ATTACHMENT 2

Consumers Power Company
Palisades Plant
Docket 50-255

SERVICE LIFE ASSESSMENT OF PALISADES SPRAY AND SURGE NOZZLE SAFE ENDS

BWNT CALC No. 51-1235130-01

April 24, 1995

B&W NUCLEAR TECHNOLOGIES

ENGINEERING INFORMATION RECORD

Document Identifier 51-1235130-01

Title Service Life Assessment of Pressurizer Spray and Surge Nozzle Safe Ends

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Remarks:

This document presents service life assessments of the pressurizer spray nozzle safe end and surge nozzle safe end at Palisades. Both safe ends were fabricated from Alloy 600 and are a concern with regard to PWSCC. The relative susceptibilities of these safe ends to PWSCC are evaluated in comparison to the PORV safe end (also fabricated from Alloy 600), which will be replaced during the 1995 refueling outage.

This document is a deliverable for Task III.1, "Service Life Extension for the Existing Spray Nozzle," and Task V.1, "Service Life Extension for the Existing Surge Nozzle Safe End."

Revision 01 is the non-proprietary version of Revision 00.

*** NON-PROPRIETARY ***

1.0 Purpose

The purpose of this document is to present the service life assessments for the Palisades pressurizer spray nozzle safe end and surge nozzle safe end.

2.0 Background

Alloy 600 is used extensively in the primary coolant system (PCS) of pressurized water reactors (PWRs). For example, pressurizer nozzles and safe ends, control element drive mechanism nozzles, and steam generator tubing have all been fabricated from Alloy 600. In recent years, however, numerous failures of Alloy 600 components have occurred due to primary water stress corrosion cracking (PWSCC). Steam generator tubing is known for numerous failures, but pressurizer, control rod drive mechanism, and hot leg nozzles have also been affected. The pressurizer power operated relief valve (PORV) safe end at Palisades was repaired in September/October 1993 following detection of PWSCC cracks in the vicinity of the safe end weld. This safe end will be replaced during the 1995 refueling outage.

Following the detection of PWSCC in the PORV safe end at Palisades and its repair in 1993, Consumers Power Company (CPCo) is currently reviewing the Alloy 600 locations throughout the pressurizer and primary coolant piping to determine appropriate actions to be taken. In the pressurizer, the spray nozzle safe end and surge nozzle safe end are of concern. The spray nozzle safe end was fabricated from the same heat of material as the PORV safe end (which has already failed) and the surge nozzle safe end, which operates at approximately 640°F, was fabricated from material also believed to be relatively susceptible to PWSCC. [Note: The temperature element nozzles in the pressurizer at Palisades, also fabricated from Alloy 600, have been addressed separately.]

The following sections describe the requirements for PWSCC of Alloy 600 components to occur, and the assessed service life for both the spray nozzle safe end and surge nozzle safe end relative to the PORV safe end, which has already failed due to PWSCC.

3.0 Primary Water Stress Corrosion Cracking

Primary water stress corrosion cracking is a degradation mechanism of Alloy 600 that occurs as a result of

- o a susceptible material,
- o a tensile stress (including both operating and residual stress), and
- o a pressurized water reactor (PWR) primary water environment.

All of these factors must be present in order for PWSCC to occur.

The susceptibility of Alloy 600 material depends on several factors including the chemical composition, heat treatment during manufacture of the material, heat treatment during fabrication of the component, and operating parameters of the component. Chemical composition and heat treatment are interrelated in several ways. For example, one reason for annealing Alloy 600 is to solutionize the carbon in the alloy. (Figure 1 illustrates the solubility of carbon in Alloy 600 as a function of annealing temperature.) As the material cools, chromium carbides precipitate from solution at both intragranular and intergranular locations. If the cooldown from the anneal is sufficiently slow, a greater number of carbides will precipitate at the grain boundaries (i.e., intergranularly), and the resistance to PWSCC will be improved. Well decorated grain boundaries are an indication that an Alloy 600 material has received a proper heat treatment and that sufficient carbon was available in solution to combine with chromium. If adequate amounts of carbon and chromium exist but the anneal was not at a high enough temperature or sufficient time was not allowed to solutionize the carbon, an adequate amount of carbon will not be available to precipitate intergranularly as chromium carbides, leading to minimal grain boundary decoration. Most precipitation occurs during cooldown following annealing; however, stress relief treatments can lead to additional precipitation. The primary goal of stress relief, however, is to allow a local realignment of highly strained regions to reduce internal stresses. Carbon and chromium concentration gradients are also reduced given extended time at temperature. Thus, if the anneal has not adequately solutionized carbon for chromium carbide precipitation at the grain boundaries, stress relief treatment will not affect intergranular carbide precipitation and will not reduce susceptibility to PWSCC.

Tensile stresses, resulting from both residual and operating stresses, can be significant for some Alloy 600 components. Operating stresses are produced from mechanical and thermal loading, while residual stresses are generated as a result of fabrication, installation, and welding processes. Residual stresses are more difficult to quantify than operating stresses and, in many instances, are of a higher magnitude than operating stresses.

PWSCC is a thermally activated degradation mechanism; that is, as the temperature increases, the rate of PWSCC increases. Thus, the hot leg

temperature of the RCS creates a more aggressive environment in which the Alloy 600 components must operate.

The cracking observed in PWRs to date is typically axially-oriented (although circumferentially-oriented cracks have been observed) and occurs in an area, such as a weld heat affected zone (HAZ), that has high residual tensile stresses. In partial penetration welded components such as nozzles, the residual stresses are inherently higher in the circumferential direction than in the axial direction. In this case, therefore, cracking in a homogeneous material with no initial flaws would be expected to occur axially due to the higher circumferential residual stresses. However, axially-oriented residual stresses on the inside surface of nozzle-to-safe-end welds (i.e., butt welds) have been shown to be greater than circumferentially-oriented residual stresses at this location.[1]

4.0 Assessment of Palisades Pressurizer Safe Ends

CPCo has provided BWNT with available information regarding the spray nozzle safe end, surge nozzle safe end, and PORV safe end. This information has been reviewed and the material characteristics and operating conditions for each of these safe ends is tabulated below.

	Spray Nozzle Safe End	Surge Nozzle Safe End	PORV Safe End
Heat Number	NX5222	26190	NX5222
Carbon Content (%)	0.090	0.065	0.090
Yield Strength (ksi)	77.5	51.2	77.5
Ultimate Tensile Strength (ksi)	114.0	100.3	114.0
Anneal Temp. (°F)*	1650	1650	1650
Operating Temp. (°F)	540**	640	640
Environment	liquid	liquid	steam
Flow Rate (gpm)	50-70**	stagnant#	stagnant
Outside Diameter (in.)	4.500	12.750	6.000
Inside Diameter (in.)	3.692	10.740	3.000
Nominal Wall Thickness (in.)	0.404	1.005	1.500+
Attachment Weld	Full	Full	Full
Stress Relief [Vessel side/Piping side]	Yes/No##	Yes/No##	Yes/No##

* Annealing temperature is assumed to be approximately 1650°F based on standard industry practice for Alloy 600 material.

** Flow rate through the spray nozzle and safe end is believed to be approximately 50-70 gpm. This continuous high flow rate (from the cold leg piping) leads to an operating temperature of approximately 540°F, that of the cold leg piping.

\# Flow through the surge nozzle safe end during normal operation is minimal, thus the environment is essentially stagnant.

\## It is believed that all three safe ends were shop-installed; therefore, it is assumed that the pressurizer-to-safe-end weld was stress relieved with the pressurizer. The safe-end-to-piping weld, on the other hand, would not have received any stress relief treatment.

\+ The <u>nominal</u> wall thickness of the PORV safe end is 1.5"; however, the thickness of this safe end at the location of failure (at the safe-end-to-piping weld) is approximately 0.5".

Figures 2 through 4 illustrate the spray nozzle safe end, surge nozzle safe end, and PORV safe end, respectively.

The spray nozzle safe end and PORV safe end were fabricated from the same heat of material (NX5222), while the surge nozzle safe end was fabricated from a separate heat (26190). However, the carbon contents of heats NX5222 and 26190 are relatively high at 0.090% and 0.065%, respectively, as shown above. Since the actual annealing temperatures for these heats are not available, a temperature of 1650°F is assumed (as identified in the above table) for both material heats. A 1650°F anneal temperature is insufficient to solutionize 0.065% carbon as shown in Figure 1 -- the solubility curve for carbon in Alloy 600, which follows the following equations:[2]

$$^{\circ}C = 1449 + 130.3[\ln(\%C)] \tag{1}$$

or,

$$^{\circ}F = 2640 + 234.5[\ln(\%C)] \tag{2}$$

where %C is the weight percent carbon in the material. At 1650°F, only 0.015% carbon will go into solution. Thus, since very little of the carbon is able to go into solution during a 1650°F anneal, neither of the two material heats is expected to have extensive grain boundary carbide decoration. Also, extensive intragranular carbides (within each grain) are expected for these materials due to the high carbon contents of the two heats. Based on composition and expected microstructural

features following heat treatment, both material heats are relatively susceptible to PWSCC.

