	0.973	1.92694	35.40159	34.19505	0.898	1.27024	41.39787	39.05685	0.823	0.92686	44.92759	41.81268	
36	0.972	1.91104	35.53513	34.30582	0.897	1.26464	41.45326	39.09941	0.822	0.92301	44.96883	41.84445	
37	0.971	1.89570	35.66527	34.41366	0.896	1.25908	41.50791	39.14289	0.821	0.91918	45.00989	41.87607	
38	0.970	1.88079	35.79221	34.51875	0.895	1.25357	41.55625	39.18603	0.820	0.91537	45.05077	41.90754	
39	0.969	1.86630	35.91602	34.62113	0.894	1.24808	41.61686	39.22904	0.819	0.91156	45.09199	41.93904	
40	0.968	1.85218	36.03707	34.72114	0.893	1.24264	41.67084	39.27170	0.818	0.90777	45.13244	41.97039	
41	0.967	1.83842	36.15543	34.81884	0.892	1.23723	41.72460	39.31417	0.817	0.90399	45.17311	42.00187	
42	0.966	1.82501	36.27115	34.91428	0.891	1.23186	41.77803	39.35635	0.816	0.90023	45.21360	42.03261	
43	0.965	1.81191	36.38456	35.00770	0.890	1.22653	41.83112	39.39826	0.815	0.89647	45.25413	42.06396	
44	0.964	1.79912	36.49582	35.09912	0.889	1.22123	41.88399	39.43997	0.814	0.89273	45.29448	42.09497	
45	0.963	1.78681	36.60459	35.18873	0.888	1.21596	41.93682	39.48147	0.813	0.88901	45.33468	42.12563	
46	0.962	1.77436	36.71142	35.27652	0.887	1.21072	41.98902	39.52278	0.812	0.88529	45.37488	42.15670	
47	0.961	1.76241	36.81829	35.36262	0.886	1.20553	42.04098	39.56373	0.811	0.88159	45.41489	42.18743	
48	0.960	1.75099	36.91926	35.44709	0.885	1.20036	42.09281	39.60455	0.810	0.87790	45.45484	42.21810	
49	0.959	1.73920	37.02048	35.53007	0.884	1.19522	42.14440	39.64517	0.809	0.87422	45.49472	42.24869	
50	0.958	1.72793	37.12004	35.61181	0.883	1.19012	42.19585	39.68550	0.808	0.87055	45.53452	42.27922	
51	0.957	1.71699	37.21782	35.69184	0.882	1.18504	42.24676	39.72571	0.807	0.86689	45.57425	42.30969	
52	0.956	1.70604	37.31418	35.77043	0.881	1.18000	42.29753	39.76564	0.806	0.86325	45.61380	42.34001	
53	0.955	1.69540	37.40991	35.84784	0.880	1.17499	42.34806	39.80536	0.805	0.85962	45.65328	42.37028	
54	0.954	1.68494	37.50227	35.92408	0.879	1.17000	42.39845	39.84495	0.804	0.85600	45.69266	42.40044	
55	0.953	1.67466	37.59425	35.99914	0.878	1.16505	42.44849	39.88426	0.803	0.85239	45.73200	42.43058	
56	0.952	1.66456	37.68485	36.07300	0.877	1.16012	42.49836	39.92344	0.802	0.84879	45.77125	42.46061	
57	0.951	1.65463	37.77413	36.14575	0.876	1.15522	42.54804	39.96241	0.801	0.84520	45.81042	42.49059	
58	0.950	1.64485	37.86226	36.21751	0.875	1.15035	42.59745	40.00117	0.800	0.84162	45.84952	42.52051	
59	0.949	1.63523	37.94916	36.28822	0.874	1.14551	42.64661	40.03973	0.799	0.83805	45.88854	42.55036	
60	0.948	1.62576	38.03480	36.35793	0.873	1.14069	42.69562	40.07815	0.798	0.83450	45.92738	42.58008	
61	0.947	1.61644	38.11947	36.42665	0.872	1.13590	42.74436	40.11637	0.797	0.83095	45.96625	42.60978	
62	0.946	1.60725	38.20304	36.49451	0.871	1.13113	42.79300	40.15445	0.796	0.82742	46.00493	42.63934	
63	0.945	1.59819	38.28561	36.56152	0.870	1.12639	42.84136	40.19232	0.795	0.82390	46.04354	42.66884	
64	0.944	1.58927	38.36707	36.62759	0.869	1.12168	42.88947	40.22999	0.794	0.82038	46.08218	42.69835	
65	0.943	1.58047	38.44762	36.69266	0.868	1.11699	42.93744	40.26752	0.793	0.81687	46.12074	42.72780	
66	0.942	1.57179	38.52723	36.75734	0.867	1.11232	42.98525	40.30491	0.792	0.81338	46.15911	42.75709	
67	0.941	1.56322	38.60599	36.82110	0.866	1.10768	43.03280	40.34210	0.791	0.80990	46.19741	42.78632	
68	0.940	1.55477	38.68380	36.88405	0.865	1.10308	43.08020	40.37915	0.790	0.80642	46.23573	42.81556	
69	0.939	1.54643	38.76076	36.94627	0.864	1.09847	43.12735	40.41599	0.789	0.80296	46.27387	42.84464	
70	0.938	1.53820	38.83685	37.00775	0.863	1.09390	43.17434	40.45270	0.788	0.79950	46.31204	42.87375	
71	0.937	1.53007	38.91217	37.06857	0.862	1.08935	43.22118	40.48927	0.787	0.79606	46.35002	42.90270	
72	0.936	1.52204	38.98670	37.12871	0.861	1.08482	43.26786	40.52570	0.786	0.79262	46.38803	42.93168	
73	0.935	1.51410	39.06054	37.18827	0.860	1.08032	43.31429	40.56192	0.785	0.78919	46.42596	42.96058	
74	0.934	1.50628	39.13358	37.24715	0.859	1.07584	43.36055	40.59801	0.784	0.78577	46.46382	42.98939	
75	0.933	1.49851	39.20592	37.30543	0.858	1.07138	43.40666	40.63396	0.783	0.78237	46.50148	43.01806	
76	0.932	1.49085	39.27755	37.36310	0.857	1.06694	43.45261	40.66977	0.782	0.77897	46.53917	43.04675	
77	0.931	1.48328	39.34847	37.42017	0.856	1.06252	43.49841	40.70545	0.781	0.77557	46.57689	43.07546	
78	0.930	1.47579	39.41878	37.47671	0.855	1.05812	43.54404	40.74099	0.780	0.77219	46.61442	43.10401	
79	0.929	1.46836	39.48843	37.53271	0.854	1.05374	43.58951	40.77640	0.779	0.76882	46.65187	43.13249	
80	0.928	1.46106	39.55737	37.58810	0.853	1.04939	43.63472	40.81158	0.778	0.76546			

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Wrought Type 304 stainless steel plate				85.92	median UTS				0.141	median failure strain		
2	350F				56.03	median failure stress				59.26	NUREG/CR-5603 failure stress		
3	1.0E-04 failure probability				26.83	median yield stress				25.12	NUREG/CR-5603 yield stress		
4					0.198	beta				0.120	adjusted failure strain		
5													
6	survival		adjusted		survival			adjusted		survival			adjusted
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902	26.83000	26.83000									
9	0.999	3.09023	30.36738	29.94882	0.924	1.43250	42.19383	39.68407		0.849	1.03215	45.67482	42.38678
10	0.998	2.87816	31.69057	31.06804	0.923	1.42554	42.25202	39.72964		0.848	1.02789	45.71336	42.41628
11	0.997	2.74778	32.51938	31.77520	0.922	1.41865	42.30670	39.77520		0.847	1.02368	45.75178	42.44569
12	0.996	2.65207	33.14153	32.30229	0.921	1.41183	42.35688	39.82014		0.846	1.01943	45.79001	42.47497
13	0.995	2.57583	33.64564	32.72744	0.920	1.40507	42.42362	39.86473		0.845	1.01522	45.82819	42.50419
14	0.994	2.51214	34.07264	33.08622	0.919	1.39838	42.47986	39.90889		0.844	1.01103	45.86623	42.53328
15	0.993	2.45726	34.44492	33.39802	0.918	1.39174	42.53575	39.95276		0.843	1.00686	45.90412	42.56227
16	0.992	2.40892	34.77520	33.67471	0.917	1.38517	42.59112	39.99521		0.842	1.00271	45.94186	42.59113
17	0.991	2.36582	35.07565	33.92418	0.916	1.37868	42.64606	40.03629		0.841	0.99858	45.97944	42.61988
18	0.990	2.32835	35.34945	34.15177	0.915	1.37220	42.70164	40.08209		0.840	0.99448	46.01697	42.64854
19	0.989	2.29373	35.60220	34.36141	0.914	1.36581	42.75470	40.12445		0.839	0.99036	46.05434	42.67708
20	0.988	2.26173	35.83730	34.55604	0.913	1.35946	42.80580	40.16686		0.838	0.98627	46.09185	42.70569
21	0.987	2.23221	36.05738	34.73791	0.912	1.35317	42.86185	40.20636		0.837	0.98220	46.12861	42.73398
22	0.986	2.19729	36.26448	34.90674	0.911	1.34694	42.91475	40.24677		0.836	0.97815	46.16582	42.76221
23	0.985	2.17009	36.48030	35.07005	0.910	1.34078	42.96730	40.28688		0.835	0.97411	46.20277	42.79040
24	0.984	2.14441	36.64617	35.22291	0.909	1.33462	43.01957	40.33176		0.834	0.97008	46.23956	42.81847
25	0.983	2.12007	36.82321	35.36830	0.908	1.32854	43.07139	40.37227		0.833	0.96609	46.27620	42.84642
26	0.982	2.09693	36.99232	35.50699	0.907	1.32251	43.12285	40.41248		0.832	0.96210	46.31277	42.87430
27	0.981	2.07485	37.15441	35.63974	0.906	1.31652	43.17403	40.45245		0.831	0.95812	46.34928	42.90214
28	0.980	2.05375	37.30996	35.76699	0.905	1.31058	43.22484	40.49212		0.830	0.95416	46.38564	42.92984
29	0.979	2.03352	37.45972	35.88934	0.904	1.30469	43.27528	40.53149		0.829	0.95022	46.42184	42.95742
30	0.978	2.01409	37.60411	36.00718	0.903	1.29884	43.32544	40.57082		0.828	0.94629	46.45798	42.98485
31	0.977	1.99539	37.74361	36.12069	0.902	1.29303	43.37531	40.60952		0.827	0.94238	46.49396	43.01235
32	0.976	1.97737	37.87853	36.23075	0.901	1.28727	43.42481	40.64811		0.826	0.93848	46.52986	43.03968
33	0.975	1.95996	38.00933	36.33715	0.900	1.28155	43.47402	40.68648		0.825	0.93458	46.56563	43.06704
34	0.974	1.94313	38.13621	36.44025	0.899	1.27587	43.52294	40.72457		0.824	0.93072	46.60143	43.09413
35	0.973	1.92684	38.25942	36.54027	0.898	1.27024	43.57149	40.76237		0.823	0.92686	46.63707	43.12123
36	0.972	1.91104	38.37930	36.63750	0.897	1.26464	43.61983	40.80000		0.822	0.92301	46.67263	43.14828
37	0.971	1.89570	38.49506	36.73210	0.896	1.25908	43.66788	40.83739		0.821	0.91918	46.70804	43.17518
38	0.970	1.88079	38.60686	36.82425	0.895	1.25357	43.71555	40.87448		0.820	0.91537	46.74329	43.20198
39	0.969	1.86630	38.72082	36.91398	0.894	1.24808	43.76310	40.91143		0.819	0.91156	46.77857	43.22878
40	0.968	1.85218	38.82923	37.00159	0.893	1.24264	43.81028	40.94809		0.818	0.90777	46.81369	43.25548
41	0.967	1.83842	38.93517	37.08713	0.892	1.23723	43.85722	40.98458		0.817	0.90399	46.84874	43.28208
42	0.966	1.82501	39.03869	37.17065	0.891	1.23186	43.90393	41.02082		0.816	0.90023	46.88363	43.30857
43	0.965	1.81191	39.14006	37.25239	0.890	1.22653	43.95024	41.05681		0.815	0.89647	46.91855	43.33507
44	0.964	1.79912	39.23933	37.33233	0.889	1.22123	43.99639	41.09283		0.814	0.89273	46.95331	43.36144
45	0.963	1.78661	39.33665	37.41066	0.888	1.21596	44.04232	41.12827		0.813	0.88901	46.98791	43.38769
46	0.962	1.77438	39.43203	37.48737	0.887	1.21072	44.08804	41.16373		0.812	0.88529	47.02253	43.41395
47	0.961	1.76241	39.52560	37.56258	0.886	1.20553	44.13337	41.19888		0.811	0.88159	47.05699	43.44007
48	0.960	1.75069	39.61743	37.63633	0.885	1.20038	44.17858	41.23391		0.810	0.87790	47.09139	43.46614
49	0.959	1.73920	39.70767	37.70875	0.884	1.19522	44.22356	41.26877		0.809	0.87422	47.12572	43.49218
