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Dear Dr. Sharon:

Enclosed are the results of a project given to my Penn State Graduate Students on finding pipe failure data over a range of pipe sizes and conditions. We specifically looked for stainless steel data as well as carbon steel pipe data. Since the data is from several sources other than nuclear the pipe wall thickness may not always be comparable to reactor pipe wall thicknesses. In some of the reports the students did separate the failure and leakage data by mechanism such that we could then screen the data.

I had the students normalize the data in such a fashion that we could then compare to the break frequency spectrum curves generated by the NRC experts group. I did talk to Rob Tenoning on the best way of normalizing our data such that we would be consistent with the break frequency plots. The key findings from the students work is that the data, when plotted in the same manner as the break frequency spectrum plots from the NRC experts work, shows a much flatter behavior at the larger pipe sizes indicating a more similar probability level for failure as compared to a more significant decrease in the failure probability as given by the NRC break frequency spectrum.

I am complying all the independent sets of data in a spread sheet and will attempt a further screening. Once complete, I will send you a copy of the data. I wanted you to have these report now with all the data so you could make an independent assessment.

Please let me know if you need anything else.

Very truly yours,

L.E. Hochreiter
Professor of Nuclear and Mechanical Engineering

NucE 597D - Project 1

DATA COLLECTION OF PIPE FAILURES OCCURING IN STAINLESS STEEL AND CARBON STEEL PIPING

Pennsylvania State University
Dr. L.E. Hochreiter
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Executive Summary

Currently the Nuclear Regulatory Commission (NRC) is contemplating changing the acceptance criteria for Emergency Core Cooling Systems (ECCS) for light-water nuclear power reactors contained in NRC Regulation 10 CFR 50.46. This regulation sets specific numerical acceptance criteria for peak cladding temperature, clad oxidation, total hydrogen generation, and core cooling under loss-of-coolant accident (LOCA) situations. Furthermore, the regulation requires that a spectrum of break sizes and locations be analyzed to determine the most severe case and to ensure the plant design can meet the acceptance criteria under such conditions.

Currently the regulation states that breaks of pipes in the reactor coolant pressure boundary up to, and including, a break equivalent in size to the double-ended rupture of the largest pipe in the reactor coolant system must be considered. While this restricts the design, it maintains a large safety margin ensuring the plant is covered under all LOCA situations. However, an impetus for change has resulted from materials research, analysis, and experience that indicate that the catastrophic rupture of a limiting size pipe at a nuclear power plant is a very low probability event.

If approved, the proposed change would divide the break spectrum into two categories based upon the likelihood of a break. Breaks of higher likelihood, breaks smaller than 10 inches, would need to meet the current requirements set forth in 10 CFR 50.46. Breaks of a lower likelihood, those larger than 10 inches, would only need to meet the requirements of maintaining a coolable geometry and having the capability for long term cooling.

The purpose of this project was to collect data on instances of pipe failures including cracks, leaks, and ruptures. For each instance of failure the plant type, pipe diameter, type of pipe, failure mechanism, and type of failure was recorded. The data was then collapsed based on plant type (PWR or BWR), type of pipe (carbon or stainless steel), pipe size, and failure mechanism. Then, normalized failure frequencies were calculated as a function of both pipe size and failure mechanism per reactor year. Plots of the frequency distributions were generated on a semi-log scale, and the frequency distributions as a function of pipe size were compared to the NRC predicted failure frequencies.

For this project our group collected two, independent sets of data. The first set was provided by the OECD Pipe Failure Data Exchange Project (OPDE), with a total of 2891 data points. The second set consists of 67 data points collected by our group from various sources. The two sets of data were not combined due to the lack of information accompanying the data presented in the OPDE database, such as plant name or exact failure size. This made it impossible to identify overlapping coverage and combine the information. Rather, within this report we have analyzed each data set individually in order to make an overall comparison of the trends observed for each data set and the NRC predictions.

The results from both the OPDE and the independent sets of data detailed in this report do not support the NRC's assertion that larger sized pipes do not break frequently enough to be used as design criteria. The overall trends of both sets of data show that the frequency of failures does not decrease as sharply with increasing pipe size as the NRC predicts.

Table of Contents

1.0 Detailed Introduction to the Problem 6

2.0 Data Collected 8

2.1 OECD Pipe Failure Data Exchange Project 8

2.2 *Independently Collected Data* 9

3.0 Collapsing and Analyzing the Collected Data 12

4.0 Results and comparisons 15

4.1 Failure Frequency as a function of Pipe Size *15*

4.2 Failure Frequency as a function of Failure Mechanism 25

5.0 Conclusions 31

6.0 References 33

Appendix A – OPDE-Light Database

Appendix B – Independent Database

Appendix C – Collapsed OPDE Data

Appendix D – Copies of References

List of Figures

Figure 4.1-1. Normalized pipe failure frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants

Figure 4.1-2 Normalized rupture frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants

Figure 4.1-3. Normalized Failure Frequency Distribution for PWRs

Figure 4.1-4. Normalized Failure Frequency Distribution for BWRs

Figure 4.1-5. Normalized pipe failure frequencies as a function of pipe size for PWRs

Figure 4.1-6. Normalized pipe failure frequencies as a function of pipe size for BWRs

Figure 4.1-7. Normalized pipe failure frequencies as a function of pipe size for PWRs using the Modified Analysis Method.

Figure 4.1-8. Normalized pipe failure frequencies as a function of pipe size for PWRs using the Modified Analysis Method.

Figure 4.2-1. Normalized pipe failure frequency as a function of Pipe Group Size for PWRs

Figure 4.2-2. Normalized pipe failure frequency as a function of Pipe Group Size for BWRs

Figure 4.3-1. PWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

Figure 4.3-2. BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

Figure 4.3-3. PWR and BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

Figure 4.3-4. Pipe Failure by Corrosion as a Function of Pipe Size (PWR & BWR)

Figure 4.3-5. Pipe Failure by Fatigue as a Function of Pipe Size (PWR & BWR)

Figure 4.3-6. Pipe Failure by Mechanical Failures as a Function of Pipe Size (PWR & BWR)

Figure 4.3-7. Pipe Failure by Stress Corrosion Cracking as a Function of Pipe Size (PWR & BWR)

List of Tables

Table 1-1. NRC Total Preliminary BWR and PWR Frequencies

Table 2-1. Excerpt from "OPDE-Light" Database

Table 2-2. Description of Plant Systems and Type of Piping

Table 2-3. Definition of OPDE Pipe Size Groups

Table 2-4. OPDE Pipe Failure Definitions

Table 3-1. Definition of Pipe Size Groups

Table 3-2. Definition of NRC LOCA Groups

Table 4.1-1. OPDE Calculated, and NRC Predicted, Normalized Failure Frequencies (1/cal-yrs).

Table 4.1-2. Normalized Rupture Frequencies

Table 4.1-3. Summary of PWR Pipe Failures from the OPDE Database as of 2-24-05

Table 4.1-4. Summary of BWR Pipe Failures from OPDE Database as of 2-24-05

Table 4.1-6. Summary of PWR Pipe Failures from OPDE Database as of 2-24-05, using the Modified Analysis Method.

Table 4.1-7. Summary of BWR Pipe Failures from OPDE Database as of 2-24-05, using the Modified Analysis Method.

Table 4.2-1. OPDE Calculated, NRC Predicted, and Independent Database Calculated, Normalized Failure Frequencies (1/cal-yrs)

Table 4.3-1. Failure Frequencies of Pipes for each Failure Mechanism

1.0 Detailed Introduction of Problem

In order to ensure the safety of nuclear plants the cooling performance of the Emergency Core Cooling System (ECCS) must be calculated in accordance with an acceptable evaluation model, and must be calculated for a number of postulated loss-of-coolant accidents (LOCA) resulting from pipe breaks of different sizes, locations, and other properties. This is done to provide sufficient assurance that a plant can handle even the most severe postulated LOCA. LOCA's are hypothetical accidents that would result from the loss of reactor coolant, at a rate in excess of the capability of the reactor coolant makeup system. Currently, the evaluation criteria for these types of accidents state that pipe breaks in the reactor coolant pressure boundary up to and including a break equivalent in size to the double-ended rupture of the largest pipe in the reactor coolant system must be considered. In the case of such an event the NRC has set forth the following criteria that must be met for a design to be considered acceptable [37]:

a. Peak cladding temperature must not exceed 2200° F.

b. Maximum cladding oxidation must not exceed 0.17 times the total cladding thickness before oxidation.

c. Maximum hydrogen generation. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

d. A coolable geometry of the core must be maintained.

e. After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

While requiring that all plants be analyzed in the case of a double-ended guillotine break of the largest pipe restricts the design, it does maintain a large safety margin ensuring the plant is covered in all pipe break situations. However, an impetus for change has resulted from materials research, analysis, and experience which indicate that the catastrophic rupture of a large pipe at a nuclear power plant is a very low probability event. The hypothesis that is currently being set forth is that small pipes break more frequently than large pipes. The criteria would change so that the NRC would refocus their analysis efforts because they want to make sure that the appropriate amount of time and money are being invested in the areas of most concern.

Furthermore, risk analyses indicate that large break LOCA's are not significant contributors to plant risk. According to a presentation given by Dr. Brian Sheron of the NRC at Penn State in the Fall 2004, "using the double ended break of the largest pipe in the reactor coolant system as the design basis for the plant results in ECCS equipment requirements which are inconsistent with risk insights and places an unwarranted emphasis and resource expenditure on low risk

contributors. This also places constraints on operations which are unnecessary from a public health and safety perspective." Therefore, the proposed rule change would use the pipe size with the largest break frequency as the design basis for pipe rupture and accident analysis of the plant. A pipe size with a 10 inch diameter is currently being suggested. [37]

The proposed change would divide the break spectrum into two categories based upon the likelihood of a break. Breaks of higher likelihood, or those smaller than 10 inches, would need to meet the current requirements set forth in 10 CFR 50.46. These include criteria (a) through (e) above. On the other hand, breaks of a lower likelihood, or those larger than 10 inches up to and including a double-ended guillotine break of the largest pipe in the reactor coolant system, would only need to meet the requirements of maintaining a coolable geometry and having the capability for long term cooling. Thus, criteria (a), (b), and (c) would be eliminated for these cases. [37]

The purpose of this project was to collect data on instances of pipe breaks, leaks, and cracking. These failures included pipe failures from broken pipes either by splits, ruptures, or guillotines, and cracks in pipes, either circumferential or length wise. For each instance found the plant type, pipe diameter, type of pipe, failure mechanism, and type of failure was recorded. Only stainless steel and carbon steel pipes were considered. Then, normalized failure frequency distributions were developed and compared to NRC predictions.

The predicted NRC failure frequencies were taken from Table 3 on page 14 of 10 CFR 50.46, LOCA Frequency Development [38]. This table is replicated below.

Table 1-1. NRC Total Preliminary BWR and PWR Frequencies.

Plant Type	Effective Break Size (inches)	Current Day Estimates (per cal. yr)			
		5%	Median	Mean	95%
BWR	1/2	3.0E-05	2.2E-04	4.7E-04	1.7E-03
	1 7/8	2.2E-06	4.3E-05	1.3E-04	5.0E-04
	3 1/4	2.7E-07	5.7E-06	2.4E-05	9.4E-05
	7	6.6E-08	1.4E-06	6.0E-06	2.3E-05
	18	1.5E-08	1.1E-07	2.2E-06	6.3E-06
	41	3.5E-11	8.5E-10	2.3E-06	8.6E-09
PWR	1/2	7.3E-04	3.7E-03	6.3E-03	2.0E-02
	1 7/8	6.9E-06	9.9E-05	2.3E-04	8.5E-04
	3 1/4	1.6E-07	4.9E-06	1.6E-05	6.2E-05
	7	1.1E-08	6.3E-07	2.3E-06	8.8E-06
	18	5.7E-10	7.5E-09	3.9E-08	1.5E-07
	41	4.2E-11	1.4E-09	2.3E-08	7.0E-08

2.0 Data Collected

For this project our group collected two, independent sets of data. The first set was provided by the OECD Pipe Failure Data Exchange Project (OPDE), with a total of 2891 data points. The second set consists of 67 data points collected by our group from various sources listed as references in this report. The two sets of data were not combined due to the lack of information accompanying the data presented in the OPDE database, such as plant name and exact failure size, which made identifying overlapping coverage impossible. Rather, within this report each data set was individually analyzed in order to make an overall comparison of the trends observed for each data set and the NRC predictions.

OECD Pipe Failure Data Exchange Project [3]

OECD Pipe Failure Data Exchange Project (OPDE) was established in 2002 as an international forum for the exchange of pipe failure information. It is a 3-year project with participants from twelve countries, including Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Republic of Korea, Spain, Sweden, Switzerland and the United States. "The objective of OPDE is to establish a well structured, comprehensive database on pipe failure events and to make the database available to project member organizations that provide data." [3] The OPDE database evolved from what existed in the "SLAP database" at the end of 1998 [2].

OPDE covers piping in primary-side and secondary-side process systems, standby safety systems, auxiliary systems, containment systems, support systems and fire protection systems. Furthermore, ASME Code Class 1 through 3 and non-Code piping has been considered. At the end of 2003, the OPDE database included approximately 4,400 records on pipe failure. The database also includes an additional 450 records on water hammer events where the structural integrity of piping was challenged but did not fail.

Access to the actual OPDE database is restricted to organizations providing input data. However, a "OPDE-Light" version of the database will be made available later this year to non-member organizations contracted by a project member to perform work or which pipe failure data is needed. This version will not include proprietary data, such as the exact pipe diameter, where failure occurred, and preclude any plant identities or dates. Our group was fortunate enough to get a copy of this "light" version of the database for BWR and PWR pipe failures reported as of February 24, 2005. A total of 2891 failures (1536 for PWR plants and 1355 for BWR plants) were provided in this database, and considered for this project.

The database listed the plant type, reactor system, apparent cause of failure, pipe size group, number of total failures for each cause and pipe size group, and then a break down of the type of failure within the category. An excerpt from the OPDE-Light database has been provided for clarification in Table 2-1 on the following page. The database, in its entirety, has been included in Appendix A of this report.

However, there are a few problems with this database related to the purpose of this project. First, since the database did not provide the type of pipe (carbon or stainless) for each failure, a reasonable prediction of what type of pipe was involved in the failure based on the plant system, which was given, was made. The type of pipe assumed for each system is also given in the following page in Table 2-2.

Additionally, as previously mentioned, no explicit pipe diameters were given for each failure due to the proprietary nature of this information. Rather, the failures were collected into group sizes before it was sent out. A total of six group sizes were utilized by OPDE. The range of pipe diameters that comprise each group is given in Table 2-3. The main problem with these groupings, and the database in general, is that pipes larger than 10 inches in diameter are all grouped together and there is no way of determining how much larger than 10 inches they actually were. Finally, for the purpose of this analysis any crack, leak, or issue (i.e. wall thinning) with the pipe was considered to be a failure. However, the OPDE database lists the information by type of failure. The definitions of each failure type have been included in Table 2-4.

Independently Collected Data [5-36]

For the purpose of this project our group collected separate information on instances of piping failures and their causes. The information was collected primarily from Nuclear Regulatory Commission (NRC) bulletins, information notices, event reports, and generic letters. Our group was able to compile a total of 67 instances of piping failures. This database is provided in Appendix B. While our database is much smaller than the one compiled by the OECD Pipe Failure Exchange Project, it provides an independent check of the trends observed by that database.

A list of references is provided at the end of this report, and some of the actual references, printed from the NRC website, have been included in Appendix D.

Table 2-1. Excerpt from "OPDE-Light" Database

PLANT TYPE	PIPE TYPE	SYSTEM GROUP	APPARENT CAUSE	PIPE SIZE GROUP	TOTAL NO. OF RECORDS	Crack-Full	Crack-Part	Deformation	Large Leak	Leak	P/H-Leak	Rupture	Severance	Small Leak	Wall thinning
BWR	SS	RAS	Severe overloading	2	3			1				2			
BWR	SS	RCPB	external damage	3	1			1							
BWR	SS	RCPB	Severe Overloading	4	1			1							
BWR	SS	SIR	Severe overloading	6	1			1							
BWR	CS	STEAM	Water Hammer	6	1			1							
BWR	SS	RCPB	HF:Welding Error	3	7	1				1	1			4	
BWR	SS	RAS	TGSCC - Transgranular SCC	2	7	1	1				1			4	
BWR	SS	SIR	IGSCC - Intergranular SCC	4	4	1					2			1	
BWR	SS	RAS	IGSCC - Intergranular SCC	4	56	1	32				9		1	13	
BWR	SS	SIR		0	1	1									
BWR	SS	RCPB	TGSCC - Transgranular SCC	1	1	1									
BWR	SS	SIR	IGSCC - Intergranular SCC	2	3	1	1							1	
BWR	SS	RCPB	Overpressurization	4	2	1						1			
BWR	CS	AUXC	Vibration-Fatigue	5	1	1									

Table 2-2. Description of Plant Systems and Type of Piping.

Plant Group	Representative Plant System Names	Type of Piping
AUXC	Service Water Systems, Raw Water Cooling Systems	Carbon
CS	Containment Spray System	Stainless
EHC	Electro-Hydraulic Control System	Carbon
EPS	Emergency Diesel Generator System	Stainless
FPS	Fire Protection System	Carbon
FWC	Feedwater & Condensate Systems	Stainless
IA-SA	Instrument Air & Service Air Systems	Carbon
PCS	Power Conversion Systems (incl. Steam Extraction Lines, Heater Drain Lines, etc.)	Carbon
RAS	Reactor Auxiliary Systems (incl., CVCS, RWCU, CCWS, CRD)	Stainless
RCPB	Reactor Coolant Pressure Boundary	Stainless
SG	Steam Generator Systems (e.g., S/G Blowdown System)	Carbon
SIR	Safety Injection & Recirculation Systems	Stainless
STEAM	Main Steam (from nuclear boiler/steam generator up to turbine steam admission)	Carbon

Table 2-3. Definition of OPDE Pipe Size Groups.

Pipe Size Group	Corresponding Pipe Diameters (mm)	Corresponding Pipe Diameters (inches)
1	DN < 15	DN < 0.6
2	15 < DN < 25	0.6 < DN < 1.0
3	25 < DN < 50	1.0 < DN < 2.0
4	50 < DN < 100	2.0 < DN < 4.0
5	100 < DN < 250	4.0 < DN < 10.0
6	DN > 250	DN > 10.0

Table 2-4. OPDE Pipe Failure Definitions.

Type	Description
Crack - Part	Part through-wall crack (≥ 10% of wall thickness)
Crack - Full	Through-wall but no active leakage; leakage may be detected given a plant mode change involving cooldown and depressurization.
Wall Thinning	Internal pipe wall thinning due to flow accelerated corrosion - FAC
Small Leak	Leak rate within Technical Specification limits
Pinhole Leak	Differs from "small leak" only in terms of the geometry of the throughwall defect and the underlying degradation or damage mechanism
Large Leak	Leak rate in excess of Technical Specification limits but within the makeup capability of safety injection systems
Severance	Full circumferential crack – caused by external impact/force, including high-cycle mechanical fatigue – limited to small-diameter piping, typically
Rupture	Large flow rate and major, sudden loss of structural integrity. Invariably caused by influences of a degradation mechanism (e.g., FAC) in combination with a severe overload condition (e.g., water hammer)

3.0 Collapsing and Analyzing the Collected Data

The next important step in this analysis was collapsing the collected information into a usable form by specifying pipe size groups and failure mechanisms. The data was broken into separate bins based on plant type (PWR or BWR), pipe type (carbon or stainless), failure mechanism, and pipe size. Table 3-1 below lists the pipe diameters included in each bin for this analysis.

Table 3-1. Definition of Pipe Size Groups.

OPDE Pipe Size Groups	Corresponding Pipe Diameters (inches)
1+2	0.0-1.0
3	1.0-2.0
4	2.0-4.0
5	4.0-10.0
6	> 10.0

Note: This grouping of piping diameters includes one less bin than used by the OPDE database. Combination of the data from groups 1 and 2 of the OPDE database allowed the bin sizes to correspond more readily with those used by the NRC for listing predicted failure frequencies, taken from page 14 of 10 CFR 50.46, LOCA Frequency Development. The categories used for the NRC predicted failure frequencies are given in Table 3-2. [38]

Table 3-2. Definition of NRC LOCA Groups.

LOCA Category	Effective Break Size (inches)
1	1/2
2	1 7/8
3	3 1/4
4	7
5	18
6	41

It can be seen that for LOCA categories 1 though 5 the effective break sizes fall within the ranges listed for the pipe size groups, after pipe size groups 1 and 2 from the OPDE database were combined. LOCA category 6 was not considered in this analysis since the OPDE database did not provide specific information for pipes larger than 10 inches. The effect of this on the results will be discussed later in this report.

After collapsing the data based on pipe size, the data was then collapsed further by combining some of the failure mechanisms. The following is a list of the failure mechanisms that are used to group the data. Several items have been placed into general categories for simplification purposes.

1. Corrosion
2. Flow Accelerated Corrosion (FAC)
3. Microbiological Induced Corrosion (MIC)
4. Erosion
5. Fatigue
    a. Thermal Fatigue
    b. Vibration Fatigue
6. Human Factors (already combined in the OPDE database)
    a. Welding Error
    b. Fabrication Error
    c. Human Error
7. Mechanical Failures
    a. Excessive Vibration
    b. Overpressurization
    c. Overstressed
    d. Severe Overloading
8. Stress Corrosion Cracking
9. Water Hammer
10. Miscellaneous
    a. Brittle Fracture
    b. Cavitation
    c. External Damage
    d. Fretting
    e. Freezing
    f. Hot Cracking
    g. Hydrogen Embrittlement
    h. Unreported

After collapsing the data, it needed to be normalized so that failure frequency distributions could be calculated. Failure frequencies were calculated in for carbon steel pipes, stainless steel pipes, and a composite (both carbon and stainless) pipes as a function of both pipe group size and failure mechanism, separately for PWR and BWR plants.

The number of failures in each bin was normalized by dividing by the total number of failures. This gives the fraction of failures for each bin size. For example, when looking at carbon steel pipes in BWRs the number of failures in each pipe group size, regardless of failure mechanism, was divided by the total number of pipe failures (carbon + stainless) in BWRs. Similarly, the number of pipe failures in each failure mechanism bin, regardless of pipe size, was divided by the total number of pipe failures in BWRs.

Then, after normalizing the data, the fractional size in each bin was divided by 3390 calendar years of operation. This gives a failure frequency in 1/calander-years for each bin size. The number 3390 represents the number of reactor years experience in the US (2745 years) as of the end of 2003; divided by an assumed availability factor of 0.81 to get calendar years.

The normalization by pipe size (regardless of failure mechanism) and failure mechanism (regardless of pipe size) was repeated for BWR stainless steel failures, BWR composite failures, PWR carbon failures, PWR stainless steel failures, PWR composite failures, total carbon steel failures, total stainless steel failures, and total composite failures for a total of nine situations analyzed and a total of eighteen frequency distributions developed (nine as a function of pipe size and nine as a function of failure mechanism).

Finally, the frequency distributions developed were based both on pipe size and failure mechanisms for the different types of pipes had to be plotted against the NRC's predicted frequencies. Semi-log plots of failure frequency as a function of pipe group size were used.

OPDE Database

In order to use this database it had to be collapsed into a more useful form. First, after determining the type of pipe associated with each system, the plant system was no longer taken into consideration. Next, for the purpose of this project any type of failure (i.e. crack, rupture, wall thinning) was considered to be a pipe failure. Furthermore, as shown above several causes of failure were combined together into one failure mechanism category. The collapsed form of this database is provided in Appendix C.

Independent Database

There were 67 incidents recorded, which in the end did not provide enough data points in each bin to come up with a good normalized frequency distribution. When the data was sorted on plant type, then pipe material and finally on pipe size, various bins of pipe sizes had zero incidents. Appendix B is a listing of all of the incidents which were found. This listing is sorted on plant type, pipe material, and finally on pipe size. The highlighted incidents throughout the appendix represent incidents for which not enough information was given in the source to include this data in our analysis.

Failure mechanism plots were not made due to the lack of variety in failure mechanisms. The majority of the failure mechanisms were erosion/corrosion and stress corrosion cracking.

4.0 Results and Comparisons

4.1 Pipe Failures as a function of Pipe Size from OPDE Data

This section of the report examines the results of pipe failures as a function of pipe size. Normalized failure frequencies for carbon steel, stainless steel, and composite (carbon and stainless) pipes are presented individually for PWRs and BWRs. The NRC has developed their own failure frequencies for PWR and BWR plants as function of pipe size, but does not have separate frequencies for carbon and stainless steel pipes.

Table 4.1-1 lists the normalized failure frequencies for both PWR and BWR plants, regardless of pipe type, calculated from the OPDE database data and the NRC mean predictions [38].

Table 4.1-1. OPDE Calculated, and NRC Predicted, Normalized Failure Frequencies (1/cal-yrs).

Plant Type	Pipe Size Groups (inches)	OPDE Results	NRC Predictions
PWR	0.0-1.0	1.3E-04	6.3E-03
	1.0-2.0	4.4E-05	2.3E-04
	2.0-4.0	2.9E-05	1.6E-05
	4.0-10.0	4.6E-05	2.3E-06
	> 10.0	4.2E-05	3.9E-08
BWR	0.0-1.0	8.2E-05	4.7E-04
	1.0-2.0	2.3E-05	1.3E-04
	2.0-4.0	5.6E-05	2.4E-05
	4.0-10.0	6.2E-05	6.0E-06
	> 10.0	7.2E-05	2.2E-06

Figure 4.1-1 displays this information graphically on a semi-log plot with normalized failure frequencies on the y-axis and the pipe size groups on the x-axis. The figure shows that the results of the OPDE database underestimate the failure frequency for the smaller pipe size groups and overestimate the failure frequency for the larger pipe size groups compared to the NRC predictions for both PWRs and BWRs. However, there is less disparity in the two BWR predictions than the two PWR predictions.

The NRC predicts that PWR plants are much more likely to have pipe failures in smaller pipes than larger pipes. This trend remains the same in NRC prediction for BWR plants, but is not nearly as drastic. The OPDE results for both PWR and BWR plants show a much more consistent failure frequency both over the range of pipe sizes and between PWR and BWR plants.

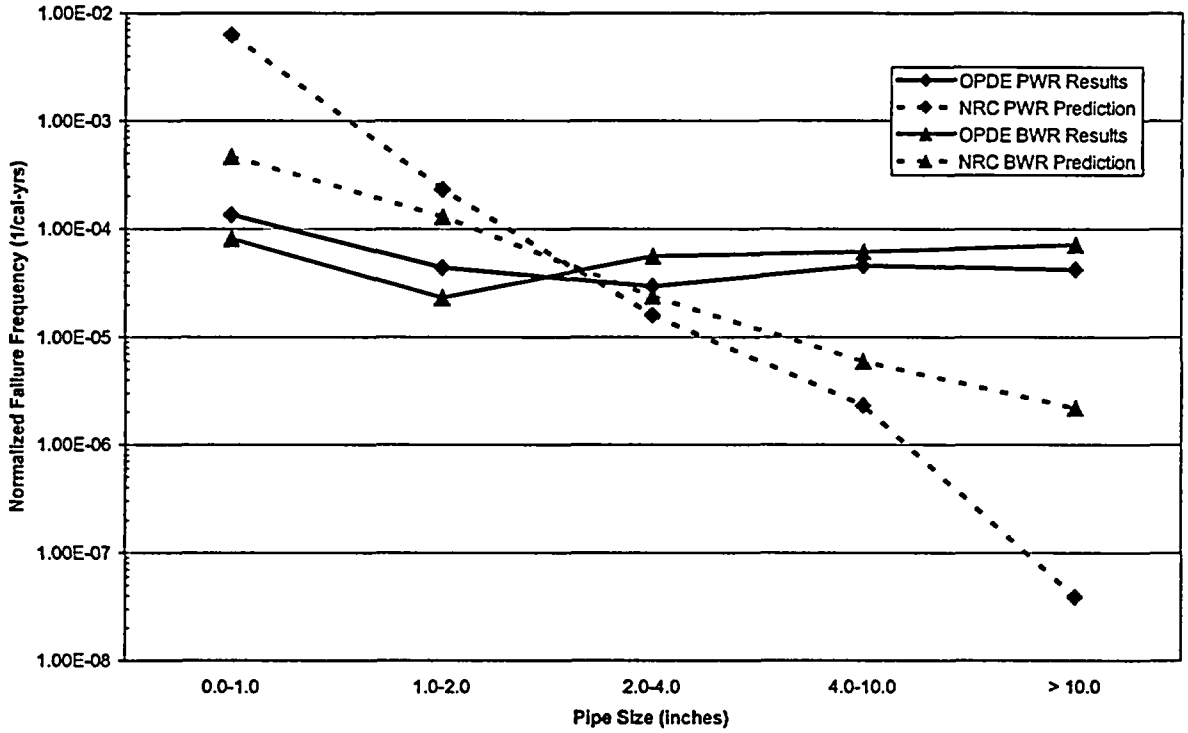

Figure 4.1-1. Normalized pipe failure frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants.

There were three issues in the data analysis that were initially thought to factor into the difference in results between the analyzed OPDE database and the NRC predictions. The first assumption was that all types of cracks, leaks, ruptures, or other issues were considered to be a complete failure in the pipe. In actuality this is not true since inspections or other indicators may catch a crack or leak before a complete failure occurs. As a result, a separate analysis considering only the pipe ruptures listed in the OPDE database was conducted. However, the calculated frequency distribution considering only ruptures did not change significantly, in either trend or magnitude, from the results obtained when considering all issues to be a failure. The results of this rupture only analysis are shown below in Figure 4.1-2.

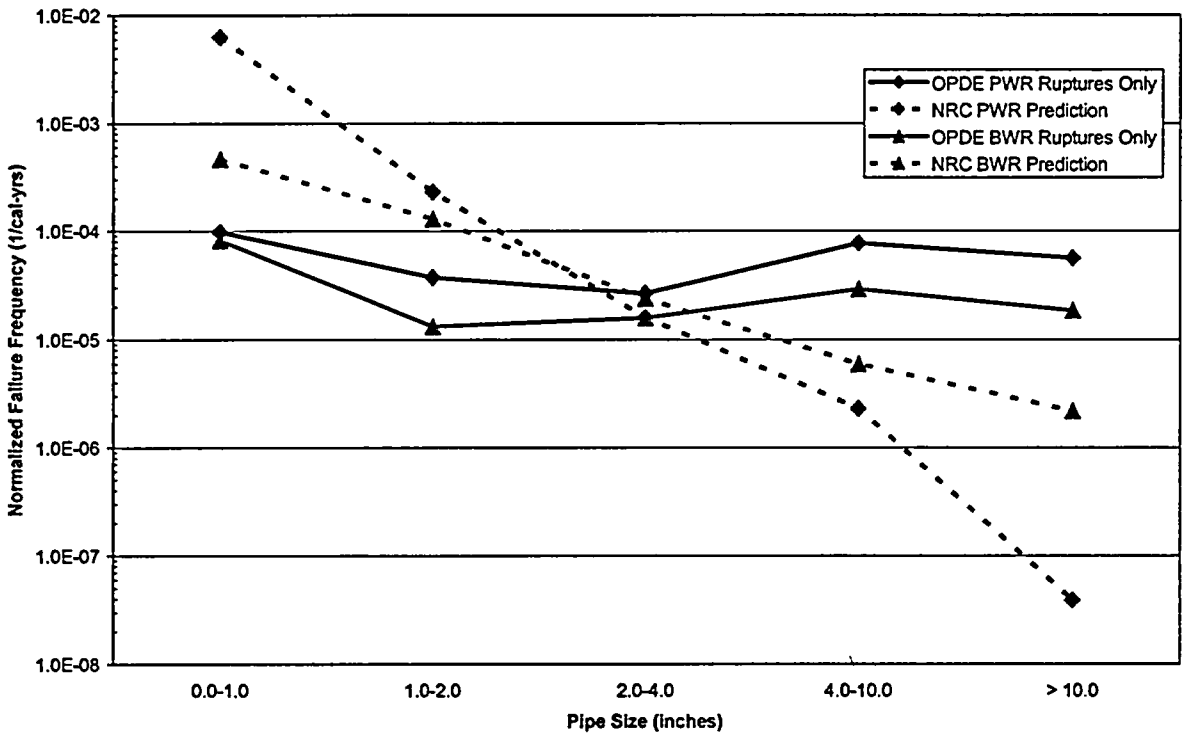

Figure 4.1-2 Normalized rupture frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants.

The data for this plot is shown in Table 4.1-2.

Table 4.1-2. Normalized Rupture Frequencies.

Plant Type	Pipe Size (inches)	Instances of Rupture	Normalized Failure Frequency (1/cal-yrs)
PWR	0.0-1.0	37	9.8E-05
	1.0-2.0	14	3.7E-05
	2.0-4.0	10	2.7E-05
	4.0-10.0	29	7.7E-05
	> 10.0	21	5.6E-05
	Total	111	---
BWR	0.0-1.0	31	8.2E-05
	1.0-2.0	5	1.3E-05
	2.0-4.0	6	1.6E-05
	4.0-10.0	11	2.9E-05
	> 10.0	7	1.9E-05
	Total	60	---

The second assumption of concern is the nature of the information contained in the OPDE database. Since the "light" version of the database did not specify the exact pipe size due to the proprietary nature of this information, all pipe failures greater than 10 inches were included in one bin for this analysis. However, for the NRC predictions there are two categories for pipes greater than 10 inches, LOCA categories 5 and 6. As a result, the OPDE calculated failure frequencies for the largest pipe group size would be expected to be larger in magnitude than the NRC's predictions since it covers a wider range of pipe sizes, and thereby a greater fraction of the total when normalized.

The final concern is the OPDE database excludes instances of steam generator tube rupture (SGTR) from consideration. By doing this the total number of failures in the smaller pipe size groups is reduced, and the calculated frequencies are lower for the smaller pipe size groups than if SGTR had been considered.

The next two plots, Figure 4.1-3 and Figure 4.1-4, present the same data as is included in Figure 4.1-1, but these figures include the ranges for the NRC prediction. It can be seen that even when the range of validity is taken into consideration, a large portion of the distribution still falls outside the boundaries for both PWRs and BWRs.

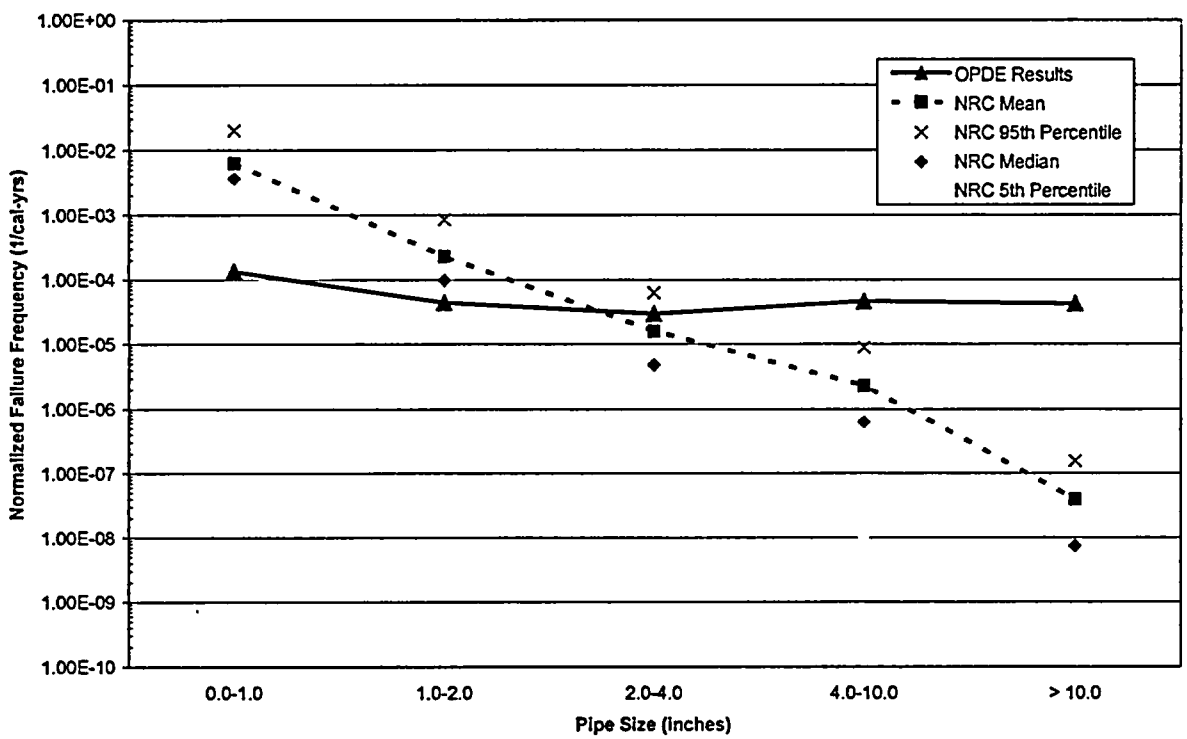

Figure 4.1-3. Normalized Failure Frequency Distribution for PWRs.

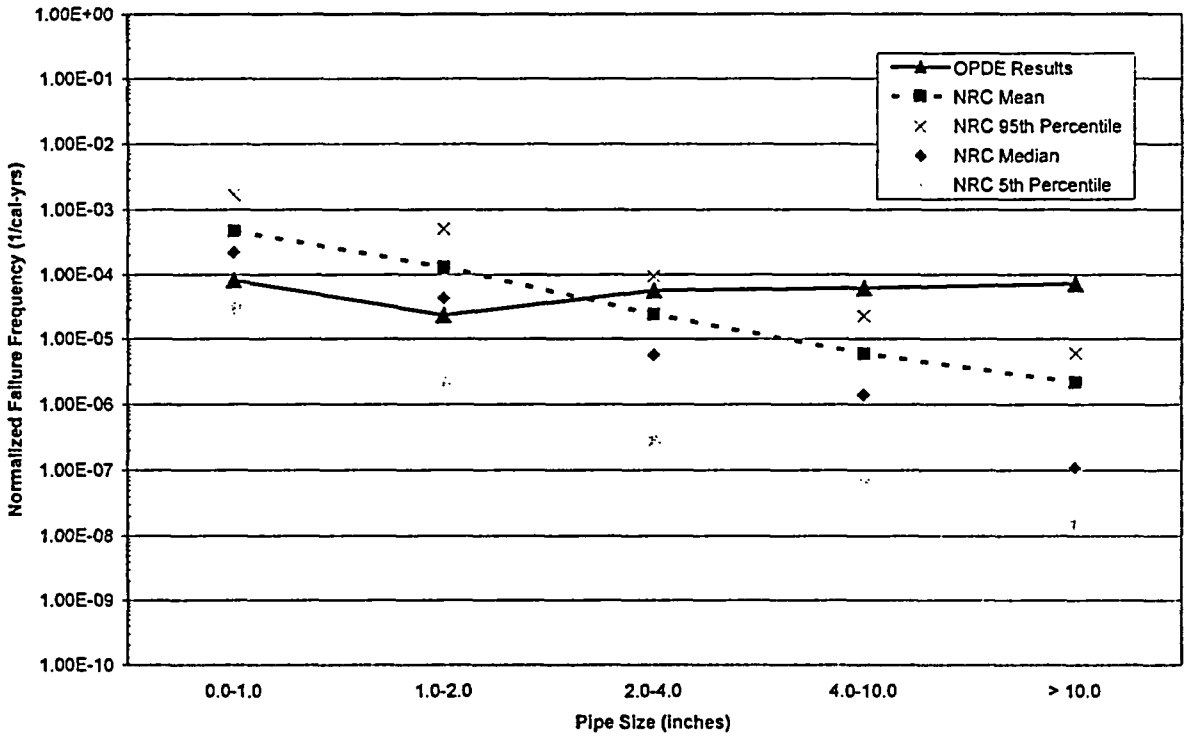

Figure 4.1-4. Normalized Failure Frequency Distribution for BWRs.

Table 4.1-3 and Table 4.1-4 serve as summaries of the information on pipe failure as a function of pipe size and pipe type from the OPDE database for PWRs and BWRs respectively. All the data contained in these tables was normalized based on the total number of failures for the given plant type (1355 for BWR and 1536 for PWR).

Table 4.1-3. Summary of PWR Pipe Failures from OPDE Database as of 2-24-05

Pipe Size (inches)	Both Carbon Steel and Stainless Steel Pipes		Carbon Steel Pipes Only		Stainless Steel Pipes Only	
	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)
0.0-1.0	698	1.3E-04	154	3.0E-05	544	1.0E-04
1.0-2.0	228	4.4E-05	74	1.4E-05	154	3.0E-05
2.0-4.0	153	2.9E-05	78	1.5E-05	75	1.4E-05
4.0-10.0	238	4.6E-05	126	2.4E-05	112	2.2E-05
> 10.0	219	4.2E-05	93	1.8E-05	126	2.4E-05
Total	1536	---	525	---	1011	---

Table 4.1-4. Summary of BWR Pipe Failures from the OPDE Database as of 2-24-05

Pipe Size (inches)	Both Carbon Steel and Stainless Steel Pipes		Carbon Steel Pipes Only		Stainless Steel Pipes Only	
	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)
0.0-1.0	375	8.2E-05	118	2.6E-05	257	5.6E-05
1.0-2.0	107	1.1E-05	32	7.0E-06	75	1.6E-05
2.0-4.0	259	2.6E-05	32	7.0E-06	227	4.9E-05
4.0-10.0	284	2.9E-05	50	1.1E-05	234	5.1E-05
> 10.0	330	3.4E-05	39	8.5E-06	291	6.3E-05
Total	**1355**	---	**271**	---	**1084**	---

There are a few important things to note from these tables. The first is that there have been a similar number of failures reported in BWRs as PWRs (1355 vs. 1536). Second, there were 4 times as many failures of stainless steel pipes as carbon steel pipes in BWRs (1084 vs. 271), and almost two times as many stainless steel failures than carbon steel failures in PWRs (1011 vs. 525). It was not expected to find more stainless steel failures than carbon steel failures. It should also be noted that while the number of stainless steel pipe failures is about the same for both BWRs and PWRs, but nearly twice as many carbon steel failures were observed in PWR plants than BWR plants (525 vs. 271).

Figure 4.1-5 and Figure 4.1-6 shows a more detailed representation of failure frequencies as a function of pipe size for PWR plants only, and BWR plants only, respectively. These figures present the separate failure frequency distributions for carbon steel and stainless steel pipes, where the data is normalized based on the total number of failures for each plant type. Figure 4.1-5 shows that failures of stainless steel pipes are more frequent than carbon steel pipes only for smaller pipe sizes in PWRs. Figure 4.1-6 shows that stainless steel pipe failures are much more frequent than carbon steel pipe failures at all pipe sizes in BWRs.

As previously mentioned, the data for these two figures (4.1-5 and 4.1-6) was normalized using the methodology explained in the Data Analysis Section, using the total number of failures (carbon + stainless) for each plant type. Conducting the analysis in this manner allows for relative comparisons of failure frequencies to be made between the two types of pipes, however, it does not allow for the failure frequencies to be compared to the NRC predictions. As a result, a second analysis was done where the data was normalized based on the number of failures for a given pipe type in each plant type. In other words, the BWR carbon steel failures would be normalized by the total number of carbon failures in BWRs. The results of this modified analysis are given in Figure 4.1-7 and 4.1-8 for PWRs and BWRs, respectively. The summary tables, with the recalculated frequencies, have also been included as Table 4.1-5 and Table 4.1-6.

It can be seen from these two figures that conducting the analysis in this modified manner collapses the data, meaning that the failure frequencies, based strictly on pipe size, are very similar for carbon and stainless steel pipes in both types of plants. However, the fact remains that stainless pipes are still more likely to fail than carbon pipes in both plant types, based in the relative number of failures for each. More importantly, however, conducting this modified analysis did not show any substantial improvement in matching the data to the NRC predictions.

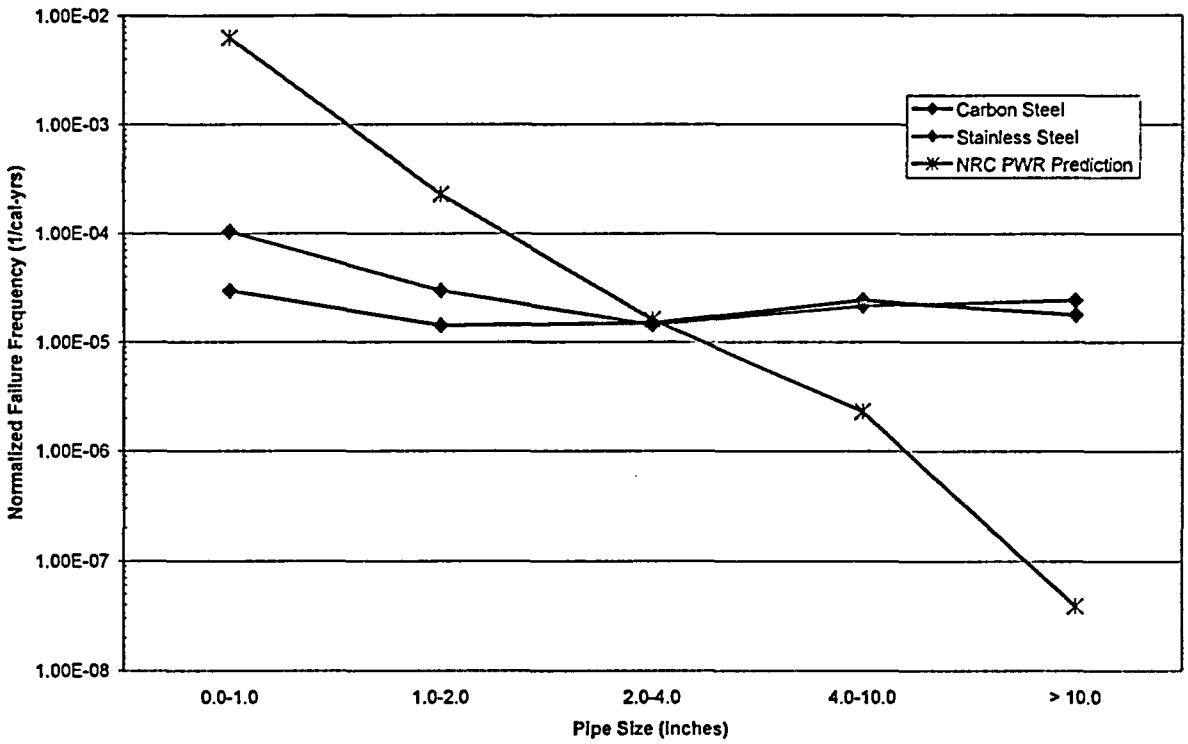

Figure 4.1-5. Normalized pipe failure frequencies as a function of pipe size for PWRs.

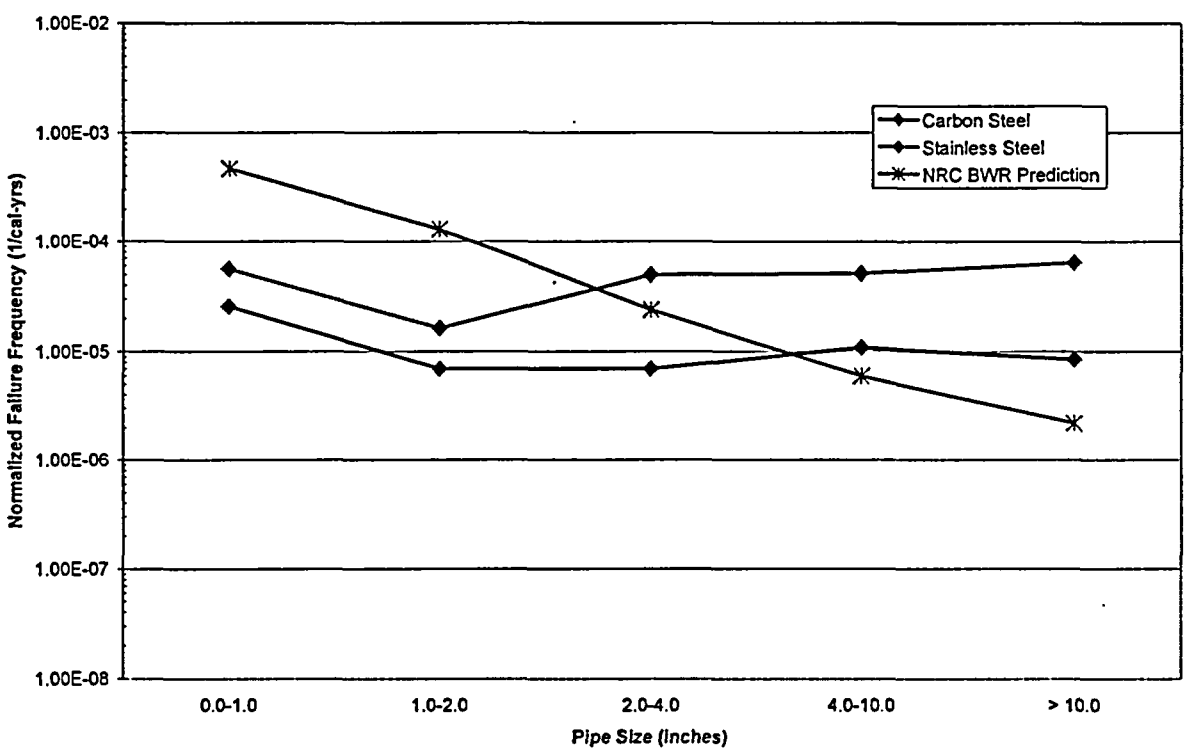

Figure 4.1-6. Normalized pipe failure frequencies as a function of pipe size for BWRs.

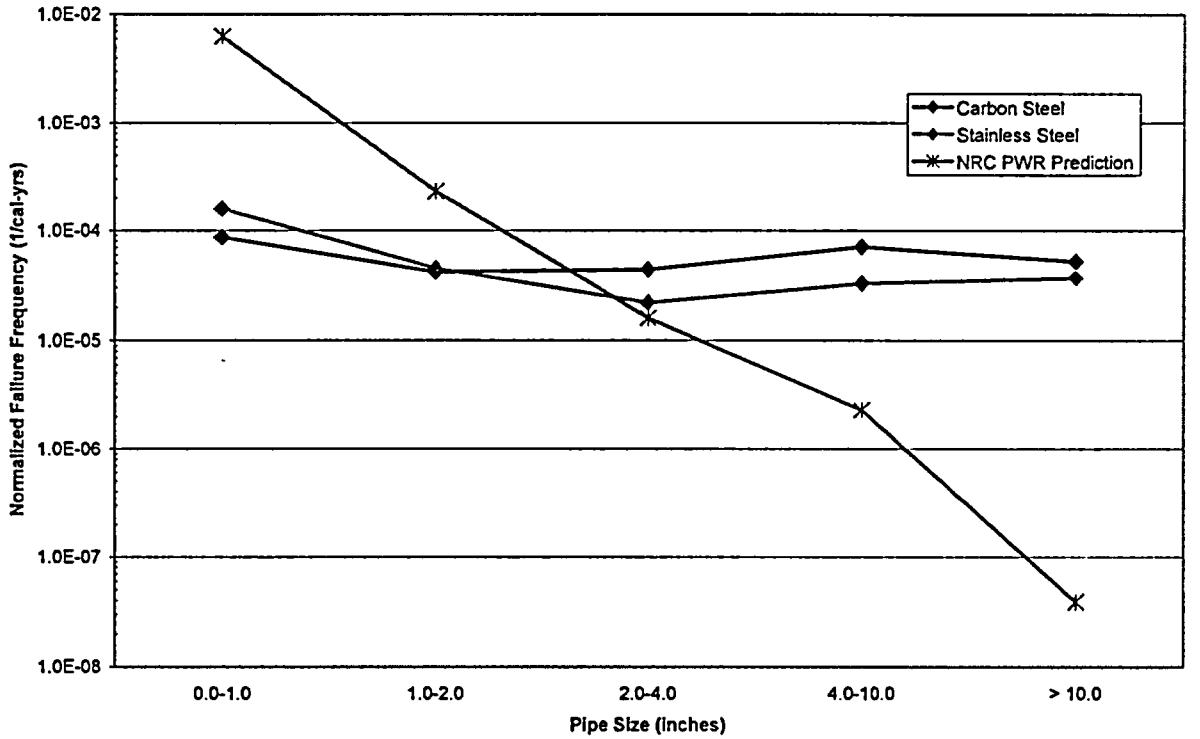

Figure 4.1-7. Normalized pipe failure frequencies as a function of pipe size for PWRs using the Modified Analysis Method.

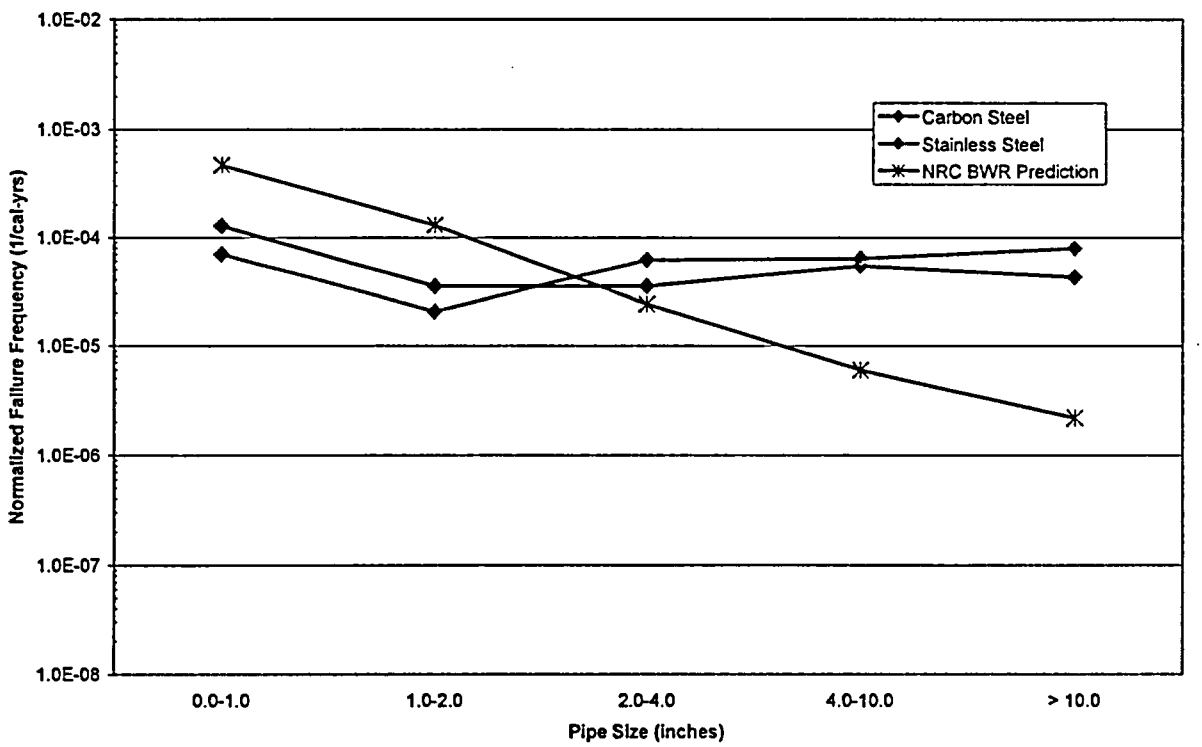

Figure 4.1-8. Normalized pipe failure frequencies as a function of pipe size for BWRs using the Modified Analysis Method.

Table 4.1-5. Summary of PWR Pipe Failures from OPDE Database as of 2-24-05, using the Modified Analysis Method.

Pipe Size (inches)	Both Carbon Steel and Stainless Steel Pipes		Carbon Steel Pipes Only		Stainless Steel Pipes Only	
	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)
0.0-1.0	698	1.3E-04	154	8.7E-05	544	1.6E-04
1.0-2.0	228	4.4E-05	74	4.2E-05	154	4.5E-05
2.0-4.0	153	2.9E-05	78	4.4E-05	75	2.2E-05
4.0-10.0	238	4.6E-05	126	7.1E-05	112	3.3E-05
> 10.0	219	4.2E-05	93	5.2E-05	126	3.7E-05
Total	**1536**	---	**525**	---	**1011**	---

Table 4.1-6. Summary of PWR Pipe Failures from OPDE Database as of 2-24-05, using the Modified Analysis Method.

Pipe Size (inches)	Both Carbon Steel and Stainless Steel Pipes		Carbon Steel Pipes Only		Stainless Steel Pipes Only	
	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)
0.0-1.0	698	1.3E-04	154	3.4E-05	544	7.0E-05
1.0-2.0	228	4.4E-05	74	9.3E-06	154	2.0E-05
2.0-4.0	153	2.9E-05	78	9.3E-06	75	6.2E-05
4.0-10.0	238	4.6E-05	126	1.5E-05	112	6.4E-05
> 10.0	219	4.2E-05	93	1.1E-05	126	7.9E-05
Total	**1536**	---	**525**	---	**1011**	---

4.2 Pipe Failures as a function of Pipe Size from Independent Data

The independent database was used primarily to confirm the OPDE database predictions, along with comparing this set of data to the NRC data. Due to the small number of incidents found in this database, some of the pipe group size data groups had values of zero. When plotted on a semi-log scale, similar to the NRC and the OPDE plots, the points do not appear on the plot for that particular pipe size group. This occurs only once for the total normalized frequency plot for BWR data.

Table 4.2-1 shows the comparison of the OPDE, NRC and the independent database frequencies.

Table 4.2-1. OPDE Calculated, NRC Predicted, and Independent Database Calculated, Normalized Failure Frequencies (1/cal-yrs).

Plant Type	Pipe Size (inches)	OPDE Data	NRC Prediction	Independent Database
PWR	0.0-1.0	1.3E-04	6.3E-03	3.6E-05
	1.0-2.0	4.4E-05	2.3E-04	3.6E-05
	2.0-4.0	2.9E-05	1.6E-05	9.4E-05
	4.0-10.0	4.6E-05	2.3E-06	2.2E-05
	> 10.0	4.2E-05	3.9E-08	1.1E-04
BWR	0.0-1.0	8.2E-05	4.7E-04	2.3E-05
	1.0-2.0	2.3E-05	1.3E-04	0.0E+00
	2.0-4.0	5.6E-05	2.4E-05	3.4E-05
	4.0-10.0	6.2E-05	6.0E-06	2.3E-05
	> 10.0	7.2E-05	2.2E-06	2.2E-04

The Figure 4.2-1 presents the overall normalized frequencies of PWR plants in the United States, and roughly 10 foreign plants for the independent database, the entire OPDE-light, and the NRC mean data given in reports. As seen, the NRC mean values of frequency decrease as the pipe size increases. Although in the two other independent sets of data obtained, the frequencies remain relatively the same throughout the pipe size groups. Pipe sizes which were less than roughly two inches had a lower frequency for the two independent data sets compared to the NRC data, and the pipe sizes above the two to four inches group size show a higher frequency compared to what the NRC's expert elicitation has predicted. This figure shows that the two independent data sources follow similar trends compared to what the NRC's prediction. The PWR frequency shows a vast difference at the higher pipe size groups which in turn contradicts the thinking that larger the pipe size have a smaller break frequency.

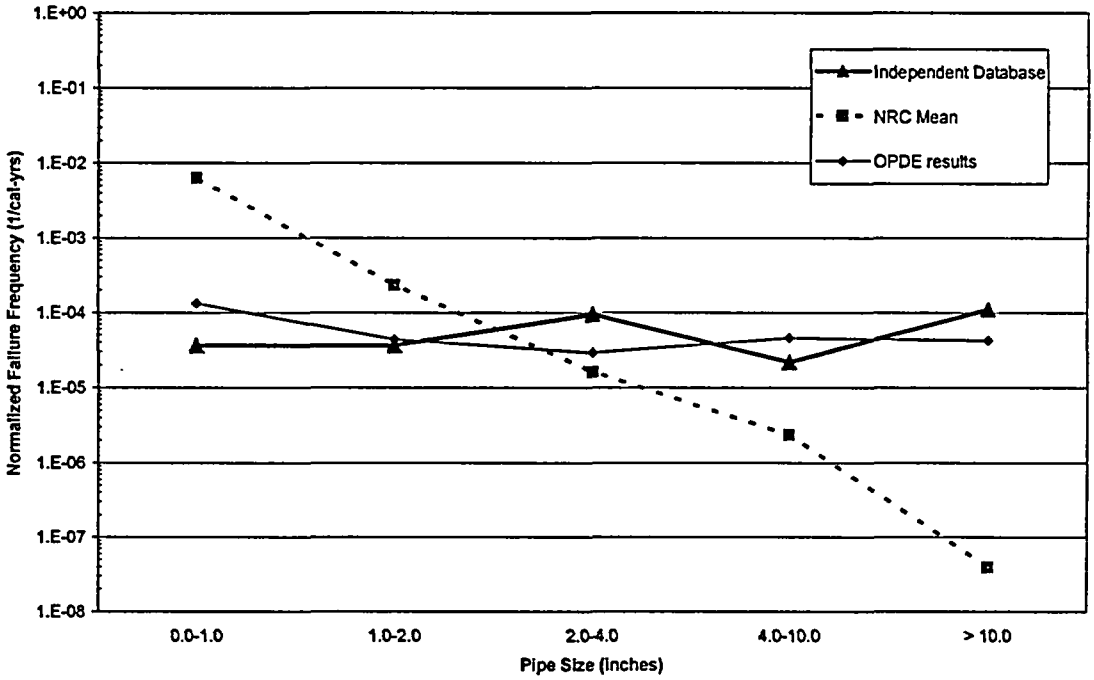

Figure 4.2-1. Normalized pipe failure frequency as a function of Pipe Group Size for PWRs.

Figure 4.2-2 presents the overall BWR data for the independent data, the OPDE-light, and the NRC data. A similar trend for each data set can be seen in BWR's as in PWR's, except that the frequency range is much smaller for BWR's than PWR's. The independent data provided no pipe failures in the pipe size group of one to two inches, and thus on a log-scale, no data point appears on the figure. Once again the independent data and the OPDE-light data coincide throughout the pipe size groups, and contradict the NRC prediction of pipe failure frequencies; except for the range of two to four inches again they are similar. Pipes which are larger than ten inches prove to have a higher frequency in the two independent data sets when compared to that of the NRC data set provided by expert elicitation.

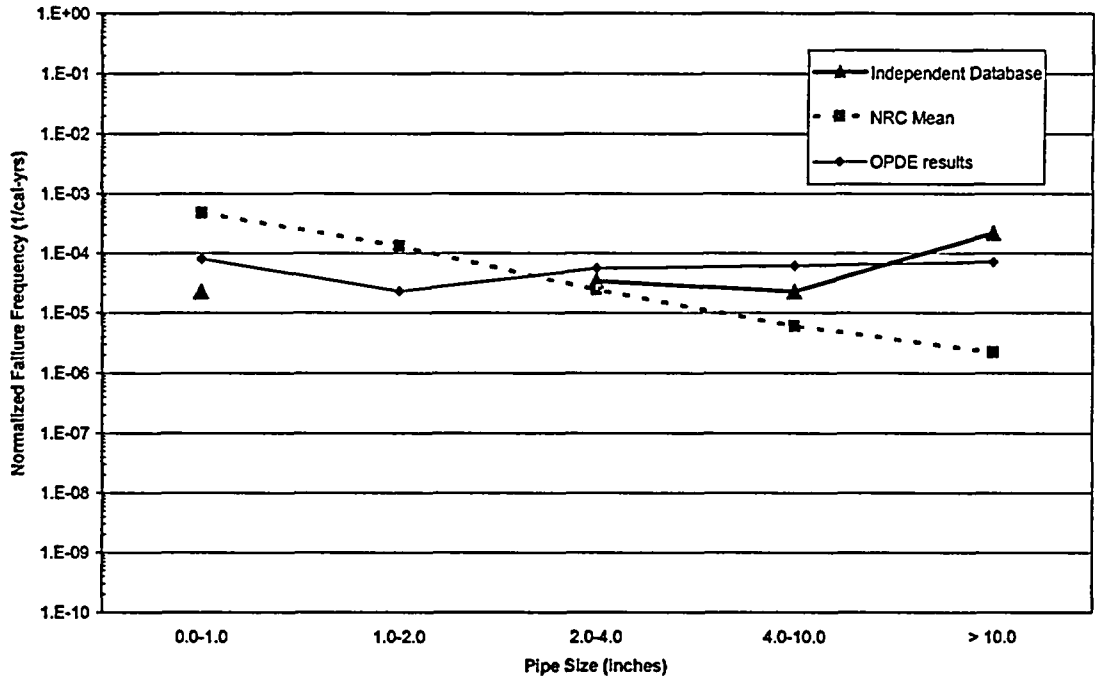

Figure 4.2-2. Normalized pipe failure frequency as a function of Pipe Group Size for BWRs.

Overall, the two independent data sets show contradicting trends when compared to the NRC normalized frequencies. Instead of the double-ended guillotine break being analyzed for every plant for the largest pipe in that plant, the NRC is trying to make the maximum break size which needs to be analyzed ten inches. The reasoning for this is due to low frequency of breaks in pipes of larger diameter than ten inches. This data above shows that the frequency from raw data does not agree with the current NRC predictions by expert elicitation. There is a high frequency of occurrence in pipe sizes greater than ten inches according to the independent data found.

4.3 Pipe Failures as a function of Failure Mechanism

This section of the report summarizes the frequency of failure mechanisms for carbon and stainless steel pipes. The information presented in figures 4.3-1 through 4.3-3 represents the normalized failure frequencies for each failure mechanism. This data is also presented in tabular form in table 4.3-1. The data was collapsed by pipe sizes and broken apart by steel type and plant type. The data was normalized for each type of steel based on the number of reactor years and the total amount of failures (carbon +stainless) for each plant.

Table 4.3-1. Failure Frequencies of Pipes for each Failure Mechanism.

Plant Type	Failure Mechanism	Carbon Steel Failure Frequency	Stainless Steel Failure Frequency	Total Failure Frequency
PWR	Corrosion	2.04E-05	5.38E-06	2.57E-05
PWR	FAC	2.29E-05	2.32E-05	4.61E-05
PWR	MIC	8.26E-06	1.92E-07	8.45E-06
PWR	Erosion	1.84E-05	2.30E-06	2.07E-05
PWR	Fatigue	1.77E-05	9.62E-05	1.14E-04
PWR	Human Factors	6.91E-06	2.42E-05	3.11E-05
PWR	Mechanical Failures	4.23E-06	7.11E-06	1.13E-05
PWR	SCC	9.60E-07	3.25E-05	3.34E-05
PWR	Water Hammer	0.00E+00	3.84E-07	3.84E-07
PWR	Misc	1.15E-06	2.69E-06	3.84E-06
BWR	Corrosion	6.31E-06	6.97E-06	1.33E-05
BWR	FAC	1.26E-05	1.37E-05	2.63E-05
BWR	MIC	1.31E-06	2.18E-07	1.52E-06
BWR	Erosion	8.71E-06	1.96E-06	1.07E-05
BWR	Fatigue	1.55E-05	4.90E-05	6.44E-05
BWR	Human Factors	5.22E-06	1.85E-05	2.37E-05
BWR	Mechanical Failures	3.92E-06	5.44E-06	9.36E-06
BWR	SCC	4.14E-06	1.36E-04	1.40E-04
BWR	Water Hammer	4.35E-07	2.18E-07	6.53E-07
BWR	Misc	8.71E-07	4.14E-06	5.01E-06

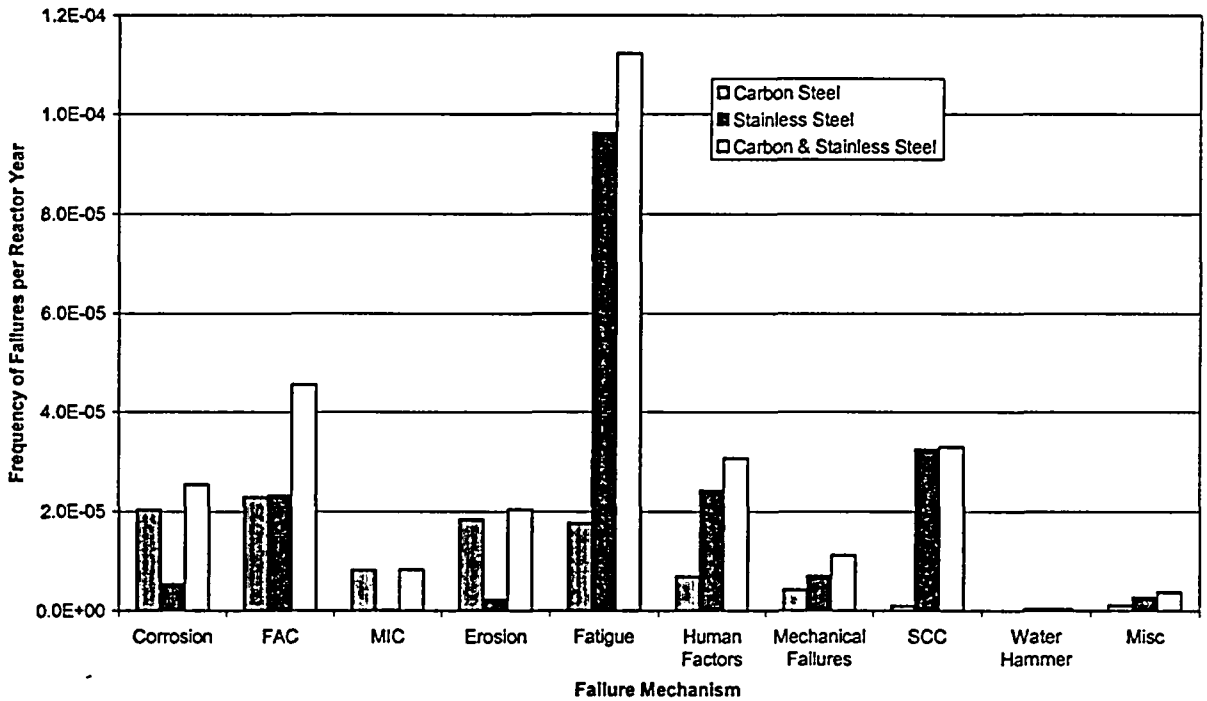

Figure 4.3-1. PWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

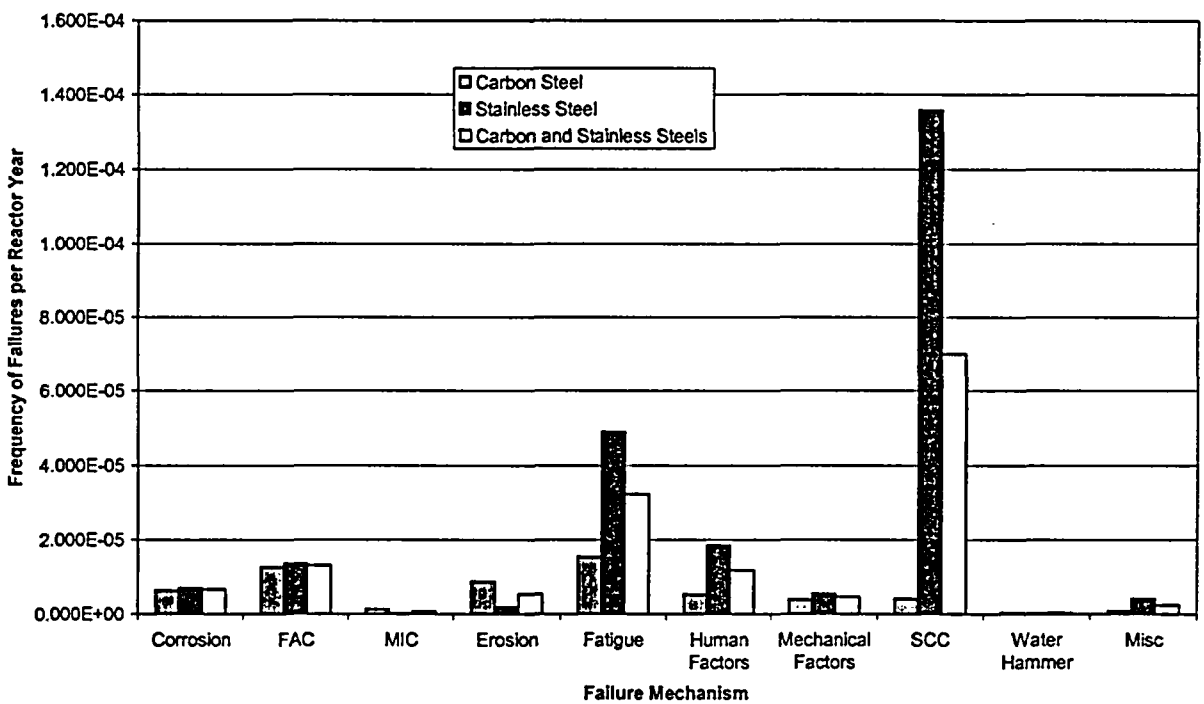

Figure 4.3-2. BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

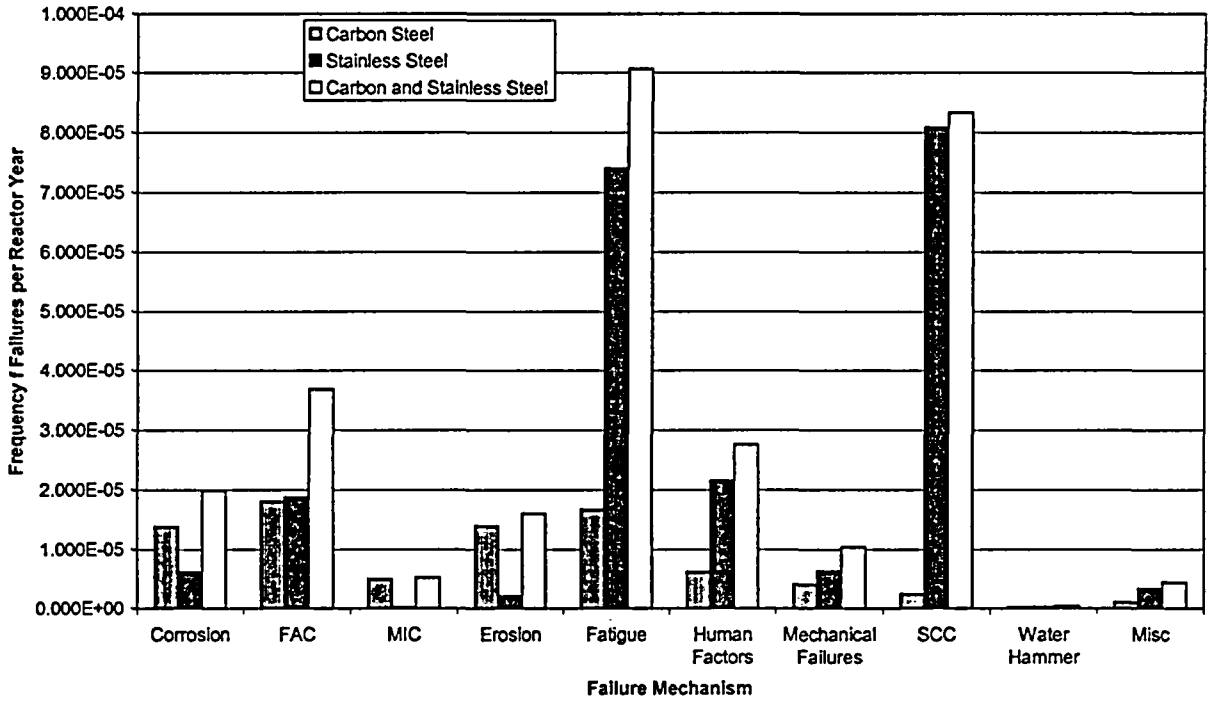

Figure 4.3-3. PWR and BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

From these plots it was determined that PWR plants are dominated by fatigue failures and BWR plants are dominated by stress corrosion cracking failures. However, in general the most frequent failure mechanisms for both plants are corrosion, fatigue, mechanical factors, and stress corrosion cracking. These four failure mechanisms were analyzed as a function of pipe size in figures 4.3-4 through 4.4-7.