The operating temperature of the spray nozzle safe end is 540°F, which is essentially the temperature of the cold leg; this temperature is due to the continuous flow of primary coolant within the spray nozzle safe end (except at shutdown conditions). The operating temperature of both the surge nozzle safe end and PORV safe end is significantly higher at 640°F. The environments within the PORV safe end and surge nozzle safe end are considered to be essentially stagnant. Based on temperature alone, PWSCC susceptibility of the spray nozzle safe end is lower than that of the other two safe ends.

The total stress states of the three safe ends are not known. Compared to residual stresses, the operating stresses are considered to be low. Residual stresses within the safe ends resulting from fabrication and installation (including welding) have not been determined to date but peak tensile stresses can be conservatively estimated to be approximately the yield strength of the material. Thus, residual tensile stresses in the spray nozzle safe end and PORV safe end could be somewhat higher than the residual tensile stresses within the surge nozzle safe end (yet similar relative to the different yield strengths of the two materials). It should also be noted that poor welding (e.g., poor reworking) of the PORV and surge nozzle safe ends has been identified,[3,4] and it is believed that the spray nozzle safe end weld was reworked in a similar manner. This rework increases the residual stresses at these locations.

It is assumed (as noted in the above table) that the three safe ends were installed in the shop and, thus, were stress relieved with the pressurizer. However, the safe-end-to-piping welds did not receive any stress relief treatment since these welds were completed in the field. Stress relief may have slightly reduced PWSCC susceptibility of the safe end materials at the pressurizer-to-safe-end welds. At the safe-end-to-piping weld, the safe end materials are expected to be somewhat more susceptible to PWSCC. It should be noted, however, that the safe ends are still believed to be susceptible to PWSCC based on previous heat treatments and composition of the safe end materials.

One other difference to note is that the three safe ends vary significantly in size. The surge nozzle safe end has the largest nominal diameter of the three safe ends, followed by the PORV safe end, with the spray nozzle safe end having the smallest diameter. [Note: As mentioned earlier, the PORV safe end is significantly thinner at the safe-end-to-piping weld (~0.5") than its nominal thickness of 1.5".] All safe end welds are full penetration welds, and (based on diameter) the surge nozzle safe end is expected to have the largest welds, by volume, of the three safe ends.

Based on a materials standpoint, both the surge nozzle and spray nozzle safe ends are relatively susceptible to PWSCC due to composition (i.e.,

high carbon content), insufficient heat treatment, and poor welding of the safe ends leading to significant residual stresses.

5.0 PWSCC Crack Growth Assessment

A crack growth assessment has been performed for the spray nozzle safe end and the surge nozzle safe end.[5] In this assessment, both PWSCC and fatigue crack growth were evaluated to determine the remaining service life of these two safe ends. Three aspect ratios (i.e., crack length/crack depth) were considered for various initial flaw depths in this assessment.

Postulated semi-elliptical axial and circumferential internal surface flaws were evaluated in accordance with the fracture toughness requirements set by the ASME Boiler and Pressure Vessel Code, Section XI, IWB-3612,[6] considering the potential for crack growth and failure by net section collapse (limit load). Critical flaw sizes were determined considering both fatigue crack growth due to design cyclic loading and stress corrosion crack growth due to steady state stresses. Two approaches were used to assess the remaining service life of the pressurizer surge and spray nozzle safe ends for postulated surface flaws. The first approach uses a conservative, constant through-wall stress to account for residual and applied loading mechanisms, while the second approach utilizes a residual stress distribution from NUREG-0313[1] and actual applied stresses.

It is recognized that circumferential PWSCC could be the primary mode of failure for full penetration type nozzles with girth butt welded (i.e., full penetration welded) safe ends for two reasons: (1) high residual axial stresses may be present at the location of the girth butt weld; and (2) additional operational loads are produced by the attached piping. At the same time, compressive circumferential stress at the root of the weld, typical of butt welded piping components, tends to decrease the likelihood of axially-oriented PWSCC. Although the probability of finding axial flaws may be low, both axial and circumferential failure modes are addressed in the constant through-wall stress approach.

The use of a constant through-wall stress distribution was meant to be a conservative approach that precludes the need to determine actual loading conditions. The combination of weld shrinkage, pressure loads, material discontinuity, and external piping loads produces a complicated stress pattern that can best be predicted using a detailed analytical technique, such as elastic-plastic finite element analysis. Alternatively, a constant through-wall stress equal to the material yield strength at room temperature can be used to bound the total stress at operating temperature. Based on tabulated yield strengths from Section III of ASME Code, room temperature yield strengths are approximately 125% of yield strengths at operating temperatures greater than 500°F. Room temperature yield strength was applied as a constant

through-wall operating stress level for the evaluation of both axial and circumferential flaws. Consistent with this conservative approach for treating residual plus operational loads, the axial load used to assess the potential for net section collapse was derived considering a constant through-wall axial stress equal to the material yield strength at operating temperature.

Based on research conducted on large diameter boiling water reactor (BWR) stainless steel piping, it may be particularly conservative to assume a constant value of through-wall axial stress for evaluating circumferential flaws in girth butt welded safe ends. NUREG-0313 presents a nonlinear through-wall stress distribution (described by a fourth order polynomial) for axial residual stresses in 12" diameter piping joined by girth butt welds.

In the second approach, the inner surface residual stress was set equal to the material yield strength at operating temperature, and the remaining through-wall distribution followed the fourth-order polynomial described in NUREG-0313.[1] A constant through-wall primary plus secondary operating stress was derived from Section NB-3653, Equation (10), of the ASME Boiler and Pressure Vessel Code,[7] considering contributions from internal pressure, external piping moments, and thermal discontinuity between the Alloy 600 safe end and stainless steel piping. The resultant external piping moment is due to deadweight and thermal loads. Although operating stresses add directly to residual stresses in a purely linear analysis, the total is limited by elastic-plastic material behavior. To account for some strain hardening, but still control the magnitude of the total stress, the total stress at operation was limited to 125% of the operating temperature yield strength in this analysis.

Since an upper bound, constant through-wall stress condition used in the first approach is not used with the NUREG-based approach, the normal condition fracture toughness acceptance criterion no longer inherently bounds the faulted condition criterion. This required that the faulted condition fracture toughness acceptance criterion be checked at each crack depth, along with the normal condition criterion. A constant through-wall axial stress was calculated for faulted conditions using Equation (10) of the ASME Code[7] considering design pressure, deadweight plus thermal plus safe shutdown earthquake (SSE) seismic loads, and thermal discontinuity. In addition, the equivalent axial load used to check for net section collapse (limit load) was based on this same faulted condition stress.

The Palisades plant has 500 heatup and cooldown design cycles. In calculating fatigue crack growth, the maximum stress (i.e., yield strength) is combined with the minimum stress (i.e., zero at shutdown) to determine a cyclic stress range. The amount of fatigue crack growth was found to contribute only about 1% of the total crack growth as compared to PWSCC. For this reason, and based on experience, it was determined that accounting for smaller transients in the fatigue crack

growth analysis was not required. For stress corrosion crack growth at a given location, the maximum stress state is used to evaluate the corrosion crack growth within a given time span.

The leading industry thoughts on initial flaw size is that machining or fabrication processes leave a thin layer of high residual stress at the surface. Some quantitative measurements have been made using the X-ray diffraction technique; measured depths range from 0.002" in some cases to 0.010", which was measured at approximately 50 ksi. These values are dependent upon surface finishes and reaming following extrusion or machining. It is conservative, therefore, to assume an initial crack size of 0.010" for subcritical crack growth analysis for PWSCC. Thus, an initial flaw depth of 0.010" was implemented.[5]

5.1 Results from Initial Analysis - Constant Through-Wall Stress

For an initial flaw depth of 0.010", the remaining service life (i.e., time-to-failure) of the safe ends was calculated based on a constant through-wall stress for both axial and circumferential flaws. This data is tabulated below:

Component	Time-to-Failure (years) Based on Constant Through-Wall Stress					
	Axial Flaw			Circumferential Flaw		
	l/a#=2	l/a=4	l/a=6	l/a=2	l/a=4	l/a=6
Surge Nozzle Safe End	40.00	40.00	40.00	40.00	40.00	40.00
Spray Nozzle Safe End*	40.00 37.12	40.00 6.32	35.12 2.64	40.00 38.64	40.00 8.00	40.00 3.60

\# l/a is aspect ratio (length/depth);
* Top number in each cell is for the spray nozzle safe end at 540°F; bottom number is at 640°F.

Since a flaw depth of 0.010" is below minimum detection limits by ultrasonic (UT) inspection, plots of remaining life vs. crack depth were also developed.[5] Remaining life is shown as a function of crack depth for the spray nozzle safe end at 540°F and 640°F and the surge nozzle safe end in Figures 5 through 7 for axial flaws and in Figures 8 through 10 for circumferential flaws. These plots can be used to determine the remaining life based on an existing (and detectable) PWSCC crack. The allowable flaw sizes for the surge and spray nozzle safe ends are identified below for one operating cycle (18 months).