50	0.958	1.72793	39.79638	37.77969	0.883	1.19012	44.26824	41.30338		0.808	0.87055	47.15999	43.51811
51	0.957	1.71689	39.88347	37.84988	0.882	1.18504	44.31279	41.33787		0.807	0.86689	47.19417	43.54400
52	0.956	1.70604	39.96925	37.91938	0.881	1.18000	44.35704	41.37212		0.806	0.86325	47.22819	43.56977
53	0.955	1.69540	40.05355	37.98855	0.880	1.17499	44.40107	41.40618		0.805	0.85962	47.26218	43.59548
54	0.954	1.68494	40.13659	38.05227	0.879	1.17000	44.44498	41.44013		0.804	0.85600	47.29604	43.62112
55	0.953	1.67466	40.21837	38.11764	0.878	1.16505	44.48854	41.47383		0.803	0.85239	47.32986	43.64671
56	0.952	1.66456	40.29889	38.18195	0.877	1.16012	44.53199	41.50741		0.802	0.84879	47.36361	43.67224
57	0.951	1.65463	40.37820	38.24527	0.876	1.15522	44.57522	41.54082		0.801	0.84520	47.39729	43.69771
58	0.950	1.64485	40.45647	38.30772	0.875	1.15035	44.61823	41.57404		0.800	0.84162	47.43090	43.72312
59	0.949	1.63523	40.53361	38.36922	0.874	1.14551	44.66101	41.60707		0.799	0.83805	47.46444	43.74847
60	0.948	1.62576	40.60969	38.42964	0.873	1.14069	44.70385	41.63999		0.798	0.83450	47.49782	43.77369
61	0.947	1.61644	40.68470	38.48958	0.872	1.13590	44.74607	41.67272		0.797	0.83095	47.53122	43.79892
62	0.946	1.60725	40.75880	38.54856	0.871	1.13113	44.78835	41.70534		0.796	0.82742	47.56445	43.82402
63	0.945	1.59819	40.83199	38.60678	0.870	1.12639	44.83041	41.73778		0.795	0.82390	47.59762	43.84908
64	0.944	1.58927	40.90417	38.66417	0.869	1.12168	44.87224	41.77002		0.794	0.82038	47.63080	43.87411
65	0.943	1.58047	40.97551	38.72085	0.868	1.11699	44.91393	41.80215		0.793	0.81687	47.66392	43.89910
66	0.942	1.57179	41.04599	38.77682	0.867	1.11232	44.95548	41.83417		0.792	0.81338	47.69697	43.92396
67	0.941	1.56322	41.11570	38.83216	0.866	1.10768	44.99681	41.86599		0.791	0.80990	47.72975	43.94876
68	0.940	1.55477	41.18455	38.88677	0.865	1.10306	45.03799	41.89770		0.790	0.80642	47.76265	43.97358
69	0.939	1.54643	41.25262	38.94074	0.864	1.09847	45.07894	41.92922		0.789	0.80296	47.79538	43.99825
70	0.938	1.53820	41.31990	38.99406	0.863	1.09390	45.11975	41.96063		0.788	0.79950	47.82814	44.02294
71	0.937	1.53007	41.38648	39.04678	0.862	1.08935	45.16042	41.99191		0.787	0.79606	47.86073	44.04750
72	0.936	1.52204	41.45233	39.09862	0.861	1.08482	45.20096	42.02307		0.786	0.79262	47.89334	44.07207
73	0.935	1.51410	41.51758	39.15052	0.860	1.08032	45.24124	42.05405		0.785	0.78919	47.92588	44.09658
74	0.934	1.50626	41.58206	39.20153	0.859	1.07584	45.28139	42.08491		0.784	0.78577	47.95834	44.12102
75	0.933	1.49851	41.64562	39.25201	0.858	1.07138	45.32140	42.11564		0.783	0.78237	47.99064	44.14534
76	0.932	1.49085	41.70913	39.30195	0.857	1.06694	45.36128	42.14628		0.782	0.77897	48.02298	44.16968
77	0.931	1.48328	41.77170	39.35136	0.856	1.06252	45.40098	42.17675		0.781	0.77557	48.05530	44.19400
78	0.930	1.47579	41.83370	39.40029	0.855	1.05812	45.44055	42.20713		0.780	0.77219	48.08748	44.21820
79	0.929	1.46838	41.89512	39.44875	0.854	1.05374	45.47998	42.23738		0.779	0.76882	48.11958	44.24234
80	0.928	1.46108	41.95589	39.49666	0.853	1.04939	45.51917	42.26745					

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Cast Type 304 stainless steel				63.167	median UTS				0.195	median failure strain		
2	350F				63.71	median failure stress				64.56	NUREG/CR-5603 failure stress		
3	1.0E-03 failure probability				25.893	median yield stress				25.12	NUREG/CR-5603 yield stress		
4					0.236	beta				0.137	adjusted failure strain		
5													
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902											
9	0.999	3.08023	25.89300	25.89300	0.924	1.43250	36.29674	36.08781		0.849	1.03215	42.09327	36.97682
10	0.996	2.87818	27.22247	27.04501	0.923	1.42554	36.35972	36.13626		0.848	1.02789	42.13563	36.00849
11	0.997	2.74778	28.07348	27.77456	0.922	1.41858	36.42217	36.18460		0.847	1.02365	42.17783	36.04004
12	0.996	2.65207	28.71509	28.32063	0.921	1.41183	36.48409	36.23249		0.846	1.01943	42.21987	36.07145
13	0.995	2.57583	29.23685	28.76200	0.920	1.40507	36.54556	36.28000		0.845	1.01522	42.26186	36.10261
14	0.994	2.51214	29.67961	29.13511	0.919	1.39838	36.60649	36.32707		0.844	1.01103	42.30369	36.13403
15	0.993	2.45728	30.06698	29.48963	0.918	1.39174	36.66706	36.37383		0.843	1.00686	42.34536	36.16513
16	0.992	2.40892	30.41180	29.74834	0.917	1.38517	36.72709	36.42014		0.842	1.00271	42.38687	36.19610
17	0.991	2.36562	30.72430	30.00878	0.916	1.37866	36.78666	36.46608		0.841	0.99856	42.42822	36.22693
18	0.990	2.32835	31.01049	30.24655	0.915	1.37220	36.84586	36.51171		0.840	0.99444	42.46951	36.25771
19	0.989	2.29037	31.27505	30.46578	0.914	1.36581	36.90451	36.55689		0.839	0.99036	42.51084	36.28836
20	0.988	2.25713	31.52146	30.66948	0.913	1.35946	36.96266	36.60183		0.838	0.98627	42.55171	36.31895
21	0.987	2.22821	31.75242	30.85997	0.912	1.35317	37.02079	36.64639		0.837	0.98220	42.59282	36.34941
22	0.986	2.19729	31.96998	31.03902	0.911	1.34694	37.07823	36.69057		0.836	0.97815	42.63337	36.37974
23	0.985	2.17009	32.17594	31.20819	0.910	1.34076	37.13529	36.73443		0.835	0.97411	42.67405	36.41001
24	0.984	2.14441	32.37161	31.36860	0.909	1.33462	37.19206	36.77805		0.834	0.97009	42.71458	36.44015
25	0.983	2.12007	32.55818	31.52126	0.908	1.32854	37.24836	36.82128		0.833	0.96609	42.75494	36.47015
26	0.982	2.09693	32.73584	31.66665	0.907	1.32251	37.30428	36.86419		0.832	0.96210	42.79523	36.50010
27	0.981	2.07485	32.90765	31.80648	0.906	1.31652	37.35991	36.90686		0.831	0.95812	42.83546	36.52999
28	0.980	2.05375	33.07199	31.94029	0.905	1.31058	37.41515	36.94921		0.830	0.95416	42.87553	36.55975
29	0.979	2.03352	33.23033	32.06901	0.904	1.30469	37.47000	36.99124		0.829	0.95022	42.91544	36.58937
30	0.978	2.01409	33.38313	32.19303	0.903	1.29884	37.52455	37.03303		0.828	0.94629	42.95527	36.61893
31	0.977	1.99539	33.53084	32.31276	0.902	1.29303	37.57880	37.07486		0.827	0.94236	42.99486	36.64837
32	0.976	1.97737	33.67361	32.42848	0.901	1.28727	37.63267	37.11577		0.826	0.93848	43.03456	36.67774
33	0.975	1.96096	33.81251	32.54060	0.900	1.28155	37.68623	37.15673		0.825	0.93456	43.07420	36.70713
34	0.974	1.94513	33.94713	32.64929	0.899	1.27587	37.73948	37.19744		0.824	0.93072	43.11347	36.73623
35	0.973	1.92984	34.07795	32.75476	0.898	1.27024	37.79234	37.23782		0.823	0.92686	43.15278	36.76536
36	0.972	1.91504	34.20531	32.85732	0.897	1.26464	37.84499	37.27803		0.822	0.92301	43.19203	36.79441
37	0.971	1.90070	34.32942	32.95715	0.896	1.25906	37.89733	37.31787		0.821	0.91918	43.23110	36.82333
38	0.970	1.88679	34.45048	33.05441	0.895	1.25357	37.94927	37.35700		0.820	0.91537	43.27001	36.85212
39	0.969	1.88330	34.56854	33.14916	0.894	1.24808	40.00108	37.39711		0.819	0.91156	43.30866	36.88093
40	0.968	1.88018	34.68367	33.24169	0.893	1.24264	40.05249	37.43629		0.818	0.90777	43.34772	36.90960
41	0.967	1.87642	34.79584	33.33207	0.892	1.23723	40.10328	37.47529		0.817	0.90399	43.38642	36.93821
42	0.966	1.87301	34.90718	33.42033	0.891	1.23185	40.15456	37.51403		0.816	0.90023	43.42486	36.96666
43	0.965	1.86911	35.01532	33.50674	0.890	1.22653	40.20512	37.55261		0.815	0.89647	43.46352	36.99517
44	0.964	1.79912	35.12121	33.59127	0.889	1.22123	40.25547	37.59081		0.814	0.89273	43.50182	40.02363
45	0.963	1.79561	35.22510	33.67412	0.888	1.21596	40.30559	37.62892		0.813	0.88901	43.54014	40.05174
46	0.962	1.77438	35.32696	33.75527	0.887	1.21072	40.35548	37.66684		0.812	0.88529	43.57840	40.07967
47	0.961	1.76241	35.42694	33.83486	0.886	1.20553	40.40498	37.70443		0.811	0.88159	43.61649	40.10807
48	0.960	1.75069	35.52511	33.91291	0.885	1.20036	40.45431	37.74190		0.810	0.87790	43.65480	40.13610
49	0.959	1.73920	35.62161	33.98966	0.884	1.19522	40.50344	37.77919		0.809	0.87422	43.69245	40.16407
50	0.958	1.72793	35.71652	34.06492	0.883	1.19012	40.55224	37.81621		0.808	0.87055	43.73032	40.19198
51	0.957	1.71689	35.80974	34.13865	0.882	1.18504	40.60090	37.85312		0.807	0.86689	43.76813	40.21983
52	0.956	1.70604	35.90159	34.21163	0.881	1.18000	40.64924	37.88976		0.806	0.86325	43.80576	40.24764
53	0.955	1.69540	35.99189	34.28312	0.880	1.17499	40.69736	37.92621		0.805	0.85962	43.84332	40.27519
54	0.954	1.68494	36.08089	34.35352	0.879	1.17000	40.74533	37.96264		0.804	0.85600	43.88081	40.30278
55	0.953	1.67466	36.16857	34.42281	0.878	1.16505	40.79298	37.99881		0.803	0.85239	43.91822	40.33030
56	0.952	1.66456	36.25492	34.49101	0.877	1.16012	40.84049	38.03456		0.802	0.84879	43.95567	40.35777
57	0.951	1.65463	36.34002	34.55818	0.876	1.15522	40.88776	38.07031		0.801	0.84520	43.99284	40.38517
58	0.950	1.64485	36.42403	34.62439	0.875	1.15035	40.93480	38.10587		0.800	0.84162	44.03004	40.41251
59	0.949	1.63523	36.50685	34.68965	0.874	1.14551	40.98181	38.14124		0.799	0.83805	44.06717	40.43978
60	0.948	1.62576	36.58857	34.75398	0.873	1.14069	41.02827	38.17649		0.798	0.83450	44.10412	40.46682
61	0.947	1.61644	36.66917	34.81736	0.872	1.13590	41.07470	38.21154		0.797	0.83095	44.14110	40.49407
62	0.946	1.60725	36.74862	34.87999	0.871	1.13113	41.12098	38.24647		0.796	0.82742	44.17791	40.52108
63	0.945	1.59819	36.82751	34.94180	0.870	1.12639	41.16703	38.28120		0.795	0.82390	44.21484	40.54803
64	0.944	1.58927	36.90515	35.00274	0.869	1.12166	41.21283	38.31574		0.794	0.82038	44.25140	40.57499
65	0.943	1.58047	36.98191	35.06294	0.868	1.11699	41.25849	38.35018		0.793	0.81687	44.28806	40.60189