For these plots corrosion includes general corrosion, flow accelerated corrosion, and microbiological corrosion. Stress corrosion cracking was not included with corrosion because the pipe failure method for stress corrosion cracking is different than the other corrosion types. Though mechanical failure frequency was not the highest, mechanical failures were chosen because they appear to be independent of pipe type and plant type. Human factors were ignored because they are a factor of quality assurance as opposed to the other failure mechanisms which are primarily a factor of operation. In regards to human factors it is not known if they have decreased with reactor operating experience because the dates of failures was not included with the OPDE data.

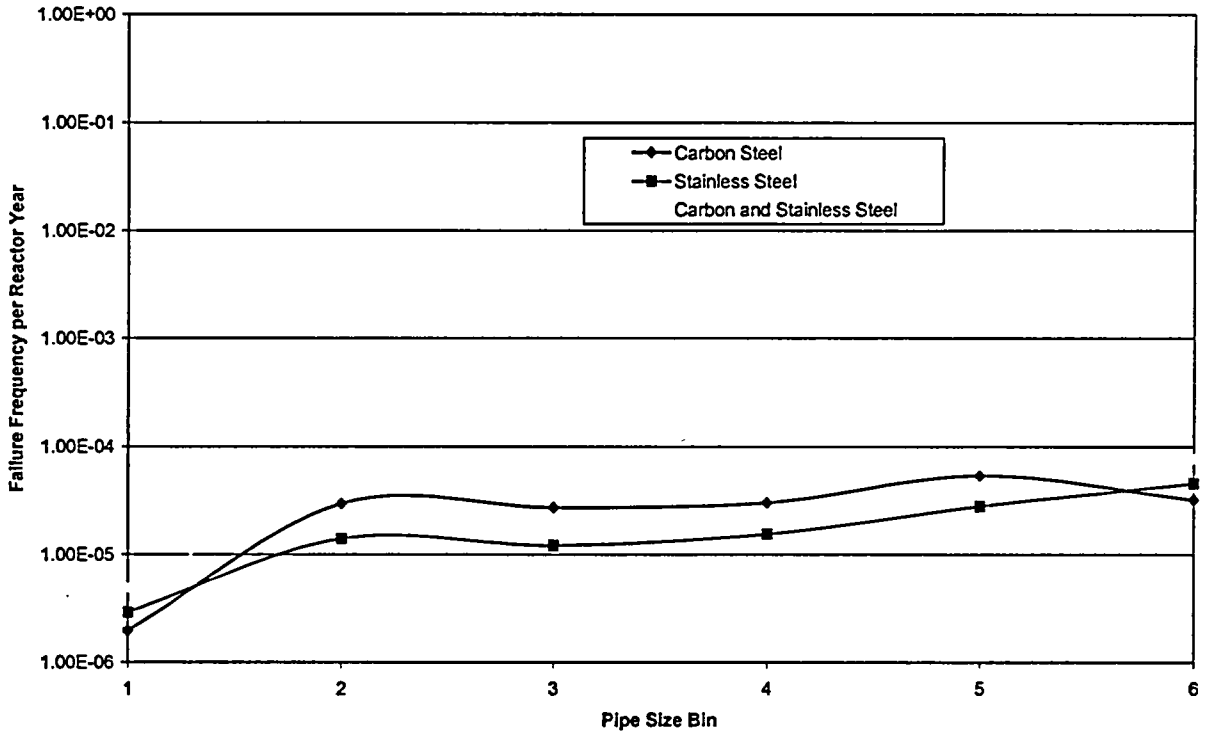

Figure 4.3-4. Pipe Failure by Corrosion as a Function of Pipe Size (PWR & BWR)

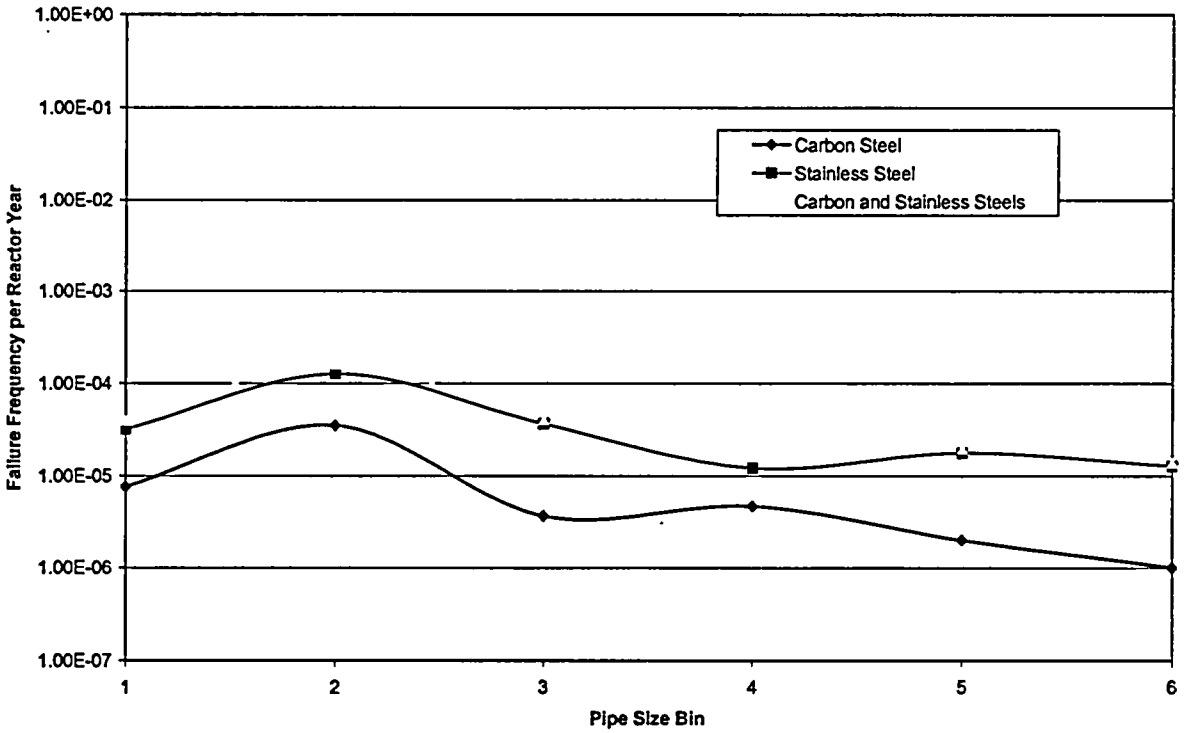

Figure 4.3-5. Pipe Failure by Fatigue as a Function of Pipe Size (PWR & BWR)

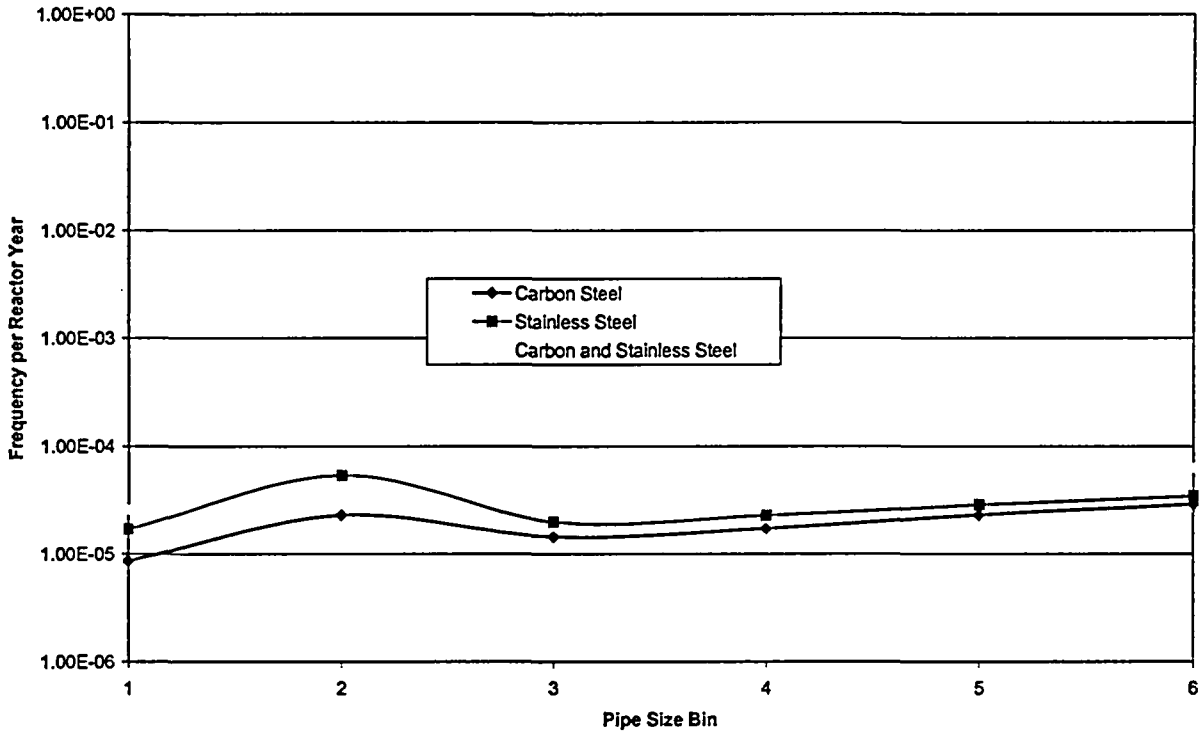

Figure 4.3-6. Pipe Failure by Mechanical Failures as a Function of Pipe Size (PWR & BWR)

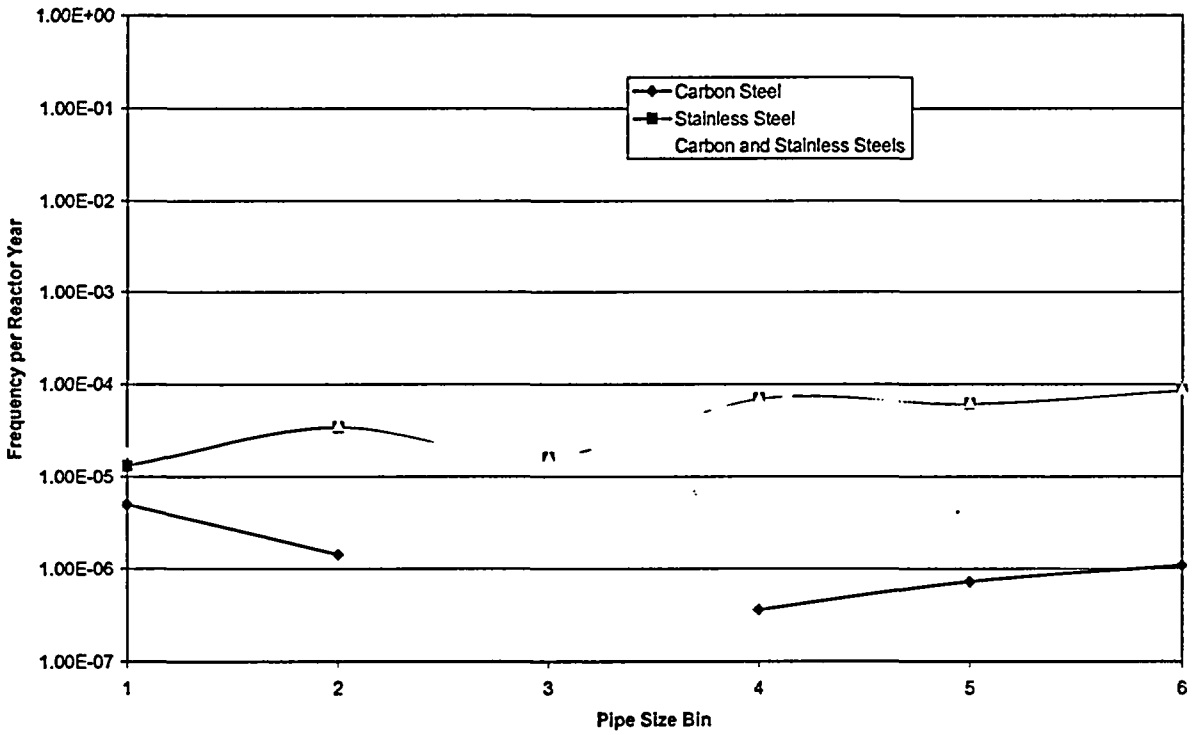

Figure 4.3-7. Pipe Failure by Stress Corrosion Cracking as a Function of Pipe Size (PWR & BWR)

The frequencies of pipe failures by corrosion shown in Figure 4.3-4 are nearly independent of pipe size. With the exception of the smallest of pipe sizes (< 1.0 inches) the frequency of failure for each type of steel is relatively constant. Stainless steel has a lower frequency of failure due to corrosion than carbon steel, which is expected because stainless steel is meant to be corrosion resistant.

Figure 4.3-5 shows that carbon steel is less likely to fail by fatigue than stainless steel for all pipe sizes. The figure also shows that as the pipes increase in size they fail less frequently by fatigue. This is more than likely due to greater movement of the pipes as they decrease in size. The amount of force required to fatigue a larger pipe is greater than that of a smaller pipe.

Figure 4.3-6 supports the information from figure 4.3-3 that shows mechanical failures being relatively equal for all pipe sizes and types. The frequencies of the different pipes in each bin are roughly the same and they stay relatively constant across the spectrum of pipe sizes. The different failures that were grouped into mechanical failures as listed in the section 3.0 are excessive vibration, overpressurization, overstressed, and severe overloading. Though the instances of these failures are low they seem to affect all pipes relatively equally.

Stress corrosion cracking appears to be much more prevalent in stainless steel pipes as opposed to carbon steel pipes as shown in Figure 4.3-7. The discontinuity in the carbon steel data is due to plotting a frequency of zero on a log scale. For both stainless and carbon pipes the frequency of failure increases for the largest pipe size (> 10 inches).

5.0 Conclusions from Data

5.1 Pipe Failures as a function of Pipe Size from OPDE Data

1. The main problem with the OPDE database is it does not have any resolution beyond pipe sizes greater than 10 inches.

2. For both PWRs and BWRs the results of the OPDE database underestimate the failure frequency for the smaller pipe size groups, and overestimate the failure frequency for the larger pipe size groups, compared to the NRC predictions. In both cases the OPDE data does not predict as drastic of a difference in the frequencies for small pipes and large pipes as the NRC does.

3. The OPDE database excludes instances of steam generator tube rupture (SGTR) from consideration. By doing this the total number of failures in the smaller pipe size groups are reduced, and the calculated frequencies are lower at smaller pipe sizes than if SGTR had been considered. This may be one source of difference in the OPDE results and NRC prediction.

4. The OPDE database reports failures of stainless steel pipes are more frequent than carbon steel pipes for smaller pipe sizes in PWRs and stainless steel pipe failures are much more frequent than carbon steel pipe failures at all pipe sizes in BWRs.

5.2 Pipe Failures as a function of Pipe Size from Independent Data

1. The data set collected independently by our group compares very well with the trends observed in the OPDE data, but does not match the results predicted by the NRC.

2. The main problem with this data set is the limited amount of data points.

3. Failure mechanism plots were not made due to the lack of variety in failure mechanisms. The majority of the failure mechanisms were erosion/corrosion and stress corrosion cracking.

5.3 Pipe Failures as a function of Failure Mechanism

1. The failure mechanism that appears to dominate PWR plants is fatigue failure, and BWR plants are dominated by stress corrosion cracking failures. In general both plants are limited by corrosion, fatigue, and stress corrosion cracking.

2. For some failure mechanisms the frequency of failure increases as pipe size increases. Stress corrosion cracking is one failure mechanism where this trend is seen. It should be noted that this does not necessarily contradict the NRC's assertion that larger pipes break less frequently. This conclusion only states that for some failure mechanisms large pipes fail more frequently.

3. Although the OPDE data does not show water hammer to be a significant failure mechanism, it should be noted that the OPDE database listed 450 separate water hammer events where structural pipe integrity was challenged but not failed. Had this data points been included as probable failures, water hammer would have become one of the leading failure mechanisms.

6.0 References

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PLANT TYPE	PIPE TYPE	SYSTEM GROUP	APPARENT CAUSE	PIPE SIZE GROUP	TOTAL NO. OF RECORDS	Crack-Full	Crack-Part	Deformation	Large Leak	Leak	P/H-Leak	Rupture	Severance	Small Leak	Wall thinning
PWR	CS	AUXC	Cavitation	5	1						1				
PWR	CS	AUXC	Cavitation-erosion	5	1									1	
PWR	CS	AUXC	Cavitation-erosion	6	1						1				
PWR	CS	AUXC	Corrosion	2	15				1		2		1	10	1
PWR	CS	AUXC	Corrosion	3	17		1				3			10	3
PWR	CS	AUXC	Corrosion	4	15	1					3			11	
PWR	CS	AUXC	Corrosion	5	20	1				1	9			8	1
PWR	CS	AUXC	Corrosion	6	18	1				1	5			10	1
PWR	CS	AUXC	Erosion-cavitation	6	2									1	1
PWR	CS	AUXC	Erosion-corrosion	1	4						1			3	
PWR	CS	AUXC	Erosion-corrosion	2	17					1	2			14	
PWR	CS	AUXC	Erosion-corrosion	3	15						5			10	
PWR	CS	AUXC	Erosion-corrosion	4	13	1	1			1	4			5	1
PWR	CS	AUXC	Erosion-corrosion	5	20	1				3	5	1		10	
PWR	CS	AUXC	Erosion-corrosion	6	20				3	1	9			7	
PWR	CS	AUXC	External impact	5	1									1	
PWR	CS	AUXC	FAC - Flow Accelerated Corrosion	6	1									1	
PWR	CS	AUXC	Galvanic Corrosion	2	1									1	
PWR	CS	AUXC	HF.CONST/INST	1	1									1	
PWR	CS	AUXC	HF.CONST/INST	2	4									4	
PWR	CS	AUXC	HF.CONST/INST	4	2						1			1	
PWR	CS	AUXC	HF:CONST/INST	5	2		1		1						
PWR	CS	AUXC	HF.Human Error	2	1									1	
PWR	CS	AUXC	HF.Human Error	5	1						1				
PWR	CS	AUXC	HF.Welding Error	3	5									5	
PWR	CS	AUXC	HF.Welding Error	6	1						1				
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	2	2						1			1	
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	3	4						3				1
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	4	11						7			1	3
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	5	12	1	1			1	3			5	1
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	6	3					1	1			1	
PWR	CS	AUXC	Severe overloading	1	1									1	
PWR	CS	AUXC	Severe overloading	4	2								2		
PWR	CS	AUXC	Thermal fatigue	4	1									1	
PWR	CS	AUXC	Unreported	3	1									1	
PWR	CS	AUXC	Vibration-Fatigue	2	17									17	
PWR	CS	AUXC	Vibration-fatigue	4	7	5								2	
PWR	SS	CS	HF.CONST/INST	2	1									1	
PWR	SS	CS	HF.Welding Error	3	1						1				
PWR	SS	CS	IGSCC - Intergranular SCC	5	3						3				
PWR	SS	CS	TGSCC - Transgranular SCC	5	3									3	
PWR	SS	CS	Unreported	5	1									1	
PWR	SS	CS	Vibration-fatigue	2	6		1							5	
PWR	SS	CS	Vibration-fatigue	6	1		1								
PWR	CS	EHC	Severe Overloading	2	2								2		
PWR	CS	EHC	Vibration-Fatigue	1	3					1			1	1	
PWR	CS	EHC	Vibration-Fatigue	2	9							1	1	7	
PWR	CS	EHC	Vibration-fatigue	4	1									1	
PWR	SS	EPS	Vibration-fatigue	1	11		2					2		7	
PWR	SS	EPS	Vibration-fatigue	2	3							1		2	
PWR	CS	FPS	Corrosion	2	4						1			3	
PWR	CS	FPS	Corrosion	3	3						1			2	
PWR	CS	FPS	Corrosion	4	3									3	
PWR	CS	FPS	Corrosion	5	4				1		1	1		1	
PWR	CS	FPS	Corrosion	6	2						1	1			
PWR	CS	FPS	HF.CONST/INST	5	2								1	1	
PWR	CS	FPS	HF.Human error	3	1								1		
PWR	CS	FPS	HF:REPAIR/MAINT	6	1							1			
PWR	CS	FPS	HF:Welding Error	6	1						1				
PWR	CS	FPS	MIC - Microbiologically Induced Corrosion	5	7				1	1	2			1	2
PWR	CS	FPS	MIC - Microbiologically Induced Corrosion	6	4										4
PWR	CS	FPS	Severe overloading	3	1							1			
PWR	CS	FPS	Severe overloading	4	1							1			
PWR	CS	FPS	Severe overloading	5	2							2			
PWR	CS	FPS	Severe overloading	6	1							1			

PWR	SS	FWC	Corrosion	3	3							1		2	
PWR	SS	FWC	Corrosion	4	1					1					
PWR	SS	FWC	Corrosion	6	3		1				1			1	
PWR	SS	FWC	Corrosion-fatigue	4	1		1								
PWR	SS	FWC	Corrosion-fatigue	6	3		2							1	
PWR	SS	FWC	Erosion	2	2									2	
PWR	SS	FWC	Erosion	5	1									1	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	1	2						1			1	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	2	4					1	1	1		1	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	3	7				1		3	1		2	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	4	11		1			1	2	3		2	2
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	5	27				1	2	1	11		4	8
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	6	67				1	1		7		8	50
PWR	SS	FWC	Fatigue	2	3								1	2	
PWR	SS	FWC	Fatigue	3	1									1	
PWR	SS	FWC	Fatigue	4	1									1	
PWR	SS	FWC	Galvanic Corrosion	3	2					2					
PWR	SS	FWC	HF.CONST/INST	2	2					1				1	
PWR	SS	FWC	HF.CONST/INST	4	2									2	
PWR	SS	FWC	HF.CONST/INST	6	1										1
PWR	SS	FWC	HF.Design error	1	1									1	
PWR	SS	FWC	HF.Fabrication Error	4	1										1
PWR	SS	FWC	HF:REPAIR/MAINT	4	1						1				
PWR	SS	FWC	HF:REPAIR/MAINT	6	1									1	
PWR	SS	FWC	HF.Welding Error	1	1									1	
PWR	SS	FWC	HF.Welding Error	2	2						2				
PWR	SS	FWC	HF.Welding error	3	2						1			1	
PWR	SS	FWC	HF.Welding error	5	1									1	
PWR	SS	FWC	HF.Welding Error	6	3		1				1			1	
PWR	SS	FWC	Severe overloading	2	5		1							4	
PWR	SS	FWC	Severe overloading	3	1							1			
PWR	SS	FWC	Severe overloading	4	2			1						1	
PWR	SS	FWC	Severe overloading	5	2		1					1			
PWR	SS	FWC	Severe overloading	6	6		1					4		1	
PWR	SS	FWC	Thermal Fatigue	2	2							1		1	
PWR	SS	FWC	Thermal Fatigue	3	2							1		1	
PWR	SS	FWC	Thermal Fatigue	6	13		9			1				3	
PWR	SS	FWC	Thermal Fatigue - Cycling	6	1									1	
PWR	SS	FWC	Thermal Fatigue - Stratification	6	5		5								
PWR	SS	FWC	Vibration-fatigue	1	5							3		2	
PWR	SS	FWC	Vibration-Fatigue	2	23					1		2	2	18	
PWR	SS	FWC	Vibration-fatigue	3	5	1						3		1	
PWR	SS	FWC	Vibration-Fatigue	4	2					1				1	
PWR	SS	FWC	Vibration-Fatigue	5	4	1	1							2	
PWR	SS	FWC	Vibration-fatigue	6	5		4							1	
PWR	SS	FWC	Water Hammer	5	1							1			
PWR	SS	FWC	Water Hammer	6	1					1					
PWR	CS	IA-SA	Fatigue	2	1								1		
PWR	CS	IA-SA	HF.Human error	1	2							1	1		
PWR	CS	IA-SA	HF:Human error	2	2								2		
PWR	CS	IA-SA	Severe overloading	2	1									1	
PWR	CS	IA-SA	Severe overloading	3	1								1		
PWR	CS	IA-SA	Vibration-fatigue	1	4							1	2	1	
PWR	CS	IA-SA	Vibration-fatigue	2	11							5	4	2	
PWR	CS	PCS	Corrosion	2	1									1	
PWR	CS	PCS	Erosion	5	2									2	
PWR	CS	PCS	Erosion	6	1		1								
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	2	4							1		3	
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	3	7							2		5	
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	4	9					1		4		3	1
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	5	28					3		6		20	
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	6	12					2		3		7	
PWR	CS	PCS	Fatigue	5	1									1	
PWR	CS	PCS	Fretting	3	1									1	
PWR	CS	PCS	HF.Welding error	5	1					1					
PWR	CS	PCS	PWSCC	4	1									1	
PWR	CS	PCS	Severe overloading	2	1							1			

PWR	CS	PCS	Severe overloading	6	2							2			
PWR	CS	PCS	Thermal fatigue	3	1									1	
PWR	CS	PCS	Vibration-Fatigue	1	2								1	1	
PWR	CS	PCS	Vibration-fatigue	2	10								1	9	
PWR	CS	PCS	Vibration-fatigue	3	1									1	
PWR	CS	PCS	Vibration-fatigue	5	4									4	
PWR	SS	RAS	B/A-SCC	2	2						1			1	
PWR	SS	RAS	B/A-SCC	3	5		1							4	
PWR	SS	RAS	Brittle-Fracture	1	1				1						
PWR	SS	RAS	Cavitation-erosion	5	1									1	
PWR	SS	RAS	Corrosion	1	1									1	
PWR	SS	RAS	Corrosion	2	2						1			1	
PWR	SS	RAS	Corrosion	4	5					1	3			1	
PWR	SS	RAS	Corrosion	5	2						1			1	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	1	6						4			2	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	2	1									1	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	3	1									1	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	4	2									2	
PWR	SS	RAS	Erosion-cavitation	4	2									2	
PWR	SS	RAS	Excessive Vibration	3	1									1	
PWR	SS	RAS	FAC - Flow Accelerated Corrosion	2	1									1	
PWR	SS	RAS	FAC - Flow Accelerated Corrosion	3	1									1	
PWR	SS	RAS	Fretting	1	1									1	
PWR	SS	RAS	Fretting	3	1									1	
PWR	SS	RAS	HF.CONST/INST	1	3				1		1			1	
PWR	SS	RAS	HF.CONST/INST	2	6				1					5	
PWR	SS	RAS	HF.CONST/INST	3	5						1			4	
PWR	SS	RAS	HF:CONST/INST	4	3									3	
PWR	SS	RAS	HF.Fabrication Error	2	1									1	
PWR	SS	RAS	HF.Human error	2	1									1	
PWR	SS	RAS	HF:Human error	3	1						1				
PWR	SS	RAS	HF.REPAIR/MAINT	1	1									1	
PWR	SS	RAS	HF.Welding Error	1	4						1			3	
PWR	SS	RAS	HF.Welding Error	2	7					1	2			4	
PWR	SS	RAS	HF.Welding Error	3	4	2					1			1	
PWR	SS	RAS	HF.Welding error	4	2						1			1	
PWR	SS	RAS	IGSCC - Intergranular SCC	4	1					1					
PWR	SS	RAS	MIC - Microbiologically Induced Corrosion	2	1									1	
PWR	SS	RAS	Overpressurization	5	1							1			
PWR	SS	RAS	PWSCC	2	2					1				1	
PWR	SS	RAS	PWSCC	3	7						1			6	
PWR	SS	RAS	PWSCC	4	5					1				4	
PWR	SS	RAS	PWSCC	5	3						1			2	
PWR	SS	RAS	Severe overloading	2	1									1	
PWR	SS	RAS	Severe overloading	3	3		3								
PWR	SS	RAS	TGSCC - Transgranular SCC	1	5									5	
PWR	SS	RAS	TGSCC - Transgranular SCC	2	1	1									
PWR	SS	RAS	TGSCC - Transgranular SCC	3	3						1			2	
PWR	SS	RAS	TGSCC - Transgranular SCC	4	1									1	
PWR	SS	RAS	Thermal Fatigue	3	5				1	1				3	
PWR	SS	RAS	Thermal Fatigue	4	2				1					1	
PWR	SS	RAS	Thermal Fatigue - Cycling	3	1		1								
PWR	SS	RAS	Unreported	4	1									1	
PWR	SS	RAS	Unreported	5	1						1				
PWR	SS	RAS	Vibration-fatigue	1	10		1					1		8	
PWR	SS	RAS	Vibration-fatigue	2	105		2		7	3	12	2	3	76	
PWR	SS	RAS	Vibration-fatigue	3	44	1	2		2	7	7			25	
PWR	SS	RAS	Vibration-fatigue	4	10				1		2			7	
PWR	SS	RAS	Vibration-fatigue	5	4		1							3	
PWR	SS	RAS	Vibration-fatigue	6	1									1	
PWR	SS	RCPB	B/A-SCC	1	1									1	
PWR	SS	RCPB	B/A-SCC	2	1									1	
PWR	SS	RCPB	Corrosion	2	2		1			1					
PWR	SS	RCPB	Corrosion-fatigue	2	1				1						
PWR	SS	RCPB	Corrosion-fatigue	4	1							1			
PWR	SS	RCPB	ECSCC - External Chloride Induced SCC	1	1	1									
PWR	SS	RCPB	Fretting	1	1		1								

PWR	SS	RCPB	HF.CONSTANST	1	5				2					3	
PWR	SS	RCPB	HF:CONSTANST	2	12	4			1					7	
PWR	SS	RCPB	HF.CONSTANST	3	2									2	
PWR	SS	RCPB	HF CONSTANST	4	1									1	
PWR	SS	RCPB	HF.CONSTANST	5	1									1	
PWR	SS	RCPB	HF.Design Error	1	1									1	
PWR	SS	RCPB	HF:Design error	2	1							1			
PWR	SS	RCPB	HF:REPAIR/MAINT	1	1							1			
PWR	SS	RCPB	HF Welding Error	1	3						2			1	
PWR	SS	RCPB	HF:Welding Error	2	11					1			1	9	
PWR	SS	RCPB	HF.Welding Error	3	2									2	
PWR	SS	RCPB	HF Welding error	6	1		1								
PWR	SS	RCPB	Hydrogen embrittlement	1	1				1						
PWR	SS	RCPB	IGSCC - Intergranular SCC	5	1		1								
PWR	SS	RCPB	PWSCC	1	2						1			1	
PWR	SS	RCPB	PWSCC	2	44	26	2			1	4		1	10	
PWR	SS	RCPB	PWSCC	3	6		1							5	
PWR	SS	RCPB	PWSCC	4	3		1							2	
PWR	SS	RCPB	PWSCC	5	2		1							1	
PWR	SS	RCPB	PWSCC	6	7		2				2			3	
PWR	SS	RCPB	Severe overloading	2	3									3	
PWR	SS	RCPB	Severe overloading	3	1							1			
PWR	SS	RCPB	TGSCC - Transgranular SCC	1	7	1	1				1			4	
PWR	SS	RCPB	TGSCC - Transgranular SCC	2	5						1			4	
PWR	SS	RCPB	TGSCC - Transgranular SCC	5	1					1					
PWR	SS	RCPB	Thermal fatigue	1	4									4	
PWR	SS	RCPB	Thermal fatigue	2	1									1	
PWR	SS	RCPB	Thermal fatigue	3	4		1			1	1			1	
PWR	SS	RCPB	Thermal fatigue	6	1		1								
PWR	SS	RCPB	Thermal Fatigue - Cycling	3	1									1	
PWR	SS	RCPB	Thermal Fatigue - Cycling	6	1		1								
PWR	SS	RCPB	Vibration-Fatigue	1	31				1	5			1	24	
PWR	SS	RCPB	Vibration-Fatigue	2	82	2			3	10	1			66	
PWR	SS	RCPB	Vibration-fatigue	3	11					4				7	
PWR	SS	RCPB	Vibration-fatigue	4	2					1				1	
PWR	SS	RCPB	Vibration-Fatigue	6	2									2	
PWR	SS	RCS-INSTR	Fatigue	1	1									1	
PWR	SS	RCS-INSTR	HF.CONSTANST	1	1					1					
PWR	SS	RCS-INSTR	HF:CONSTANST	2	1				1						
PWR	SS	RCS-INSTR	Vibration-Fatigue	1	1									1	
PWR	SS	RCS-INSTR	Vibration-fatigue	2	1									1	
PWR	CS	SG	Corrosion	1	1									1	
PWR	CS	SG	Deformation/Thermal Fatigue	2	1									1	
PWR	CS	SG	FAC - Flow Accelerated Corrosion	3	3							1		2	
PWR	CS	SG	HF.Welding Error	6	1						1				
PWR	CS	SG	PWSCC	1	3	3									
PWR	CS	SG	TGSCC - Transgranular SCC	2	1									1	
PWR	CS	SG	Vibration-Fatigue	2	2									2	
PWR	CS	SG	Vibration-fatigue	4	1									1	
PWR	SS	SIR	B/A-SCC	3	1									1	
PWR	SS	SIR	B/A-SCC	5	3		1							2	
PWR	SS	SIR	Cavitation-erosion	3	1							1			
PWR	SS	SIR	Cavitation-erosion	5	2									2	
PWR	SS	SIR	Corrosion	2	1									1	
PWR	SS	SIR	ECSCC - External Chloride Induced SCC	5	3		2				1				
PWR	SS	SIR	ECSCC - External Chloride Induced SCC	6	1						1				
PWR	SS	SIR	Erosion-cavitation	2	3						1			2	
PWR	SS	SIR	FAC - Flow Accelerated Corrosion	2	1						1				
PWR	SS	SIR	Freezing	1	1	1									
PWR	SS	SIR	Fretting	5	1										1
PWR	SS	SIR	HF.CONSTANST	1	1									1	
PWR	SS	SIR	HF:CONSTANST	2	4						1			3	
PWR	SS	SIR	HF.CONSTANST	5	2					1				1	
PWR	SS	SIR	HF Human error	2	1									1	
PWR	SS	SIR	HF.REPAIR/MAINT	5	1									1	
PWR	SS	SIR	HF.Welding Error	1	3						2			1	
PWR	SS	SIR	HF:Welding error	2	7					1	1	1		4	

PWR	SS	SIR	HF.Welding Error	3	1									1	
PWR	SS	SIR	HF.Welding Error	4	2						1			1	
PWR	SS	SIR	HF.Welding Error	5	2	1	1								
PWR	SS	SIR	HF.Welding Error	6	1		1								
PWR	SS	SIR	Overstressed	1	3									3	
PWR	SS	SIR	PWSCC	2	1						1				
PWR	SS	SIR	PWSCC	3	5									5	
PWR	SS	SIR	PWSCC	4	2		2								
PWR	SS	SIR	PWSCC	5	17		2			2	3			10	
PWR	SS	SIR	Severe Overloading	1	1									1	
PWR	SS	SIR	Severe overloading	2	3							2		1	
PWR	SS	SIR	Severe overloading	5	2		1							1	
PWR	SS	SIR	Severe overloading	6	2		1	1							
PWR	SS	SIR	TGSCC - Transgranular SCC	1	1	1									
PWR	SS	SIR	TGSCC - Transgranular SCC	2	1									1	
PWR	SS	SIR	TGSCC - Transgranular SCC	4	1						1				
PWR	SS	SIR	TGSCC - Transgranular SCC	5	1		1								
PWR	SS	SIR	Thermal fatigue	3	1		1								
PWR	SS	SIR	Thermal fatigue	4	3		2		1						
PWR	SS	SIR	Thermal fatigue	5	8		2		2	4					
PWR	SS	SIR	Thermal Fatigue - Cycling	3	1		1								
PWR	SS	SIR	Thermal Fatigue - Cycling	4	1									1	
PWR	SS	SIR	Unreported	3	2									2	
PWR	SS	SIR	Unreported	5	1		1								
PWR	SS	SIR	Unreported	6	1						1				
PWR	SS	SIR	Vibration-fatigue	0	3					1		1		1	
PWR	SS	SIR	Vibration-fatigue	1	8							2		6	
PWR	SS	SIR	Vibration-fatigue	2	42		2		1	3	3	2		31	
PWR	SS	SIR	Vibration-fatigue	3	9		1						1	7	
PWR	SS	SIR	Vibration-fatigue	4	3									3	
PWR	SS	SIR	Vibration-fatigue	5	7	1	1			1				4	
PWR	CS	STEAM	Corrosion	3	1					1					
PWR	CS	STEAM	Corrosion-fatigue	6	1									1	
PWR	CS	STEAM	Erosion	4	1									1	
PWR	CS	STEAM	Erosion	5	1						1				
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	2	10							1		9	
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	3	9									9	
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	4	8					1	1	1		5	
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	5	14					1		3		9	1
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	6	14					1		1		10	2
PWR	CS	STEAM	Fretting	3	1						1				
PWR	CS	STEAM	HF.CONSTANST	2	3							1		2	
PWR	CS	STEAM	HF.Human Error	2	1							1			
PWR	CS	STEAM	HF.Human error	6	1									1	
PWR	CS	STEAM	HF.Welding Error		1						1				
PWR	CS	STEAM	HF.Welding Error	3	1						1				
PWR	CS	STEAM	HF.Welding error	6	2		2								
PWR	CS	STEAM	Overstressed	1	1					1					
PWR	CS	STEAM	Severe overloading	4	1									1	
PWR	CS	STEAM	Severe overloading	5	2							2			
PWR	CS	STEAM	Severe overloading	6	3		2					1			
PWR	CS	STEAM	Vibration-fatigue	1	2							1		1	
PWR	CS	STEAM	Vibration-fatigue	2	9		1					1	1	6	
PWR	CS	STEAM	Vibration-fatigue	3	2							1		1	
PWR	CS	STEAM	Vibration-fatigue	4	1									1	
PWR	CS	STEAM	Vibration-fatigue	6	1									1	

PLANT TYPE	PIPE TYPE	SYSTEM GROUP	APPARENT CAUSE	PIPE SIZE GROUP	TOTAL NO. OF RECORDS	Crack-Full	Crack-Part	Deformation	Large Leak	Leak	P/H-Leak	Rupture	Severance	Small Leak	Wall thinning
BWR	CS	AUXC	Corrosion	1	1				1						
BWR	CS	AUXC	Corrosion	2	4						1			3	
BWR	CS	AUXC	Corrosion	3	2					1				1	
BWR	CS	AUXC	Corrosion	4	3					1	1			1	
BWR	CS	AUXC	Corrosion	5	4					1	1			1	1
BWR	CS	AUXC	Corrosion	6	7				2		2			2	1
BWR	CS	AUXC	Erosion-cavitation	3	1						1				
BWR	CS	AUXC	Erosion-cavitation	6	1						1				
BWR	CS	AUXC	Erosion-corrosion	3	4						2			2	
BWR	CS	AUXC	Erosion-corrosion	4	7				1	2	1			3	
BWR	CS	AUXC	Erosion-corrosion	5	9						3			5	1
BWR	CS	AUXC	Erosion-corrosion	6	15					2	8			2	3
BWR	CS	AUXC	HF.CONST/INST	2	1									1	
BWR	CS	AUXC	HF:CONST/INST	5	1						1				
BWR	CS	AUXC	HF:Fabrication Error	5	1		1								
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	2	1					1					
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	4	2						2				
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	5	1						1				
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	6	1									1	
BWR	CS	AUXC	Severe overloading	3	3									3	
BWR	CS	AUXC	Severe overloading	5	2							1		1	
BWR	CS	AUXC	Severe overloading	6	2								2		
BWR	CS	AUXC	Unreported	5	1									1	
BWR	CS	AUXC	Vibration-fatigue	2	11					1			2	8	
BWR	CS	AUXC	Vibration-Fatigue	3	1									1	
BWR	CS	AUXC	Vibration-Fatigue	4	1									1	
BWR	CS	AUXC	Vibration-Fatigue	5	1	1									
BWR	SS	Containment System	Brittle fracture	5	1		1								
BWR	SS	Containment System	Corrosion	2	1									1	
BWR	SS	Containment System	HF.CONST/INST	5	1		1								
BWR	SS	Containment System	IGSCC - Intergranular SCC	5	1		1								
BWR	SS	Containment System	Severe overloading	5	1								1		
BWR	SS	Containment System	Severe overloading	6	2	1								1	
BWR	SS	Containment System	Vibration-Fatigue	1	1								1		
BWR	SS	CS	Fatigue	1	1							1			
BWR	SS	CS	HF.Welding Error	0	1										1
BWR	SS	CS	IGSCC - Intergranular SCC	4	1						1				
BWR	SS	CS	TGSCC - Transgranular SCC	5	1									1	
BWR	CS	EHC		2	1					1					
BWR	CS	EHC	Fretting	1	2					1	1				
BWR	CS	EHC	HF:CONST/INST	1	1									1	
BWR	CS	EHC	HF:Human error	1	1									1	
BWR	CS	EHC	HF.Human error	4	1									1	
BWR	CS	EHC	HF.Welding Error	2	1							1			
BWR	CS	EHC	Vibration-Fatigue	1	3							3			
BWR	CS	EHC	Vibration-fatigue	2	7				1	2		2		2	
BWR	CS	EHC	Vibration-fatigue	3	1									1	
BWR	SS	EPS	Fatigue	1	1								1		
BWR	SS	EPS	Vibration-fatigue	1	7							1	2	4	
BWR	SS	EPS	Vibration-fatigue	2	2									2	
BWR	CS	FPS	Corrosion	1	1						1				
BWR	CS	FPS	Corrosion	4	1						1				
BWR	CS	FPS	Corrosion	5	2					1	1				
BWR	CS	FPS	FAC - Flow Accelerated Corrosion	4	1						1				
BWR	CS	FPS	Fretting	5	1									1	
BWR	CS	FPS	HF.CONST/INST	5	1								1		
BWR	CS	FPS	HF.Human error	3	1							1			
BWR	CS	FPS	HF:Human Error	6	1				1						
BWR	CS	FPS	HF.INST/CONST	5	1									1	
BWR	CS	FPS	HF.Welding Error	4	1						1				
BWR	CS	FPS	MIC - Microbiologically Induced Corrosion	3	1						1				
BWR	CS	FPS	Severe overloading	4	1							1			
BWR	CS	FPS	Severe Overloading	5	2									2	
BWR	CS	FPS	Vibration-fatigue	1	1									1	
BWR	CS	FPS	Vibration-fatigue	3	1								1		

BWR	SS	FWC	Corrosion	2	2									2	
BWR	SS	FWC	Corrosion	3	1				1						
BWR	SS	FWC	Corrosion	4	2									2	
BWR	SS	FWC	Corrosion	5	2									2	
BWR	SS	FWC	Corrosion	6	1									1	
BWR	SS	FWC	Corrosion-fatigue	2	1		1								
BWR	SS	FWC	Corrosion-fatigue	3	1									1	
BWR	SS	FWC	ECSCC - External Chloride Induced SCC	1	1						1				
BWR	SS	FWC	Erosion	2	2									2	
BWR	SS	FWC	Erosion	3	1						1				
BWR	SS	FWC	Erosion	4	1									1	
BWR	SS	FWC	Erosion	5	1									1	
BWR	SS	FWC	Erosion-cavitation	4	2		1				1				
BWR	SS	FWC	Erosion-cavitation	5	2						2				
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	1	1									1	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	2	4					1				3	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	3	2				1					1	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	4	3						1			2	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	5	22		1			1	1	1		10	8
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	6	20							2		1	17
BWR	SS	FWC	Fatigue	6	1									1	
BWR	SS	FWC	HF.CONSTANST	4	1									1	
BWR	SS	FWC	HF.CONSTANST	5	1									1	
BWR	SS	FWC	HF.CONSTANST	6	1		1								
BWR	SS	FWC	HF:Human error	1	1								1		
BWR	SS	FWC	HF.Welding Error	2	2									2	
BWR	SS	FWC	HF Welding error	5	1									1	
BWR	SS	FWC	IGSCC - Intergranular SCC	4	1						1				
BWR	SS	FWC	Severe overloading	1	1								1		
BWR	SS	FWC	Severe overloading	3	1							1			
BWR	SS	FWC	Severe overloading	4	1							1			
BWR	SS	FWC	Severe overloading	5	3							2		1	
BWR	SS	FWC	Severe overloading	6	1							1			
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	2	1									1	
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	4	1									1	
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	5	3		1							2	
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	6	4		3							1	
BWR	SS	FWC	Thermal fatigue	2	3									3	
BWR	SS	FWC	Thermal Fatigue	3	3		1			1		1			
BWR	SS	FWC	Thermal fatigue	5	5		5								
BWR	SS	FWC	Thermal fatigue	6	5		4							1	
BWR	SS	FWC	Unreported	3	1									1	
BWR	SS	FWC	Unreported	4	1									1	
BWR	SS	FWC	Unreported	6	2		1					1			
BWR	SS	FWC	Vibration-fatigue	1	2				1					1	
BWR	SS	FWC	Vibration-fatigue	2	21					1		3	2	15	
BWR	SS	FWC	Vibration-fatigue	3	8		1				1	1		5	
BWR	SS	FWC	Vibration-fatigue	4	3							1		2	
BWR	SS	FWC	Vibration-fatigue	5	5					1		1	1	2	
BWR	SS	FWC	Vibration-fatigue	6	1		1								
BWR	CS	IA-SA		2	1					1					
BWR	CS	IA-SA	Corrosion	2	1							1			
BWR	CS	IA-SA	Fretting	2	1					1					
BWR	CS	IA-SA	HF:Human error	1	1								1		
BWR	CS	IA-SA	IGSCC - Intergranular SCC	2	1									1	
BWR	CS	IA-SA	Severe Overloading	1	1								1		
BWR	CS	IA-SA	Severe Overloading	2	1									1	
BWR	CS	IA-SA	Vibration-fatigue	1	5					1		1	3		
BWR	CS	IA-SA	Vibration-Fatigue	2	4					1		1	1	1	
BWR	CS	PCS			1					1					
BWR	CS	PCS	Corrosion	1	1									1	
BWR	CS	PCS	Corrosion	3	1									1	
BWR	CS	PCS	Erosion	5	1									1	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	2	2				1					1	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	3	1									1	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	4	6									6	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	5	12							4		8	

BWR	CS	PCS	FAC - Flow Accelerated Corrosion	6	2							1		1	
BWR	CS	PCS	HF.Welding error	2	1									1	
BWR	CS	PCS	Severe overloading	2	2					1				1	
BWR	CS	PCS	Severe overloading	6	2							1		1	
BWR	CS	PCS	Thermal fatigue	2	1							1			
BWR	CS	PCS	Vibration-fatigue	1	1							1			
BWR	CS	PCS	Vibration-fatigue	2	7							4		3	
BWR	CS	PCS	Vibration-fatigue	3	1							1			
BWR	CS	PCS	Vibration-fatigue	4	2									2	
BWR	SS	RAS	Cavitation-erosion	5	1						1				
BWR	SS	RAS	Corrosion	2	3					2			1		
BWR	SS	RAS	Corrosion	3	4									4	
BWR	SS	RAS	Corrosion	4	6									6	
BWR	SS	RAS	Corrosion	5	3									3	
BWR	SS	RAS	Corrosion-fatigue	1	1									1	
BWR	SS	RAS	ECSCC - External Chloride Induced SCC	1	1									1	
BWR	SS	RAS	ECSCC - External Chloride Induced SCC	2	17		8							9	
BWR	SS	RAS	ECSCC - External Chloride Induced SCC	3	2	2									
BWR	SS	RAS	FAC - Flow Accelerated Corrosion	3	1						1				
BWR	SS	RAS	Fatigue	4	1		1								
BWR	SS	RAS	HF.CONST/INST	2	1									1	
BWR	SS	RAS	HF.CONST/INST	3	1						1				
BWR	SS	RAS	HF.CONST/INST	4	1									1	
BWR	SS	RAS	HF.CONST/INST	5	1									1	
BWR	SS	RAS	HF.Human error	1	1								1		
BWR	SS	RAS	HF.Human error	2	2				1				1		
BWR	SS	RAS	HF.REPAIR/MAINT	1	1								1		
BWR	SS	RAS	HF.REPAIR/MAINT	2	1									1	
BWR	SS	RAS	HF.REPAIR/MAINT	4	1		1								
BWR	SS	RAS	HF.Welding error	2	2						2				
BWR	SS	RAS	HF.Welding error	3	2						1			1	
BWR	SS	RAS	HF.Welding error	4	1									1	
BWR	SS	RAS	HF.Welding Error	5	4		1				1			2	
BWR	SS	RAS	IDSCC - Interdendritic SCC	4	1					1					
BWR	SS	RAS	IGSCC - Intergranular SCC	2	5						1			4	
BWR	SS	RAS	IGSCC - Intergranular SCC	3	4						2			2	
BWR	SS	RAS	IGSCC - Intergranular SCC	4	56	1	32				9		1	13	
BWR	SS	RAS	IGSCC - Intergranular SCC	5	56	2	35			4	8			7	
BWR	SS	RAS	IGSCC - Intergranular SCC	6	2		1				1				
BWR	SS	RAS	Severe overloading	1	1							1			
BWR	SS	RAS	Severe overloading	2	3			1				2			
BWR	SS	RAS	Severe overloading	4	1							1			
BWR	SS	RAS	TGSCC - Transgranular SCC	1	1									1	
BWR	SS	RAS	TGSCC - Transgranular SCC	2	7	1	1				1			4	
BWR	SS	RAS	TGSCC - Transgranular SCC	3	7		6							1	
BWR	SS	RAS	TGSCC - Transgranular SCC	4	96		96								
BWR	SS	RAS	TGSCC - Transgranular SCC	5	1					1					
BWR	SS	RAS	Thermal fatigue	1	1									1	
BWR	SS	RAS	Thermal fatigue	2	2						1			1	
BWR	SS	RAS	Thermal fatigue	3	1		1								
BWR	SS	RAS	Thermal Fatigue	4	1									1	
BWR	SS	RAS	Thermal fatigue	5	10		5							5	
BWR	SS	RAS	Thermal Fatigue - Cycling	4	3									3	
BWR	SS	RAS	Thermal Fatigue - Cycling	5	1		1								
BWR	SS	RAS	Thermal Fatigue - Cycling	6	1		1								
BWR	SS	RAS	Unreported	3	1		1								
BWR	SS	RAS	Unreported	5	1									1	
BWR	SS	RAS	Vibration-fatigue	1	4		1							3	
BWR	SS	RAS	Vibration-fatigue	2	15				1		1	1	1	11	
BWR	SS	RAS	Vibration-fatigue	3	7		1		1	1				4	
BWR	SS	RAS	Vibration-fatigue	4	2		1							1	
BWR	SS	RAS	Vibration-fatigue	5	1									1	
BWR	SS	RAS	Water Hammer	1	1				1						
BWR	SS	RCPB		2	1										1
BWR	SS	RCPB	Corrosion	1	1									1	
BWR	SS	RCPB	Corrosion	2	1						1				
BWR	SS	RCPB	ECSCC - External Chloride Induced SCC	1	3	2								1	

BWR	SS	RCPB	ECSCC - External Chloride Induced SCC	4	1		1								
BWR	SS	RCPB	Erosion	2	1					1					
BWR	SS	RCPB	external damage	3	1			1							
BWR	SS	RCPB	HF:CONSTANST	1	1						1				
BWR	SS	RCPB	HF:CONSTANST	6	2		2								
BWR	SS	RCPB	HF:Fabrication Error	2	1						1				
BWR	SS	RCPB	HF:Fabrication Error	3	1									1	
BWR	SS	RCPB	HF:Fabrication Error	6	1		1								
BWR	SS	RCPB	HF:REPAIR/MAINT	2	1									1	
BWR	SS	RCPB	HF.Welding error	1	1						1				
BWR	SS	RCPB	HF.Welding error	2	2									2	
BWR	SS	RCPB	HF:Welding Error	3	7	1				1	1			4	
BWR	SS	RCPB	HF.Welding error	5	1									1	
BWR	SS	RCPB	HF.Welding error	6	8		8								
BWR	SS	RCPB	Hot cracking	4	1									1	
BWR	SS	RCPB	IGSCC - Intergranular SCC	1	4		2			1				1	
BWR	SS	RCPB	IGSCC - Intergranular SCC	2	3						2			1	
BWR	SS	RCPB	IGSCC - Intergranular SCC	3	2						2				
BWR	SS	RCPB	IGSCC - Intergranular SCC	4	20	2	5			2	7			4	
BWR	SS	RCPB	IGSCC - Intergranular SCC	5	10		7			1	2				
BWR	SS	RCPB	IGSCC - Intergranular SCC	6	203	3	174			1	22			3	
BWR	SS	RCPB	Overpressurization	4	2	1						1			
BWR	SS	RCPB	Severe Overloading	4	1			1							
BWR	SS	RCPB	SICC - Strain-rate Induced Corrosion Cracking	6	1		1								
BWR	SS	RCPB	TGSCC - Transgranular SCC	1	1	1									
BWR	SS	RCPB	TGSCC - Transgranular SCC	2	1		1								
BWR	SS	RCPB	TGSCC - Transgranular SCC	3	1									1	
BWR	SS	RCPB	Thermal Fatigue	2	2									2	
BWR	SS	RCPB	Thermal Fatigue	3	1									1	
BWR	SS	RCPB	Vibration-fatigue	1	3									3	
BWR	SS	RCPB	Vibration-Fatigue	2	42	2	1			4	2			33	
BWR	SS	RCPB	Vibration-Fatigue	3	4									4	
BWR	SS	RCPB	Vibration-fatigue	4	1									1	
BWR	SS	RCS-INSTR	ECSCC - External Chloride Induced SCC	2	1		1								
BWR	SS	RCS-INSTR	ECSCC - External Chloride Induced SCC	3	1		1								
BWR	SS	RCS-INSTR	HF:Welding error	2	2					1				1	
BWR	SS	RCS-INSTR	IGSCC - Intergranular SCC	4	2						1			1	
BWR	SS	RCS-INSTR	TGSCC - Transgranular SCC	1	2					1				1	
BWR	SS	RCS-INSTR	TGSCC - Transgranular SCC	2	1									1	
BWR	SS	SIR		0	1	1									
BWR	SS	SIR	Brittle fracture	5	4		4								
BWR	SS	SIR	Corrosion	3	1									1	
BWR	SS	SIR	Corrosion-fatigue	5	1									1	
BWR	SS	SIR	ECSCC - External Chloride Induced SCC	1	1									1	
BWR	SS	SIR	ECSCC - External Chloride Induced SCC	6	1		1								
BWR	SS	SIR	Erosion	2	2						1			1	
BWR	SS	SIR	Erosion	5	1										1
BWR	SS	SIR	FAC - Flow Accelerated Corrosion	2	4									4	
BWR	SS	SIR	FAC - Flow Accelerated Corrosion	3	4				1					2	1
BWR	SS	SIR	FAC - Flow Accelerated Corrosion	4	2						1				1
BWR	SS	SIR	Fatigue	1	1									1	
BWR	SS	SIR	Fatigue	2	1					1					
BWR	SS	SIR	Fatigue	5	1									1	
BWR	SS	SIR	Fatigue	6	1									1	
BWR	SS	SIR	HF.CONSTANST	2	2									2	
BWR	SS	SIR	HF.CONSTANST	3	1									1	
BWR	SS	SIR	HF.CONSTANST	4	1										1
BWR	SS	SIR	HF.CONSTANST	5	1									1	
BWR	SS	SIR	HF:Fabrication Error	5	2		2								
BWR	SS	SIR	HF.Fabrication Error	6	1		1								
BWR	SS	SIR	HF.Human error	1	1									1	
BWR	SS	SIR	HF:Human error	2	1									1	
BWR	SS	SIR	HF.Welding Error	2	2									2	
BWR	SS	SIR	HF.Welding Error	4	1								1		
BWR	SS	SIR	HF:Welding Error	5	10		9			1					
BWR	SS	SIR	HF.Welding Error	6	6	1	2					1		2	
BWR	SS	SIR	IGSCC - Intergranular SCC	2	3	1	1							1	

BWR	SS	SIR	IGSCC - Intergranular SCC	4	4	1					2			1	
BWR	SS	SIR	IGSCC - Intergranular SCC	5	64	2	51				6			5	
BWR	SS	SIR	IGSCC - Intergranular SCC	6	22		18				4				
BWR	SS	SIR	MIC - Microbiologically Induced Corrosion	5	1							1			
BWR	SS	SIR	Overpressurization	5	1							1			
BWR	SS	SIR	Overstressed	2	2									2	
BWR	SS	SIR	Severe overloading	2	2								1	1	
BWR	SS	SIR	Severe overloading	4	1									1	
BWR	SS	SIR	Severe overloading	6	1			1							
BWR	SS	SIR	TGSCC - Transgranular SCC	5	1					1					
BWR	SS	SIR	TGSCC - Transgranular SCC	6	1		1								
BWR	SS	SIR	Thermal fatigue	2	3									3	
BWR	SS	SIR	Thermal fatigue	5	3		3								
BWR	SS	SIR	Thermal fatigue	6	1		1								
BWR	SS	SIR	Thermal Fatigue - Cycling	5	2		1							1	
BWR	SS	SIR	Unreported	5	1									1	
BWR	SS	SIR	Vibration-Fatigue	0	2					2					
BWR	SS	SIR	Vibration-fatigue	1	6		1							5	
BWR	SS	SIR	Vibration-fatigue	2	27		2			1	1	1	1	21	
BWR	SS	SIR	Vibration-fatigue	3	3		1							2	
BWR	SS	SIR	Vibration-fatigue	4	2									2	
BWR	SS	SIR	Vibration-fatigue	5	1									1	
BWR	SS	SIR	Vibration-fatigue	6	1				1						
BWR	CS	STEAM	Corrosion	2	1									1	
BWR	CS	STEAM	ECSCC - External Chloride Induced SCC	1	1							1			
BWR	CS	STEAM	Erosion	3	1									1	
BWR	CS	STEAM	Erosion	4	1									1	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	2	16						3	1		12	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	3	7									6	1
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	4	3									3	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	5	7									7	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	6	1									1	
BWR	CS	STEAM	Fatigue	2	3					1			1	1	
BWR	CS	STEAM	HF:CONST/INST	2	1									1	
BWR	CS	STEAM	HF:CONST/INST	3	1									1	
BWR	CS	STEAM	HF:CONST/INST	4	1					1					
BWR	CS	STEAM	HF:REPAIR/MAINT	1	1								1		
BWR	CS	STEAM	HF:Welding error	2	2									2	
BWR	CS	STEAM	HF:Welding error	3	2									2	
BWR	CS	STEAM	HF:Welding error	5	1					1					
BWR	CS	STEAM	HF:Welding Error	6	1		1								
BWR	CS	STEAM	IGSCC - Intergranular SCC	5	1		1								
BWR	CS	STEAM	Overpressurization	2	1							1			
BWR	CS	STEAM	Severe overloading	4	1							1			
BWR	CS	STEAM	SICC - Strain-rate Induced Corrosion Cracking	5	1		1								
BWR	CS	STEAM	SICC - Strain-rate Induced Corrosion Cracking	6	3		3								
BWR	CS	STEAM	TGSCC - Transgranular SCC	1	10		4			2				4	
BWR	CS	STEAM	TGSCC - Transgranular SCC	2	2		1							1	
BWR	CS	STEAM	Thermal fatigue	2	1									1	
BWR	CS	STEAM	Thermal fatigue	3	1									1	
BWR	CS	STEAM	Thermal fatigue	6	1									1	
BWR	CS	STEAM	Vibration-Fatigue	1	2							1		1	
BWR	CS	STEAM	Vibration-fatigue	2	12					1	1	2	2	6	
BWR	CS	STEAM	Vibration-fatigue	3	2									2	
BWR	CS	STEAM	Vibration-Fatigue	6	1									1	
BWR	CS	STEAM	Water Hammer	5	1		1								
BWR	CS	STEAM	Water Hammer	6	1			1							

Appendix B

Haddam Neck	PWR	CS	2.25	4	Erosion	GL 89-08
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
Millstone Unit 3	PWR	CS	6	5	Erosion/Corrosion	IN 91-18
Arkansas Nuclear One Unit 2	PWR	CS	14	6	Erosion	IN 89-53
DC Cook Unit 2	PWR	CS	16	6	Erosion	Bulletin 79-13
DC Cook Unit 2	PWR	CS	16	6	Erosion	Bulletin 79-13
Fort Calhoun Station	PWR	CS	12	6	FAC	IN 97-84
Surry Unit 1	PWR	CS	30	6	Not yet determined	IN 81-04
Surry Unit 2	PWR	CS	18	6	Erosion/Corrosion	IN 86-106
Trojan 1	PWR	CS	14	6	Erosion	IN 87-36
Zion 1	PWR	CS	24	6	Human Factor	IN 82-25
FR (Framatome Reactors)	PWR	CS	10	6	Corrosion	Korean
FR (Framatome Reactors)	PWR	CS	28	6	Corrosion	Korean
Diablo Canyon Unit	PWR	CS			Thermal Fatigue	IN 92-20
Loviisa Unit 1	PWR	CS			Erosion/Corrosion	IN 91-18
Sequoyah Unit 1	PWR	CS			Thermal Fatigue	IN 92-20
Surry Unit 1	PWR	CS			Erosion/Corrosion	IN 91-18
Wolf Creek	PWR	SS	0.25	1	Vibration	IN 89-07
KSNP Korean Standard Nuclear Power Plant	PWR	SS	0.375	1	Thermal Fatigue	Korean
Oconee Unit 3	PWR	SS	0.75	1	Mechanical Failure	IN 92-15
WH-3	PWR	SS	0.75	1	Flow Induced Vibration	Korean
WH-3	PWR	SS	0.75	1	Flow Induced Vibration	Korean
H.B. Robinson Unit 2	PWR	SS	2	3	SCC	IN 91-05
Oconee Unit 2	PWR	SS	2	3	Vibration	IN 97-46
Prairie Island Unit 2	PWR	SS	2	3	SCC	IN 91-05
WH-3	PWR	SS	2	3	Flow Induced Vibration	Korean
WH-3	PWR	SS	2	3	Flow Induced Vibration	Korean
WH-3	PWR	SS	2	3	Flow Induced Vibration	Korean
Crystal River Unit 3	PWR	SS	2.5	4	Fatigue	IN 82-09
Fort Calhoun Station	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Ginna	PWR	SS	8	5	SCC	IE Circular76-06
Foreign	PWR	SS	8	5	Thermal Stress	Bulletin 88-08
Arkansas Nuclear One Unit 1	PWR	SS	10	6	SCC	IE Circular76-06
Oconee Unit 2	PWR	SS	24	6	Erosion	IN 82-22
Sequoyah Unit 1	PWR	SS	16	6	Fatigue	IN 95-11
Sequoyah Unit 2	PWR	SS	10	6	Human Factor	IN 97-19
Surry Unit 2	PWR	SS	10	6	SCC	IE Circular76-06
Palo Verde	PWR	SS	Var		Human Factor	Bulletin 79-03
San Onofre Unit 2	PWR	SS	Var		Human Factor	Bulletin 79-03
San Onofre Unit 3	PWR	SS	Var		Human Factor	Bulletin 79-03
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
Farley Unit 2	PWR					IN 88-01
Point Beach Unit 1	PWR					IN 99-19

Appendix B (cont.)

Plant	Type	Material	Diameter	Pipe Size Group	Failure Mechanism	Reference
Dresden Unit 2	BWR	CS	4	4	Human Factor	Bulletin 74-10
Nine Mile Point Unit 2	BWR	CS	8	5	Fatigue	Event 36016
Vermont Yankee	BWR	CS	12	6	SCC	IN 82-22
Cooper Station	BWR	SS	0.25	1	Vibration	IN 89-07
Pilgrim	BWR	SS	1	2	Corrosion	IN 85-34
Browns Ferry 3	BWR	SS	4	4	SCC	IN 84-41
Browns Ferry 3	BWR	SS	4	4	SCC	IN 84-41
Nine Mile Point Unit 1	BWR	SS	6	5	SCC	Bulletin 76-04
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	20	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	24	6	SCC	IN 83-02
Montecello	BWR	SS	22	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Browns Ferry 1	BWR					IN 82-24
Dresden Unit 1	BWR				Freezing	IN 94-38

Highlighted plants were not used in the data analysis due to missing information.

Appendix C. Collapsed OPDE Database

Collapsed OPDE Raw Data as function of Pipe Size

Plant Type	Pipe Size Group (inches)	Resulting Number of Failures		
		CS	SS	CS+SS
PWR	0.0-1.0	154	544	698
	1.0-2.0	74	154	228
	2.0-4.0	78	75	153
	4.0-10.0	126	112	238
	> 10.0	93	126	219
	Total	*525*	*1011*	*1536*
BWR	0.0-1.0	118	257	375
	1.0-2.0	32	75	107
	2.0-4.0	32	227	259
	4.0-10.0	50	234	284
	> 10.0	39	291	330
	Total	*271*	*1084*	*1355*
PWR+BWR	0.0-1.0	272	801	1073
	1.0-2.0	106	229	335
	2.0-4.0	110	302	412
	4.0-10.0	176	346	522
	> 10.0	132	417	549
	Total	*796*	*2095*	*2891*

Collapsed OPDE Raw Data as function of Failure Mechanism

Plant Type	Failure Mechanism	Resulting Number of Failures		
		CS	SS	CS+SS
PWR	Corrosion	106	28	134
	FAC	119	121	240
	MIC	43	1	44
	Erosion	96	12	108
	Fatigue	92	501	593
	Human Factors	36	126	162
	Mechanical Failures	22	37	59
	SCC	5	169	174
	Water Hammer	0	2	2
	Misc	6	14	20
	Total	*525*	*1011*	*1536*
BWR	Corrosion	29	32	61
	FAC	58	63	121
	MIC	6	1	7
	Erosion	40	9	49
	Fatigue	71	225	296
	Human Factors	24	85	109
	Mechanical Failures	18	25	43
	SCC	19	624	643
	Water Hammer	2	1	3
	Misc	4	19	23
	Total	*271*	*1084*	*1355*
PWR+BWR	Corrosion	135	60	195
	FAC	177	184	361
	MIC	49	2	51
	Erosion	136	21	157
	Fatigue	163	726	889
	Human Factors	60	211	271
	Mechanical Failures	40	62	102
	SCC	24	793	817
	Water Hammer	2	3	5
	Misc	10	33	43
	Total	*796*	*2095*	*2891*

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Piping Failures in Nuclear Power Plants

The Pennsylvania State University
NE 597D Spring 2005
6 April 2005

EXECUTIVE SUMMARY

The Nuclear Regulatory Commission (NRC) is examining the technical basis for the largest pipe size failure required for the design basis loss of coolant accident analysis. Based on expert elicitation and fracture mechanics modeling, very low failure frequencies are predicted for such large pipes. [1]

It was the objective of this paper to examine data from piping failures in nuclear power plants and other industry in comparison to the failure frequencies predicted by the NRC. The data was divided by materials into stainless steel and carbon steel, by failure type into leaks and cracks versus ruptures, severances, and breaks, and by plant type into pressurized water reactor (PWR) and boiling water reactor (BWR). The failure frequencies were calculated based on 3390 reactor calendar years. These calculated failure frequencies were compared to the NRC estimates.

Examination of all of the data together and then divided into stainless and carbon steel subsets indicated that the pipe failure frequencies for smaller sized pipes were comparable to or less than the NRC estimates. However, for larger pipe sizes, failure frequencies of one to two orders of magnitude higher than the NRC estimates were calculated.

In general the failure frequencies calculated from the data agreed well with the NRC estimates for small pipe sizes; for larger pipe sizes the calculated failure frequency was generally higher than the NRC estimates.

Better agreement was seen in large pipe sizes when the data was compared to the NRC BWR failure frequencies. This may be due to the NRC's higher failure frequency in bin 5 for BWRs than PWRs.

The data indicated failure frequencies on the same order of magnitude regardless of whether the data was classified into PWR and BWR bins. This was observed for the database in general and for subsets of the database.