Component	Maximum Allowable Flaw Size (Inches) Based on Constant Through-Wall Stress					
	Axial Flaw			Circumferential Flaw		
	l/a#=2	l/a=4	l/a=6	l/a=2	l/a=4	l/a=6
Surge Nozzle Safe End	0.270	0.135	0.075	0.270	0.145	0.085
Spray Nozzle Safe End*	0.285 0.035	0.215 0.015	0.155 0.010	0.320 0.035	0.270 0.020	0.205 0.015

\# l/a is aspect ratio (length/depth);
* Top number in each cell is for the spray nozzle safe end at 540°F; bottom number is at 640°F.

Flaws that exceed the maximum allowable sizes identified above are not acceptable for one cycle of operation.

Since the spray nozzle safe end is much smaller (nominally) than both the surge nozzle and PORV safe ends, failure of the spray nozzle safe end is more dependent upon the temperature at which this safe end operates when compared to the surge nozzle safe end. At an operating temperature of 540°F, PWSCC failure of the spray nozzle safe end is of less concern; however, at an operating temperature of 640°F, time-to-failure of the spray nozzle safe end is calculated to be 2.64 years for an axial flaw and 3.60 years for a circumferential flaw, each having a 6/1 aspect ratio. [Note: Time-to-failure was calculated at both 540 and 640°F for the spray nozzle safe end since the operating temperature of this safe end depends on the flow rate of coolant through the safe end. It is assumed that the flow rate is high (50-70 gpm), leading to an operating temperature approaching that of the cold leg piping (540°F).] Also, the maximum allowable flaw sizes calculated for an operating temperature of 640°F are not detectable by UT inspection.

It should be noted that lower flow rates (including fluctuation of flow rate during operation) and the resulting higher operating temperatures of the spray nozzle safe end would lead to increased crack growth rates.

5.2 Results from Alternate Analysis - NUREG-0313 Approach

For an initial circumferential flaw depth of 0.010", the remaining service life (i.e., time-to-failure) of the safe ends was calculated based on NUREG-0313 and is identified below:

Component	Time-to-Failure (years) Based on NUREG-0313					
	Axial Flaw			Circumferential Flaw		
	1/a#=2	1/a=4	1/a=6	1/a=2	1/a=4	1/a=6
Surge Nozzle Safe End	N/A	N/A	N/A	40.00	40.00	40.00
Spray Nozzle Safe End*	N/A N/A	N/A N/A	N/A N/A	40.00 40.00	40.00 10.64	40.00 5.36

\# 1/a is aspect ratio (length/depth);
* Top number in each cell is for the spray nozzle safe end at 540°F; bottom number is at 640°F.
N/A Not applicable

Similarly, the maximum allowable flaw sizes were calculated for the surge and spray nozzle safe ends using the NUREG-0313 approach; this data is tabulated below:

Component	Maximum Allowable Flaw Size (Inches) Based on NUREG-0313					
	Axial Flaw			Circumferential Flaw		
	1/a#=2	1/a=4	1/a=6	1/a=2	1/a=4	1/a=6
Surge Nozzle Safe End	N/A	N/A	N/A	0.550	0.415	0.320
Spray Nozzle Safe End*	N/A N/A	N/A N/A	N/A N/A	0.360 0.240	0.360 0.180	0.360 0.130

\# 1/a is aspect ratio (length/depth);
* Top number in each cell is for the spray nozzle safe end at 540°F; bottom number is at 640°F.
N/A Not applicable

Again, flaws that exceed the maximum allowable sizes as shown above are not acceptable for one cycle of operation, based on the NUREG-0313 approach. Figures 11 through 13 illustrate remaining life vs. flaw size for the three cases tabulated above.

The maximum allowable flaw sizes shown above, unlike those calculated for constant through-wall stress (per Section 5.1), are all greater than

the UT detection limit of 2 mm (0.079"). However, the maximum allowable flaw size calculated for the spray nozzle safe end at an operating temperature of 640°F is significantly less than that corresponding to a 540°F operating temperature.

6.0 Summary

From a materials standpoint, all three safe ends are considered highly susceptible to PWSCC based on the chemical compositions, fabrication information, operational parameters, and details of installation known at this time. Thus, both the surge nozzle and spray nozzle safe ends are considered to be of concern with regard to PWSCC crack growth. The surge nozzle safe end operates at the same operating temperature (640°F) as the PORV nozzle safe end, although the surge nozzle safe end has a constant wall thickness of 1.005" whereas the wall thickness of the PORV safe end decreases from 1.5" (nominal) to approximately 0.5" at the safe end-to-piping weld where the failure occurred. It should be noted that the carbon content of the surge nozzle safe end is somewhat lower than that of the PORV and spray nozzle safe end material, but this difference is insignificant relative to the insufficient annealing treatments that both material heats received. Again, the stress relief treatment given to the three safe ends and safe-end-to-pressurizer welds is not believed to have significantly improved resistance to PWSCC at these locations.

The PORV safe end, which leaked and was repaired in 1993, failed after 23 years of service (~9 EFPY). It is known that poor fabrication and welding were performed on this safe end, as mentioned previously. It is expected that the spray nozzle safe end would be somewhat less susceptible to PWSCC at a normal operating temperature of 540°F, although some rework is believed to have been done on the spray nozzle safe end weld as well. Since the heat of material is the same for both of these safe ends, however, extensive additional life (i.e., resistance to PWSCC cracking) of the spray nozzle safe end is not expected, even at a low operating temperature. The surge nozzle safe end, since it was fabricated from a different heat of material, may be slightly less susceptible than the other two safe ends, although the rework completed on this safe end weld would increase susceptibility to PWSCC due to the induced residual stresses.

With regard to the PWSCC crack growth calculations described in Section 5.1, the remaining life of the spray nozzle safe end is calculated to be relatively short at an operating temperature of 640°F once a PWSCC crack initiates. At 540°F, the time-to-failure of this safe end is calculated to be 35.12 years for an axial flaw or 40 years for a circumferential flaw, each with an initial flaw size of 0.010" and a 6/1 aspect ratio. The results of the alternate analysis, reported in Section 5.2, identify the time-to-failure of the spray nozzle safe end to be 40 years and 5.36 years, respectively, for operating temperatures of 540°F and 640°F. This data is based on a circumferential flaw with an initial flaw size of 0.010" and a 6/1 aspect ratio. The surge nozzle safe end was

determined to have a remaining life of 40 years for an axial or circumferential flaw (based on both analyses), also for an initial flaw size of 0.010" and a 6/1 aspect ratio.

There are other items to consider as well. For example, if the spray nozzle safe end fails due to PWSCC and the plant operates for some time before the leak is detected, there is a concern regarding boric acid corrosion of carbon and low alloy steel components in the vicinity. Much of the coolant is expected to flash to steam, but low flowing leaks of liquid coolant can cause severe degradation of these susceptible materials to occur.[8] Also, failure of the surge nozzle could lead to significant leakage below the pressurizer in an area that is difficult to access.

7.0 Recommendations

Based on the above information, failure of both the surge nozzle safe end and spray nozzle safe end due to PWSCC is of concern. The spray nozzle safe end is believed to be somewhat more susceptible to PWSCC and would be expected to fail sooner due to its smaller size. As a minimum, therefore, it is recommended that Alloy 690 material be procured and stored for fabrication of a replacement spray nozzle safe end in the event that failure of this safe end occurs. As mentioned above, if the operating temperature of the existing spray nozzle safe end remains approximately 540°F, PWSCC of the safe end will be delayed. If 640°F is the more appropriate operating temperature, PWSCC of the spray nozzle safe end will occur sooner, and fabrication of the procured material into a replacement safe end should be considered.

Since remaining life is calculated based upon the size of an existing flaw, it is also recommended that regular non-destructive examinations be performed on the spray nozzle safe end, at a minimum, so that any flaws within this safe end can be detected as early as possible. [Note: If no flaws are detected during the 1995 inspection based on an approximate minimum detection limit of 2 mm (0.079"), the next inspection should be performed after two operating cycles.] Once a crack is detected, however, repair of the spray nozzle safe end needs to be performed since a detectable crack is expected to grow through-wall within 1-2 operating cycles, depending on the operating temperature.

NDE inspection of the surge nozzle safe end is not as critical due to its large size. However, due to the consequences of a leak at this location -- a possible loss of coolant accident (LOCA) -- an initial inspection of this safe end is recommended to identify if any cracks do exist. Follow-up inspections can be performed at the utility's discretion (based on the results of previous inspections) to identify the initiation of new cracks or to monitor the growth of existing cracks. In order to avoid a "special order" and a long lead time in the event of a failure, it is recommended that Alloy 690 material be procured and stored for fabrication of a replacement surge nozzle safe end.

8.0 References

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3. Czajkowski, C.J., "Palisades Nuclear Plant Safe-End to Pipe Cracking," MCE-E2089-02, Brookhaven National Laboratory, Upton, NY, January 1994.

4. Consumers Power Company Document Control Center Cartridge No. 67, Frame 2220.

5. Killian, D.E., "Fracture Mechanics Assessment of Palisades Alloy 600 Components," BWNT Document No. 32-1238965-00, B&W Nuclear Technologies, Lynchburg, Virginia, April 1995.