66	0.942	1.57179	37.05777	35.12240	0.867	1.11232	41.30401	38.38445		0.792	0.81336	44.32459	40.62865
67	0.941	1.56322	37.13283	35.18119	0.866	1.10768	41.34928	38.41855		0.791	0.80990	44.36103	40.65534
68	0.940	1.55477	37.20699	35.23923	0.865	1.10306	41.39441	38.45252		0.790	0.80642	44.39749	40.68205
69	0.939	1.54643	37.28032	35.29656	0.864	1.09847	41.43929	38.48629		0.789	0.80296	44.43377	40.70861
70	0.938	1.53820	37.35283	35.35328	0.863	1.09390	41.48403	38.51994		0.788	0.79950	44.47009	40.73519
71	0.937	1.53007	37.42480	35.40931	0.862	1.08935	41.52862	38.55347		0.787	0.79606	44.50622	40.76163
72	0.936	1.52204	37.49562	35.46475	0.861	1.08482	41.57308	38.58687		0.786	0.79262	44.54236	40.78809
73	0.935	1.51410	37.56598	35.51963	0.860	1.08032	41.61725	38.62007		0.785	0.78919	44.57847	40.81447
74	0.934	1.50626	37.63558	35.57388	0.859	1.07584	41.66130	38.65314		0.784	0.78577	44.61448	40.84080
75	0.933	1.49851	37.70451	35.62756	0.858	1.07138	41.70519	38.68609		0.783	0.78237	44.65031	40.86698
76	0.932	1.49085	37.77276	35.68071	0.857	1.06694	41.74893	38.71891		0.782	0.77897	44.68616	40.89318
77	0.931	1.48328	37.84033	35.73328	0.856	1.06252	41.79252	38.75161		0.781	0.77557	44.72205	40.91938
78	0.930	1.47579	37.90731	35.78536	0.855	1.05812	41.83596	38.78417		0.780	0.77219	44.75775	40.94545
79	0.929	1.46836	37.97368	35.83694	0.854	1.05374	41.87925	38.81661		0.779	0.76882	44.79338	40.97145
80	0.928	1.46106	38.03937	35.88795	0.853	1.04939	41.92228	38.84885		0.778	0.76548		

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Cast Type 304 stainless steel				63.187 median UTS					0.195 median failure strain			
2	350F				53.71 median failure stress					64.56 NUREG/CR-5503 failure stress			
3	1.0E-04 failure probability				25.893 median yield stress					25.12 NUREG/CR-5503 yield stress			
4					0.198 beta					0.137 adjusted failure strain			
5													
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902	25.89300	25.89300									
9	0.999	3.09023	29.29248	28.80910	0.924	1.43250	40.55050	37.81489	0.849	1.03215	43.86382	40.29028	
10	0.998	2.67816	30.53687	29.68265	0.923	1.42554	40.60591	37.85591	0.848	1.02769	43.90049	40.31728	
11	0.997	2.74778	31.32802	30.50962	0.922	1.41865	40.66063	37.89654	0.847	1.02365	43.93702	40.34413	
12	0.996	2.65207	31.92182	30.99942	0.921	1.41183	40.71527	37.93678	0.846	1.01943	43.97341	40.37089	
13	0.995	2.57583	32.40286	31.39418	0.920	1.40507	40.76930	37.98069	0.845	1.01522	44.00975	40.39759	
14	0.994	2.51214	32.81027	31.72710	0.919	1.39838	40.82284	38.02121	0.844	1.01103	44.04594	40.42419	
15	0.993	2.45728	33.18543	32.01827	0.918	1.39174	40.87608	38.06148	0.843	1.00686	44.08199	40.45067	
16	0.992	2.40892	33.48145	32.27274	0.917	1.38517	40.92878	38.10132	0.842	1.00271	44.11789	40.47703	
17	0.991	2.36692	33.78707	32.50389	0.916	1.37866	40.98108	38.14084	0.841	0.99858	44.15365	40.50328	
18	0.990	2.32838	34.08822	32.71468	0.915	1.37220	41.03305	38.18010	0.840	0.99446	44.18935	40.52948	
19	0.989	2.29037	34.28927	32.90878	0.914	1.36581	41.08452	38.21896	0.839	0.99038	44.22491	40.55558	
20	0.988	2.25713	34.49347	33.08893	0.913	1.35946	41.13574	38.25760	0.838	0.98627	44.26041	40.58160	
21	0.987	2.22821	34.70334	33.25721	0.912	1.35317	41.18653	38.29591	0.837	0.98220	44.29577	40.60752	
22	0.986	2.19729	34.90079	33.41522	0.911	1.34694	41.23690	38.33388	0.836	0.97815	44.33098	40.63332	
23	0.985	2.17009	35.08783	33.56439	0.910	1.34076	41.28693	38.37158	0.835	0.97411	44.36612	40.65907	
24	0.984	2.14441	35.26474	33.70571	0.909	1.33462	41.33669	38.40906	0.834	0.97009	44.40113	40.68471	
25	0.983	2.12007	35.43354	33.84010	0.908	1.32854	41.38602	38.44621	0.833	0.96609	44.43598	40.71023	
26	0.982	2.09693	35.59476	33.96826	0.907	1.32251	41.43501	38.48307	0.832	0.96210	44.47078	40.73570	
27	0.981	2.07495	35.74928	34.09091	0.906	1.31652	41.48373	38.51972	0.831	0.95812	44.50552	40.76112	
28	0.980	2.05375	35.89757	34.20844	0.905	1.31058	41.53210	38.55609	0.830	0.95416	44.54011	40.78642	
29	0.979	2.03352	36.04032	34.32144	0.904	1.30469	41.58012	38.59217	0.829	0.95022	44.57455	40.81161	
30	0.978	2.01409	36.17797	34.43024	0.903	1.29884	41.62787	38.62804	0.828	0.94629	44.60893	40.83674	
31	0.977	1.99539	36.31093	34.53521	0.902	1.29303	41.67534	38.66369	0.827	0.94238	44.64318	40.86178	
32	0.976	1.97737	36.43963	34.63661	0.901	1.28727	41.72248	38.69905	0.826	0.93848	44.67733	40.88672	
33	0.975	1.95996	36.56420	34.73480	0.900	1.28155	41.76931	38.73420	0.825	0.93458	44.71153	40.91170	
34	0.974	1.94313	36.68513	34.82993	0.899	1.27587	41.81588	38.76912	0.824	0.93072	44.74580	40.93643	
35	0.973	1.92694	36.80255	34.92220	0.898	1.27024	41.86209	38.80376	0.823	0.92686	44.77929	40.96117	
36	0.972	1.91104	36.91681	35.01188	0.897	1.26464	41.90811	38.83824	0.822	0.92301	44.81313	40.98598	
37	0.971	1.89570	37.02807	35.09913	0.896	1.25908	41.95384	38.87249	0.821	0.91918	44.84681	41.01043	
38	0.970	1.88079	37.13684	35.18409	0.895	1.25357	41.99922	38.90646	0.820	0.91537	44.88035	41.03489	
39	0.969	1.86630	37.24226	35.26682	0.894	1.24808	42.04448	38.94033	0.819	0.91159	44.91391	41.05935	
40	0.968	1.85218	37.34557	35.34768	0.893	1.24264	42.08937	38.97391	0.818	0.90777	44.94731	41.08370	
41	0.967	1.83842	37.44682	35.42642	0.892	1.23723	42.13407	39.00733	0.817	0.90399	44.98068	41.10800	
42	0.966	1.82501	37.54518	35.50339	0.891	1.23186	42.17848	39.04053	0.816	0.90023	45.01385	41.13217	
43	0.965	1.81191	37.64177	35.57871	0.890	1.22653	42.22261	39.07349	0.815	0.89647	45.04707	41.15636	
44	0.964	1.79912	37.73634	35.65238	0.889	1.22123	42.26653	39.10630	0.814	0.89273	45.08013	41.18043	
45	0.963	1.78661	37.82907	35.72452	0.888	1.21596	42.31025	39.13893	0.813	0.88901	45.11304	41.20438	
46	0.962	1.77436	37.91994	35.79618	0.887	1.21072	42.35377	39.17141	0.812	0.88529	45.14598	41.22834	
47	0.961	1.76241	38.00910	35.86444	0.886	1.20553	42.39692	39.20359	0.811	0.88159	45.17878	41.25218	
48	0.960	1.75069	38.09659	35.93236	0.885	1.20038	42.43994	39.23567	0.810	0.87790	45.21148	41.27597	
49	0.959	1.73920	38.18298	36.00004	0.884	1.19522	42.48276	39.26758	0.809	0.87422	45.24413	41.29970	
50	0.958	1.72793	38.26707	36.06484	0.883	1.19012	42.52528	39.29927	0.808	0.87056	45.27672	41.32338	
51	0.957	1.71689	38.35005	36.12879	0.882	1.18504	42.56769	39.33084	0.807	0.86699	45.30924	41.34701	
52	0.956	1.70604	38.43178	36.19202	0.881	1.18000	42.60980	39.36219	0.806	0.86325	45.34160	41.37051	
53	0.955	1.69540	38.51207	36.25411	0.880	1.17499	42.65170	39.39337	0.805	0.85952	45.37391	41.39396	
54	0.954	1.68494	38.59118	36.31524	0.879	1.17000	42.69347	39.42445	0.804	0.85580	45.40614	41.41738	
55	0.953	1.67466	38.66909	36.37539	0.878	1.16505	42.73495	39.45530	0.803	0.85209	45.43831	41.44070	
56	0.952	1.66456	38.74578	36.43456	0.877	1.16012	42.77630	39.48603	0.802	0.84879	45.47041	41.46399	
57	0.951	1.65463	38.82134	36.49261	0.876	1.15522	42.81744	39.51660	0.801	0.84520	45.50245	41.48722	
58	0.950	1.64486	38.89599	36.55028	0.875	1.15035	42.85837	39.54700	0.800	0.84162	45.53442	41.51040	
59	0.949	1.63523	38.96937	36.60683	0.874	1.14551	42.89909	39.57723	0.799	0.83805	45.56632	41.53352	
60	0.948	1.62576	39.04184	36.66258	0.873	1.14069	42.93967	39.60736	0.798	0.83450	45.59806	41.55662	
61	0.947	1.61644	39.11329	36.71752	0.872	1.13590	42.98004	39.63731	0.797	0.83095	45.62983	41.57953	
62	0.946	1.60725	39.18387	36.77175	0.871	1.13113	43.02028	39.66715	0.796	0.82742	45.66144	41.60242	
63	0.945	1.59819	39.25358	36.82528	0.870	1.12639	43.06030	39.69683	0.795	0.82390	45.69299	41.62525	
64	0.944	1.58927	39.32233	36.87804	0.869	1.12168	43.10011	39.72633	0.794	0.82038	45.72455	41.64810	
65	0.943	1.58047	39.39027	36.93015	0.868	1.11699	43.13979	39.75572	0.793	0.81687	45.75605	41.67089	
66	0.942	1.57179	39.45741	36.98180	0.867	1.11232	43.17933	39.78501	0.792	0.81338	45.78739	41.69355	
67	0.941	1.56322	39.52380	37.03245	0.866	1.10768	43.21865	39.81412	0.791	0.80990	45.81886	41.71617	
68	0.940	1.55477	39.58938	37.08265	0.865	1.10306	43.25784	39.84312	0.790	0.80642	45.84995	41.73879	
69	0.939	1.54643	39.65421	37.13224	0.864	1.09847	43.29681	39.87195	0.789	0.80296	45.88108	41.76129	
70	0.938	1.53820	39.71826	37.18124	0.863	1.09390	43.33565	39.90067	0.788	0.79950	45.91224	41.78380	
71	0.937	1.53007	39.78168	37.22968	0.862	1.08935	43.37435	39.92928	0.787	0.79605	45.94323	41.80618	
72	0.936	1.52204	39.84440	37.27758	0.861	1.08482	43.41291	39.95778	0.786	0.79262	45.97425	41.82858	
73	0.935	1.51410	39.90651	37.32498	0.860	1.08032	43.45125	39.98611	0.785	0.78919	46.00519	41.85092	
74	0.934	1.50628	39.96794	37.37184	0.859	1.07584	43.48948	40.01433	0.784	0.78577	46.03607	41.87320	
75	0.933	1.49851	40.02876	37.41820	0.858	1.07138	43.52753	40.04243	0.783	0.78237	46.06679	41.89541	
76	0.932	1.49085	40.08895	37.46407	0.857	1.06694	43.56548	40.07042	0.782	0.77897	46.09753	41.91754	
77	0.931	1.48328	40.14853	37.50944	0.856	1.06252	43.60325	40.09831	0.781	0.77557	46.12829	41.93972	
78	0.930	1.47579	40.20757	37.55438	0.855	1.05812	43.64091	40.12606	0.780	0.77219	46.15888	41.96178	
79	0.929	1.46836	40.26607	37.59887	0.854	1.05374	43.67842	40.15373	0.779	0.76882	46.18941	41.98378	
80	0.928	1.46108	40.32393	37.64298	0.853	1.04939	43.71571	40.18122	0.778				

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Type 316 stainless steel				66.72	median UTS				0.154	median failure strain		