Table of Contents

pg.
1.0 Introduction 6
1.1 Project Introduction and Objective 6
1.2 Data Collection 7
1.2.2 Initial Searches 7
1.2.3 National Transportation Safety Board 8
1.2.4 Database of Nuclear Power Plant Failures 8
1.3 Data Reduction to Final Database 9
1.3.1 Separation of Data into Stainless and Carbon Steels 9
1.3.2 Removal of Data Due to Size Uncertainty 11
1.3.3 Removal of Data due to Material Uncertainty 11
1.3.4 Questionable Large Pipes 11
1.3.5 Final Database for Analysis 11
1.4 Data Analysis Approach 13
1.4.1 Failure Size Classification 13
1.4.2 NRC Failure Frequency 13
1.4.3 Conversion of Data to Failure Frequency 14
1.4.4 Calculated Failure Frequencies 15
1.4.5 Failure Mechanisms 15
2.0 Results and Discussion 16
2.0.1 Discussion of Large Pipe Effect 16
2.1 All Data 17
2.1.1 Failure Frequency: All Data Examined 17
2.1.1.1 Effect of National Transportation Safety Board Data 19
2.1.2 Failure Frequencies: Stainless Steel and Carbon Steel Pipes Separated 19
2.1.2.1 Effect of National Transportation Safety Board Data 21
2.1.3 Summary and Discussion of Results: All Data 21
2.2 Rupture Analysis: 23
2.2.1 Failure Frequencies: Carbon and Stainless Steel Ruptured Data 23
2.2.2 Failure Frequencies: PWR and BWR Plant Type Ruptured Data 25
2.2.3 Effect of National Transportation Safety Board Data 27
2.3 Plant Data 28
2.3.1 Pressurized Water Reactor Data Set 28
2.3.2 Boiling Water Reactor 30
2.3.3 Plant Data Conclusion 32
2.4 Failure Mechanisms 34
2.4.1 Failure Mechanism: PWR Data Set 34
2.4.2 Failure Mechanism: BWR Data Set 34
2.4.3 Failure Mechanism: Summary 35
2.4.4 Effect of National Transportation Safety Board Data 35
3.0 Conclusions 36
4.0 References 37
5.0 Appendices 38

List of Figures

pg.
Figure 1.4.1: Flow Chart of Failure Frequency Calculations 15
Figure 2.1.1: All Data, PWR Bins 17
Figure 2.1.2: All Data, BWR Bins 18
Figure 2.1.3: All Carbon and Stainless Steel Data, PWR Bins 19
Figure 2.1.4: All Carbon and Stainless Steel Data, BWR Bins 20
Figure 2.2.1: Carbon and Stainless Steel Rupture Data in PWR Bins 23
Figure 2.2.2: Carbon and Stainless Steel Rupture Data in BWR Bins 24
Figure 2.2.3: PWR Rupture Data in PWR Bins 25
Figure 2.2.4: BWR Rupture Data in BWR Bins 26
Figure 2.3.1: All Collected PWR Data Failure Frequency 29
Figure 2.3.2: Carbon and Stainless Steel PWR Data Failure Frequency 30
Figure 2.3.3: All Collected BWR Data Failure Frequency 31
Figure 2.3.4: Carbon and Stainless Steel BWR Data Failure Frequency 32

List of Tables

pg.
Table 1.3.1: System Designation of Carbon or Stainless Steel 9
Table 1.3.1 continued: System Designation of Carbon or Stainless Steel 10
Table 1.4.1: NRC Classification of Break Size 13
Table 1.4.2: NRC Calculated Failure Frequencies 14
Table 2.1.1: Failure Frequencies, All Data 18
Table 2.1.2: Failure Frequencies, Carbon Steel Data 20
Table 2.1.3: Failure Frequencies, Stainless Steel Data 20
Table 2.1.4: Large Pipe Range Estimated and Calculated Failure Frequency 22
Table 2.2.1: Failure Frequencies in PWR Bins for Rupture Data 24
Table 2.2.2: Failure Frequencies in BWR Bins for Rupture Data 25
Table 2.2.3: PWR Rupture Data Set in PWR Bins 26
Table 2.2.4: BWR Rupture Data Set in BWR Bins 27
Table 2.3.1: All Collected PWR Data 28
Table 2.3.2: PWR Carbon Steel Failures 29
Table 2.3.3: PWR Stainless Steel Failures 29
Table 2.3.4: All Collected BWR Data 30
Table 2.3.5: BWR Carbon Steel Failures 31
Table 2.3.6: BWR Stainless Steel Failures 32
Table 2.4.1: Failure Mechanisms for the PWR Data Set in PWR Bins 34
Table 2.4.2: Failure Mechanisms for the BWR Data Set in BWR Bins 35
Table 2.4.3: Summary of Failure Mechanisms 35

1.0 Introduction

1.1 Project Introduction and Objective

The Nuclear Regulatory Commission (NRC) is examining the technical basis for the largest pipe size failure required for the design basis Loss of Coolant Accident (LOCA) analysis. In current regulations this design basis accident is initiated by a double ended guillotine break of the reactor coolant system cold leg. Based on expert elicitation and fracture mechanics modeling, very low failure frequencies are predicted for such large pipes. [1]

It was the objective of this paper to examine data from piping failures in nuclear power plants and other industries in comparison to the failure frequencies predicted by the NRC. In order to do this, the data was divided by three main criteria: materials, which was further broken up into stainless steel and carbon steel; failure type, which was divided further into leaks and cracks versus ruptures, severances, and breaks; and by plant type, which was divided into pressurized water reactor (PWR) and boiling water reactor (BWR). Data collection, reduction, and analysis approach are examined in Sections 1.2, 1.3, and 1.4, respectively.

1.2 Data Collection

1.2.1 General Search Approach

A literature search was conducted to search for failed pipe data. When references were obtained which summarized data results, the original references were obtained when possible to examine the original data.

Initial search results were not promising, yielding many failures that were thrown out because the failures occurred in laboratories and not in service. Laboratory failures were generally caused by purposeful testing to failure and were therefore not applicable for this study. However, a large database of nuclear power plant piping failures was found and formed the analyzed database.

1.2.2 Initial Searches

Initial searches for data yielded results from laboratories and the petrochemical industry. A number of conference proceedings were available with summaries of piping failures in various industries. Some of this data was unusable in the database because the failures occurred in a laboratory setting, not in the pipe's service function.

Rejected Data:

1. Cronin and Roy created a database of pipe failures with 80 carbon steel pipes taken out of service from the Canadian petrochemical industry due to excessive corrosion. The researchers then pressurized the pipe sections in the laboratory to failure. This data was removed from the database because the pipes did not fail under their designed operating conditions.
2. Neto, Maneschy, and Nobrega used cracked pipes and stressed them to failure. Again, as the pipes did not fail under their designed operating conditions, this data was discarded.
3. Roos, et al, failed pipes in the laboratory, and this data was discarded because the pipes did not fail in their designed setting.

Acceptable Data:

1. The failure of pipe in a petroleum refinery catalytic reforming unit, as discussed by Buchheim, was retained because the pipe failed in service due to creep rupture. It should be noted that this pipe was manufactured to ASTM A691 criteria, different than those set for pipes in nuclear power plants. Due to this difference and the inability to classify the pipe failure as a PWR or BWR failure this data was not included.

The search of journal and conference papers did not yield substantial results. However, the literature survey did indicate that databases of nuclear power plant pipe failure data exist. Access to these existing databases was pursued, in addition to other, more general, internet searches for failed pipe data.

1.2.3 National Transportation Safety Board

The National Transportation Safety Board (NTSB) website was found through a general internet search for failed pipes. A number of reports of oil or gas pipeline failures were available. These reports were read and the pertinent data taken for the database. It should be noted that these pipes, which failed in service, were designed to American Petroleum Institute standards. The failure mechanisms were applicable to nuclear power plants, such as corrosion and fatigue. When the failure mechanism was obviously not applicable to a nuclear power plant, such as failure due to blunt force applied to the pipe the data was excluded.

Because these pipes were not designed to the same standards as those in nuclear power plants and could not be segregated into PWR or BWR plant type these failures were not included in the final database. However, their effects on the failure frequencies calculated from the final database are discussed where applicable.

1.2.4 Database of Nuclear Power Plant Failures

During the literature survey for failed pipe data, papers were found which referenced a database of failures in nuclear power plants compiled over the course of many years by Dr. Spencer Bush of Review & Synthesis Associates of Richland, Washington. Dr. Bush was contacted for permission to access the database. He indicated that he no longer had the data in electronic form, but was willing to send Penn State a hardcopy of the database. The hardcopy was received and examined.

The database consisted of failures in nuclear power plants from the early 1970s to 1996. Data was tabulated; the plant, failure date, system name, pipe size, break definition, references, and comments were given. One section of data consisted entirely of non-leaking cracks and wall thinning; this data was not included in the final database examined for this study. The leaking cracks, failures, ruptures and severed pipe data were transcribed to electronic form to constitute the database studied here.

1.3 Data Reduction to Final Database

As briefly described in Section 1.2, many of the data points found in the literature for pipe failure were discarded because they were intentionally failed in laboratory conditions. The original Bush database had to be further examined in order to separate the data into stainless steel and carbon steel components, and to eliminate data points for which there was insufficient information to accurately classify them.

1.3.1 Separation of Data into Stainless and Carbon Steels

Each pipe failure was assigned stainless or carbon steel based on the system in which the failure was found. It was assumed that primary system components were stainless steel; secondary system components were carbon steel. The system designation is given in Table 1.3.1 below. Due to inconsistency in labeling in the original database, there may be some overlap in system nomenclature.

Table 1.3.1: System Designation of Carbon or Stainless Steel

Carbon Steel	Stainless Steel
Aux. Feedwater	accumulator
Bellows at steam relief valve	AFW minimum flow line
Blown down line	Atm dump
CCW - component cooling water	Atmosphere control header
CCW HX	Bldg Spray
CFCU	Boiler feed
chillers	Borated Line
circulation	Boric Acid
Closed Cooling Water	boron injection
Component coolers	boron transporter
Condensate	Buried RCIC
Cont. fan cooler	Charging
Cont. recir. SWS	Chemical and Volume Control
containment	Chemical waste
Containment Air cooler	Chlorination
containment fan cooler	Cleanup
Containment heat removal	Cold Leg Drain
D.G. cooler	Containment spay
D.G. SWS	Control Rod Drive
Discharge line condensate to river	Coolant pump seal return line
Drain in steam line	Coolant recirculation
ERCW	Core Aux Cooling
ESW	Core spray
Expansion joint condensate	Demineralizer
Fan cooler	Desuperheater

Table 1.3.1 continued: System Designation of Carbon or Stainless Steel

Carbon Steel	Stainless Steel
Feedwater	Drains from drain tank to flash tank
Fire header	ECW- Emergency cooling water (system)
Fire Main	Emergency core cooling
Fire Main	Extraction steam line
Fire Prevention	Flow sensor
Fire Protection	Flow Sensor
Fire suppression	flow transmitter
Header to pier 1	flux thimbles
Main steam	Gas line
RBCW	High pressure core injection
salt SWS	In core instrument nozzle
seal line	Inst. Air cooler
Service water	Inst. Pressure sensing line, clean water storage tank
Spent Fuel Pool	Instrument air
Spray pond line	instrument line
Steam	intake cooling water
Steam Generator Blow Down	Jet pump rod inst line
SWS	Laundry discharge
Turbine drain line	Let down line
Turbine Exhaust	LPCI
turbine return line	lube cooling
waste concentrate	Makeup System
Water to D.G.	Moisture separator reheater
	Pressurizer
	Pump seal line
	Radwaste
	Reactor Coolant
	Reactor recirculation
	Reactor Sensor Line
	Reactor Water Cleanup
	Recirculation
	Residual Heat Removal
	Safety Injection
	SIS
	thimble tube
	Torus spray/LPSI
	Vent line
	Water box

1.3.2 Removal of Data Due to Size Uncertainty

A number of data points were removed from the database due to uncertainty in the leak size. Some of the pipe sizes were simply given as "unknown"; others were given in a range of numbers such as 3-24. This was interpreted to mean that the pipe that failed had a diameter between 3 and 24 inches. Due to this uncertainty, these points were removed.

The bulk of the data removed due to size was from failures which occurred at junctions. For these points, the pipe size is given as, for example, 12x16, indicating a junction from a 12 inch to a 16 inch pipe. As it is unknown where the failure occurred, and a number of these failures occurred in pipes whose sizes did not fall in the same analysis bins (see Section 1.4), these data points were discarded.

A list of the data discarded from the original Bush database due to size uncertainty is given in Appendix B1.

1.3.3 Removal of Data due to Material Uncertainty

A number of data points were removed due to the uncertainty of suitability of their material for this database. In some data points, the system in which failure occurred was unknown. These data points could have been maintained in the database for graphs which were not examined by material, but for simplicity they were removed. Other pipes were clearly not made of stainless or carbon steel; they were labeled in the comments as aluminum, copper, fiberglass, etc.

Other data points were removed because their systems did not clearly indicate whether the pipe would be stainless or carbon steel.

A list of the data discarded due to material uncertainty is given in Appendix B2.

1.3.4 Questionable Large Pipes

The Bush database included 10 large pipes of diameter 100 in or 120 in. Nine were classified as carbon steel, one was classified as stainless. It was uncertain, upon examining these data, whether pipes this large existed in the plants or whether the pipe sizes were typos. It was decided to include the data. The effect of removing these data on the calculated failure frequencies is discussed briefly below.

1.3.5 Final Database for Analysis

The final database for analysis consists of only the applicable nuclear power plant data from the Bush database, after data points were discarded due to their unsuitability as discussed in Sections 1.3.2 and 1.3.3. The National Transportation Safety Board data was not included as the pipes were manufactured to different specifications than those required for nuclear-grade pipes. However, these pipes were designed to meet

specifications and failed in service. Their effect on the failure frequencies calculated is discussed where applicable.

The analyzed data is given in tabulated form in Appendix A. The National Transportation Safety Board data is given in Appendix C. There are a total of 2529 data points in the final database, and an additional 11 points from the National Transportation Safety Board accident reports.

1.4 Data Analysis Approach

The final database, shown in Appendix A, was analyzed based on pipe size, material, plant type in which the pipe was in service, and failure type. The failure frequencies calculated were converted to a per calendar year of reactor operation basis and the failures were grouped according the NRC's pipe size bins in order to better compare the data gathered to the NRC estimated failure frequencies.

1.4.1 Failure Size Classification

The NRC published information regarding pipe failures gives the estimated frequency of failure per calendar year as a function of the flow that would be caused by the failure. Therefore, the pipe break size for the same flow differs for PWR- and BWR-type plants. The NRC flow ranges and corresponding ranges of pipe size for PWRs and BWRs are shown in Table 1.4.1. [1]

Table 1.4.1: NRC Classification of Break Size

Bin #	LOCA Size (GPM)	PWR Effective Break Size (in)	BWR Effective Break Size (in)
1	> 100	$0.5 < x \leq 1.625$	$0.5 < x \leq 1.875$
2	>1,500	$1.625 < x \leq 3$	$1.875 < x \leq 3.25$
3	>5,000	$3 < x \leq 7$	$3.25 < x \leq 7$
4	>25,000	$7 < x \leq 14$	$7 < x \leq 18$
5	>100,000	$14 < x \leq 31$	$18 < x \leq 41$
6	>500,000	$31 < x$	$41 < x$

As the compiled data gave pipe diameter sizes, the data was sorted into bins for frequency analysis based on the NRC break size classifications for PWRs and BWRs. The data was sorted into the 5 largest categories as given in Table 1.4.1. However, for the smallest category, Bin 1 was extended from zero inches to the maximum of the bin, 1.625in for PWRs and 1.875in for BWRs.

The sizes of a number of pipes in the database were given as "less than 1 inch" or "greater than 1 in" without further identification of pipe size. All of these cases were classified into the lowest pipe size bin for data analysis. This classification was made on the assumption that the pipe size was close to 1 inch and the failure belonged in the lowest bin.

1.4.2 NRC Failure Frequency

The NRC failure frequencies are given in Table 1.4.2. [1] Mean, 5% and 95% failure frequencies per calendar year are estimated for the U.S. nuclear fleet at the end of the original licenses. "X-axis point" refers to the data point used for graphing purposes; it is the lower bound of the bin size.

Table 1.4.2: NRC Calculated Failure Frequencies

Plant Type	Effective Break Size (in)	x-axis point	Failure Frequency (1/cal-yr)		
			5%	Mean	95%
PWR	0.5 <x≤ 1.625	0.5	3.0E-04	2.1E-03	7.5E-03
	1.625 <x≤ 3	1.625	4.9E-06	2.5E-04	9.3E-04
	3 <x≤ 7	3	3.1E-07	1.8E-05	7.0E-05
	7 <x≤ 14	7	6.0E-08	2.5E-06	9.6E-06
	14 <x≤ 31	14	9.3E-10	6.1E-08	2.4E-07
	31 <x	31	1.0E-10	4.6E-08	1.7E-07
BWR	0.5 <x≤ 1.875	0.5	2.30E-05	5.10E-04	1.90E-03
	1.875<x≤3.25	1.875	1.80E-06	1.20E-04	4.70E-04
	3.25 <x≤ 7	3.25	2.40E-07	2.10E-05	8.00E-05
	7 <x≤ 18	7	5.70E-08	6.60E-06	2.50E-05
	18 <x≤ 41	18	1.00E-08	2.40E-06	6.90E-06
	41 <x	41	2.80E-11	2.50E-09	9.50E-09

1.4.3 Conversion of Data to Failure Frequency

In order to convert the data compiled into a failure frequency, the data was divided into bins based on the pipe size, as described in Section 1.4.1. The failure frequency was calculated from the number of failures in that bin divided by the total number of failures. If A is the number of breaks in the bin of interest, and B is the total number of failures, then the failure frequency F' is given by:

$$F' = \frac{A}{B}$$

This gave the frequency of failure of that pipe size range as a function of all failures. In order to study the frequency per calendar year of operation, 3390 calendar years of operation were assumed. 3390 calendar years accounts for 2745 reactor years of experience in the United States as of the end of 2003, divided by an assumed availability factor of 0.81.

It should be noted that as the data in the database extends from the early 1970s to 1996, the use of 3390 calendar years to calculate the failure frequency is not a conservative assumption. The actual number of calendar years of operation for the time span of the data is less than that used in the analysis and would therefore indicate higher failure frequencies than those calculated.

Therefore, the frequency of failure for a given range of pipe sizes, F', was divided by Y, the 3390 calendar years of operation to give the failure frequency F in failures per calendar year.

$$F = \frac{F'}{3390} \rightarrow \text{failure frequency per calendar year}$$

When the data was subdivided, such as by material or plant type, the failure frequencies were calculated on the basis of the number of failures in the subdivided data section, not the total number of failures in the entire database.

1.4.4 Calculated Failure Frequencies

Failure frequencies were calculated based on all of the data and a number of subsets of the data. Figure 1.4.1 shows a flow chart of which failure frequencies were calculated.

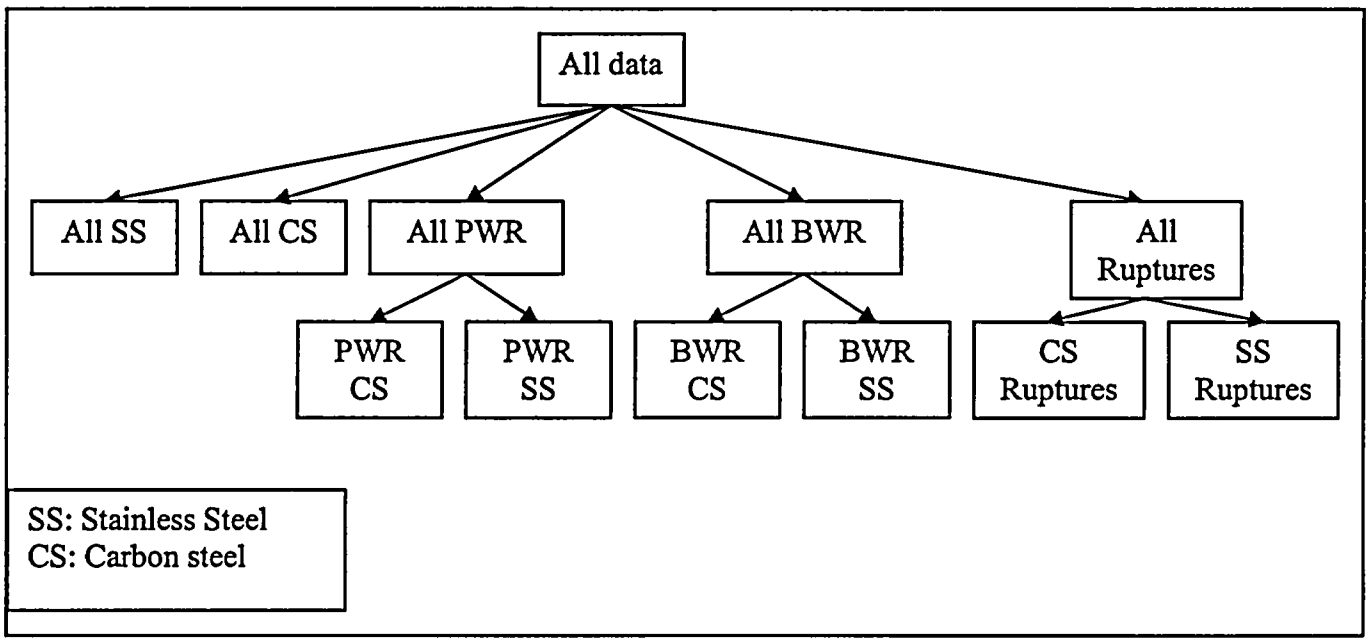


Figure 1.4.1: Flow Chart of Failure Frequency Calculations

Data was examined based on the pipe material, the plant type in which the pipe was operating, and on the failure type.

1.4.5 Failure Mechanisms

The failure mechanisms were examined to determine if there were dominating mechanisms across the database or the subsets described in Section 1.4.4.

2.0 Results and Discussion

The failure frequencies calculated, as described in section 1.4, are presented and discussed. Section 2.1 discusses the database as a whole. Section 2.2 shows failure frequencies for only pipes which ruptured, severed, or broke, not those whose failure was by cracking and leaking. Section 2.3 discusses the data when it is separated by plant type. Section 2.4 gives an overview of the failure mechanisms observed in the data.

All of the data is compared to the appropriate NRC failure frequency bins. When there is not an inherently appropriate bin, such as for data not divided by plant type, the calculated failure frequencies are compared to both the NRC PWR and BWR failure frequency estimates. In these cases the database is divided into the appropriate ranges based on the NRC pipe size ranges for PWR and BWR failures.

2.0.1 Discussion of Large Pipe Effect

As discussed in Section 1.3.4 there were ten large pipes in the database whose sizes were questionable. As the data was felt to be reliable, these data points were included in the database. When the all of the data was examined by material type, the effect was negligible as discussed below. However, the effect of these pipes on the calculated failure frequencies could be significant when the data was subdivided by plant type or particularly, failure type.

If the one large stainless steel pipe in doubt is removed from the stainless steel database, then the stainless steel failure frequency for pipes larger than 31 inches drops from 8.07×10^{-7} failures per calendar year to 5.38×10^{-7} failures per calendar year. Dropping it from the BWR bins decreases the failure frequency for pipes larger than 41 inches from 5.38×10^{-7} failures per calendar year to 2.69×10^{-7} failures per calendar year. These values are still outside the 95% range of the corresponding NRC calculations.

If the 9 large carbon steel pipes are removed from the carbon steel subset of data, the carbon steel failure frequency for pipes larger than 31 inches drops from 3.91×10^{-6} failures per calendar year to 2.07×10^{-6} failures per calendar year. Dropping it from the BWR bins decreases the failure frequency for pipes larger than 41 inches from 2.27×10^{-6} failures per calendar year to 4.17×10^{-7} failures per calendar year. These values remain well outside the 95% range of the corresponding NRC calculations.

2.1 All Data

All of the data was examined against the NRC BWR and PWR failure frequencies. Then the data was divided between carbon steel and stainless steel failures and compared against the NRC BWR and PWR failure frequencies.

2.1.1 Failure Frequency: All Data Examined

Figures 2.1.1 and 2.1.2 show the frequency plot for all of the failure data, regardless of pipe material or plant type, against the NRC PWR and BWR failure frequencies, respectively. Table 2.1.1 gives the numerical failure frequency.

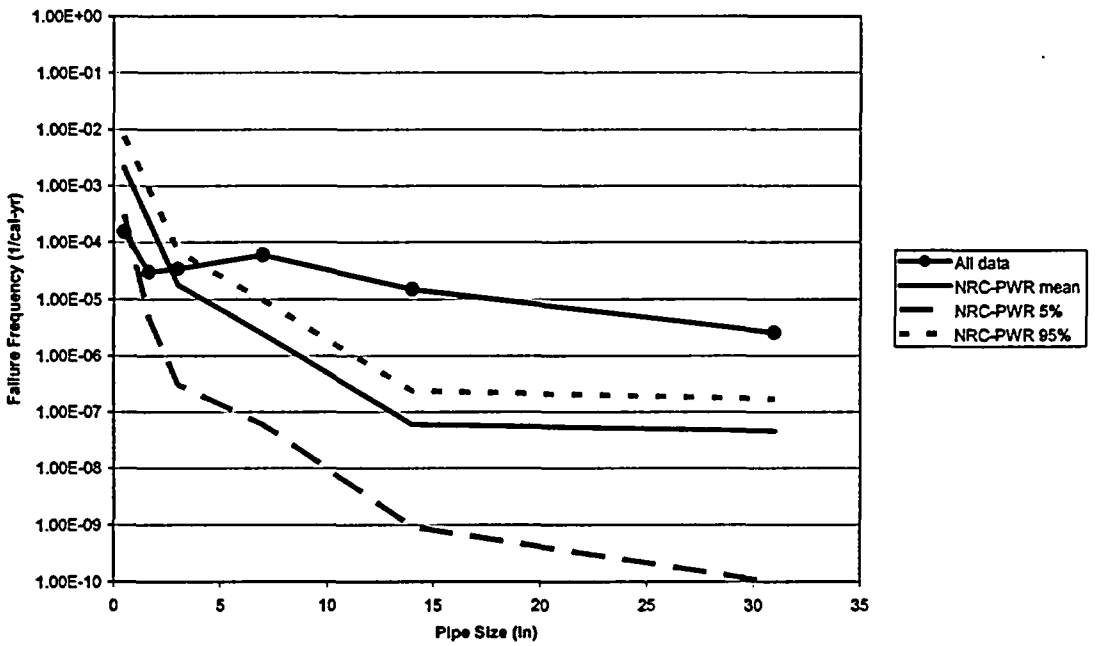


Figure 2.1.1: All Data, PWR Bins

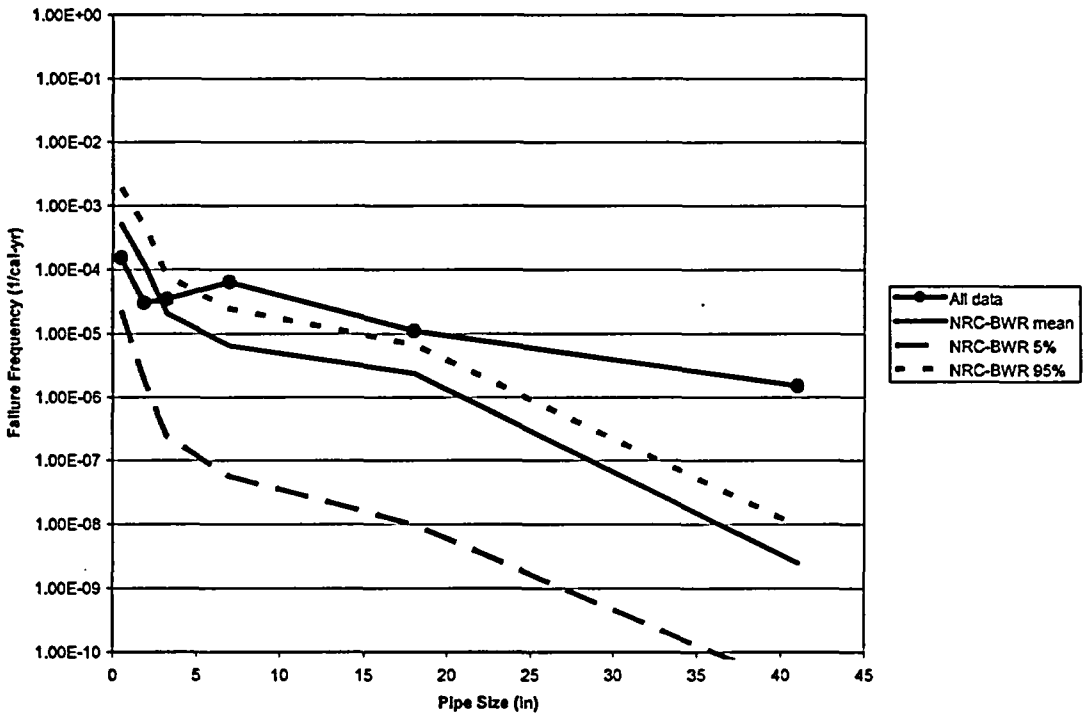


Figure 2.1.2: All Data, BWR Bins

Table 2.1.1: Failure Frequencies, All Data

NRC PWR Bins			NRC BWR Bins		
Range (in)	Frequency (no. events)	Frequency (1/cal-yr)	Range (in)	Frequency (no. events)	Frequency (1/cal-yr)
0-1.625	1310	1.53E-04	0-1.875	1310	1.53E-04
1.625-3	260	3.03E-05	1.875-3.25	260	3.03E-05
3-7	297	3.46E-05	3.25-7	297	3.46E-05
7-14	511	5.96E-05	7-18	554	6.46E-05
14-31	129	1.50E-05	18-41	95	1.11E-05
>31	22	2.57E-06	>41	13	1.52E-06

Figures 2.1.1 and 2.1.2 show relatively good agreement between the failure frequency calculated from the compiled data and the NRC estimated failure frequency for small pipe failures. If the failure frequencies for the data were calculated using a more realistic number of reactor calendar years appropriate to the database coverage, the agreement would be better for the small pipe failures.

However, Figures 2.1.1 and 2.1.2 indicate that for large pipe sizes, the failure frequency calculated from the data is higher than that estimated by the NRC when all of the data is considered. This is especially true for the PWR bin sizes. The BWR bin sizes show better agreement between the data and the NRC calculations. However, the BWR failure frequencies are still outside the 95% NRC calculated line for 7-18 inch and 18-41 inch failures. The PWR failure frequencies show even less agreement at the fourth and fifth bin ranges (7-14in and 14-31in); the failure frequency calculated from the data is

approximately an order of magnitude higher than the NRC estimation for these bin ranges.

2.1.1.1 Effect of National Transportation Safety Board Data

The inclusion of the National Transportation Safety Board Data slightly increased the failure frequencies of the larger pipe sizes, further distancing them from the NRC estimates. The exception is the greater than 41 inches bin, which slightly decreased. The smaller pipe failure frequencies decreased slightly. The failure frequencies with the National Transportation Safety Board data are given in Appendix E.

2.1.2 Failure Frequencies: Stainless Steel and Carbon Steel Pipes Separated

The data were separated into stainless steel and carbon steel pipes according to their given system, as discussed in Section 1.3.1. These data could be separately analyzed for failure frequency according to the method given in Section 1.4.3.

Figure 2.1.3 shows the failure frequency data for carbon and stainless steel for the NRC's PWR bins. Figure 2.1.4 shows the same data in the BWR bins. Tables 2.1.2 and 2.1.3 give the numerical failure frequencies for carbon and stainless steel, respectively.

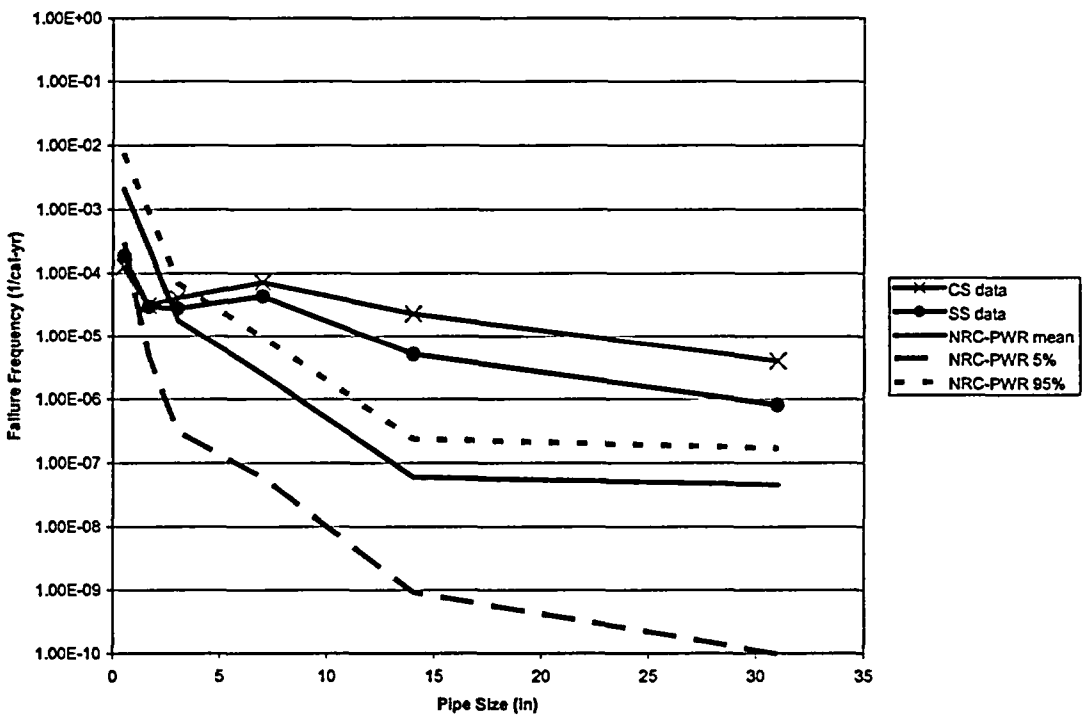


Figure 2.1.3: All Carbon and Stainless Steel Data, PWR Bins

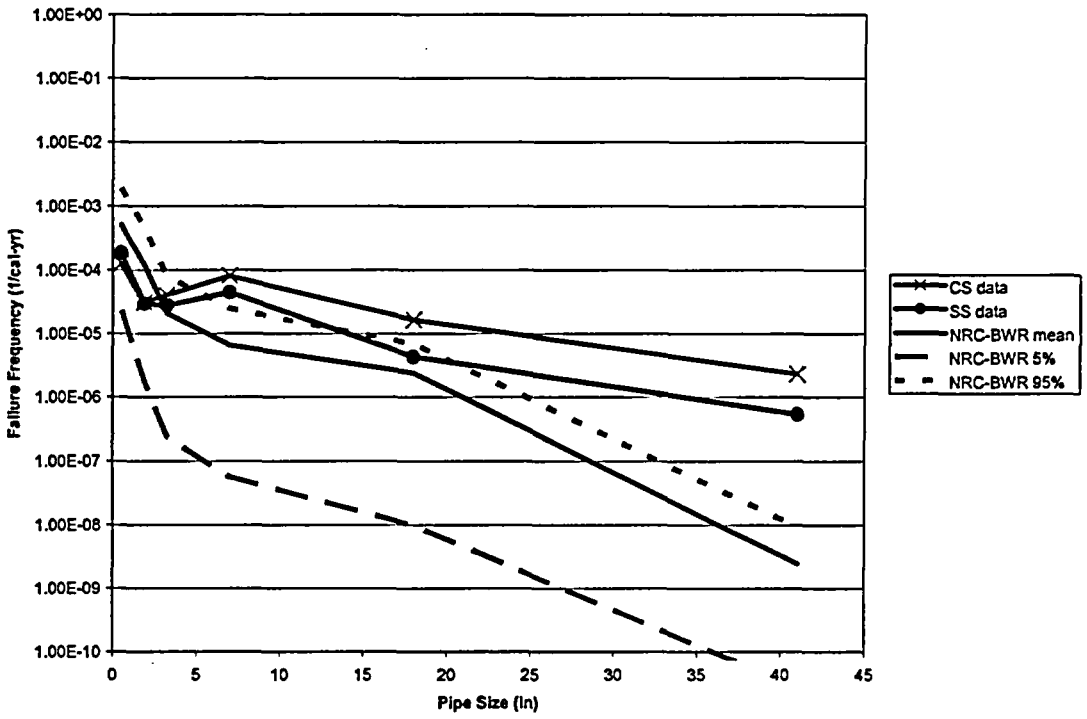


Figure 2.1.4: All Carbon and Stainless Steel Data, BWR Bins

Table 2.1.2: Failure Frequencies, Carbon Steel Data

NRC PWR Bins			NRC BWR Bins		
Range (in)	Frequency (no. events)	Frequency (1/cal-yr)	Range (in)	Frequency (no. events)	Frequency (1/cal-yr)
0-1.625	611	1.26E-04	0-1.875	611	1.26E-04
1.625-3	149	3.07E-05	1.875-3.25	149	3.07E-05
3-7	194	4.00E-05	3.25-7	194	4.00E-05
7-14	349	7.19E-05	7-18	388	7.99E-05
14-31	110	2.27E-05	18-41	79	1.63E-05
>31	19	3.91E-06	>41	11	2.27E-06

Table 2.1.3: Failure Frequencies, Stainless Steel Data

NRC PWR Bins			NRC BWR Bins		
Range (in)	Frequency (no. events)	Frequency (1/cal-yr)	Range (in)	Frequency (no. events)	Frequency (1/cal-yr)
0-1.625	699	1.88E-04	0-1.875	699	1.88E-04
1.625-3	111	2.98E-05	1.875-3.25	111	2.98E-05
3-7	103	2.77E-05	3.25-7	103	2.77E-05
7-14	162	4.36E-05	7-18	166	4.46E-05
14-31	19	5.11E-06	18-41	16	4.30E-06
>31	3	8.07E-07	>41	2	5.38E-07

Figures 2.1.3 and 2.1.4 show that carbon steel pipes have consistently higher failure frequencies than stainless steel pipes except at the smallest sizes. For pipes 7 inches and larger the carbon steel pipes fail more frequently; for smaller pipes the failure frequency is approximately equal.

For the PWR binned data, the carbon and stainless steel failure frequencies remain significantly higher than the NRC calculations, especially in the 14-31inch range. For the BWR binned data, the agreement is better, especially in the 18-41 inch range. For the 18-41 inch range the stainless steel failure frequency falls within the 95% line of the NRC calculation. However, divergence is again observed for very large pipes in the BWR bins.

2.1.2.1 Effect of National Transportation Safety Board Data

As all of the National Transportation Safety Board data are for carbon steel pipes, the stainless steel frequency distributions are not affected.

For the carbon steel pipes, the failure frequency of the pipe bins greater than 7 inches increased slightly. A large increase was seen in the largest PWR bin, for pipes greater than 30 inches, from 3.91×10^{-6} to 4.50×10^{-6} failures per calendar year. The increased failure frequencies for the larger pipe bins when the National Transportation Safety Board data are included are given in Appendix E.

2.1.3 Summary and Discussion of Results: All Data

At the smaller pipe size ranges the calculated failure frequencies agree fairly well with the NRC frequencies and the NRC estimated failure frequencies are often higher than those calculated from the data. However, for the large pipe size ranges (14-31in and >31in for a PWR; 18-41 in and >41in for a BWR), significant deviation is shown between the calculated failure frequencies and the NRC estimates. This is especially true when the data is separated into the PWR bins and compared to the PWR failure frequencies, and in the largest bin size of the BWR ranges (>41in). When the data is separated into the BWR bins and compared to the BWR failure frequencies the agreement is better in the 18-41inch bin but more divergence is seen in the largest bin size than in comparison to the largest PWR bin size.

Examination of the numerical values of the failure frequencies estimated and calculated indicates the NRC BWR failure frequency in the second to largest bin is one to two orders of magnitude higher than the corresponding NRC PWR frequency. For the largest pipe size bin, >31in in a PWR and >41 inches in a BWR, the BWR failure frequency estimate is one to two orders of magnitude lower than the PWR estimate. The failure frequencies calculated from the data are on the same order of magnitude regardless of how the data is classified. This is summarized in Table 2.1.4; the NRC's mean value is given but the trend is also seen in the 5% and 95% values.

Table 2.1.4: Large Pipe Range Estimated and Calculated Failure Frequency

	NRC Mean value (1/cal-yr)	All Data (1/cal-yr)	Carbon Steel (1/cal-yr)	Stainless Steel (1/cal-yr)
PWR: 14-31in	6.10E-8	1.50E-5	2.27E-5	5.11E-6
BWR: 18-41 in	2.40E-6	1.11E-5	1.63E-5	4.30E-6
PWR: >31 in	4.60E-8	2.57E-6	3.91E-6	8.07E-7
BWR: >41 in	2.50E-9	1.52E-6	2.27E-6	5.38E-7

This difference between the NRC PWR and BWR failure frequency estimates for the larger pipe sizes is further examined in Section 2.3 where the data is divided by plant type.

2.2 Rupture Analysis:

The data included in this section is the rupture only data set. The rupture data set is defined as any failure, break, rupture, or severed pipe from the original pipe database. The rupture data set excludes any leaks or cracks. All the rupture data was divided into carbon and stainless steel and evaluated against the NRC PWR and BWR failure frequencies. Then the rupture data was divided into PWR and BWR plant types and evaluated against the NRC PWR and BWR failure frequencies.

2.2.1 Failure Frequencies: Carbon and Stainless Steel Ruptured Data

Figure 2.2.1 shows the frequency plot for all carbon and stainless steel ruptured data in PWR bins against the NRC PWR failure frequencies. At larger pipe sizes the carbon steel pipes have a higher failure frequency compared to stainless steel pipes and the NRC data. The failure frequencies for the smaller pipe sizes for both carbon and stainless steel are in good agreement with the NRC's estimated failure frequencies. Table 2.2.1 gives the numerical failure frequencies.

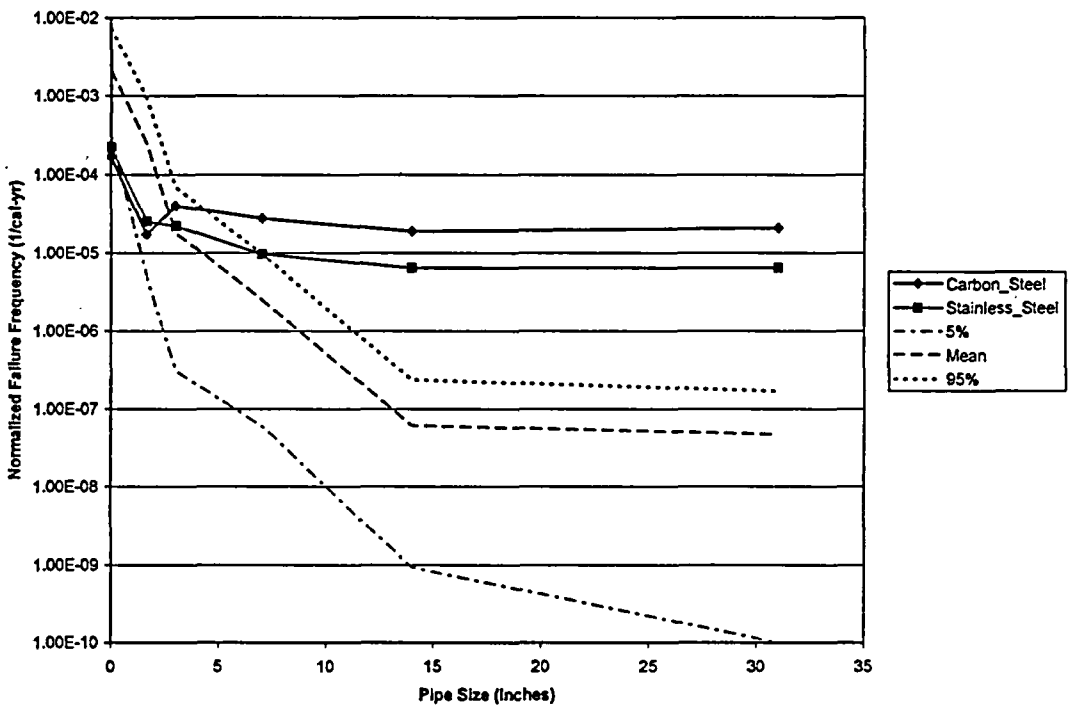


Figure 2.2.1: Carbon and Stainless Steel Rupture Data in PWR Bins

(normalized to Ruptures, failures, Severences only)

Table 2.2.1: Failure Frequencies in PWR Bins for Rupture Data

NRC PWR Bins - Carbon Steel			NRC PWR Bins - Stainless Steel		
Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)	Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)
0 - 1.625	97	1.69E-04	0 - 1.625	69	2.24E-04
1.625-3	10	1.75E-05	1.625-3	8	2.59E-05
3 – 7	23	4.01E-05	3 - 7	7	2.27E-05
7 - 14	16	2.79E-05	7 - 14	3	9.72E-06
14 - 31	11	1.92E-05	14 - 31	2	6.48E-06
>31	12	2.09E-05	>31	2	6.48E-06

Figure 2.2.2 shows the frequency plot for carbon and stainless steel ruptured data using all data in BWR bins against the NRC BWR failure frequencies. In Figure 2.2.2 the pipe database failure frequencies are in good agreement with the NRC BWR failure frequencies except for the largest bin size (Bin 6 - >41in). For pipes greater than 41 inches the pipe databases failure frequency is larger than the NRC BWR estimated failure frequencies. An important note is that the BWR normalized failure frequency for larger pipes is smaller than the NRC PWR normalized frequency for larger pipes by approximately one to two orders of magnitude. From Figures 2.2.1 and 2.2.2 the failure frequency variation between PWR and BWR pipe database failure frequencies are on the same order of magnitude. Table 2.2.2 gives the numerical failure frequencies.

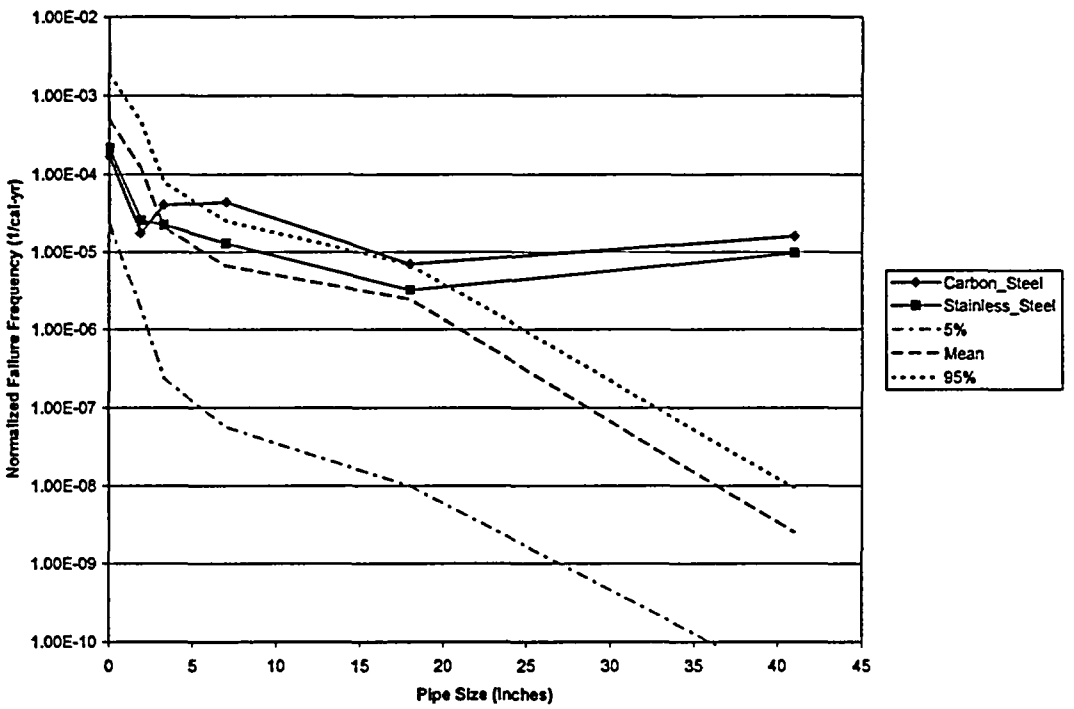


Figure 2.2.2: Carbon and Stainless Steel Rupture Data in BWR Bins

(normalized to Ruptures failure Severeces only)

Table 2.2.2: Failure Frequencies in BWR Bins for Rupture Data

NRC BWR Bins - Carbon Steel			NRC BWR Bins - Stainless Steel		
Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)	Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)
0 - 1.875	97	1.70E-04	0 - 1.875	97	2.20E-04
1.875 - 3.25	10	1.76E-05	1.875 - 3.25	10	2.59E-05
3.25 -7	23	4.04E-05	3.25 -7	23	2.27E-05
7 -18	25	4.39E-05	7 -18	25	1.30E-05
18 - 41	4	7.02E-06	18 - 41	4	3.24E-06
>41	9	1.58E-05	>41	9	9.72E-06

2.2.2 Failure Frequencies: PWR and BWR Plant Type Ruptured Data

Figure 2.2.3 shows the frequency plot for the PWR plant type ruptured data set in PWR bins against the NRC PWR failure frequencies. In Figure 2.2.3 the PWR plant type failure frequencies for the smaller pipe sizes (Bins 1 through 3) are in good agreement with the NRC PWR estimate failure frequencies. However, at the larger pipe sizes the PWR rupture data set calculated a higher failure frequency then the NRC PWR estimated failure frequencies. Table 2.2.3 gives the numerical failure frequencies.

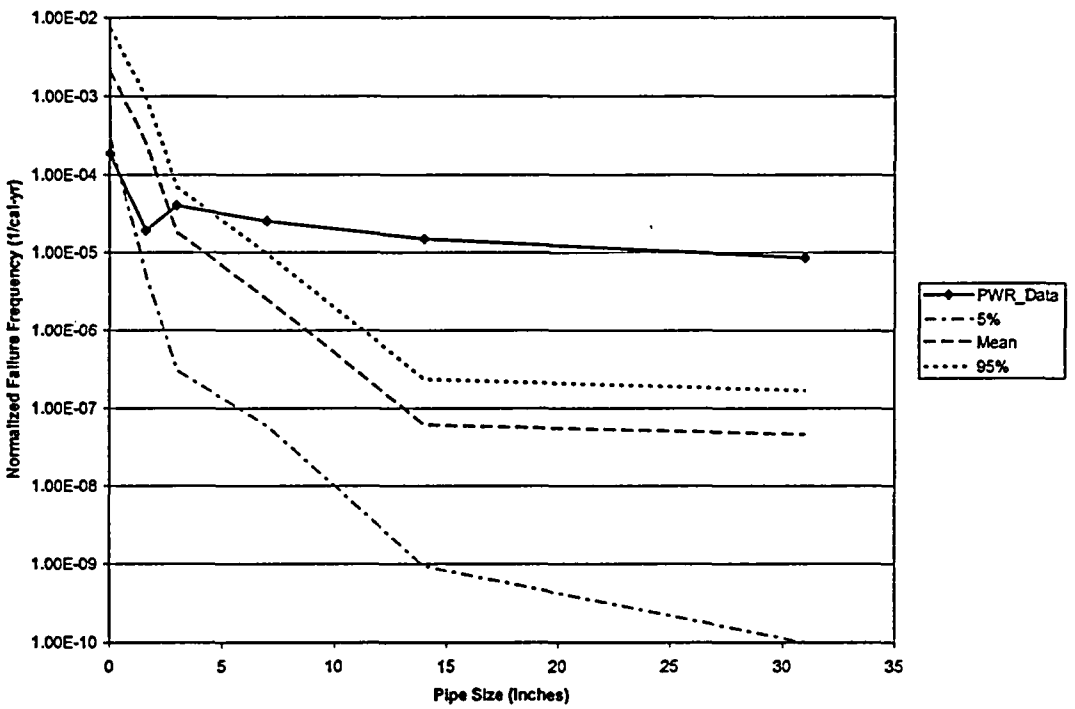


Figure 2.2.3: PWR Rupture Data in PWR Bins

(normalized to Ruptures, failures, Seravences)

Table 2.2.3: PWR Rupture Data Set in PWR Bins

NRC PWR Bins		
Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)
0 - 1.625	88	1.87E-04
1.625-3	9	1.91E-05
3 - 7	19	4.03E-05
7 - 14	12	2.55E-05
14 - 31	7	1.49E-05
>31	4	8.49E-06

Figure 2.2.4 shows the frequency plot for the BWR plant type ruptured data set in BWR bins against the NRC BWR failure frequencies. In Figure 2.2.3 the BWR plant type failure frequencies for pipe sizes up to 41 inches (Bins 1 through 5) are in good agreement with the NRC BWR estimate failure frequencies. However, at the largest bin (>41 inches) the BWR rupture data set calculated a higher failure frequency then the NRC BWR estimated failure frequencies. Table 2.2.3 gives the numerical failure frequencies.

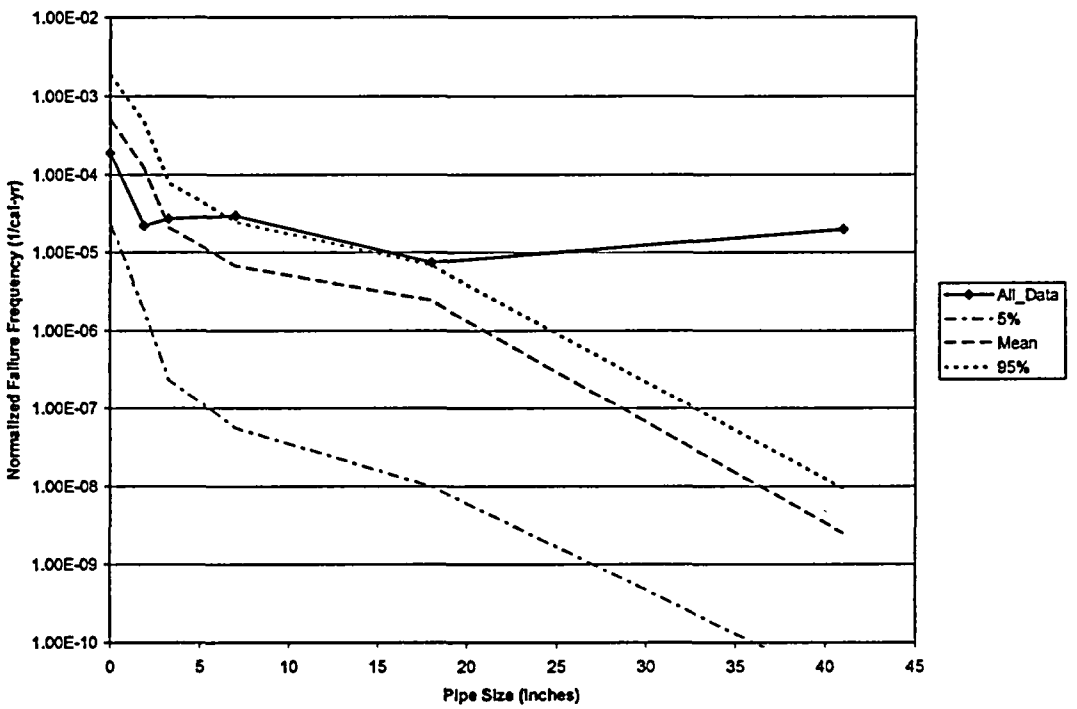
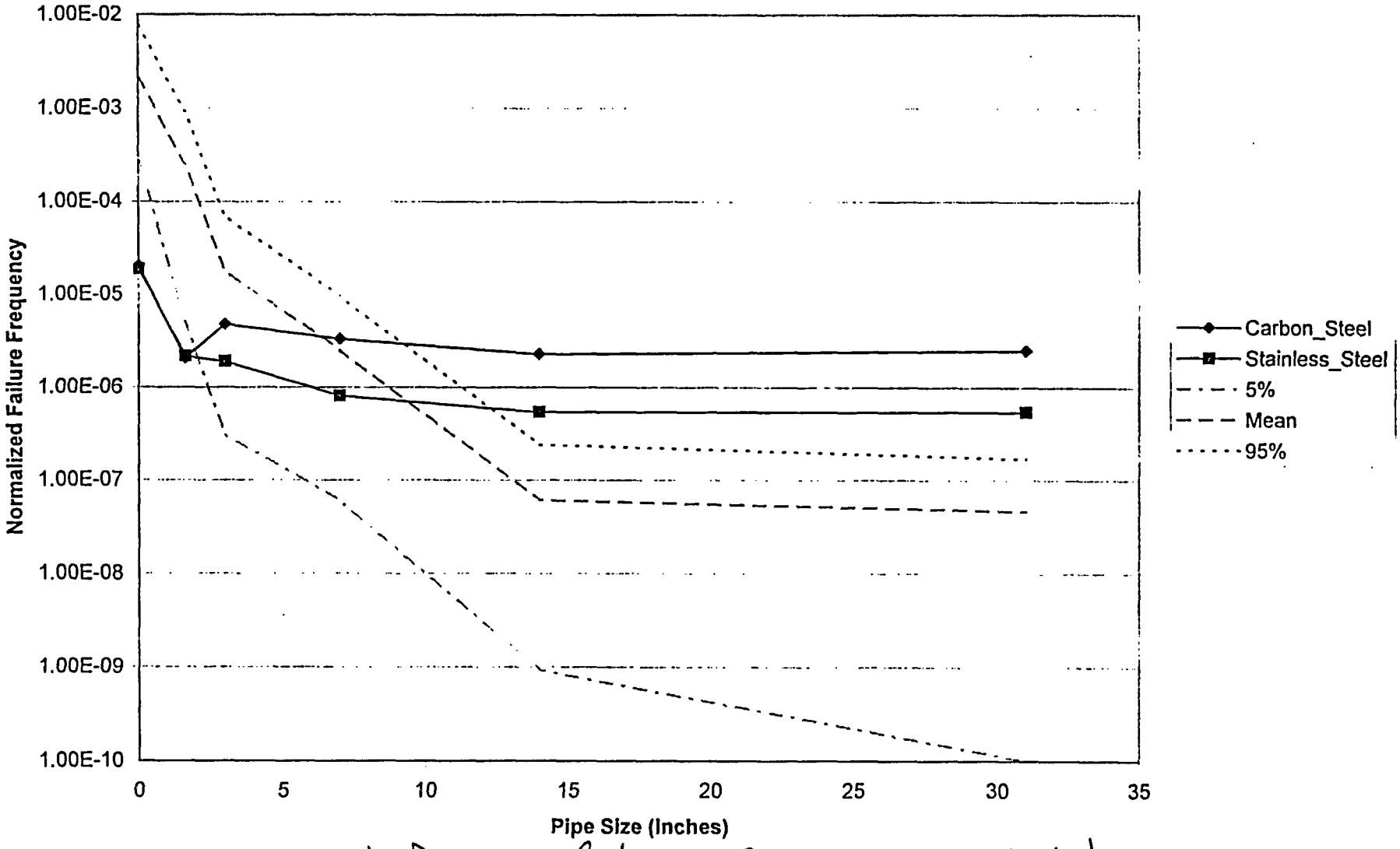


Figure 2.2.4: BWR Rupture Data in BWR Bins

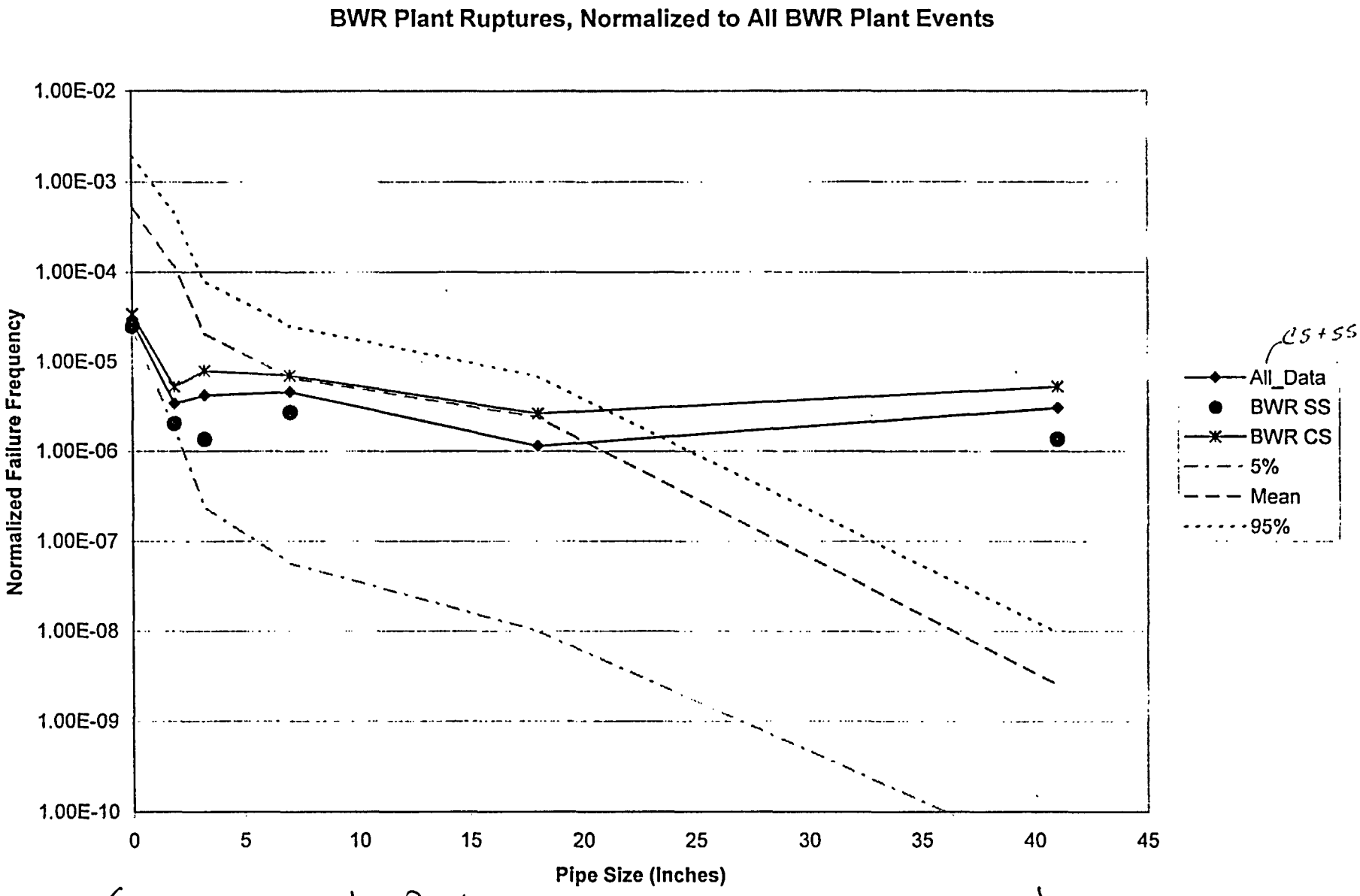
(normalized to Ruptures, failure, Sequences)

(PWR and BWR)

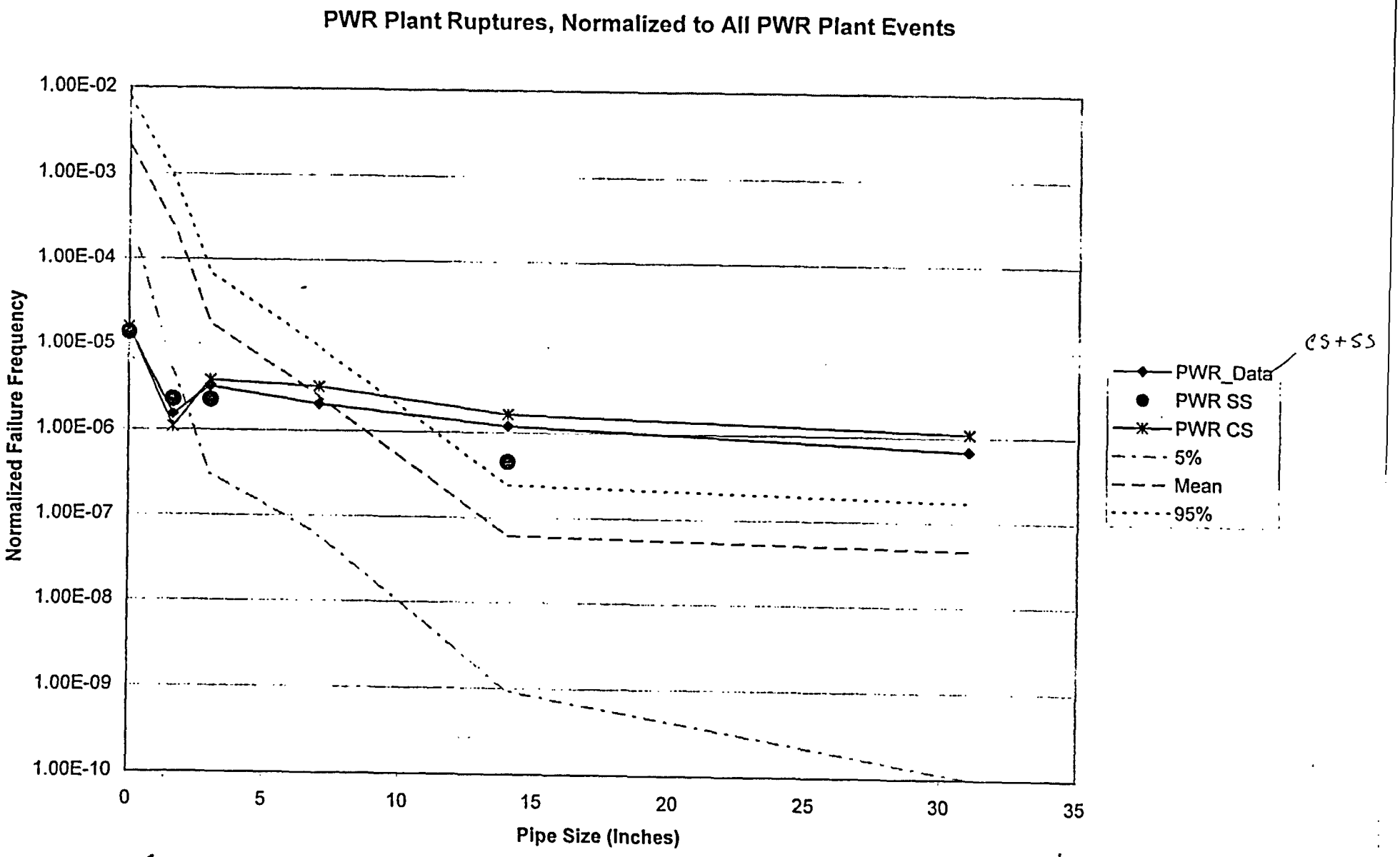
PWR Bins, Ruptures and Failures Normalized to All Data for Material Type



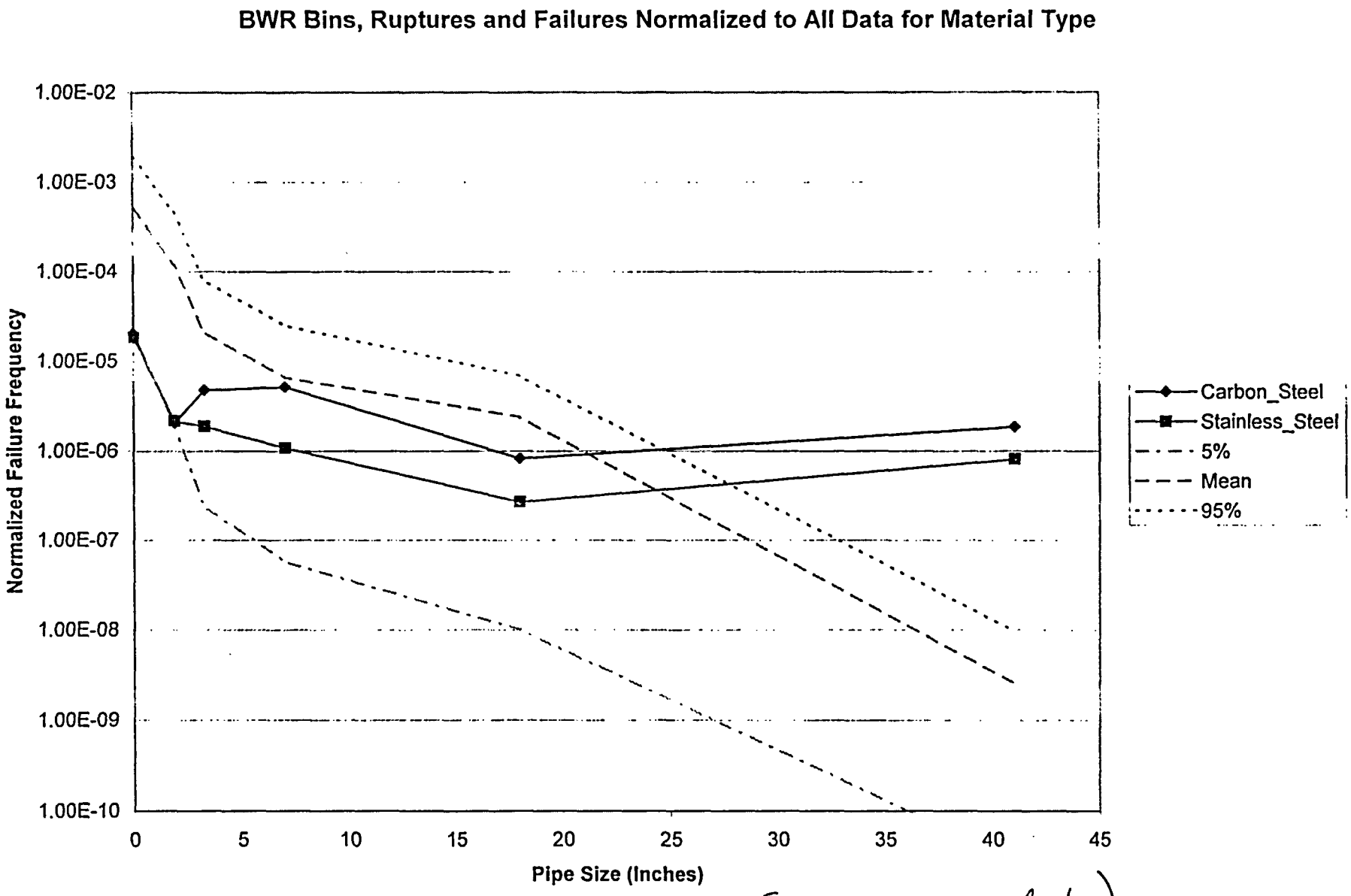
(normalized to Ruptures, failures, Severences, and leaks)



(Normalized to Ruptures, failures, Severenes, and leaks)



(normalized to Ruptures, failures, Severences, and leaks)



(normalized to Ruptures, failures, Surveys, and leaks)

BWR Bins - No Leaks or Cracks - All Data

	Bin 1	Bin 2		Bin 3	Bin 4	Bin 5	Bin 6
CS	97	10		23	25	4	9
SS	68	8		7	4	1	3

Calendar Years 3390

Carbon Steel - BWR NRC Bins

Bins		Total Entries	Normalized Frequency (Mean) Total Events	Normalized Frequency
0	1.875	97	0.06774	2.00E-05
1.875	3.25	10	0.00698	2.06E-06
3.25	7	23	0.01606	4.74E-06
7	18	25	0.01746	5.15E-06
18	41	4	0.00279	8.24E-07
41 greater		9	0.00628	1.85E-06
	Sum	168		

Total Carbon Steel Events 1432

CFR 50.46 Guidance - BWR

NRC #s

Bins		Normalized Frequency (5%)	Normalized Frequency (Mean)	Normalized Frequency (95%)
0	1.875	2.30E-05	5.10E-04	1.90E-03
1.875	3.25	1.80E-06	1.20E-04	4.70E-04
3.25	7	2.40E-07	2.10E-05	8.00E-05
7	18	5.70E-08	6.60E-06	2.50E-05
18	41	1.00E-08	2.40E-06	6.90E-06
41 greater		2.80E-11	2.50E-09	9.50E-09

NRC BWR Bins - Carbon Steel				NRC BWR Bins - Stainless Steel			
Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)	Normalized Frequency (Total Events)	Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)	Normalized Frequency (Total Events)
0 - 1.875	97	1.70E-04	2.00E-05	0 - 1.875	97	2.20E-04	1.83E-05
1.875 - 3.25	10	1.76E-05	2.06E-06	1.875 - 3.25	10	2.59E-05	2.15E-06
3.25 - 7	23	4.04E-05	4.74E-06	3.25 - 7	23	2.27E-05	1.88E-06
7 - 18	25	4.39E-05	5.15E-06	7 - 18	25	1.30E-05	1.08E-06
18 - 41	4	7.02E-06	8.24E-07	18 - 41	4	3.24E-06	2.69E-07
>41	9	1.58E-05	1.85E-06	>41	9	9.72E-06	8.07E-07

normalized to rupture data

normalized to rupture data

all CS >41in: 2.27×10^{-6} /cal yr

all SS >41in: 5.38×10^{-7} /cal-yr

Calendar Years 3390

Stainless Steel - BWR NRC Bins

Bins		Total Entrie	Normalized Frequency (Mean) Total Events	Normalized Frequency
0	1.875	68	0.06199	1.83E-05
1.875	3.25	8	0.00729	2.15E-06
3.25	7	7	0.00638	1.88E-06
7	18	4	0.00365	1.08E-06
18	41	1	0.00091	2.69E-07
41	greater	3	0.00273	8.07E-07
	Sum	91		
	Total SS Events	1097		

PWR Bins - No Leaks or Cracks - All Data

	Bin 1	Bin 2		Bin 3	Bin 4	Bin 5	Bin 6
CS	97	10		23	16	11	12
SS	69	8		7	3	2	2

Calendar Years 3390

Carbon Steel - PWR NRC Bins

Bins	Bin Minimum Limit	Range	Total Entries	Normalized	Normalized Frequency
1	0	0 - 1.625	97	0.06774	2.00E-05
2	1.625	1.625-3	10	0.00698	2.06E-06
3	3	3 - 7	23	0.01606	4.74E-06
4	7	7 - 14	16	0.01117	3.30E-06
5	14	14 - 31	11	0.00768	2.27E-06
6	31	>31	12	0.00838	2.47E-06
		Sum	169		
		Total Carbon Steel Events	~~1432~~		

CFR 50.46 Guidance - PWR

NRC #s

Bins	Bins Minimum Limit	Bin Maximum Limit	Normalized Frequency (5%)	Normalized Frequency (Mean)	Normalized Frequency (95%)
1	0	1.625	3.0E-04	2.1E-03	7.5E-03
2	1.625	3	4.9E-06	2.5E-04	9.3E-04
3	3	7	3.1E-07	1.8E-05	7.0E-05
4	7	14	6.0E-08	2.5E-06	9.6E-06
5	14	31	9.3E-10	6.1E-08	2.4E-07
6	31	greater	1.0E-10	4.6E-08	1.7E-07

NRC PWR Bins - Carbon Steel				NRC PWR Bins - Stainless Steel			
Range (Inches)	Frequency (no. Events)	Norm. to Rupture data Normalized Frequency (1/cal-yr)	Normalized Frequency Total Events	Range (Inches)	Frequency (no. Events)	Norm. to Rupture data Normalized Frequency (1/cal-yr)	Normalized Frequency Total Events
0 - 1.625	97	1.69E-04	2.00E-05	0 - 1.625	69	2.24E-04	1.86E-05
1.625-3	10	1.75E-05	2.06E-06	1.625-3	8	2.59E-05	2.15E-06
3 - 7	23	4.01E-05	4.74E-06	3 - 7	7	2.27E-05	1.88E-06
7 - 14	16	2.79E-05	3.30E-06	7 - 14	3	9.72E-06	8.07E-07
14 - 31	11	1.92E-05	2.27E-06	14 - 31	2	6.48E-06	5.38E-07
>31	12	2.09E-05	2.47E-06	>31	2	6.48E-06	5.38E-07

all CS data >31 in: 3.91×10^{-6} /cal-yr

all SS data >31 in: 8.07×10^{-7} /cal-yr

Calendar Years 3390

Stainless Steel * PWR NRC Bins

Bins	Bins Minimum Limit	Bin Maximum Limit	Total Entries	Normalized	Normalized Frequency
1	0	1.625	69	0.06290	1.86E-05
2	1.625	3	8	0.00729	2.15E-06
3	3	7	7	0.00638	1.88E-06
4	7	14	3	0.00273	8.07E-07
5	14	31	2	0.00182	5.38E-07
6	31	greater	2	0.00182	5.38E-07
		Sum	91		
		Total SS Events	1097		

Table 2.2.4: BWR Rupture Data Set in BWR Bins

NRC BWR Bins		
Range (Inches)	Frequency (no. Events)	Normalized Frequency (1/cal-yr)
0 - 1.875	76	1.88E-04
1.875 - 3.25	9	2.23E-05
3.25 -7	11	2.73E-05
7 -18	12	2.97E-05
18 - 41	3	7.44E-06
>41	8	1.98E-05

2.2.3 Effect of National Transportation Safety Board Data

The figures and tables in section 2.2 evaluated the effect of the NSTB data. In Section 2.2.1, if the NSTB ruptures were included the normalized failure frequency would increase slightly for the carbon steel pipes. In Section 2.2.2, the NTSB ruptures were not included due to the inability to segregate the ruptures into a PWR or BWR plant specific failure.