6. ASME Boiler and Pressure Vessel Code, Section XI, 1986 Edition.

7. ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, 1986 Edition.

8. Ouellette, C.A., "B&W Boric Acid Corrosion Research and the Wastage and Inspection Procedures for RCS Leakage," BAW-2126, B&W Nuclear Technologies, Lynchburg, Virginia, December 1990.

FIGURE 1

SOLUBILITY DIAGRAM FOR ALLOY 600

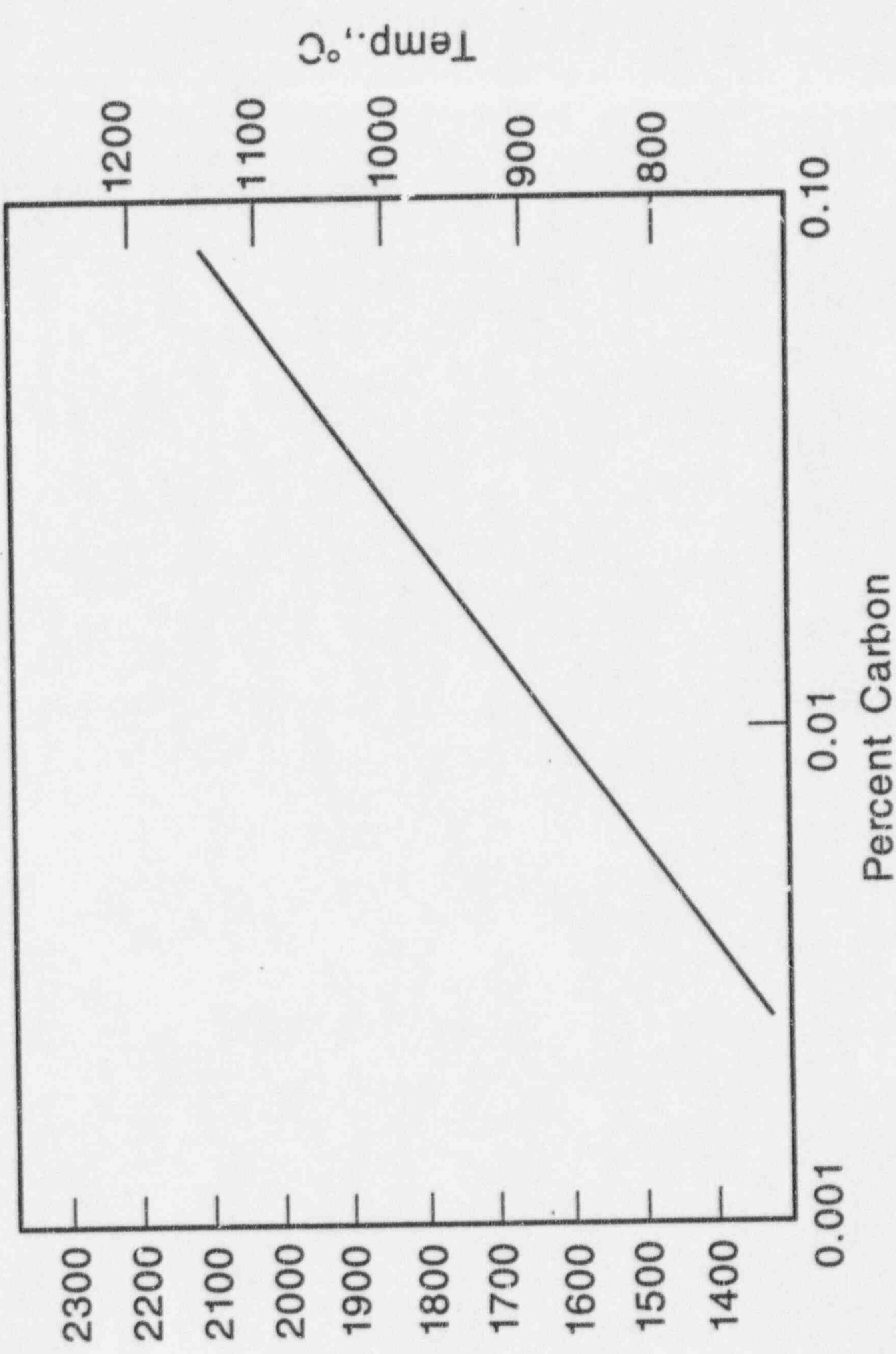

FIGURE 2

SPRAY NOZZLE SAFE END