2	350F				55.86	median failure stress				64.25	NUREG/CR-5803 failure stress		
3	1.0E-03 failure probability				26.85	median yield stress				36.06	NUREG/CR-5803 yield stress		
4					0.241	beta				0.160	adjusted failure strain		
5													
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902											
9	0.999	3.09023	26.55000	26.55000	0.924	1.43260	39.56974	39.95026	0.849	1.03215	43.57283	39.87670	
10	0.998	2.87818	27.94051	27.73055	0.923	1.42554	39.63609	39.96974	0.848	1.02789	43.61783	39.90873	
11	0.997	2.74778	28.83130	28.47756	0.922	1.41865	39.70188	37.04876	0.847	1.02365	43.66207	39.94062	
12	0.996	2.65207	29.50324	29.03832	0.921	1.41183	39.76712	37.06734	0.846	1.01943	43.70645	39.97237	
13	0.995	2.57583	30.04968	29.48777	0.920	1.40507	39.83188	37.14553	0.845	1.01522	43.75076	40.00407	
14	0.994	2.51214	30.51391	29.88924	0.919	1.39838	39.89607	37.19328	0.844	1.01103	43.79491	40.03564	
15	0.993	2.45726	30.91989	30.20112	0.918	1.39174	39.95989	37.24071	0.843	1.00688	43.83889	40.06708	
16	0.992	2.40892	31.28157	30.49590	0.917	1.38517	40.02314	37.28788	0.842	1.00271	43.88271	40.09838	
17	0.991	2.36562	31.60932	30.78189	0.916	1.37866	40.08590	37.33427	0.841	0.99856	43.92635	40.12955	
18	0.990	2.32635	31.90953	31.00473	0.915	1.37220	40.14829	37.38055	0.840	0.99446	43.96994	40.16068	
19	0.989	2.29037	32.18708	31.22857	0.914	1.36581	40.21009	37.42636	0.839	0.99036	44.01335	40.19163	
20	0.988	2.25713	32.44586	31.43850	0.913	1.35948	40.27180	37.47193	0.838	0.98627	44.05671	40.22255	
21	0.987	2.22621	32.68805	31.63090	0.912	1.35317	40.32622	37.51711	0.837	0.98220	44.09989	40.25334	
22	0.986	2.19729	32.91640	31.81358	0.911	1.34694	40.38315	37.56190	0.836	0.97815	44.14290	40.28399	
23	0.985	2.17009	33.13262	31.98617	0.910	1.34078	40.43328	37.60637	0.835	0.97411	44.18585	40.31458	
24	0.984	2.14441	33.33806	32.14978	0.909	1.33462	40.51311	37.65059	0.834	0.97009	44.22863	40.34503	
25	0.983	2.12007	33.53398	32.30547	0.908	1.32854	40.57245	37.69441	0.833	0.96609	44.27124	40.37535	
26	0.982	2.09693	33.72127	32.45402	0.907	1.32251	40.63138	37.73791	0.832	0.96210	44.31378	40.40561	
27	0.981	2.07485	33.90097	32.59628	0.906	1.31652	40.69001	37.78118	0.831	0.95812	44.35625	40.43582	
28	0.980	2.05375	34.07359	32.73267	0.905	1.31058	40.74823	37.82409	0.830	0.95416	44.39855	40.46588	
29	0.979	2.03352	34.23992	32.86387	0.904	1.30469	40.80604	37.86689	0.829	0.95022	44.44068	40.49581	
30	0.978	2.01409	34.40044	32.99026	0.903	1.29884	40.86354	37.90904	0.828	0.94629	44.48274	40.52568	
31	0.977	1.99539	34.55583	33.11226	0.902	1.29303	40.92073	37.95113	0.827	0.94236	44.52463	40.55542	
32	0.976	1.97737	34.70585	33.23015	0.901	1.28727	40.97751	37.99289	0.826	0.93848	44.56644	40.58509	
33	0.975	1.95998	34.85180	33.34437	0.900	1.28155	41.03397	38.03440	0.825	0.93458	44.60830	40.61478	
34	0.974	1.94313	34.99307	33.45507	0.899	1.27587	41.09011	38.07584	0.824	0.93072	44.64977	40.64418	
35	0.973	1.92684	35.13056	33.56249	0.898	1.27024	41.14583	38.11658	0.823	0.92688	44.69127	40.67359	
36	0.972	1.91104	35.26442	33.66693	0.897	1.26484	41.20134	38.15730	0.822	0.92301	44.73271	40.70284	
37	0.971	1.89570	35.39488	33.76858	0.896	1.25908	41.25651	38.19777	0.821	0.91918	44.77397	40.73216	
38	0.970	1.88079	35.52214	33.86780	0.895	1.25357	41.31127	38.23791	0.820	0.91537	44.81505	40.76124	
39	0.969	1.86630	35.64825	33.96405	0.894	1.24808	41.36590	38.27794	0.819	0.91156	44.85617	40.79033	
40	0.968	1.85218	35.77282	34.05825	0.893	1.24264	41.42010	38.31763	0.818	0.90777	44.89711	40.81929	
41	0.967	1.83842	35.89628	34.15023	0.892	1.23723	41.47408	38.35713	0.817	0.90399	44.93798	40.84818	
42	0.966	1.82501	36.00231	34.24008	0.891	1.23186	41.52772	38.39637	0.816	0.90023	44.97867	40.87694	
43	0.965	1.81191	36.11801	34.32798	0.890	1.22653	41.58104	38.43535	0.815	0.89647	45.01940	40.90570	
44	0.964	1.79912	36.22738	34.41400	0.889	1.22123	41.63412	38.47414	0.814	0.89273	45.05995	40.93434	
45	0.963	1.78661	36.33963	34.49829	0.888	1.21596	41.68697	38.51273	0.813	0.88901	45.10031	40.96283	
46	0.962	1.77438	36.44376	34.58085	0.887	1.21072	41.73958	38.55114	0.812	0.88529	45.14072	40.99133	
47	0.961	1.76241	36.54892	34.66180	0.886	1.20553	41.79178	38.58920	0.811	0.88159	45.18094	41.01970	
48	0.960	1.75069	36.65517	34.74120	0.885	1.20036	41.84380	38.62718	0.810	0.87790	45.22109	41.04800	
49	0.959	1.73920	36.76399	34.81918	0.884	1.19522	41.89590	38.66491	0.809	0.87422	45.26116	41.07625	
50	0.958	1.72793	36.87533	34.89579	0.883	1.19012	41.94707	38.70239	0.808	0.87055	45.30117	41.10442	
51	0.957	1.71689	36.98159	34.97097	0.882	1.18504	41.99839	38.73978	0.807	0.86689	45.34109	41.13254	
52	0.956	1.70604	37.08423	35.04497	0.881	1.18000	42.04937	38.77686	0.806	0.86325	45.38084	41.16051	
53	0.955	1.69540	37.18324	35.11786	0.880	1.17499	42.10012	38.81376	0.805	0.85962	45.42051	41.18843	
54	0.954	1.68494	37.27868	35.18922	0.879	1.17000	42.15071	38.85054	0.804	0.85600	45.46010	41.21627	
55	0.953	1.67468	37.32913	35.25967	0.878	1.16506	42.20097	38.88705	0.803	0.85239	45.49963	41.24408	
56	0.952	1.66456	37.42000	35.32899	0.877	1.16012	42.25108	38.92344	0.802	0.84879	45.53907	41.27178	
57	0.951	1.65463	37.50955	35.39724	0.876	1.15522	42.30094	38.95963	0.801	0.84520	45.57844	41.29944	
58	0.950	1.64485	37.59798	35.46456	0.875	1.15035	42.35058	38.99563	0.800	0.84162	45.61773	41.32703	
59	0.949	1.63523	37.68512	35.53087	0.874	1.14551	42.39993	39.03142	0.799	0.83805	45.65695	41.35458	
60	0.948	1.62576	37.77112	35.59624	0.873	1.14069	42.44915	39.06710	0.798	0.83450	45.69598	41.38165	
61	0.947	1.61644	37.85595	35.66086	0.872	1.13590	42.49812	39.10257	0.797	0.83095	45.73505	41.40935	
62	0.946	1.60725	37.93979	35.72428	0.871	1.13113	42.54695	39.13792	0.796	0.82742	45.77393	41.43680	
63	0.945	1.59819	38.02262	35.78707	0.870	1.12639	42.59552	39.17307	0.795	0.82390	45.81273	41.46380	
64	0.944	1.58927	38.10435	35.84898	0.869	1.12168	42.64384	39.20802	0.794	0.82037	45.85156	41.49101	
65	0.943	1.58047	38.18515	35.91013	0.868	1.11699	42.69201	39.24285	0.793	0.81684	45.89032	41.51815	
66	0.942	1.57179	38.26502	35.97053	0.867	1.11232	42.74003	39.27755	0.792	0.81338	45.92899	41.54515	
67	0.941	1.56322	38.34403	36.03024	0.866	1.10768	42.78779	39.31204	0.791	0.80990	45.96738	41.57208	
68	0.940	1.55477	38.42211	36.08918	0.865	1.10306	42.83540	39.34642	0.790	0.80642	46.00560	41.59903	
69	0.939	1.54643	38.49932	36.14743	0.864	1.09847	42.88275	39.38059	0.789	0.80296	46.04423	41.62584	
70	0.938	1.53820	38.57586	36.20498	0.863	1.09390	42.92995	39.41483	0.788	0.79950	46.08280	41.65265	
71	0.937	1.53007	38.65123	36.26190	0.862	1.08935	42.97700	39.44854	0.787	0.79606	46.12077	41.67931	
72	0.936	1.52204	38.72601	36.31819	0.861	1.08482	43.02399	39.48233	0.786	0.79262	46.15898	41.70601	
73	0.935	1.51410	38.80010	36.37391	0.860	1.08032	43.07052	39.51591	0.785	0.78919	46.19710	41.73263	
74	0.934	1.50626	38.87339	36.42899	0.859	1.07584	43.11699	39.54937	0.784	0.78577	46.23515	41.75919	
75	0.933	1.49851	38.94597	36.48350	0.858	1.07138	43.16330	39.58299	0.783	0.78237	46.27300	41.78560	
76	0.932	1.49085	39.01785	36.53743	0.857	1.06694	43.20948	39.61589	0.782	0.77897	46.31089	41.81202	
77	0.931	1.48328	39.08901	36.59079	0.856	1.06252	43.25545	39.64898	0.781	0.77557	46.34881	41.83846	
78	0.930	1.47579	39.15955	36.64385	0.855	1.05812	43.30129	39.68189	0.780	0.77219	46.38653	41.86475	
79	0.929	1.46838	39.22946	36.69680	0.854	1.05374	43.34697	39.71470	0.779	0.76882	46.42418	41.89097	
80	0.928	1.46108	39.29885	36.74776	0.853	1.04939	43.39238	39.74730	0.778	0.76548	46.46		

type 316 stainless steel	69.72 median UTS	65.60 median failure stress	25.66 median yield stress	36.09 NUREG/CR-6503 yield stress	0.160 adjusted failure strain
adjusted	survival	adjusted	survival	adjusted	survival
confidence	x	confidence	x	confidence	x
0.999	3.71802	26.55000	26.55000	0.999	4.42218
0.998	3.08023	30.10816	29.53583	0.998	4.42218
0.997	2.87818	31.47424	30.80248	0.997	4.42218
0.996	2.47878	31.27332	32.42868	0.996	4.42218
0.995	2.56507	32.88558	31.77318	0.995	4.42218
0.994	2.57587	32.17587	32.17587	0.994	4.42218
0.993	2.61214	33.78988	32.51535	0.993	4.42218
0.992	2.45882	34.50373	33.07149	0.992	4.42218
0.991	2.39582	34.80386	33.30887	0.991	4.42218
0.990	2.32938	35.07165	33.52168	0.990	4.42218
0.989	2.29037	35.33133	33.71833	0.989	4.42218
0.988	2.26821	35.78788	34.07404	0.988	4.42218
0.987	2.18728	35.99558	34.23486	0.987	4.42218
0.986	2.17828	36.19855	34.38655	0.986	4.42218
0.985	2.17008	36.39855	34.53043	0.985	4.42218
0.984	2.14441	36.57833	34.65404	0.984	4.42218
0.983	2.12007	36.75588	34.66714	0.983	4.42218
0.982	2.09888	36.72544	34.78749	0.982	4.42218
0.981	2.07485	36.68788	34.82222	0.981	4.42218
0.980	2.05375	36.64173	34.84400	0.980	4.42218
0.979	2.03352	36.59418	34.81981	0.979	4.42218
0.978	2.01408	36.54722	34.79392	0.978	4.42218
0.977	1.99839	36.47784	34.77382	0.977	4.42218
0.976	1.97737	36.41427	34.74987	0.976	4.42218
0.975	1.95988	36.34587	34.72458	0.975	4.42218
0.974	1.94313	36.27275	34.69741	0.974	4.42218
0.973	1.92848	36.19852	34.66827	0.973	4.42218
0.972	1.91504	36.11862	34.63855	0.972	4.42218
0.971	1.90279	36.03818	34.60888	0.971	4.42218
0.970	1.89168	35.95745	34.57945	0.970	4.42218
0.969	1.88168	35.87681	34.54984	0.969	4.42218
0.968	1.87275	35.79638	34.52022	0.968	4.42218
0.967	1.86488	35.71695	34.49059	0.967	4.42218