2.3 Plant Data

The United States Light Water Reactor designs may be divided into Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR). Though many similarities exist between these two plants designs, each design has different system parameters that will affect pipe leakage and failures. More specifically, the operating pressure of a PWR is roughly double that of a BWR. Also, the physical plants designs employ a different range of pipe sizes. Due to the different pipe sizing used in each plant design, the NRC found in necessary to create different bin sizes for the piping failure frequency. Because of the different operating conditions and different size of the piping used it was found to be useful to break down the collected data into PWR and BWR sections for comparison.

2.3.1 Pressurized Water Reactor Data Set

The PWR data was broken up into the prescribed bin size used by the Nuclear Regulatory Commission (NRC) [1]. Table 2.3.1 displays all PWR data collected and the normalized frequency of the data.

Table 2.3.1: All Collected PWR Data

Range (in)	Total Entries	Normalized Frequency (1/cal-yr)
0-1.625	879	1.48E-04
1.625-3	182	3.07E-05
3-7	179	3.02E-05
7-14	413	6.97E-05
14-31	83	1.40E-05
>31	12	2.03E-06

There were a total of 1748 usable pipe failure incidents found in PWR operating systems. A plot for comparison between the collected PWR data and the NRC mean, 5% and 95% failure frequencies per calendar year is shown in Figure 2.3.1. The data was estimated for the U.S. nuclear fleet at the end of the original licenses. Figure 2.3.1 displays an agreement between the NRC data and the collected data at lower bin sizes; however, deviations between the two data sets occur as bin size increases.

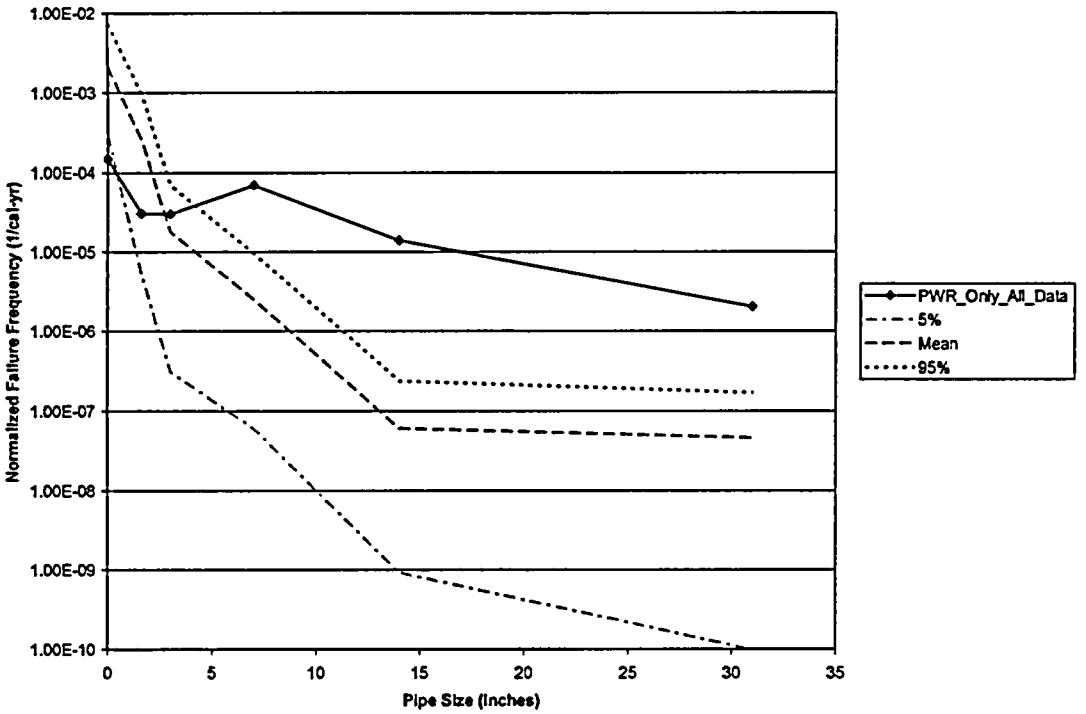


Figure 2.3.1: All Collected PWR Data Failure Frequency

To further analyze the PWR pipe failure frequency, the pipe data was broken into carbon and stainless steel incidents. Table 2.3.2 and Table 2.3.3 show the PWR plant failures subdivided by pipe material.

Table 2.3.2: PWR Carbon Steel Failures

Range (in)	Total Entries	Normalized Frequency (1/cal-yr)
0-1.625	432	1.17E-04
1.625-3	117	3.17E-05
3-7	143	3.87E-05
7-14	314	8.50E-05
14-31	75	2.03E-05
>31	9	2.44E-06

Table 2.3.3: PWR Stainless Steel Failures

Range (in)	Total Entries	Normalized Frequency (1/cal-yr)
0-1.625	447	2.00E-04
1.625-3	65	2.91E-05
3-7	36	1.61E-05
7-14	99	4.44E-05
14-31	8	3.59E-06
>31	3	1.34E-06

The PWR data collected has a total of 1090 carbon steel failure compared to 658 stainless steel failures. Figure 2.3.2 compares the PWR carbon and stainless steel failure data collected to the NRC mean 5% and 95% failure frequencies per calendar year. The carbon steel has a higher failure frequency then the stainless steel, which is expected. Both were significantly higher than the NRC predicted failure frequencies.

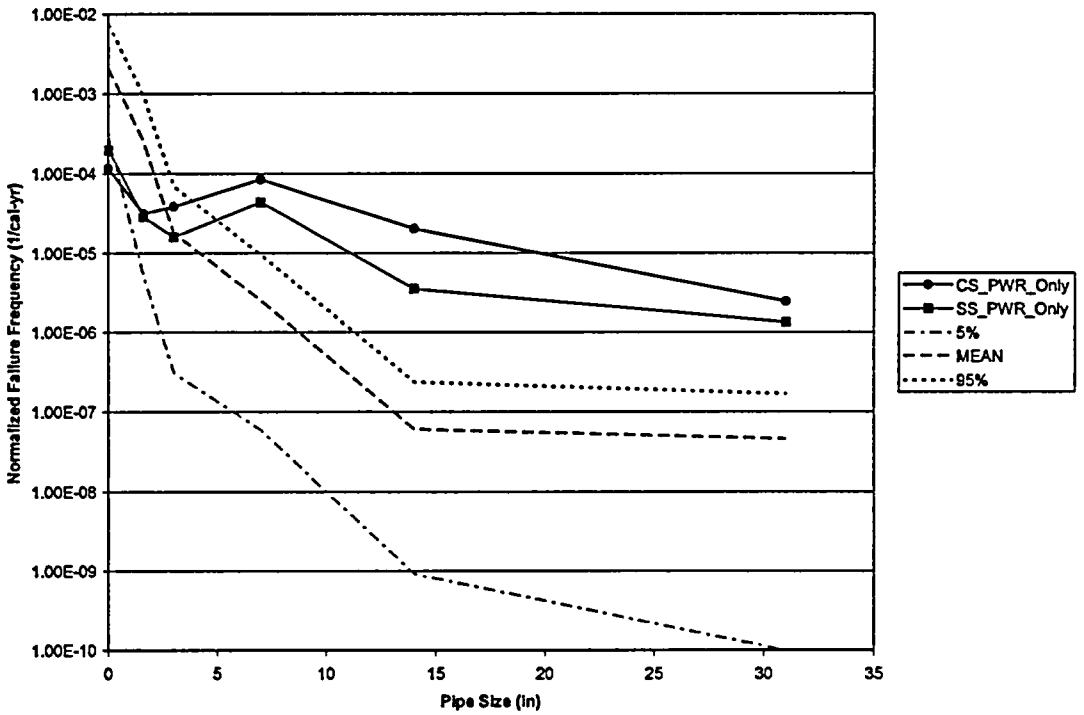


Figure 2.3.2: Carbon and Stainless Steel PWR Data Failure Frequency

2.3.2 Boiling Water Reactor

The BWR data was broken up into the prescribe bin size used by the Nuclear Regulatory Commission (NRC) as discussed Section 1.4.1. Table 2.3.4 displays all BWR data collected and the normalized frequency of the data.

Table 2.3.4: All Collected BWR Data

Range (in)	Total Entries	Normalized Frequency (1/cal-yr)
0-1.875	426	1.62E-04
1.875-3.25	78	2.97E-05
3.25-7	118	4.49E-05
7-18	114	4.34E-05
18-41	31	1.18E-05
>41	8	3.05E-06

A total of 775 pipe failures were collected from BWR plant operation. A similar plot to Figure 2.3.1 is shown in Figure 2.3.3 for the comparison between the collected BWR data and the NRC mean 5% and 95% failure frequencies per calendar year. Similar to the PWR failure frequencies, the BWR data agreed well with the NRC data at lower bin sizes and began to diverge from the NRC data at larger bin sizes. For the bin 5 data, the comparison was better with the NRC BWR predicted frequency than the NRC PWR predicted frequency.

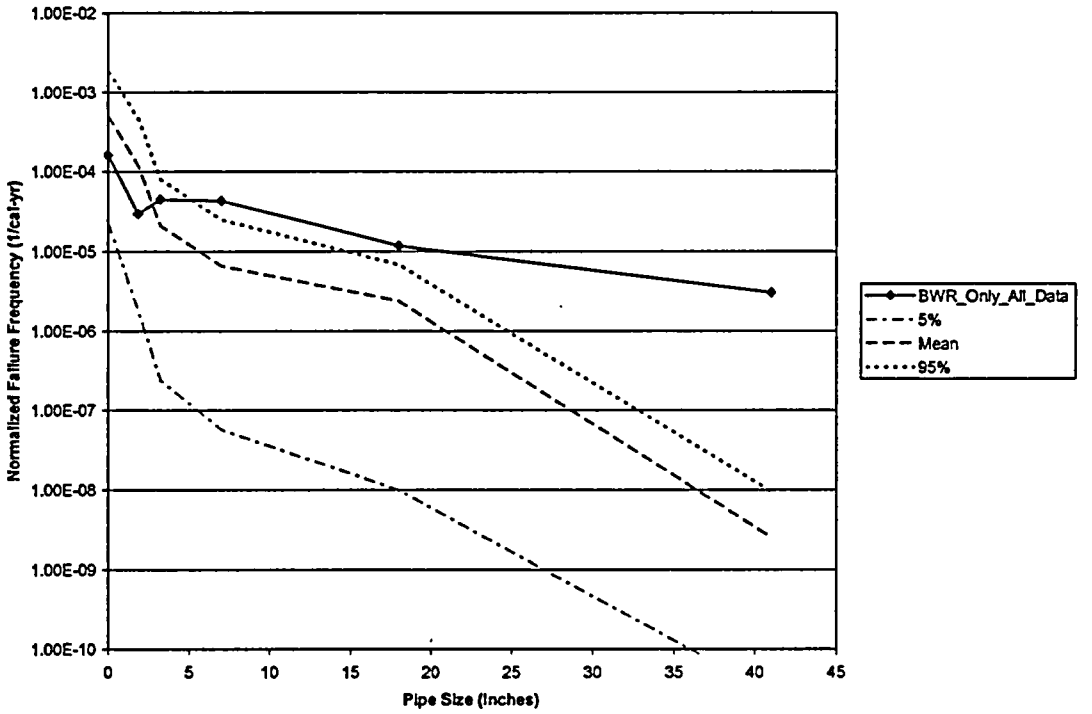


Figure 2.3.3: All Collected BWR Data Failure Frequency

The BWR data was also divided into carbon and stainless steel failure incidents, which are displayed in Table 2.3.5 and Table 2.3.6.

Table 2.3.5: BWR Carbon Steel Failures

Range (in)	Total Entries	Normalized Frequency (1/cal-yr)
0-1.875	177	1.55E-04
1.875-3.25	32	2.80E-05
3.25-7	51	4.46E-05
7-18	49	4.29E-05
18-41	22	1.93E-05
>41	6	5.25E-06

Table 2.3.6: BWR Stainless Steel Failures

Range (in)	Total Entries	Normalized Frequency (1/cal-yr)
0-1.875	249	1.68E-04
1.875-3.25	46	3.10E-05
3.25-7	67	4.51E-05
7-18	65	4.38E-05
18-41	9	6.06E-06
>41	2	1.35E-06

A total of 337 carbon steel failures in BWRs were found compared to 438 total BWR stainless steel failures. Figure 2.3.4 compares the BWR carbon and stainless steal failure data collected to the NRC mean, 5% and 95% failure frequencies per calendar year.

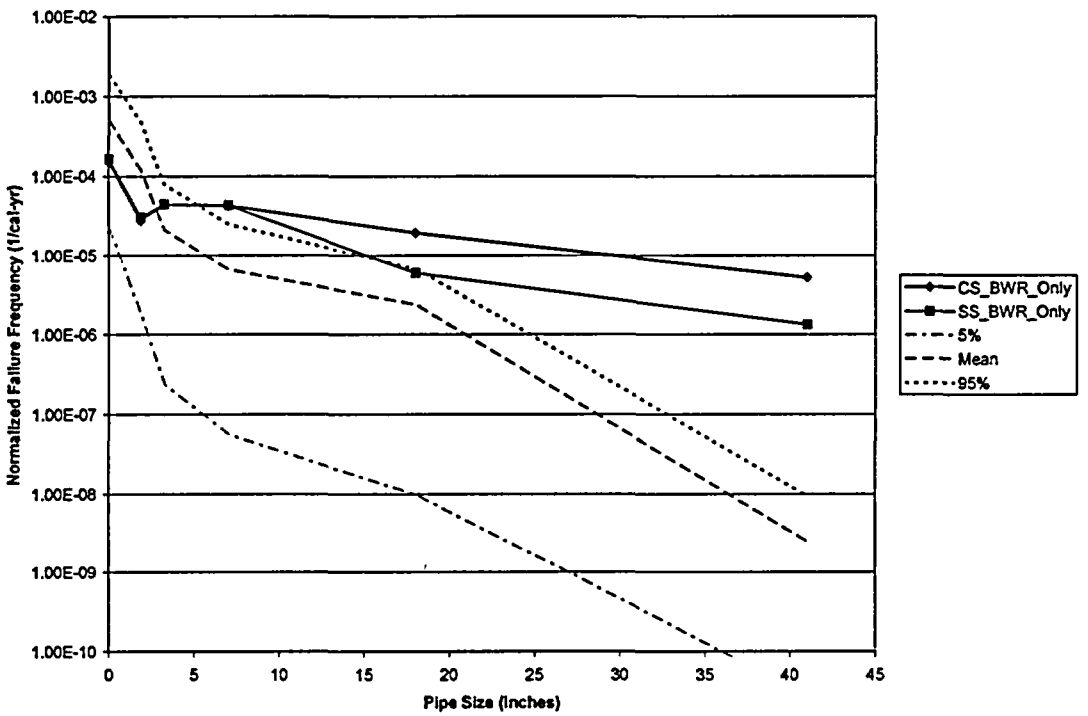


Figure 2.3.4: Carbon and Stainless Steel BWR Data Failure Frequency

2.3.3 Plant Data Conclusion

The comparison of the PWR and BWR plant data collected for this report showed similar failure frequencies at the NRC report, however at larger bin sizes significant deviations between the two data sets were observed. The BWR data collected showed better comparison to the NRC data than the PWR data collected for the larger bin sizes.

The NRC BWR estimated failure frequency in bin 5 was one to two orders of magnitude higher than the NRC PWR estimated failure frequency for the same bin. This trend was not observed in the collected data. The failure frequencies for all PWR data, PWR stainless steel data, PWR carbon steel data, all BWR data, and BWR carbon steel data were all on the order of 10^{-5} failures per calendar year. The BWR stainless steel failure frequency was slightly lower, on the order of 10^{-6} failures per calendar year.

2.4 Failure Mechanisms

The failure mechanisms were evaluated for the PWR, BWR, all, carbon steel, and stainless steel data sets using percentages. The percentages were obtained by dividing the number of occurrences of a given failure mechanism in a bin by the total number of failures for the bin. Eight failure mechanisms were chosen to evaluate the percent occurrence of a given failure mechanism. The ninth failure mechanism was an "other" category. The other category consisted of the Bush data, which listed failure mechanisms as other, unknown, or not given and the irregular failure mechanisms.

2.4.1 Failure Mechanism: PWR Data Set

Table 2.4.1 below lists the failure mechanisms observed in the Pressurized Water Reactor (PWR) data set and the percent the failure mechanism occurred in a given PWR bin. The PWR bin sizes were explained in Section 1.4.1. For the PWR data set no occurrences of aging or flow assisted corrosion (FAC) occurred. For Bin 1 fatigue was the dominating failure mechanism and for the rest of the bins fatigue pipe failures were minimal. In bin 6 the dominating failure mechanism was corrosion. Appendix D contains the numerical data for the calculated percentages.

Table 2.4.1: Failure Mechanisms for the PWR Data Set in PWR Bins

Failure Mechanism	Bin 1 (%)	Bin 2 (%)	Bin 3 (%)	Bin 4 (%)	Bin 5 (%)	Bin 6 (%)
Aging	0.00	0.00	0.00	0.00	0.00	0.00
Corrosion	20.17	11.46	34.94	43.31	16.13	58.33
Defects, Construction Errors	11.54	17.36	1.14	13.52	17.56	0.00
Wear	0.29	2.26	0.00	0.13	0.36	0.00
Water Hammer	1.45	0.87	0.57	0.39	0.36	16.67
Flow Assisted Corrosion (FAC)	0.00	0.00	0.00	0.00	0.00	0.00
Fatigue	29.29	6.60	4.55	0.66	2.51	0.00
Intergranual Stress Corrosion Cracking (IGSCC)	10.67	19.10	16.76	17.45	9.32	0.00
Other	26.58	42.36	42.05	24.54	53.76	25.00

2.4.2 Failure Mechanism: BWR Data Set

Table 2.4.2 below lists the failure mechanisms observed in the Boiling Water Reactor (BWR) data set and the percent the failure mechanism occurred in a given BWR bin. The BWR bin sizes were explained in Section 1.4.1. For the BWR data set no occurrences of flow assisted corrosion (FAC) occurred. For Bin 1 other was the dominating failure mechanism. Bin 2 corrosion was the dominating failure mechanism. For Bins 3, 4, and 5, intergranual stress corrosion cracking was the dominating failure mechanism. Appendix D contains the numerical data for the calculated percentages.

Table 2.4.2: Failure Mechanisms for the BWR Data Set in BWR Bins

Failure Mechanism	Bin 1 (%)	Bin 2 (%)	Bin 3 (%)	Bin 4 (%)	Bin 5 (%)	Bin 6 (%)
Aging	0.21	0.00	0.00	0.00	0.00	12.50
Corrosion	15.02	33.33	26.15	22.81	35.48	0.00
Defects, Construction Errors	11.93	11.54	6.15	7.02	6.45	0.00
Wear	0.00	0.00	0.77	0.00	0.00	0.00
Water Hammer	1.23	2.56	2.31	0.88	0.00	12.50
Flow Assisted Corrosion (FAC)	0.00	0.00	0.00	0.00	0.00	0.00
Fatigue	25.10	11.54	6.15	7.02	0.00	0.00
Intergranual Stress Corrosion Cracking (IGSCC)	9.88	12.82	40.77	44.74	35.48	0.00
Other	36.63	28.21	17.69	17.54	22.58	75.00

2.4.3 Failure Mechanism: Summary

Table 2.4.3 below lists the percentage of occurrences for the failure mechanisms observed in all, stainless steel pipes only, carbon steel pipes only, PWR, and the BWR data sets. For stainless steel and carbon steel pipes corrosion and intergranual stress corrosion cracking contributed the most to the pipe failures. Flow Assisted Corrosion (FAC) did not occur in any of the data sets and aging caused minimal failures. Stainless steel pipes encountered more failures due to fatigue then carbon steel pipes. Carbon steel pipes have more failures due to corrosion then stainless steel. If the "other" failure mechanism is excluded because it is a combination of irregular failure mechanisms then IGSCC or corrosion is the dominating mechanism for each data set. Appendix D contains the numerical data for the calculated percentages.

Table 2.4.3: Summary of Failure Mechanisms

Failure Mechanism	All (%)	SS (%)	CS (%)	PWR (%)	BWR (%)
Aging	0.05	0.00	0.09	0.00	0.24
Corrosion	24.59	11.69	33.55	25.86	20.07
Defects, Construction Errors	11.92	12.77	11.33	12.45	10.04
Wear	0.49	0.13	0.75	0.60	0.12
Water Hammer	1.06	0.63	1.36	0.93	1.53
Flow Assisted Corrosion (FAC)	0.00	0.00	0.00	0.00	0.00
Fatigue	13.35	20.61	8.30	12.22	17.36
Intergranual Stress Corrosion Cracking (IGSCC)	15.83	25.22	9.31	14.54	20.43
Other	32.70	28.95	35.31	33.40	30.22

2.4.4 Effect of National Transportation Safety Board Data

For Section 2.4, the NTSB data set was insignificant due to the number of data points acquired. Therefore, the NSTB data was not included in this section.

3.0 Conclusions

Data from piping failures in nuclear power plants and other industry were compared to the failure frequencies predicted by the NRC. The data was divided by materials into stainless steel and carbon steel, by failure type into leaks and cracks versus ruptures, severances, and breaks, and by plant type into pressurized water reactor (PWR) and boiling water reactor (BWR).

In general the failure frequencies calculated from the data agreed well with the NRC estimates for small pipe sizes; for larger pipe sizes the calculated failure frequency was generally higher than the NRC estimates.

Better agreement was seen in large pipe sizes when the data was compared to the NRC BWR failure frequencies. This may be due to the NRC's higher failure frequency in bin 5 for BWRs than PWRs.

The data indicated failure frequencies on the same order of magnitude regardless of whether the data was classified into PWR and BWR bins. This was observed for the database in general and for subsets of the database.

4.0 References

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[4] Roos, E., et al. "Assessment of Large Scale Pipe Tests by Fracture Mechanics Approximations Procedures with Regard to Leak-Before-Break." *Nuclear Engineering and Design.* Volume 112, 1989, pp 183-195.

[5] Cronin, Duane S. and Roy J. Pick. "Experimental Database for Corroded Pipe: Evaluation of Rstreng and B31G." International Pipeline Conference 2000. Calgary, Alberta, Canada. October 1-5, 2000. Volume 2, pp 757-767.

[6] Buchheim, G.M., et al. "Failure Investigation of a Low Chrome Long-Seam Weld in a High Temperature Refinery Piping System." ASME PVP: Service Experience and Reliability Improvement: Nuclear, Fossil, and Petrochemical Plants. Minneapolis, Minnesota. June 19-23, 1994. Volume 288, pp 363.

[7] National Transportation and Safety Board. Published Pipeline Accidents. From http://www.ntsb.gov/Publictn/P_Acc.htm. Please see Appendix C for more detailed references on specific reports.

5.0 Appendices

List of Appendices

Appendix A: Pipe data
Appendix B: Data removed from Bush Database
    Appendix B1: Data Removed due to Size
    Appendix B2: Data Removed due to Material
Appendix C: National Transportation Safety Board Data and References
Appendix D: Failure Mechanism Numerical Data
Appendix F: Selected Failure Frequencies with NTSB Data