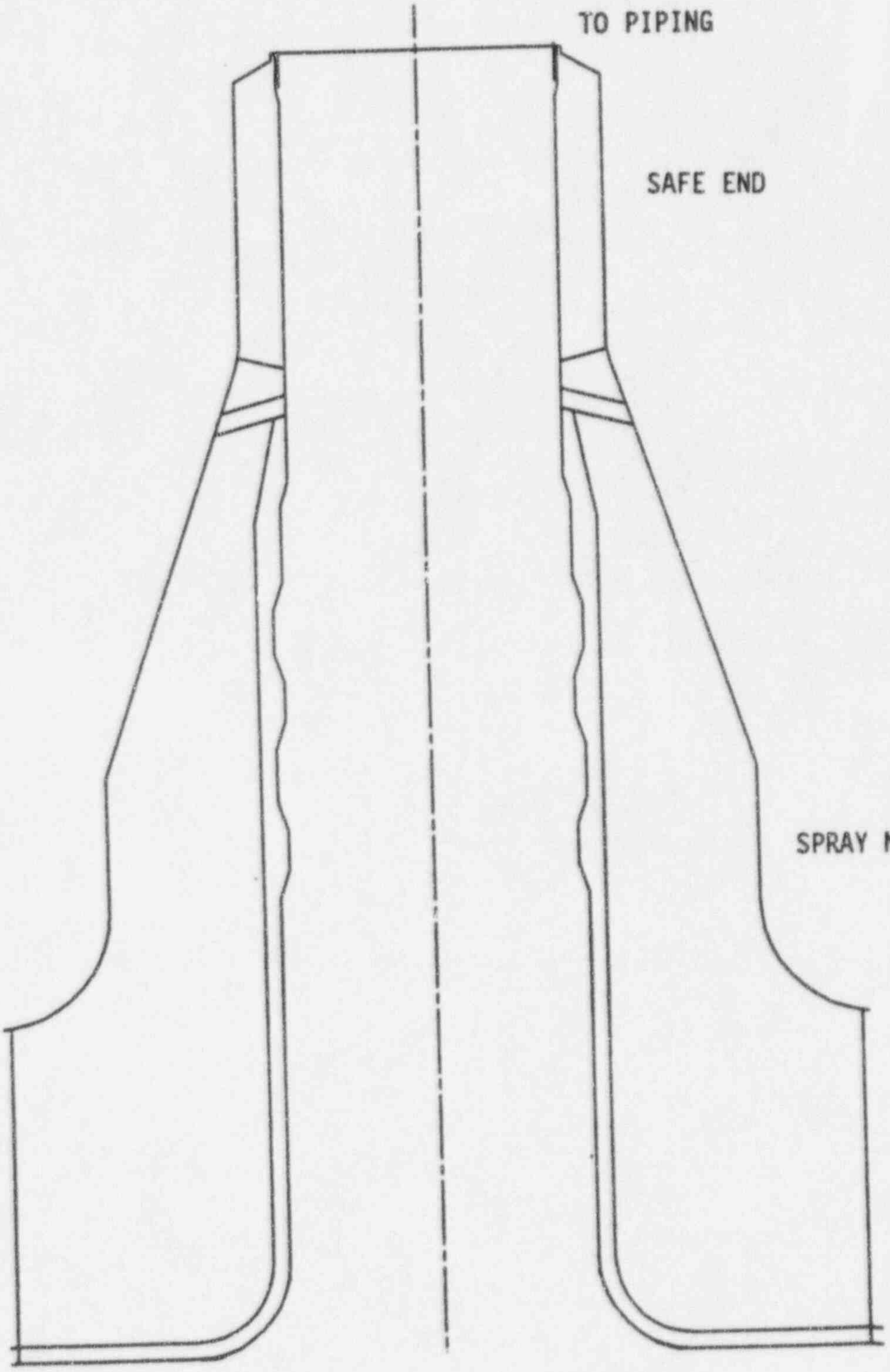

FIGURE 3

SURGE NOZZLE SAFE END

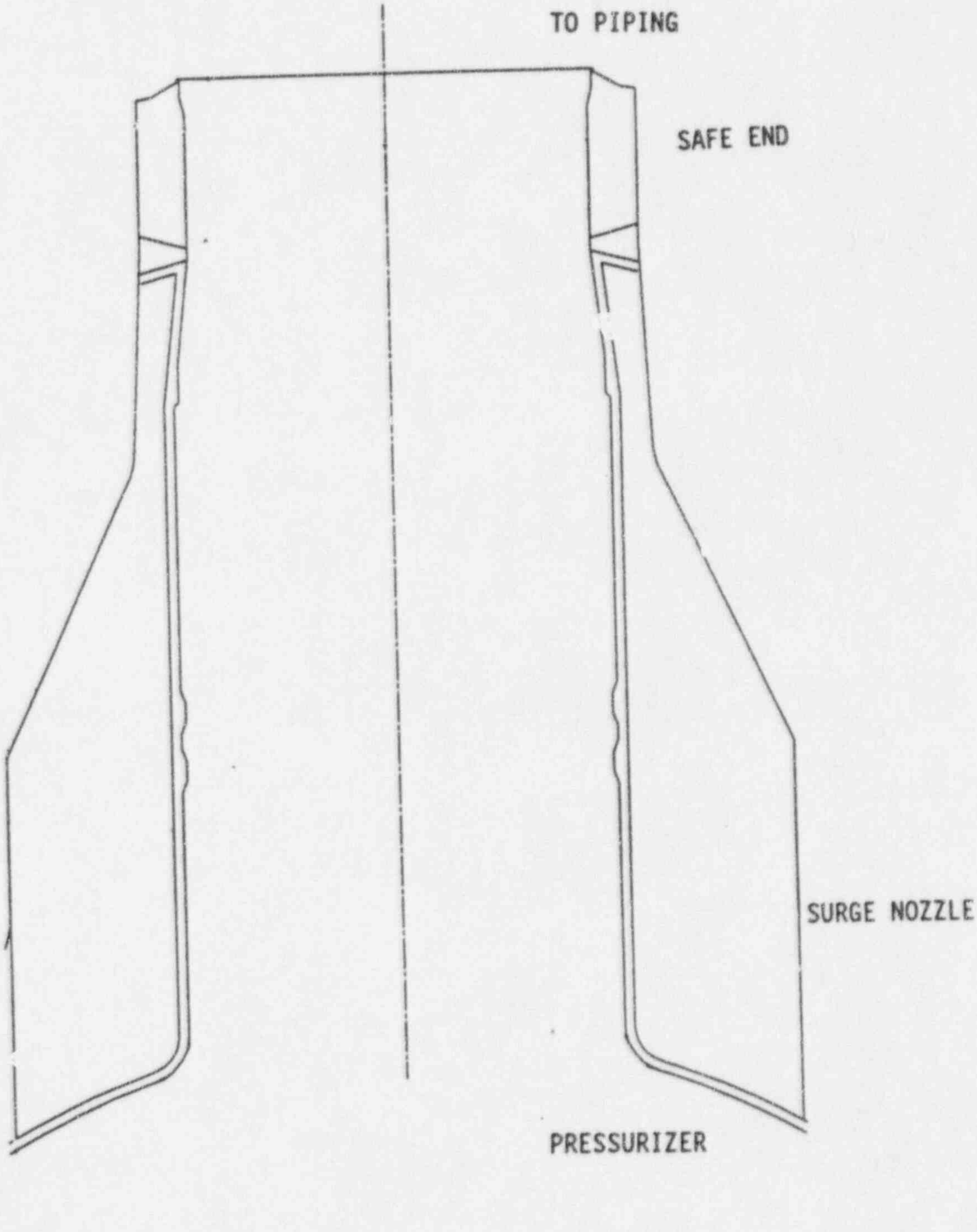

FIGURE 4

PORV SAFE END

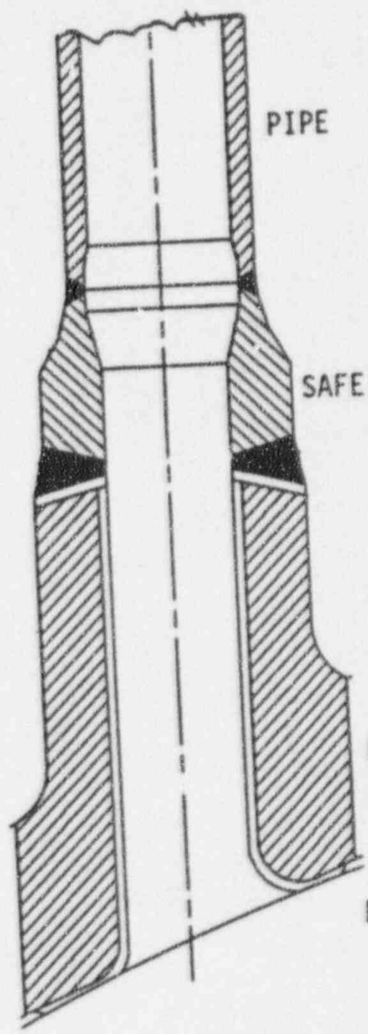

FIGURE 5

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SPRAY NOZZLE SAFE END
AXIAL FLAW AT T_{op}=540°F
(Ref. 5)

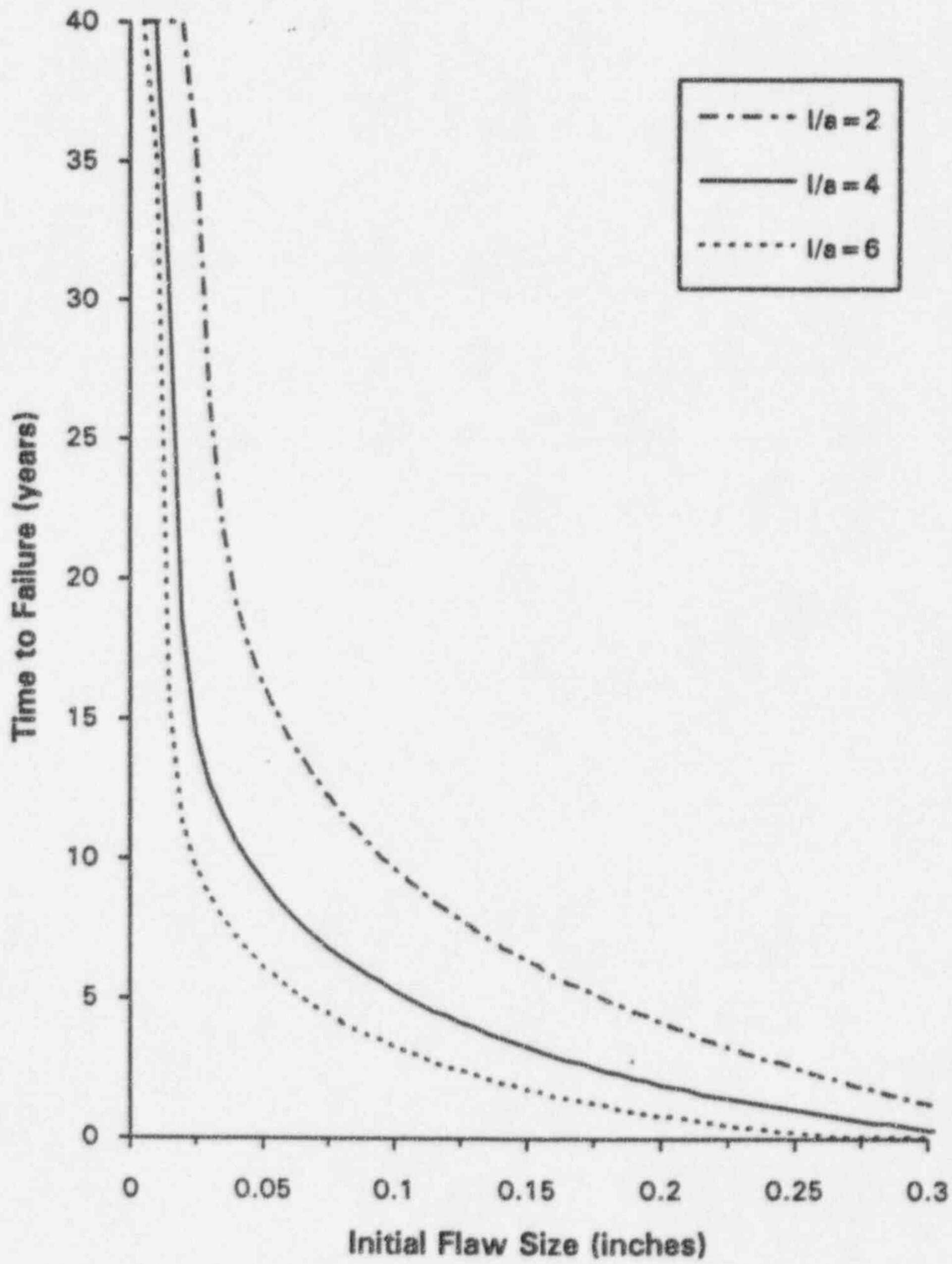

FIGURE 6

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SPRAY NOZZLE SAFE END
AXIAL FLAW AT T_{op}=640°F
(Ref. 5)