0.966	1.85798	35.63818	34.46098	0.966	4.42218
0.965	1.85198	35.55941	34.43137	0.965	4.42218
0.964	1.84688	35.48064	34.40176	0.964	4.42218
0.963	1.84168	35.40187	34.37215	0.963	4.42218
0.962	1.83648	35.32308	34.34254	0.962	4.42218
0.961	1.83128	35.24429	34.31293	0.961	4.42218
0.960	1.82608	35.16550	34.28332	0.960	4.42218
0.959	1.82088	35.08671	34.25371	0.959	4.42218
0.958	1.81568	35.00792	34.22410	0.958	4.42218
0.957	1.81048	34.92913	34.19449	0.957	4.42218
0.956	1.80528	34.85034	34.16488	0.956	4.42218
0.955	1.80008	34.77155	34.13527	0.955	4.42218
0.954	1.79488	34.69276	34.10566	0.954	4.42218
0.953	1.78968	34.61397	34.07605	0.953	4.42218
0.952	1.78448	34.53518	34.04644	0.952	4.42218
0.951	1.77928	34.45639	34.01683	0.951	4.42218
0.950	1.77408	34.37760	33.98722	0.950	4.42218
0.949	1.76888	34.29881	33.95761	0.949	4.42218
0.948	1.76368	34.21999	33.92799	0.948	4.42218
0.947	1.75848	34.14117	33.89838	0.947	4.42218
0.946	1.75328	34.06235	33.86877	0.946	4.42218
0.945	1.74808	33.98353	33.83916	0.945	4.42218
0.944	1.74288	33.90471	33.80955	0.944	4.42218
0.943	1.73768	33.82589	33.77994	0.943	4.42218
0.942	1.73248	33.74707	33.75033	0.942	4.42218
0.941	1.72728	33.66825	33.72072	0.941	4.42218
0.940	1.72208	33.58943	33.69111	0.940	4.42218
0.939	1.71688	33.51061	33.66150	0.939	4.42218
0.938	1.71168	33.43179	33.63189	0.938	4.42218
0.937	1.70648	33.35297	33.60228	0.937	4.42218
0.936	1.70128	33.27415	33.57267	0.936	4.42218
0.935	1.69608	33.19533	33.54306	0.935	4.42218
0.934	1.69088	33.11651	33.51345	0.934	4.42218
0.933	1.68568	33.03769	33.48384	0.933	4.42218
0.932	1.68048	32.95887	33.45423	0.932	4.42218
0.931	1.67528	32.87999	33.42462	0.931	4.42218
0.930	1.67008	32.80117	33.39501	0.930	4.42218
0.929	1.66488	32.72235	33.36540	0.929	4.42218
0.928	1.65968	32.64353	33.33579	0.928	4.42218
0.927	1.65448	32.56471	33.30618	0.927	4.42218
0.926	1.64928	32.48589	33.27657	0.926	4.42218
0.925	1.64408	32.40707	33.24696	0.925	4.42218
0.924	1.63888	32.32825	33.21735	0.924	4.42218
0.923	1.63368	32.24943	33.18774	0.923	4.42218
0.922	1.62848	32.17061	33.15813	0.922	4.42218
0.921	1.62328	32.09179	33.12852	0.921	4.42218
0.920	1.61808	32.01297	33.09891	0.920	4.42218
0.919	1.61288	31.93415	33.06930	0.919	4.42218
0.918	1.60768	31.85533	33.03969	0.918	4.42218
0.917	1.60248	31.77651	33.01008	0.917	4.42218
0.916	1.59728	31.69769	32.98047	0.916	4.42218
0.915	1.59208	31.61887	32.95086	0.915	4.42218
0.914	1.58688	31.54005	32.92125	0.914	4.42218
0.913	1.58168	31.46123	32.89164	0.913	4.42218
0.912	1.57648	31.38241	32.86203	0.912	4.42218
0.911	1.57128	31.30359	32.83242	0.911	4.42218
0.910	1.56608	31.22477	32.80281	0.910	4.42218
0.909	1.56088	31.14595	32.77320	0.909	4.42218
0.908	1.55568	31.06713	32.74359	0.908	4.42218
0.907	1.55048	30.98831	32.71398	0.907	4.42218
0.906	1.54528	30.90949	32.68437	0.906	4.42218
0.905	1.54008	30.83067	32.65476	0.905	4.42218
0.904	1.53488	30.75185	32.62515	0.904	4.42218
0.903	1.52968	30.67303	32.59554	0.903	4.42218
0.902	1.52448	30.59421	32.56593	0.902	4.42218
0.901	1.51928	30.51539	32.53632	0.901	4.42218
0.900	1.51408	30.43657	32.50671	0.900	4.42218
0.899	1.50888	30.35775	32.47710	0.899	4.42218
0.898	1.50368	30.27893	32.44749	0.898	4.42218
0.897	1.49848	30.19999	32.41788	0.897	4.42218
0.896	1.49328	30.12117	32.38827	0.896	4.42218
0.895	1.48808	30.04235	32.35866	0.895	4.42218
0.894	1.48288	29.96353	32.32905	0.894	4.42218
0.893	1.47768	29.88471	32.29944	0.893	4.42218
0.892	1.47248	29.80589	32.26983	0.892	4.42218
0.891	1.46728	29.72707	32.24022	0.891	4.42218
0.890	1.46208	29.64825	32.21061	0.890	4.42218
0.889	1.45688	29.56943	32.18100	0.889	4.42218
0.888	1.45168	29.49061	32.15139	0.888	4.42218
0.887	1.44648	29.41179	32.12178	0.887	4.42218
0.886	1.44128	29.33297	32.09217	0.886	4.42218
0.885	1.43608	29.25415	32.06256	0.885	4.42218
0.884	1.43088	29.17533	32.03295	0.884	4.42218
0.883	1.42568	29.09651	32.00334	0.883	4.42218
0.882	1.42048	29.01769	31.97373	0.882	4.42218
0.881	1.41528	28.93887	31.94412	0.881	4.42218
0.880	1.41008	28.85999	31.91451	0.880	4.42218
0.879	1.40488	28.78117	31.88490	0.879	4.42218
0.878	1.39968	28.70235	31.85529	0.878	4.42218
0.877	1.39448	28.62353	31.82568	0.877	4.42218
0.876	1.38928	28.54471	31.79607	0.876	4.42218
0.875	1.38408	28.46589	31.76646	0.875	4.42218
0.874	1.37888	28.38707	31.73685	0.874	4.42218
0.873	1.37368	28.30825	31.70724	0.873	4.42218
0.872	1.36848	28.22943	31.67763	0.872	4.42218
0.871	1.36328	28.15061	31.64802	0.871	4.42218
0.870	1.35808	28.07179	31.61841	0.870	4.42218
0.869	1.35288	27.99297	31.58880	0.869	4.42218
0.868	1.34768	27.91415	31.55919	0.868	4.42218
0.867	1.34248	27.83533	31.52958	0.867	4.42218
0.866	1.33728	27.75651	31.49997	0.866	4.42218
0.865	1.33208	27.67769	31.47036	0.865	4.42218
0.864	1.32688	27.59887	31.44075	0.864	4.42218
0.863	1.32168	27.51999	31.41114	0.863	4.42218
0.862	1.31648	27.44117	31.38153	0.862	4.42218
0.861	1.31128	27.36235	31.35192	0.861	4.42218
0.860	1.30608	27.28353	31.32231	0.860	4.42218
0.859	1.30088	27.20471	31.29270	0.859	4.42218
0.858	1.29568	27.12589	31.26309	0.858	4.42218
0.857	1.29048	27.04707	31.23348	0.857	4.42218
0.856	1.28528	26.96825	31.20387	0.856	4.42218
0.855	1.28008	26.88943	31.17426	0.855	4.42218
0.854	1.27488	26.81061	31.14465	0.854	4.42218
0.853	1.26968	26.73179	31.11504	0.853	4.42218
0.852	1.26448	26.65297	31.08543	0.852	4.42218
0.851	1.25928	26.57415	31.05582	0.851	4.42218
0.850	1.25408	26.49533	31.02621	0.850	4.42218
0.849	1.24888	26.41651	30.99660	0.849	4.42218
0.848	1.24368	26.33769	30.96699	0.848	4.42218
0.847	1.23848	26.25887	30.93738	0.847	4.42218
0.846	1.23328	26.17999	30.90777	0.846	4.42218
0.845	1.22808	26.10117	30.87816	0.845	4.42218
0.844	1.22288	26.02235	30.84855	0.844	4.42218
0.843	1.21768	25.94353	30.81894	0.843	4.42218
0.842	1.21248	25.86471	30.78933	0.842	4.42218
0.841	1.20728	25.78589	30.75972	0.841	4.42218
0.840	1.20208	25.70707	30.73011	0.840	4.42218
0.839	1.19688	25.62825	30.70050	0.839	4.42218
0.838	1.19168	25.54943	30.67089	0.838	4.42218
0.837	1.18648	25.47061	30.64128	0.837	4.42218
0.836	1.18128	25.39179	30.61167	0.836	4.42218
0.835	1.17608	25.31297	30.58206	0.835	4.42218

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	SA-108 Gr. B carbon steel				64.25	median failure stress				0.088	median failure strain		
2	350F				37.69	median yield stress				67.59	NUREG/CR-5803 failure stress		
3	1.0E-03 failure probability				0.171	beta				37.99	NUREG/CR-5803 yield stress		
4										0.088	adjusted failure strain		
5													
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902											
9	0.999	3.09023	37.88788	37.88788	0.924	1.43250	50.29931	48.28868	0.849	1.03215	53.85195	51.12233	
10	0.998	2.87816	39.28650	39.10302	0.923	1.42554	50.35919	48.33684	0.848	1.02789	53.90119	51.15318	
11	0.997	2.74778	40.17188	39.88641	0.922	1.41865	50.41853	48.38456	0.847	1.02365	53.94027	51.18389	
12	0.996	2.65207	40.83449	40.43478	0.921	1.41183	50.47734	48.43183	0.846	1.01943	53.97919	51.21448	
13	0.995	2.57583	41.37012	40.89241	0.920	1.40507	50.53571	48.47872	0.845	1.01522	54.01805	51.24501	
14	0.994	2.51214	41.82297	41.27734	0.919	1.39838	50.59353	48.52518	0.844	1.01103	54.05675	51.27541	
15	0.993	2.45726	42.21715	41.81277	0.918	1.39174	50.65098	48.57128	0.843	1.00686	54.09529	51.30588	
16	0.992	2.40892	42.59743	41.90950	0.917	1.38517	50.70790	48.61896	0.842	1.00271	54.13368	51.33582	
17	0.991	2.36562	42.88386	42.17878	0.916	1.37868	50.76436	48.66225	0.841	0.99858	54.17191	51.36582	
18	0.990	2.32635	43.17248	42.42042	0.915	1.37220	50.82044	48.70723	0.840	0.99448	54.21007	51.39577	
19	0.989	2.29037	43.43882	42.64468	0.914	1.36581	50.87598	48.75175	0.839	0.99036	54.24808	51.42559	
20	0.988	2.25713	43.68633	42.85273	0.913	1.35946	50.93123	48.79603	0.838	0.98627	54.28602	51.45534	
21	0.987	2.22621	43.91783	43.04703	0.912	1.35317	50.98602	48.83992	0.837	0.98220	54.32380	51.48497	
22	0.986	2.19729	44.13547	43.22941	0.911	1.34694	51.04035	48.88343	0.836	0.97815	54.36142	51.51446	
23	0.985	2.17009	44.34115	43.40154	0.910	1.34076	51.09429	48.92661	0.835	0.97411	54.39897	51.54389	
24	0.984	2.14441	44.53622	43.56457	0.909	1.33462	51.14795	48.96955	0.834	0.97009	54.43637	51.57319	
25	0.983	2.12007	44.72190	43.71955	0.908	1.32854	51.20113	49.01210	0.833	0.96609	54.47360	51.60238	
26	0.982	2.09693	44.89914	43.86732	0.907	1.32251	51.25393	49.05432	0.832	0.96210	54.51078	51.63147	
27	0.981	2.07485	45.06892	44.00871	0.906	1.31652	51.30644	49.09630	0.831	0.95812	54.54786	51.66052	
28	0.980	2.05375	45.23176	44.14417	0.905	1.31058	51.35856	49.13795	0.830	0.95418	54.58479	51.68943	
29	0.979	2.03352	45.38844	44.27438	0.904	1.30469	51.41029	49.17828	0.829	0.95022	54.62157	51.71821	
30	0.978	2.01409	45.53944	44.39973	0.903	1.29884	51.48172	49.22036	0.828	0.94629	54.65827	51.74693	
31	0.977	1.99539	45.68523	44.52034	0.902	1.29303	51.51286	49.26118	0.827	0.94238	54.69482	51.77552	
32	0.976	1.97737	45.82617	44.63742	0.901	1.28727	51.56360	49.30188	0.826	0.93848	54.73129	51.80405	
33	0.975	1.95998	45.96275	44.75048	0.900	1.28155	51.61404	49.34193	0.825	0.93458	54.76779	51.83259	
34	0.974	1.94313	46.09517	44.86000	0.899	1.27587	51.66418	49.38191	0.824	0.93072	54.80394	51.86085	
35	0.973	1.92684	46.22370	44.96622	0.898	1.27024	51.71392	49.42158	0.823	0.92686	54.84011	51.88912	