Appendix A

Pipe Failure Database

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oconee 1	BWR	5/19/1973	Instrument line	0.125	Leak		Unknown	tube leak, unknown cause	SS
LaCrosse	BWR	5/1/1973	Core spray	0.25	Leak		Unknown	Stress Corrosion	SS
Dresden 3	BWR	4/25/1975	Main steam	0.25	Severed	ORNL-NSIC-126:102289	Construction Defect/Errors	Maintenance error	CS
Oyster Creek	BWR	4/25/1976	Flow sensor	0.25	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Dresden 3	BWR	11/8/1976	Instrument line	0.25	Leak	76-033	Construction Defect/Errors	Cross-threaded	SS
Robinson 2	PWR	12/2/1976	service water	0.25	failed	80-030/3L	fatigue-vibrational	fatigue-vibration	CS
Oconee 1	BWR	1/26/1977	Instrument line	0.25	Leak		Unknown	Plugged tubes	SS
Palisades	PWR	2/11/1977	Component cooling	0.25	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Salem 1	PWR	5/19/1977	component cooling	0.25	leak	81-053	other	personnel error	CS
Sequoyah 2	PWR	11/11/1977	instrument line	0.25	leak	81-136	fatigue-vibrational	fatigue-vibrational	SS
Dresden 1	BWR	2/3/1978	Reactor Water Cleanup	0.25	Rupture	RO 78-8	Other	Frozen line	SS
Calvert Cliffs 2	PWR	3/16/1980	Service water	0.25	leak	80-017	Erosion/Corrosion	Erosion/Corrosion	CS
Oyster Creek	BWR	10/2/1980	Core spray	0.25	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Hatch 2	BWR	11/13/1980	Residual heat removal	0.25	Leak		other	Test tubing cracked, overstressed	SS
Indian Point 3	PWR	12/5/1980	Reactor Coolant	0.25	Leak		Erosion/Corrosion	Erosion/Corrosion of fan cooler tube	SS
Browns Ferry 2	BWR	7/1/1981	Residual Heat Removal	0.25	Leak	81-031	Corrosion/Fatigue	Corrosion/Fatigue	SS
Indian Point 3	PWR	12/8/1981	Reactor Coolant	0.25	Leak		Erosion/Corrosion	Erosion/Corrosion of fan cooler tube	SS
McGuire 1	PWR	6/20/1982	Containment heat removal	0.25	Leak		Erosion/Corrosion	Erosion/corrosion, capillary line	CS
Browns Ferry 1	BWR	8/28/1982	Residual Heat Removal	0.25	Severed	82-074	Construction Defect/Error	Maintenance Error	SS
Kewaunee	PWR	12/6/1983	Reactor Coolant	0.25	Leak		Erosion/Corrosion	Erosion of cooling coils	SS
Catawba 1	PWR	10/23/1984	Instrument line	0.25	leak	84-018	unknown	Leaked thermocouple tube, separation of fitting	SS
Indian Point 2	PWR	10/4/1985	Containment heat removal	0.25	Leak		Unknown	Leaked tube in fan cooler	CS
Salem 1	PWR	11/29/1986	service water	0.25	leak	90-026-04	erosion/corrosion	erosion/corrosion, instrument tubing leak	CS
Dresden 3	BWR	10/1/1974	Chemical and volume control	0.275	Failed	ORNL NSIC 095883	Construction Defect/Errors	Maintenance error	SS
Point Beach 2	PWR	8/31/1970	sample lines	0.375	leak	NPE PWR-2-XIV-No. 16	not given		CS
Yankee Rowe	PWR	12/1/1970	thimble tube	0.375	leak	Ltr DL 8/30/74	unknown	unknown cause	SS
Oconee 1	BWR	7/5/1973	Instrument line	0.375	Leak		Unknown	tube leak, unknown cause	SS
Kewaunee	PWR	2/8/1974	Instrument line	0.375	Crack/Leak		Unknown	Unknown cause	SS
Kewaunee	PWR	4/18/1974	Instrument line	0.375	Crack/Leak		Unknown	Unknown cause	SS
Kewaunee	PWR	7/9/1974	Instrument line	0.375	Leak		Unknown	Fatigue-Vibration	SS
Oconee 3	BWR	10/29/1974	Core spray	0.375	Leak		Fatigue-Vibrational	Fatigue-vibration	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
ANO1	PWR	11/9/1974	Instrument Line	0.375	Leak	RO 74-01, AO 74-12	Stress Corrosion Cracking, IGSCC	Leaked weld (1/3), IGSCC, poor weld	SS
ANO1	PWR	11/9/1974	Instrument Line	0.375	Leak	RO 74-01, AO 74-12	Stress Corrosion Cracking, IGSCC	Leaked weld (2/3), IGSCC, poor weld	SS
ANO1	PWR	11/9/1974	Instrument Line	0.375	Leak	RO 74-01, AO 74-12	Stress Corrosion Cracking, IGSCC	Leaked weld (3/3), IGSCC, poor weld	SS
Oconee 1	BWR	11/12/1974	Safety Injection	0.375	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Millstone 2	PWR	10/18/1975	Instrument line	0.375	Leak		Construction Defects/Errors	Improper weld, construction defect	SS
Indian Point 3	PWR	4/15/1976	Pressurizer	0.375	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Millstone 2	PWR	1/12/1977	Safety Injection	0.375	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Surry 1	PWR	5/23/1978	steam	0.375	leak	82-024	construction defect/errors	poor weld, construction defect	CS
Yankee Rowe	PWR	10/8/1978	coolant recirculation	0.375	leak	82-034	thermal fatigue	thermal fatigue	SS
Surry 2	PWR	9/20/1979	coolant recirculation	0.375	leak	83-038	construction defect/errors	construction defects/errors	SS
Trojan	PWR	9/16/1980	pressurizer	0.375	leak	PNO-V-84-062	unknown	loose fitting	SS
Grand Gulf	BWR	10/20/1980	Component cooling	0.375	Leak	Part 21 Report	Unknown	leak at swage lock, unknown cause	CS
Calvert Cliffs 2	PWR	11/9/1981	Reactor Coolant	0.375	leak	81-051	Fatigue-Vibrational	Fatigue-vibration	SS
Hatch 1	BWR	2/12/1982	Reactor Coolant	0.375	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Fort Calhoun	PWR	3/24/1982	Component cooling	0.375	Leak	82-007	Fatigue-Vibrational	Fatigue-vibration, cracked tube in diesel generator	CS
Indian Point 2	PWR	4/22/1983	Containment heat removal	0.375	Leak		Construction Defect/Errors	Construction defects/errors during inspection	CS
Ginna	PWR	6/20/1983	Pressurizer	0.375	Leak	83-025	Thermal Fatigue	Thermal Fatigue	SS
Salem 1	PWR	12/6/1986	residual heat removal	0.375	leak	90-026-04	erosion/corrosion	erosion/corrosion	SS
Salem 1	PWR	12/11/1986	residual heat removal	0.375	leak	90-026-04	erosion/corrosion	erosion/corrosion	SS
Cook 1	PWR	9/7/1988	Reactor Coolant	0.375	leak	PNO-III-88-079	Fatigue-vibrational	fatigue-vibration	SS
ANO2	PWR	9/22/1988	Flow Sensor	0.375	Leak	PNO-IV-88-062A	Corrosion/Fatigue	Sensign line seal leak, corrosion/fatigue	SS
Grand Gulf	BWR	9/30/1988	Component cooling	0.375	Leak	Part 21 Report	Other	Intercooler tube rupture from freezing	CS
Zion 1	PWR	12/30/1988	flow sensor	0.375	leak	special report OSR-008-93	unknown	leaked tube due to failed fittings	SS
San Onofre 3	PWR	9/18/1992	RCS	0.375	leak	96-004	fatigue-vibrational		SS
Turkey Point 4	PWR	10/14/1970	reactor coolant	0.5	leak	AO 74-14	construction defect/errors	missing connection plug on drywell penetration, personnel error	SS
Point Beach 2	PWR	8/11/1972	boric acid	0.5	leak	76-013	fatigue-vibrational	fatigue-vibration	SS
Three Mile Island 1	PWR	3/23/1974	service water	0.5	leak	78-017	unknown	damaged weld joint	CS
Three Mile Island 2	PWR	3/23/1974	residual heat removal	0.5	leak	78-017	fatigue-vibrational	fatigue-vibrational	SS
Browns Ferry 1	BWR	9/1/1974	Service Water	0.5	Failed	AO 74-43	Fatigue-Vibrational	Fatigue-vibrational (1/2)	CS
Browns Ferry 1	BWR	9/1/1974	Service Water	0.5	Failed	AO 74-43	Fatigue-Vibrational	Fatigue-vibrational (2/2)	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Browns Ferry 1	BWR	9/20/1974	RHR	0.5	Failed	ROBFAO-7448T	Fatigue-Vibrational		SS
Browns Ferry 2	BWR	9/20/1974	Residual Heat Removal	0.5	Failed	RO BFAO-50-260-7448T	Fatigue-Vibrational	Fatigue/vibrational	SS
Dresden 1	BWR	10/17/1974	Main steam	0.5	Leak	AO 74-15	Erosion/Corrosion	Leaks at 3 threaded joints, erosion	CS
ANO1	PWR	1/23/1975	Makeup System	0.5	Leak	AO 75-02	Construction Defect/Error	Construction Defect/Error	SS
Ginna	PWR	6/17/1975	Instrument line	0.5	Failed	AO	Water Hammer	Water Hammer	SS
Peach Bottom 3	BWR	6/25/1975	steam	0.5	leak	PNO-79-194	fatigue-vibrational	fatigue-vibration	CS
Monticello	BWR	8/1/1975	Service water	0.5	Leak		Fatigue-Vibrational		CS
Monticello	BWR	8/18/1975	Reactor water cleanup	0.5	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Monticello	BWR	8/26/1975	Reactor water cleanup	0.5	Leak		Construction Defect/Errors	Construction defect	SS
Ginna	PWR	12/14/1975	Feedwater	0.5	Leak	75-012	Construction Defect/Errors	Construction Defect/Errors	CS
Monticello	BWR	2/20/1976	Condensate	0.5	Leak		Erosion/Corrosion	Erosion from steam	CS
ANO1	PWR	5/26/1976	Flow Sensor	0.5	Leak	RO 76-10	Fatigue-Vibrational	Cracked weld due to vibration or improper fit	SS
Monticello	BWR	8/2/1976	Steam	0.5	Leak		Erosion/Corrosion	Erosion/corrosion	CS
ANO1	PWR	8/28/1976	Residual Heat Removal Socket Weld	0.5	Leak	RO 76-24	Fatigue-Vibrational	Leaked welds on valve, fatigue-vibration	SS
Calvert Cliffs 2	PWR	5/1/1977	instrument line	0.5	leak	77-030	fatigue-vibrational	cracked weld	SS
Calvert Cliffs 2	PWR	5/11/1977	safety injection	0.5	leak	77-035	fatigue-vibrational	fatigue-vibration	SS
Salem 2	PWR	5/31/1977	SWS	0.5	leak	NPE VII.C.72	not given	threaded connection backed off	CS
Salem 2	PWR	6/22/1977	chemical and volume control	0.5	leak	81-038	fatigue-vibrational	fatigue-vibrational	SS
ANO1	PWR	8/24/1977	Makeup System	0.5	Leak	RO 77-17	Unknown	Unknown Cause	SS
Calvert Cliffs 2	PWR	10/7/1977	Instrument line	0.5	leak	77-073	Fatigue-vibrational	fatigue-vibration	SS
Salem 2	PWR	11/9/1977	service water	0.5	leak	81-118	construction defect/errors	pipe leaked during maintenance work, error	CS
Quad Cities 1	BWR	8/7/1978	residual heat removal	0.5	leak	82-021	fatigue-vibrational	fatigue-vibration	SS
Quad Cities 1	BWR	8/12/1978	residual heat removal	0.5	leak	82-021	fatigue-vibrational	fatigue-vibration	SS
Three Mile Island 2	PWR	2/15/1979	fire protection	0.5	leak	83-004	other	frozen pipe	CS
Monticello	BWR	7/9/1979	Instrument line	0.5	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Calvert Cliffs 1	PWR	1/26/1980	Containment heat removal	0.5	Leak	80-008	Other	Through wall leak due to wear	CS
Duane Arnold	BWR	1/28/1980	High pressure core injection	0.5	Leak	80-003	Unknown	Damaged nipple pipe fitting	SS
Browns Ferry 1	BWR	6/2/1980	Flow Sensor	0.5	Leak	80-048	Corrosion	Corrosion cracking of nipple threading	SS
ANO2	PWR	11/3/1980	Flow Sensor	0.5	Leak	80-086	Fatigue-Vibrational	Fatigue-vibration	SS
Big Rock Point	BWR	12/12/1980	RWCU	0.5	Leak	LER 96-001	IGSCC	Branch connect	SS
Maine Yankee 1	PWR	12/23/1981	Coolant recirculation	0.5	Leak		Unknown	Cracking, unknown cause	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Hatch 1	BWR	1/19/1982	Coolant recirculation	0.5	Leak		Unknown	3 pinhole leaks next to a weld. Sensing line replace, unknown	SS
Dresden 3	BWR	3/17/1982	Containment heat removal	0.5	Leak	82-014	Erosion/Corrosion	Erosion/Corrosion	CS
Cook 2	PWR	5/20/1982	Service Water	0.5	leak	82-046	Construction Defect/Errors	Construction Defect/Errors	CS
Oyster Creek	BWR	6/16/1982	Condensate	0.5	Severed		Fatigue-Vibrational	Fatigue-vibrational	CS
Big Rock Point	BWR	10/27/1982	Containment heat removal	0.5	Leak	82-029	Construction Defect/Error	Construction Defect/Error	CS
Big Rock Point	BWR	10/29/1982	Flow Sensor	0.5	Leak	RO	Unknown	Unknown Cause	SS
LaSalle 1	BWR	11/18/1982	Reactor water cleanup	0.5	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Browns Ferry 1	BWR	12/8/1982	Core Spray	0.5	Leak	82-099	Fatigue-Vibrational	Fatigue-Vibrational	SS
LaSalle 1	BWR	3/20/1983	Main steam	0.5	Leak		Construction Defect/Errors	Construction defect/errors	CS
Big Rock Point	BWR	8/15/1983	Flow Sensor	0.5	Leak	83-008	Construction Defect/Error	Poor weld, Construction defect	SS
Big Rock Point	BWR	8/15/1983	Flow Sensor	0.5	Leak	RO	Unknown	Unknown Cause	SS
Indian Point 2	PWR	10/11/1983	Feedwater	0.5	Failed		Unknown	Nipple failure	CS
Calvert Cliffs 2	PWR	11/23/1983	Containment heat removal	0.5	Leak	83-062	Fatigue-Vibrational	Fatigue-vibrational	CS
Catawba 1	PWR	10/10/1985	Reactor Coolant	0.5	leak	85-059	Construction defect/errors	Leaked compression tube fitting on flow sensor, untightened fitting, error	SS
Salem 2	PWR	12/19/1986	service water	0.5	leak	90-042	corrosion	corrosion. Pipe painted for protection	CS
Trojan	PWR	1/21/1987	instrument line	0.5	leak	91-002 [10-91:294]	fatigue-vibrational	thimble tube leakage due to vibration	SS
Calvert Cliffs 2	PWR	3/24/1987	Service Water	0.5	Leak	87-003	Erosion/Corrosion	Erosion/Corrosion	CS
Calvert Cliffs 1	PWR	5/7/1987	SIS	0.5	Leak	NPE VII.A.552	Fatigue-Vibrational		SS
Calvert Cliffs 2	PWR	5/7/1987	Service Water	0.5	Leak	87-004	Erosion/Corrosion	Erosion./Corrosion	CS
Turkey Point 4	PWR	6/15/1988	main steam	0.5	leak	ACN:9207060014	erosion/corrosion		CS
Fitzpatrick	BWR	9/17/1991	High pressure core injection	0.5	Leak	91-019 [11-91:52]	Fatigue-Vibrational	Fatigue-vibrational, poor weld	SS
Ginna	PWR	10/11/1991	Service Water	0.5	Leak	RO	Construction Defect/Errors	Defect copper tubes	CS
Limerick 2	BWR	3/15/1994	Instrument line	0.5	Leak		Construction Defects/Errors	Installation error, construction defect	SS
Millstone 3	PWR	12/2/1995	RHR	0.5	Leak		Not Given	Leak at valve stem leak off pipe	SS
Fermi 2	BWR	5/28/1988	Instrument line	0.625	Leak	PNO-III-88-052	Water Hammer	Water Hammer	SS
Ginna	PWR	9/3/1991	Service Water	0.625	Leak	Special Report	Unknown	Unknown cause	CS
Calvert Cliffs 2	PWR	5/11/1977	Reactor Coolant Vent Line	0.74	leak	77-038	fatigue-vibrational	fatigue-vibration, leaked sealants	SS
Zion 1	PWR	6/8/1969	service water	0.75	breakage	DL ltr 6/20/73	fatigue-vibrational	fatigue-vibration	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Zion 1	PWR	7/31/1969	charging pump relief line	0.75	severed	fatigue-vibrational	letter DL		SS
Zion 1	PWR	11/24/1969	charging line	0.75	leak	letter to NRC 11/6/73	construction defect/errors	construction defect	SS
Zion 1	PWR	12/5/1969	reactor coolant	0.75	leak	Ltr DL 12/6/73	fatigue-vibrational	fatigue-vibration	SS
Zion 2	PWR	1/16/1970	control rod drive	0.75	leak	letter 6/29/74	stress corrosion/IGSCC	stress corrosion	SS
Quad Cities 1	BWR	4/12/1970	condensate	0.75	rupture	NUREG/CR-2781	unknown	failed rubber expansion joint	CS
Quad Cities 2	BWR	6/18/1970	feedwater	0.75	leak	AO 74-14	fatigue-vibrational	fatigue-vibrational	CS
Point Beach 2	PWR	9/22/1970	reactor coolant	0.75	leak	AO 74-25	fatigue-vibrational	fatigue-vibration	SS
Zion 2	PWR	9/30/1970	charging line	0.75	leak	NPE VIII.A.64	fatigue-vibrational		SS
Turkey Point 4	PWR	10/20/1970	safety injection	0.75	leak	AO 74-7	construction defect/errors	poor fit between pipe and coupling	SS
Zion 2	PWR	10/31/1970	pressurizer	0.75	leak	AO 50-304/74-43	fatigue-vibrational	fatigue-vibration	SS
Turkey Point 4	PWR	11/7/1970	SIS	0.75	leak	AO-74-7	fatigue-vibrational		SS
Zion 2	PWR	11/20/1970	pressurizer	0.75	leak	AO 50-304/74-48	fatigue-vibrational	fatigue-vibration	SS
Zion 2	PWR	12/30/1970	reactor coolant	0.75	crack/leak	AO 74-56	fatigue-vibrational	fatigue-vibrational	SS
Point Beach 1	PWR	12/31/1970	service water	0.75	severed	Ltr DL; 1/22/75	fatigue-vibrational	fatigue-vibration	CS
Turkey Point 4	PWR	1/27/1971	SIS vent line	0.75	leak	letter DR	installation error		SS
Quad Cities 1	BWR	2/22/1971	reactor coolant	0.75	leak	AO 75-5	construction defect/errors	poor weld, construction defect	SS
Zion 2	PWR	4/27/1971	reactor coolant	0.75	leak	AO 75-19	fatigue-vibrational	fatigue-vibration	SS
Quad Cities 2	BWR	5/19/1971	reactor water cleanup	0.75	breakage	AO 75-19	fatigue-vibrational	fatigue-vibrational	SS
Quad Cities 1	BWR	5/22/1971	reactor water cleanup	0.75	leak	AO	fatigue-vibrational	fatigue-vibration	SS
Ginna	PWR	5/28/1971	Pressurizer	0.75	Leak	3rd Semiannual Report under shutdown	Stress Corrosion/IGSCC	IGSCC	SS
Prairie Island 2	PWR	5/31/1971	RHR	0.75	leak	NPE VIII.B.73	improper support		SS
Zion 2	PWR	6/15/1971	pressurizer	0.75	leak	AO 50-304/75-26	fatigue-vibrational	fatigue-vibrational	SS
Prairie Island 1	PWR	6/26/1971	residual heat removal	0.75	leak	AO 75-22A	design-dynamic load	improper support of pipe, dynamic load	SS
Three Mile Island 1	PWR	7/10/1971	makeup system	0.75	leak	AO 75-22	fatigue-vibrational	fatigue-vibrational	SS
Palisades	PWR	8/19/1971	Pressurizer	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Quad Cities 2	BWR	8/30/1971	feedwater	0.75	failed	75-036	fatigue-vibrational	fatigue-vibrational	CS
Indian Point 1	PWR	9/9/1971	Reactor Coolant	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Peach Bottom 2	BWR	11/8/1971	residual heat removal	0.75	leak	AO 75-72	fatigue-vibrational	fatigue-vibration	SS
Oyster Creek	BWR	12/11/1971	Residual heat removal	0.75	Failed		Fatigue-Vibrational		SS
Palisades	PWR	12/28/1971	Atm dump	0.75	Leak		Fatigue		SS
Quad Cities 1	BWR	1/4/1972	reactor coolant	0.75	leak	RO 76-001	fatigue-vibrational	fatigue-vibration	SS
Oyster Creek	BWR	1/12/1972	Isolation condenser vent line	0.75	Leak		Fatigue-Vibrational		CS
St. Lucie 2	PWR	2/25/1972	residual heat removal	0.75	leak	NSIC 138	fatigue-vibrational	fatigue-vibrational	SS
Oyster Creek	BWR	2/26/1972	Service water	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	CS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Oconee 1	BWR	3/1/1972	In core instrument nozzle	0.75	Failed		Not Given	Nozzle 1 of 21 nozzles broke off, 14 were cracked	SS
Salem 1	PWR	3/15/1972	residual heat removal	0.75	failed	ORNL-NSIC-138:112141	fatigue-vibrational	fatigue-vibration	SS
Indian Point 2	PWR	9/26/1972	Vent line	0.75	Leak		Fabrication Defect	Several welds found lacking full penetration	SS
Indian Point 2	PWR	10/31/1972	Vent line	0.75	Leak		Fabrication Defect	Several welds found lacking full penetration	SS
Salem 1	PWR	1/2/1973	chemical and volume control	0.75	severed	77-002/3L	fatigue-vibrational		SS
Indian Point 2	PWR	5/15/1973	Residual heat removal	0.75	Leak		Unknown	Unknown cause	SS
Oyster Creek	BWR	10/17/1973	Service water	0.75	Failed		Corrosion	Corrosion	CS
Indian Point 2	PWR	10/31/1973	Residual heat removal	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Ginna	PWR	12/11/1973	Pressurizer	0.75	Leak	8th Semiannual Report under shutdown	Construction Defect/Errors	defect weld	SS
Indian Point 2	PWR	1/21/1974	Instrumentation	0.75	Leak		Construction Defect/Errors	Construction defects/errors during inspection	SS
LaCrosse	BWR	1/23/1974	Core spray	0.75	Leak		Stress Corrosion/IGSCC	Improper fitting at hose	SS
Dresden 3	BWR	4/2/1974	Control Rod Drive	0.75	Leak	Letter to NRC (6/11/74)	Fatigue-Vibrational	Fatigue-vibration	SS
Fort Calhoun	PWR	4/15/1974	Flow sensor	0.75	Severed	NSIC-122;090422	Fatigue-Vibrational	Fatigue-Vibrational	SS
Ginna	PWR	4/18/1974	Chemical and volume control	0.75	Leak	AO 74-5	Stress Corrosion/IGSCC	Stress corrosion	SS
Turkey Point 3	PWR	4/30/1974	charging	0.75	leak	NPE VIII.A.317	fatigue-vibrational		SS
Oconee 2	BWR	5/11/1974	Core spray	0.75	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Haddam Neck 1	PWR	6/1/1974	Feedwater	0.75	Failed		Fatigue-Vibrational	Fatigue-Vibrational	CS
Dresden 3	BWR	6/10/1974	Feedwater	0.75	Rupture	Ltr DL; 6/18/74	Fatigue-Vibrational	Fatigue-vibration	CS
Ginna	PWR	6/29/1974	Service Water	0.75	Leak	AO 74-12	Fatigue-Vibrational	Fatigue-Vibrational	CS
Ginna	PWR	7/2/1974	Service Water	0.75	Leak	AO 74-13	Construction Defect/Errors	Construction defect/errors and fatigue-vibration	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palisades	PWR	8/1/1974	Letdown line	0.75	Leak		Design Error		SS
Zion 1	PWR	9/3/1974	steam	0.75	leak	78-096	fatigue-vibrational	fatigue-vibration	CS
Zion 1	PWR	9/7/1974	steam	0.75	leak	78-088	fatigue-vibrational	fatigue-vibration	CS
Palisades	PWR	9/9/1974	Reactor coolant	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Zion 1	PWR	9/13/1974	steam	0.75	leak	78-090	fatigue-vibrational	fatigue-vibration	CS
Dresden 3	BWR	9/20/1974	Feedwater	0.75	Leak	AO 74-28	Fatigue-Vibrational	Fatigue-vibration	CS
Kewaunee	PWR	1/17/1975	Reactor Coolant	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibration	SS
Quad Cities 1	BWR	1/31/1975	RHR vent line	0.75	leak	NPE VII.D. 179 (BWR-2, Book-2)	fatigue-vibrational		SS
Browns Ferry 1	BWR	2/5/1975	Core Spray	0.75	Leak	AO BFAO 50-259-752T	Corrosion/Fatigue	Corrosion/Fatigue	SS
Dresden 3	BWR	2/8/1975	Feedwater	0.75	Crack/Leak	AO 75-5	Construction Defect/Errors	Construction defect	CS
Dresden 1	BWR	4/12/1975	Core Spray	0.75	Leak	AO 75-6	Construction Defect/Errors	Construction defect, slag inclusion and poor adhesion	SS
Duane Arnold	BWR	4/18/1975	High pressure core injection	0.75	Leak	AO 75-21	Fatigue-Vibrational	Fatigue-vibration	SS
Beaver Valley 1	PWR	6/8/1975	Safety Injection	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
ANO1	PWR	7/1/1975	Makeup System	0.75	Leak	NPE VIII.A 90	Weld Defect		SS
Millstone 1	PWR	11/13/1975	Jet pump rod inst line	0.75	Leak		Fatigue-Vibrational		SS
Millstone 2	PWR	11/16/1975	Instrument line	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Quad Cities 1	BWR	11/18/1975	feedwater	0.75	crack/leak	PNO-II-79-041	fatigue-vibrational	fatigue-vibration	CS
Ginna	PWR	11/20/1975	Service Water	0.75	Leak	75-011	Construction Defect/Errors	Construction defects in discharge drain line	CS
Millstone 2	PWR	11/29/1975	Reactor coolant	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Maine Yankee 1	PWR	12/9/1975	Reactor Coolant	0.75	Leak		Construction Defects/Errors	Weld porosity, construction defect	SS
Fort Calhoun	PWR	12/28/1975	Containment heat removal	0.75	Severed	75-026	Fatigue-Vibrational	Fatigue-Vibrational	CS
Millstone 2	PWR	1/3/1976	Service water	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	CS
Salem 1	PWR	2/17/1976	main steam	0.75	leak	80-002	erosion/corrosion	erosion/corrosion	CS
Indian Point 3	PWR	4/5/1976	Feedwater	0.75	Leak		Construction Defect/Errors	Excessive stress at weld connection at installation, error	CS
Monticello	BWR	5/15/1976	Moisture separator reheater	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Quad Cities 2	BWR	6/3/1976	high pressure core injection	0.75	leak	80-015	thermal fatigue	thermal fatigue	SS
Calvert Cliffs 1	PWR	6/21/1976	SWS	0.75	Leak	RO 76-31	Unknown	Unknown Cause	CS
Calvert Cliffs 1	PWR	7/12/1976	Service Water	0.75	Leak	RO 76-43	Fatigue-Vibrational		CS
Millstone 2	PWR	8/2/1976	Service water	0.75	Leak		Fatigue-Vibrational	Fatigue-vibration	CS
Dresden 1	BWR	9/13/1976	Core Spray	0.75	Leak	AO 75-6	Construction Defect/Errors	Construction defect	SS
Fitzpatrick	BWR	9/13/1976	Residual heat removal	0.75	Leak	76-054	Unknown	Unknown cause	SS
ANO1	PWR	10/3/1976	Makeup System	0.75	Leak	RO 76-29	Fatigue-Vibrational	Fatigue-vibration	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Ginna	PWR	10/10/1976	Residual heat removal	0.75	Leak	RO 76-25, LER 76-025	Construction Defect/Errors	Construction defect, improper fitup	SS
Calvert Cliffs 1	PWR	11/1/1976	Charging	0.75	Leak	NPE VIII.A.238	Fatigue-Vibrational		SS
Beaver Valley 1	PWR	11/5/1976	Aux. Feedwater Drain Line	0.75	Rupture	76-83	Water Hammer		CS
Salem 1	PWR	12/17/1976	main steam	0.75	rupture	80-065	erosion/corrosion	erosion/corrosion	CS
Calvert Cliffs 2	PWR	1/3/1977	Reactor Coolant	0.75	crack/leak	77-010	fatigue-vibrational	fatigue-vibration	SS
Brunswick 2	BWR	2/14/1977	Coolant Recirculation	0.75	Leak	RO 2-77-2	Unknown	Cracked weld, unknown cause	SS
Turkey Point 4	PWR	2/17/1977	core spray	0.75	leak	81-003	fatigue-vibrational	fatigue-vibrational	SS
Maine Yankee 1	PWR	3/31/1977	Reactor Coolant	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 2	PWR	6/8/1977	chemical and volume control	0.75	leak	81-040	fatigue-vibrational	fatigue-vibrational	SS
Salem 1	PWR	7/14/1977	service water	0.75	leak	81-064	unknown	cracked weld	CS
Calvert Cliffs 1	PWR	8/25/1977	Reactor Coolant	0.75	Leak	77-077	Fatigue-Vibrational		SS
Calvert Cliffs 2	PWR	9/19/1977	Service Water	0.75	leak	77-068	Fatigue-vibrational	fatigue-vibration, cracked weld	CS
Ginna	PWR	9/20/1977	Pressurizer	0.75	Leak	RO 75-11and 75-12	Construction Defect/Errors	Construction defect, lack of weld fusion	SS
Calvert Cliffs 1	PWR	9/23/1977	Charging	0.75	Leak	NPE VIII.A.238	Fatigue-Vibrational		SS
ANO1	PWR	12/3/1977	Residual Heat Removal	0.75	Leak	77-027	Fatigue-Vibrational	Fatigue-vibration	SS
Big Rock Point	BWR	12/8/1977	Control Rod Drive	0.75	Leak	RO 77-49	Fatigue-Vibrational	Fatigue-vibration	SS
Big Rock Point	BWR	12/16/1977	Control Rod Drive	0.75	Leak	RO-77-49	Fatigue-Vibrational		SS
Calvert Cliffs 1	PWR	1/7/1978	Reactor Coolant	0.75	Leak	RO 78-22/3L	Fatigue-Vibrational	Fatigue-vibration	SS
Ginna	PWR	1/11/1978	Pressurizer	0.75	Leak	78-001	Fatigue-Vibrational	Fatigue-vibration	SS
Quad Cities 2	BWR	2/22/1978	control rod drive	0.75	leak	82-003	erosion/corrosion	pitting of line, 0.25 gpm leak, sch 80	SS
Hatch 1	BWR	3/6/1978	Reactor Coolant	0.75	Leak		Stress Corrosion/IGSCC	Stress Corrosion	SS
Millstone 1	PWR	3/19/1978	Coolant recirculation	0.75	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
ANO2	PWR	8/1/1978	LPSI	0.75	Leak	NPE VII.A.192	Fatigue-Vibrational		SS
Salem 2	PWR	10/4/1978	containment heat removal	0.75	leak	82-112	unknown	1 gpm leak from containment flange coil	CS
Pilgrim	BWR	10/7/1978	reactor water cleanup	0.75	leak	82-047	construction defect/errors	construction defects/errors, faulty weld	SS
Big Rock Point	BWR	10/18/1978	Containment heat removal	0.75	Leak	78-044	Fatigue-Vibrational	Fatigue-vibrational	CS
Big Rock Point	BWR	10/18/1978	RWCU	0.75	Leak	LER 96-001	IGSCC	Branch connect	SS
Dresden 2	BWR	11/24/1978	Reactor Water Cleanup	0.75	Leak	78-064	Corrosion	Acid corrosion	SS
Big Rock Point	BWR	4/23/1979	Control Rod Drive	0.75	Leak	PNO 79-90	Unknown	Leaked thimble tube weld, unknown cause	SS
North Anna 1	PWR	5/3/1979	Component cooling	0.75	Leak		Construction Defects/Errors	Construction defect	CS
Oyster Creek	BWR	5/18/1979	Radwaste	0.75	Leak		Construction Defect/Errors	Poor weld	SS
Monticello	BWR	8/6/1979	Main steam	0.75	Leak		Erosion/Corrosion	Erosion/Corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Calvert Cliffs 1	PWR	8/31/1979	Containment heat removal	0.75	Leak	79-039	Fatigue-Vibrational	Fatigue-vibrational (1/2)	CS
Calvert Cliffs 1	PWR	8/31/1979	Containment heat removal	0.75	Leak	79-039	Fatigue-Vibrational	Fatigue-vibrational (2/2)	CS
Brunswick 2	BWR	12/28/1979	Coolant Recirculation	0.75	Leak	79-109	Other	Personnel error, weld arc stick on reducing insert	SS
Indian Point 3	PWR	1/10/1980	Charging	0.75	Leak		Fabrication Defect		SS
Yankee Rowe	PWR	1/23/1980	main steam	0.75	leak	84-001	stress corrosion/IGSCC	chloride stress corrosion	CS
Maine Yankee 1	PWR	1/31/1980	Safety Injection	0.75	Leak		Unknown	Unknown cause	SS
Indian Point 3	PWR	3/11/1980	Boiler feed	0.75	Leak		Not Given		SS
Brunswick 2	BWR	4/1/1980	RWCU	0.75	Leak	NPE VIII.A.64 (BWR-2, Book 2)	Unknown		SS
Trojan	PWR	8/29/1980	chemical and volume control	0.75	leak	PNO-V-84-056	unknown	unknown cause	SS
Salem 1	PWR	11/17/1980	service water	0.75	leak	84-027	corrosion	external surface corrosion	CS
Dresden 2	BWR	1/1/1981	Turbine floor drain	0.75	Rupture	NPE VI.E.142 (BWR-2, Book-8)	Fatigue-Vibrational		CS
Beaver Valley 1	PWR	1/22/1981	Residual heat removal	0.75	leak	PNO-I-81-027	Fatigue-Vibrational	Fatigue-vibration	SS
WPPSS 2		2/2/1981	pressurizer	0.75	leak	85-011	fatigue-vibrational	fatigue-vibrational	SS
Dresden 2	BWR	4/26/1981	Condensate	0.75	Leak	81-019	Thermal Fatigue	Thermal fatigue	CS
Dresden 2	BWR	4/26/1981	Containment spray	0.75	Leak	81-018	Fatigue-Vibrational	Fatigue-vibration	SS
Dresden 2	BWR	5/3/1981	Condensate	0.75	Failed	81-022	Thermal Fatigue	Thermal fatigue	CS
Trojan	PWR	5/31/1981	containment heat removal	0.75	leak	85-005	fatigue-vibrational	fatigue-vibrational	CS
Salem 1	PWR	7/28/1981	containment heat removal	0.75	leak	85-008	unknown	leaked pipe plug, unknown cause	CS
Salem 2	PWR	9/10/1981	containment heat removal	0.75	leak	85-019	unknown	damaged nipple	CS
Big Rock Point	BWR	2/19/1982	Control Rod Drive	0.75	Crack	82-005	Fatigue-Vibrational	Fatigue-vibration at threaded connection	SS
San Onofre 3	PWR	2/26/1982	instrument line	0.75	leak	86-003	stress corrosion/IGSCC	IGSCC	SS
Browns Ferry 1	BWR	3/20/1982	Reactor Water Cleanup	0.75	Leak	82-020	Fatigue-Vibrational	Fatigue-vibration, large leak	SS
Dresden 3	BWR	4/17/1982	Core Spray	0.75	Leak	82-019	Fatigue-Vibrational	Cracked weld	SS
Calvert Cliffs 2	PWR	7/1/1982	Service Water	0.75	leak	82-035	Corrosion	Corrosion, salt water attack	CS
Millstone 2	PWR	7/2/1982	Reactor coolant	0.75	Leak		Erosion/Corrosion	Erosion/corrosion	SS
Maine Yankee 1	PWR	8/8/1982	High pressure core injection	0.75	Leak		Construction Defects/Errors	Construction defects/errors	SS
Calvert Cliffs 1	PWR	11/1/1982	Charging	0.75	Leak	NPE VIII.A.647	Fatigue-Vibrational		SS
LaSalle 1	BWR	11/24/1982	Condensate	0.75	Leak		Fatigue-Vibrational	Fatigue-vibrational	CS
Calvert Cliffs 2	PWR	11/27/1982	Service Water	0.75	Leak	82-074	Fatigue-Vibrational	Vibrational, thermal fatigue	CS
Calvert Cliffs 1	PWR	12/7/1982	Chemical and Volume Control	0.75	Leak	82-074	Fatigue-Vibrational		SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Calvert Cliffs 2	PWR	4/18/1983	Service Water	0.75	Leak	83-024	Fatigue-Vibrational	Cracked socket weld, Vibration	CS
Ginna	PWR	4/18/1983	Boric Acid	0.75	Leak	83-016	Stress Corrosion/IGSCC	Stress corrosion	SS
Indian Point 3	PWR	5/31/1983	Service water	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Dresden 2	BWR	6/3/1983	Main steam	0.75	Leak	83-044	Fatigue-Vibrational	Fatigue-vibration	CS
Indian Point 3	PWR	6/4/1983	Reactor Coolant	0.75	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Oyster Creek	BWR	6/6/1983	Chlorine	0.75	Leak		Unknown	Chlorine plastic line	SS
Indian Point 2	PWR	8/6/1983	Safety Injection	0.75	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
ANO1	PWR	9/6/1983	Reactor Coolant	0.75	Leak	83-019	Fatigue-Vibrational	Fatigue-vibration	SS
Fitzpatrick	BWR	11/4/1983	High pressure core injection	0.75	Leak	83-054	Thermal Fatigue	Thermal fatigue	SS
Nine Mile Point 1	BWR	11/10/1983	Core spray	0.75	Crack/Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Calvert Cliffs 2	PWR	12/20/1983	Service Water	0.75	Leak	83-077	Fatigue-Vibrational	Fatigue-vibrational	CS
Cooper	BWR	4/9/1984	Coolant recirculation	0.75	Leak	84-005	Unknown	Circumferential crack in weld joint, unknown cause	SS
Calvert Cliffs 2	PWR	7/9/1984	Containment heat removal	0.75	Leak	84-006	Fatigue-Vibrational	Vibration fatigue	CS
Salem 2	PWR	7/25/1984	service water	0.75	leak	88-015	erosion/corrosion	erosion/corrosion	CS
Palisades	PWR	8/10/1984	Coolant recirculation	0.75	Leak		Unknown	Cracked socket weld	SS
Vogtle 1	PWR	1/18/1985	reactor coolant	0.75	leak	89-004	fatigue-vibrational	fatigue-vibration	SS
Browns Ferry 3	BWR	2/10/1985	RWCU	0.75	Leak	LER 85-005	Fatigue-Vibrational		SS
WPPSS 2		5/11/1985	core spray	0.75	severed	89-015	fatigue-vibrational	fatigue-vibrational	SS
Millstone 1	PWR	7/23/1985	RWCU	0.75	Rupture		Fatigue-Vibrational		SS
Byron 1	PWR	7/30/1985	Condensate Drain	0.75	Leak	NPRDS	Erosion/Corrosion, Fatigue-Vibrational	Sch 80, location 1 out of 2, plant outage	CS
Byron 1	PWR	7/30/1985	Condensate Drain	0.75	Leak	NPRDS	Erosion/Corrosion, Fatigue-Vibrational	Sch 80, location 2 out of 2, plant outage	CS
Surry 1	PWR	10/30/1985	reactor coolant	0.75	leak	89-042	fatigue-vibrational	fatigue-vibrational	SS
North Anna 1	PWR	12/28/1985	Chemical and volume control	0.75	Leak		Fatigue-Vibrational	Cracks, fatigue-vibrational	SS
LaSalle 1	BWR	5/21/1986	RHR	0.75	Leak		Weld Defect	Leak 1 of 2	SS
LaSalle 1	BWR	5/21/1986	RHR	0.75	Leak		Weld Defect	Leak 2 of 2	SS
Nine Mile Point 1	BWR	6/18/1986	Flow sensor	0.75	Leak		Unknown	Unknown cause	SS
Millstone 1	PWR	8/16/1986	Torus spray/LPSI	0.75	Rupture		Fatigue-Vibrational		SS
Catawba 2	PWR	9/1/1986	Feedwater heater	0.75	leak	NPRDS	not given	Sch 80, normal operation	CS
WPPSS 2		10/22/1986	high pressure core injection	0.75	leak	90-028	fatigue-vibrational		SS
ANO1	PWR	10/23/1986	High Pressure Core Injection	0.75	Leak	86-006	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS
Salem 1	PWR	11/22/1986	service water	0.75	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Catawba 2	PWR	11/23/1986	Feedwater heater	0.75	rupture	NPRDS	not given	Sch 80, normal operation	CS
Salem 1	PWR	11/27/1986	service water	0.75	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Perry	BWR	3/31/1987	coolant recirculation	0.75	leak	PNO-III-91-012	fatigue-vibrational	fatigue-vibration	SS
Catawba 2	PWR	5/6/1987	Feedwater elbow	0.75	rupture	NPRDS	not given	Sch 80, normal operation	CS
Catawba 1	PWR	7/11/1987	Heater to feedwater	0.75	rupture	NPRDS	not given	Sch 80, overpressure	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
WPPSS 2		11/3/1987	residual heat removal	0.75	leak	91-030	fatigue-vibrational	fatigue-vibration	SS
Turkey Point 4	PWR	1/27/1988	steam	0.75	leak	PNO-II-92-005	erosion/corrosion	erosion/corrosion	CS
Big Rock Point	BWR	2/7/1988	Primary Steam	0.75	Leak	88-003	Erosion/Corrosion	Erosion	SS
San Onofre 2	PWR	2/17/1988	Instrument line	0.75	crack/leak	92-004	stress corrosion/IGSCC	IGSCC	SS
Brunswick 2	BWR	3/19/1988	Control Rod Drive	0.75	Leak	88-007	Stress Corrosion/IGSCC	Stress Corrosion	SS
Hatch 1	BWR	4/15/1988	Service water drain	0.75	Severed		Fatigue-Vibrational	Fatigue-Vibrational	CS
Brunswick 2	BWR	9/8/1988	Service Water	0.75	Leak	88-016	Erosion/Corrosion	Erosion/Corrosion	CS
Haddam Neck 1	PWR	12/9/1988	Component cooling	0.75	Failed		Unknown	threaded nipple, mode-1	CS
Zion 1	PWR	12/29/1988	flow sensor	0.75	breakage	special report OSR-008-93	unknown	unknown cause	SS
Zion 1	PWR	1/2/1989	flow sensor	0.75	leak	special report OSR-008-93	construction defect/errors	leaked tube due to incorrect seating, construction defect	SS
Millstone 3	PWR	4/11/1989	RCS, mode 1	0.75	Leak		Fatigue-Vibrational	Prior leak in same line	SS
Millstone 3	PWR	4/12/1989	Let down line	0.75	Leak		Fatigue-Vibrational		SS
Surry 1	PWR	8/20/1989	steam	0.75	leak	93-010	stress corrosion/IGSCC	IGSCC	CS
Duane Arnold	BWR	5/19/1990	Control Rod Drive	0.75	Leak	90-010	Fatigue-Vibrational	Fatigue-vibration	SS
Diablo Canyon 1	PWR	7/26/1990	Chemical and volume control	0.75	Leak	90-010	Fatigue-Vibrational	Fatigue-vibration	SS
Braidwood 1	PWR	8/30/1990	Residual Heat Removal	0.75	Leak	90-012	Unknown	Unknown	SS
Millstone 3	PWR	12/3/1990	SWS	0.75	Leak		Not Given		CS
Beaver Valley 1	PWR	1/16/1991	Containment heat removal	0.75	Leak	91-002	Erosion/Corrosion	Erosion/Corrosion, Pressure boundary leakages	CS
Nine Mile Point 2	BWR	3/30/1991	Containment heat removal	0.75	Leak		Construction Defects/Errors	Fabrication defect	CS
North Anna 1	PWR	5/11/1991	Containment heat removal	0.75	Crack/Leak		Fatigue-Vibrational	Fatigue-vibrational	CS
San Onofre 3	PWR	7/21/1991	reactor coolant	0.75	leak	95-001	stress corrosion/IGSCC	IGSCC	SS
Oconee 3	BWR	11/1/1991	Instrument line	0.75	Leak		Erosion/Corrosion	Erosion/corrosion	SS
Oconee 3	BWR	11/25/1991	Containment heat removal	0.75	Severed		Unknown	Compression fitting failed	CS
Oconee 3	BWR	12/15/1991	Boric Acid	0.75	Leak		Stress Corrosion/IGSCC	Stress Corrosion/IGSCC	SS
Palo Verde 1	PWR	1/2/1992	Pressurizer instrument nozzle	0.75	Leak		Stress Corrosion/IGSCC	PWSCC	SS
Comanche Peak 2	PWR	6/22/1992	Spray pump	0.75	leak	CP-92-010	fatigue-vibrational		SS
Catawba 1	PWR	6/12/1993	D.G. cooling water	0.75	rupture	IR-50-414-93-22	fatigue-vibrational		CS
McGuire 3	PWR	9/10/1993	Reactor Coolant	0.75	Leak		Water hammer	Water hammer	SS
Diablo Canyon 2	PWR	3/28/1994	Reactor Coolant	0.75	Leak	PNO-V-94-7,94-001	Fatigue-Vibrational	Fatigue-vibration	SS
Millstone 3	PWR	4/22/1994	Sews	0.75	Leak		Erosion/Corrosion		CS
Calvert Cliffs 2	PWR	7/11/1994	Safety Injection	0.75	Leak	94-003	Fatigue-Vibrational	Crack from fatigue-vibration	SS
LaSalle 2	BWR	10/19/1994	Turbine line	0.75	Leak		Construction Defect/Errors	Faulty connector, construction defects/errors	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Comanche Peak	PWR	3/10/1996	safety injection	0.75	leak	LER 96-005	fatigue-vibrational	Leaking cracked weld at piping flange socket weld for valve, replaced 3/4 in. pipe	SS
Nine Mile Point 1	BWR	8/30/1971	Steam line	0.875	Leak		IGSCC		CS
Millstone 1	PWR	2/14/1972	Flow sensor	0.875	Leak		Thermal Fatigue	Fatigue-vibration	SS
Salem 2	PWR	3/1/1988	component cooling	0.875	leak	special report 92-3	unknown	diesel generator jacket water leaked, compression fitting failed and replaced	CS
Indian Point 1	PWR	8/8/1969	Reactor Coolant	1	Failed		Fatigue-Vibrational	Fatigue-Vibrational	SS
Quad Cities 1	BWR	10/11/1970	instrument line	1	leak	AO 74-33	construction defect/errors	poor weld, construction defect	SS
Quad Cities 1	BWR	10/21/1970	instrument line	1	leak	Ltr DL 10/22/74	fatigue-vibrational	fatigue-vibration	SS
Yankee Rowe	PWR	2/28/1971	service water	1	failed	AO 75-03	construction defect/errors	construction defect	CS
Dresden 2	BWR	3/17/1971	Containment heat removal	1	Failed	AECL	Unknown	Unknown, fitting broke	CS
Three Mile Island 1	PWR	8/20/1971	makeup system	1	leak	AO 75-27	fatigue-vibrational	fatigue-vibrational	SS
Vermont Yankee	BWR	8/25/1971	instrument line	1	leak	75-017	fatigue-vibrational	fatigue-vibration	SS
St. Lucie 1	PWR	9/1/1971	service water	1	leak	letter to NRC (11/13/75)	fatigue-vibrational	weld failure, fatigue-vibrational	CS
St. Lucie 1	PWR	9/5/1971	safety injection	1	leak	ORNL-NSIC-127:107985	fatigue-vibrational	fatigue-vibrational	SS
Peach Bottom 2	BWR	11/6/1971	residual heat removal	1	leak	AO 75-71	fatigue-vibrational	fatigue-vibration	SS
Yankee Rowe	PWR	2/3/1972	reactor coolant	1	leak	RO 76-01	fatigue-vibrational	fatigue-vibrational	SS
Dresden 1	BWR	4/21/1972	Reactor Coolant	1	Leak	ORNL-NSIC-109:70038	Fatigue-Vibrational	Fatigue-vibration	SS
Yankee Rowe	PWR	5/19/1972	feedwater	1	leak	76-005	construction defect/errors	installation error	CS
Vermont Yankee	BWR	5/31/1972	instrument line	1	leak	AO 75-17	corrosion	corrosion cracking	SS
Prairie Island 2	PWR	6/18/1972	coolant pump seal return line	1	leak	RO 76-31	fatigue-vibrational		SS
Rancho Seco	PWR	8/4/1972	reactor coolant	1	leak	RO 76-11	fatigue-vibrational	fatigue-vibrational	SS
Yankee Rowe	PWR	9/6/1972	feedwater	1	leak	76-011	construction defect/errors	construction defect	CS
Salem 1	PWR	10/20/1972	containment heat removal	1	rupture	RO 76-05	fatigue-vibrational	fatigue-vibration	CS
Palisades	PWR	11/2/1972	Control rod drive	1	Leak		Construction Defects/Errors	Maintenance error	SS
St. Lucie 1	PWR	5/9/1973	safety injection	1	crack/leak	RO 77-29	construction defect/errors	construction defect	SS
Millstone 1	PWR	7/11/1973	Feedwater	1	Leak		Water hammer	Fatigue-vibration	CS
Peach Bottom 2	BWR	9/13/1973	residual heat removal	1	leak	77-041	unknown	failed threading	SS
Indian Point 2	PWR	10/26/1973	Containment heat removal	1	Leak		Corrosion/Fatigue	Corrosion/fatigue	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Dresden 2	BWR	12/3/1973	High pressure core injection	1	Leak	AO	Erosion/Corrosion	Erosion	SS
Peach Bottom 2	BWR	2/6/1974	residual heat removal	1	leak	78-012	fatigue-vibrational	fatigue-vibration	SS
Trojan	PWR	3/7/1974	spent fuel pool	1	leak	78-007	construction defect/errors	construction defect/errors	CS
Trojan	PWR	5/23/1974	reactor coolant	1	leak	78-019	construction defect/errors	construction defect/errors	SS
Pilgrim	BWR	6/15/1974	spent fuel pool	1	leak	78-028	fatigue-vibrational	fatigue-vibration	CS
Ginna	PWR	8/1/1974	Feedwater	1	Failed	ORNL NSIC 094753	Fatigue-Vibrational	Fatigue-Vibrational	CS
Dresden 2	BWR	9/1/1974	Condensate booster pump vent line	1	Rupture	AO 74-43, 50237-606	Fatigue-Vibrational	In run mode, failed at nipple at pump, wall thickness reduced	CS
Browns Ferry 1	BWR	9/22/1974	Coolant Recirculation	1	Failed	AO 74-49W	Fatigue-Vibrational	Fatigue-vibrational	SS
Dresden 2	BWR	10/22/1974	High pressure core injection	1	Leak	AO 74-54	Construction Defect/Errors	Poor weld joint at gland leak off line, construction defect	SS
Ginna	PWR	1/17/1975	Pressurizer	1	Breakage	NUREG/CR 2781	Water Hammer	Water Hammer	SS
St. Lucie 1	PWR	3/5/1975	service water	1	failed	79-011	water hammer	failed socket weld	CS
Ginna	PWR	4/18/1975	Service Water	1	Leak	75-002-03L	Construction Defect/Errors	Poor weld, construction defect	CS
St. Lucie 1	PWR	5/6/1975	service water	1	failed	79-017	water hammer	failed socket weld	CS
Ginna	PWR	5/8/1975	Letdown drain line	1	Leak	75-2	Construction Error	lack of weld fusion	SS
Brunswick 2	BWR	5/20/1975	High Pressure Core Injection	1	Leak	AO 75-46	Unknown	Defective plug	SS
Brunswick 2	BWR	6/11/1975	DG Drain	1	Leak	AO 75-55	Corrosion	Corrosion, Constuction defect	CS
Cook 1	PWR	6/24/1975	chemical and volume control	1	leak	AO 75-27	Corrosion	Socket weld crack, corrosion	SS
Oconee 1	BWR	6/24/1975	Containment heat removal	1	Failed		other	Valve plug in relief valve blew out, overpressuzation	CS
Brunswick 2	BWR	8/11/1975	High Pressure Core Injection	1	Leak	AO 75-89	Erosion/Corrosion	Erosion	SS
Millstone 2	PWR	9/1/1975	Instrument line	1	Leak		Porosity		SS
Nine Mile Point 1	BWR	9/13/1975	Coolant recirculation	1	Leak		Unknown	Pump part failed	SS
Millstone 2	PWR	9/16/1975	Instrument line	1	Leak		Unknown	Weld failure, unknown cause	SS
Brunswick 2	BWR	9/25/1975	High Pressure Core Injection	1	Leak	AO 75-94	Construction Defect/Error	Cross threaded pipe	SS
Millstone 2	PWR	9/30/1975	Instrument line	1	Leak		Unknown	Weld failure, unknown cause	SS
Monticello	BWR	10/3/1975	Reactor coolant	1	Leak		Unknown	Unknown cause	SS
Oconee 3	BWR	10/5/1975	Core spray	1	Severed		Water hammer	Water hammer	SS
Dresden 3	BWR	10/7/1975	Feedwater	1	Leak	AO 75-43	Construction Defect/Errors	Poor weld, construction defect	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Monticello	BWR	11/1/1975	Core spray	1	Crack/Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Rancho Seco	PWR	11/24/1975	makeup	1	leak	NPE VIII.A.400	fabrication defect		SS
Nine Mile Point 1	BWR	11/29/1975	Coolant recirculation	1	Leak		Unknown	Unknown cause	SS
Big Rock Point	BWR	12/9/1975	Service Water	1	Leak	RO 29-75	Fatigue-Vibrational	Fatigue-vibrational	CS
Cook 1	PWR	12/25/1975	high pressure core injection	1	leak	RO 76-07	fatigue-vibrational	fatigue-vibration	SS
Calvert Cliffs 1	PWR	12/27/1975	Steam Generator Blow Down	1	Leak	76-004	Erosion/Corrosion	Erosion/Corrosion	CS
Surry 2	PWR	3/5/1976	coolant recirculation	1	leak	80-005	construction defect/errors	construction defect	SS
Peach Bottom 3	BWR	4/13/1976	residual heat removal	1	leak	80-009	fatigue-vibrational	fatigue-vibration	SS
Zion 2	PWR	5/11/1976	reactor coolant	1	leak	PNO-III-80-091	unknown	pipe separated from valve bonnet, unknown cause	SS
Turkey Point 4	PWR	6/16/1976	component cooling	1	leak	80-010	corrosion	corrosion	CS
Sequoyah 1	PWR	6/23/1976	pressurizer	1	failed	80-098	unknown	compression fitting failed	SS
Beaver Valley 1	PWR	7/1/1976	Instrument Line	1	Leak	76-041	Unknown	Swage-lock Failed	SS
Haddam Neck 1	PWR	7/12/1976	Service water	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Millstone 2	PWR	7/29/1976	Instrument line	1	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Indian Point 3	PWR	8/16/1976	Containment heat removal	1	Breakage		Unknown	Parted at swage lock	CS
Monticello	BWR	8/28/1976	Main steam	1	Leak		Erosion/Corrosion	Erosion/corrosion	CS
ANO1	PWR	9/2/1976	Primary Makeup System	1	Leak	RO 76-26	Construction Defect/Error	Construction defect - socket weld, schedule 40	SS
Dresden 3	BWR	9/12/1976	Feedwater	1	Leak	76-015	Corrosion/Fatigue	Fatigue-vibration	CS
Sequoyah 1	PWR	9/30/1976	seal line	1	leak	NPE V.A. 93	fatigue-vibrational		CS
Point Beach 1	PWR	10/4/1976	service water	1	leak	80-012	construction defect/errors	construction defects/errors	CS
Monticello	BWR	11/12/1976	Condensate	1	Leak		Erosion/Corrosion	Erosion/corrosion	CS
Calvert Cliffs 1	PWR	11/28/1976	Chemical and Volume Control	1	Leak	76-049	Fatigue-Vibrational		SS
Cooper	BWR	12/1/1976	Service Water	1	Rupture	76-057	Corrosion	Corrosion and bumped by maintenance man	CS
Palisades	PWR	12/2/1976	Service water	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Calvert Cliffs 2	PWR	12/7/1976	Boric Acid	1	leak	76-015	Construction Defect/Errors	Construction defect	SS
Millstone 2	PWR	12/12/1976	Reactor coolant	1	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Ginna	PWR	12/17/1976	Reactor Water Cleanup	1	Leak	RO 76-030	Erosion/Corrosion	Erosion/Corrosion	SS
Calvert Cliffs 2	PWR	12/22/1976	Reactor coolant	1	leak	76-014	fatigue-vibrational	fatigue-vibration	SS
Calvert Cliffs 1	PWR	12/27/1976	Service Water	1	Leak	76-056	Erosion/Corrosion		CS
Indian Point 2	PWR	12/30/1976	Containment heat removal	1	Breakage		Unknown	Swage-lock fitting failed	CS
Salem 1	PWR	1/8/1977	component cooling	1	leak	81-003	construction defect/errors	dissimilar metal weld, construction defect	CS
Calvert Cliffs 1	PWR	1/15/1977	Charging Pump	1	Leak	LER 77-008	Fatigue-Vibrational		SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Three Mile Island 1	PWR	1/16/1977	reactor coolant	1	leak	81-001	fatigue-vibrational	fatigue-vibration, corrosion	SS
Robinson 2	PWR	1/28/1977	chemical and volume control	1	rupture	81-005	fatigue-vibrational	cap off drain; valve vibrated open; about 3000 gal.; estimate 100 gpm, fatigue-vibration	SS
Cooper	BWR	2/6/1977	Residual heat removal	1	Leak	77-010	Fatigue-Vibrational	Fatigue-vibration	SS
Salem 1	PWR	2/13/1977	component cooling	1	leak	81-018	unknown	cracked nipple, unknown cause	CS
Dresden 2	BWR	3/2/1977	Reactor Coolant	1	Leak	RO 77-10	Construction Defect/Errors	Construction defect	SS
Calvert Cliffs 2	PWR	3/14/1977	auxiliary feedwater	1	leak	77-022	Fatigue	damaged threads	CS
Dresden 2	BWR	3/15/1977	Reactor Coolant	1	Leak	77-002-6(B)	Fatigue-Vibrational	Fatigue-vibration	SS
Indian Point 2	PWR	3/15/1977	Pressurizer	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Davis Besse	PWR	3/24/1977	Main steam	1	Rupture	No LER	Unknown	Valve pulled from line, unknown cause	CS
Indian Point 2	PWR	3/29/1977	Pressurizer	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Millstone 2	PWR	4/20/1977	Instrument line	1	Leak		Fatigue-Vibrational	Fatigue-vibration	SS
Dresden 1	BWR	4/21/1977	Containment heat removal	1	Rupture	77-009	Corrosion	Corroded nipple broke off	CS
Indian Point 2	PWR	4/27/1977	Residual heat removal	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Vermont Yankee	BWR	5/6/1977	reactor water cleanup	1	leak	81-011	stress corrosion/IGSCC	IGSCC	SS
Indian Point 2	PWR	5/13/1977	Pressurizer	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Dresden 3	BWR	6/7/1977	Condensate	1	Leak	RO 77-20	Fatigue-Vibrational	Fatigue-vibration	CS
Calvert Cliffs 2	PWR	6/13/1977	Charging pump	1	leak	LER-77-041	Fatigue-vibrational		SS
Millstone 1	PWR	6/14/1977	Coolant recirculation	1	Leak		Unknown	Unknown cause	SS
Monticello	BWR	6/17/1977	Moisture separator reheater	1	Leak		Construction Defects/Errors	Poor weld, construction	SS
Vermont Yankee	BWR	6/21/1977	reactor water cleanup	1	leak	81-016	stress corrosion/IGSCC	IGSCC	SS
Zion 1	PWR	6/28/1977	reactor coolant	1	leak	81-032	fatigue-vibrational	fatigue-vibration	SS
Monticello	BWR	7/7/1977	Containment heat removal	1	Leak		Construction Defects/Errors	Construction Defects/Errors	CS
Monticello	BWR	8/2/1977	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Hatch 1	BWR	8/14/1977	Instrument line	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 1	PWR	9/1/1977	SWS	1	leak	81-085	not given		CS
Dresden 2	BWR	9/20/1977	Safety injection	1	Leak	Not Given	Construction Defect/Errors	Construction defect	SS
Farley 1	PWR	12/13/1977	Auxiliary feedwater	1	Failed	77-059	Fatigue-Vibrational	Fatigue-vibration	CS
Salem 1	PWR	12/27/1977	service water	1	leak	81-121	erosion/corrosion	erosion/corrosion	CS
ANO1	PWR	2/3/1978	Reactor Coolant	1	Leak	78-003	Unknown	Unknown Cause	SS
Calvert Cliffs 2	PWR	2/22/1978	Reactor Coolant	1	leak	78-005	Fatigue-vibrational	fatigue-vibration	SS
Turkey Point 3	PWR	2/28/1978	containment heat removal	1	leak	82-003	fatigue-vibrational	fatigue-vibrational	CS
Monticello	BWR	5/5/1978	Reactor coolant	1	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
Monticello	BWR	5/8/1978	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Surry 2	PWR	5/23/1978	coolant recirculation	1	leak	82-024	construction defect/errors	construction defects	SS
Calvert Cliffs 1	PWR	5/31/1978	Reactor Coolant	1	Leak	78-031	Fatigue-Vibrational	Fatigue-vibration	SS
San Onofre 2	PWR	6/10/1978	feedwater	1	severed	82-027	fatigue-vibrational	fatigue-vibrational	CS
San Onofre 2	PWR	6/16/1978	feedwater	1	severed	82-032	fatigue-vibrational	fatigue-vibrational	CS
Indian Point 2	PWR	6/29/1978	Safety Injection	1	Leak		Unknown	Unknown cause	SS
Monticello	BWR	7/19/1978	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Point Beach 2	PWR	7/27/1978	chemical and volume control	1	leak	82-006	other	welding of nearby restraint, error	SS
Salem 2	PWR	8/17/1978	containment heat removal	1	leak	82-077	erosion/corrosion	erosion/corrosion	CS
Salem 1	PWR	8/30/1978	service water	1	leak	82-069	erosion/corrosion	erosion/corrosion	CS
Zion 1	PWR	9/4/1978	containment spray	1	leak	82-027	corrosion	corrosion	SS
Salem 2	PWR	9/27/1978	service water	1	leak	82-115	erosion/corrosion	silt induced erosion/corrosion	CS
ANO1	PWR	9/29/1978	Spent Fuel Pool	1	Leak	78-028	Stress Corrosion Cracking, IGSCC	Crack in pipe, nipple, stress corrosion	CS
Monticello	BWR	11/14/1978	Residual heat removal	1	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
Monticello	BWR	11/17/1978	Main steam	1	Leak		Construction Defects/Errors	Construction Defects/Errors	CS
Monticello	BWR	11/24/1978	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Prairie Island 1	PWR	12/27/1978	containment heat removal	1	leak	82-029	thermal fatigue	thermal fatigue	CS
Monticello	BWR	1/10/1979	Steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Salem 1	PWR	1/23/1979	component cooling	1	leak	83-004	construction defect/errors	construction defect/errors	CS
Big Rock Point	BWR	2/21/1979	Reactor Water Cleanup	1	Leak	79-006	Stress Corrosion Cracking, IGSCC	Stress Corrosion	SS
ANO2	PWR	3/1/1979	LPSI	1	Leak	NPE VII.A.208	Unknown		SS
Crystal River 3	PWR	3/1/1979	SWS	1	Leak	79-004	Installation Error		CS
Oyster Creek	BWR	3/1/1979	Containment spay	1	Leak		Construction Defects/Errors	Improper installed connection, defect	SS
Monticello	BWR	4/4/1979	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Ginna	PWR	4/6/1979	Boric Acid	1	Leak	79-008	Corrosion	External caustic pitting, chemical corrosion	SS
ANO1	PWR	4/25/1979	Sevice Water	1	Leak	79-003	Fatigue-Vibrational	Fatigue-vibration	CS
Dresden 2	BWR	5/9/1979	Feedwater	1	Leak	79-031	Corrosion/Fatigue	Corrosion/Fatigue of carbon steel	CS
St. Lucie 2	PWR	5/10/1979	safety injection	1	leak	83-006	unknown	cracked weld, 1 qt/min leaks	SS
Oconee 1	BWR	6/2/1979	Component cooling	1	Leak		Unknown	Faulty joint, joint and cooler tubing replace	CS
Millstone 2	PWR	6/4/1979	Service water	1	Failed		Water hammer	Failed socket weld	CS
Monticello	BWR	7/1/1979	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Oconee 1	BWR	7/3/1979	Service water	1	Leak		Unknown	Bad joint	CS
Salem 2	PWR	7/6/1979	main steam	1	leak	83-033	erosion/corrosion	erosion/corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Crystal River 3	PWR	7/9/1979	Service Water	1	Leak	79-063	Fatigue-Vibrational	Fatigue-vibration	CS
Calvert Cliffs 1	PWR	7/19/1979	Containment heat removal	1	Leak	79-026	Fatigue-Vibrational	Fatigue-Vibrational	CS
Yankee Rowe	PWR	7/30/1979	coolant recirculation	1	leak	83-025	construction defect/errors	construction defect/errors	SS
Oyster Creek	BWR	8/12/1979	Laundry discharge	1	Leak		other	Personnel error, stepped on vent line	SS
Calvert Cliffs 1	PWR	9/13/1979	Reactor Coolant	1	Leak	79-044	Thermal Fatigue	Thermal Fatigue	SS
Oyster Creek	BWR	9/14/1979	Containment spray	1	Leak		Corrosion	Corrosion	SS
Crystal River 3	PWR	10/24/1979	Makeup system	1	Leak	79-103	Fatigue-Vibrational	Fatigue-vibration	SS
ANO2	PWR	11/14/1979	Safety Injection	1	Leak	79-087	Fatigue-Vibrational	Fatigue-vibration	SS
Millstone 2	PWR	11/14/1979	Boric Acid	1	Leak		Stress Corrosion/IGSCC	Stress Corrosion	SS
Dresden 3	BWR	11/20/1979	Feedwater	1	Leak	79-032	Stress Corrosion/IGSCC	Corrosion at minimum flow line	CS
Monticello	BWR	12/20/1979	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Zion 1	PWR	1/19/1980	coolant recirculation	1	leak	84-005	construction defect/errors	construction defect/errors	SS
Indian Point 3	PWR	1/29/1980	Containment heat removal	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Salem 1	PWR	2/1/1980	service water	1	leak	84-006	construction defect/errors	construction defect/errors	CS
Haddam Neck 1	PWR	2/7/1980	Boric Acid	1	Leak		Unknown	Cracked weld	SS
ANO2	PWR	4/10/1980	Makeup System	1	Leak	80-019	Fatigue-Vibrational	Fatigue-vibration	SS
Sequoyah 1	PWR	4/18/1980	thimble tube	1	failed	84-030	unknown	compression fitting; cleaning maintenance; 30 gpm	SS
Calvert Cliffs 1	PWR	4/30/1980	Containment heat removal	1	Leak	80-024	Fatigue-Vibrational	Fatigue-vibration	CS
Beaver Valley 1	PWR	5/14/1980	Boric Acid	1	Crack	80-036	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS
ANO2	PWR	5/31/1980	Feedwater	1	Leak	80-034	Fatigue-Vibrational	Fatigue-vibration	CS
North Anna 2	PWR	6/10/1980	Emergency core cooling	1	Leak		Unknown	Failed fitting, fitting repaired	SS
ANO2	PWR	7/28/1980	Feedwater	1	Leak	80-061	Fatigue-Vibrational	Fatigue-vibration	CS
Monticello	BWR	8/25/1980	Main steam	1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Trojan	PWR	9/12/1980	thimble tube	1	failed	84-014	unknown	compression fitting; failed during repair	SS
Cook 1	PWR	9/16/1980	Main Steam	1	leak	80-023	thermal fatigue	leaked socket weld, thermal fatigue	CS
North Anna 1	PWR	10/30/1980	Service water	1	Leak		Construction Defects/Errors	Poor weld, Construction defect	CS
Ginna	PWR	11/25/1980	Residual heat removal	1	Leak	80-010	Construction Defect/Errors	Poor weld, construction defect	SS
Oyster Creek	BWR	11/30/1980	Core spray	1	Leak		Unknown	Worn gaskets, open ended conduits	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Pilgrim	BWR	12/6/1980	instrument line	1	leak	IN 85-34	stress corrosion/IGSCC	chloride stress corrosion cracking	SS
North Anna 2	PWR	12/18/1980	Reactor coolant	1	Leak		Unknown	Leaked weld, unknown cause	SS
Turkey Point 3	PWR	12/21/1980	component cooling	1	leak	84-038	fatigue-vibrational	fatigue-vibration	CS
Cook 2	PWR	1/3/1981	auxiliary feedwater	1	failed	81-002	other	overpressurization	CS
Robinson 2	PWR	2/22/1981	SWS	1	leak	NPRDS	erosion/corrosion	sch 40, questionable failure mechanism, normal op	CS
Ginna	PWR	4/26/1981	Residual heat removal	1	Leak	81-011	Erosion/Corrosion	Worn pump seal fitting threads, erosion	SS
Cook 1	PWR	4/28/1981	Main Steam	1	leak	81-012	unknown	unknown cause	CS
Farley2	PWR	5/5/1981	Component cooling	1	Failed	81-013	Fatigue-Vibrational	Compression fittion failed, fatigue-vibration	CS
Quad Cities 1	BWR	6/16/1981	residual heat removal	1	rupture	85-001; 008	fatigue-vibrational	fatigue-vibration	SS
Palisades	PWR	7/3/1981	Component cooling	1	Leak		Fatigue-Vibrational	Vibration, personnel errors	CS
Maine Yankee 1	PWR	7/18/1981	Service water	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Monticello	BWR	7/24/1981	Main steam	1	Leak		Erosion/Corrosion	Erosion/corrosion	CS
San Onofre 2	PWR	10/17/1981	moister separator reheater	1	failed	85-050	thermal fatigue	failed pipe nipple	SS
Kewaunee	PWR	12/18/1981	Chemical and volume control	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational, discharge pump relief pipe	SS
Peach Bottom 2	BWR	12/25/1981	condensate drain	1	rupture	NPE VI.E. 218 (BWR-2, Book-8)	water hammer		CS
Cook 1	PWR	1/23/1982	component cooling	1	failed	82-006	unknown	valve failed to close, unknown cause	CS
McGuire 1	PWR	2/12/1982	High pressure core injection	1	Severed		Unknown	Instrument line to PHI, unknown cause	SS
ANO2	PWR	2/16/1982	Sevice Water	1	Leak	82-007	Fatigue-Vibrational	Fatigue-vibration	CS
Oconee 1	BWR	2/17/1982	Makeup system	1	Crack/Leak		Construction Defects/Errors	Construction defect/errors	SS
Crystal River 3	PWR	2/28/1982	Makeup system	1	Leak	82-013	Fatigue-Vibrational	Vibration damage weld	SS
ANO2	PWR	4/4/1982	Accumulators	1	Leak	82-007	Fatigue-Vibrational	Fatigue-vibration	SS
Dresden 3	BWR	4/7/1982	Condensate	1	Leak	82-017	Unknown	Fatigue-vibration	CS
Duane Arnold	BWR	4/10/1982	Residual heat removal	1	Leak	82-028	Corrosion	Corrosion	SS
Three Mile Island 1	PWR	4/23/1982	steam	1	leak	PNO-I-86-034	fatigue-vibrational	fatigue-vibration, corrosion	CS
ANO2	PWR	5/5/1982	Reactor Water Cleanup	1	Leak	82-017	Fatigue	Cracked weld	SS
Brunswick 1	BWR	5/5/1982	Instrument Line	1	Rupture	82-050	Unknown	Unknown Cause	SS
Crystal River 3	PWR	5/10/1982	Makeup system	1	Leak	82-037	Fatigue-Vibrational	Fatigue-vibration	SS
Beaver Valley 1	PWR	5/21/1982	Containment heat removal	1	Leak	82-019	Erosion/Corrosion	Erosion/Corrosion	CS
Salem 1	PWR	6/3/1982	auxiliary feedwater	1	leak	special report 86-3	unknown	other, plugged pipe and gasket failure	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
San Onofre 1	PWR	6/4/1982	CCW	1	leak	NPRDS	not given		CS
Dresden 3	BWR	6/5/1982	Feedwater	1	Leak	82-025	Unknown	Fatigue-vibration	CS
Duane Arnold	BWR	6/10/1982	Diesel generator cooler	1	Leak	XI.A. 447 (NPE, BWR-2, Book-3)	Fatigue-Vibrational		CS
Duane Arnold	BWR	6/10/1982	Reactor coolant	1	Leak	82-040	Fatigue-Vibrational	Dynamic load and vibration	SS
Humboldt Bay 3	BWR	6/20/1982	Service water	1	Leak		Unknown	Weld failure, unknown cause	CS
Humboldt Bay 3	BWR	6/20/1982	Service water	1	Leak		Unknown	Weld failure, unknown cause	CS
ANO1	PWR	6/28/1982	Spent Fuel Pool	1	Leak	82-013	Fatigue-Vibrational	Fatigue-vibration	CS
ANO1	PWR	7/6/1982	Spent Fuel Pool	1	Rupture	82-014	Fatigue-Vibrational	Fatigue-vibration	CS
Cook 2	PWR	7/19/1982	Containment heat removal	1	leak	82-016	Fatigue-vibrational		CS
Dresden 2	BWR	7/26/1982	High pressure core injection	1	Leak	82-034	Erosion/Corrosion	Erosion	SS
Browns Ferry 1	BWR	8/10/1982	Pressurizer	1	Leak	82-056	Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 2	PWR	8/24/1982	safety injection	1	leak	special report 86-8	corrosion	galvanic corrosion	SS
Cook 2	PWR	9/1/1982	Feedwater drain	1	leak	NPE PWR-2-VI-E-No. 440	Fabrication Defect		CS
LaSalle 1	BWR	10/18/1982	Condensate	1	Leak		Construction Defect/Errors	Construction Defects/Errors	CS
LaSalle 1	BWR	10/19/1982	Condensate	1	Leak		Fatigue-Vibrational	Fatigue-vibrational	CS
Dresden 3	BWR	11/12/1982	Feedwater	1	Leak	82-046	Thermal Fatigue	IGSCC	CS
LaSalle 1	BWR	12/1/1982	Instrument line RCIC	1	Failed		Unknown	Compression fitting failed	SS
Dresden 2	BWR	12/24/1982	Feedwater	1	Leak	82-057	Fatigue-Vibrational	Fatigue-vibration	CS
Dresden 2	BWR	1/1/1983	Feedwater	1	Leak	83-001	Fatigue-Vibrational	Fatigue-vibration	CS
LaSalle 1	BWR	3/20/1983	Steam	1	Leak		Construction Defect/Errors	Construction defects/errors, defective socket weld	CS
LaSalle 1	BWR	4/14/1983	Instrument line	1	Leak		Construction Defect/Errors	Poor welds, construction defect	SS
Calvert Cliffs 1	PWR	4/23/1983	Containment heat removal	1	Leak	83-020	Fatigue-Vibrational		CS
Trojan	PWR	5/11/1983	accumulator fill	1	rupture	LER 87-013	fatigue-vibrational		SS
Trojan	PWR	5/11/1983	mode 6 1-in fill line to "A" accumulator	1	rupture	LER 87-013	fatigue	low cycle fatigue, line repaired, failed a second time, cause: excessive backflow through valves	SS
Indian Point 3	PWR	5/12/1983	Residual heat removal	1	Leak		Unknown	Unknown cause	SS
Crystal River 3	PWR	5/16/1983	Service Water	1	Leak	83-022	Erosion/Corrosion	Erosion/corrosion	CS
Perry	BWR	5/23/1983	condensate	1	severed	87-027	fatigue-vibrational	fatigue-vibration	CS
Millstone 1	PWR	6/7/1983	Reactor water cleanup	1	Crack/Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Monticello	BWR	6/15/1983	Service water	1	Leak		Stress Corrosion/IGSCC	IGSCC	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
LaSalle 1	BWR	6/24/1983	Radwaste	1	Leak		Construction Defect/Errors	Construction defects/errors, defective socket weld	SS
Turkey Point 4	PWR	7/11/1983	feedwater	1	leak	87-014	unknown	unknown	CS
LaSalle 1	BWR	7/18/1983	Feedwater	1	Leak		Construction Defect/Errors	Construction defects/errors	CS
LaSalle 1	BWR	7/26/1983	Chemical and volume control	1	Leak		Construction Defect/Errors	Construction defects/ errors, faulty weld	SS
Big Rock Point	BWR	8/21/1983	Coolant Recirculation	1	Leak	83-010	Construction Defect/Error	Construction Defect/Error	SS
Calvert Cliffs 2	PWR	9/9/1983	Containment heat removal	1	Leak	83-049	Fatigue-Vibrational	Fatigue-vibrational	CS
Beaver Valley 1	PWR	9/19/1983	Containment heat removal	1	Leak	83-026	Construction Defect/Error	Construction defects/errors, broken weld	CS
Beaver Valley 1	PWR	10/29/1983	Control Rod Drive	1	Severed	83-003	Construction Defect/Error	Errors, maintenance-caused failure	SS
South Texas 1	PWR	11/4/1983	auxillary feedwater	1	rupture	87-016, IN 91-50	water hammer	water hammer	CS
Palo Verde 1	PWR	1/1/1984	Core spray	1	Leak		Corrosion	Corrosion by microbiological	SS
South Texas 1	PWR	3/31/1984	containment heat removal	1	leak	88-028	erosion/corrosion	erosion/corrosion	CS
South Texas 1	PWR	8/29/1984	main steam	1	leak	PNO-IV-88-072	fatigue-vibrational	fatigue-vibrational	CS
Fort Calhoun	PWR	11/18/1984	Pressurizer	1	Leak	84-023	Unknown	unknown	SS
Wolf Creek	PWR	12/6/1984	service water	1	leak	88-023	erosion/corrosion	erosion/corrosion	CS
Yankee Rowe	PWR	8/23/1985	coolant recirculation	1	leak	89-012	fatigue-vibrational	fatigue-vibrational	SS
Robinson 2	PWR	11/17/1985	SWS	1	rupture	NPRDS	fatigue-vibrational	sch 40, shutdown	CS
Sequoyah 1	PWR	12/14/1985	chemical and volume control	1	leak	89-034	unknown	loose threaded fitting, fitting tightened	SS
Comanche Peak	PWR	12/26/1985	SWS	1	leak	DEF-RPT-CP-86-07	Erosion/Corrosion		CS
Salem 2	PWR	1/16/1986	boron injection	1	leak	90-005	erosion/corrosion	leaked weld, corrosion, mode 3	SS
Salem 2	PWR	1/16/1986	emergency core cooling	1	leak	90-005	fatigue-vibrational	fatigue-vibration, pipe to cap socket weld joint repaired	SS
ANO1	PWR	1/21/1986	Diesel Generator Lube Oil Cooler	1	Leak	NPRDS	Wear	Sch 40, cold shutdown hose	CS
Salem 2	PWR	6/10/1986	service water	1	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Catawba 1	PWR	6/13/1986	Letdown/CVCS	1	rupture	LER 86-031	fatigue-vibrational		SS
Catawba 1	PWR	6/13/1986	service water	1	breakage	86-031	water hammer	water hammer	CS
Dresden 2	BWR	7/13/1986	Condensate	1	Severed	86-016	Other	Disconnected pipe union	CS
Millstone 1	PWR	7/23/1986	Reactor water cleanup	1	Separation		Unknown	90 deg elbow	SS
Calvert Cliffs 2	PWR	7/25/1986	Reactor Coolant	1	- Severed	86-005	Unknown	Compression fitting failed	SS
Salem 1	PWR	7/31/1986	service water	1	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 2	PWR	9/30/1986	main steam drain line elbow	1	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Salem 2	PWR	10/18/1986	residual heat removal	1	leak	90-026-04	erosion/corrosion	erosion/corrosion	SS
Fermi 2	BWR	11/17/1986	Condensate	1	Severed	86-045	Other	Overpressurized	CS
Salem 1	PWR	11/29/1986	service water	1	leak	90-026-04	erosion/corrosion	erosion/corrosion, SW pump flexible hose leak	CS
Robinson 2	PWR	12/14/1986	CCW	1	leak	NPRDS	erosion/corrosion	sch 40, refueling	CS
Robinson 2	PWR	12/14/1986	RHR	1	leak	NPRDS	erosion/corrosion	sch 40, refueling	SS
Oyster Creek	BWR	12/29/1986	Main steam	1	Leak		Unknown	Unknown cause	CS
Salem 2	PWR	1/9/1987	service water	1	leak	91-003	erosion/corrosion	leakages in charging pump 21 and 22 cooler piping, erosion/corrosion	CS
Salem 1	PWR	1/16/1987	service water	1	leak	91-002	corrosion	galvanic corrosion, erosion	CS
Turkey Point 3	PWR	1/28/1987	accumulator line	1	leak	NPRDS	fatigue	sch 46, questionable failure mechanism, hydro	SS
River Bend	BWR	2/27/1987	service water	1	leak	information report	fatigue-vibrational	fatigue-vibrational	CS
Oconee 2	BWR	4/8/1987	Instrument line	1	Leak		Construction Defect/Errors	Construction Defect/Errors	SS
Dresden 3	BWR	4/9/1987	Condensate	1	Severed	87-010	Unknown	Failed inside condenser, unknown cause	CS
Brunswick 2	BWR	5/4/1987	Chlorine Supply Line	1	Leak	NPE VI.F.53 (BWR-2, Book 8)	Unknown		SS
Brunswick 2	BWR	5/6/1987	Chlorine Supply Line	1	Leak	NPE VI.F.53 (BWR-2, Book 8)	Corrosion	Buried line	SS
Nine Mile Point 2	BWR	7/11/1987	Component cooling	1	Rupture		Fatigue-Vibrational	Fatigue-Vibrational	CS
Hatch 2	BWR	8/19/1987	Service water	1	Failed		Fatigue-Vibrational	Fatigue-Vibrational	CS
Turkey Point 3	PWR	1/24/1988	pressurizer	1	leak	92-014	construction defect/errors	construction defect/errors	SS
Peach Bottom 2	BWR	4/6/1988	service water	1	leak	92-006	fatigue - vibrational	fatigue - vibration	CS
Byron 1	PWR	11/5/1988	Accumulators	1	Crack/Leak	88-010	Fatigue-Vibrational	Fatigue-vibration	SS
Vogtle 2	PWR	12/26/1988	feedwater pump seal line	1	leak	NPRDS	weld defect	sch 80, defect in socket weld	CS
Turkey Point 3	PWR	1/14/1989	pressurizer	1	leak	93-002	construction defect/errors SCC?	construction defect/errors/SCC?	SS
Sequoyah 2	PWR	1/27/1989	moisture separator reheater	1	leak	PNO-II-93-003	erosion/corrosion	erosion/corrosion	SS
St. Lucie 2	PWR	3/1/1989	pressurizer	1	leak	93-004	unknown	cracked nozzles, unknown cause	SS
ANO1	PWR	5/17/1989	Sevice Water	1	Leak	PNO-IV-89-034	Unknown	Unknown Cause	CS
Palo Verde 2	PWR	7/4/1989	Feedwater	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Palo Verde 2	PWR	7/4/1989	Feedwater drain	1	Leak		Fatigue-Vibrational		CS
McGuire 6	PWR	9/5/1989	Containment heat removal	1	Leak		other	Procedure errors	CS
Diablo Canyon 1	PWR	10/20/1989	Thimble tube	1	Leak	89-010	Fatigue-Vibrational	Vibration, corrosion/fatigue	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Indian Point 2	PWR	10/24/1989	Reactor Coolant	1	Leak		Stress Corrosion/IGSCC	Stress Corrosion	SS
Clinton	BWR	11/22/1989	high pressure core injection	1	leak	89-041	unknown	unknown	SS
Hope Creek	BWR	12/31/1989	Instrument line	1	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
Turkey Point 4	PWR	3/9/1990	boric acid	1	leak	94-002	stress corrosion/IGSCC	stress corrosion	SS
Prairie Island 2	PWR	7/20/1990	fire protection	1	leak	94-002	unknown	sprinkler head failed, unknown cause	CS
Hope Creek	BWR	11/4/1990	Instrument line	1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Bryon 2	PWR	12/20/1990	Main Steam	1	Severed	90-010	Construction Defect/Error	Construction Defect/Error	CS
Three Mile Island 1	PWR	3/6/1991	containment heat removal	1	leak	95-001	construction defect/errors	construction defect/errors, compression fitting failure	CS
Palo Verde 3	PWR	4/11/1991	Service Water	1	Leak	95-001	construction defect/error	construction defect/error	CS
McGuire 1	PWR	6/16/1991	Component cooling	1	Leak		Construction Defects/Errors	Poor casting, construction defect	CS
Cook 2	PWR	2/4/1992	Feedwater reheater	1	leak	NPRDS	fatigue-vibrational	Sch 80, 70% power	CS
Fort Calhoun	PWR	12/3/1992	Main steam	1	Leak	92-031	Other	Lack of system control	CS
Cook 1	PWR	12/14/1992	Feedwater	1	leak	NPRDS	Fatigue-vibrational	Sch 80, 100% power	CS
Millstone 1	PWR	12/14/1992	Feedwater	1	Leak		Fatigue-Vibrational	Sch 80, full power	CS
McGuire 5	PWR	3/22/1993	Emergency core cooling	1	Leak		Construction Defect/Errors	Construction defects/errors	SS
McGuire 4	PWR	9/1/1993	Main steam	1	Leak		other	Pressure forces cap off nipple while pipe under repair	CS
Grand Gulf	BWR	11/2/1993	Coolant recirculation	1	Leak	93-014	Fatigue-Vibrational	Fatigue-vibrational (2 events)	SS
Calvert Cliffs 2	PWR	3/21/1994	Containment heat removal	1	Leak	94-003	Stress Corrosion/IGSCC	Stress Corrosion	CS
Diablo Canyon 1	PWR	3/28/1994	Coolant recirculation	1	Leak	94-001	Construction Defect/Errors	Construction defects/errors	SS
Dresden 2	BWR	3/30/1994	Coolant recirculation	1	Leak	94-009	Unknown	Unknow cause	SS
North Anna 1	PWR	6/1/1994	Containment heat removal	1	Leak		Unknown	Weld, seal failure	CS
Davis Besse	PWR	7/28/1994	Service Water	1	Leak	94-002	Construction Defect/Errors	Pump vent line failure, contruction defects/errors	CS
Ginna	PWR	8/8/1994	Coolant recirculation	1	Leak	94-009	Unknown	Socket weld failure	SS
Millstone 3	PWR	9/9/1994	Containment heat removal	1	Leak		Construction Defects/Errors	Construction defect/errors	CS
Palisades	PWR	8/15/1995	RCS	1	Leak		Not Given	Compression fitting failed	SS
Beaver Valley 1	PWR	8/18/1995	Reactor Coolant	1	Leak	95-006	Erosion/Corrosion	Weld leak at seal injection, erosion/corrosion	SS
Oconee 2	BWR		CI 3	1	Leak		Unknown		SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
ANO2	PWR	12/5/1980	Makeup System	1.25	Leak	80-090	Fatigue-Vibrational	Fatigue-vibration	SS
Monticello	BWR	4/13/1983	Feedwater	1.25	Leak		Erosion/Corrosion	Erosion/corrosion	CS
Monticello	BWR	6/14/1983	Feedwater	1.25	Leak		Erosion/Corrosion	Erosion/corrosion	CS
South Texas 1	PWR	6/21/1988	thermo well	1.25	leak	ACN:9206290087	not given	*four leaks cited see fiche* 62188 pp 354-5, report ST-HL-AE-3984	CS
Salem 2	PWR	9/8/1985	component cooling	1.375	leak	special report 89-3	fatigue-vibrational	cracked nipple, fatigue-vibration	CS
Humboldt Bay 3	BWR	6/15/1970	Instrument line	1.5	Leak		Stress Corrosion/IGSCC	IGSCC	SS
Humboldt Bay 3	BWR	7/17/1970	Instrument line	1.5	Leak		SCC	SCC	SS
Oconee 2	BWR	1/1/1974	Pump seal line	1.5	Leak		Unknown		SS
Dresden 3	BWR	6/11/1974	Main steam	1.5	Leak	Letter to NRC (6/11/74)	Unknown	Unknown cause	CS
Oconee 3	BWR	9/1/1974	Pump seal line	1.5	Leak		L-O-K		SS
Oconee 3	BWR	9/3/1974	Reactor coolant	1.5	Leak		Construction Defects/Errors	Construction Defects/Errors	SS
ANO1	PWR	10/1/1974	Cold Leg Drain	1.5	Leak	NPE V.B 8	Fatigue-Vibrational	Leak 1 out of 2 leaks	SS
ANO1	PWR	10/1/1974	Cold Leg Drain	1.5	Leak	NPE V.B 8	Fatigue-Vibrational	Leak 2 out of 2 leaks	SS
ANO1	PWR	10/17/1974	Reactor Coolant	1.5	Leak	AO 74-09	Unknown	Unknown Cause	SS
ANO1	PWR	10/25/1974	Sevice Water	1.5	Leak	AO 74-10A	Fatigue-Vibrational	Fatigue fracture	CS
ANO1	PWR	11/4/1974	Reactor Coolant Drain Line	1.5	Leak	AO 74-10	Fatigue-Vibrational	Second crack same weld	SS
Millstone 2	PWR	4/22/1976	Boric Acid	1.5	Leak		Stress Corrosion/IGSCC	Chloride stress corrosion	SS
Sequoyah 1	PWR	10/4/1976	pressurizer	1.5	leak	80-156	fatigue-vibrational	fatigue-vibrational	SS
Millstone 2	PWR	8/18/1977	SIS	1.5	Leak		Fatigue-Vibrational	Sch 40	SS
Millstone 2	PWR	11/1/1979	Boric Acid	1.5	Leak		Stress Corrosion Cracking	Cl SCC	SS
San Onofre 3	PWR	3/11/1981	instrument line	1.5	leak	85-003	unknown	leaked thermowell, unknown cause	SS
Millstone 2	PWR	6/17/1981	SIS	1.5	Leak		Fatigue-Vibrational		SS
Big Rock Point	BWR	10/14/1981	Service Water	1.5	Leak	81-025	Corrosion	Corrosion	CS
Millstone 2	PWR	6/17/1982	Safety Injection	1.5	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
ANO1	PWR	4/10/1985	Sevice Water	1.5	Leak	PNO-IV-85-015	Erosion/Corrosion	Erosion/Corrosion	CS
Salem 1	PWR	9/5/1986	service water	1.5	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Salem 1	PWR	9/5/1986	SWS	1.5	leak	LER 90-26	erosion/corrosion	sch 40	CS
Salem 1	PWR	1/23/1987	RHR pump cooler	1.5	leak	LER 91-002	not given	sch 40, stran crack of tee, 100% power	SS
Seabrook	PWR	5/7/1987	condenser	1.5	leak	NPRDS	erosion/corrosion	sch 80	CS
Seabrook	PWR	7/6/1987	main steam pump	1.5	leak	NPRDS	erosion/corrosion	sch 80	CS
Salem 1	PWR	11/14/1987	SWS bearing cooler	1.5	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Salem 2	PWR	3/22/1988	SWS	1.5	leak	NPRDS	erosion/corrosion	sch 40, 20 gpm, refueling	CS
Susquehanna 2	BWR	3/22/1988	SWS	1.5	leak	NPRDS	unknown		CS
Millstone 3	PWR	5/12/1988	SWS	1.5	Leak		Erosion/Corrosion	Sch 40, 5 gpm, Cu-Ni	CS
Millstone 3	PWR	10/25/1988	SIS	1.5	Leak		Erosion/Corrosion	Sch 40, Cu-Ni, cold shutdown	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
ANO1	PWR	1/20/1989	Sevice Water	1.5	Leak	PNO-IV-89-004	Construction Defect/Error	Weld construction defect	CS
Millstone 3	PWR	6/16/1989	SIS	1.5	Leak		Erosion/Corrosion	Sch 40, Cu-Ni	SS
Millstone 3	PWR	10/31/1989	SWS/SIS	1.5	Leak		Erosion/Corrosion	Sch 40, Cu-Ni	CS
Millstone 3	PWR	4/10/1990	SWS	1.5	Leak		Erosion/Corrosion	Sch 40, pinhole leak, Cu-Ni	CS
Millstone 3	PWR	5/1/1990	SWS	1.5	Leak		Erosion/Corrosion	Sch 40, Cu-Ni	CS
Brunswick 1	BWR	11/6/1990	Closed Cooling Water	1.5	Leak	NPRDS	Aging	Sch 80, leak at weld-o-let to 16 inch header	CS
Brunswick 1	BWR	11/20/1990	Closed Cooling Water	1.5	Leak	NPRDS	Unknown	Unknown	CS
Millstone 3	PWR	1/15/1991	SWS	1.5	Leak		Erosion/Corrosion	Sch 40, Cu-Ni, coast down	CS
Millstone 3	PWR	2/8/1991	SIS	1.5	Leak		Erosion/Corrosion	Sch 40, pinhole leak, Cu-Ni	SS
Millstone 2	PWR	4/22/1991	Steam	1.5	Leak		Erosion/Corrosion	Erosion/corrosion	CS
Vermont Yankee	BWR	11/1/1991	fire system SWS (CI-3)	1.5	leak	ACN:9512050064	microbiologically induced corrosion		CS
Indian Point 2	PWR	11/10/1991	Turbine line	1.5	Leak		Erosion/Corrosion	Sch 80, power reduction	CS
Vermont Yankee	BWR	11/30/1991	SWS	1.5	leak	class 3 relief request 12/1/95	microbiologically induced corrosion	small leak	CS
Vermont Yankee	BWR	12/31/1991	SWS	1.5	leak	ACN:9601230402	erosion/corrosion	questionable failure mechanism	CS
Millstone 3	PWR	6/17/1992	SWS/SIS	1.5	Leak		Erosion/Corrosion	Sch 40, pinhole leak, Cu-Ni, 100% power	CS
Millstone 3	PWR	8/14/1992	Lube oil cooler SWS-lube	1.5	Leak		Erosion/Corrosion		SS
Millstone 3	PWR	5/14/1993	SWS	1.5	Leak		Erosion/Corrosion		CS
Millstone 3	PWR	5/22/1993	SWS	1.5	Leak		Erosion/Corrosion		CS
Millstone 3	PWR	8/16/1994	SWS	1.5	Leak		Erosion/Corrosion		CS
Crystal River 3	PWR	1/1/1995	Emergency feedwater	1.5	Leak	CAN:9512140209	Erosion/Corrosion	Questionalbe failure mechanism	CS
Dresden 1	BWR	2/5/1976	Demineralizer	1.625	Leak	ORNL-NSIC-137:110935	Thermal Fatigue	Thermal fatigue	SS
Dresden 1	BWR	2/1/1971	Instrument air	2	Leak	Ltr DL 4/22/71	Stress Corrosion/IGSCC	IGSCC	SS
Surry 1	PWR	4/15/1971	chemical and volume control	2	leak	AO 75-011	fatigue-vibrational	fatigue-vibrational	SS
Surry 1	PWR	4/15/1971	circulation	2	leak	AO-S1-75-117	not given		CS
Surry 2	PWR	12/29/1971	main steam	2	leak	75-021	erosion/corrosion	erosion/corrosion	CS
Trojan	PWR	2/28/1973	reactor coolant	2	crack/leak	77-003L	fatigue-vibrational	fatigue-vibrational, SCC? 1/2	SS
Trojan	PWR	2/28/1973	reactor coolant	2	crack/leak	77-003L	fatigue-vibrational	fatigue-vibrational, SCC? 2/2	SS
Browns Ferry 1	BWR	5/10/1973	Service Water	2	Rupture	Ltr DL; 7/9/73	Water Hammer	Water Hammer	CS
Browns Ferry 1	BWR	5/23/1973	Residual Heat Removal	2	Rupture	Ltr DL; 7/9/73	Water Hammer	Water Hammer	SS
Quad Cities 2	BWR	3/4/1974	reactor coolant	2	leak	78-013	unknown	unknown cause	SS
ANO1	PWR	4/15/1974	Makeup System	2	Leak	Ltr DL 4/15/74	Fatigue-Vibrational	Fatigue-vibration	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oyster Creek	BWR	5/29/1974	Reactor coolant	2	Leak		Unknown	Unknown cause	SS
Dresden 2	BWR	7/31/1974	Feedwater	2	Crack/Leak	RO	Unknown	Cracked weld, unknown	CS
Browns Ferry 2	BWR	10/16/1974	Coolant Recirculation	2	Leak	AO 74-19W	Fatigue-Vibrational	Fatigue-vibrational	SS
Dresden 1	BWR	10/25/1974	Core Spray	2	Leak	Letter to NRC (11/25/74)	Erosion/Corrosion	Erosion and cavitation	SS
Vermont Yankee	BWR	1/9/1975	RWCU	2	leak	LER 79-001	unknown		SS
Cook 1	PWR	11/30/1975	RHR	2	leak	NPE VIII.B.102	fatigue-vibrational		SS
Trojan	PWR	12/7/1975	component cooling	2	leak	79-016	construction defect/errors	construction defect/errors	CS
Calvert Cliffs 1	PWR	12/12/1975	Main Steam	2	Leak	75-003L	Erosion/Corrosion	Erosion/Corrosion	CS
Humboldt Bay 3	BWR	3/16/1976	Reactor water cleanup	2	Leak		Unknown	Unknown cause	SS
Humboldt Bay 3	BWR	3/16/1976	Reactor water cleanup	2	Leak		Unknown	Unknown cause	SS
Salem 2	PWR	6/17/1976	chemical and volume control	2	rupture	80-001	fatigue-vibrational	fatigue-vibration	SS
Haddam Neck 1	PWR	7/20/1976	Flow sensor	2	Leak		other	Worn threaded fitting	SS
Fort Calhoun	PWR	10/1/1976	Reactor Coolant	2	Leak	76-0325	Fatigue-Vibrational	Fatigue-Vibrational	SS
Pilgrim	BWR	10/31/1976	reactor water cleanup	2	rupture	NPE; BWR-2; 72	fatigue-vibrational	socket weld failed, fatigue-vibration	SS
Cooper	BWR	11/4/1976	Reactor Coolant	2	Leak	RO 76-44	Construction Defect/Errors	Construction defect/error	SS
Pilgrim	BWR	11/12/1976	service water	2	leak	80-084	construction defect/errors	fabrication defect	CS
Ginna	PWR	12/16/1976	Reactor Water Cleanup	2	Leak	RO 76-027	Erosion/Corrosion	Erosion/Corrosion	SS
Indian Point 2	PWR	3/11/1977	Chemical and volume control	2	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Calvert Cliffs 2	PWR	4/27/1977	CVCS	2	leak	77-34-03L	fatigue-vibrational		SS
Maine Yankee 1	PWR	6/2/1977	Chemical and volume control	2	Failed		Erosion/Corrosion	Erosion/corrosion	SS
Davis Besse	PWR	9/24/1977	Main steam	2	Leak	RO NP-32-77-16	Unknown	Steam valve pulled away from pipe, unknown cause	CS
Monticello	BWR	10/10/1977	Residual heat removal	2	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 1	PWR	12/5/1977	service water	2	leak	81-119	corrosion	corrosion	CS
Three Mile Island 1	PWR	1/27/1978	feedwater	2	leak	82-002	stress corrosion/IGSCC	stress corrosion	CS
Calvert Cliffs 1	PWR	4/12/1978	Reactor Coolant	2	Leak	78-016	Fatigue-Vibrational	Fatigue-vibration	SS
Fort Calhoun	PWR	5/20/1978	Chemical and volume control	2	Leak	78-014	Fatigue-Vibrational	Fatigue-vibrational	SS
Dresden 2	BWR	8/7/1978	Reactor Coolant	2	Leak	78-046	Construction Defect/Errors	Construction defects/errors	SS
Monticello	BWR	11/21/1978	Main steam	2	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Surry 2	PWR	12/18/1978	coolant recirculation	2	leak	82-075	construction defect/errors	construction defects/errors	SS
Turkey Point 3	PWR	1/6/1979	chemical and volume control	2	leak	83-001	fatigue-vibrational	fatigue-vibrational	SS
Vermont Yankee	BWR	1/7/1979	feedwater	2	leak	83-002	unknown	unknown cause	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Haddam Neck 1	PWR	3/10/1979	Chemical and volume control	2	Crack/Leak		Thermal Fatigue	Thermal Fatigue, stress, corrosion, IGSCC	SS
Pilgrim	BWR	4/9/1979	fire protection	2	rupture	83-019	unknown	threaded connection failed	CS
ANO2	PWR	4/18/1979	Chemical and Volume Control	2	Leak	79-031	Fatigue-Vibrational	Fatigue-vibration	SS
Dresden 2	BWR	5/3/1979	Service Water	2	Leak	79-008	Erosion/Corrosion	Erosion/corrosion	CS
Quad Cities 1	BWR	5/19/1979	residual heat removal	2	leak	83-021	construction defect/errors	construction defects/errors	SS
Yankee Rowe	PWR	8/31/1979	main steam	2	leak	83-028	erosion/corrosion	steam erosion/corrosion	CS
Calvert Cliffs 1	PWR	9/1/1979	Salt Water	2	Leak	NPE VIII.B.273	Wrong Material		CS
St. Lucie 2	PWR	11/7/1979	chemical and volume control	2	leak	83-071	unknown	unknown	SS
Prairie Island 1	PWR	3/13/1980	boric acid line	2	leak	NPRDS	unknown	sch 40	SS
Indian Point 2	PWR	5/12/1980	Service water	2	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Peach Bottom 2	BWR	6/6/1980	instrument line	2	leak	84-010	stress corrosion/IGSCC	IGSCC	SS
Salem 2	PWR	7/4/1980	feedwater	2	leak	84-016	unknown	3 in. crack in pipe, unknown cause	CS
Millstone 2	PWR	7/29/1980	Safety Injection	2	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
LaSalle 1	BWR	9/20/1980	Radwaste	2	Leak		Corrosion	Corrosion	SS
Dresden 3	BWR	10/1/1980	RWCU equalizer	2	Leak	NPE VIII.A.70 (BWR-2, Book-2)	Unknown	IGSCC	SS
Big Rock Point	BWR	12/6/1980	Control Rod Drive	2	Leak	80-042	Erosion/Corrosion	Erosion/Corrosion	SS