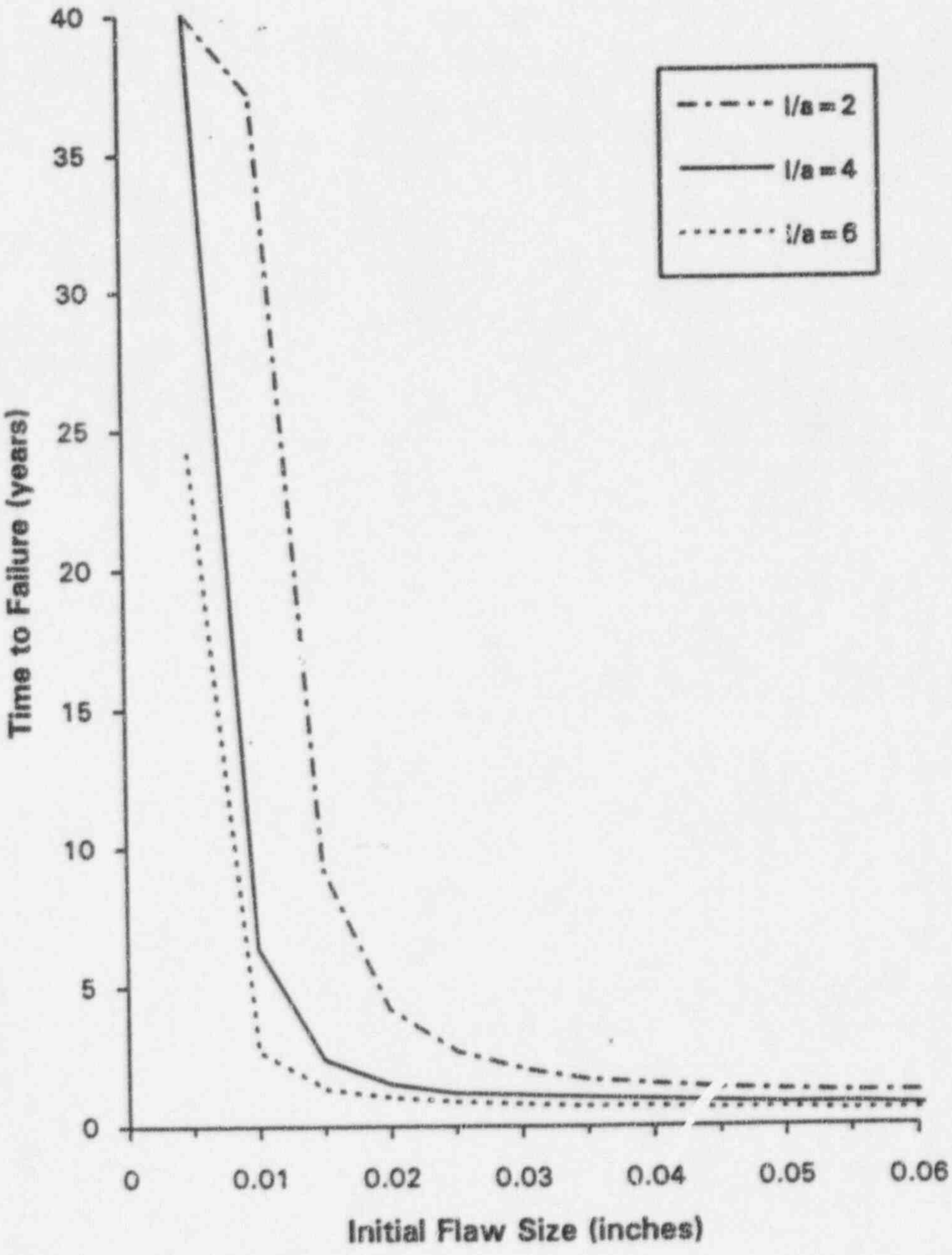

FIGURE 7

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SURGE NOZZLE SAFE END
AXIAL FLAW
(Ref. 5)

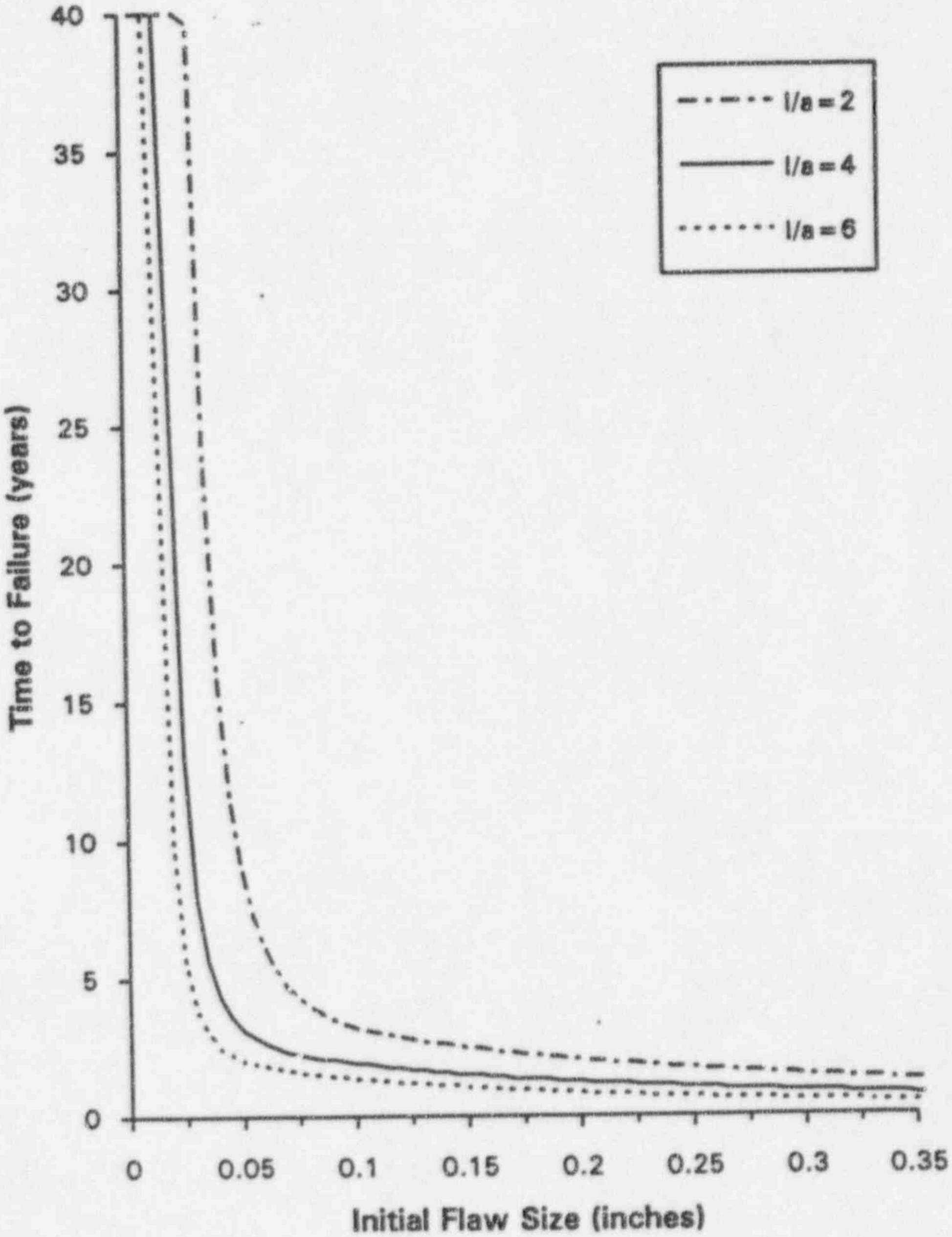

FIGURE 8

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SPRAY NOZZLE SAFE END
CIRCUMFERENTIAL FLAW AT T_{op}=540°F
(Ref. 5)