36	0.972	1.91104	46.34870	45.06944	0.897	1.26464	51.76344	49.46105	0.822	0.92301	54.87621	51.91733	
37	0.971	1.89570	46.47039	45.16984	0.896	1.25908	51.81266	49.50027	0.821	0.91918	54.91215	51.94540	
38	0.970	1.88079	46.58898	45.26760	0.895	1.25357	51.86149	49.53916	0.820	0.91537	54.94792	51.97334	
39	0.969	1.86630	46.70452	45.36278	0.894	1.24808	51.91018	49.57794	0.819	0.91158	54.98372	52.00129	
40	0.968	1.85218	46.81738	45.45568	0.893	1.24264	51.95847	49.61638	0.818	0.90777	55.01935	52.02911	
41	0.967	1.83842	46.92762	45.54636	0.892	1.23723	52.00654	49.65464	0.817	0.90399	55.05491	52.05687	
42	0.966	1.82501	47.03531	45.63488	0.891	1.23186	52.05430	49.69264	0.816	0.90023	55.09031	52.08449	
43	0.965	1.81191	47.14075	45.72149	0.890	1.22653	52.10174	49.73038	0.815	0.89647	55.12572	52.11212	
44	0.964	1.79912	47.24393	45.80618	0.889	1.22123	52.14897	49.76792	0.814	0.89273	55.16098	52.13961	
45	0.963	1.78661	47.34506	45.88914	0.888	1.21598	52.19586	49.80528	0.813	0.88901	55.19606	52.16697	
46	0.962	1.77438	47.44414	45.97036	0.887	1.21072	52.24274	49.84245	0.812	0.88529	55.23117	52.19435	
47	0.961	1.76241	47.54131	46.04997	0.886	1.20553	52.28910	49.87928	0.811	0.88159	55.26611	52.22158	
48	0.960	1.75069	47.63665	46.12803	0.885	1.20036	52.33533	49.91600	0.810	0.87790	55.30098	52.24875	
49	0.959	1.73920	47.73030	46.20486	0.884	1.19522	52.38134	49.95262	0.809	0.87422	55.33578	52.27587	
50	0.958	1.72793	47.82234	46.27992	0.883	1.19012	52.42702	49.98878	0.808	0.87055	55.37050	52.30291	
51	0.957	1.71689	47.91267	46.35374	0.882	1.18504	52.47256	50.02492	0.807	0.86689	55.40518	52.32990	
52	0.956	1.70604	48.00161	46.42639	0.881	1.18000	52.51779	50.06079	0.806	0.86325	55.43984	52.35675	
53	0.955	1.69540	48.08899	46.49772	0.880	1.17499	52.56278	50.09647	0.805	0.85962	55.47405	52.38353	
54	0.954	1.68494	48.17505	46.56793	0.879	1.17000	52.60763	50.13203	0.804	0.85600	55.50839	52.41026	
55	0.953	1.67466	48.25977	46.63702	0.878	1.16505	52.65217	50.16733	0.803	0.85239	55.54265	52.43692	
56	0.952	1.66456	48.34316	46.70497	0.877	1.16012	52.69655	50.20260	0.802	0.84879	55.57684	52.46351	
57	0.951	1.65463	48.42529	46.77187	0.876	1.15522	52.74071	50.23747	0.801	0.84520	55.61095	52.49005	
58	0.950	1.64485	48.50631	46.83783	0.875	1.15035	52.78483	50.27225	0.800	0.84162	55.64499	52.51652	
59	0.949	1.63523	48.58614	46.90278	0.874	1.14551	52.82832	50.30684	0.799	0.83805	55.67898	52.54292	
60	0.948	1.62576	48.66485	46.96679	0.873	1.14068	52.87186	50.34130	0.798	0.83450	55.71278	52.56919	
61	0.947	1.61644	48.74244	47.02986	0.872	1.13590	52.91517	50.37557	0.797	0.83095	55.74658	52.59547	
62	0.946	1.60725	48.81907	47.09211	0.871	1.13113	52.95833	50.40971	0.796	0.82742	55.78022	52.62161	
63	0.945	1.59819	48.89473	47.15355	0.870	1.12639	53.00126	50.44365	0.795	0.82390	55.81379	52.64789	
64	0.944	1.58927	48.96934	47.21411	0.869	1.12168	53.04395	50.47740	0.794	0.82038	55.84739	52.67377	
65	0.943	1.58047	49.04305	47.27391	0.868	1.11699	53.08649	50.51103	0.793	0.81687	55.88090	52.69980	
66	0.942	1.57179	49.11587	47.33296	0.867	1.11232	53.12888	50.54452	0.792	0.81338	55.91425	52.72568	
67	0.941	1.56322	49.18787	47.39131	0.866	1.10768	53.17103	50.57782	0.791	0.80990	55.94752	52.75150	
68	0.940	1.55477	49.25897	47.44891	0.865	1.10306	53.21304	50.61100	0.790	0.80642	55.98081	52.77734	
69	0.939	1.54643	49.32924	47.50581	0.864	1.09847	53.25481	50.64397	0.789	0.80296	56.01393	52.80303	
70	0.938	1.53820	49.39869	47.56202	0.863	1.09390	53.29642	50.67682	0.788	0.79950	56.04707	52.82873	
71	0.937	1.53007	49.46738	47.61759	0.862	1.08935	53.33789	50.70954	0.787	0.79606	56.08003	52.85429	
72	0.936	1.52204	49.53533	47.67254	0.861	1.08482	53.37921	50.74213	0.786	0.79262	56.11302	52.87987	
73	0.935	1.51410	49.60280	47.72692	0.860	1.08032	53.42028	50.77453	0.785	0.78919	56.14593	52.90537	
74	0.934	1.50626	49.66912	47.78066	0.859	1.07584	53.46121	50.80680	0.784	0.78577	56.17878	52.93082	
75	0.933	1.49851	49.73496	47.83383	0.858	1.07138	53.50198	50.83893	0.783	0.78237	56.21142	52.95612	
76	0.932	1.49085	49.80013	47.88644	0.857	1.06694	53.54260	50.87095	0.782	0.77897	56.24409	52.98143	
77	0.931	1.48328	49.86461	47.93847	0.856	1.06252	53.58307	50.90283	0.781	0.77557	56.27679	53.00678	
78	0.930	1.47579	49.92849	47.99000	0.855	1.05812	53.62338	50.93458	0.780	0.77219	56.30932	53.03194	
79	0.929	1.46836	49.99177	48.04102	0.854	1.05374	53.66354	50.96621	0.779	0.76882	56.34178	53.05708	
80	0.928	1.46108	50.05436	48.09146	0.853	1.04939	53.70346	50.99783	0.778	0.76548	56.37413</		

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	SA-106 Gr. B carbon steel												
2	350F				64.25	median failure stress				0.088	median failure strain		
3	1.0E-04 failure probability				37.89	median yield stress				64.25	NUREG/CR-5803 failure stress		
4					0.142	beta				37.89	NUREG/CR-5803 yield stress		
5										0.088	adjusted failure strain		
6	survival		adjusted		survival		adjusted		survival		adjusted		
7	confidence	x	stress	stress	confidence	x	stress	stress	confidence	x	stress	stress	
8	0.9999	3.71902	37.86788	37.86788									
9	0.999	3.09023	41.42729	40.94115	0.924	1.43250	52.42539	49.96749	0.849	1.03215	55.49283	52.39815	
10	0.998	2.87818	42.89409	42.01662	0.923	1.42554	52.47724	50.02863	0.848	1.02789	55.52641	52.42428	
11	0.997	2.74778	43.48208	42.68948	0.922	1.41865	52.52862	50.08939	0.847	1.02365	55.55888	52.45031	
12	0.996	2.65207	44.06734	43.18910	0.921	1.41183	52.57953	50.10975	0.846	1.01943	55.59317	52.47622	
13	0.995	2.57583	44.56734	43.59055	0.920	1.40507	52.63004	50.14979	0.845	1.01522	55.62643	52.50208	
14	0.994	2.51214	44.97232	43.92829	0.919	1.39838	52.68007	50.18944	0.844	1.01103	55.65954	52.52782	
15	0.993	2.45726	45.32424	44.22104	0.918	1.39174	52.72978	50.22881	0.843	1.00686	55.69251	52.55348	
16	0.992	2.40892	45.63650	44.48024	0.917	1.38517	52.77901	50.26780	0.842	1.00271	55.72535	52.57898	
17	0.991	2.36582	45.91803	44.71347	0.916	1.37866	52.82783	50.30645	0.841	0.99858	55.75805	52.60438	
18	0.990	2.32835	46.17486	44.92587	0.915	1.37220	52.87632	50.34483	0.840	0.99446	55.79089	52.62974	
19	0.989	2.29037	46.41143	45.12120	0.914	1.36581	52.92433	50.38282	0.839	0.99038	55.82319	52.65498	
20	0.988	2.25713	46.63106	45.30228	0.913	1.35946	52.97209	50.42059	0.838	0.98627	55.85562	52.68017	
21	0.987	2.22621	46.83630	45.47125	0.912	1.35317	53.01943	50.45803	0.837	0.98220	55.88792	52.70525	
22	0.986	2.19729	47.02908	45.62976	0.911	1.34694	53.06837	50.49513	0.836	0.97815	55.92008	52.73021	
23	0.985	2.17009	47.21112	45.77926	0.910	1.34078	53.11297	50.53195	0.835	0.97411	55.95218	52.75512	
24	0.984	2.14441	47.38363	45.92077	0.909	1.33462	53.15931	50.56856	0.834	0.97009	55.98413	52.77991	
25	0.983	2.12007	47.54772	46.05522	0.908	1.32854	53.20523	50.60483	0.833	0.96609	56.01595	52.80459	
26	0.982	2.09693	47.70425	46.18335	0.907	1.32251	53.25082	50.64082	0.832	0.96210	56.04770	52.82922	
27	0.981	2.07485	47.85409	46.30588	0.906	1.31652	53.29815	50.67680	0.831	0.95812	56.07939	52.85380	
28	0.980	2.05375	47.99772	46.42321	0.905	1.31058	53.34113	50.71209	0.830	0.95416	56.11094	52.87828	
29	0.979	2.03352	48.13583	46.53594	0.904	1.30469	53.38577	50.74731	0.829	0.95022	56.14235	52.90280	
30	0.978	2.01409	48.26885	46.64442	0.903	1.29884	53.43015	50.78231	0.828	0.94629	56.17370	52.92690	
31	0.977	1.99539	48.39723	46.74901	0.902	1.29303	53.47426	50.81708	0.827	0.94238	56.20490	52.95108	
32	0.976	1.97737	48.52125	46.84999	0.901	1.28727	53.51802	50.85158	0.826	0.93848	56.23605	52.97520	
33	0.975	1.95996	48.64138	46.94771	0.900	1.28155	53.56152	50.88505	0.825	0.93458	56.26720	52.99933	
34	0.974	1.94313	48.75780	47.04234	0.899	1.27587	53.60475	50.91991	0.824	0.93072	56.29808	53.02323	
35	0.973	1.92684	48.87074	47.13408	0.898	1.27024	53.64783	50.95368	0.823	0.92686	56.32893	53.04713	
36	0.972	1.91104	48.98053	47.22319	0.897	1.26464	53.69032	50.98729	0.822	0.92301	56.35975	53.07098	
37	0.971	1.89570	49.08737	47.30985	0.896	1.25908	53.73273	51.02067	0.821	0.91918	56.39041	53.09471	
38	0.970	1.88079	49.19143	47.39419	0.895	1.25357	53.77480	51.05377	0.820	0.91537	56.42094	53.11833	
39	0.969	1.86630	49.29277	47.47628	0.894	1.24808	53.81675	51.08677	0.819	0.91156	56.45148	53.14198	
40	0.968	1.85218	49.39173	47.55639	0.893	1.24264	53.85835	51.11949	0.818	0.90777	56.48187	53.16547	
41	0.967	1.83842	49.48835	47.63455	0.892	1.23723	53.89975	51.15204	0.817	0.90399	56.51220	53.18883	
42	0.966	1.82501	49.58270	47.71063	0.891	1.23186	53.94087	51.18437	0.816	0.90023	56.54239	53.21227	
43	0.965	1.81191	49.67504	47.78544	0.890	1.22653	53.98172	51.21647	0.815	0.89647	56.57260	53.23562	
44	0.964	1.79912	49.76536	47.85838	0.889	1.22123	54.02237	51.24841	0.814	0.89273	56.60266	53.25885	
45	0.963	1.78661	49.85386	47.92980	0.888	1.21596	54.06282	51.28018	0.813	0.88901	56.63257	53.28198	
46	0.962	1.77420	49.94054	47.99971	0.887	1.21072	54.10308	51.31179	0.812	0.88526	56.66250	53.30509	
47	0.961	1.76241	50.02552	48.06822	0.886	1.20553	54.14297	51.34311	0.811	0.88159	56.69229	53.32809	
48	0.960	1.75089	50.10886	48.13537	0.885	1.20036	54.18274	51.37433	0.810	0.87790	56.72201	53.35105	
49	0.959	1.73920	50.19070	48.20127	0.884	1.19522	54.22231	51.40537	0.809	0.87422	56.75166	53.37395	
50	0.958	1.72793	50.27111	48.26599	0.883	1.19012	54.26161	51.43620	0.808	0.87055	56.78125	53.39679	