Millstone 2	PWR	1/3/1981	Safety Injection	2	Leak		Fatigue-Vibrational		SS
Pilgrim	BWR	2/14/1981	service water	2	leak	85-004	construction defect/errors	construction defects/errors	CS
Ginna	PWR	3/23/1981	Boric Acid	2	Leak	81-006	Stress Corrosion/IGSCC	Stress corrosion	SS
Prairie Island 1	PWR	5/7/1981	instrument air	2	breakage	85-009	unknown	unknown	SS
Sequoyah 1	PWR	7/28/1981	containment heat removal	2	leak	85-031	fatigue-vibrational	fatigue-vibrational	CS
Indian Point 2	PWR	8/29/1981	SWS fan cooler elbow	2	Leak		Erosion/Corrosion	Sch 40 Cu-Ni, pinhole leak, cold shutdown	CS
Big Rock Point	BWR	9/6/1981	Coolant Recirculation	2	Leak	81-020	Corrosion	Corrosion	SS
Oconee 2	BWR	11/24/1981	Fire protection	2	Leak		other	Personnel error	CS
Millstone 2	PWR	4/1/1982	Service water	2	Leak		Erosion/Corrosion	Erosion/corrosion	CS
Big Rock Point	BWR	4/22/1982	Radwaste	2	Leak	82-014	Corrosion	Corrosion and excessive acid	SS
ANO2	PWR	6/3/1982	Pressurizer	2	Leak	PNO-IV-82	Unknown		SS
Indian Point 2	PWR	8/11/1982	Residual heat removal	2	Leak		Corrosion	Corrosion of flexible hose, 5 hoses corroded, sch 80	SS
Indian Point 2	PWR	9/2/1982	Cont. fan cooler	2	Leak		Corrosion	Leaked tube in fan cooler, corrosion, sch 80	CS
Ginna	PWR	10/11/1982	Boric Acid	2	Leak	82-027	Stress Corrosion/IGSCC	Stress corrosion	SS
Haddam Neck 1	PWR	10/15/1982	Coolant recirculation	2	Leak		Fatigue-Vibrational	Weld joint failure	SS
Dresden 2	BWR	12/26/1982	Reactor Water Cleanup	2	Leak	82-058	Stress Corrosion/IGSCC	Stress corrosion	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Dresden 3	BWR	1/5/1983	Reactor Water Cleanup	2	Leak	83-003	Stress Corrosion/IGSCC	IGSCC	SS
LaSalle 1	BWR	2/2/1983	Main steam	2	Leak		Construction Defect/Errors	Construction defect/errors	CS
LaSalle 1	BWR	2/5/1983	Main steam	2	Leak		Construction Defect/Errors	Construction defect/errors	CS
Fitzpatrick	BWR	6/7/1983	Control Rod Drive	2	Leak	83-023	Stress Corrosion/IGSCC	IGSCC	SS
Ginna	PWR	9/16/1983	Boric Acid	2	Leak	83-028	Construction Defect/Errors	Construction Defect/Errors	SS
Dresden 3	BWR	10/4/1983	Coolant recirculation	2	Leak	83-035	Construction Defect/Errors	Construction defect	SS
St. Lucie 1	PWR	10/7/1983	reactor coolant	2	leak	87-014	fatigue-vibrational	fatigue-vibrational	SS
Crystal River 3	PWR	10/26/1983	Coolant recirculation	2	Leak	83-048	Fatigue-Vibrational	Fatigue-vibration	SS
Dresden 3	BWR	11/15/1983	Reactor Water Cleanup	2	Leak	83-039	Stress Corrosion/IGSCC	Stress corrosion	SS
Prairie Island 2	PWR	1/14/1984	safety injection	2	leak	IN 91-05	stress corrosion/IGSCC	IGSCC	SS
Big Rock Point	BWR	5/30/1984	Sevice Water	2	Leak	84-003	Erosion/Corrosion	Erosion/corrosion	CS
Palisades	PWR	7/4/1984	Aux. feedwater recirc. line	2	Leak		Fatigue-Vibrational	Sch 80, socket weld	CS
McGuire 9	PWR	8/5/1984	Residual heat removal	2	Severed		Water hammer	Water hammer	SS
Salem 1	PWR	8/30/1984	SWS fan cooler	2	leak	NPRDS	erosion/corrosion	sch 40	CS
Turkey Point 4	PWR	1/4/1985	lube cooling	2	leak	NPRDS	corrosion	sch 46, galvanic corrosion, defueled	SS
McGuire 7	PWR	6/24/1985	Feedwater	2	Severed		Water hammer	Water hammer	CS
Salem 1	PWR	7/17/1985	condensate	2	leak	NPRDS	erosion/corrosion	sch 80	CS
Kewaunee	PWR	8/8/1985	Steam vent	2	Rupture		Erosion/Corrosion		CS
ANO2	PWR	8/13/1985	Condensate	2	Rupture	85-015, 016	Water Hammer	Water Hammer	CS
Crystal River 3	PWR	8/20/1985	Turbine drain line	2	Severed	85-015	Fatigue-Vibrational	Fatigue-vibration	CS
Calvert Cliffs 1	PWR	10/9/1985	Containment heat removal	2	Leak	85-043	Construction Defect/Error	Construction Defect/Error	CS
Salem 2	PWR	7/4/1986	service water	2	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Robinson 2	PWR	9/30/1986	safety injection	2	leak	IN 91-05	stress corrosion/IGSCC	IGSCC	SS
Salem 2	PWR	10/23/1986	service water	2	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Robinson 2	PWR	12/15/1986	RHR	2	leak	NPRDS	erosion/corrosion	sch 40, refueling	SS
Salem 2	PWR	1/9/1987	SWS room cooler	2	leak	LER 91-003	erosion/corrosion	sch 40, 100% power	CS
Salem 2	PWR	1/29/1987	SWS lube oil cooler	2	leak	LER 91-003	erosion/corrosion	sch 40, 100% power	CS
Hope Creek	BWR	2/11/1987	Coolant recirculation	2	Failed		Fatigue-Vibrational	Fatigue-Vibrational	SS
Robinson 2	PWR	3/10/1987	aux. Feedwater recirc	2	leak	NPRDS	construction defect	sch 80, slag in weld, 29% power	CS
Beaver Valley 2	PWR	6/10/1987	Component Cooling	2	Leak	Special Report	Corrosion	Corrosion from microorganism	CS
Turkey Point 3	PWR	10/2/1987	feedwater	2	leak	NPRDS	fatigue-vibrational	sch 46, startup mode	CS
Monticello	BWR	11/25/1987	Coolant recirculation	2	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Susquehanna 2	BWR	12/15/1987	high pressure core injection	2	leak	91-015 [2-92:307]	erosion/corrosion	erosion/corrosion	SS
Maine Yankee	PWR	2/23/1988	RHR refueling tank line	2	Leak		Water hammer	Sch 40, full power	SS
Indian Point 3	PWR	3/31/1988	Feedwater	2	Leak		Water hammer	Water hammer	CS
Sequoyah 1	PWR	6/1/1988	ERCW	2	leak	ACN:9208110083	erosion/corrosion		CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
McGuire 1	PWR	8/5/1988	Main steam bypass to condenser	2	Leak		Not Given	Sch 80, cracked coupling	CS
Sequoyah 1	PWR	11/22/1988	raw cooling water	2	leak	ACN:9304290090	microbiologically induced corrosion		CS
Surry 2	PWR	12/14/1988	containment heat removal	2	leak	92-008	construction defect/errors	fitting failure, construction defects/errors	CS
Indian Point 3	PWR	2/13/1989	SWS	2	Leak		Not Given		CS
Surry 1	PWR	5/12/1989	chillers	2	leak	LER-93-6	corrosion		CS
Pilgrim	BWR	9/21/1989	containment heat removal	2	leak	93-018	construction defect/errors	construction defects/errors	CS
Millstone 3	PWR	11/30/1989	D.G. SWS	2	Leak		Erosion/Corrosion	Sch 40, pinhole leak, Cu-Ni	CS
Millstone 3	PWR	12/2/1989	D.G. SWS	2	Leak		Erosion/Corrosion	Sch 40, Cu-Ni	CS
Indian Point 3	PWR	9/26/1990	SWS	2	Leak		Not Given		CS
Robinson 2	PWR	10/3/1990	CVCS (CI-3)	2	leak	CAN:9411250117	stress corrosion cracking		SS
Summer	PWR	12/4/1990	containment heat removal	2	leak	94-006	construction defect/errors	construction defect/errors	CS
Diablo Canyon 1	PWR	12/11/1990	CVCS	2	Leak	IR 50-312-90-3, IR 50-275-90-31	Fatigue-Vibrational	Leak 1 out of 4 leaks found between 12/11-19-90. Previous cracks/leaks found in socket welds on 9/16/89, 6/24/90, 10/30/90, 12/4/90.	SS
Diablo Canyon 1	PWR	12/11/1990	CVCS	2	Leak	IR 50-312-90-3, IR 50-275-90-31	Fatigue-Vibrational	Leak 2 out of 4 leaks found between 12/11-19-90. Previous cracks/leaks found in socket welds on 9/16/89, 6/24/90, 10/30/90, 12/4/90.	SS
Diablo Canyon 1	PWR	12/11/1990	CVCS	2	Leak	IR 50-312-90-3, IR 50-275-90-31	Fatigue-Vibrational	Leak 3 out of 4 leaks found between 12/11-19-90. Previous cracks/leaks found in socket welds on 9/16/89, 6/24/90, 10/30/90, 12/4/90.	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Diablo Canyon 1	PWR	12/11/1990	CVCS	2	Leak	IR 50-312-90-3, IR 50-275-90-31	Fatigue-Vibrational	Leak 4 out of 4 leaks found between 12/11-19-90. Previous cracks/leaks found in socket welds on 9/16/89, 6/24/90, 10/30/90, 12/4/90.	SS
ANO1	PWR	12/22/1990	Containment heat removal	2	Leak	90-021	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	CS
Duane Arnold	BWR	1/6/1991	Main steam	2	Rupture	91-001	Fatigue-Vibrational	Fatigue-vibration	CS
Sequoyah 1	PWR	2/22/1991	containment heat removal	2	leak	95-002	unknown	instrument line failure	CS
Brunswick 1	BWR	2/26/1991	Main Steam Isolation	2	Leak	NPRDS	Mechanical Damage	Sch 40, steam leak at flow orifice, 20% power	CS
McGuire 1	PWR	4/15/1991	Main steam drain	2	Leak		Erosion/Corrosion	Sch 80	CS
Indian Point 2	PWR	7/21/1991	Service water	2	Leak		Corrosion	Leak, 4 gpm, sch 40 mic	CS
Millstone 2	PWR	8/17/1991	SWS	2	Leak		Microbiologically induced corrosion	Sch 40, mode 3	CS
Catawba 1	PWR	6/22/1992	chemical and volume control	2	leak	92-006	thermal fatigue	thermal fatigue	SS
Diablo Canyon 1	PWR	6/22/1992	Chemical and volume control	2	Leak	92-009	Thermal Fatigue	Thermal fatigue	SS
Maine Yankee 1	PWR	7/22/1992	Moisture separator reheater	2	Rupture		Erosion/Corrosion	Erosion/corrosion	SS
Calvert Cliffs 1	PWR	8/13/1992	Steam Generator Blow Down	2	Leak	NPRDS	Erosion/Corrosion	Sch 80, pinhole leak, hot standby	CS
Millstone 3	PWR	6/15/1993	SWS	2	Leak		Erosion/Corrosion	Questionable failure mechanism	CS
Millstone 2	PWR	6/29/1993	D.G. SWS	2	Leak		IGSCC	Questionable failure mechanism	CS
Millstone 2	PWR	6/29/1993	SWS	2	Leak		Erosion/Corrosion	Sch 40, <1 gpm, 100% power	CS
Millstone 2	PWR	1/11/1994	SWS to pump bearings	2	Leak		Corrosion	Sch 40, 90% power	CS
Dresden 1	BWR	1/25/1994	Service Water	2	Rupture	94-001-01, PNO-III-94-036, IN 94-38	Erosion/Corrosion	Erosion, Pipe coating failue, Cathodic protection system upfgraded	CS
Millstone 2	PWR	2/8/1994	Cooling coil Cu-Ni	2	Leak		Erosion/Corrosion		SS
Millstone 2	PWR	5/16/1994	Boric Acid	2	Leak		Erosion/Corrosion	Erosion/corrosion	SS
Browns Ferry 2	BWR	2/9/1995	Containment heat removal	2	Leak	95-002	Unknown	Unknown	CS
Ginna	PWR	7/23/1996	Containment spray	2	Leak	96-009	fabrication defect	Weld defect	SS
Quad Cities 1	BWR	5/6/1980	SWS/RHR	2.5	leak	84-7	fatigue-vibrational	leak 1 of 2 leaks found in 2.5" line	CS
Quad Cities 1	BWR	5/6/1980	SWS/RHR	2.5	leak	84-7	fatigue-vibrational	leak 2 of 2 leaks found in 2.5" line	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Dresden 2	BWR	4/26/1981	Core Spray	2.5	Leak	81-020	Stress Corrosion/IGSCC	IGSCC	SS
Prairie Island 1	PWR	10/15/1981	containment heat removal	2.5	leak	85-016	fatigue-vibrational	fatigue-vibration	CS
Prairie Island 1	PWR	10/15/1981	fan cooler	2.5	leak	LER 85-016	fatigue-vibrational		CS
Crystal River 3	PWR	1/29/1982	Reactor Coolant	2.5	Leak	82-004, PNO II-82-013, IN 82-09	Construction Defect/Errors	Cracked weld, Construction defects/errors	SS
Crystal River 3	PWR	2/1/1982	Reactor Coolant	2.5	Leak	IN 82-09	Thermal Fatigue	Thermal fatigue	SS
Dresden 2	BWR	5/2/1982	Radwaste	2.5	Leak	82-014	Erosion/Corrosion	Crack due to corrosion	SS
Crystal River 3	PWR	5/21/1982	Makeup system	2.5	Leak	82-037	Fatigue-Vibrational	Fatigue-vibration	SS
Crystal River 3	PWR	5/31/1982	Makeup system	2.5	Leak	82-037	Fatigue-Vibrational	Fatigue-vibration	SS
Millstone 1	PWR	2/7/1985	ESW SWS	2.5	Leak		Erosion/Corrosion	Sch 40	SS
Indian Point 2	PWR	1/9/1986	Inst. Air cooler	2.5	Leak		Corrosion	Sch 40; pinhole leak, refueling	SS
Millstone 1	PWR	6/26/1992	ESW SWS	2.5	Leak		Erosion/Corrosion	Sch 40, pinhole leak, salt water, full power	SS
Hatch 1	BWR	4/9/1993	RPV inst nozzle	2.5	Leak		Not Given	No cause	SS
Cooper	BWR	4/1/1995	Fire Protection	2.5	Leak	95-009	Corrosion	Corrosion/lack of fusion	CS
Indian Point 3	PWR	6/19/1985	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	7/15/1985	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	2/11/1987	Fan cooler hose	2.86	Leak		Wear	Sch 40, normal op., leak 1 of 2	CS
Indian Point 3	PWR	2/11/1987	Fan cooler hose	2.86	Leak		Wear	Sch 40, normal op., leak 2 of 2	CS
Indian Point 3	PWR	8/4/1987	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	8/12/1987	Fan cooler	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	10/24/1988	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	2/14/1989	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	8/23/1989	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	9/21/1989	Fan cooler hose	2.86	Leak		Wear	Sch 40, normal op.	CS
Indian Point 3	PWR	7/20/1990	Fan cooler hose	2.86	Leak		Wear, Corrosion	Sch 40	CS
Indian Point 3	PWR	8/10/1990	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	12/12/1991	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Indian Point 3	PWR	3/21/1992	Fan cooler hose	2.86	Leak		Corrosion	Sch 40, full power	CS
Indian Point 3	PWR	9/8/1996	Fan cooler hose	2.86	Leak		Wear	Sch 40	CS
Vermont Yankee	BWR	5/2/1970	control rod drive	3	leak	DL No. 116	unknown	unknown cause	SS
Oyster Creek	BWR	12/6/1972	Service water	3	Failed		Erosion/Corrosion	Erosion/corrosion	CS
Dresden 2	BWR	4/27/1974	Reactor Water Cleanup	3	Crack/Leak	AO, NPE-XII-22	Corrosion	External corrosion	SS
Humboldt Bay 3	BWR	4/27/1974	Torus transfer	3	Leak		Corrosion		SS
San Onofre 1	PWR	10/22/1974	CVCS	3	leak	NPRDS	not given	leak 1 of 2 leaks	SS
San Onofre 1	PWR	10/22/1974	CVCS	3	leak	NPRDS	not given	leak 2 of 2 leaks	SS
Dresden 3	BWR	11/9/1974	Feedwater	3	Leak	AO 74-33	Erosion/Corrosion	Erosion, turbulent flow	CS
Point Beach 1	PWR	3/11/1975	containment heat removal	3	leak	79-02/01T	erosion/corrosion	erosion/corrosion	CS
Pilgrim	BWR	7/9/1975	control rod drive	3	leak	79-021	unknown	unknown	SS
Millstone 2	PWR	10/11/1979	Boric Acid	3	Leak		Stress Corrosion/IGSCC	Cl-stree corrosion	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Cooper	PWR	12/3/1979	Service Water	3	Leak	79-40	Fatigue-Vibrational	High velocity flow solids content, fatigue-vibration	CS
Vermont Yankee	BWR	10/21/1980	rinse line for radwaste	3	leak	ACN:8410300264	unknown		SS
Big Rock Point	BWR	3/15/1981	Radwaste	3	Leak	81-004	Corrosion	Corrosion	SS
North Anna 1	PWR	4/21/1981	Service water	3	Leak		Corrosion	Corrosion, Through wall leak is supply header to 2 charging pumps caused by sulfate reducing bacteria	CS
North Anna 1	PWR	5/27/1981	Service water	3	Leak		Corrosion	Corrosion (mic)	CS
North Anna 1	PWR	5/27/1981	Service water	3	Leak		Corrosion	Corrosion, Through wall leak is supply header to 2 charging pumps caused by sulfate reducing bacteria	CS
North Anna 1	PWR	8/27/1981	Service water	3	Leak		Corrosion	Corrosion (mic)	CS
North Anna 1	PWR	12/2/1981	Service water	3	Leak		Corrosion	Corrosion, aggressive water , bacterial	CS
Peach Bottom 2	BWR	6/17/1982	ESW	3	leak	LER 86-014	corrosion	pit corrosion	SS
Peach Bottom 2	BWR	6/17/1982	RHR	3	leak	86-014	corrosion	pitting, sch 40	SS
Browns Ferry 2	BWR	9/21/1982	Fire Protection	3	Leak	82-029	Erosion/Corrosion	Corrosion, pitting	CS
Browns Ferry 2	BWR	10/6/1982	Fire Protection	3	Leak	82-030	Erosion/Corrosion	Erosion/corrosion	CS
North Anna 1	PWR	12/3/1982	Service water	3	Leak		Corrosion	Corrosion (mic)	CS
Salem 1	PWR	3/2/1983	containment heat removal	3	leak	special report 87-1	erosion/corrosion	pitting corrosion	CS
Perry	BWR	4/2/1983	main steam	3	severed	87-027	erosion/corrosion	erosion/corrosion	CS
Diablo Canyon 1	PWR	4/29/1983	Component cooling	3	Leak	83-007	Construction Defect/Errors	Construction defects/errors	CS
Grand Gulf	BWR	4/30/1984	Residual heat removal	3	Crack/Leak	84-024, PNO-II-84-31	Design-Dynamic Load	Design-dynamic loads, support failure	SS
Indian Point 2	PWR	11/6/1985	SWS to air comp.	3	Leak		Erosion/Corrosion	Sch, hot shutdown	CS
Salem 2	PWR	10/23/1986	SWS hypochlorite header	3	leak	LER 90-026	erosion/corrosion	sch 40, 100% power	CS
Zion 2	PWR	5/27/1987	letdown line	3	leak	NPRDS	fatigue	sch 40, cold shutdown	SS
Surry 1	PWR	8/27/1987	component cooling	3	crack/leak	91-019 [10-91:283]	unknown	through wall crack, unknown cause	CS
Millstone 2	PWR	9/1/1988	SWS	3	Leak		Erosion/Corrosion	Sch 40	CS
Millstone 3	PWR	11/7/1988	SWS	3	Leak		Erosion/Corrosion	Sch 40, leak 1 of 2 leaks	CS
Millstone 3	PWR	11/7/1988	SWS	3	Leak		Erosion/Corrosion	Sch 40, leak 2 of 2 leaks	CS
Surry 1	PWR	12/28/1988	letdown	3	leak	inspection reports 50-280-91-37 & 50-281-91-37	erosion/corrosion	socket weld	SS
Millstone 3	PWR	5/31/1989	SIS	3	Leak		Erosion/Corrosion	Sch 40, several leaks, Cu-Ni, hydro	SS
Limerick 1	BWR	6/23/1989	HPCI/ESW	3	Leak		Microbiologically induced corrosion	Sch 40, 75% power	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Vermont Yankee	BWR	7/14/1989	SWS	3	leak	NPRDS	corrosion	sch 80	CS
Vermont Yankee	BWR	7/31/1989	SWS (Cl-3)	3	leak	ACN:9308260358	pitting	occurrence 1 of 2	CS
Fort Calhoun	PWR	3/20/1990	Extraction steam line	3	Leak	NPRDS	Erosion/Corrosion	Sch 40, large leak, shutdown	SS
Big Rock Point	BWR	7/1/1990	RWCU	3	Leak	LER 96-001	IGSCC	Pipe valve	SS
Big Rock Point	BWR	7/22/1990	Reactor Water Cleanup	3	Leak	90-003	Thermal Fatigue	Thermal fatigue	SS
Vermont Yankee	BWR	8/30/1990	SWS (Cl-3)	3	leak	ACN:9409220148	microbiologically induced corrosion		CS
Millstone 3	PWR	11/3/1990	SWS	3	Leak		Not Given		CS
Millstone 3	PWR	11/15/1990	SWS	3	Leak		Not Given		CS
Millstone 3	PWR	12/7/1990	SWS	3	Leak		Not Given		CS
Millstone 2	PWR	1/15/1991	SWS	3	Leak		Erosion/Corrosion	Sch 40	CS
Millstone 3	PWR	4/8/1991	Service water	3	Leak		Erosion/Corrosion	Erosion/corrosion	CS
San Onofre 3	PWR	6/18/1991	boric acid makeup	3	leak	ACN:9601300226	IGSCC		SS
North Anna 1	PWR	9/5/1991	Service water	3	Leak		Corrosion	Corrosion (mic)	CS
Limerick 2	BWR	10/30/1991	SEW	3	Leak		Microbiologically induced corrosion	Sch 40 full power	CS
Browns Ferry 3	BWR	11/4/1991	Fire Protection	3	Leak	91-4	Unknown		CS
Millstone 2	PWR	11/15/1991	Header to pier 1	3	Leak		IGSCC	Questionable failure mechanism	CS
Millstone 2	PWR	11/15/1991	SWS	3	Leak		Microbiologically induced corrosion	Sch 40	CS
Indian Point 3	PWR	4/2/1992	Instrument air cooler	3	Leak		Corrosion	Sch 80, pinhole leaks, full power	SS
Fort Calhoun	PWR	8/4/1992	CVCS elbow	3	Leak	NPRDS	fabrication defect	Sch 80, lack of penetration, shutdown	SS
North Anna 1	PWR	8/26/1992	Main steam	3	Leak		Erosion/Corrosion		CS
Comanche Peak 2	PWR	12/18/1992	Main Steam	3	leak	CP-92-018	Construction defect/errors	Porosity in intial casting, construction defect	CS
Millstone 3	PWR	2/23/1993	SWS to SIS	3	Leak		Erosion/Corrosion	Sch 40, pinhole leak, 100% power	CS
Millstone 3	PWR	5/24/1993	SWS	3	Leak		Erosion/Corrosion		CS
Cooper	BWR	6/6/1993	Service Water	3	Leak	ACN:9308250	Unknown	Event dates: 6/6-7-17/93	CS
Catawba 1	PWR	6/16/1993	Containment vent	3	leak	NPRDS	Corrosion	Sch 40, at power	CS
Palisades	PWR	9/19/1993	Service water	3	Leak		Stress Corrosion/IGSCC	Stress corrosion in heat affected zone of power-operated relief valve line	CS
Catawba 1	PWR	10/18/1993	Containment vent	3	leak	NPRDS	Corrosion	Sch 40, 100% Power	CS
Indian Point 2	PWR	6/20/1995	SWS	3	Leak		Unknown		CS
Big Rock Point	BWR	1/5/1996	RWCU	3	Leak	LER 96-001	IGSCC		SS
Big Rock Point	BWR	1/15/1996	RWCU	3	Leak	LER 96-001	Not Given	Steam leak 1 out of 2 in SS pipe found during refueling outage	SS
Big Rock Point	BWR	1/15/1996	RWCU	3	Leak	LER 96-001	Not Given	Steam leak 2 out of 2 in SS pipe found during refueling outage	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Quad Cities 2	BWR	12/31/1965	RWCU	4	leak	NPE VII.A.63 (BWR-2, Book-2)	IGSCC	leak 3 of 3 leaks, questionable failure mechanism	SS
Dresden 1	BWR	2/1/1966	Reactor Water Cleanup	4	Leak	NUREG/75-067	Stress Corrosion/IGSCC	IGSCC	SS
Oyster Creek	BWR	10/1/1967	Control rod drive	4	Leak		Stress Corrosion/IGSCC	IGSCC prior to operation	SS
Zion 2	PWR	7/17/1968	reactor coolant	4	leak	ORNL-NSIC-109:73235	construction defect/errors	construction defect	SS
Surry 1	PWR	8/6/1968	condensate	4	severed	NISC-109; 72747	unknown	73425; vent pipe; valve pulled out	CS
Quad Cities 2	BWR	6/9/1970	feedwater	4	rupture	NSIC-122;09044;Power reactor-Aug.Sept.75; AO 74-14	unknown	valve body failed; 4000-7000 gal; low flow feedwater valve	CS
Quad Cities 2	BWR	9/15/1970	coolant recirculation	4	crack/leak	AO 74-25	stress corrosion/IGSCC		SS
Dresden 1	BWR	11/1/1970	Coolant recirculation	4	Leak	Ltr DL 4/22/71	Stress Corrosion/IGSCC	IGSCC	SS
Quad Cities 2	BWR	11/9/1970	FW bypass	4	rupture	not given	not given		CS
Dresden 1	BWR	12/17/1970	Circulation pump nipple with blind flange	4	Leak	Letter DL	IGSCC	Questionable failure mechanism: crack at flange had IGSCC?	SS
Quad Cities 2	BWR	12/22/1970	core spray	4	leak	NUREG/75-067	stress corrosion/IGSCC	IGSCC	SS
Quad Cities 1	BWR	1/9/1971	coolant recirculation	4	leak	NUREG/75-067, AO 75-3	stress corrosion/IGSCC	IGSCC, 3 cracks	SS
Dresden 1	BWR	2/3/1971	Demineralizer	4	Leak	Letter to NRC (3/5/71)	Stress Corrosion/IGSCC	IGSCC	SS
Haddam Neck 1	PWR	7/1/1971	Service water	4	Rupture		Construction Defect/Errors	Poor welds, construction defect	CS
Quad Cities 2	BWR	7/19/1971	feedwater	4	crack/leak	AO 75-24	stress corrosion/IGSCC	stress corrosion	CS
Quad Cities 2	BWR	10/6/1971	feedwater	4	crack/leak	AO 75-37	unknown	unknown	CS
Millstone 1	PWR	1/1/1972	Main steam	4	Failed		Water hammer	Water hammer	CS
Quad Cities 1	BWR	1/7/1972	coolant recirculation	4	leak	RO 76-04	stress corrosion/IGSCC	IGSCC	SS
LaCrosse	BWR	1/20/1972	Main steam	4	Rupture		Construction Defect/Errors	Failed threaded fitting, 7 failures	CS
Salem 1	PWR	3/30/1972	chemical and volume control	4	failed	ORNL-NSIC-138:112159	fatigue-vibrational	fatigue-vibration	SS
Pilgrim	BWR	9/4/1972	reactor water cleanup	4	leak	76-021	stress corrosion/IGSCC	IGSCC	SS
Indian Point 1	PWR	12/29/1972	Desuperheater	4	Rupture		Unknown	Unknown cause	SS
Trojan	PWR	9/22/1973	chemical and volume control	4	leak	77-038	fatigue-vibrational	fatigue-vibrational	SS
Millstone 1	PWR	12/12/1973	Main steam	4	Rupture		Unknown	Water hammer	CS
Quad Cities 2	BWR	2/28/1974	reactor head vent	4	leak	NPE VII.C.132 (BWR-2, Book-2)	IGSCC		SS
Quad Cities 2	BWR	3/4/1974	service water	4	leak	78-017	corrosion/corrosion	erosion/corrosion	CS
Robinson 2	PWR	3/4/1974	boric acid	4	leak	NUREG-0679	stress corrosion/IGSCC	stress corrosion	SS
Quad Cities 2	BWR	5/21/1974	reactor water cleanup	4	leak	78-023	stress corrosion/IGSCC	IGSCC	SS
Quad Cities 1	BWR	5/25/1974	reactor water cleanup	4	leak	No LER	erosion/corrosion	erosion/corrosion	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
ANO1	PWR	6/26/1974	Residual Heat Removal	4	Leak	AO 74-02, NUREG-0691	Construction Defect/Error	Construction defects/errors, SCC	SS
Dresden 2	BWR	9/13/1974	Coolant recirculation	4	Leak	NUREG/75-067, AO 74-M26	Stress Corrosion/IGSCC	IGSCC	SS
Dresden 2	BWR	9/15/1974	Coolant recirculation	4	Leak	NUREG/75-067	Stress Corrosion/IGSCC	IGSCC	SS
Millstone 1	PWR	9/16/1974	Coolant recirculation	4	Leak		Fatigue-Vibrational	IGSCC	SS
Dresden 1	BWR	11/2/1974	Reactor Water Cleanup	4	Leak	AO 74-16	Corrosion	Corrosion	SS
Dresden 2	BWR	12/13/1974	Coolant recirculation	4	Crack/Leak	AO 74-77	Stress Corrosion/IGSCC	IGSCC	SS
Quad Cities 2	BWR	12/31/1974	RWCU	4	leak	NPE VII.A.63 (BWR-2, Book-2)	thermal fatigue	leak 1 of 3 leaks, questionable failure mechanism	SS
Quad Cities 2	BWR	12/31/1974	RWCU	4	leak	NPE VII.A.63 (BWR-2, Book-2)	unknown	leak 2 of 3 leaks	SS
Salem 1	PWR	12/31/1974	charging	4	failed	NPE VIII.A.393	fatigue-vibrational		SS
Big Rock Point	BWR	2/24/1975	Condensate	4	Leak	AO 75-7	Construction Defect/Error	Construction defect	CS
Turkey Point 4	PWR	3/14/1975	chemical and volume control	4	leak	79-003/3L	fatigue-vibrational	fatigue-vibrational	SS
Quad Cities 2	BWR	4/4/1975	reactor water cleanup	4	leak	79-007	erosion/corrosion	erosion/corrosion	SS
Ginna	PWR	4/22/1975	Control Rod Drive	4	Leak	AO 75-09	Construction Defect/Errors	Installation error	SS
Quad Cities 2	BWR	4/26/1975	reactor water cleanup	4	leak	no LER	erosion/corrosion	erosion/corrosion	SS
ANO1	PWR	6/24/1976	Feedwater	4	Leak	RO 76-13	Corrosion	Galvanic Corrosion, schedule 40	CS
Millstone 2	PWR	10/14/1976	Chemical and volume control	4	Leak		Design-Dynamic Load	Crack, poor design	SS
Vermont Yankee	BWR	10/26/1976	reactor water cleanup	4	leak	80-037	stress corrosion/IGSCC	IGSCC in 5 of 13 welds	SS
Millstone 1	PWR	11/21/1976	Core spray	4	Leak		stress Corrosion/IGCSS	Cracked pipe reducer, IGSCC	SS
Brunswick 2	BWR	12/1/1976	RHR at cleanout	4	Leak	NPE VII.D.111 (BWR-2, Book 2)	Thermal Fatigue	Questionable failure mechanism	SS
Vermont Yankee	BWR	12/28/1976	cleanup	4	leak	PNO-I-80-181	not given	leak 1 out of 2 leaks	SS
Vermont Yankee	BWR	12/28/1976	cleanup	4	leak	PNO-I-80-181	not given	leak 2 out of 2 leaks	SS
Vermont Yankee	BWR	12/28/1976	reactor water cleanup	4	leak	80-041	stress corrosion/IGSCC	IGSCC	SS
Duane Arnold	BWR	3/22/1977	Recirc bypass	4	Leak	77-22	IGSCC		SS
Hatch 1	BWR	4/12/1977	Recirculation	4	Leak		Not Given	Indications of leak	SS
Haddam Neck 1	PWR	4/13/1977	Boric Acid	4	Crack/Leak		Stress Corrosion/IGSCC	Stress Corrosion	SS
Brunswick 2	BWR	8/25/1977	RHR Suction	4	Leak	2-77-49	Unknown	4-in weld o-let	SS
Salem 1	PWR	9/21/1977	service water	4	leak	81-090	construction defect/errors	cracks in dissimilar weld between valve and pipe, construction defect	CS
Duane Arnold	BWR	3/25/1978	Reactor Water Cleanup	4	Leak	78-017	Stress Corrosion/IGSCC		SS
Palisades	PWR	6/4/1978	Chemical and volume control	4	Leak		Fatigue-Vibrational	Fatigue-vibrational	SS
Dresden 1	BWR	10/7/1978	Main steam bypass	4	Leak	78-031	Erosion/Corrosion	Erosion/corrosion	CS
Fitzpatrick	BWR	3/20/1979	Condensate	4	Leak	79-018	Thermal Fatigue	Thermal fatigue	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Dresden 2	BWR	3/22/1979	Feedwater	4	Crack/Leak	79-019	Corrosion	Corrosion	CS
Duane Arnold	BWR	3/26/1979	Reactor Water Cleanup	4	Leak	79-008	Stress Corrosion/IGSCC	Stress corrosion	SS
Millstone 2	PWR	8/8/1979	Aux. feedwater turbine line	4	Leak		Fatigue-Vibrational	Sch 40	CS
Monticello	BWR	8/8/1979	Steam	4	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Millstone 2	PWR	11/13/1979	Chemical and volume control	4	Leak		Stress Corrosion/IGSCC	Cracks due to chloride containment	SS
Salem 1	PWR	12/24/1979	fire protection	4	rupture	83-066	other	water froze in elbow, burst line	CS
Salem 1	PWR	12/25/1979	fire protection	4	rupture	83-69	not given	frozen	CS
Cooper	BWR	1/16/1980	Main steam	4	Crack/Leak	80-005	Stress Corrosion/IGSCC	IGSCC	CS
ANO2	PWR	12/1/1980	Charging	4	Leak	NPE VIII.A.530	Fatigue-Vibrational		SS
St. Lucie 2	PWR	12/18/1980	condensate	4	failed	84-016	fatigue-vibrational	fatigue-vibrational, 2 events, sch 40	CS
St. Lucie 2	PWR	12/18/1980	condensate	4	leak	LER 84-016	fatigue-vibrational	sch 40, 2 events	CS
Monticello	BWR	6/17/1981	Reactor water cleanup	4	Leak		Construction Defects/Errors	Construction Defects/Errors	SS
McGuire 1	PWR	8/25/1981	Feedwater	4	Rupture		other	Pump suction failure, over pressurization	CS
Hatch 1	BWR	12/15/1981	Fire Protection	4	Rupture		Unknown	Rupture	CS
North Anna 1	PWR	2/5/1982	Service water	4	Leak		Corrosion	Corrosion, aggressive water , bacterial	CS
Pilgrim	BWR	3/6/1982	feedwater	4	leak	86-005	other	pressure surge	CS
ANO2	PWR	4/1/1982	Steam Generator Blow Down	4	Leak	NPE V.D 367	Erosion/Corrosion		CS
ANO2	PWR	4/15/1982	Steam Generator Blow Down	4	Leak	82-011	Erosion/Corrosion	Erosion/Corrosion	CS
Browns Ferry 1	BWR	12/8/1982	Coolant Recirculation	4	Leak	82-100	Unknown	Failed thread sealant	SS
North Anna 1	PWR	1/13/1983	Service water	4	Leak		Corrosion	Corrosion	CS
North Anna 2	PWR	1/13/1983	Service water	4	Leak		Corrosion	Bacterial induced corrosion	CS
North Anna 2	PWR	2/1/1983	Service water	4	Leak		Corrosion	Bacterial induced corrosion	CS
Indian Point 2	PWR	10/17/1983	Service water	4	Leak		Corrosion	Corrosion	CS
Brunswick 2	BWR	11/2/1983	Fire Protection	4	Leak	RO 2-83-95	Construction Defect/Error	Leaked seal, lack of additional barrier material	CS
North Anna 1	PWR	12/1/1983	Service water	4	Leak		Corrosion	Corrosion	CS
Nine Mile Point 1	BWR	3/27/1984	Control rod drive	4	Leak		Stress Corrosion/IGSCC	IGSCC	SS
St. Lucie 2	PWR	4/27/1984	intake cooling water	4	leak	NPRDS	corrosion	sch 40, salt water corrosion	SS
Salem 2	PWR	7/27/1984	SWS chiller	4	leak	NPRDS	erosion/corrosion	erosion/corrosion	CS
Salem 2	PWR	8/21/1985	SWS condenser	4	leak	NPRDS	erosion/corrosion	sch 40, 50% power	CS
Surry 1	PWR	3/22/1986	moisture separator reheater	4	failed	90-003	erosion/corrosion	erosion/corrosion	SS
Salem 1	PWR	5/23/1986	lube oil cooler	4	leak	NPRDS	erosion/corrosion	sch 40	SS
Browns Ferry 2	BWR	7/22/1986	ESW	4	Leak	NPRDS	Not Given		CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 2	PWR	7/22/1986	service water	4	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Browns Ferry 2	BWR	7/31/1986	Emergency Power	4	Leak	NPRDS	Not Given		CS
Salem 1	PWR	12/5/1986	SWS	4	leak	LER 90-026	erosion/corrosion	sch 40, 100% power	CS
Salem 1	PWR	12/6/1986	service water	4	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Oyster Creek	BWR	1/26/1987	Condensate	4	Leak		Unknown	Unknown cause	CS
Salem 2	PWR	2/24/1987	service water	4	leak	91-003	erosion/corrosion		CS
Cook 1	PWR	2/28/1987	Feedwater	4	leak	NPRDS	Erosion/corrosion	Sch 80, multiple smal leaks, operations	CS
Cook 1	PWR	2/28/1987	Feedwater	4	leak	NPRDS	Erosion/corrosion	Sch 80, multiple smal leaks, operations	CS
Cook 1	PWR	2/28/1987	Feedwater	4	leak	NPRDS	Erosion/corrosion	Sch 80, multiple smal leaks, operations	CS
Cook 1	PWR	2/28/1987	Feedwater	4	leak	NPRDS	Erosion/corrosion	Sch 80, multiple smal leaks, operations	CS
Salem 1	PWR	9/17/1987	oil cooler line	4	leak	NPRDS	erosion/corrosion	sch 40	SS
Salem 2	PWR	9/18/1987	SWS chiller no. 21	4	leak	NPRDS	erosion/corrosion	sch 40, several small leaks, 100% power	CS
Salem 2	PWR	9/18/1987	SWS chiller no. 22	4	leak	NPRDS	erosion/corrosion	sch 40, several small leaks, 100% power	CS
Diablo Canyon 2	PWR	10/9/1987	Coolant recirculation	4	Leak	87-023	Stress Corrosion/IGSCC	Stress corrosion	SS
St. Lucie 1	PWR	10/16/1987	containment spray	4	leak	NPRDS	unknown	sch 40, standby	SS
Salem 1	PWR	11/14/1987	SWS	4	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Pilgrim	BWR	12/23/1987	RWCU	4	leak	CAN:9201060175	fatigue		SS
Brunswick 2	BWR	1/2/1988	Main Steam	4	Leak	88-001	Construction Defect/Error	Many leaks, pipe seating material installed, construction defect	CS
Susquehanna 2	BWR	1/5/1988	SWS	4	leak	NPRDS	IGSCC		CS
Salem 2	PWR	1/15/1988	SWS chiller	4	leak	NPRDS	erosion/corrosion	sch 40, refueling	CS
Salem 2	PWR	1/15/1988	SWS condenser	4	leak	NPRDS	erosion/corrosion	sch 40, refueling	CS
Salem 2	PWR	2/2/1988	SWS chiller condenser	4	leak	NPRDS	erosion/corrosion	sch 40, refueling	CS
Salem 2	PWR	6/22/1988	SWS condenser elbow	4	leak	NPRDS	erosion/corrosion	sch 40, offline	CS
Salem 2	PWR	6/25/1988	SWS chiller condenser	4	leak	NPRDS	erosion/corrosion	sch 40, offline	CS
Salem 2	PWR	7/4/1988	SWS chiller condenser	4	leak	NPRDS	erosion/corrosion	sch 40, offline, leak 1 of 2 leaks	CS
Salem 2	PWR	7/4/1988	SWS chiller condenser	4	leak	NPRDS	erosion/corrosion	sch 40, offline, leak 2 of 2 leaks	CS
Susquehanna 2	BWR	7/4/1988	SWS	4	leak	NPRDS	stress corrosion cracking		CS
Salem 2	PWR	7/6/1988	SWS condenser	4	leak	NPRDS	erosion/corrosion	sch 40, offline	CS
Susquehanna 2	BWR	7/6/1988	SWS	4	leak	NPRDS	IGSCC		CS
Beaver Valley 1	PWR	11/25/1988	Containment heat removal	4	Leak	88-016	Unknown	Weld crack, unknown cause	CS
Vermont Yankee	BWR	7/31/1989	SWS (CI-3)	4	leak	ACN:9308250210	erosion/corrosion	occurrence 2 of 2	CS
River Bend	BWR	10/9/1990	control rod drive	4	leak	94-027	stress corrosion/IGSCC	stress corrosion	SS
Vermont Yankee	BWR	11/29/1990	service water	4	leak	94-016	corrosion	mic	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Vermont Yankee	BWR	11/29/1990	SWS (Cl-3)	4	leak	94-016	microbiologically induced corrosion		CS
Peach Bottom 3	BWR	11/8/1991	RWCU	4	leak	LER?	IGSCC	leak elbow to pipe	SS
Vogtle 1	PWR	2/19/1992	nuclear service cooling water pump discharge line	4	leak	LER 96-001	fatigue	location 6 our of 6 with cracks	CS
North Anna 1	PWR	3/10/1992	Fire Protection	4	Leak		Unknown	Unknown cause	CS
Davis Besse	PWR	6/26/1992	Decay heat, SWS	4	Leak	CAN:9207300129	Microbiologically Induced Corrosion	Four prior leaks in same pipe since 6/90	CS
Millstone 2	PWR	7/6/1992	Water to D.G.	4	Leak		Erosion/Corrosion	Sch 46, pinhole leak, outage	CS
Browns Ferry 1	BWR	12/11/1992	Coolant Recirculation	4	Leak	92-005	Construction Defect/Error	Construction/Defect errors	SS
Palisades	PWR	6/10/1993	CCW HX	4	Leak		Erosion/Corrosion	Pinhole leak 1 of 2 pinhole leaks	CS
Limerick 1	BWR	8/6/1993	Main steam drain line	4	Leak		Erosion/Corrosion	Sch 80, full power	CS
Palisades	PWR	9/17/1993	Pressurizer	4	Leak		Stress Corrosion/IGSCC	PWSCC	SS
Catawba 1	PWR	5/11/1995	SWS (Cl-3)	4	leak	ACN: 9505230147	microbiologically induced corrosion		CS
Dresden 1	BWR	1/1/1964	Condensate	6	Rupture	AECL-MISC-204	Fatigue-Vibrational	Pump seizure, split pipe, vibration	CS
Dresden 1	BWR	12/1/1965	Coolant recirculation	6	Leak	NUREG/75-067	Stress Corrosion/IGSCC	IGSCC	SS
Dresden 1	BWR	4/1/1966	Demineralizer	6	Leak	NUREG/75-067, RO 68-3	Stress Corrosion/IGSCC	IGSCC	SS
Dresden 1	BWR	3/1/1967	Discharge line condensate to river	6	Leak	XII.12 (NPE, BWR-2, Book-3)	Corrosion	Leak 1 of 2 leaks	CS
Dresden 1	BWR	3/1/1967	Discharge line condensate to river	6	Leak	XII.12 (NPE, BWR-2, Book-3)	Corrosion	Leak 2 of 2 leaks	CS
Dresden 1	BWR	7/1/1969	Radwaste	6	Leak	NSIC-87;40488	Erosion/Corrosion	Electrolytic corrosion	SS
San Onofre 1	PWR	1/16/1973	containment spray	6	leak	77-002	stress corrosion/IGSCC	IGSCC	SS
San Onofre 1	PWR	2/14/1973	containment heat removal	6	leak	RO 77-04	stress corrosion/IGSCC	stress corrosion	CS
Dresden 2	BWR	8/23/1974	Reactor coolant	6	Leak	AO 50-237/74-41	Erosion/Corrosion	Erosion of pump minimum flow line	SS
Dresden 2	BWR	9/12/1974	Reactor coolant	6	Leak	AO 50-237/74-46	Erosion/Corrosion	Erosion of pump minimum flow line	SS
San Onofre 1	PWR	10/22/1974	coolant recirculation	6	leak	78-012	stress corrosion/IGSCC	stress corrosion	SS
Dresden 3	BWR	12/1/1974	Feedwater	6	Leak	AO 74-36	Erosion/Corrosion	Erosion	CS
Dresden 3	BWR	12/1/1974	Service Water	6	Leak	AO 74-37	Erosion/Corrosion	Erosion of minimum flow line	CS
Peach Bottom 2	BWR	7/2/1975	reactor water cleanup	6	leak	no LER	erosion/corrosion	erosion/corrosion	SS
Millstone 2	PWR	8/29/1975	Service water	6	Leak		Corrosion	Corrosion	CS
Dresden 1	BWR	9/1/1975	Demineralizer	6	Crack/Leak	AO 75-12	Thermal Fatigue	Thermal fatigue	SS
ANO1	PWR	11/1/1975	Boric Acid	6	Leak	AO 75-08	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
ANO1	PWR	11/24/1975	Boric Acid	6	Leak	AO 75-07	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS
Nine Mile Point 1	BWR	3/19/1976	Reactor water cleanup	6	Leak		Stress Corrosion/IGSCC	IGSCC	SS
Nine Mile Point 1	BWR	3/22/1976	Reactor water cleanup	6	Leak		Stress Corrosion/IGSCC	IGSCC	SS
Indian Point 3	PWR	9/19/1976	Boric Acid	6	Leak		Corrosion	Corrosion at outlet nozzle	SS
Haddam Neck 1	PWR	12/14/1976	Service water	6	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Dresden 3	BWR	6/7/1977	Feedwater	6	Leak	LER?	Erosion/Corrosion	Sch 120, pinhole leak, shutdown	CS
Browns Ferry 3	BWR	11/1/1977	High Pressure Core Injection	6	Leak	NPE VII	Unknown	Failed at welded joint. 80000gallon leak.	SS
Salem 1	PWR	12/31/1977	SWS	6	leak	NPE VII.B.458	corrosion		CS
Trojan	PWR	1/10/1978	main steam	6	failed	AEOD/E4 16	erosion/corrosion	erosion/corrosion	CS
Quad Cities 2	BWR	1/14/1978	reactor water cleanup	6	leak	82-001	stress corrosion/IGSCC		SS
North Anna 1	PWR	1/15/1978	Reactor coolant	6	Leak		Construction Defects/Errors	Construction defect	SS
Dresden 3	BWR	3/6/1978	Feedwater	6	Leak	78-005	Erosion/Corrosion	Erosion/Corrosion	CS
Haddam Neck 1	PWR	3/17/1978	Service water	6	Leak		Thermal Fatigue	Thermal Fatigue	CS
Hatch 1	BWR	3/29/1978	Reactor water cleanup	6	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
Browns Ferry 3	BWR	4/1/1978	High Pressure Core Injection	6	Failed	NPE VII	Fatigue-Vibrational	Fatigue-vibrational	SS
Hatch 1	BWR	5/10/1978	Reactor water cleanup	6	Leak		Unknown	Unknown cause	SS
Calvert Cliffs 2	PWR	6/25/1978	chemical and volume control	6	leak	78-18/03L	Fatigue-vibrational	fatigue-vibrational	SS
Dresden 3	BWR	7/24/1978	Feedwater	6	Leak	78-030	Erosion/Corrosion	Erosion/Corrosion	CS
Calvert Cliffs 2	PWR	8/2/1978	chemical and volume control	6	leak	78-024/03L	Fatigue-vibrational	fatigue-vibrational	SS
Dresden 3	BWR	9/18/1978	Feedwater	6	Leak	78-037	Water Hammer	High flow velocity, Water hammer	CS
Dresden 2	BWR	3/26/1979	Reactor coolant	6	Leak	79-016	Construction Defect/Errors	Construction defects/errors	SS
San Onofre 2	PWR	4/13/1979	feedwater	6	leak	83-035	erosion/corrosion	miniflow line for AFW pump. Erosion/corrosion	CS
Oyster Creek	BWR	1/1/1980	Condensate	6	Leak		Not Given		CS
San Onofre 2	PWR	6/15/1980	fire protection	6	severed	84-033 R1	other	overpressurized	CS
Hatch 1	BWR	7/6/1980	Reactor water cleanup	6	Leak		Stress Corrosion/IGSCC	Stress Corrosion	SS
Robinson 2	PWR	11/18/1980	service water	6	leak	IN 85-30	corrosion	mic	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 1 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 2 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 3 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 4 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 5 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 6 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 7 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint8 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 9 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 10 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 11 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 12 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 13 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 14 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 15 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 16 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 17 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 18 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 19 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 20 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 21 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 22 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 23 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 24 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 25 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 26 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 27 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 28 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 29 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 30 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 31 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 32 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 33 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 34 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 35 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 36 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 37 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 38 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 39 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 40 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 41 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 42 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 43 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 44 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 45 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 46 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 47 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 48 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 49 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 50 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 51 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 52 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 53 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Robinson 2	PWR	12/31/1980	service water to containment chiller	6	leak	IN 85-30	microbiologically induced corrosion	weld joint 54 out of 54 weld joints leaked (32 inside, 22 outside containment)	CS
Dresden 2	BWR	8/30/1981	Service Water	6	Leak	81-055	Corrosion	Corrosive solutions	CS
Dresden 3	BWR	8/30/1981	Service Water	6	Leak	81-055	Erosion/Corrosion	Butt weld corroded, erosion/corrosion	CS
Dresden 3	BWR	9/1/1981	Reactor Water Cleanup	6	Leak	81-021	Stress Corrosion/IGSCC	Stress corrosion	SS
Ginna	PWR	1/13/1982	Containment heat removal	6	Leak	82-002	Stress Corrosion/IGSCC	Stress corrosion	CS
Cook 2	PWR	1/19/1982	Containment heat removal	6	leak	82-003	fatigue-vibrational	fatigue-vibrational	CS
Brunswick 2	BWR	5/25/1982	Reactor Water Cleanup	6	Leak	82-080, PNO-II-82-060	Construction Defect/Error	Construction defects/errors	SS
San Onofre 2	PWR	5/26/1982	CVCS	6	leak	NPRDS	not given		SS
Oconee 1	BWR	7/1/1982	Feedwater	6	Rupture		Erosion/Corrosion	Erosion/corrosion	CS
Surry 2	PWR	2/12/1983	service water	6	leak	PNO-II-87-011A	unknown	leaked fiberglass line, unknown cause	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oconee 2	BWR	3/19/1983	Moisture separator reheater	6	Rupture		Erosion/Corrosion	Erosion/Corrosion	SS
Cooper	BWR	6/29/1983	Reactor Water Cleanup	6	Leak	83-009	Stress Corrosion/IGSCC	IGSCC	SS
Cooper	BWR	7/10/1983	RWCU	6	Leak	LER 83-011	IGSCC	Leak 1 of 2 lekas	SS
Cooper	BWR	7/10/1983	RWCU	6	Leak	LER 83-011	IGSCC	Leak 2 of 2 leaks	SS
Cooper	BWR	4/19/1984	Fire Protection	6	Breakage	AEOD/E4/26	Water Hammer	Water Hammer	CS
Quad Cities 2	BWR	5/3/1984	reactor water cleanup	6	leak	88-008	stress corrosion/IGSCC	IGSCC	SS
Haddam Neck 1	PWR	3/16/1985	Feedwater	6	Rupture		Erosion/Corrosion	Erosion/Corrosion	CS
McGuire 8	PWR	5/29/1985	Fire Protection	6	Rupture		Unknown	Pile driver broke, unknown cause	CS
Duane Arnold	BWR	8/12/1985	Fire Protection	6	Leak	85-029	Water Hammer	Water Hammer	CS
Brunswick 2	BWR	8/13/1985	D.G. Outlet Pipe	6	Leak	NPRDS	Not Given	Sch 40, pinhole leak, 100% power, normal wear	CS
Salem 1	PWR	8/20/1985	D.G. cooling jacket	6	leak	NPRDS	erosion/corrosion	sch 40	CS
Dresden 2	BWR	9/29/1985	Condensate	6	Rupture	83-035	Unknown	Expansion joint	CS
Brunswick 2	BWR	11/13/1985	D.G. Jacket Cooler	6	Leak	NPRDS	Corrosion	Sch 40, 90% power, salt water corrosion	CS
San Onofre 2	PWR	7/1/1986	feedwater bypass line	6	leak	IN 91-18	erosion/corrosion		CS
Surry 1	PWR	7/26/1986	containment heat removal	6	leak	90-008	design-dynamic load	design-dynamic load	CS
Ginna	PWR	7/29/1986	Feedwater	6	Rupture	86-004	Erosion/Corrosion	Erosion/Corrosion	CS
Salem 1	PWR	9/19/1986	D.G. jacket SWS	6	leak	LER 90-026	erosion/corrosion	erosion/corrosion	CS
Salem 1	PWR	10/2/1986	service water	6	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Salem 2	PWR	10/7/1986	service water	6	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Salem 2	PWR	10/7/1986	SWS D.G. jacket cooler	6	leak	LER 90-026	erosion/corrosion	sch 40, 85% power	CS
River Bend	BWR	10/12/1986	SWS drywell cooler	6	leak	NPRDS	erosion/corrosion	Sch 40, questionable failure mechanism, outage	CS
Salem 2	PWR	10/25/1986	SWS D.G. jacket cooler	6	leak	LER 90-026	erosion/corrosion	sch 40, 100% power	CS
Salem 2	PWR	10/25/1986	SWS D.G. oil cooler	6	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Oyster Creek	BWR	1/1/1987	Drains from drain tank to flash tank	6	Leak		Erosion/Corrosion	6 in 45 deg elbow with through wall leak temporarily repaired with clamp	SS
Millstone 2	PWR	3/9/1987	SWS	6	Leak		Erosion/Corrosion	Sch 40	CS
Sequoyah 1	PWR	6/17/1987	fire protection	6	leak	special report 91-08	water hammer	underground pipe rupture, water hammer	CS
Salem 1	PWR	10/29/1987	D.G. jacket cooler	6	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Salem 1	PWR	11/10/1987	SWS	6	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Brunswick 2	BWR	11/19/1987	ESW SWS	6	Leak	NPRDS	Corrosion	Sch 40, pinhole leak, 89% power	CS
Farley 2	PWR	12/9/1987	Coolant recirculation	6	Leak	87-010	Thermal Fatigue	Thermal fatigue	SS
Salem 2	PWR	12/9/1987	SWS chiller condenser	6	leak	NPRDS	erosion/corrosion	sch 46, refueling	CS
Hope Creek	BWR	2/15/1988	ESWS SWS	6	Leak		Unknown	Sch 40, outage	SS
Salem 1	PWR	3/5/1988	D.G. cooler	6	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Byron 1	PWR	6/1/1988	Aux. Feedwater Line	6	Leak	NPRDS	Erosion/Corrosion	Sch 40, leak 1 of 2 leaks	CS
Byron 1	PWR	6/1/1988	Aux. Feedwater Line	6	Leak	NPRDS	Erosion/Corrosion	Sch 40, leak 2 of 2 leaks	CS
Robinson 2	PWR	6/26/1988	steam line header	6	leak	NPRDS	not given	sch 40, crack in welded cap, 68% power	CS
Hope Creek	BWR	10/5/1988	SWS to river	6	Leak		Not Given	Sch 40, cracked weld, operation	CS
Haddam Neck	PWR	3/10/1989	Containment Air cooler	6	Leak	NPRDS	Corrosion	Sch 40, nipple broke off	CS
Brunswick 2	BWR	3/23/1989	Diesel Generator Jacket Cooler	6	Leak	NPRDS	Corrosion	Sch 40, startup, salt water corrosion	CS
Haddam Neck	PWR	10/13/1989	SWS to cont. cooling	6	Leak	NPRDS	Pitting	Sch 40, external pitting	CS
Brunswick 1	BWR	3/2/1990	Main Steam	6	Rupture	90-003	Erosion/Corrosion	Erosion/Corrosion	CS
Millstone 2	PWR	3/26/1990	SWS	6	Leak		Erosion/Corrosion	Sch 40	CS
Millstone 2	PWR	4/23/1990	SWS	6	Leak		Erosion/Corrosion	Sch 40, pinhole	CS
Monticello	BWR	8/22/1990	Reactor water cleanup	6	Leak		Fatigue-Vibrational	Fatigue-Vibrational cracking	SS
Brunswick 2	BWR	12/13/1990	Diesel Generator Jacket Cooler	6	Leak	NPRDS	Unknown	Sch 80, 100% Power	CS
Millstone 3	PWR	12/30/1990	Moisture separator reheater	6	Rupture		Erosion/Corrosion	Erosion/corrosion, two lines failed	SS
Cook 2	PWR	8/3/1991	Reactor coolant pump oil cooler	6	leak	NPRDS	IGSCC	Sch 40, outage	SS
Surry 2	PWR	2/21/1992	RHR	6	leak	LER-96-001	IGSCC	thru-wall leak (small); check LER 94-003, 91-019, 89-042, 89-011	SS
Oyster Creek	BWR	2/5/1993	Core spray	6	Leak		IGSCC	Questionable failure mechanism	SS
Haddam Neck	PWR	3/9/1993	SWS	6	Leak	ACN:9301450044	Erosion/Corrosion	Leak 1 of 2	CS
Haddam Neck	PWR	3/9/1993	SWS	6	Leak	ACN:9301450044	Erosion/Corrosion	Leak 2 of 2	CS
Millstone 1	PWR	11/2/1994	SWS	6	Leak		Erosion/Corrosion	Erosion/corrosion with coating failure	CS
Dresden 2	BWR	2/23/1996	Core Spray	6	Crack/Leak	ACN:9602280278	Unknown		SS
Robinson 2	PWR	3/31/2867	main steam	6	rupture	NSIC-91;47813	construction defect/errors	construction defects/errors	CS
Cooper	BWR	10/5/1991	SWS	6.25	Leak	NPRDS	Wear	Sch 80, hydro	CS
Seabrook	PWR	10/13/1987	condenser elbow	7.625	leak	NPRDS	erosion/corrosion	sch 80, questionable failure mechanism, post-refuel outage	CS
Nine Mile Point 1	BWR	1/18/1972	Reheat	8	Leak		Unknown		SS
Browns Ferry 1	BWR	6/24/1972	Moisture Separator Reheater	8	Leak	No LER	Erosion/Corrosion	Erosion/Corrosion	SS
ANO1	PWR	4/15/1973	Containment Spray	8	Leak	DL LTR 5/25/73	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS
San Onofre 1	PWR	6/14/1973	safety injection	8	leak	NUREG-0691	stress corrosion/IGSCC	stress corrosion	SS
Fort Calhoun	PWR	9/7/1973	Main steam	8	Rupture	73-003	Fatigue-Vibrational	Fatigue-vibrational	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Dresden 1	BWR	1/10/1974	Core Spray	8	Leak	Letter to NRC (2/8/74)	Stress Corrosion/IGSCC	IGSCC, Leaked minimum flow line of core spray pump, erosion	SS
Dresden 2	BWR	7/24/1974	Containment heat removal	8	Crack/Leak	AO 74032	Unknown	Deteriorated rubber valve seat	CS
Hatch 1	BWR	12/15/1974	Residual heat removal	8	Leak		Stress Corrosion/IGSCC	IGSCC, Weld failure	SS
Yankee Rowe	PWR	2/18/1975	fire protection	8	leak	79-006	construction defect/errors	leaked joints, construction defect	CS
Three Mile Island 1	PWR	4/4/1975	spent fuel pool	8	leak	79-011, NUREG-0691	stress corrosion/IGSCC	stress corrosion, leak 1/5	CS
Three Mile Island 1	PWR	4/4/1975	spent fuel pool	8	leak	79-011, NUREG-0691	stress corrosion/IGSCC	stress corrosion, leak 2/5	CS
Three Mile Island 1	PWR	4/4/1975	spent fuel pool	8	leak	79-011, NUREG-0691	stress corrosion/IGSCC	stress corrosion, leak 3/5	CS
Three Mile Island 1	PWR	4/4/1975	spent fuel pool	8	leak	79-011, NUREG-0691	stress corrosion/IGSCC	stress corrosion, leak 4/5	CS
Three Mile Island 1	PWR	4/4/1975	spent fuel pool	8	leak	79-011, NUREG-0691	stress corrosion/IGSCC	stress corrosion, leak 5/5	CS
San Onofre 1	PWR	9/15/1975	service water	8	crack/leak	79-013	stress corrosion/IGSCC	Cl-stress corrosion 1/6	CS
San Onofre 1	PWR	9/15/1975	service water	8	crack/leak	79-013	stress corrosion/IGSCC	Cl-stress corrosion 2/6	CS
San Onofre 1	PWR	9/15/1975	service water	8	crack/leak	79-013	stress corrosion/IGSCC	Cl-stress corrosion 3/6	CS
San Onofre 1	PWR	9/15/1975	service water	8	crack/leak	79-013	stress corrosion/IGSCC	Cl-stress corrosion 4/6	CS
San Onofre 1	PWR	9/15/1975	service water	8	crack/leak	79-013	stress corrosion/IGSCC	Cl-stress corrosion 5/6	CS
San Onofre 1	PWR	9/15/1975	service water	8	crack/leak	79-013	stress corrosion/IGSCC	Cl-stress corrosion 6/6	CS
ANO1	PWR	8/10/1976	Demineralizer	8	Leak	RO 76-21	Stress Corrosion Cracking, IGSCC	IGSCC	SS
Ginna	PWR	10/8/1976	Boric Acid	8	Leak	RO 76-24	Stress Corrosion/IGSCC	Stress corrosion	SS
Crystal River 3	PWR	1/11/1977	Containment spray	8	Crack/Leak	RO 77-01,NUREG-0691	Stress Corrosion/IGSCC	Stress corrosion	SS
Crystal River 3	PWR	1/30/1977	Containment heat removal	8	Leak	RO 77-06	Stress Corrosion/IGSCC	Stress corrosion	CS
Ginna	PWR	2/10/1977	Boric Acid	8	Leak	AO	Corrosion	Corrosion	SS
Indian Point 2	PWR	8/30/1978	Residual heat removal	8	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Millstone 1	PWR	1/6/1979	Reactor water cleanup	8	Leak		stress Corrosion/IGCSS	IGSCC	SS
Dresden 1	BWR	6/1/1979	Steam	8	Leak	NUREG/75-067	Stress Corrosion/IGSCC	IGSCC	CS
Brunswick 2	BWR	9/12/1979	Service Water	8	Leak	79-084	Corrosion	Corrosion	CS
Susquehanna 2	BWR	7/4/1980	CVCS	8	leak	NPRDS	IGSCC		SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 42 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 43 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 44 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 45 of 52 weld leaks	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 46 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 47 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 48 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 49 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 50 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 51 of 52 weld leaks	SS
Palo Verde 2	PWR	2/28/1981	ECWS	8	leak	PNO-V-85-013	microbiologically induced corrosion	weld leak 52 of 52 weld leaks	SS
LaSalle 1	BWR	6/9/1982	RHR	8	Leak		Thermal Fatigue		SS
Millstone 2	PWR	6/28/1982	D.G. SWS	8	Leak		Erosion/Corrosion	Sch 40	CS
Browns Ferry 1	BWR	8/24/1982	Main Steam	8	Rupture	AEOD/E4 16	Erosion/Corrosion	Erosion./Corrosion	CS
Browns Ferry 1	BWR	9/3/1982	Moisture Separator	8	Failed	ACN:8709230232	Erosion/Corrosion		SS
Browns Ferry 1	BWR	9/29/1982	Main Steam	8	Rupture	82-115	Erosion/Corrosion	Erosion/Corrosion	CS
Kewaunee	PWR	12/29/1982	Main steam	8	Leak		Unknown	Crack in drain line	CS
Dresden 2	BWR	1/7/1983	Spent fuel pool	8	Leak	83-002	Fatigue-Vibrational	Fatigue-vibration	CS
Zion 1	PWR	2/21/1983	SWS. D.G. jacket	8	leak	NPRDS	wear	sch 40, rubber aged/worn, flexible rubber coupling	CS
Dresden 2	BWR	6/4/1983	Service Water	8	Leak	83-004	Fatigue-Vibrational	Fatigue-vibration	CS
Cook 1	PWR	7/11/1983	component cooling	8	leak	83-066	unknown	Valve failure	CS
Salem 2	PWR	10/13/1984	SWS	8	leak	NPRDS	erosion/corrosion	sch 40	CS
Millstone 2	PWR	1/3/1985	SWS	8	Leak		Erosion/Corrosion	Sch 40, eroded tar coating, sea water corroded	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 1	PWR	3/1/1985	Spray pond line	8	Leak		Not Given	Occurrence 1 of 15, Unit 1: 10 defects, 2 weld leaks, 3 leaks	CS
Palo Verde 2	PWR	3/1/1985	Coolant water	8	Leak		Stress Corrosion/IGSCC	Stress corrosion, leaks in 51 welds	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS
Palo Verde 2	PWR	3/1/1985	ECWS	8	Leak		Microbiologically induced corrosion	Weld leak 1 of 52 leaks	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	204 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	205 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	206 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	207 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	208 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	209 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	210 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	211 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	212 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	213 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	214 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	215 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	216 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	217 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	218 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	219 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	220 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	221 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	222 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	223 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	224 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	225 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	226 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	227 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	228 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	229 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	230 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	231 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	232 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	233 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	234 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	235 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	236 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	237 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	238 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	239 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	240 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	241 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	242 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	243 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	244 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	245 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	246 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	247 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	248 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	249 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	250 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	251 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	252 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	253 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	254 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	255 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	256 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	257 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	258 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	259 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	260 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	261 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	262 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	263 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	264 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	265 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	266 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	267 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	268 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	269 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	270 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	271 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	272 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	273 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	274 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	275 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	276 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	277 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	278 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	279 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	280 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	281 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	282 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	283 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	284 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	285 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	286 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	287 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	288 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	289 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	290 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	291 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	292 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	293 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	294 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	295 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	296 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	297 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	298 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	299 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	300 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	301 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	302 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	303 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	304 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	305 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	306 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	307 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	308 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	309 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	310 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	311 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	312 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	313 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	314 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	315 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	316 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	317 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	318 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	319 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	320 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	321 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	322 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	323 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	324 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	325 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	326 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	327 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	328 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	329 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	330 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	331 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	332 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	333 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	334 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	335 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	336 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	337 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	338 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	339 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	340 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	341 total records, Unit 2: 99 defects; 46 weld leaks; 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	342 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	343 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	344 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	345 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	346 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	347 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	348 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	349 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	350 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	351 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	352 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	353 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	354 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	355 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	356 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	357 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	358 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	359 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	360 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	361 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	362 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	363 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	364 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	365 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	366 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	367 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	368 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	369 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	370 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	371 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	372 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	373 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	374 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	375 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	376 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	377 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	378 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	379 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	380 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	381 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	382 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	383 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	384 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	385 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	386 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	387 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	388 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	389 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	390 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	391 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	392 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	393 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	394 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	395 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	396 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	397 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	398 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	399 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	400 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	401 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	402 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	403 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	404 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	405 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	406 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Palo Verde 2	PWR	3/1/1985	Spray pond line	8	Leak		Microbiologically induced corrosion	407 total records, Unit 2: 99 defects, 46 weld leaks, 59 leaks	CS
Salem 1	PWR	3/10/1985	containment spray	8	leak	special report 89-1	stress corrosion/IGSCC	IGSCC	SS
Oyster Creek	BWR	3/22/1986	Condensate	8	Leak		Stress Corrosion/IGSCC	IGSCC	CS
Millstone 2	PWR	4/28/1986	SWS	8	Leak		Corrosion	Sch 40, sea water corrosion	CS
Salem 2	PWR	5/24/1986	SWS turbine building	8	leak	NPRDS	erosion/corrosion	sch 40	CS
LaCrosse	BWR	7/18/1986	Residual heat removal	8	Leak		Unknown	Unknown cause	SS
Millstone 2	PWR	6/16/1987	D.G. SWS	8	Leak		Erosion/Corrosion	Sch 40, eroded mastic, salt water corrosion	CS
Millstone 2	PWR	8/20/1987	D.G. SWS elbow	8	Leak		Erosion/Corrosion	Sch 40	CS
Salem 2	PWR	9/29/1987	SWS D.G. jacket cooler	8	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Millstone 2	PWR	4/15/1988	D.G. SWS	8	Leak		Erosion/Corrosion	Sch 40	CS
Susquehanna 1	BWR	6/2/1988	cont. spray	8	leak	NPRDS	stress corrosion cracking		SS
Millstone 2	PWR	6/21/1988	D.G. SWS	8	Leak		Corrosion	Sch 40, salt water	CS
Millstone 3	PWR	10/25/1988	SWS	8	Leak		Erosion/Corrosion	Sch 40	CS
Quad Cities 2	BWR	3/5/1989	service water	8	leak	93-006	unknown	sheared off discharge header, unknown cause	CS
Millstone 2	PWR	12/12/1989	D.G. SWS	8	Leak		Erosion/Corrosion	Sch 40, pinhole	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Clinton	BWR	3/3/1990	Condensate drain	8	leak	NPRDS	Cavitation	Sch 40, pinhole leak, shutdown	CS
Vermont Yankee	BWR	8/17/1991	SWS (Cl-3)	8	leak	ACN:9509220083	microbiologically induced corrosion		CS
Millstone 2	PWR	9/23/1991	SWS	8	Leak		Microbiologically induced corrosion	Sch 40, pinhole leak, 100% power	CS
Millstone 2	PWR	10/16/1991	SWS to diesel	8	Leak		Microbiologically induced corrosion	Leak 1 of 2 leaks	CS
Millstone 2	PWR	10/16/1991	SWS to diesel	8	Leak		Microbiologically induced corrosion	Leak 2 of 2 leaks	CS
Millstone 2	PWR	10/31/1991	SWS	8	Rupture		Microbiologically induced corrosion	Sch 40, pinhole leak	CS
Millstone 2	PWR	11/6/1991	Moisture separator reheater	8	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
Millstone 2	PWR	11/10/1991	Header to pier 1	8	Leak		Microbiologically induced corrosion	Sch 40, leak 1 out of 6 pinhole leaks, mode 3	CS
Millstone 2	PWR	11/10/1991	Header to pier 1	8	Leak		Microbiologically induced corrosion	Sch 40, leak 2 out of 6 pinhole leaks, mode 4	CS
Millstone 2	PWR	11/10/1991	Header to pier 1	8	Leak		Microbiologically induced corrosion	Sch 40, leak 6 out of 6 pinhole leaks, mode 8	CS
Millstone 2	PWR	11/11/1991	Header to pier 1	8	Leak		Microbiologically induced corrosion	Sch 40, leak 3 out of 6 pinhole leaks, mode 5	CS
Millstone 2	PWR	11/12/1991	Header to pier 1	8	Leak		Microbiologically induced corrosion	Sch 40, leak 4 out of 6 pinhole leaks, mode 6	CS
Millstone 2	PWR	11/13/1991	Header to pier 1	8	Leak		Microbiologically induced corrosion	Sch 40, leak 5 out of 6 pinhole leaks, mode 7	CS
Millstone 1	PWR	2/25/1992	SWS	8	Leak		Corrosion	Sch 46, pinhole leak, cold shutdown	CS
Millstone 3	PWR	4/3/1992	Expansion joint SWS	8	Leak		Pitting		CS
Millstone 2	PWR	6/12/1992	RBCW	8	Leak		Microbiologically induced corrosion	Sch 40, cold shutdown	CS
Palisades	PWR	10/9/1993	Pressurizer	8	Leak		Stress Corrosion/IGSCC	Stress corrosion	SS
Millstone 1	PWR	1/26/1995	SWS	8	Leak		Erosion/Corrosion	Questionable failure mechanism	CS
Millstone 1	PWR	2/27/1995	SWS	8	Leak		Erosion/Corrosion	Erosion/corrosion	CS
Millstone 1	PWR	8/8/1995	Coolant recirculation	8	Leak		Erosion/Corrosion		SS
Millstone 2	PWR	8/8/1995	Steam	8	Rupture		Erosion/Corrosion	E/C	CS
LaCrosse	BWR	10/1/1969	Feedwater	10	Leak		Stress Corrosion/IGSCC	IGSCC	CS
Nine Mile Point 1	BWR	3/1/1970	Containment spray	10	Leak		Stress Corrosion/IGSCC	IGSCC in furnace sensitized safe ends	SS
Indian Point 3	PWR	10/1/1970	Fire main	10	Rupture		Unknown		CS
Surry 1	PWR	9/30/1972	containment spray	10	leak	NUREG-0691	stress corrosion/IGSCC	stress corrosion	SS
Surry 2	PWR	10/5/1972	coolant recirculation	10	leak	76-15, NUREG-0691	stress corrosion/IGSCC	stress corrosion	SS
Surry 2	PWR	10/14/1972	containment spray	10	leak	76-015	stress corrosion/IGSCC	chloride stress corrosion	SS
Dresden 2	BWR	8/6/1974	Feedwater	10	Leak	Ltr DL 8/6 74	Fatigue-Vibrational	Fatigue-vibration	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 1	PWR	8/20/1974	service water	10	leak	78-050	erosion/corrosion	E/C, repaired by weld	CS
ANO1	PWR	11/7/1974	Containment Spray	10	Leak	AO-74-11A	Stress Corrosion Cracking, IGSCC	IGSCC	SS
ANO1	PWR	11/11/1974	Core Spray	10	Leak	AO 74-07	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS
ANO1	PWR	11/13/1974	Spray	10	Crack	LTR 2/7/75	Stress Corrosion Cracking, IGSCC	Occurrence 1 of 5	SS
ANO1	PWR	11/13/1974	Spray	10	Crack	LTR 2/7/75	Stress Corrosion Cracking, IGSCC	Occurrence 2 of 5	SS
ANO1	PWR	11/13/1974	Spray	10	Crack	LTR 2/7/75	Stress Corrosion Cracking, IGSCC	Occurrence 3 of 5	SS
ANO1	PWR	11/13/1974	Spray	10	Crack	LTR 2/7/75	Stress Corrosion Cracking, IGSCC	Occurrence 4 of 5	SS
ANO1	PWR	11/13/1974	Spray	10	Crack	LTR 2/7/75	Stress Corrosion Cracking, IGSCC	Occurrence 5 of 5	SS
ANO1	PWR	12/28/1974	Sevice Water	10	Leak	AO 74-14, NUREG-0691	Thermal Fatigue	Thermal fatigue, SCC	CS
Dresden 2	BWR	1/27/1975	Core Spray	10	Leak	NUREG/75-067, AO 75-11A	Stress Corrosion/IGSCC	IGSCC, 2 leaks	SS
Three Mile Island 1	PWR	6/19/1975	residual heat removal decay heat	10	leak	79-013-1T, NUREG-0691	stress corrosion/IGSCC	stress corrosion/IGSCC	SS
Dresden 3	BWR	9/27/1975	Feedwater	10	Leak	AO 75-43	Construction Defect/Errors	Construction defect	CS
Quad Cities 2	BWR	2/29/1976	core spray	10	leak	NPE VII.C.88 (BWR-2, Book-2)	IGSCC	several cracks too	SS
ANO1	PWR	8/31/1976	Residual Heat Removal	10	Leak	RO 76-25	Stress Corrosion Cracking, IGSCC	IGSCC, pipe section replaced	SS
Quad Cities 1	BWR	9/1/1976	core spray	10	leak	PNO-III-80-164	stress corrosion/IGSCC	IGSCC	SS
ANO1	PWR	9/26/1976	Coolant Recirculation	10	Leak	RO 76-28	Stress Corrosion Cracking, IGSCC	IGSCC, outlet nozzle and pipe section replaced	SS
Nine Mile Point 1	BWR	7/3/1977	Condensate	10	Leak		Erosion/Corrosion	Erosion/corrosion	CS
ANO1	PWR	11/25/1977	Core Spray	10	Leak	77-023	Erosion/Corrosion	Erosion/Corrosion	SS
Duane Arnold	BWR	6/17/1978	Coolant recirculation	10	Leak	78-030, NUREG-0531	Stress Corrosion/IGSCC	IGSCC, 360 degree crack	SS
Dresden 1	BWR	10/20/1978	Feedwater	10	Leak	78-051	Erosion/Corrosion	Erosion/corrosion	CS
Dresden 3	BWR	10/20/1978	Feedwater	10	Leak	78-051	Erosion/Corrosion	Cracked support, Erosion/Corrosion	CS
Dresden 3	BWR	11/1/1978	Feedwater heater drain	10	Leak	NPE VIII.C.160 (BWR-2, Book-2)	Not Given	Lack of fusion	CS
ANO1	PWR	1/10/1980	Bldg Spray	10	Leak	NPE VII.B 76	IGSCC		SS
Hatch 1	BWR	4/9/1980	Fire Protection	10	Leak		other	Separation of main pipe fitting due to settling of concrete ditch	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Humboldt Bay 3	BWR	9/26/1980	Service water	10	Severed		other	Settling of solid; one line over other broke; plant shutdown for several years	CS
Humboldt Bay 3	BWR	9/26/1980	Service water	10	Severed		other	Settling of solid; one line over other broke; plant shutdown for several years	CS
Duane Arnold	BWR	11/6/1981	Reactor Water Cleanup	10	Leak	81-041	Stress Corrosion/IGSCC	Stress corrosion	SS
San Onofre 1	PWR	11/20/1981	feedwater	10	leak	NUREG-1190	water hammer	water hammer	CS
Millstone 1	PWR	9/25/1982	Core spray	10	Crack/Leak		stress Corrosion/IGCSS	Stress Corrosion	SS
Cooper	BWR	7/10/1983	Core Spray	10	Crack/Leak	83-011	Stress Corrosion/IGSCC	IGSCC, Leak welds discovered during weld grinding	SS
Duane Arnold	BWR	3/13/1985	Recirc	10	Leak	PNO-III-85-022	IGSCC		SS
LaSalle 2	BWR	5/27/1985	Core spray	10	Failed		Erosion/Corrosion	Erosion/Corrosion	SS
Limerick 1	BWR	2/14/1986	Recirc. Pipe elbow	10	Leak		Erosion/Corrosion	Sch 80, full power	SS
Limerick 1	BWR	2/25/1986	Recirc. Pipe elbow	10	Leak		Erosion/Corrosion	Sch 80, full power	SS
Oconee 3	BWR	9/17/1986	Moisture separator reheater	10	Rupture		Erosion/Corrosion	Erosion/corrosion	SS
Oconee 2	BWR	10/14/1986	SWS	10	Leak		Erosion/Corrosion	Sch 40	CS
Salem 1	PWR	12/2/1986	service water	10	leak	90-026-04	erosion/corrosion	erosion/corrosion, leak in penetration area pipe	CS
Salem 1	PWR	12/2/1986	SWS cont. fan cooler	10	leak	LER 90-026	erosion/corrosion	sch 40, 100% power	CS
Turkey Point 3	PWR	2/20/1987	recirculation line elbow	10	leak	NPRDS	unknown	sch 40, 10 small leaks, hydro (10 yr)	SS
Salem 1	PWR	6/4/1987	SWS cont. fan cooler	10	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Salem 1	PWR	8/5/1987	SWS cont. fan cooler	10	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Salem 2	PWR	11/24/1987	SWS cont. fan cooler	10	leak	NPRDS	erosion/corrosion	Sch 40, 100% power	CS
South Texas 2	PWR	4/13/1988	ECW	10	leak	NPRDS	dealloying	sch 40, dealloying of SS Al-bronze	SS
Sequoyah 1	PWR	5/1/1988	fire protection	10	leak	special report 92-05	construction defect/errors	misaligned pipe, construction defect	CS
South Texas 1	PWR	12/17/1988	ECW	10	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	SS
Indian Point 3	PWR	2/21/1989	Service water	10	Leak		Construction Defect/Errors	Construction defects/error, sch 40	CS
Sequoyah 2	PWR	2/28/1989	steam	10	leak	PNO-II-93-008	erosion/corrosion	erosion/corrosion	CS
Fort Calhoun	PWR	3/31/1989	Feedwater heater line	10	Leak	NPRDS	Erosion/Corrosion	Sch 40	CS
Millstone 2	PWR	11/8/1990	Condensate line	10	Leak		Erosion/Corrosion	Sch 40 , 0.5 in hole	CS
Indian Point 3	PWR	6/27/1991	SWS header	10	Leak		Fabrication Defect	Sch 80, poor weld joint, full power	CS
Indian Point 3	PWR	1/3/1992	D.G. cooling header	10	Leak		Fabrication Defect	Sch 80, leak 1 of 2 pinhole leaks, poor weld, full power	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Indian Point 3	PWR	1/3/1992	D.G. cooling header	10	Leak		Fabrication Defect	Sch 80, leak 2 of 2 pinhole leaks, poor weld, full power	CS
Millstone 3	PWR	12/2/1993	Diesel line SWS	10	Leak		Unknown		CS
Turkey Point 3	PWR	12/3/1967	main steam	12	rupture	12/15/75 letter to region II	construction defect/errors	construction defect/errors	CS
Nine Mile Point 1	BWR	3/23/1974	Reactor water cleanup	12	Crack/Leak		Construction Defects/Errors	Construction Defects/Errors	SS
Dresden 2	BWR	9/5/1976	High pressure core injection	12	Leak	RO 76-060	Stress Corrosion/IGSCC	Chloride stress corrosion	SS
ANO1	PWR	5/5/1977	Spent Fuel Pool	12	Leak	RO 77-12	Unknown	Unknown Cause	CS
Brunswick 2	BWR	10/1/1977	Core Spray	12	Leak	NPE VII.C.74 (BWR 2, Book-2)	IGSCC	Leak 1 of 3 leaks	SS
Brunswick 2	BWR	10/1/1977	Core Spray	12	Leak	NPE VII.C.74 (BWR 2, Book-2)	IGSCC	Leak 2 of 3 leaks	SS
Brunswick 2	BWR	10/1/1977	Core Spray	12	Leak	NPE VII.C.74 (BWR 2, Book-2)	IGSCC	Leak 3 of 3 leaks	SS
Vermont Yankee	BWR	1/24/1978	main steam	12	leak	82-001	erosion/corrosion	erosion/corrosion	CS
Vermont Yankee	BWR	1/26/1978	turbine exhaust	12	leak	NPE VI.D.262	erosion/corrosion		CS
Hatch 1	BWR	5/7/1978	Gas line	12	Leak		other	Building settlement	SS
Pilgrim	BWR	12/31/1978	extraction steam	12	leak	EPRI NP-6066	erosion/corrosion	leak through wall in 1 elbow, elbow replaced	CS
Quad Cities 1	BWR	4/13/1980	reactor coolant	12	leak	84-005	stress corrosion/IGSCC	IGSCC, leak 1/4	SS
Quad Cities 1	BWR	4/13/1980	reactor coolant	12	leak	84-005	stress corrosion/IGSCC	IGSCC, leak 2/4	SS
Quad Cities 1	BWR	4/13/1980	reactor coolant	12	leak	84-005	stress corrosion/IGSCC	IGSCC, leak 3/4	SS
Quad Cities 1	BWR	4/13/1980	reactor coolant	12	leak	LER-84-005	stress corrosion/IGSCC	IGSCC, leak 4/4	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, E riser pipe to elbow	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 9 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02E-S4)	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, G riser elbow to pipe	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 7 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02G-S3)	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, H riser pipe to elbow	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 5 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02H-S4)	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, H riser to pipe weld	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 6 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02H-S3)	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, J riser elbow to pipe	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 8 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02J-S3)	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Quad Cities 1	BWR	4/13/1980	reactor recirculation, J riser pipe to elbow	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 1 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02J-S4)	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, J riser sweepolet to pipe	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 4 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02J-F6)	SS
Quad Cities 1	BWR	4/13/1980	reactor recirculation, K riser elbow to pipe	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 2 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02K-S3)	SS
Quad Cities 1	BWR	4/13/1980	Reactor recirculation, K riser pipe to elbow	12	leak	LER-84-005	IGSCC	probable IGSCC, weld 3 (out of 9 welds) leaked out of pinholes or axial cracks (weld #02K-S4)	SS
St. Lucie 2	PWR	11/26/1980	condensate	12	leak	NPRDS	vibration, water hammer	sch 40	CS
Quad Cities 2	BWR	3/31/1981	recirculation	12	leak	LER 85-008	IGSCC		SS
Beaver Valley 1	PWR	10/29/1981	Fire Protection	12	Rupture	81-091R1	Corrosion	Underground external corrosion	CS
Beaver Valley 1	PWR	9/8/1982	Fire Protection	12	Rupture	82-032	Construction Defect/Error	Construction defects/errors	CS
Monticello	BWR	10/20/1982	Coolant recirculation	12	Leak		Stress Corrosion/IGSCC	IGSCC	SS
Quad Cities 2	BWR	11/4/1982	reactor coolant	12	leak	86-017	stress corrosion/IGSCC	IGSCC	SS
Brunswick 1	BWR	1/26/1983	Coolant Recirculation	12	Leak	83-001	Stress Corrosion/IGSCC	IGSCC	SS
Cook 2	PWR	1/18/1984	Containment spray tee	12	leak	LER 82-003	fatigue	Sch 40	SS
North Anna 1	PWR	11/27/1984	Fire protection main header	12	Rupture		Fracture	Brittle Fracture	CS
Browns Ferry 2	BWR	2/21/1985	Recirc Riser	12	Leak	LER 85-001	IGSCC		SS
Brunswick 1	BWR	5/10/1985	Recirc Pipe Riser	12	Leak	LER -85-026	IGSCC	Sch 80, refuel maintenance mod, leak 1 of 5 leaks in difference locations	SS
Brunswick 1	BWR	5/10/1985	Recirc Pipe Riser	12	Leak	LER -85-026	IGSCC	Sch 80, refuel maintenance mod, leak 2 of 5 leaks in difference locations	SS
Brunswick 1	BWR	5/10/1985	Recirc Pipe Riser	12	Leak	LER -85-026	IGSCC	Sch 80, refuel maintenance mod, leak 3 of 5 leaks in difference locations	SS
Brunswick 1	BWR	5/10/1985	Recirc Pipe Riser	12	Leak	LER -85-026	IGSCC	Sch 80, refuel maintenance mod, leak 4 of 5 leaks in difference locations	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Brunswick 1	BWR	5/10/1985	Recirc Pipe Riser	12	Leak	LER -85-026	IGSCC	Sch 80, refuel maintenance mod, leak 5 of 5 leaks in difference locations	SS
Brunswick 1	BWR	7/1/1985	Recirculation	12	Leak	LER 85-026	IGSCC	92 indications in weld 1 out of 23 of 79 welds; pinhole leaks in weld 1 out of 5 welds; 77 axial	SS
Brunswick 1	BWR	7/1/1985	Recirculation	12	Leak	LER 85-026	IGSCC	92 indications in weld 2 out of 23 of 79 welds; pinhole leaks in weld 2 out of 5 welds; 77 axial	SS
Brunswick 1	BWR	7/1/1985	Recirculation	12	Leak	LER 85-026	IGSCC	92 indications in weld 3 out of 23 of 79 welds; pinhole leaks in weld 3 out of 5 welds; 77 axial	SS