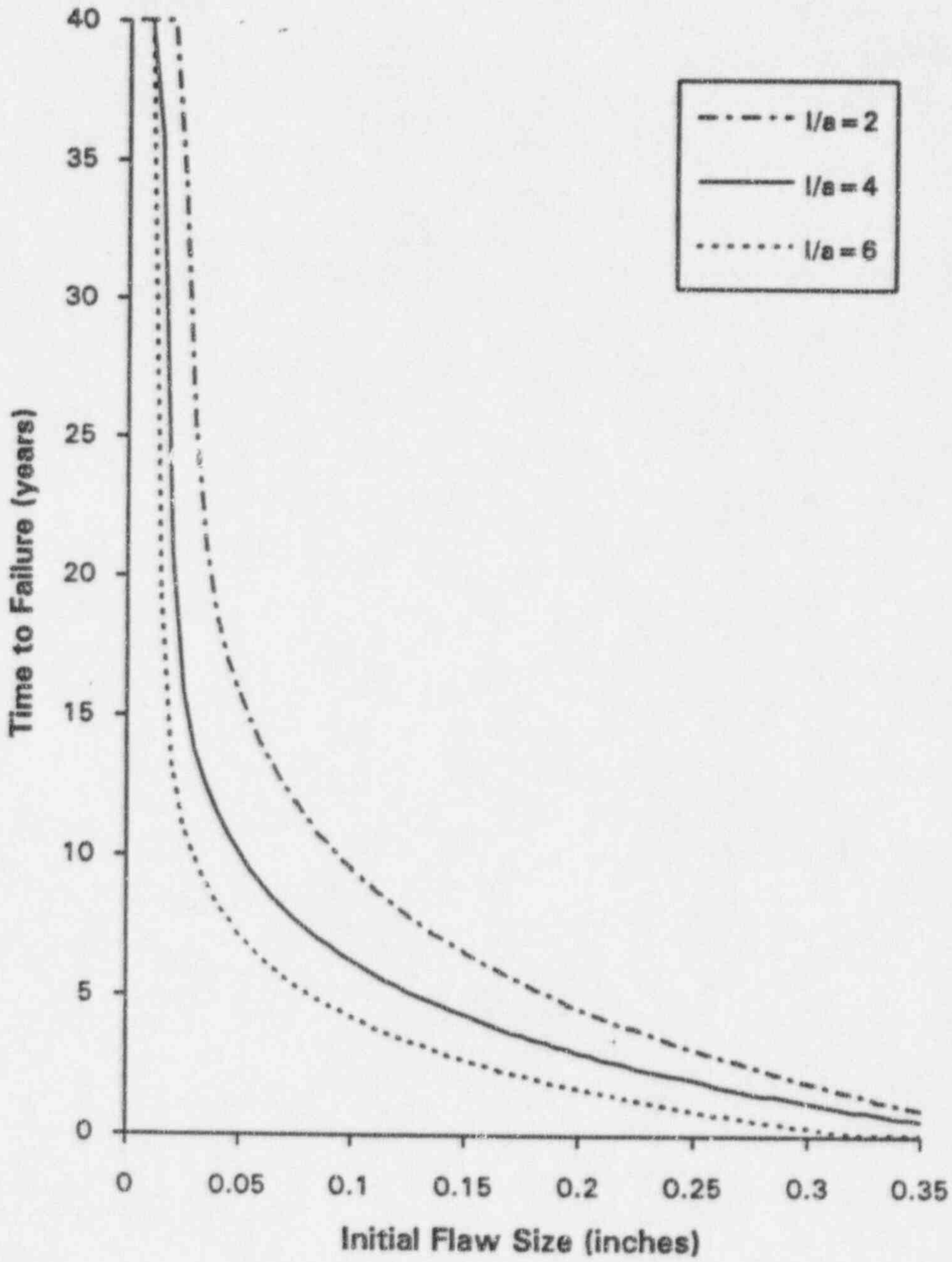

FIGURE 9

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SPRAY NOZZLE SAFE END
CIRCUMFERENTIAL FLAW AT T_{op}=640°F
(Ref. 5)

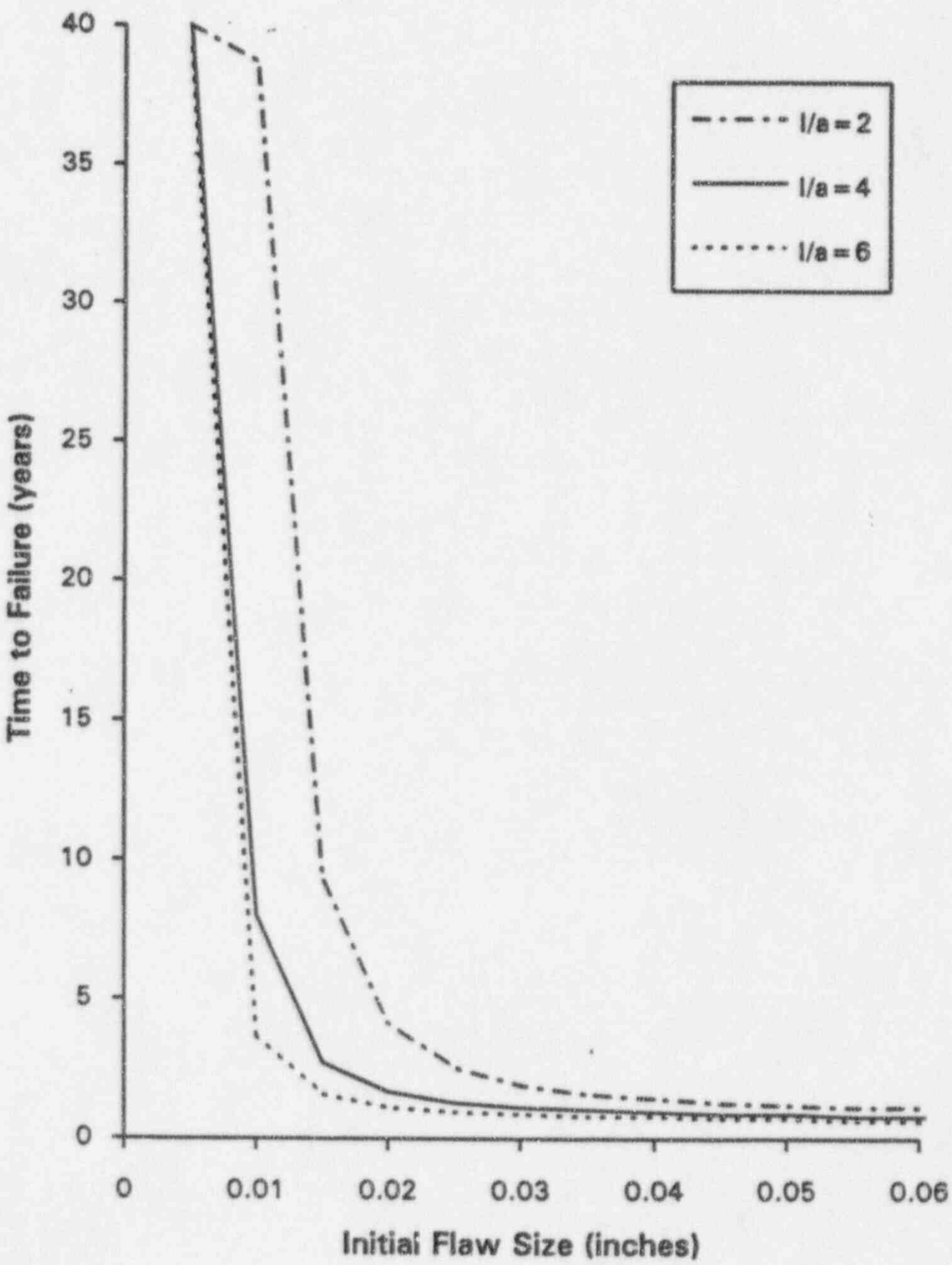

FIGURE 10

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SURGE NOZZLE SAFE END
CIRCUMFERENTIAL FLAW
(Ref. 5)

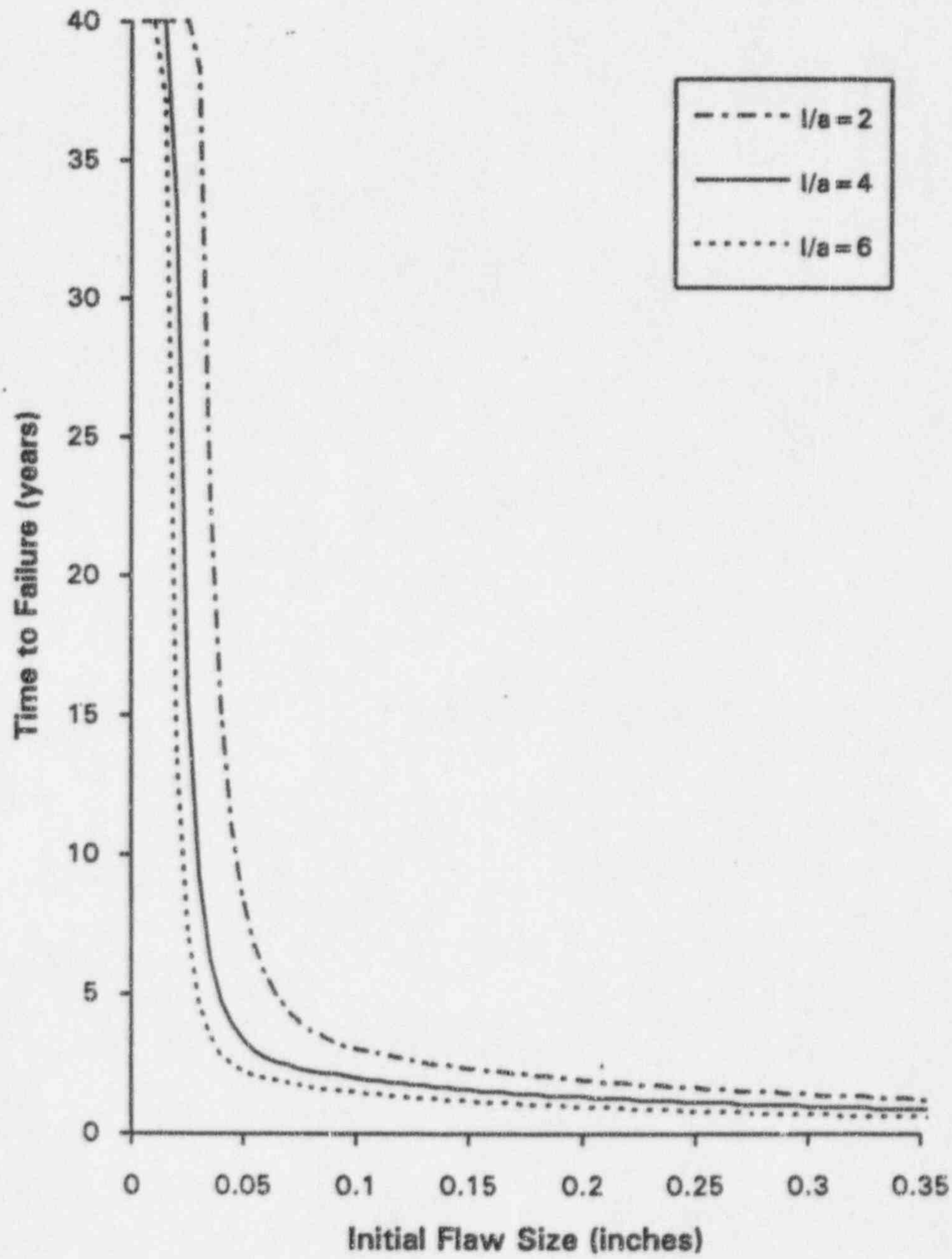

FIGURE 11

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SPRAY NOZZLE SAFE END
CIRCUMFERENTIAL FLAW AT T_{op}=540°F
BASED ON NUREG-0313
(Ref. 5)