51	0.957	1.71689	50.34999	48.32945	0.882	1.18504	54.30077	51.46691	0.807	0.86689	56.81078	53.41958	
52	0.956	1.70604	50.42765	48.39188	0.881	1.18000	54.33968	51.49740	0.806	0.86325	56.84015	53.44225	
53	0.955	1.69540	50.50391	48.45317	0.880	1.17499	54.37834	51.52772	0.805	0.85962	56.86947	53.46487	
54	0.954	1.68494	50.57900	48.51349	0.879	1.17000	54.41689	51.55794	0.804	0.85600	56.89872	53.48743	
55	0.953	1.67466	50.65290	48.57282	0.878	1.16505	54.45516	51.58792	0.803	0.85239	56.92790	53.50994	
56	0.952	1.66456	50.72562	48.63118	0.877	1.16012	54.49331	51.61780	0.802	0.84879	56.95701	53.53239	
57	0.951	1.65463	50.79721	48.68880	0.876	1.15522	54.53124	51.64751	0.801	0.84520	56.98608	53.55479	
58	0.950	1.64485	50.86782	48.74521	0.875	1.15035	54.56898	51.67705	0.800	0.84162	57.01505	53.57713	
59	0.949	1.63523	50.93737	48.80095	0.874	1.14551	54.60650	51.70642	0.799	0.83805	57.04396	53.59942	
60	0.948	1.62576	51.00593	48.85587	0.873	1.14069	54.64380	51.73569	0.798	0.83450	57.07273	53.62159	
61	0.947	1.61644	51.07349	48.90997	0.872	1.13590	54.68109	51.76478	0.797	0.83095	57.10152	53.64376	
62	0.946	1.60725	51.14020	48.96335	0.871	1.13113	54.71815	51.79377	0.796	0.82742	57.13015	53.66582	
63	0.945	1.59819	51.20605	49.01603	0.870	1.12639	54.75500	51.82259	0.795	0.82390	57.15872	53.68783	
64	0.944	1.58927	51.27097	49.06794	0.869	1.12168	54.79184	51.85123	0.794	0.82038	57.18731	53.70984	
65	0.943	1.58047	51.33509	49.11920	0.868	1.11699	54.82815	51.87977	0.793	0.81687	57.21582	53.73179	
66	0.942	1.57179	51.39842	49.16980	0.867	1.11232	54.86453	51.90820	0.792	0.81338	57.24419	53.75363	
67	0.941	1.56322	51.46102	49.21980	0.866	1.10768	54.90070	51.93648	0.791	0.80990	57.27249	53.77541	
68	0.940	1.55477	51.52282	49.26913	0.865	1.10308	54.93673	51.96480	0.790	0.80642	57.30081	53.79720	
69	0.939	1.54643	51.58389	49.31787	0.864	1.09847	54.97256	51.99258	0.789	0.80298	57.32897	53.81887	
70	0.938	1.53820	51.64422	49.36600	0.863	1.09390	55.00825	52.02045	0.788	0.79950	57.35715	53.84054	
71	0.937	1.53007	51.70389	49.41358	0.862	1.08935	55.04382	52.04821	0.787	0.79606	57.38519	53.86210	
72	0.936	1.52204	51.76289	49.46061	0.861	1.08482	55.07924	52.07585	0.786	0.79262	57.41323	53.88367	
73	0.935	1.51410	51.82130	49.50715	0.860	1.08032	55.11446	52.10333	0.785	0.78919	57.44121	53.90518	
74	0.934	1.50626	51.87904	49.55314	0.859	1.07584	55.14954	52.13069	0.784	0.78577	57.46912	53.92683	
75	0.933	1.49851	51.93617	49.59864	0.858	1.07138	55.18448	52.15794	0.783	0.78237	57.49688	53.94798	
76	0.932	1.49085	51.99271	49.64364	0.857	1.06694	55.21930	52.18509	0.782	0.77897	57.52465	53.96930	
77	0.931	1.48328	52.04894	49.68814	0.856	1.06252	55.25397	52.21212	0.781	0.77557	57.55243	53.99065	
78	0.930	1.47579	52.10404	49.73220	0.855	1.05812	55.28851	52.23904	0.780	0.77219	57.58007	54.01188	
79	0.929	1.46838	52.15891	49.77583	0.854	1.05374	55.32292	52.26585	0.779	0.76882	57.60764	54.03305	
80	0.928	1.46106	52.21318	49.81895	0.853	1.04939	55.35711	52.29248	0.778	0.7			

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	SA-516 Gr. 70 carbon steel				81.05	median UTS				0.041	median failure strain		
2	350F				72.95	median failure stress				77.89	NUREG/CR-5803 failure stress		
3	1.0E-03 failure probability				37.99	median yield stress				40.91	NUREG/CR-5803 yield stress		
4					0.211	beta				0.039	adjusted failure strain		
5													
6	survival		adjusted		survival			adjusted		survival			adjusted
7	confidence	x	stress	stress	confidence	x	stress	stress		confidence	x	stress	stress
8	0.9999	3.71902											
9	0.999	3.09023	37.99000	37.99000	0.924	1.43250	53.90853	52.97839		0.849	1.03215	58.66288	57.35515
10	0.998	2.87818	39.72948	39.65340	0.923	1.42554	53.98779	53.05174		0.848	1.02789	58.71568	57.40349
11	0.997	2.74778	40.83621	40.71032	0.922	1.41865	54.06638	53.12444		0.847	1.02365	58.76824	57.45184
12	0.996	2.65207	41.67175	41.50322	0.921	1.41183	54.14428	53.19849		0.846	1.01943	58.82062	57.49960
13	0.995	2.57583	42.34789	42.14533	0.920	1.40507	54.22160	53.26800		0.845	1.01522	58.87292	57.54748
14	0.994	2.51214	42.92113	42.68897	0.919	1.39838	54.29824	53.33885		0.844	1.01103	58.92502	57.59517
15	0.993	2.45728	43.42130	43.16275	0.918	1.39174	54.37441	53.40927		0.843	1.00686	58.97692	57.64287
16	0.992	2.40892	43.86669	43.58420	0.917	1.38517	54.44988	53.47902		0.842	1.00271	59.02861	57.69068
17	0.991	2.36562	44.26652	43.96503	0.916	1.37866	54.52476	53.54823		0.841	0.99858	59.08010	57.73710
18	0.990	2.32635	44.63805	44.31314	0.915	1.37220	54.59917	53.61699		0.840	0.99448	59.13151	57.78414
19	0.989	2.29037	44.97841	44.63438	0.914	1.36581	54.67287	53.68508		0.839	0.99036	59.18271	57.83098
20	0.988	2.25713	45.29515	44.93312	0.913	1.35946	54.74622	53.75282		0.838	0.98627	59.23383	57.87775
21	0.987	2.22621	45.59178	45.21271	0.912	1.35317	54.81896	53.82001		0.837	0.98220	59.28475	57.92432
22	0.986	2.19729	45.87098	45.47571	0.911	1.34694	54.89111	53.88683		0.836	0.97815	59.33546	57.97070
23	0.985	2.17009	46.13514	45.72438	0.910	1.34076	54.96277	53.95280		0.835	0.97411	59.38608	58.01700
24	0.984	2.14441	46.38594	45.96034	0.909	1.33462	55.03406	54.01881		0.834	0.97009	59.43651	58.06310
25	0.983	2.12007	46.62490	46.18508	0.908	1.32854	55.10474	54.08385		0.833	0.96609	59.48672	58.10901
26	0.982	2.09693	46.85323	46.39985	0.907	1.32251	55.17494	54.14863		0.832	0.96210	59.53685	58.15484
27	0.981	2.07485	47.07214	46.60530	0.906	1.31652	55.24475	54.21305		0.831	0.95812	59.58690	58.20058
28	0.980	2.05375	47.28229	46.80282	0.905	1.31058	55.31407	54.27700		0.830	0.95416	59.63673	58.24613
29	0.979	2.03362	47.48465	46.99255	0.904	1.30469	55.38290	54.34049		0.829	0.95022	59.68638	58.29148
30	0.978	2.01409	47.67983	47.17566	0.903	1.29884	55.45134	54.40361		0.828	0.94629	59.73590	58.33675
31	0.977	1.99539	47.86843	47.35252	0.902	1.29303	55.51939	54.46637		0.827	0.94238	59.78523	58.38182
32	0.976	1.97737	48.05088	47.52354	0.901	1.28727	55.58694	54.52885		0.826	0.93848	59.83447	58.42681
33	0.975	1.95998	48.22781	47.68933	0.900	1.28155	55.65411	54.59057		0.825	0.93458	59.88375	58.47183
34	0.974	1.94313	48.39947	47.85011	0.899	1.27587	55.72069	54.65212		0.824	0.93072	59.93257	58.51643
35	0.973	1.92684	48.56620	48.00622	0.898	1.27024	55.78715	54.71320		0.823	0.92686	59.98143	58.56105
36	0.972	1.91104	48.72847	48.15810	0.897	1.26464	55.85314	54.77401		0.822	0.92301	60.03020	58.60559
37	0.971	1.89570	48.88653	48.30599	0.896	1.25908	55.91874	54.83445		0.821	0.91918	60.07878	58.64993
38	0.970	1.88079	49.04065	48.45014	0.895	1.25357	55.98383	54.89441		0.820	0.91537	60.12710	58.69408
39	0.969	1.86630	49.19089	48.59682	0.894	1.24809	56.04875	54.95421		0.819	0.91156	60.17548	58.73823
40	0.968	1.85218	49.33775	48.72789	0.893	1.24264	56.11315	55.01353		0.818	0.90777	60.22365	58.78220
41	0.967	1.83842	49.48128	48.86200	0.892	1.23723	56.17728	55.07257		0.817	0.90399	60.27173	58.82608
42	0.966	1.82501	49.62156	48.99304	0.891	1.23186	56.24100	55.13125		0.816	0.90023	60.31959	58.86978
43	0.965	1.81191	49.75898	49.12137	0.890	1.22653	56.30432	55.18954		0.815	0.89647	60.36749	58.91347
44	0.964	1.79912	49.89351	49.24897	0.889	1.22123	56.36735	55.24758		0.814	0.89273	60.41517	58.95698
45	0.963	1.78661	50.02546	49.37011	0.888	1.21596	56.43010	55.30531		0.813	0.88901	60.46264	59.00029
46	0.962	1.77438	50.15478	49.49078	0.887	1.21072	56.49256	55.36278		0.812	0.88529	60.51014	59.04362
47	0.961	1.76241	50.28189	49.60915	0.886	1.20553	56.55449	55.41977		0.811	0.88159	60.55742	59.08675
48	0.960	1.75069	50.40625	49.72530	0.885	1.20036	56.61625	55.47658		0.810	0.87790	60.60461	59.12980
49	0.959	1.73920	50.52866	49.83943	0.884	1.19522	56.67772	55.53313		0.809	0.87422	60.65172	59.17275
50	0.958	1.72793	50.64903	49.95181	0.883	1.19012	56.73877	55.58928		0.808	0.87055	60.69873	59.21582
51	0.957	1.71689	50.76721	50.06173	0.882	1.18504	56.79988	55.64527		0.807	0.86689	60.74584	59.25840
52	0.956	1.70604	50.88383	50.17018	0.881	1.18000	56.86012	55.70087		0.806	0.86325	60.79234	59.30098
53	0.955	1.69540	50.99805	50.27674	0.880	1.17499	56.92029	55.75619		0.805	0.85962	60.83895	59.34348
54	0.954	1.68494	51.11079	50.38171	0.879	1.17000	56.98029	55.81134		0.804	0.85600	60.88548	59.38586
55	0.953	1.67468	51.22184	50.48508	0.878	1.16505	57.03966	55.86609		0.803	0.85239	60.93188	59.42817
56	0.952	1.66456	51.33117	50.58682	0.877	1.16012	57.09926	55.92068		0.802	0.84879	60.97820	59.47039
57	0.951	1.65463	51.43889	50.68705	0.876	1.15522	57.15836	55.97498		0.801	0.84520	61.02444	59.51252
58	0.950	1.64485	51.54520	50.78594	0.875	1.15035	57.21715	56.02900		0.800	0.84162	61.07057	59.55456
59	0.949	1.63523	51.64999	50.88339	0.874	1.14551	57.27585	56.08274		0.799	0.83805	61.11662	59.59651
60	0.948	1.62578	51.75336	50.97949	0.873	1.14069	57.33396	56.13630		0.798	0.83450	61.16244	59.63825
61	0.947	1.61644	51.85528	51.07424	0.872	1.13590	57.39196	56.18958		0.797	0.83095	61.20829	59.68002
62	0.946	1.60725	51.95599	51.16783	0.871	1.13113	57.44979	56.24268		0.796	0.82742	61.25393	59.72158
63	0.945	1.59819	52.05548	51.26025	0.870	1.12639	57.50730	56.29549		0.795	0.82390	61.29948	59.76305
64	0.944	1.58927	52.15357	51.35140	0.869	1.12168	57.56451	56.34801		0.794	0.82038	61.34503	59.80455
65	0.943	1.58047	52.25055	51.44147	0.868	1.11699	57.62154	56.40036		0.793	0.81687	61.39050	59.84595