Brunswick 1	BWR	7/1/1985	Recirculation	12	Leak	LER 85-026	IGSCC	92 indications in weld 4 out of 23 of 79 welds; pinhole leaks in weld 4 out of 5 welds; 77 axial	SS
Brunswick 1	BWR	7/1/1985	Recirculation	12	Leak	LER 85-026	IGSCC	92 indications in weld 5 out of 23 of 79 welds; pinhole leaks in weld 5 out of 5 welds; 77 axial	SS
Quad Cities 2	BWR	1/27/1986	RHR	12	leak	NPRDS	erosion/corrosion	sch 40	SS
Robinson 2	PWR	1/15/1987	SWS	12	leak	NPRDS	erosion/corrosion	sch 40, refueling	CS
Pilgrim	BWR	5/19/1987	salt SWS	12	leak	NPRDS	erosion/corrosion	Sch 40, 3-5 gpm, rubber lined pipe, refueling	CS
Salem 1	PWR	8/28/1987	SWS	12	leak	NPRDS	erosion/corrosion	sch 40, 100% power	CS
Fitzpatrick	BWR	6/13/1988	SWS CWHX	12	Leak	NPRDS	Erosion/Corrosion	Sch 80, normal op.	CS
Clinton	BWR	4/12/1990	Recirculation piping	12	leak	NPRDS	Fabrication defect	Sch 40, leak 1 of 3 pinhole leaks; casting defects	SS
Clinton	PWR	4/12/1990	Recirculation piping	12	leak	NPRDS	Fabrication defect	Sch 40, leak 2 of 3 pinhole leaks, casting defects	SS
Clinton	BWR	4/12/1990	Recirculation piping	12	leak	NPRDS	Fabrication defect	Sch 40, leak 3 of 3 pinhole leaks, casting defects	SS
Vermont Yankee	BWR	11/29/1990	SWS (CI-3)	12	leak	94-016	microbiologically induced corrosion		CS
Salem 2	PWR	1/18/1991		12	leak	94-002-05	stress corrosion/IGSCC	feedwater pipe chloride induced corrosion-erosion/corrosion	CS
Clinton	BWR	3/29/1991	Recirculation piping	12	leak	NPRDS	unknown	Sch 40, 10-20 gpm, 99.9% power	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oyster Creek	BWR	7/22/1991	Condensate	12	Leak		Unknown	Underground leak, unknown cause	CS
Oconee 3	BWR	12/15/1991	LPCI	12	Leak		Fatigue-Vibrational		SS
Fermi 2	BWR	9/17/1993	FeedwaTer	12	Leak	No LER	Erosion/Corrosion	Erosion/corrosion	CS
Haddam Neck 1	PWR	2/12/1994	Service water	12	Leak		Corrosion	Mic	CS
Comanche Peak 2	PWR	5/19/1994	containment spray	12	leak	94-005	fatigue-vibrational	fatigue-vibrational	SS
Nine Mile Point 1	BWR	5/7/1984	High pressure core injection	12.75	Leak		Stress Corrosion/IGCSS	IGSCC, chloride contamination	SS
Indian Point 2	PWR	9/20/1978	Residual heat removal	13	Leak		RAC	Cavitation/impingement	SS
Surry 1	PWR	9/30/1968	main steam	14	failed	Ltr DL; 10/11/72	water hammer	water hammer	CS
Dresden 2	BWR	3/24/1976	High pressure core injection	14	Leak	76-016	Stress Corrosion/IGSCC	IGSCC	SS
Dresden 2	BWR	4/6/1976	Condensate	14	Leak	NUREG-0691	Stress Corrosion/IGSCC	IGSCC	CS
Dresden 2	BWR	9/15/1976	High pressure core injection	14	Leak	76-061	Construction Defect/Errors	Construction defect	SS
Trojan	PWR	3/8/1981	feedwater	14	rupture	85-002; NUREG/BR-0051V7 #3	erosion/corrosion	erosion/corrosion	CS
Maine Yankee 1	PWR	1/25/1983	Feedwater	14	Breakage		Water hammer	Water hammer, sch 80	CS
Brunswick 1	BWR	6/10/1984	Main Steam	14	Leak	PNO-II-84-034	Thermal Fatigue	Thermal Fatigue	CS
LaSalle 2	BWR	5/27/1985	Condensate return	14	Leak		Microbiologically induced corrosion	Leak 1 of 2, 14" pipe, sch 10	CS
LaSalle 2	BWR	5/27/1985	Condensate return	14	Leak		Microbiologically induced corrosion	Leak 2 of 2, 14" pipe, sch 11	CS
Millstone 1	PWR	6/19/1985	SWS	14	Leak		Erosion/Corrosion	Sch 80, 65% power	CS
Salem 1	PWR	8/18/1985	CCW	14	leak	NPRDS	erosion/corrosion	sch 40, questionable failure mechanism, 100% power	CS
Maine Yankee	PWR	10/12/1985	Primary component coolant	14	Leak		Microbiologically induced corrosion	Sch 40, multiple leaks, microbiologically induced corrosion and water corrosion, buried line, outage	CS
Byron 1	PWR	3/29/1986	Feedwater Elbow	14	Leak	NPRDS	Erosion/Corrosion	Sch 80, 100% power	CS
Byron 1	PWR	4/2/1986	Feedwater Line	14	Leak	NPRDS	Erosion/Corrosion	Sch 80, 98% power	CS
Byron 1	PWR	5/26/1986	Feedwater Line	14	Leak	NPRDS	Erosion/Corrosion	Sch 80, at power	CS
Salem 1	PWR	7/22/1986	service water	14	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Crystal River 3	PWR	8/12/1986	Service Water	14	Leak	86-014	Erosion/Corrosion	Erosion/corrosion	CS
Salem 1	PWR	10/8/1986	service water	14	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Salem 1	PWR	3/16/1987	CCW	14	leak	NPRDS	erosion/corrosion	sch 80	CS
Cook 1 and 2	PWR	8/20/1987	CCW	14	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC		CS
Bryon 2	PWR	11/24/1988	Feedwater Elbow	14	Leak	NPRDS	Erosion/Corrosion	Sch 80	CS
ANO2	PWR	4/18/1989	Main Steam	14	Rupture	89-006	Erosion/Corrosion	Erosion/Corrosion	CS
Byron 1	PWR	5/23/1989	Feedwater Elbow	14	Leak	NPRDS	Erosion/Corrosion	Sch 80	CS
Byron 1	PWR	6/18/1989	Feedwater Line	14	Leak	NPRDS	Erosion/Corrosion	Sch 80, 89% power	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Braidwood 2	PWR	10/10/1989	Feedwater Elbow	14	Leak	NPRDS	Erosion/Corrosion	Sch 80, 94% power	CS
Braidwood 2	BWR	10/31/1989	Feedwater Elbow	14	Leak	NPRDS	Thermal Stress	Sch 80, leak on patch, patch thermally stressed, repair inadequate	CS
Byron 1	PWR	12/3/1989	Feedwater Elbow	14	Leak	NPRDS	Erosion/Corrosion	Sch 80, 100% power, leak at patel	CS
Indian Point 3	PWR	6/1/1991	Condensate line	14	Leak		Corrosion	Sch 80, full power	CS
Quad Cities 2	BWR	4/5/1970	SWS/RHR	16	leak	AO-74-7	unknown		CS
Diablo Canyon 1	PWR	3/18/1977	Feedwater	16	Leak	Letter to NRC (4/18/77)	Construction Defect/Errors	Construction defect	CS
Quad Cities 1	BWR	11/20/1977	residual heat removal	16	breakage	81-020R2	construction defect/errors	construction defects/errors	SS
Browns Ferry 1	BWR	3/1/1979	Feedwater	16	Leak	NPE VI.E 113 (BWR-2, Book-8)	Not Given	Overstressed	CS
Cook 2	PWR	5/19/1979	service water	16	leak	82-011	Erosion/Corrosion	Erosion/Corrosion	CS
Quad Cities 1	BWR	5/6/1980	SWS/RHR	16	leak	84-7	fatigue-vibrational	leak 1 of 2 leaks found in 16" line	CS
Quad Cities 1	BWR	5/6/1980	SWS/RHR	16	leak	84-7	fatigue-vibrational	leak 2 of 2 leaks found in 16" line	CS
McGuire 1	PWR	10/1/1981	Fire main	16	Rupture		Not Given	Overload	CS
Calvert Cliffs 1	PWR	11/23/1981	Main Steam	16	Leak	AEOD/E4 16	Stress Corrosion/IGSCC	5-inch split in steam line, S/C	CS
Maine Yankee 1	PWR	9/10/1982	Main steam	16	Leak		Unknown	2 in. hole developed in the high pressure turbine extraction steam line	CS
Calvert Cliffs 1	PWR	11/23/1983	Main Steam	16	Leak	83-046	Erosion/Corrosion	Erosion/corrosion	CS
LaSalle 1	BWR	1/16/1984	Condensate	16	Failed		Unknown	Expansion joint	CS
LaSalle 1	BWR	2/8/1984	Condensate	16	Failed		Unknown	Expansion joint	CS
Zion 1	PWR	7/21/1984	steam	16	leak	PNO-II-88-067	erosion/corrosion	erosion/corrosion	CS
Calvert Cliffs 1	PWR	11/20/1984	Condensate	16	Rupture	88-084	Erosion/Corrosion	Erosion/Corrosion	CS
Salem 1	PWR	9/12/1985	SWS cont. fan cooler	16	leak	NPRDS	erosion/corrosion	sch 40	CS
Salem 1	PWR	11/22/1986	service water	16	leak	90-026-04	erosion/corrosion	erosion/corrosion	CS
Salem 1	PWR	11/22/1986	SWS	16	leak	LER 90-026	erosion/corrosion	sch 40, 100% power	CS
Cook 1	PWR	7/21/1987	ESW elbow	16	leak	NPRDS	Erosion/Corrosion	Sch 40, operations, questionalbe failure mechanism	SS
Nine Mile Point 2	BWR	12/26/1987	Condenser	16	Leak		Unknown		CS
Beaver Valley 1	PWR	12/28/1987	Feedwater	16	Crack	88-012	Thermal Fatigue		CS
Millstone 3	PWR	6/29/1989	Cont. recir. SWS	16	Leak		Corrosion	Sch 40, local corrosion	CS
Millstone 1	PWR	10/6/1990	SWS	16	Leak		Erosion/Corrosion	Sch 40, pinhole leak, cold shutdown	CS
Dresden 2	BWR	11/24/1990	Reactor Coolant	16	Leak	93-014	Stress Corrosion/IGSCC	IGSCC	SS
Sequoyah 1	PWR	11/28/1990	condensate	16	breakage	IN 95-11	erosion/corrosion	erosion/corrosion, 180 deg. Crack	CS
Palisades	PWR	6/10/1993	CCW HX	16	Leak		Erosion/Corrosion	Pinhole leak 1 of 2 pinhole leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Millstone 1	PWR	10/15/1993	Service water	16	Leak		Construction Defects/Errors	Construction defects/errors	CS
Dresden 2	BWR	5/27/1971	Condensate	18	Rupture	Ltr DL 6/4/71	Construction Defect/Errors	Construction defect/error	CS
Millstone 1	PWR	9/25/1972	Atmosphere control header	18	Leak		Fatigue-Vibrational	Liquid nitrogen problem, 2 cracks	SS
Indian Point 2	PWR	11/13/1973	Feedwater	18	Breakage		Water hammer	Water hammer, breakage 180 deg	CS
Cooper	BWR	10/11/1975	Service Water	18	Leak	UE 75-18, letter to NRC (11/10/75)	Erosion/Corrosion	Erosion/corrosion	CS
Cooper	BWR	9/12/1977	Service Water	18	Leak	RO 77-49	Erosion/Corrosion	Erosion/corrosion	CS
Beaver Valley 1	PWR	6/18/1979	Feedwater	18	Crack	79-014	Thermal Fatigue		CS
Surry 2	PWR	12/8/1982	feedwater	18	rupture	86-020	erosion/corrosion	erosion/corrosion	CS
Byron 1	PWR	5/29/1986	Feedwater Elbow	18	Leak	NPRDS	Erosion/Corrosion	Elbow, Sch 120, mode-1	CS
Susquehanna 2	BWR	2/3/1988	service water	18	leak	NPDES	unknown	unknown cause	CS
Sequoyah 1	PWR	6/14/1988	feedwater	18	leak	IN 93-020	thermal fatigue	thermal fatigue	CS
Indian Point 2	PWR	5/27/1991	SWS cont. fan coolers	18	Leak		Erosion/Corrosion	Sch 40, 0.5 gpm, outage	CS
Diablo Canyon 1	PWR	9/24/1992	Feedwater	18	Crack/Leak	92-022	Thermal Fatigue	Thermal fatigue	CS
Brunswick 1	BWR	10/19/1992	Service Water	18	Leak	92-008	Unknown	Unknown	CS
Cooper	BWR	3/16/1993	Service Water	18	Leak	93-014	Construction Defect/Errors	Bad valve design	CS
Beaver Valley 1	PWR	8/8/1994	SWS (CI-3)	18	Leak	ACN: 9412290 334	Not Given		CS
Oconee 2	BWR	9/24/1996	Drain in steam line	18	Rupture		Water hammer		CS
Three Mile Island 1	PWR	11/21/1972	river water decay heal line	20	leak	RO-76-42	not given	local stress	CS
Beaver Valley 1	PWR	5/10/1974	SWS	20	Leak	Letter DRO	Design Error		CS
Hatch 1	BWR	3/9/1978	Residual heat removal	20	Leak		Stress Corrosion/IGSCC	IGSCC, indications of leak	SS
Salem 1	PWR	9/15/1982	turbine return line	20	leak	PNO-I-86-075	erosion/corrosion		CS
Pilgrim	BWR	7/9/1983	salt SWS	20	leak	NPRDS	erosion/corrosion	sch 40, rubber lined pipe	CS
Haddam Neck 1	PWR	4/25/1986	Steam extraction	20	Rupture		Erosion/Corrosion	28 in x G25	CS
Millstone 1	PWR	5/22/1989	SWS	20	Leak		Erosion/Corrosion	Sch 40	CS
Clinton	BWR	9/13/1989	SWS CCW	20	leak	NPRDS	Cavitation	Sch 40, pinhole leak, at power	CS
Clinton	BWR	8/21/1990	CCW SWS	20	leak	NPRDS	Cavitation	Sch 40, small leak, poor design	CS
Brunswick 2	BWR	11/9/1990	SWS	20	Leak	NPRDS	Corrosion, Pitting	Sch 40, leak 1 of 2 leaks	CS
Brunswick 2	BWR	11/9/1990	SWS	20	Leak	NPRDS	Not Given	Sch 40, leak 2 of 2 leaks	CS
Quad Cities 2	BWR	3/15/1976	steam	22	leak	80-017	stress corrosion/IGSCC	IGSCC	CS
Monticello	BWR	9/28/1982	Coolant recirculation	22	Leak		Stress corrosion	Stress Corrosion	SS
Monticello	BWR	11/2/1982	Steam	22	Leak		Stress Corrosion/IGSCC	IGSCC	CS
Monticello	BWR	11/3/1982	Steam	22	Leak		Stress Corrosion/IGSCC	IGSCC	CS
Pilgrim	BWR	7/7/1983	salt SWS	22	leak	NPRDS	erosion/corrosion	sch 40, 7gpm, buried 20ft x 1/4 in?	CS
Hatch 1	BWR	10/11/1984	Recirculation	22	Leak		Not Given	15 cracks	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Pilgrim	BWR	3/21/1987	salt SWS	22	leak	NPRDS	erosion/corrosion	Sch 40, 3-5 gpm, rubber lined pipe, refueling	CS
Oconee 3	BWR	1/1/1976	Steam line	24	Leak		Erosion/Corrosion	Pinhole leak in elbow	CS
Haddam Neck 1	PWR	6/15/1976	Main steam	24	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Trojan	PWR	1/8/1978	turbine exhaust	24	leak	NPE VI.D.262	erosion/corrosion		CS
Zion 1	PWR	2/15/1978	main steam	24	leak	PNO-III-82-21A	corrosion/fatigue	8" crack at weld, corrosion/fatigue, E/C, pipe size 24-37.5	CS
Browns Ferry 3	BWR	4/1/1978	Condensate Header	24	Leak	NPE VII.E.147 (BWR-2, Book-2)	Not Given	20"-24" junction, large leak, 80,000 gallons lost, similar event in 11/77	CS
Dresden 3	BWR	11/4/1978	Main steam	24	Leak	78-052	Erosion/Corrosion	Leak at bottom of an elbow in the moisture separator area, Erosion/Corrosion	CS
Salem 2	PWR	6/21/1979	service water	24	leak	83-032	unknown	gasket failure	CS
Sequoyah 1	PWR	10/6/1979	ERCW	24	leak	NPRDS	erosion/corrosion	sch 40	CS
Surry 1	PWR	10/14/1979	high pressure core injection	24	rupture	PNO-II-83-082	unknown	unknown cause	SS
Sequoyah 1	PWR	11/6/1979	ERCW	24	leak	NPRDS	erosion/corrosion	sch 40, elbow	CS
Sequoyah 1	PWR	2/13/1980	ERCW	24	leak	NPRDS	erosion/corrosion	sch 40	CS
Sequoyah 1	PWR	2/13/1980	ERCW	24	leak	NPRDS	erosion/corrosion	sch 40	CS
Millstone 2	PWR	4/1/1982	SWS	24	Leak		Corrosion	Sch 40 , coating failures	CS
Browns Ferry 1	BWR	6/24/1982	Turbine Exhaust	24	Leak	NPE VI.D 262	Erosion/Corrosion		CS
Oconee 2	BWR	6/25/1982	Main steam	24	Rupture		Erosion/Corrosion	Erosion/Corrosion	CS
Millstone 2	PWR	10/31/1984	Reactor building cooling water	24	Leak		Erosion/Corrosion	Sch 40	CS
Byron 1	PWR	6/11/1985	Feedwater pump discharge line	24	Leak	NPRDS	Weld Defect		CS
Millstone 2	PWR	4/10/1987	RBCW	24	Leak		Corrosion	Sch 40	CS
Millstone 2	PWR	5/28/1987	RRCU	24	Leak		Erosion/Corrosion	Sch 40	CS
Millstone 2	PWR	10/15/1987	RBCW	24	Leak		Erosion/Corrosion	Sch 40, questionable failure mechanism, brackish water	CS
South Texas 2	PWR	12/9/1987	main steam drain	24	leak	NPRDS	stress corrosion cracking	sch 80	CS
Hope Creek	BWR	7/12/1988	SWS aux. cooling	24	Leak		Not Given	Sch 40, pinhole leak, epoxy coating failed	CS
Millstone 2	PWR	10/27/1988	Reactor building cooling water	24	Leak		Construction Defect	Sch 40, poor weld	CS
Surry 1	PWR	2/3/1990	SWS spray	24	leak	LER-94-3	not given	failure of tar epoxy coating	CS
Millstone 2	PWR	5/15/1990	SWS	24	Leak		Erosion/Corrosion	Sch 40, 1 in hole	CS
Millstone 2	PWR	8/28/1990	SWS	24	Leak		Erosion/Corrosion	Sch 40	CS
Millstone 2	PWR	10/1/1990	SWS	24	Leak		Erosion/Corrosion	Sch 40	CS
Millstone 1	PWR	4/8/1992	SWS	24	Leak		Erosion/Corrosion	Degraded coating	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Millstone 1	PWR	10/29/1993	Service water	24	Leak		Erosion/Corrosion	Questionable failure mechanism	CS
Millstone 2	PWR		SWS	24	Leak		Not Given	Ductile iron	CS
Millstone 3	PWR		SWS	24	Leak		Not Given	Ductile iron	CS
Nine Mile Point 1	BWR	3/23/1982	Coolant recirculation	28	Crack/Leak		Stress Corrosion/IGSCC	IGSCC	SS
Monticello	BWR	10/9/1982	Recirc.	28	Crack/Leak		IGSCC		SS
Dresden 2	BWR	1/15/1983	Coolant recirculation	28	Leak	83-008	Stress Corrosion/IGSCC	IGSCC	SS
Brunswick 1	BWR	1/18/1983	Coolant Recirculation	28	Crack/Leak	83-004	Stress Corrosion/IGSCC	IGSCC (2/2)	SS
Brunswick 1	BWR	1/18/1983	Coolant Recirculation	28	Crack/Leak	83-004	Stress Corrosion/IGSCC	IGSCC (1/2)	SS
Cook 1	PWR	5/1/1973	Steam	30	leak	NPE VI.D.62	Construction defect/errors		CS
Calvert Cliffs 1	PWR	12/2/1974	Service Water	30	Leak	AO 74-13	Erosion/Corrosion	Erosion	CS
Calvert Cliffs 1	PWR	3/31/1976	Service Water	30	Leak	RO 76-11	Erosion/Corrosion	Erosion	CS
Calvert Cliffs 1	PWR	3/31/1976	Service Water	30	Leak	76-003L	Erosion/Corrosion	Erosion	CS
Calvert Cliffs 2	PWR	6/13/1977	Service water	30	leak	77-042	Erosion/Corrosion	Welded carbon steel pipe lined with concrete mortar, E/C	CS
Dresden 2	BWR	2/25/1983	Coolant recirculation	30	Leak	83-015	Stress Corrosion/IGSCC	Stress corrosion	SS
St. Lucie 1	PWR	4/19/1984	CCW (saltwater)	30	leak	NPRDS	corrosion	sch 40, salt water corrosion	CS
WPPSS 2		9/8/1984	condensate	30	leak	88-034	other	nitrogen; liquid; shocked	CS
Calvert Cliffs 1	PWR	11/10/1984	SWS	30	Leak	NPRDS	Erosion	Sch 40, cast iron, saltwater	CS
Wolf Creek	PWR	3/23/1986	ESW	30	leak	NPRDS	erosion/corrosion	sch 80, 100% power	SS
St. Lucie 2	PWR	4/13/1986	SWS	30	leak	NPRDS	erosion/corrosion	sch 40	CS
South Texas 2	PWR	9/23/1986	ECW	30	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	SS
South Texas 1	PWR	8/5/1987	CCW	30	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	CS
St. Lucie 2	PWR	9/6/1987	intake cooling water elbow	30	leak	NPRDS	corrosion	sch 40, threaded connection, salt water corrosion	SS
South Texas 1	PWR	11/6/1987	CCW	30	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	CS
South Texas 1	PWR	11/13/1987	ECW	30	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	SS
South Texas 1	PWR	5/8/1988	CCW	30	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	CS
Perry	BWR	10/10/1988	condensate	30	leak	NPRDS	construction defect	sch 80, 10 gpm, 9.5-in. circ crack, poor weld	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
South Texas 1	PWR	6/10/1989	ECW	30	leak	NPRDS	dealloying	sch 40, cracked weld, dealloying of SS Al-bronze interface	SS
Hope Creek	BWR	6/18/1990	SWS	30	Leak		Erosion/Corrosion	Leak 1 of 2 leaks found between June 18 and June 22	CS
Hope Creek	BWR	12/27/1990	Service water	30	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Millstone 3	PWR	3/11/1991	SWS	30	Leak		Pitting	Leak 1 of 2 leaks found in expansion joint due to pitting	CS
Millstone 3	PWR	3/11/1991	SWS	30	Leak		Pitting	Leak 2 of 2 leaks found in expansion joint due to pitting	CS
Millstone 3	PWR	7/4/1991	SWS	30	Leak		Erosion/Corrosion		CS
Calvert Cliffs 1	PWR	11/24/1991	Saltwater Header	30	Leak	ACN:9112650012	Corrosion		CS
Indian Point 3	PWR	11/30/1992	Condensate expansion joint	30	Leak		Fatigue	Sch 80, air in-leakage, 75% power	CS
Indian Point 3	PWR	12/8/1992	Condensate expansion joint	30	Leak		Not Given	Sch 80, overload, full power	CS
Indian Point 3	PWR	1/6/1993	Condensate expansion joint	30	Leak		Wear	Sch 80, air in-leakage, full power	CS
Indian Point 3	PWR	1/14/1993	Expansion joint condensate	30	Leak		Deformation	Sch 80, air in-leakage, full power	CS
Indian Point 3	PWR	1/20/1993	Condensate expansion joint	30	Leak		Deformation	Sch 80, air in-leakage, full power	CS
Indian Point 3	PWR	2/3/1993	Condensate expansion joint	30	Leak		Construction Defect/Errors	Sch 80, air in-leakage, wrong parts used, full power	CS
Hope Creek	BWR	6/18/1990	SWS	31	Leak		Erosion/Corrosion	Leak 1 of 2 leaks found between June 18 and June 23	CS
Millstone 1	PWR	7/31/1985	SWS	34	Leak		Corrosion	Sch 80	CS
Millstone 1	PWR	8/1/1985	ESW	34	Leak		Erosion/Corrosion	Sch 80	SS
Millstone 1	PWR	11/8/1989	SWS	34	Leak		Erosion/Corrosion	Sch 80, questionable failure mechanism	CS
Millstone 1	PWR	12/29/1989	SWS	34	Leak		Erosion/Corrosion	Sch 80, salt water	CS
Millstone 1	PWR	2/24/1992	SWS	34	Leak		Erosion/Corrosion	Sch 80, salt water	CS
Millstone 1	PWR	7/12/1992	SWS	34	Leak		Erosion/Corrosion	Sch 80, salt water	CS
Millstone 1	PWR	7/24/1985	SWS	36	Leak		Erosion/Corrosion	Sch 40	CS
Perry	BWR	12/21/1987	circ. Water to turbine bay	36	rupture	not given	not given	fiberglass pipe at elbow	CS
Perry	BWR	12/21/1987	component cooling	36	rupture	91-027 [2-92:241]	construction defect/errors	construction defects/errors	CS
Catawba 1	PWR	7/22/1992	Turbine line	50	rupture	92-009	unknown	unknown cause	CS
Hatch 2	BWR	2/3/1984	Vent header	66	Fracture		Not Given	Brittle Fracture	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Prairie Island 1	PWR	9/9/1971	condensate	84	leak	75-007	unknown	cooling tower leak, unknown cause	CS
Oyster Creek	BWR	6/15/1972	Emergency core cooling	100	Rupture		Unknown	Exp. Joint; NISC 109	SS
Three Mile Island 2	PWR	1/14/1975	main steam atmospheric relief valve bellows	100	rupture	PNO-I-79-06	unknown	cause not determined	CS
LaSalle 1	BWR	11/16/1984	Turbine line	100	Rupture		Not Given	Bellows failed	CS
Dresden 2	BWR	9/29/1985	Bellows at steam relief valve	100	Rupture	LER-85-35	Not Given	Bellows failed	CS
Clinton	BWR	7/14/1989	Condensate	100	failed	89-029	Aged	Aged expansion joint	CS
Grand Gulf	BWR	8/14/1989	Condensate	100	Breakage	89-012	Unknown	Expansion joint	CS
Oconee 2	BWR	5/4/1995	Steam extraction line	100	Rupture		Not Given	Expansion joint	CS
Quad Cities 1	BWR	6/8/1968	condensate	120	rupture	letter on 6/11/72	water hammer	water hammer, exp. Joint	CS
Palo Verde	PWR	6/28/1987	Line near condenser	120	Rupture		Water hammer	Several leaks	CS
Palo Verde 1	PWR	6/28/1987	Circ water loop	120	Rupture		Water hammer		CS
Turkey Point 3	PWR	1/5/1969	reactor coolant	<1	leak	AO 73-1	unknown	leaked flow transmitter, unknown cause	SS
Indian Point 1	PWR	8/8/1969	Reactor Coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Indian Point 1	PWR	9/12/1969	RCS	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Oyster Creek	BWR	3/25/1970	Flow sensor	<1	Leak		Unknown	Fitting failed	SS
Three Mile Island 1	PWR	6/2/1970	reactor coolant	<1	leak	AO 74-06	fatigue-vibrational	fatigue-vibrational	SS
Yankee Rowe	PWR	8/24/1970	instrumentation	<1	leak	AO 74-5	unknown	unknown cause	SS
Prairie Island 2	PWR	12/15/1970	pressurizer	<1	leak	letter to NRC (3/4/75)	other	leaked tube caused by personnel error	SS
Surry 2	PWR	12/31/1970	flow transmitter	<1	failed	fiche 50281-385	not given		SS
Yankee Rowe	PWR	2/7/1971	flow sensor	<1	leak	AO 75-1	fatigue-vibrational	fatigue-vibrational	SS
Yankee Rowe	PWR	2/18/1971	flow sensor	<1	leak	AO 75-3	fatigue-vibrational	fatigue-vibration	SS
Prairie Island 2	PWR	3/3/1971	reactor coolant	<1	leak	ORNL-NSIC-127:100426	construction defect/errors	construction defect	SS
Yankee Rowe	PWR	3/20/1971	flow sensor	<1	leak	AO 75-4	fatigue-vibrational	fatigue-vibration, IGSCC	SS
Prairie Island 1	PWR	7/6/1971	reactor coolant seal injection line	<1	leak	ORNL-NSIC-127:104085	fatigue-vibrational		SS
Yankee Rowe	PWR	8/6/1971	reactor coolant	<1	leak	AO 75-7	fatigue-vibrational	fatigue-vibration at nozzle	SS
Palisades	PWR	2/26/1972	Charging	<1	Leak		Fatigue-Vibrational		SS
Palisades	PWR	3/6/1972	Charging pump line socket weld	<1	Leak		Fatigue-Vibrational		SS
Palisades	PWR	11/2/1972	Reactor coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Cook 1	PWR	12/1/1972	Component coolers	<1	leak	ORNL-NSIC-87:35027	fatigue-vibrational	fatigue-vibration	CS
Cook 2	PWR	12/1/1972	Component coolers	<1	leak	ORNL-NSIC-87:35027	fatigue-vibrational	fatigue-vibrational	CS
San Onofre 1	PWR	1/23/1973	residual heat removal	<1	leak	77-003	construction defect/errors	maintenance error	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Yankee Rowe	PWR	2/23/1973	service water	<1	leak	77-010	unknown	weld failure, unknown cause, overstressed	CS
Turkey Point 3	PWR	6/9/1973	component cooling	<1	leak	RO 77-6	unknown	leaked radiator, unknown cause	CS
Ginna	PWR	8/1/1973	Feedwater	<1	Severed	Ltr DR; 8/1/73	Unknown	swage lock pulled away from flow orifice	CS
Millstone 1	PWR	12/30/1973	Condensate	<1	Leak		stress Corrosion/IGCSS	Tube cracked, unknown cause	CS
Turkey Point 4	PWR	2/28/1974	charging	<1	leak	NPE VIII>A.288	fatigue-vibrational		SS
Oyster Creek	BWR	6/7/1974	Instrument line	<1	Leak		Unknown	Unknown cause	SS
Surry 1	PWR	8/1/1974	component cooling	<1	failed	78-026	corrosion	corrosion	CS
Salem 1	PWR	8/29/1974	service water	<1	leak	78-059	erosion/corrosion	leaked fittings, erosion/corrosion	CS
Salem 1	PWR	9/30/1974	component cooling	<1	leak	78-069	corrosion	corrosion	CS
Dresden 2	BWR	12/10/1974	Reactor coolant/LPCI	<1	Crack/Leak	AO 74-73	Construction Defect/Errors	Construction defects	SS
Dresden 2	BWR	12/20/1974	LPCI drain line	<1	Leak	Letter DRO	Construction Error	Weld L-O-P, poor weld	SS
Maine Yankee 1	PWR	1/22/1975	Coolant recirculation	<1	Leak		Erosion/Corrosion	Erosion	SS
Fitzpatrick	BWR	1/29/1975	Containment spray	<1	Leak	AO 75-13	Unknown	Weld leak, unknown cause	SS
Indian Point 2	PWR	1/29/1975	Reactor Coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Calvert Cliffs 1	PWR	3/1/1975	Pump Pressure Sensor	<1	Leak	NPE V.A.46	Unknown		SS
Calvert Cliffs 1	PWR	3/17/1975	Reactor Coolant Sensing Line	<1	Leak	AO 75-25	Fatigue	Weld Failure	SS
Turkey Point 3	PWR	3/27/1975	instrument line	<1	leak	79-009	unknown	leaked water level indication line, unknown cause	SS
Zion 1	PWR	4/15/1975	feedwater/condenser	<1	leak	LER-79-031	fatigue, construction defect		CS
Cook 1	PWR	5/27/1975	RHR	<1	leak	NPE VIII.B.102	fatigue-vibrational		SS
Indian Point 1	PWR	6/16/1975	Inst. Pressure sensing line, clean water storage tank	<1	Puncture		Not Given	Drilled hole punctured line	SS
Monticello	BWR	7/13/1975	Flow sensor	<1	Leak		Unknown	Leaked reactor pressure gauge sensor, unknown cause	SS
ANO1	PWR	7/20/1975	Flow Sensor	<1	Leak	AO 75-3	Fatigue-Vibrational	Fatigue-vibration	SS
Calvert Cliffs 1	PWR	9/1/1975	Instrument Line	<1	Leak	NPE VIII.A.279	Fatigue-Vibrational		SS
Hatch 1	BWR	10/17/1975	High pressure core injection	<1	Leak		Unknown	Unknown cause	SS
Calvert Cliffs 1	PWR	10/24/1975	Service Water	<1	Leak	AO 75-55	Fatigue-Vibrational	Fatigue-vibration	CS
Rancho Seco	PWR	11/24/1975	containment heat removal	<1	leak	79-019	fatigue-vibrational	fatigue-vibrational	CS
Surry 1	PWR	12/13/1975	boric acid	<1	leak	79-039	stress corrosion/IGSCC	stress corrosion	SS
Cook 1	PWR	1/10/1976	Instrument line	<1	leak	RO 76-07	fatigue-vibrational		SS
Cook 1	PWR	3/15/1976	Instrument line	<1	leak	RO 76-07	Fatigue-vibrational	fatigue-vibrational	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Indian Point 3	PWR	3/17/1976	Accumulators	<1	Crack/Leak		Construction Defect/Errors	Fatigue, poor weld contour, construction defect	SS
Indian Point 3	PWR	3/30/1976	Reactor Coolant	<1	Crack/Leak		Fatigue		SS
Calvert Cliffs 1	PWR	4/2/1976	Coolant Recirculation	<1	Leak	RO 76-12	Erosion/Corrosion	Two-phase	SS
Cook 1	PWR	4/30/1976	component cooling	<1	leak	RO 76-16	unknown	unknown cause	CS
Turkey Point 3	PWR	4/30/1976	boron transporter	<1	leak	NPE VIII.A.524	stress corrosion cracking	SCC	SS
Sequoyah 1	PWR	5/11/1976	flow sensor	<1	rupture	80-057	unknown	compression fitting failed, unknown cause	SS
Salem 1	PWR	5/31/1976	charging	<1	leak	NPE VIII.A.437	fatigue		SS
Calvert Cliffs 1	PWR	6/1/1976	Service Water	<1	Leak	76-033	Erosion/Corrosion	Erosion/Corrosion	CS
Monticello	BWR	6/14/1976	Service water	<1	Leak		Construction Defects/Errors	construction defect	CS
ANO1	PWR	6/22/1976	Makeup System	<1	Leak	RO 76-12	Fatigue-Vibrational	Fatigue-vibration	SS
Brunswick 2	BWR	7/2/1976	Service Water	<1	Leak	RO 76-92	Fatigue-Vibrational	Fatigue-vibration	CS
Brunswick 2	BWR	7/2/1976	Service Water	<1	Leak	RO 76-91	Fatigue-Vibrational	Fatigue-vibration	CS
Indian Point 3	PWR	9/2/1976	Pressurizer	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Monticello	BWR	9/29/1976	Feedwater	<1	Leak		Fatigue-Vibrational	Fatigue-vibration	CS
Vermont Yankee	BWR	10/13/1976	core spray sparger	<1	leak	80-33	IGSCC		SS
Robinson 2	PWR	11/29/1976	pressure gauge tap sock-o-let to regenerative HX	<1	leak	80-030	fatigue-vibrational		SS
Calvert Cliffs 2	PWR	12/1/1976	Chemical and Volume Control	<1	Leak	LER-76-005/IP	Fatigue-Vibrational		SS
Calvert Cliffs 2	PWR	12/1/1976	Chemical and Volume Control	<1	Leak	LER-76-006/IP	Fatigue-Vibrational		SS
Calvert Cliffs 2	PWR	12/1/1976	chemical and volume control	<1	crack/leak	76-005	fatigue-vibrational	fatigue-vibration	SS
Robinson 2	PWR	12/1/1976	pressure gauge tap sock-o-let to regenerative HX	<1	leak	80-030	fatigue-vibrational		SS
Robinson 2	PWR	12/1/1976	pressure gauge tap sock-o-let to regenerative HX	<1	leak	80-030	fatigue-vibrational		SS
Calvert Cliffs 1	PWR	12/6/1976	Pressurizer	<1	Crack/Leak	76-055	Thermal Fatigue	Cracked weld, fatigue	SS
Calvert Cliffs 2	PWR	1/15/1977	chemical and volume control	<1	leak	77-008	fatigue-vibrational	cracked weld	SS
Salem 1	PWR	1/25/1977	containment heat removal	<1	leak	81-010	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Indian Point 2	PWR	2/1/1977	Reactor Coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 1	PWR	3/10/1977	thimble tube	<1	leak	81-028	unknown	fretting between tubes and nozzle blocks	SS
Indian Point 2	PWR	3/11/1977	Pressurizer	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 1	PWR	3/23/1977	containment heat removal	<1	leak	81-031	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 1	PWR	4/21/1977	containment heat removal	<1	leak	81-039	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Calvert Cliffs 2	PWR	6/27/1977	CCW	<1	leak	77-050	Loose Joint		CS
Calvert Cliffs 2	PWR	6/30/1977	service water	<1	leak	77-046	fatigue-vibrational	Fatigue-vibrational, cracked weld	CS
Salem 1	PWR	7/8/1977	thimble tube	<1	leak	81-028	unknown	fretting between tubes and nozzle blocks	SS
Turkey Point 4	PWR	7/16/1977	reactor coolant	<1	leak	81-008	stress corrosion/IGSCC	stress corrosion cracking at nipple	SS
Browns Ferry 2	BWR	8/1/1977	Reactor Sensor Line	<1	Leak	IX.E. 1008 (NPE, BWR-2 Book-3)	IGSCC		SS
Salem 2	PWR	8/5/1977	service water	<1	leak	81-064	erosion/corrosion	leaked fan cooler, erosion/corrosion	CS
Salem 1	PWR	8/12/1977	containment heat removal	<1	leak	81-072	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
San Onofre 1	PWR	8/15/1977	reactor coolant	<1	leak	81-019	corrosion/fatigue	threaded joint wear, corrosion fatigue, joint tightened	SS
Salem 1	PWR	8/23/1977	instrument line	<1	leak	81-080	unknown	leaked flow transmitter, unknown cause	SS
San Onofre 1	PWR	8/24/1977	pump seal coolant	<1	leak	NPE VIII.A.546	wear		SS
Salem 1	PWR	8/25/1977	containment heat removal	<1	leak	81-074	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	9/1/1977	containment heat removal	<1	leak	81-076	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	9/1/1977	containment heat removal	<1	leak	81-077	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	9/2/1977	containment heat removal	<1	leak	81-078	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	9/12/1977	containment heat removal	<1	leak	82-090	erosion/corrosion	containment fan coil leaks, corrosion	CS
Salem 1	PWR	10/19/1977	containment heat removal	<1	leak	81-092	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	10/27/1977	containment heat removal	<1	leak	81-094	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	11/6/1977	containment heat removal	<1	leak	81-096	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Zion 2	PWR	11/10/1977	chemical and volume control	<1	failed	81-027	unknown	compression fitting failed	SS
Salem 1	PWR	11/15/1977	thimble tube	<1	leak	81-028	fatigue-vibrational	fretting between tubes and nozzle blocks, vibration	SS
Salem 1	PWR	11/16/1977	containment heat removal	<1	leak	81-105	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	11/18/1977	containment heat removal	<1	leak	81-114	erosion/corrosion	leaked tubes, corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 1	PWR	11/23/1977	containment heat removal	<1	leak	81-108	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	11/24/1977	containment	<1	leak	81-115	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	11/24/1977	containment heat removal	<1	leak	81-115	erosion/corrosion	containment fan coil leaks, corrosion	CS
Salem 1	PWR	11/27/1977	containment heat removal	<1	leak	81-109	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 1	PWR	12/7/1977	containment heat removal	<1	leak	81-114	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Dresden 2	BWR	12/19/1977	High pressure core injection	<1	Leak	RO	Unknown	Steam leak, unknown cause	SS
Salem 1	PWR	12/25/1977	service water	<1	leak	81-118	erosion/corrosion	leaked tubes, erosion/corrosion	CS
Fort Calhoun	PWR	1/17/1978	Charging line	<1	Leak	78-003	Fatigue-Vibrational	Fatigue-vibrational	SS
Pilgrim	BWR	1/17/1978	fire pump sensor	<1	rupture	NPE VII.F. 149 (BWR-2, Book 2)	frozen		CS
Indian Point 2	PWR	2/13/1978	Instrumentation	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Indian Point 2	PWR	2/13/1978	Reactor Coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
North Anna 1	PWR	3/22/1978	Residual heat removal	<1	Leak		Construction Defects/Errors	Construction defect	SS
Salem 1	PWR	4/4/1978	steam	<1	leak	82-021	unknown	leaked tubes due to loose fittings	CS
Calvert Cliffs 1	PWR	4/17/1978	Reactor Coolant	<1	Leak	78-022	Fatigue-Vibrational	Fatigue-vibration	SS
Salem 2	PWR	5/2/1978	containment heat removal	<1	leak	82-028	erosion/corrosion	containment fan coil leaks, corrosion	CS
Salem 2	PWR	5/18/1978	containment heat removal	<1	leak	82-046	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Calvert Cliffs 2	PWR	5/23/1978	Reactor Coolant	<1	leak	78-013	Fatigue-vibrational	fatigue-vibration	SS
Indian Point 2	PWR	6/26/1978	Instrument line	<1	Leak		Erosion/Corrosion	Erosion/Corrosion	SS
Nine Mile Point 1	BWR	6/28/1978	Instrument line waste conc.	<1	Leak		Corrosion	Corrosion	SS
Robinson 2	PWR	7/14/1978	containment heat removal	<1	leak	82-006	erosion/corrosion	leaked tubes, erosion/corrosion	CS
Dresden 3	BWR	8/1/1978	RWCU HX vent line	<1	Leak	NPE VII.A.46 (BWR-2, Book-2)	Fatigue-Vibrational	Questionable failure mechanism	SS
Salem 2	PWR	8/8/1978	containment heat removal	<1	leak	82-070	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	8/12/1978	containment heat removal	<1	leak	82-074	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
ANO1	PWR	8/18/1978	Flow Sensor	<1	Leak	78-021	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	SS
Salem 2	PWR	8/18/1978	containment heat removal	<1	leak	82-078	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	8/20/1978	containment heat removal	<1	leak	80-080	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 2	PWR	8/28/1978	containment heat removal	<1	leak	82-084	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	8/29/1978	containment heat removal	<1	leak	82-089	construction defect/errors	containment fan coil leaks, failed repair	CS
Salem 2	PWR	9/5/1978	containment heat removal	<1	leak	82-091	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	9/7/1978	containment heat removal	<1	leak	82-092	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	9/9/1978	containment heat removal	<1	leak	82-093	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	9/14/1978	containment heat removal	<1	leak	82-100	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	9/15/1978	containment heat removal	<1	leak	82-101	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	9/22/1978	containment heat removal	<1	leak	82-109	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	10/1/1978	containment heat removal	<1	leak	82-111	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	10/4/1978	containment heat removal	<1	leak	82-113	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	10/7/1978	containment heat removal	<1	leak	82-119	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	10/10/1978	containment heat removal	<1	leak	82-120	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	10/17/1978	containment heat removal	<1	leak	82-122	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	10/30/1978	containment heat removal	<1	leak	82-128	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Calvert Cliffs 2	PWR	11/15/1978	Reactor Coolant	<1	leak	78-039	Fatigue-vibrational	fatigue-vibration	SS
Indian Point 2	PWR	11/16/1978	Reactor Coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Salem 2	PWR	11/20/1978	containment heat removal	<1	leak	82-136	erosion/corrosion	containment fan coil leaks, corrosion	CS
Salem 2	PWR	11/20/1978	containment heat removal	<1	leak	82-135	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Salem 2	PWR	11/23/1978	containment heat removal	<1	leak	82-136	erosion/corrosion	containment fan coil leaks, corrosion	CS
Calvert Cliffs 2	PWR	12/25/1978	flow sensor	<1	leak	78-050	corrosion/fatigue	fatigue/corrosion	SS
Fort Calhoun	PWR	12/27/1978	Service Water	<1	Leak	78-046	Fatigue-Vibrational	Fatigue-vibrational	CS
Indian Point 1	PWR	1/1/1979	CVCS	<1	Leak		Fatigue-Vibrational		SS
Sequoyah 1	PWR	2/3/1979	flow sensor	<1	rupture	83-035	construction defect/errors	compression fitting failed; construction defect	SS
Fort Calhoun	PWR	2/26/1979	Reactor Coolant	<1	Leak	79-004	Fatigue-Vibrational	Fatigue-vibrational	SS
Oconee 1	BWR	3/15/1979	Component cooling	<1	Leak		Erosion/Corrosion	Leaked pump cooler tubes, unknown cause	CS
Indian Point 2	PWR	3/29/1979	Service water	<1	Leak		Unknown	Unknown cause	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Robinson 2	PWR	4/9/1979	containment heat removal/SWS	<1	leak	83-003	erosion/corrosion	erosion/corrosion	CS
Oconee 1	BWR	4/19/1979	Component cooling	<1	Leak		Unknown	Leaked pump cooler tubes, unknown cause	CS
Dresden 3	BWR	6/1/1979	Core spray pump bleed line	<1	Leak	NPE VII.C. 81 (BWR-2, Book-2)	Fatigue-Vibrational		SS
Big Rock Point	BWR	6/11/1979	Control Rod Drive	<1	Leak	PNO 79-151	Unknown	Leaked thimble tube weld, unknown cause	SS
Salem 1	PWR	6/30/1979	flux thimbles	<1	leak	NPE PWR-2-II-No.43	wear		SS
Robinson 2	PWR	7/3/1979	service water	<1	leak	83-014	erosion/corrosion	leaked tubes, erosion/corrosion	CS
Indian Point 2	PWR	7/4/1979	Pressurizer	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Three Mile Island 1	PWR	7/7/1979	flow sensor	<1	leak	PNO-TMI-83-004	fatigue-vibrational	loose fittings, vibration	SS
Salem 1	PWR	8/14/1979	chemical and volume control	<1	leak	83-048	erosion/corrosion	leaked tubes, erosion/corrosion	SS
Crystal River 3	PWR	8/22/1979	Makeup system	<1	Leak	79-082	Fatigue-Vibrational	Fatigue-vibration	SS
Robinson 2	PWR	8/22/1979	service water	<1	leak	83-022	unknown	leaked fan cooler, unknown cause	CS
Oconee 1, 2, & 3	BWR	9/1/1979	SWS	<1	Leak		Erosion		CS
St. Lucie 2	PWR	9/7/1979	service water	<1	leak	83-054	construction defect/errors	construction defect/errors	CS
Robinson 2	PWR	9/25/1979	containment heat removal	<1	leak	83-025	erosion/corrosion	leaked tubes, erosion/corrosion	CS
Crystal River 3	PWR	9/29/1979	Makeup	<1	Leak	NPE VIII.A.403	Fatigue-Vibrational		SS
Robinson 2	PWR	10/11/1979	containment	<1	leak	83-026	erosion/corrosion	leaked tubes, erosion/corrosion	CS
Robinson 2	PWR	11/2/1979	containment heat removal	<1	leak	83-027	erosion/corrosion	leaked tubes, erosion/corrosion	CS
Salem 1	PWR	11/9/1979	reactor coolant	<1	leak	83-055	unknown	containment fan coil leaks, unknown cause	SS
Oconee 1	BWR	12/10/1979	Component cooling	<1	Leak		Unknown	Leaked pump cooler tubes, unknown cause	CS
Zion 2	PWR	12/12/1979	containment heat removal	<1	leak	83-0145	erosion/corrosion	leaked tube, corrosion pitting	CS
Salem 1	PWR	12/22/1979	component cooling	<1	leak	83-073	fatigue-vibrational	leaked diesel generator jacket water heater, fatigue-vibration	CS
Crystal River 3	PWR	12/24/1979	Makeup	<1	Leak	NPE VIII.A.403	Fatigue-Vibrational		SS
Zion 1	PWR	1/19/1980	seal tabs	<1	leak	LER 84-005	, IN 84-55	not given	CS
Oconee 1	BWR	2/16/1980	Service water	<1	Leak		Erosion/Corrosion	Erosion/corrosion	CS
Calvert Cliffs 2	PWR	4/17/1980	Instrument Line	<1	leak	80-024	Unknown	Unknown cause, failed part contaimnated	SS
Zion 2	PWR	5/2/1980	containment heat removal	<1	leak	84-013	erosion/corrosion	fan coil thinning, corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Oconee 1	BWR	6/1/1980	Component cooling	<1	Leak		Erosion/Corrosion	Leaked pump cooler tubes, unknown cause	CS
Peach Bottom 3	BWR	6/9/1980	instrument line- jet pump	<1	leak	84-008	stress corrosion/IGSCC	IGSCC	SS
Oconee 1	BWR	7/7/1980	Component cooling	<1	Leak		Erosion/Corrosion	Leaked pump cooler tubes, erosion/corrosion	CS
Dresden 2	BWR	7/28/1980	Reactor Water Cleanup	<1	Leak	80-029	Thermal Fatigue	Thermal Fatigue Cracking	SS
ANO2	PWR	8/23/1980	Sevice Water	<1	Leak	80-068	Fatigue-Vibrational	Fatigue-vibration	CS
Fort Calhoun	PWR	10/27/1980	Pressurizer	<1	Leak	80-025	Fatigue-Vibrational	Fatigue-vibrational	SS
Calvert Cliffs 2	PWR	12/9/1980	component cooling	<1	leak	80-055	Unknown	compression fitting failed, unknown cause	CS
ANO2	PWR	1/1/1981	Charging	<1	Leak	NPE VIII.A.530	Fabrication Defect		SS
Ginna	PWR	2/11/1981	Condensate	<1	Leak	RO 81-004	Unknown	Plugged drain, unknown cause	CS
Beaver Valley 1	PWR	2/21/1981	Reactor Coolant	<1	Leak	81-014	Corrosion	Corrosion	SS
Calvert Cliffs 2	PWR	3/3/1981	Containment Heat Removal	<1	leak	81-035	Construction Defect/Errors	Construction Defect/Errors	CS
Salem 1	PWR	3/19/1981	containment heat removal	<1	leak	85-006	erosion/corrosion	containment fan coil leaks, erosion/corrosion	CS
Turkey Point 4	PWR	4/10/1981	pressurizer	<1	leak	85-008	unknown	loose fitting	SS
Browns Ferry 3	BWR	5/1/1981	Reactor Sensor Line	<1	Leak	IX.E. 1008 (NPE, BWR-2 Book-3)	IGSCC		SS
Indian Point 2	PWR	5/11/1981	Residual heat removal	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Beaver Valley 1	PWR	5/19/1981	Instrument Line	<1	Leak	81-062	Unknown	Pipe threading failure, unknown cause	SS
Beaver Valley 1	PWR	6/19/1981	Aux. Feedwater	<1	Leak	81-062	Fatigue-Vibrational	Questionable failure mechanism	CS
Browns Ferry 3	BWR	7/1/1981	Residual Heat Removal	<1	Leak	81-032	Unknown	Unknown Cause	SS
Cook 1	PWR	7/1/1981	Service water	<1	leak	81-020	Construction Defect/Errors	leaked coil, construction defect	CS
Farley 2	PWR	7/17/1981	Instrumentation	<1	Failed	81-028	Fatigue-Vibrational	Fatigue-vibration	SS
Farley 1	PWR	7/24/1981	Instrument line	<1	Leak	81-052	Fatigue-Vibrational	Fatigue-vibration	SS
McGuire 1	PWR	8/11/1981	Service water	<1	Leak		Unknown	Leaked tube from loose fitting	CS
Beaver Valley 1	PWR	8/17/1981	Containment heat removal	<1	Leak	81-077	Thermal Fatigue	Thermal Fatigue	CS
ANO1	PWR	8/26/1981	Residual Heat Removal	<1	Leak	81-013	Fatigue-Vibrational	Fatigue-vibration	SS
Fort Calhoun	PWR	9/24/1981	Instrument air	<1	Leak	81-009	Construction Defect/Errors	Pressurized air leak, stripped threading, construction defect	SS
Big Rock Point	BWR	9/30/1981	Coolant Recirculation	<1	Leak	81-024	Erosion/Corrosion	Corrosion in cooling unit coils	SS
Calvert Cliffs 1	PWR	11/16/1981	Spent Fuel Pool	<1	Failed	81-080	Unknown	Cracked weld, unknown cause	CS
Browns Ferry 1	BWR	12/11/1981	Component Cooling	<1	Leak	81-089	Unknown	Cracked nipple, unknown cause	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
St. Lucie 2	PWR	1/6/1982	component cooling	<1	leak	86-001	other	personnel error	CS
Cook 1	PWR	1/15/1982	Instrument air	<1	leak	82-005	unknown	broken threded ripple, unknown cause	SS
Beaver Valley 1	PWR	1/19/1982	Coolant Recirculation	<1	Crack	82-002	Other	Frozen Pipe	SS
Big Rock Point	BWR	1/28/1982	Coolant Recirculation	<1	Leak	82-003	Corrosion	Corrosion	SS
Salem 1	PWR	6/3/1982	SWS/CFCU	<1	leak	SR 86-3	corrosion		CS
Palo Verde 1	PWR	7/9/1982	Reactor coolant	<1	Leak		Thermal Fatigue	Thermal Fatigue	SS
Kewaunee	PWR	8/1/1982	Boric Acid	<1	Leak		Corrosion	Corrosion	SS
Oconee 1	BWR	8/11/1982	Component cooling	<1	Leak		Erosion/Corrosion	Leaked pump cooler tubes, erosion/corrosion	CS
Calvert Cliffs 1	PWR	8/20/1982	Reactor Coolant	<1	Leak	82-055	Unknown	Unknown Cause	SS
ANO1	PWR	1/7/1983	Spent Fuel Pool	<1	Leak	83-002	Fatigue-Vibrational	Fatigue-vibration	CS
Salem 1	PWR	5/13/1983	containment heat removal	<1	leak	special report 87-3	erosion/corrosion	leaked tubes, corrosion	CS
McGuire 12	PWR	5/21/1983	Flow sensor	<1	Leak		Unknown	Tube fitting leaked, fitting replace	SS
Salem 1	PWR	5/26/1983	containment heat removal	<1	leak	special report 87-4	unknown	leaked gasket in fan coil	CS
Browns Ferry 1	BWR	6/14/1983	Instrument Line	<1	Leak	83-031	Unknown	Unknown Cause	SS
ANO2	PWR	8/25/1983	Reactor Coolant Pump Pressure Sensing Line	<1	Leak	83-039	Fatigue-Vibrational		SS
Dresden 2	BWR	9/5/1983	Steam	<1	Leak	83-064	Thermal Fatigue	Thermal fatigue	CS
Salem 1	PWR	9/27/1983	containment heat removal	<1	leak	special report 87-8	corrosion	corrosion of spool weld	CS
Calvert Cliffs 1	PWR	10/10/1983	Instrumentation	<1	Leak	83-057	Fatigue-Vibrational	Fatigue-vibration	SS
McGuire 11	PWR	10/25/1983	Instrument line	<1	Leak		Unknown	Compression fitting failed	SS
Kewaunee	PWR	10/28/1983	Charging line	<1	Leak		Fatigue-Vibrational		SS
Cook 2	PWR	11/5/1983	Component Cooling	<1	leak	83-107	Fatigue-vibrational	Compression fitting failed, fatigue-vibration	CS
McGuire 10	PWR	11/14/1983	Instrument line	<1	Leak		Unknown	Compression fitting failed	SS
Salem 2	PWR	12/8/1983	containment heat removal	<1	leak	special report 87-6	other	containment fan coil leaks, loose plug, plug tightened	CS
Cooper	BWR	9/15/1984	Control Rod Drive	<1	Leak	PNO-IV-84-018	Fatigue-Vibrational	Fatigue-vibration	SS
Prairie Island 1	PWR	11/7/1984	condensate	<1	leak	PNO-III-88-091	unknown	steam tube leaked, unknown cause	CS
Browns Ferry 3	BWR	11/20/1984	Reactor Sensor Line	<1	Leak	IX.E. 1008 (NPE, BWR-2 Book-3)	IGSCC		SS
Turkey Point 3	PWR	1/15/1985	reactor coolant	<1	leak	89-002	stress corrosion/IGSCC	stress corrosion cracking	SS
Browns Ferry 3	BWR	2/13/1985	Reactor Sensor Line	<1	Leak	IX.E. 1008 (NPE, BWR-2 Book-3)	IGSCC		SS
Fort Calhoun	PWR	3/6/1985	Charging	<1	Leak	NPE VIII.A.739	Unknown		SS
Browns Ferry 3	BWR	3/12/1985	Reactor Sensor Line	<1	Leak	IX.E. 1008 (NPE, BWR-2 Book-3)	IGSCC		SS
Oyster Creek	BWR	12/1/1986	Condenser sensor	<1	Leak		Not Given	External damage	CS
Davis Besse	PWR	12/30/1986	Main steam	<1	Leak	PNO-III-86-156	Fatigue-Vibrational	Fatigue-vibration	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Fermi 2	BWR	1/2/1987	Instrument line	<1	Leak	PNO-III-87-001	Fatigue-Vibrational	Fatigue-vibration, 4 pipe lines failed	SS
Fermi 2	BWR	1/5/1987	Instrument line	<1	Leak	PNO-III-87-001A	Fatigue-Vibrational	Fatigue-vibration, 4 pipe lines failed	SS
Fermi 2	BWR	1/29/1987	Instrument line	<1	Leak	PNO-III-87-016	Fatigue-Vibrational	Fatigue-vibration	SS
Fermi 2	BWR	4/10/1987	Instrument line	<1	Leak	PNO-III-87-055	Fatigue-Vibrational	Fatigue-vibration	SS
ANO2	PWR	4/24/1987	Pressurizer	<1	Leak	87-003	PWSCC	PWSCC	SS
ANO2	PWR	7/6/1987	Reactor Coolant	<1	Leak	87-006	Construction Defect/Error	Construction defect/error	SS
Beaver Valley 2	PWR	7/26/1987	Main Steam	<1	Leak	Special Report	Unknown	Unknown Cause	CS
ANO2	PWR	5/4/1988	Chemical and Volume Control	<1	Leak	88-008	Other	Faulty procedures for connection of threaded fitting for water level transmitter	SS
ANO2	PWR	5/25/1988	Instrument Line	<1	Leak	88-010	Other	Low water level, in injection tank, error	SS
ANO2	PWR	8/1/1988	Pump Seal Pressure Sensing Line	<1	Leak	88-015	Fatigue	Failed, 20 gpm, questionable failure mechanism	SS
Nine Mile Point 1	BWR	1/27/1989	RWCU	<1	Leak		Not Given	Tygess tupc	SS
Calvert Cliffs 2	PWR	5/5/1989	Pressurizer	<1	Leak	89-007, IN 90-10	Stress Corrosion/IGSCC	Stress Corrosion cracking, 23 or 120 penetrations leaked	SS
Indian Point 2	PWR	5/31/1989	Reactor Coolant	<1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
ANO2	PWR	6/23/1989	Reactor Coolant	<1	Leak	PNO-IV-89-042	Fatigue-Vibrational	Fatigue-vibration at pressure sensing line sealant	SS
Susquehanna 2	BWR	12/10/1989	component cooling	<1	leak	93-009	fatigue-vibrational	cracked weld, fatigue-vibrational	CS
ANO1	PWR	2/28/1990	Sevice Water	<1	Leak	90-001	Erosion/Corrosion	Cooling coil leaks, corrosion pitting	CS
Fermi 2	BWR	4/24/1990	RHR	<1	Leak	ACN: 9005160288	Fatigue-Vibrational	Previous leaks found: pump discharge 1987 160 deg. Crack, pump suction nipple 1988, & pump suction pinhole 1989. Previous 135 degree crack in LPCI vent found in 1990.	SS
Palo Verde 3	PWR	5/29/1990	SG instrument and sample nozzles	<1	leak	LER 94-004	weld defect	defective welds	CS
Catawba 2	BWR	9/14/1990	Containment heat removal	<1	leak	Investigation Rpt 2-C90-0294	Construction defect/errors	Construction defect, deficient flanges	CS
Vermont Yankee	BWR	10/12/1990	service water	<1	leak	94-013	unknown	unknown	CS
Crystal River 3	PWR	11/28/1990	Service Water	<1	Leak	90-018	Corrosion	Galvanic corrosion	CS
Sequoyah 2	PWR	2/22/1991	reactor coolant	<1	leak	PNO-II-95-011	unknown	failed fitting	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Beaver Valley 1	PWR	7/4/1991	Thermo couple cono seal	<1	Leak	91-019	Not Given		CS
Ginna	PWR	7/2/1992	Containment heat removal	<1	Leak	Special Report	Erosion/Corrosion	Erosion at fan cooling coils	CS
Ginna	PWR	8/10/1992	Containment heat removal	<1	Leak	Special Report	Erosion/Corrosion	Corrosion at fan cooling coils	CS
Ginna	PWR	8/13/1992	Containment heat removal	<1	Leak	Special Report	Erosion/Corrosion	Corrosion at fan cooling coils	CS
Limerick 1	BWR	8/28/1995	Reactor Coolant	<1	Leak		Construction Defect/Errors	Misaligned flange, construction defect	SS
Dresden 1	BWR	1/1/1962	condenser circ. Line	>1	Leak	NPE VI.F. 5 (BWR-2, Book-8)	Not Given	Repeated leaks of concrete pipe	CS
Point Beach 2	PWR	6/30/1968	CRD housing >1	>1	leak	NPE PWR-2-III-No. 8	stress corrosion cracking	leak 1 of 3 pinhole leaks	SS
Point Beach 2	PWR	6/30/1968	CRD housing >1	>1	leak	NPE PWR-2-III-No. 8	stress corrosion cracking	leak 2 of 3 pinhole leaks	SS
Point Beach 2	PWR	6/30/1968	CRD housing >1	>1	leak	NPE PWR-2-III-No. 8	stress corrosion cracking	leak 3 of 3 pinhole leaks	SS
Vermont Yankee	BWR	3/8/1969	high pressure core injection	>1	leak	AO 73-07	unknown	unknown cause	SS
Prairie Island 2	PWR	12/13/1969	chemical and volume control	>1	leak	letter to NRC (2/24/75)	unknown	leaked weld, unknown cause	SS
Three Mile Island 1	PWR	5/30/1970	containment heat removal	>1	leak	74-002T	erosion/corrosion	erosion/corrosion	CS
Humboldt Bay 3	BWR	10/20/1970	Condensate	>1	Rupture		Unknown	Expansion joint rupture	CS
Surry 1	PWR	11/6/1970	CCW HX	>1	rupture	AO-SI-74-13	not given	tube rupture	CS
Pilgrim	BWR	12/6/1970	service water	>1	leak	unusual occurrence 74-19	erosion/corrosion	erosion/corrosion	CS
Surry 1	PWR	12/18/1970	CCW HX	>1	leak	AO-	not given	tube leaks	CS
Prairie Island 2	PWR	2/23/1971	reactor coolant	>1	leak	ORNL-NSIC-127:100426	unknown	unknown cause	SS
Prairie Island 1	PWR	5/31/1971	seal line	>1	leak	NPE V.A. 62	fatigue-vibrational		CS
Surry 1	PWR	7/10/1971	recirculation line	>1	leak	AO-75-11	erosion/corrosion	cavitation	SS
Prairie Island 1	PWR	7/31/1971	seal line	>1	leak	NPE V.A. 62	fatigue-vibrational		CS
Surry 1	PWR	9/14/1971	service water	>1	leak	75-017	unknown	unknown cause	CS
Peach Bottom 2	BWR	12/11/1971	condensate	>1	leak	ER 75-27	unknown	unknown	CS
Peach Bottom 3	BWR	12/11/1971	condensate	>1	leak	LER 75-27	unknown	unknown cause	CS
Palisades	PWR	12/28/1971	Condensate	>1	Failed		Thermal Fatigue	Thermal Fatigue	CS
Surry 1	PWR	12/29/1971	SWS HX	>1	leak	LER-75-30	not given		CS
Surry 2	PWR	12/31/1971	pressurizer	>1	leak	fiche 50281-603	not given		SS
Surry 2	PWR	1/8/1972	S.G. blowdown	>1	leak	AO-S2-75-21	not given		CS
Surry 1	PWR	1/12/1972	CCWS	>1	leak	fiche 50280-519	not given		CS
Rancho Seco	PWR	3/17/1972	makeup system	>1	leak	RO 76-03	construction defect/errors	defective weld, construction defect	SS
Prairie Island 2	PWR	5/31/1972	seal line	>1	leak	NPE V.A. 62	fatigue-vibrational		CS
Surry 2	PWR	11/4/1972	recirculation spray	>1	leak	fiche 50281-631	not given		SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
San Onofre 1	PWR	12/22/1972	boric acid	>1	leak	IEC 76-06	IGSCC		SS
Trojan	PWR	12/31/1972	waste concentrate	>1	leak	NPE PWR-2-XII-No.66	stress corrosion cracking	Cl SCC	CS
Pilgrim	BWR	2/2/1973	service water	>1	severed	NUREG/CR-2781	water hammer	water hammer	CS
Trojan	PWR	2/7/1973	reactor water cleanup	>1	leak	77-012	stress /IGSCC	stress corrosion	SS
Indian Point 1	PWR	3/10/1973	Steam line	>1	Rupture		Unknown		CS
Point Beach 1	PWR	6/19/1973	pressurizer	>1	leak	77-05	fatigue-vibrational	fatigue cracking from unsupported loading	SS
Dresden 1	BWR	9/27/1973	Demineralizer	>1	Leak	Ltr DL 9/27/73	Construction Defect/Errors	Construction defect	SS
Fort Calhoun	PWR	10/17/1973	Main steam	>1	Rupture	Ltr DL 9/20/73	Unknown	Joint failure, unknown cause	CS
Surry 2	PWR	12/5/1973	accumulator	>1	leak	fiche 50281-820	not given		SS
Palisades	PWR	1/1/1974	AFW minimum flow line	>1	Crack/Leak		Cavitations	Repeated failures	SS
Indian Point 2	PWR	5/1/1974	SIS	>1	Leak		IGSCC		SS
Ginna	PWR	5/11/1974	Demineralizer	>1	Leak	AO 74-8	Unknown		SS
Calvert Cliffs 1	PWR	6/1/1974	Salt Water Cooling	>1	Leak	NPE VIII.B.65	Erosion		CS
Dresden 1	BWR	6/8/1974	Condensate	>1	Leak	Ltr DL 6/8/74	Stress Corrosion/IGSCC	Stress corrosion	CS
Palisades	PWR	7/1/1974	Valve SWS	>1	Leak		Erosion/Corrosion		CS
Calvert Cliffs 1	PWR	7/8/1974	Service Water	>1	Leak	Ltr DL 7/8/74	Water Hammer	Cavitation	CS
Salem 1	PWR	7/31/1974	fan coil cooler	>1	leak	NPE VII.B.39	erosion/corrosion		CS
Dresden 2	BWR	8/30/1974	Condensate	>1	Leak	Ltr DL 8/30/74	Construction Defect/Errors	Construction defect/error	CS
Salem 1	PWR	8/31/1974	fan coil cooler	>1	leak	NPE VII.B.39	erosion/corrosion		CS
Browns Ferry 2	BWR	9/24/1974	High Pressure Core Injection	>1	Leak	RO 74-16T	Unknown	Leaked gasket, unknown cause	SS
Browns Ferry 2	BWR	10/7/1974	High Pressure Core Injection	>1	Leak	RO 74-17T	Unknown	Leaked gasket, unknown cause	SS
Pilgrim 1	BWR	10/31/1974	fire hydrant	>1	rupture	NPE VII.F. 58 (BWR-2, Book-2)	not given	valve blew off	CS
Browns Ferry 2	BWR	11/4/1974	High Pressure Core Injection	>1	Leak	RO 74-24T	Unknown	Leaked gasket, unknown cause	SS
Palisades	PWR	11/15/1974	Coolant recirculation	>1	Leak		Thermal Fatigue	Thermal Fatigue	SS
Dresden 1	BWR	11/25/1974	Core Spray	>1	Leak	Ltr DL 11/25/74	Erosion/Corrosion	Erosion/corrosion	SS
Vermont Yankee	BWR	1/14/1975	main steam atmospheric piping bellows	>1	rupture	PNO-79-06	not given	bellows failed	CS
Quad Cities 1	BWR	4/15/1975	service water	>1	leak	79-017	unknown	crack	CS
Dresden 1	BWR	5/26/1975	Turbine	>1	Leak	AO 75-8	Erosion/Corrosion	Leaked nozzle, erosion/corrosion	CS
Indian Point 2	PWR	6/20/1975	Pump seal HX thread fitting	>1	Leak		Not Given	Fit up	SS
Cook 1	PWR	6/30/1975	Residual heat removal	>1	leak	AO 75-23	fatigue-vibrational	fatigue-vibration	SS
Oconee 1	BWR	7/26/1975	Service water	>1	Leak		Erosion/Corrosion	Leaked discharge pipe from water treatment room, corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Calvert Cliffs 1	PWR	9/12/1975	Service Water	>1	Failed	ORNL-NSIC-127:105020	Water Hammer	Cavitation	CS
Oconee 2	BWR	10/17/1975	Component cooling	>1	Leak		Construction Defects/Errors	Construction defect	CS
Salem 1	PWR	1/16/1976	spent fuel pool	>1	leak	80-009	unknown	leaked weld, unknown cause	CS
Pilgrim	BWR	1/28/1976	core spray sparger	>1	leak	PNO-I-80-018	IGSCC	leak 1 out of 5 leaks	SS
Pilgrim	BWR	1/28/1976	core spray sparger	>1	leak	PNO-I-80-018	IGSCC	leak 2 out of 5 leaks	SS
Pilgrim	BWR	1/28/1976	core spray sparger	>1	leak	PNO-I-80-018	IGSCC	leak 3 out of 5 leaks	SS
Pilgrim	BWR	1/28/1976	core spray sparger	>1	leak	PNO-I-80-018	IGSCC	leak 4 out of 5 leaks	SS
Pilgrim	BWR	1/28/1976	core spray sparger	>1	leak	PNO-I-80-018	IGSCC	leak 5 out of 5 leaks	SS
Robinson 2	PWR	2/20/1976	chemical and volume control	>1	leak	80-003	other	personnel error	SS
Fitzpatrick	BWR	4/1/1976	Waster sample to condensate storage	>1	Leak	XII. 37 (NPE, BWR-2, Book-3)	Unknown		CS
Millstone 2	PWR	4/9/1976	Radwaste	>1	Leak		Stress Corrosion/IGSCC	Chloride stress corrosion	SS
Calvert Cliffs 1	PWR	5/1/1976	SWS	>1	Leak	NPE VIII.B.85	Corrosion	Several Leaks	CS
Haddam Neck	PWR	5/13/1976	SWS	>1	Leak	NPE PWR-2-XII-No. 46	Erosion/Corrosion		CS
Haddam Neck	PWR	5/22/1976	SWS	>1	Leak	NPE PWR-2-XII-No. 46	Erosion/Corrosion		CS
Dresden 3	BWR	6/1/1976	Cleanup HX	>1	Leak	NPE VIII.A.28 (BWR-2,Book-2)	Not Given	Leak 1 of 2 leaks, lack of fusion	SS
Dresden 3	BWR	6/1/1976	Cleanup HX	>1	Leak	NPE VIII.A.28 (BWR-2,Book-2)	Not Given	Leak 2 of 2 leaks, lack of fusion	SS
Calvert Cliffs 1	PWR	6/11/1976	Service Water	>1	Leak	76-023	Corrosion	Corrosion by salt water	CS
Haddam Neck	PWR	6/12/1976	SWS	>1	Leak	NPE PWR-2-XII-No. 46	Erosion/Corrosion		CS
Yankee Rowe	PWR	6/30/1976	borated line	>1	leak	NPE VII.A.441	weld defect		SS
Oconee 1	BWR	7/7/1976	Component cooling	>1	Leak		Unknown	Unknown cause	CS
Calvert Cliffs 1	PWR	7/21/1976	Service Water	>1	Crack/Leak	76-003T	Erosion/Corrosion	Erosion	CS
Calvert Cliffs 1	PWR	7/27/1976	Boric Acid	>1	Leak	RO 76-32	Corrosion	Acid Corrosion	SS
Humboldt Bay	BWR	7/30/1976	FW sparger	>1	Leak		IGSCC		CS
Salem 2	PWR	7/30/1976	component cooling	>1	leak	80-022	unknown	leaked diesel generator jacket water heater, heater equipment failed, replaced with different type heater	CS
Calvert Cliffs 1	PWR	8/20/1976	Service Water	>1	Leak	76-033	Erosion/Corrosion	Erosion	CS
Sequoyah 1	PWR	8/28/1976	control rod drive	>1	leak	80-141	unknown	unknown cause	SS
Salem 1	PWR	8/29/1976	service water	>1	leak	80-049	corrosion	corrosion	CS
Oconee 2	BWR	9/9/1976	Component cooling	>1	Leak		Unknown	cause	CS
Turkey Point 3	PWR	10/31/1976	feedwater bypass	>1	failed	NPE PWR-2-VI-E-No. 334	not given		CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Millstone 2	PWR	11/8/1976	Accumulators	>1	Leak		Stress Corrosion/IGSCC	Leak at base of waste concentrate tank, Stress corrosion cracking	SS
Robinson 2	PWR	11/17/1976	service water	>1	rupture	14 NPRDS	unknown	unknown cause	CS
St. Lucie 1	PWR	11/30/1976	component cooling	>1	leak	80-066	corrosion	corrosion	CS
ANO1	PWR	12/1/1976	Spent Fuel Cooling	>1	Leak	76-034	IGSCC		CS
Trojan	PWR	12/11/1976	fire protection	>1	leak	RO	unknown	expansion joint slippage	CS
Hatch 1	BWR	1/1/1977	Recirculation	>1	Leak		Not Given	Indications of leak	SS
Ginna	PWR	1/12/1977	Demineralizer	>1	Leak	AO	Unknown	Unknown cause	SS
ANO1	PWR	1/28/1977	Reactor Coolant	>1	Leak	RO 77-5	Unknown	Unknown Cause	SS
Salem 1	PWR	2/3/1977	fire protection	>1		leak	81-012	unknown	CS
Hatch 1	BWR	2/27/1977	Condensate	>1	Rupture		Unknown	Expansion joint failed	CS
Hatch 1	BWR	3/1/1977	Condensate	>1	Rupture		Unknown	2nd expansion joint failure	CS
Fort Calhoun	PWR	3/5/1977	Service Water	>1	Rupture	Not Given	Unknown	unknown	CS
Surry 2	PWR	4/17/1977	service water	>1	leak	RO-	not given	tubes	CS
Big Rock Point	BWR	5/5/1977	Residual Heat Removal	>1	Leak	RO 77-16	Construction Defect/Error	Leaked hose, personnel error	SS
Cooper	BWR	8/1/1977	Reactor equipment cooling	>1	Leak	NPE VIII.C.145 (BWR-2,Book-2)	Not Given	Poor weld	CS
Dresden 1	BWR	8/1/1977	Service Water	>1	Leak	77-027	Stress Corrosion/IGSCC	Stress corrosion	CS
Surry 2	PWR	8/19/1977	service water	>1	failed	81-055	unknown	cap screw to pump failed, unknown cause	CS
Salem 1	PWR	8/30/1977	service water	>1	leak	81-083	corrosion/fatigue	corrosion of reducing tee	CS
Surry 1	PWR	9/22/1977	steam line heater	>1	leak	LER-81-54	not given		CS
Salem 1	PWR	9/25/1977	fire pump	>1	leak	NPE VII.E.110	vibration		CS
Quad Cities 2	BWR	9/28/1977	RHR-SWS	>1	leak	81-019	fatigue-vibrational		SS
Surry 1	PWR	11/19/1977	steam line heater	>1	leak	LER-81-74	not given		CS
Surry 2	PWR	11/19/1977	steam line heater	>1	leak	LER-81-74	not given		CS
ANO1	PWR	11/25/1977	Spent Fuel Pool	>1	Leak	77-024	Unknown	Unknown Cause	CS
Fort Calhoun	PWR	2/14/1978	Charging line	>1	Leak	78-005	Fatigue		SS
Salem 1	PWR	2/22/1978	component cooling	>1	leak	82-012	unknown	leaked diesel generator jacket water heater, unknown cause	CS
Calvert Cliffs 2	PWR	4/30/1978	Reactor Coolant	>1	leak	78-011	Fatigue-vibrational	fatigue-vibration	SS
Yankee Rowe	PWR	5/3/1978	fire protection	>1	leak	82-008	construction defect/errors	underground pipe failure, construction defect	CS
Salem 2	PWR	5/18/1978	containment fan cooler	>1	leak	LER 82-040	erosion		CS
Salem 2	PWR	5/25/1978	containment heat removal	>1	leak	82-039	fatigue-vibrational	failure, fatigue-vibration	CS
Palisades	PWR	5/26/1978	Fire protection	>1	Rupture		Unknown	Unknown cause	CS
Haddam Neck 1	PWR	5/31/1978	Reactor Coolant	>1	Leak		Construction Defect/Errors	Construction Defect	SS
Haddam Neck	PWR	6/1/1978	Moisture Separator	>1	Leak	NPE VI.D.210	Unknown		SS
Salem 1	PWR	6/25/1978	chemical and volume control	>1	leak	82-041	erosion/corrosion	erosion/corrosion of gear oil cooler	SS
Surry 1	PWR	7/5/1978	lube oil cooler	>1	leak	LER-82-69	not given		SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Calvert Cliffs 2	PWR	7/14/1978	Reactor Coolant	>1	leak	78-021	unknown	Cracked seal, unknown cause	SS
Sequoyah 1	PWR	7/30/1978	steam	>1	leak	RO 82-003	unknown	unknown cause	CS
Prairie Island 1	PWR	7/31/1978	pressurizer	>1	leak	NPE VII.A.686	unknown		SS
Haddam Neck	PWR	8/1/1978	Moisture Separator	>1	Leak	NPE VI.D.210	Unknown		SS
Salem 2	PWR	8/12/1978	containment heat removal	>1	leak	82-073	erosion/corrosion	erosion of containment sump	CS
Salem 2	PWR	8/13/1978	service water	>1	leak	82-075	unknown	unknown cause	CS
ANO2	PWR	8/18/1978	LPSI	>1	Leak	CAN: 7811070 010	Unknown		SS
Dresden 3	BWR	9/8/1978	Steam	>1	Leak	78-035	Unknown	Cracked weld on vent line	CS
Salem 2	PWR	9/14/1978	service water	>1	leak	82-086	erosion/corrosion	erosion/corrosion of gear oil cooler	CS
Kewaunee	PWR	9/18/1978	Reactor Coolant	>1	Leak		Fatigue-Vibrational	Fatigue-Vibration	SS
Salem 2	PWR	9/30/1978	charging	>1	leak	NPE VIII.B.512	erosion		SS
Cook 1	PWR	10/27/1978	fire protection	>1	failed	Rpt. FB-01	unknown	unknown cause	CS
Dresden 3	BWR	11/15/1978	Feedwater	>1	Leak	78-055	Construction Defect/Errors	Construction defect, slag inclusion	CS
Salem 1	PWR	11/29/1978	service water	>1	leak	82-091	erosion/corrosion	extensive bifouling and corrosion of weld, erosion/corrosion	CS
North Anna 1	PWR	12/1/1978	Steam drain	>1	Leak		Erosion/Corrosion		CS
Calvert Cliffs 1	PWR	12/2/1978	Aux. Feedwater	>1	Leak	AO 74-13	Erosion/Corrosion	Erosion	CS
Palisades	PWR	1/1/1979	Fire prevention	>1	Rupture		Frozen		CS
Calvert Cliffs 2	PWR	1/6/1979	Reactor Coolant	>1	leak	79-001	corrosion/fatigue	Cracked weld, fatigue/corrosion	SS
Salem 2	PWR	1/6/1979	main steam	>1	leak	AEOD/E4 16	erosion/corrosion	erosion/corrosion	CS
Quad Cities 2	BWR	1/15/1979	RHR HX bellows	>1	leak	NPE VII.D.338 (BWR-2, Book-2)	unknown		SS
Palisades	PWR	1/17/1979	Fire protection	>1	Leak		Frozen		CS
Calvert Cliffs 2	PWR	1/20/1979	flow sensor	>1	leak	79-003	Fatigue-Vibrational	cracked weld, fatigue-vibrational	SS
Prairie Island 1	PWR	1/28/1979	boric acid	>1	leak	IN 84-18, PNO-III-83-007	stress corrosion/IGSCC	stress corrosion cracking, 1/6 leaks, 7 cracks	SS
Prairie Island 1	PWR	1/28/1979	boric acid	>1	leak	IN 84-18, PNO-III-83-007	stress corrosion/IGSCC	stress corrosion cracking,2/6 leaks, 7 cracks	SS
Prairie Island 1	PWR	1/28/1979	boric acid	>1	leak	IN 84-18, PNO-III-83-007	stress corrosion/IGSCC	stress corrosion cracking, 3/6 leaks, 7 cracks	SS
Prairie Island 1	PWR	1/28/1979	boric acid	>1	leak	IN 84-18, PNO-III-83-007	stress corrosion/IGSCC	stress corrosion cracking, 4/6 leaks, 7 cracks	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Prairie Island 1	PWR	1/28/1979	boric acid	>1	leak	IN 84-18, PNO-III-83-007	stress corrosion/IGSCC	stress corrosion cracking, 5/6 leaks, 7 cracks	SS
Prairie Island 1	PWR	1/28/1979	boric acid	>1	leak	IN 84-18, PNO-III-83-007	stress corrosion/IGSCC	stress corrosion cracking, 6/6 leaks, 7 cracks	SS
Calvert Cliffs 1	PWR	2/28/1979	Chemical and Volume Control	>1	Leak	79-007	Unknown	Weld Failure	SS
Oconee 3	BWR	3/6/1979	Reactor coolant	>1	Leak		Unknown	Unknown cause	SS
Oyster Creek	BWR	4/17/1979	Service water	>1	Leak		Unknown	Underground tunnel leaked, cause unknown	CS
Big Rock Point	PWR	4/20/1979	Control Rod Drive	>1	Leak	79-018	Construction Defect/Error	Bad weld, construction defect	SS
Oyster Creek	BWR	4/28/1979	Chemical and volume control	>1	Rupture		other	Froze, fractures	SS
Dresden 1	BWR	5/1/1979	Radwaste line	>1	Leak	XII, 65 (NPE BWR-2, Book-3)	Corrosion	Tar coating lost	SS
Dresden 3	BWR	5/3/1979	Reactor Water Cleanup	>1	Leak	79-008	Erosion/Corrosion	Erosion, cavitation	SS
ANO2	PWR	5/14/1979	Containment heat removal	>1	Leak	79-033	Erosion/Corrosion	Erosion/Corrosion	CS
Dresden 1	BWR	5/18/1979	Reactor Water Cleanup	>1	Leak	79-001	Unknown	Underground aluminum pipe leak, unknown cause	SS
Dresden 2	BWR	6/1/1979	Demineralizer hose	>1	Rupture	XII. 67 (NPE, BWR-2, Book-3)	Not Given	Line Flooded radwaste area	SS
Oyster Creek	BWR	6/27/1979	Service water	>1	Leak		Corrosion	Corrosion	CS
Beaver Valley 1	PWR	7/1/1979	Fire Main	>1	Rupture	NPE VII.E.71	Not Given	External Load	CS
Oyster Creek	BWR	8/1/1979	Control rod drive	>1	Leak		Not Given		SS
Calvert Cliffs 1	PWR	8/27/1979	High Pressure Core Injection	>1	Leak	79-046	Construction Defect/Error	Construction Defect/Error	SS
Surry 1	PWR	10/14/1979	exp. Joint heater drain	>1	rupture	NPE VI.D.320	not given	degraded joint expansion	CS
Brunswick 1	BWR	11/10/1979	Service Water	>1	Leak	79-096	Unknown	Unknown Cause	CS
Salem 1	PWR	12/19/1979	component cooling	>1	leak	83-067	corrosion/fatigue		CS
Crystal River 3	PWR	12/24/1979	Service Water	>1	Leak	79-111	Thermal Fatigue	Thermal fatigue	CS
ANO1	PWR	1/21/1980	Borated Line	>1	Crack	80-003	IGSCC	Occurrence 1 of 3	SS
ANO1	PWR	1/21/1980	Borated Line	>1	Crack	80-003	IGSCC	Occurrence 2 of 3	SS
ANO1	PWR	1/21/1980	Borated Line	>1	Crack	80-003	IGSCC	Occurrence 3 of 3	SS
LaSalle 1	BWR	1/25/1980	Blown down line	>1	Rupture		Water hammer		CS
Oyster Creek	BWR	2/13/1980	Condensate	>1	Leak		Corrosion	Severely pitted Al pipes.	CS
Calvert Cliffs 2	PWR	2/19/1980	Reactor Coolant	>1	leak	80-012	Fatigue-Vibrational		SS
Calvert Cliffs 2	PWR	3/11/1980	chemical and volume control	>1	leak	80-018	Fatigue-Vibrational		SS
Beaver Valley 1	PWR	3/26/1980	Fire Prevention	>1	Rupture	80-018	Not Given	Over Pressure	CS
Cooper	BWR	3/29/1980	Emergency core cooling	>1	Leak	80-009	Stress Corrosion/IGSCC	IGSCC	SS
Calvert Cliffs 2	PWR	4/12/1980	Service Water	>1	leak	80-022	Fatigue-Vibrational		CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Hatch 2	BWR	4/13/1980	RHR	>1	Leak		Not Given	Bellows leak	SS
Surry 2	PWR	4/17/1980	feedwater heater	>1	leak	LER-84-10	not given	tube failures	CS
Peach Bottom 2 and 3	BWR	6/28/1980	fire header	>1	rupture	NPE VII.F.238 (BWR-2, Book 2)	not given	mechanical load	CS
Beaver Valley 1	PWR	7/8/1980	Sevice Water	>1	Leak	80-048	Unknown	Expansion joint failure, unknown cause	CS
Indian Point 3	PWR	7/16/1980	Containment heat removal	>1	Leak		Fatigue-Vibrational	Fatigue-Vibrational	CS
Oyster Creek	BWR	9/5/1980	Core spray	>1	Leak		other	Personnel errors	SS
Beaver Valley 1	PWR	9/25/1980	Fire Protection	>1	Rupture	RO	Other	Operator Error	CS
Hatch 2	BWR	9/28/1980	Water box	>1	Leak		Stress Corrosion Cracking	SCC	SS
Monticello	BWR	9/30/1980	Main steam	>1	Leak		Erosion/Corrosion	Erosion/Corrosion	CS
Indian Point 2	PWR	10/17/1980	Fan Cooler	>1	Leak		Erosion/Corrosion	Questionable failure mechanism	CS
Indian Point 2	PWR	10/17/1980	SWS	>1	Leak		Corrosion	Event dates: 10/1-3,14,17/80	CS
Oyster Creek	BWR	12/4/1980	Demineralize	>1	Failed		Not Given	Frozen	SS
Fort Calhoun	PWR	12/7/1980	Service Water	>1	Leak	80-031	Fatigue-Vibrational	Fatigue-vibrational	CS
Beaver Valley 1	PWR	12/17/1980	Main Steam	>1	Leak	80-116	Unknown	Cracked weld in heat exchanges, unknown cause	CS
Millstone 2	PWR	1/27/1981	Component cooling	>1	Leak		Erosion/Corrosion	Diesel generator oil cooler leaked water, corrosion	CS
Oyster Creek	BWR	2/10/1981	Chemical waste	>1	Leak		Unknown		SS
Brunswick 2	PWR	2/24/1981	Core Aux Cooling	>1	Rupture	81-42	Unknown		SS
Duane Arnold	BWR	4/13/1981	Recirc	>1	Leak	PNO-III-81-046	Not Given		SS
Kewaunee	PWR	4/22/1981	RHR	>1	Leak		Not Given	External damage	SS
Farley 1 and 2	PWR	5/1/1981	Fire Main	>1	Rupture	NPE VII.E. 106	Unknown		CS
Millstone 2	PWR	6/13/1981	Service water	>1	Leak		Corrosion	Corrosion	CS
Calvert Cliffs 1	PWR	6/20/1981	Component Cooling	>1	Leak	81-048	Construction Defect/Error	Leaked drain, faulty nipple installation, construction defect	CS
ANO1	PWR	7/14/1981	Main Steam	>1	Leak	82-027	Erosion/Corrosion	Erosion/Corrosion	CS
Ginna	PWR	7/14/1981	Boric Acid	>1	Leak	81-013	Stress Corrosion/IGSCC	Stress corrosion	SS
Davis Besse	PWR	7/30/1981	Condensate	>1	Leak	PNO-III-81-065	Unknown	Large vacuum leak at main condenser, unknown cause	CS
Kewaunee	PWR	8/20/1981	Boric Acid	>1	Leak		Corrosion		SS
McGuire 1	PWR	8/25/1981	Charging line	>1	Leak		Fatigue-Vibrational		SS
Wolf Creek	PWR	9/7/1981	emergency service water	>1	leak	LER 88-023	erosion/corrosion, cavitation	1 leak, 4 other non-leaks, butterfly valve, no pipe size given	SS
Three Mile Island 1	PWR	10/15/1981	turbine drain	>1	leak	PNO-I-85-079	erosion/corrosion		CS
Point Beach 2	PWR	12/26/1981	CCW	>1	leak	NPE VII.B 692	fatigue-vibrational		CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Cook 1	PWR	1/28/1982	Service water	>1	leak	82-009	water hammer	water hammer, line failure, cavitation	CS
Cook 2	PWR	1/28/1982	service water	>1	leak	82-011	Erosion/Corrosion	Erosion/Corrosion, cavitation from throttling of butterfly valve	CS
Haddam Neck	PWR	2/1/1982	Fan cooler	>1	Leak	NPE VII.C.101	Erosion/Corrosion		CS
LaCrosse	BWR	3/29/1982	Emergency core cooling	>1	Leak		Construction Defect/Errors	Brittle gasket caused leak, gasket replaced	SS
Dresden 2	BWR	5/11/1982	Main steam	>1	Leak	PNO-III-82-045	Unknown	Unknow cause	CS
Calvert Cliffs 1	PWR	5/17/1982	Boric Acid	>1	Leak	82-025	Construction Defect/Error	Poor weld, Construction defect	SS
Hatch 1	BWR	6/15/1982	Condenser	>1	Leak		Not Given	Tube leaks	CS
Surry 2	PWR	6/15/1982	service water	>1	leak	86-006	erosion/corrosion	erosion/corrosion	CS
Yankee Rowe	PWR	6/18/1982	steam	>1	leak	86-006	unknown	unknown cause	CS
Fermi 2	BWR	6/19/1982	Core spray	>1	Leak	Not Given	Not given	Overpressure damaged expansion joint	SS
Dresden 2	BWR	7/24/1982	Feedwater to drain	>1	Leak	NPE VI.E.160 (BWR-2, Book-8)	Fatigue		CS
Hatch 2	BWR	8/13/1982	Service Water	>1	Leak		Not Given	Cracks, breaks	CS
Dresden 3	BWR	9/1/1982	Reactor Water Cleanup	>1	Leak	82-021	Stress Corrosion/IGSCC	Cracked weld	SS
Surry 1	PWR	9/28/1982	chemical and volume control	>1	leak	86-029	unknown	unknown cause	SS
Brunswick 2	BWR	10/10/1982	Condensate	>1	Leak	PNO-II-82-109	Stress Corrosion/IGSCC	Cracked weld of heater drain pipe. IGSCC	CS
Susquehanna 2	BWR	10/12/1982	residual heat removal	>1	leak	86-015	water hammer	water hammer	SS
Ginna	PWR	10/16/1982	Component cooling	>1	Leak	82-023	Other	Error, broken pipe nipple	CS
Brunswick 2	BWR	10/29/1982	Residual Heat Removal	>1	Leak	82-130	Unknown	Cracked weld, unknown cause	SS
Haddam Neck	PWR	11/13/1982	Fan cooler	>1	Leak	NPE VII.C.101	Erosion/Corrosion		CS
Hatch 2	BWR	12/3/1982	SWS Valve	>1	Leak		Erosion/Corrosion		CS
Brunswick 2	BWR	12/6/1982	Core Aux Cooling	>1	Rupture	82-127	Unknown		SS
Dresden 2	BWR	12/17/1982	Feedwater	>1	Leak	82-055	Fatigue-Vibrational	Fatigue-vibration	CS
Millstone 2	PWR	12/31/1982	Service water	>1	Leak		Unknown	Unknown cause	CS
Haddam Neck	PWR	1/15/1983	Fan cooler	>1	Leak	NPE VII.C.101	Erosion/Corrosion		CS
ANO1	PWR	1/20/1983	Spent Fuel Pool	>1	Leak	83-002	Fatigue-Vibrational	Fatigue-vibration	CS
Oyster Creek	BWR	1/23/1983	Radwaste line	>1	Leak		Unknown		SS
Dresden 3	BWR	3/7/1983	Feedwater	>1	Leak	83-008	Erosion/Corrosion	Erosion/corrosion at the heater shell	CS
Hatch 1 & 2	BWR	3/21/1983	Fire header	>1	Rupture		Not Given	Overload	CS
Hatch 2	BWR	3/21/1983	Fire header	>1	Rupture		Not Given	Overload	CS
Shearon Harris	PWR	4/21/1983	main steam	>1	leak	87-029	water hammer	water hammer	CS
Summer	PWR	5/25/1983	seal line	>1	leak	NPE V.A. 156	fatigue-vibrational		CS
Davis Besse	PWR	6/1/1983	Main steam	>1	Leak	No LER	Erosion/Corrosion	Erosion/corrosion	CS
North Anna 1	PWR	7/9/1983	Service water	>1	Leak		Erosion/Corrosion	Erosion/corrosion	CS
LaCrosse	BWR	7/16/1983	Containment spray	>1	Leak		Unknown	2 Cracks, unknown cause	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Calvert Cliffs 1	PWR	11/23/1983	Seal line	>1	Leak	NPE V.A. 120	Fatigue-Vibrational		CS
ANO1	PWR	11/30/1983	Chemical and Volume Control	>1	Leak	83-028	Thermal Fatigue	Thermal fatigue, pipe size = or >1	SS
Farley 1	PWR	12/1/1983	Feedwater	>1	Breakage	83-081	Construction Defect/Errors	Fittinf failure, construction defects/errors	CS
Crystal River 3	PWR	1/14/1984	Fire Protection	>1	Leak	RO 84-01	Other	System down due to inability to meet technical specification	CS
Browns Ferry 1	BWR	3/20/1984	Containment heat removal	>1	Leak	84-018	Unknown	Unknown	CS
Maine Yankee 1	PWR	3/30/1984	Chemical and volume control	>1	Leak		Thermal Fatigue	Thermal fatigue degrading rubber hose	SS
Turkey Point 3	PWR	4/26/1984	service water	>1	leak	88-007	erosion/corrosion	erosion/corrosion	CS
Hatch 1	BWR	8/10/1984	Fire Protection	>1	Leak		Unknown		CS
LaSalle 2	BWR	9/6/1984	High pressure core spray	>1	Leak		Not Given	Bellows seal failed	SS
Grand Gulf	BWR	9/21/1984	Steam	>1	Leak	PNO II-84-061A	Unknown		CS
LaSalle 1	BWR	10/2/1984	HCPS	>1	Leak		Overpressure	Bellows seal failed	SS
Indian Point 2	PWR	10/4/1984	CFCU	>1	Leak		Erosion/Corrosion		CS
North Anna 1 & 2	PWR	11/27/1984	Fire main	>1	Rupture		Fracture	Brittle Fracture	CS
LaSalle 1	BWR	12/1/1984	Buried RCIC	>1	Leak		Construction Defect/Errors	Welding problems	SS
Calvert Cliffs 1	PWR	12/10/1984	Service Water	>1	Leak	PNO-I-84-104	Erorsion/Corrosion	Erosion/Corrosion, 2 leaks	CS
River Bend	BWR	4/18/1985	service water	>1	leak	89-020	other	procedural inadequacy, error	CS
Nine Mile Point 1	BWR	5/7/1985	Containment spray HX waterbox	>1	Leak		Unknown	Leak 1 of 2 leaks, thermal fatigue?	SS
Nine Mile Point 1	BWR	5/7/1985	Containment spray HX waterbox	>1	Leak		Unknown	Leak 2 of 2 leaks, thermal fatigue?	SS
Duane Arnold	BWR	5/29/1985	Fire suppression	>1	Rupture	LER 85-015	Not Given	Pile driver penetrated	CS
Fermi 2	BWR	9/17/1985	Steam bypass	>1	Crack/Leak	PNO-III-85-083	Unknown		CS
Cook 1	PWR	12/27/1985	Fire suppression	>1	leak	LTR 1/9/86	not given	No Cause	CS
South Texas 2	PWR	5/7/1986	coolant recirculation	>1	leak	90-008	fatigue-vibrational	fatigue-vibrational	SS
Salem 1	PWR	7/1/1986	component cooling	>1	leak	90-026-04	erosion/corrosion	erosion/corrosion, 15 gpm leaks	CS
Salem 1	PWR	7/27/1986	service water	>1	leak	90-026-04	erosion/corrosion	erosion/corrosion, service water casing leaking	CS
Zion 2	PWR	9/6/1986	condensate	>1	failed	90-010	thermal fatigue	condenser boot exceeded life expectancy by 2-4 years. Thermal fatigue	CS
Brunswick 1	BWR	9/17/1986	Condensate	>1	Leak	86-026	Corrosion	Corrosion	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Salem 1	PWR	10/22/1986	service water	>1	leak	90-026-04	erosion/corrosion	erosion/corrosion, leak at header drain valve	CS
Salem 1	PWR	11/18/1986	service water	>1	leak	90-026-05	erosion/corrosion	erosion/corrosion	CS
Cook 1	PWR	3/17/1987	Fire Line	>1	leak		not given	Cement asbestos pipe	CS
Oconee 3	BWR	3/31/1987	Instrumentation	>1	Leak		Construction Defects/Errors	Construction Defects/Errors	SS
Beaver Valley 2	BWR	6/10/1987	D.G. Water Header	>1	Leak	ACN: 8706180 174	Erosion/Corrosion		CS
Nine Mile Point 1	BWR	8/25/1987	SWS	>1	Leak		Erosion/Corrosion		CS
Palo Verde 1	PWR	8/27/1987	Pressurizer	>1	Leak		other	Procedure errors	SS
Hatch 2	BWR	10/19/1987	PHI	>1	Leak		Not Given		SS
Palisades	PWR	11/6/1987	Fire protection	>1	Rupture		Unknown	Unknown cause	CS
Salem 1	PWR	11/20/1987	oil/water separator	>1	leak	CAN:9201060175	not given	external damage	SS
Sequoyah 2	PWR	1/30/1988	component cooling	>1	leak	special report 92-27	fatigue-vibrational	fatigue-vibrational	CS
Susquehanna 2	BWR	1/30/1988	component cooling	>1	leak	special report 92-1	thermal fatigue	thermal and vibrational fatigue	CS
Diablo Canyon 1	PWR	2/25/1988	CRD seal	>1	Leak	88-4	IGSCC		SS
Vogtle 1	PWR	5/13/1988	component cooling	>1	leak	92-004	corrosion/fatigue	fatigue/corrosion	CS
Hope Creek	BWR	11/4/1988	Recirculation	>1	Leak		Fatigue-Vibrational		SS
Hope Creek	BWR	11/8/1988	Recirculation	>1	Leak		Fatigue-Vibrational		SS
Duane Arnold	BWR	11/20/1988	Control Rod Drive	>1	Leak	88-019	Stress Corrosion/IGSCC	Transgranular stress corrosion	SS
WPPSS 2		8/4/1989	containment heat removal	>1	leak	93-029	construction defect/errors	construction defect/errors	CS
Surry 1	PWR	2/2/1990	coolant recirculation	>1	leak	94-001	other	leak occurred during refueling and while tack weld was performed. Leak caused by H gas in pressurizer ignited by welding	SS
Browns Ferry 1	BWR	4/26/1990	Fire Protection	>1	Failed	90-007	Other	Errors	CS
Calvert Cliffs 1	PWR	5/5/1990	Service Water	>1	Leak	90-017	Corrosion	Localized Corrosion	CS
Palo Verde 3	PWR	5/29/1990	pressurizer	>1	leak	94-004	construction defect/error	defective weld, construction defect/error	SS
Peach Bottom 3	BWR	7/7/1990	HPCI drain	>1	leak	IR-50-277-94-13, IR-50-278-94-13	not given		SS
Limerick 2	BWR	7/15/1990	Condensate	>1	Failed		Fatigue-Vibrational	Fatigue-Vibrational, insufficient support	CS
Vogtle 1	PWR	7/22/1990	pressurizer	>1	leak	94-005	construction defect/errors	defective weld, construction defect/error	SS
Peach Bottom 3	BWR	8/5/1990	steam combiner	>1	leak	IR-50-277-94-13, IR-50-278-94-13	not given		CS
Hope Creek	BWR	9/26/1990	Feedwater	>1	Leak		Construction Defect/Errors	Construction Defect/Errors	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Fort Calhoun	PWR	11/19/1990	Instrument air	>1	Leak	90-026	Construction Defect/Errors	Construction defects at pipe header	SS
Palisades	PWR	5/7/1991	Containment heat removal	>1	Leak		Construction Defects/Errors	Construction Defects/Errors	CS
Oyster Creek	BWR	7/17/1991	Component cooling	>1	Leak		Unknown	Heat exchanger failed to contain normal pressure	CS
Three Mile Island 1	PWR	9/8/1991	reactor coolant	>1	leak	95-003	unknown	cracked weld, pipe replaced	SS
McGuire 1	PWR	9/16/1992	Service Water	>1	Leak		Construction Defects/Errors	Design deficiency	CS
Pilgrim	BWR	9/16/1992	closed cooling water	>1	leak	PNO-I-96-066	corrosion		CS
Oyster Creek	BWR	12/9/1992	Service water	>1	Failed		Erosion/Corrosion	Erosion/corrosion	CS
Catawba 1	PWR	1/31/1993	RHR	>1	rupture	IR-50-413-93-22	water hammer		SS
McGuire 2	PWR	9/27/1993	Containment heat removal	>1	Leak		Unknown	Unidentified leak location, unknown cause	CS
Beaver Valley 1	PWR	5/4/1994	Pressurizer	>1	Leak	94-004	Unknown	2 ft. Section of pipe replaced, unknown cause	SS
Dresden 1	BWR	5/8/1994	Reactor Water Cleanup	>1	Leak	PNO-III-94-036	Unknown	Unknown pipe leak, unknown cause	SS
Indian Point 3	PWR	6/13/1994	Chlorination	>1	Leak		Unknown		SS
Dresden 2	BWR	10/3/1994	High pressure core injection	>1	Leak	Special Report	Erosion/Corrosion	Leaked in ground cathodic protection system, Corrosion	SS
Catawba 1	PWR	2/9/1995	fire protection	>1	rupture	Noncompliance Notification	unknown	unknown	CS
McGuire 2	PWR	3/29/1995	CVCS	>1	Leak		Unknown		SS
Indian Point 2	PWR	5/18/1995	Service water	>1	Leak		Erosion/Corrosion	Defective metal coating, erosion/corrosion	CS
Dresden 2	BWR	4/18/1996	Steam drain	>1	Leak	96-002	Erosion/Corrosion		CS
Palo Verde 1	PWR	10/29/1996	Recirc. Drain	>1	Leak		Not Given	Lack of Fusion in weld	SS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 1 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 2 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 3 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 4 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 5 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 6 out of 14 leaks	CS
Cook 2	BWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 7 out of 14 leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	References	Failure Mechnism	Comments	Material
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 8 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 9 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 10 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 11 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 12 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 13 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 14 out of 14 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 1 out of 4 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 2 out of 4 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 3 out of 4 leaks	CS
Cook 2	PWR	8/20/1987	CCW	>2	leak	IR 50-315-87-23, IR 50-316-87-23	IGSCC	Leak 4 out of 4 leaks	CS