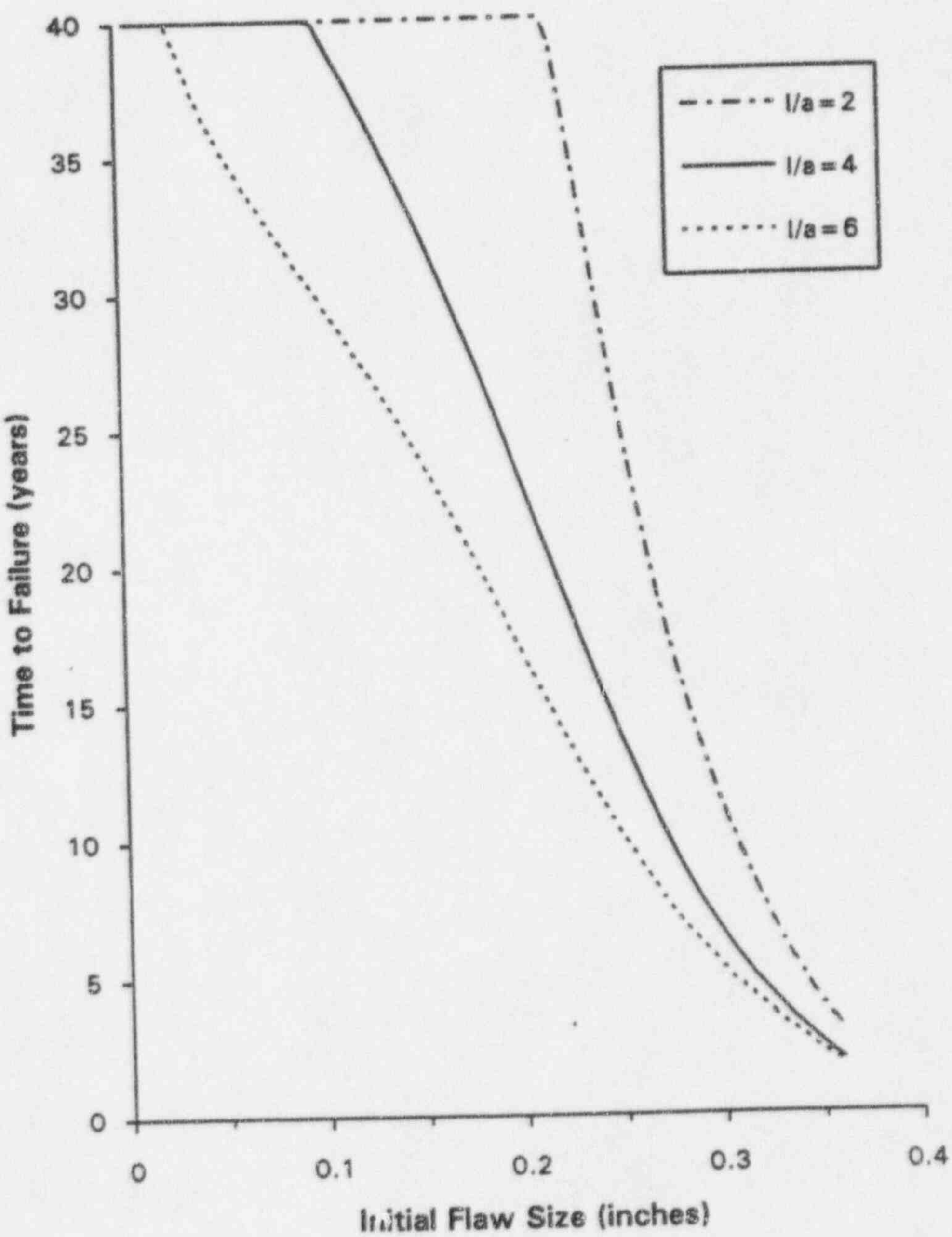

FIGURE 12

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SPRAY NOZZLE SAFE END
CIRCUMFERENTIAL FLAW AT T_{op}=640°F
BASED ON NUREG-0313
(Ref. 5)

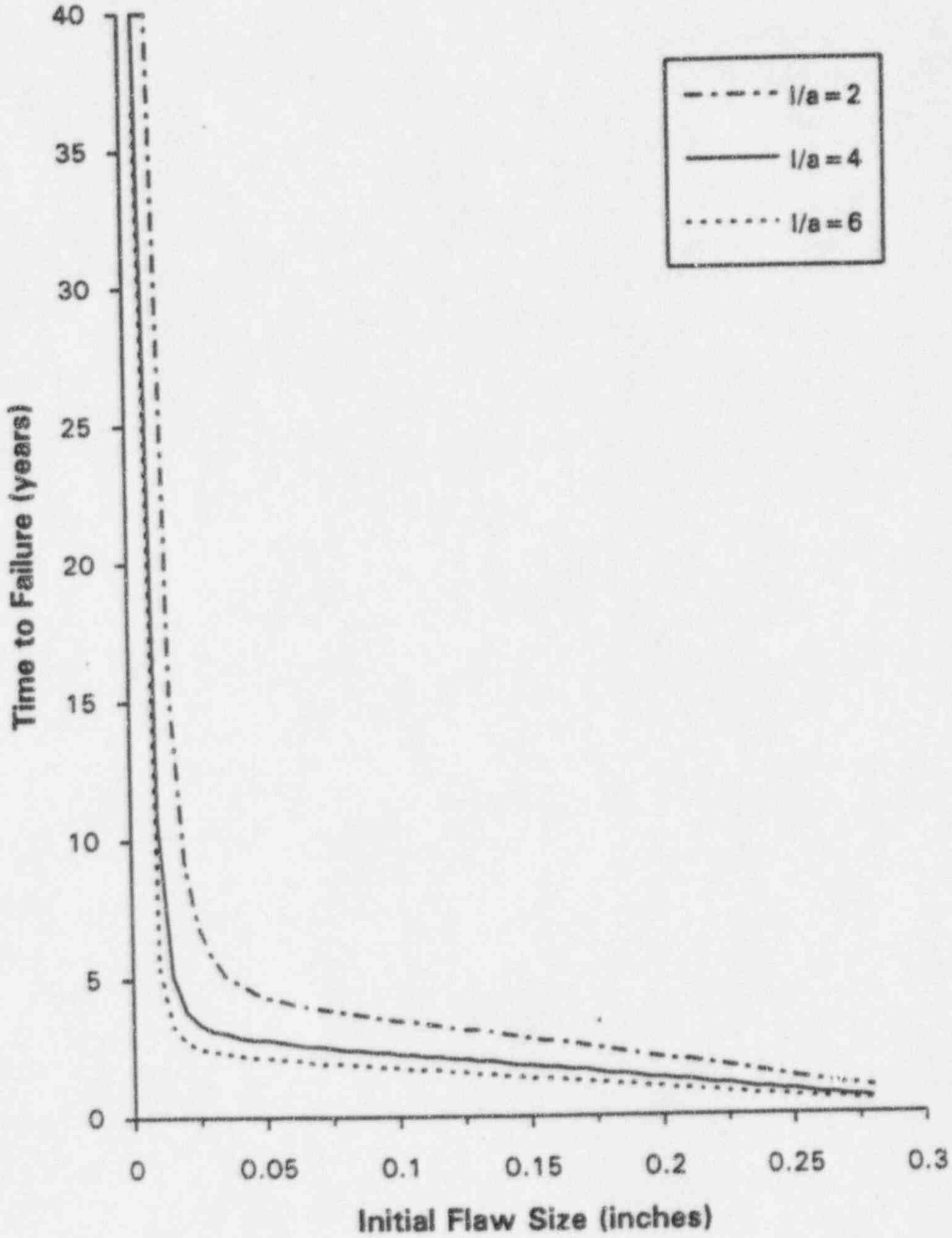

FIGURE 13

REMAINING LIFE VS. INITIAL CRACK DEPTH
FOR THE PRESSURIZER SURGE NOZZLE SAFE END
CIRCUMFERENTIAL FLAW
BASED ON NUREG-0313
(Ref. 5)