66	0.942	1.57179	52.34639	51.53048	0.867	1.11232	57.67837	56.45253		0.792	0.81338	61.43575	59.88715
67	0.941	1.56322	52.44118	51.61848	0.866	1.10768	57.73490	56.50441		0.791	0.80990	61.48090	59.92825
68	0.940	1.55477	52.53481	51.70537	0.865	1.10306	57.79124	56.55610		0.790	0.80642	61.52609	59.96938
69	0.939	1.54643	52.62739	51.79128	0.864	1.09847	57.84727	56.60751		0.789	0.80296	61.57105	60.01030
70	0.938	1.53820	52.71891	51.87619	0.863	1.09390	57.90310	56.65874		0.788	0.79950	61.61604	60.05125
71	0.937	1.53007	52.80947	51.96020	0.862	1.08935	57.95875	56.70978		0.787	0.79606	61.66080	60.09198
72	0.936	1.52204	52.89907	52.04330	0.861	1.08482	58.01420	56.76084		0.786	0.79262	61.70560	60.13274
73	0.935	1.51410	52.98781	52.12559	0.860	1.08032	58.06934	56.81121		0.785	0.78919	61.75029	60.17341
74	0.934	1.50626	53.07559	52.20696	0.859	1.07584	58.12429	56.86180		0.784	0.78577	61.79489	60.21399
75	0.933	1.49851	53.16250	52.28752	0.858	1.07138	58.17904	56.91180		0.783	0.78237	61.83928	60.25435
76	0.932	1.49085	53.24854	52.36725	0.857	1.06694	58.23360	56.96181		0.782	0.77897	61.88367	60.29474
77	0.931	1.48328	53.33370	52.44618	0.856	1.06252	58.28797	57.01185		0.781	0.77557	61.92810	60.33515
78	0.930	1.47579	53.41810	52.52435	0.855	1.05812	58.34213	57.06130		0.780	0.77219	61.97231	60.37535
79	0.929	1.46838	53.50173	52.60181	0.854	1.05374	58.39611	57.11076		0.779	0.76882	62.01641	60.41545
80	0.928	1.46106	53.58447	52.67843	0.853	1.04939	58.44978	57.15992		0.778	0.7654		

Attachment 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	SA-516 Gr. 70 carbon steel				81.05	median UTS				0.041	median failure strain		
2	350F				72.95	median failure stress				77.89	NUREG/CR-5603 failure stress		
3	1.0E-04 failure probability				37.99	median yield stress				40.91	NUREG/CR-5603 yield stress		
4					0.175	beta				0.039	adjusted failure strain		
5													
6	survival		adjusted		survival			adjusted		survival			adjusted
7	confidence	x	stress	stress	confidence	x	stress	stress		confidence	x	stress	stress
8	0.9999	3.71902	37.99000	37.99000									
9	0.999	3.09023	42.42017	42.21391	0.924	1.43250	56.73660	55.58728		0.849	1.03215	60.86438	59.36665
10	0.998	2.87818	44.02798	43.73670	0.923	1.42554	56.80582	55.65102		0.848	1.02789	60.90986	59.40812
11	0.997	2.74778	45.04853	44.69885	0.922	1.41865	56.87481	55.71419		0.847	1.02365	60.95520	59.44942
12	0.996	2.65207	45.80921	45.41753	0.921	1.41183	56.94270	55.77678		0.846	1.01943	61.00034	59.49058
13	0.995	2.57583	46.42597	45.99800	0.920	1.40507	57.01028	55.83889		0.845	1.01522	61.04541	59.53162
14	0.994	2.51214	46.94757	46.48829	0.919	1.39838	57.07720	55.90041		0.844	1.01103	61.09029	59.57252
15	0.993	2.45728	47.40171	46.91472	0.918	1.39174	57.14373	55.96154		0.843	1.00686	61.13499	59.61325
16	0.992	2.40892	47.80537	47.28339	0.917	1.38517	57.20982	56.02208		0.842	1.00271	61.17952	59.65380
17	0.991	2.36562	48.18988	47.63504	0.916	1.37868	57.27499	56.08214		0.841	0.99858	61.22388	59.69419
18	0.990	2.32635	48.50263	47.94890	0.915	1.37220	57.33993	56.14179		0.840	0.99448	61.26812	59.73451
19	0.989	2.29037	48.80963	48.23433	0.914	1.36581	57.40424	56.20085		0.839	0.99036	61.31220	59.77485
20	0.988	2.25713	49.09537	48.50131	0.913	1.35946	57.46822	56.25960		0.838	0.98627	61.35620	59.81472
21	0.987	2.22821	49.36238	48.75091	0.912	1.35317	57.53186	56.31785		0.837	0.98220	61.40003	59.85482
22	0.986	2.19729	49.61344	48.98546	0.911	1.34694	57.59457	56.37561		0.836	0.97815	61.44386	59.89435
23	0.985	2.17009	49.85073	49.20703	0.910	1.34076	57.65704	56.43295		0.835	0.97411	61.48722	59.93400
24	0.984	2.14441	50.07580	49.41708	0.909	1.33462	57.71918	56.48997		0.834	0.97008	61.53080	59.97349
25	0.983	2.12007	50.29006	49.61696	0.908	1.32854	57.78077	56.54650		0.833	0.96609	61.57379	60.01280
26	0.982	2.09693	50.49461	49.80789	0.907	1.32251	57.84192	56.60260		0.832	0.96210	61.61690	60.05203
27	0.981	2.07485	50.69057	49.99032	0.906	1.31652	57.90273	56.65839		0.831	0.95812	61.65993	60.09119
28	0.980	2.05375	50.87854	50.16544	0.905	1.31058	57.96309	56.71377		0.830	0.95418	61.70278	60.13018
29	0.979	2.03362	51.05941	50.33387	0.904	1.30469	58.02301	56.76872		0.829	0.95022	61.74544	60.16899
30	0.978	2.01409	51.23374	50.49815	0.903	1.29884	58.08259	56.82338		0.828	0.94628	61.78802	60.20773
31	0.977	1.99539	51.40208	50.65280	0.902	1.29303	58.14181	56.87786		0.827	0.94238	61.83041	60.24630
32	0.976	1.97737	51.56482	50.80418	0.901	1.28727	58.20059	56.93155		0.826	0.93848	61.87273	60.28479
33	0.975	1.95998	51.72254	50.95084	0.900	1.28155	58.25902	56.98511		0.825	0.93458	61.91507	60.32330
34	0.974	1.94313	51.87548	51.09300	0.899	1.27587	58.31709	57.03835		0.824	0.93072	61.95701	60.36144
35	0.973	1.92684	52.02391	51.23095	0.898	1.27024	58.37472	57.09118		0.823	0.92686	61.99898	60.39980
36	0.972	1.91104	52.16830	51.36508	0.897	1.26464	58.43209	57.14373		0.822	0.92301	62.04098	60.43799
37	0.971	1.89570	52.30887	51.49562	0.896	1.25908	58.48911	57.19597		0.821	0.91918	62.08256	60.47580
38	0.970	1.88079	52.44586	51.62281	0.895	1.25357	58.54567	57.24779		0.820	0.91537	62.12406	60.51333
39	0.969	1.86630	52.57934	51.74669	0.894	1.24808	58.60208	57.29948		0.819	0.91156	62.16560	60.55108
40	0.968	1.85218	52.70973	51.86768	0.893	1.24264	58.65803	57.35071		0.818	0.90777	62.20694	60.58896
41	0.967	1.83842	52.83712	51.98584	0.892	1.23723	58.71372	57.40171		0.817	0.90399	62.24820	60.62618
42	0.966	1.82501	52.96155	52.10124	0.891	1.23186	58.76905	57.45238		0.816	0.90023	62.28927	60.66349
43	0.965	1.81191	53.08340	52.21420	0.890	1.22653	58.82403	57.50272		0.815	0.89647	62.33037	60.70083
44	0.964	1.79912	53.20263	52.32471	0.889	1.22123	58.87874	57.55281		0.814	0.89273	62.37128	60.73800
45	0.963	1.78661	53.31951	52.43302	0.888	1.21595	58.93320	57.60266		0.813	0.88901	62.41199	60.77499
46	0.962	1.77438	53.43402	52.53910	0.887	1.21072	58.98739	57.65228		0.812	0.88528	62.45273	60.81200
47	0.961	1.76241	53.54634	52.64312	0.886	1.20553	59.04112	57.70143		0.811	0.88159	62.49328	60.84884
48	0.960	1.75069	53.65654	52.74516	0.885	1.20036	59.09489	57.75045		0.810	0.87790	62.53375	60.88559
49	0.959	1.73920	53.76479	52.84538	0.884	1.19522	59.14800	57.79922		0.809	0.87422	62.57413	60.92228
50	0.958	1.72793	53.87119	52.94385	0.883	1.19012	59.20094	57.84785		0.808	0.87055	62.61442	60.95988
51	0.957	1.71689	53.97582	53.04047	0.882	1.18504	59.25371	57.89593		0.807	0.86689	62.65484	60.99638
52	0.956	1.70604	54.07845	53.13580	0.881	1.18000	59.30612	57.94387		0.806	0.86325	62.69466	61.03171
53	0.955	1.69540	54.17948	53.22904	0.880	1.17499	59.35827	57.99158		0.805	0.85962	62.73459	61.06787
54	0.954	1.68494	54.27898	53.32105	0.879	1.17000	59.41025	58.03909		0.804	0.85600	62.77444	61.10415
55	0.953	1.67468	54.37695	53.41162	0.878	1.16505	59.46186	58.08628		0.803	0.85239	62.81421	61.14024
56	0.952	1.66456	54.47338	53.50074	0.877	1.16012	59.51310	58.13331		0.802	0.84879	62.85389	61.17628
57	0.951	1.65463	54.56835	53.58850	0.876	1.15522	59.56448	58.18009		0.801	0.84520	62.89348	61.21220
58	0.950	1.64485	54.66204	53.67507	0.875	1.15035	59.61539	58.22682		0.800	0.84162	62.93299	61.24805
59	0.949	1.63523	54.75438	53.76035	0.874	1.14551	59.66602	58.27290		0.799	0.83805	62.97241	61.28363
60	0.948	1.62576	54.84540	53.84442	0.873	1.14069	59.71649	58.31902		0.798	0.83450	63.01184	61.31942
61	0.947	1.61644	54.93514	53.92729	0.872	1.13590	59.76669	58.36489		0.797	0.83095	63.05089	61.35503
62	0.946	1.60725	55.02377	54.00911	0.871	1.13113	59.81672	58.41080		0.796	0.82742	63.08995	61.39048
63	0.945	1.59819	55.11129	54.08989	0.870	1.12639	59.86648	58.45605		0.795	0.82390	63.12891	61.42581
64	0.944	1.58927	55.19759	54.16953	0.869	1.12168	59.91596	58.50125		0.794	0.82038	63.16791	61.46118
65	0.943	1.58047	55.28286	54.24821	0.868	1.11699	59.96528	58.54630		0.793	0.81687	63.20681	61.49647
66	0.942	1.57179	55.36710	54.32592	0.867	1.11232	60.01442	58.59118		0.792	0.81338	63.24552	61.53157
67	0.941	1.56322	55.45040	54.40275	0.866	1.10768	60.06329	58.63580		0.791	0.80990	63.28414	61.56660
68	0.940	1.55477	55.53285	54.47880	0.865	1.10306	60.11198	58.68028		0.790	0.80642	63.32278	61.60164
69	0.939	1.54643	55.61396	54.55356	0.864	1.09847	60.16040	58.72447		0.789	0.80296	63.36123	61.63650
70	0.938	1.53820	55.69430	54.62782	0.863	1.09390	60.20865	58.76851		0.788	0.79950	63.39970	61.67137
71	0.937	1.53007	55.77379	54.70088	0.862	1.08935	60.25673	58.81239		0.787	0.79606	63.43797	61.70606
72	0.936	1.52204	55.85241	54.77333	0.861	1.08482	60.30463	58.85611		0.786	0.79262	63.47628	61.74077
73	0.935	1.51410	55.93025	54.84508	0.860	1.08032	60.35225	58.89957		0.785	0.78919	63.51448	61.77540
74	0.934	1.50626	56.00723	54.91586	0.859	1.07584	60.39970	58.94288		0.784	0.78577	63.55258	61.80995
75	0.933	1.49851	56.08342	54.98614	0.858	1.07138	60.44697	58.98600		0.783	0.78237	63.59050	61.84431
76	0.932	1.49085	56.15883	55.05559	0.857	1.06694	60.49407	59.02896		0.782	0.77897	63.62843	61.87889
77	0.931	1.48328	56.23345	55.12430	0.856	1.06252	60.54099	59.07177		0.781	0.77557	63.66639	61.91308
78	0.930	1.47579	56.30739	55.19236	0.855	1.05812	60.58774	59.11440		0.780	0.77219	63.70415	61.94729
79	0.929	1.46838	56.38062	55.25977	0.854	1.05374	60.63431	59.15688		0.779	0.76882	63.74182	61.98142
80	0.928	1.46108	56.45307	55.32644	0.853	1.04939	60.68059	59.19909					

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