Appendix B

Data Removed from the Bush Database

Appendix B1

Data Removed due to Size

Station	Plant Type	Date	System Name	Pipe Size	Break Def	Reference	Failure Mechanism	Comments	Material
ANO1	PWR	6/15/1979	Spent Fuel Pool	3x2	Leak	NUREG-0691	Stress Corrosion Cracking, IGSCC	Stress Corrosion Cracking	CS
ANO1	PWR	1/20/1977	Demineralizer	3x2	Leak	RO 77-02	Unknown	Leaked 3x2 in. reducer weld	SS
ANO1	PWR	8/3/1976	Reactor Water Cleanup		Leak	RO 76-15	Construction Defect/Error	Construction defect	SS
ANO2	PWR	11/4/1986	Body-to-bonnet valve seal ring		Leak	PNO-IV-86-033	Unknown	2-3 gpm	
ANO2	PWR	5/18/1983	Reactor Coolant Pump		Leak	83-023	Fatigue	Weld Crack	SS
ANO2	PWR	11/24/1982	Pressure Transmitter		Leak	82-041		Over Torqued	
ANO2	PWR	8/16/1978	Drain Line at LPSI	1x2	Leak		Fatigue-Vibrational	Weld at SIS, 1x2 reducer, 0.75 linear crack, 1 in weld, questionalbe failure mechanism	SS
Beaver Valley 1	PWR	7/18/1989	Fire Line		Leak	91-002	Erosion/Corrosion	Erosion/Corrosion	CS
Brunswick 2	BWR	1/11/1982	Fire		Rupture	RO 2-82-9	Frozen	Frozen Pipe	CS
Calvert Cliffs 2	PWR	5/3/1984	Component Cooling		Leak	IN 84-71	Corrosion	Graphite corrosion of cast iron	CS
Catawba 1	PWR	9/8/1994	Cooling Line with NaNO2	not given	rupture	ACN: 9409230238	not given	digging	
Catawba 1	PWR	1/11/1994	coolant recirculation	not given	leak	94-001	fatigue-vibrational	fatigue-vibration	SS
Cook 1	PWR	12/4/1975	RHR	0.25 x 0.75	leak	NPE VIII.B.102	fatigue-vibrational		SS
Cook 2	PWR	10/27/1978	fire protection		failed	Rpt. FB-01	unknown	unknown cause	CS
Cooper	BWR	7/10/1978	Service Water		Leak	78-027	Construction Defect/Error	Construction Defect	CS
Cooper	BWR	8/23/1976	Fuel Line to Diesel Generator (oil)	not given	Rupture	RO 76-34, 50298-6	Not Given	Fuel line burst	CS
Dresden 1	BWR	9/14/1978	Coolant recirculation	3x2	Leak	78-029	Erosion/Corrosion	Erosion/corrosion	SS
Dresden 1	BWR	9/1/1978	Radwaste line	3 x 2	Leak	XII. 61 (NPE, BWR	Erosion/Corrosion	3x2 reducer	SS
Dresden 1	BWR	4/21/1977	Fuel pool HX inlet vent line	not given	Rupture	RO 77-9, 50010-74	Corrosion	2000-5000gal. Fuel pool water to sphex skirt, cause: corroded and weakened short nipple on welded coupling, replaced.	CS
Dresden 1	BWR	1/29/1972	Containment heat removal	4x2	Leak	NUREG/75-067	Stress Corrosion/IGSCC	IGSCC	CS
Dresden 1	BWR	12/23/1961	Containment heat removal	4x2	Leak	NUREG/75-067	Stress Corrosion/IGSCC	IGSCC	CS
Dresden 2	BWR	11/1/1978	Radwaste eductor	6 x 6 x 4	Leak	XII. 63 (NPE, BWR	Corrosion	Acid corrosion	SS
Dresden 3	BWR	6/7/1977	Feedwater	3x6	Leak	77-021	Erosion/Corrosion	Erosion/Corrosion	CS
Dresden 3	BWR	1/7/1975	Condensate	6x3	Leak	RO 75-04	Water Hammer	Cavitation, water hammer on a 6 in. x 3 in. reducer	CS
Farley 1 and 2	PWR	7/15/1992	Fire Main	not given	Rupture	LER 92-003	Not Given	Not Given	CS
Fort Calhoun	PWR	3/29/1996	Condenser		Leak	96-002	Not Given	In tubes	CS
Ginna	PWR	4/24/1990	RHR		Leak	NPRDS	Unknown	Outage	SS
Peach Bottom 3	BWR	8/25/1981	core spray junction box between RPV and shroud	unknown	leak	LER 85-014	IGSCC	through wall leak, earlier LER 2-82-09/1X	SS
Pilgrim	BWR	3/15/1982	instrument line	2x1	leak	86-006	unknown	cracked weld	SS
Prairie Island 2	PWR	12/13/1970	reactor coolant pump seal water return line	not given	leak	50306-240	not given	leak when pipe welded to anchor pbb	SS
Quad Cities 1	BWR	3/26/1970	radwaste discharge pipe	not given	rupture	50254-363	not given	pile driver ruptured pipe	SS
Quad Cities 1	BWR	4/8/1970	radwaste pipe	not given	severed	letter DL	construction error	construction caused failure	SS
Quad Cities 1	BWR	6/9/1980	jet pump instrument line	unknown	leak	LER 84-008	IGSCC	leak 1 out of 3	SS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	Reference	Failure Mechanism	Comments	Material
Quad Cities 1	BWR	6/9/1980	jet pump instrument line	unknown	leak	LER 84-008	IGSCC	leak 2 out of 3	SS
Quad Cities 1	BWR	6/9/1980	jet pump instrument line	unknown	leak	LER 84-008	IGSCC	leak 3 out of 3	SS
Quad Cities 2	BWR	8/26/1971	feedwater	4x6	rupture	75-031; NSIC-126;	fatigue-vibrational	fatigue-vibrational	CS
Quad Cities 2	BWR	1/15/1981	turbine to condenser expansion joint	not given	leak	not given	not given	deteriorated rubber joint	CS
Robinson 2	PWR	12/19/1968	AFW to FW	4x16	leak	RO-	thermal fatigue		CS
Robinson 2	PWR	11/16/1972	CRDM canopy seal	unknown	leak	RO 76-20	not given	weld degradation	SS
Salem 1	PWR	11/21/1978	component cooling		leak	PNO-I-82-076	corrosion	corrosion	CS
San Onofre 1	PWR	6/30/1983	feedwater and condensate piping	not given	leak	EPRI NP-6066	erosion/corrosion	leak occurred in a reducer downstream of a control valve, leak repaired by	CS
San Onofre 2	PWR	12/31/1982	heater drain pump discharge	not given	leak	EPRI NP-6066	erosion/corrosion	leak occurred in one reducer downstream of a control	CS
Seabrook	PWR	9/25/1988	D.G. SWS	16x10	leak	NPRDS	erosion/corrosion	sch 80, 16x10 in. reducer, refueling outage	CS
South Texas 1	PWR	3/29/1988	ECW	30x14	leak	NPRDS	dealloying	cracked weld, dealloying of SS Al-bronze interface	SS
St. Lucie 1	PWR	3/5/1985	salt water cooling line	1x30	leak	NPRDS	corrosion	sch 40, 1x30-in, salt water corrosion	CS
Surry 1	PWR	6/15/1973	unknown	unknown	rupture	fiche 50280-844	not given		
Surry 2	PWR	1/25/1970	not given	not given	rupture	not given	not given	bellows failed	
Three Mile Island 1	PWR	7/5/1975	bldg spray, decay heat, spent fuel	10, 1.0001	crack/leak	PNO-79-181B	IGSCC	137 of 651 welds cracked, leaked	SS
Three Mile Island 1	PWR	3/3/1986	feedwater	8x6	leak	NPRDS	erosion/corrosion	sch 80, 8x6-in reducer, hole in pipe	CS
Trojan	PWR	7/9/1983	main steam line sample line steamtram	not given	leak	not given	erosion/corrosion	replaced 4 feed of piping due to leak	CS
Turkey Point 3	PWR	12/31/1978	main steam reheater safety valve inlet	not given	leak	EPRI NP-6066	erosion/corrosion	eroded areas found, weld repair of pin hole leak in a	CS
Vermont Yankee	BWR	9/8/1969	off gas	not given	rupture	AO 73-27, 50271-2	not given	explosion in off-gas system ruptured air ejector	SS
Vermont Yankee	BWR	5/24/1970	control rod drive	2.5x3	leak	AO 74-08	stress corrosion/IGSCC	leaked reducer, stress corrosion	SS
Vermont Yankee	BWR	6/12/1970	control rod drive	2.5x3	leak	Ltr DL 6/13/74	stress corrosion/IGSCC	stress corrosion	SS
Vermont Yankee	BWR	9/15/1990	SWS (CI-3)	3 to 24	leak	ACN:9504130158	microbiologically induced corrosion		CS
Vogtle 2	PWR	7/22/1990	RCS drain	2?	leak	PNO-II-94-039	fatigue		SS
Yankee Rowe	PWR	5/22/1965	instrument line		leak	ORNL-NSIC-87:35(	construction defect/errors	construction defect/errors	SS
Hatch 1	BWR	12/25/1981	Condenser	not given	Leak		Not Given	Tube leaks	CS

Station	Plant Type	Date	System Name	Pipe Size	Break Def	Reference	Failure Mechanism	Comments	Material
Hatch 1	BWR	3/6/1978	Instrument line	0.75-10	Leak		Fatigue		SS
Hatch 1	BWR	4/27/1984	Main fire header	not given	Rupture		Material Weakness	Material Weakness	CS
Hatch 2	BWR	4/25/1986	Extraction steam line at reducer	20x16	Rupture		Erosion/Corrosion	Crack rupture 18 long x .25 wide, low pressure	
Hatch 2	BWR	4/24/1984	Main fire header	not given	Leak		Not Given	Steam leak	CS
Indian Point 3	PWR	1/10/1978	Chemical and volume control		Leak		Unknown	Unknown cause	SS
Kewaunee	PWR	12/16/1982	Chemical and volume control		Leak		Fatigue-Vibrational	Fatigue-Vibrational	SS
Kewaunee	PWR	10/26/1983	Reactor Coolant		Leak		Erosion/Corrosion	Erosion	SS
Kewaunee	PWR	3/13/1974	Reactor Coolant		Leak		Unknown	Unknown cause	SS
LaSalle 1	BWR	12/10/1987	1 B feedwater line	8 x 14	Leak		Erosion/Corrosion	45 deg elbow to 8 x 14 expander had pinhole leak	
LaSalle 1	BWR	12/10/1987	2 B feedwater line	8 x 14	Leak		Erosion/Corrosion	8 x 14 expander thinning and leaking	
LaSalle 1	BWR	5/31/1985	Bellows near circ pump	not given	Rupture		Bellows failed	Expansion joint; flooded SWS pump; circulation pump; CW pump; 67500 gal	CS
LaSalle 1	BWR	8/20/1996	Sprinklers	not given	Leak		Not Given		SS
LaSalle 1	BWR	9/24/1996	Steam line	not given	Leak		Not Given		CS
Millstone 1	PWR	10/21/1974	Feedwater sparger	not given	Leak		Fatigue-Vibrational	3rd design cracked	CS
Millstone 1	PWR	6/12/1973	Feedwater sparger	not given	Crack/Leak		Fatigue-Vibrational	Two cracked, two with cracked indications	CS
Millstone 1	PWR	5/6/1996	LPCI	not given	Leak		IGSCC		SS
Millstone 1	PWR	6/27/1985	SWS	36 x 30	Leak		Erosion/Corrosion	Sch 40, 36 x 30	CS
Millstone 2	PWR		SWS	12, 24	Leak		Not Given	Steel & epoxy	CS
Millstone 2	PWR		SWS	2.5-6	Leak		Not Given	Cu-Ni	CS
Millstone 2	PWR		SWS	0.75-2.25	Leak		Not Given	Stainless steel	CS
Millstone 3	PWR		SWS	0.75-3	Leak		Not Given	Cu-Ni	CS
Millstone 3	PWR		SWS	2.5-10	Leak		Not Given	Steel & epoxy	CS
Millstone 3	PWR		SWS	2.5-6	Leak		Not Given	Cu-Ni	CS
Millstone 3	PWR		SWS	0.25-2.5	Leak		Not Given	Stainless steel	CS
Monticello	BWR		Condenser	not given	Leak		Erosion/Corrosion		CS
Monticello	BWR	5/19/1983	Moisture separator reheater	6x4	Leak		Erosion/Corrosion	Reducer leak from erosion	SS
North Anna 1	PWR	7/1/1993	SIS high head pump casing	unknown	Leak		Corrosion	Boric acid corrosion	SS
North Anna 2	PWR	6/1/1979	Feedwater	16 x 14			Fabrication Defect	Slag/porosity	CS
Oconee 2	PWR	8/1/1975	Emergency Core Cooling		Leak		Unknown	Unknown	SS
Oconee 3	BWR	1/1/1976	FW heat extraction line	not given	Leak		Erosion/Corrosion		CS
Zion 2	PWR	4/20/1971	eductor drain	1 to 6	leak	NPRDS	fatigue-vibrational	sch 40, socket weld	CS
Cooper	BWR	1/23/1977	Service Water	20X8	Leak	RO 77-5	Erosion/Corrosion	Cracked expansion joint, erosion/corrosion	CS

Appendix B2

Data Removed due to Material

Station	Plant Type	Date	System Name	Pipe Size	Break Def	Reference	Failure Mechanism	Comments
ANO1	PWR	9/1/1977	Drain Line	1	Leak	NPE VIII.A 242	Unknown	
ANO2	PWR	7/30/1976	Unknown	2	Leak	50368-281, -294, -305	Not Given	Pin-hole leaks in 2-in pipe schedule 80, no other information
Big Rock Point	BWR	3/27/1976	Unknown	>1	Leak	50153-554 and RO 5-76	Stress Corrosion Cracking	6 valve nozzles found cracked
Big Rock Point	BWR	8/4/1971	Not Given	3	Leak	Letter DL	Thermal Fatigue	
Browns Ferry 1	BWR	1/21/1985	Drywell	<1	Leak	85-001	Fatigue-Vibrational	Fatigue-vibrational
Browns Ferry 2	BWR	9/30/1978	Drywell	0.15	Leak	LER 78-16	Fatigue-Vibrational	Fatigue-vibration
Brunswick 1	BWR	3/20/1990	Unknown	>1	Failed	90-4	Not Given	PVC lack of bond, 8 prior events LERs 86-6, 87-13, 87-22, 89-10, 89-22
Callaway	PWR	10/2/1995	Desuperheater	2	Leak	PNO-IV-95-043A	Unknown	Leak at elbow weld, unknown cause
Calvert Cliffs 1	PWR	10/9/1985	Bleedoff Line	<1	Leak	NPE V.A 132	Fatigue-Vibrational	
Cooper	BWR	12/28/1979	Radiant Energy conversion	12	Leak	79-043	Not Given	
Cooper	BWR	10/12/1979	Supply	>1	Leak	LER 79-029	Not Given	No cause
Dresden 2	BWR	1/2/1987	Unknown	12	Crack/Leak	87-001	Stress Corrosion/IGSCC	IGSCC
Dresden 2	BWR	5/18/1979	Aluminum radwaste line	>1	Leak	LER 79-001	Corrosion	
Dresden 2	BWR	10/7/1975	Drywell	18	Crack/Leak	AO 75-48	Unknown	Cracked valve seat in nitrogen purge line, unknown cause
Dresden 2	BWR	3/3/1975	Unknown	8	Crack/Leak	AO 75-14	Construction Defect/Errors	Construction defects
Dresden 2	BWR	12/16/1974	Drywell	4	Leak	RO	Unknown	Unknown
Dresden 2	BWR	12/12/1974	Drywell	>1	Leak	AO 74-76	Unknown	Unknown
Dresden 2	BWR	12/12/1974	Drywell	<1	Leak	AO 74-75	Unknown	Broken tubes, tubes replaced, unknown cause
Dresden 2	BWR	9/13/1974	Drywell	4	Leak	RO	Stress Corrosion/IGSCC	IGSCC
Dresden 3	BWR	1/5/1983	TAP isolation	0.75	Leak	83-2	Unknown	Thermal Fatigue
Dresden 3	BWR	4/16/1975	Dry well line	0.25	Severed	RO-75-19 & 50-249-609	Not Given	Used as ladder
Dresden 3	BWR	9/24/1974	Drywell	18	Crack/Leak	AO 74-29	Design-Dynamic Load	Dynamic load, strained piping
Farley 1	PWR	6/11/1995	Room cooler	<1	Leak	95-005	Unknown	Unknown cause
Fermi 2	BWR	4/1/1982	Unknown	0.75	Leak	ACN:8210190332	Fatigue-Vibrational	
Ginna	PWR	12/1/1976	Demineralizer	<1	Leak	NPE VIII.A.226	Unknown	
Perry	BWR	3/25/1989	fiberglass SWS	30	rupture	93-010	not given	lack of soil support
Perry	BWR	3/25/1989	service water fiberglass pipe	30	rupture	93-010	design-dynamic load	design-dynamic load
Quad Cities 1	BWR	12/31/1966	drywell	4	leak	inquiry memo	erosion/corrosion	erosion
Quad Cities 1	BWR	10/13/1969	not given	<1	rupture	not given	not given	
San Onofre 3	PWR	10/14/1979		1	leak	83-095	unknown	plugged pipe, line failure
Surry 1	PWR	11/29/1968	RTD	0.375	failed	AO-72-06	not given	blew out
Three Mile Island 2	PWR	1/7/1975	unknown	1	leak	79-005	fatigue-vibrational	fatigue-vibrational
Turkey Point 3	PWR	1/20/1981	drywell	<1	leak	PNO-II-85-009	other	personnel error
Hatch 2	BWR	3/12/1982	Sensing tube	0.25	Leak		Not Given	Weld broke - weight of valve caused failure
LaSalle 1	BWR	11/11/1984	Drywell	1.625	Leak		Fatigue-Vibrational	Fatigue-Vibration, turbulent flow conditions
Oyster Creek	BWR	3/15/1979	Drywell equipment drain tank	>1	Leak		Not Given	

Appendix C

National Transportation Safety Board Data and References

Source	Pipe OD (in)	Pipe Thickness (in)	Break Def	Fluid	Failure Mechnism	Material
3a	24	0.25	rupture	crude oil	fatigue cracking due to a dent in the pipe	steel - API 5L X52
3b	28	0.281	rupture	gasoline	corrosion fatigue crackign, maybe preexisting weld defect	steel - API 5L X52
3c	40	0.344	through wall crack	gasoline	inadequately supported pipeline	steel
3d	10	0.25	rupture	diesal fuel, high sulfer	probable cause environment induced cracking at pipe coating failure area	steel - Grade 5L X-42 material
3e	8	0.188	rupture - overpressure	diesal fuel	operator failure to follow operation procedures	steel
3f	12.75	0.203	rupture	fuel oil	undiscovered fractur in a buckle due to a bad inline	steel - API 5L X46
3g	16	0.312	rupture	gasoline	damage done during modification, inadequate	steel - API 5L X52
3h	30	0.355	rupture	natural gas	* wall thinning due to corrosion	carbon steel - API 5L X52
3i	34	0.312	rupture	crude oil	fatigue crack growth to rupture	steel - API 5L X52
3j	36	0.281	rupture	fuel oil	corroded to 0.069in at thinnest wall point	steel
3k	8	0.188	rupture	liquid butane	corrosion	steel - API 5L X46

National Transportation Safety Board Data References

From: National Transportation and Safety Board Published Pipeline Accidents
http://www.ntsb.gov/Publictn/P_Acc.htm

Reference ID	Pipeline Accident Report Number	Report Date
3a	DCA-00-MP-004	2-May-97
3b	DCA-00-MP-005	5-Jul-97
3c	DCA-98-MP-002	21-Mar-95
3d	DCA99-MP005	8-Feb-95
3e	DCA-97-FP-002	28-Apr-95
3f	PB2002-916501	22-Jul-98
3g	PB2002-916502	7-Oct-98
3h	PB2003-916501	10-Feb-99
3i	PB2004-916501	22-Jun-00
3j	PB98-916502	3-Nov-94
3k	PB98-916503	5-Nov-94

Appendix D

Failure Mechanism Numerical Data

Failure Mechanisms for the PWR Data Set in PWR Bins

Failure Mechanism	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
Aging	0	0	0	0	0	0
Corrosion	208	66	123	330	45	7
Defects, Consturction Errors	119	100	4	103	49	0
Wear	3	13	0	1	1	0
Water Hammer	15	5	2	3	1	2
Flow Assisted Corrosion (FAC)	0	0	0	0	0	0
Fatigue	302	38	16	5	7	0
Intergranual Stress Corrosion Cracking (SCC)	110	110	59	133	26	0
Other	274	244	148	187	150	3

Failure Mechanisms for the BWR Data Set in BWR Bins

Failure Mechanism	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
Aging	1	0	0	0	0	1
Corrosion	73	26	34	26	11	0
Defects, Consturction Errors	58	9	8	8	2	0
Wear	0	0	1	0	0	0
Water Hammer	6	2	3	1	0	1
Flow Assisted Corrosion (FAC)	0	0	0	0	0	0
Fatigue	122	9	8	8	0	0
Intergranual Stress Corrosion Cracking (SCC)	48	10	53	51	11	0
Other	178	22	23	20	7	6

Summary of Failure Mechanisms

Failure Mechanism	All	SS	CS	PWR	BWR
Aging	0	0	2	0	2
Corrosion	0	185	764	779	170
Defects, Consturction Errors	0	202	258	375	85
Wear	0	2	17	18	1
Water Hammer	0	10	31	28	13
Flow Assisted Corrosion (FAC)	0	0	0	0	0
Fatigue	0	326	189	368	147
Intergranual Stress Corrosion Cracking (SCC)	0	399	212	438	173
Other	0	458	804	1006	256

Appendix E

Selected Failure Frequencies with NTSB Data

Appendix E. Failure Frequencies with National Transportation Safety Board Data

The calculated failure frequencies with the National Transportation Safety Board Data are given below in Tables E1 and E2 for all data and the carbon steel data, respectively. The additional data were all carbon steel pipes and therefore do not affect the stainless steel failure frequencies.

Table A1. Failure Frequencies with NTSB Data, All Data.

NRC PWR Bins			NRC BWR Bins		
Range (in)	Frequency (no. events)	Frequency (1/cal-yr)	Range (in)	Frequency (no. events)	Frequency (1/cal-yr)
0-1.625	1310	1.52E-04	0-1.875	1310	1.52E-04
1.625-3	260	3.02E-05	1.875-3.25	260	3.02E-05
3-7	297	3.45E-05	3.25-7	297	3.45E-05
7-14	515	5.98E-05	7-18	559	6.49E-05
14-31	133	1.54E-05	18-41	101	1.17E-05
>31	25	2.90E-06	>41	13	1.51E-06

Table A2. Failure Frequencies with NTSB Data, Carbon Steel Data.

NRC PWR Bins			NRC BWR Bins		
Range (in)	Frequency (no. events)	Frequency (1/cal-yr)	Range (in)	Frequency (no. events)	Frequency (1/cal-yr)
0-1.625	611	1.25E-04	0-1.875	611	1.25E-04
1.625-3	149	3.05E-05	1.875-3.25	149	3.05E-05
3-7	194	3.97E-05	3.25-7	194	3.97E-05
7-14	353	7.22E-05	7-18	393	8.03E-05
14-31	114	2.33E-05	18-41	85	1.74E-05
>31	22	4.50E-06	>41	11	2.25E-06

PENNSTATE Department of Mechanical and Nuclear Engineering

NucE 597-D Nuclear Reactor Safety

Project # 1

Piping Failure Database

April 06, 2005

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

Contents

1.0 Introduction 2

2.0 Assumptions Used 3

3.0 Analysis Approach 4

4.0 Discussion of the Results 5

5.0 Conclusions 23

6.0 References 24

Project Number: 1	
Analyst: '	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

1.0 Introduction

The proposed changes to 10CFR50.46 are based on the idea that small pipes break and large pipes don't. While this is an over simplification of the proposed rule change it is based on some data that the NRC has collected on pipe failures.

The scope of this project is to generate a database on pipe leakage and failure occurred in plants and facilities worldwide. Data were to be put into plots and tables in order to be used to compare with the frequency plot generated by the NRC (Reference 1). The comparison against NRC results should provide a better understanding of the nuclear pipe failure behavior. More important, the database documented in this report should be integrated with other database generated in the same fashion in the framework of the project#1 (Spring 2005) of the Nuce-597-D course at The Pennsylvania State University. The integration of various database should provide a reasonable comparison against NRC results (Reference 1), and might also include pipe failure which were not taken into account by NRC analyses.

Even though the objective of this project is related to nuclear technology applications, some data was obtained from conventional engineering applications.

The purpose of this analysis is to create a database that takes into accounts the following categories:

1) Pipe material. Only carbon steel and stainless steel pipes are considered.

2) For each type of steel piping data were divided into "leaking" or "failures or ruptures".

3) Mechanism for either leaking or failure: e.g. fatigue, corrosion, etc.

4) Failures of a type, for each different steel pipe grouped as a function of pipe size.

Frequency plots were created based upon the relation between number of failures and number of operating reactor-year. For the failure concerning the commercial Nuclear Power Plants, data on reactor-year were obtained from page 35 to page 58 of Reference 2.

Project Number: 1	
Analyst	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

2.0 Assumptions Used

The following assumptions were used in performing the required task for the analysis documented in this report:

a) Data obtained from internet websites were used without further investigations on their reliability. However, each data obtained from website was referenced.

b) The database documented in this report includes pipe failure data from both nuclear and conventional engineering fields.

c) For some of the points included into the database it was not possible to retrieve all of the information specified in Section 1.0. As a consequence these data may not be present in defined categories.

d) The number of reactor years experience in USA used was 2745 days as of the end of 2003 (Reference 3). In order to obtain the calendar year an average value of 0.81 was assumed for the availability factor.

e) The classification in six different size categories is related to the pipe internal diameter where the leakage or failure occurred.

f) Failure occurred at junction between carbon steel/stainless steel were included into the carbon steel category.

g) For a few database points where the information on steel type was not available, the material was inferred by the analyst upon engineering judgment based on the system piping location into the reactor where the events occurred.

h) Crack events where classified as leakage points into the database.

i) Whenever two different mechanisms contributed to a pipe leakage or failure, the data point was considered in each of the subdivided mechanism category. The same approach was adopted for pipe with a dimension meeting the boundary between two size classes (defined in Section 3.0). This was done in order to increase the population number into the different categories.

j) Data #20 and 21 in Table 1 relate to VVER-440 reactor type. These data were considered PWR data.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

3.0 Analysis Approach

The task was accomplished by conducting a literature survey on pipe failure papers, as well as by searching through internet websites. The data obtained were then processed according with the following procedure:

a) Separate the data into carbon steel piping and stainless steel piping.

b) Separate the data for each type of steel piping into "leaking" or "failures or ruptures".

c) Isolate the mechanism for either leaking or failure.

d) Grouping the failures of a type, for each different steel pipe as a function of pipe size. The following bins for the different pipe sizes were used:

- 0 to 1 inch -> Class 1
- 1 to 4 inches -> Class 2
- 4 to 12 inches (accumulator line size) -> Class 3
- 12 to 24 inches (pressurizer surge line size, recirculation line sizes) -> Class 4
- 24 to 30 inches (recirculation line sizes, cold leg, hot leg sizes) -> Class 5
- greater than 30 inches (main steam line sizes) -> Class 6.

e) Eliminating data from failure mode that are totally unexpected from a rector plant point of view.

f) Normalize the accepted data and calculate frequencies based on the total reactor-year operation data.

g) Compare the calculated frequencies against NRC results (Reference 1) separately for PWR and BWR plants, and, for each plant, considering carbon steel, stainless steel, and combined steel data.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

4.0 Discussion of the Results

The whole database is provided in Tables 1 and 2, which includes several information about the failures. The references for each data point are indicated in Tables 1 and 2 and specified in Section 6.0. The database is composed of 55 points.

However, according with the procedure documented in Section 2.0, data point number 50, 51, and 52 were eliminated because the "polythionic stress corrosion cracking" is a mechanism failure that does not occur in Light Water Reactor environment. The data from # 47 to 55 are not related to NPP, but they are taken from conventional plants.

The data divided by carbon and stainless steel pipes are provided in Tables 3 and 4, respectively.

Tables 5 and 6 provide data subdivided by failure mechanism and size class for carbon steel and stainless steel, respectively.

Tables 7 to 9 present normalized data as described in Section 3.0 for carbon, stainless steel, and combined data sets. The failure frequencies collected in these tables were calculated with the following procedure:

- for each steel set data, the failures were normalized in each pipe size bin by the total number of failure for the considered steel type. This provides the fraction of failure for each bin size
- Each fractional size was then divided by 3390 calendar years of operation in order to obtain a frequency in calendar-years^{-1} for each bin size.

The number 3390 is calculated by the number of reactor years experience in US, i.e. 2745 years (see assumption d) in Section 2.0) as of the end of 2003. Given an average availability factor of 0.81,

$$\frac{2745 reactor - years}{0.81} = 3390 calendar - year \qquad (1)$$

This normalization was necessary in order to compare the calculated frequencies against NRC results, which are in fact related to calendar-years. The NRC results are shown in Table 10 (from Table 3 of Reference 1). The considered NRC results are the values for end of original license from Table 3 of Reference 1.

Figures 1 to 6 show the comparison among calculated frequencies and NRC results.

The comparison of obtained results against NRC results is definitely affected by the number of data point found and included into the database documented in this report. In fact more points would be necessary in order to have significant comparisons. It should

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

be noted that for some size bin (or size classes) zero or almost zero data point were found. This means that certain LOCA categories (as indicated in Figures 1 to 6) were not filled by "enough" database points to have a significant comparison against the statistical NRC results.

Figure 1 to 6 also show that for most of the size classes in which more database points were found the calculated frequencies are comparable with NRC results. Comparisons are in fact better for the combined sets case where more points fill the different LOCA categories.

Most of the found data points fill the classes 2, 3 and 4. For these classes plots show that in among the different cases (PWR, BWR and combined) the calculated frequencies tend to be higher than NRC frequencies. It should also be noted that the trend of calculated frequencies versus LOCA categories is not really consistent with the NRC trends. These trends are confirmed even ignoring those classes which have zero or very few data points.

The calculated frequencies tend to show quite steady failure frequency values versus LOCA category, whereas NRC results show a decrease in failure frequencies going from low to high LOCA categories, both for PWR and BWR.

A few comments on the found results may give some explanations on the calculated trends. At first, the search of pipe failures was most focused on larger pipe sizes rather than smaller, this resulted in basically ignoring very small tubes and therefore classes 1 and 2 have a very few data points. For instance, the huge database on steam generators tubes failed in nuclear industry (e.g. NUREG-CR6575) were not included in this analyses.

Furthermore, the frequencies were calculated by using the US reactor-years but the database points were obtained from plant worldwide and some not even from NPPs. Probably the frequencies may be calculated using the worldwide reactor-years operating value, and this would generates lower calculated frequencies that should be much closer to the NRC ranges for classes 2,3, and 4.

Statistical results need to have at least ten points within each class in order to assume a normal distribution. This number of data points can be then considered the very least number of data needed in each class in order to have a reasonable comparison of the allocated database against the NRC results, which have been calculated with a statistical approach. From Tables 7, 8, and 9 it is evident that for BWR, PWR, or combined sets only a couple of classes were filled with about ten points.

Most common failure mechanism found was ISCC for stainless steel. This was an expected result, since is a very well known problem of stainless steel in NPP technology and a lot of analyses are available in literature concerning this issue. For carbon steel there were found three mechanisms with almost the same number of failure data points:

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

fatigue, corrosion/erosion, and mechanical damage/vibrations. These also were expected results since is well knows these are among the most common failure causes. Among these failures there are in fact a lot of secondary side pipes subject for their operating conditions to repetitive loads, thermal transients, presence of debris, corrosion and erosion.

The Reference 47 for data #44 in Tables 1 and 2 was lost. However, the data was left into the actual database.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 1: Pipe failure Database.

No.	Reactor Type	Plant Name	Unit #	Country	Pipe Position	Pipe Internal Diameter (in)
1	PWR	Genkay	1	Japan	SS piping system	5.9
2	BWR/4	Hamaoka	1	Japan	ECCS HPCI piping	5.9
3	PWR	Surry	2	USA	Main FW pipe	18
4	PWR	Civaux	1	France	RHRS pipe	7.1
5	PWR	Trojan		USA	Heater drain pump discharge pipe	14
6	PWR	Mihama	3	Japan	FW heater drain pipng	5.9
7	PWR	Main Yankee		USA	Moisture separator reheater vent pipe	1.97
8	PWR	Savannah River	k-Area	USA	Pump discharge piping	2
9	BWR	Hamaoka	2	Japan	Drain pipe in RHRS	1.06
10	BWR	Brunsbuettel		Germany	Auxiliary coolant system piping	7.9
11	PWR	Mihama	3	Japan	Excess Letdown pipe line	2
12	BWR	Hope creek	1	USA	pipe collecting water in the moist. Separator	8
13	PWR	Mihama	2	Japan	PRZ spray line	0.79
14	PWR	Mihama	2	Japan	Letdown piping of CVCS	2.36
15	BWR	Kashiwazaki	2	Japan	HP turbine exhaust press. Detection pipe	1.18
16	PWR	Ikata	1	Japan	Charging pipe from CVCS	2.37
17	PWR	Tsuruga	2	Japan	CVCS piping	3.5
18	BWR	Tsuruga	1	Japan	Piping of CR driving water system	2.37
19	BWR	Tokai-Daini		Japan	FW heater piping	0.63
20	VVER-440	Loviisa	1	Finland	Main FW	12.8
21	VVER-440	Loviisa	2	Finland	Main FW piping system	12.8
22	PWR	Millstone	3	USA	2 pipes in Moisture Separator Drain system	6
23	PWR	San Onofre	2	USA	FW regulation valve bypass pipe line	6
24	LMFBR	Monju		Japan	SS Hot leg	
25	PWR	Ikata	1	Japan		20
26	PWR	Ikata	1	Japan		35
27	PWR	Mihama	3	Japan		20
28	PWR	Mihama	3	Japan		20
29	BWR	Nine Mile Point	1	USA	Recirc Line*	20
30	BWR	Browns Ferry	2	USA	Recirc Line*	20
31	BWR	Monticello		USA	Recirc Line	22
32	BWR	Monticello		USA	Recirc Line	12
33	BWR	Monticello		USA	Recirc Line	12

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

34	BWR	Monticello		USA	Recirc Line	12
35	BWR	Monticello		USA	Recirc Line	12
36	BWR	Monticello		USA	Recirc Line	12
37	BWR	Hatch	1	USA	Recirc Line	20
38	BWR	Hatch	1	USA	Recirc Line	24
39	BWR	Hatch	1	USA	Recirc Line	22
40	BWR	Hatch	1	USA	Recirc Line	22
41	BWR	Hatch	1	USA	Recirc Line	22
42	BWR	Hatch	1	USA	Recirc Line	22
43	BWR	Hatch	1	USA	Recirc Line	22
44	PWR	Mulheim-Karlich		Germany	Feed Water Pipe	15.75
45	PWR	Oconee	3	USA	HPI line	2.5
46	PWR	Crystal River		USA	HPI line	2.5
47						4
48						6
49						10
50						2
51						6.6
52						6.7
53						2.5
54						8
55						6

*Pipe internal diameter was greater than 20in.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 2: Pipe failure Database and Reference Numbers.

No.	Pipe Thickness	Pipe Material	Type of Failure	Mechanism of Failure	Event Date	Reference # In Section 6.0
1	11mm	Carbon Steel	Leakage	Fatigue	6/6/1988	4
2	11mm	Carbon Steel	Rupture	Hydrogen Combustion	11/7/2001	5
3	0.5in	Carbon Steel	Rupture	Erosion/Corrosion	Dec-86	6
4	25mm	Carbon Steel	Leakage	Thermal Fatigue	5/12/1998	7
5	0.375in	Carbon Steel		Erosion/Corrosion	3/9/1985	8
6	1.4mm	Carbon Steel	Rupture	Cavitation and FAC	8/15/2004	9
7			Leakage	Erosion/Corrosion	7/22/1992	10
8		Carbon Steel ASTM-A53		Manufacturing Defect	/1992	11
9	3.9mm	Carbon Steel STS 42	Leakage	Vibration-Fatigue	5/25/2002	12
10		Carbon Steel	Rupture	Hydrogen Explosion	12/14/2001	13
11		Carbon Steel	Leakage	Fatigue		14
12		Carbon Steel	Leakage	Excessive stress	10/10/2004	15
13		Stainless Steel		Corrosion	11/9/2003	16
14		Stainless Steel SUS27TP		Cavitation and Fatigue	4/7/2000	17
15			Leakage	Manufacturing Defect and Fatigue	6/22/2000	18
16	8.7mm	Stainless Steel	Leakage	SCC	10/13/2000	19
17	11mm	SUS316	Leakage	Manufacturing Defect	12/24/1996	20
18	8.7mm	Carbon Steel STPT42	Leakage	Pitting Corrosion	2/20/1997	21
19	1.0mm	Stainless Steel	Leakage	Manufacturing Defect and Pit.Corrosion	4/4/1999	22
20	18mm	Carbon Steel CT20	Rupture	Erosion/Corrosion	5/28/1990	23
21	18mm	Carbon Steel CT20	Rupture	Erosion/Corrosion	/1993	24
22		Carbon Steel		Erosion/Corrosion	12/31/1990	25
23		Carbon Steel	Leakage	Erosion/Corrosion	7/2/1990	26
24			Leakage	Design Mistake and Vibration	12/8/1995	27
25		Stainless Steel	Rupture	Stress Corrosion		28
26		Carbon Steel	Rupture			29
27		carbon steel	rupture	flow assisted corrosion		30
28		carbon steel	rupture	cavitaion erosion		31

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

29		stainless steel	crack	IGSCC		32
30		stainless steel	crack	IGSCC		33
31		stainless steel	crack	IGSCC		34
32		stainless steel	crack	IGSCC		35
33		stainless steel	crack	IGSCC		36
34		stainless steel	crack	IGSCC		37
35		stainless steel	crack	IGSCC		38
36		stainless steel	crack	IGSCC		39
37		stainless steel	crack	IGSCC		40
38		stainless steel	crack	IGSCC		41
39		stainless steel	crack	IGSCC		42
40		stainless steel	crack	IGSCC		43
41		stainless steel	crack	IGSCC		44
42		stainless steel	crack	IGSCC		45
43		stainless steel	crack	IGSCC		46
44		carbon steel	Rupture	pressure transient due to heating		47
45		carbon/ss junction	crack (circum)	thermal hydraulic transients	1997	48
46		carbon/ss junction	crack	thermal hydraulic transients	1982	49
47		304H Stainless Steel	crack	stress corrosion		50
48		304H Stainless Steel	crack	stress corrosion		51
49		304H Stainless Steel	crack	stress corrosion		52
50		stainless steel	crack	polythionic stress corrosion cracking		53
51		stainless steel	crack	polythionic stress corrosion cracking		54
52		stainless steel	crack	polythionic stress corrosion cracking		55
53		carbon steel	crack	oxygen corrosion		56
54		carbon steel	leak	incomplete weld		57
55		carbon steel	leak	corrosion		58

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 3: Carbon steel pipe Database.

No.	Reactor Type	Plant Name	Unit #	Pipe Internal Diameter (in)	Pipe Material	Type of Failure	Mechanism of Failure
1	PWR	Genkay	1	5.9	Carbon Steel	Leakage	Fatigue
2	BWR/4	Hamacka	1	5.9	Carbon Steel	Rupture	Hydrogen Combustion
3	PWR	Surry	2	18	Carbon Steel	Rupture	Erosion/Corrosion
4	PWR	Civaux	1	7.1	Carbon Steel	Leakage	Thermal Fatigue
5	PWR	Trojan		14	Carbon Steel		Erosion/Corrosion
6	PWR	Mihama	3	5.9	Carbon Steel	Rupture	Cavitation and FAC
7	PWR	Main Yankee		1.97		Leakage	Erosion/Corrosion
8	PWR	Savannah River	k-Area	2	Carbon Steel ASTM-A53		Manufacturing Defect
9	BWR	Hamaoka	2	1.06	Carbon Steel STS 42	Leakage	Vibration-Fatigue
10	BWR	Brunsbuettel		7.9	Carbon Steel	Rupture	Hydrogen Explosion
11	PWR	Mihama	3	2	Carbon Steel	Leakage	Fatigue
12	BWR	Hope creek	1	8	Carbon Steel	Leakage	Excessive stress
13	BWR	Kashiwazaki	2	1.18		Leakage	Manufacturing Defect and Fatigue
14	BWR	Tsuruga	1	2.37	Carbon Steel STPT42	Leakage	Pitting Corrosion
15	VVER-440	Loviisa	1	12.8	Carbon Steel CT20	Rupture	Erosion/Corrosion
16	VVER-440	Loviisa	2	12.8	Carbon Steel CT20	Rupture	Erosion/Corrosion
17	PWR	Millstone	3	6	Carbon Steel		Erosion/Corrosion
18	PWR	San Onofre	2	6	Carbon Steel	Leakage	Erosion/Corrosion
19	LMFBR	Monju				Leakage	Design Mistake and Vibration
20	PWR	Ikata	1	35	Carbon Steel	Rupture	
21	PWR	Mihama	3	20	carbon steel	rupture	flow assisted corrosion
22	PWR	Mihama	3	20	carbon steel	rupture	cavitaion erosion
23	PWR	Mulheim-Karlich		15.75	carbon steel	Rupture	pressure transient due to heating
24	PWR	Oconee	3	2.5	carbon/ss junction	crack (circum)	thermal hydraulic transients
25	PWR	Crystal River		2.5	carbon/ss junction	crack	thermal hydraulic transients
26				2.5	carbon steel	crack	oxygen corrosion
27				8	carbon steel	leak	incomplete weld
28				6	carbon steel	leak	corrosion

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 4: Stainless steel pipe Database.

No.	Reactor Type	Plant Name	Unit #	Pipe Internal Diameter (in)	Pipe Material	Type of Failure	Mechanism of Failure
1	PWR	Mihama	2	0.79	Stainless Steel		Corrosion
2	PWR	Mihama	2	2.36	Stainless Steel SUS27TP		Cavitation and Fatigue
3	PWR	Ikata	1	2.37	Stainless Steel	Leakage	SCC
4	PWR	Tsuruga	2	3.5	SUS316	Leakage	Manufacturing Defect
5	BWR	Tokai-Dami		0.63	Stainless Steel	Leakage	Manufacturing Defect and Pit Corrosion
6	PWR	Ikata	1	20	Stainless Steel	Rupture	Stress Corrosion
7	BWR	Nine Mile Point	1	20	stainless steel	crack	IGSCC
8	BWR	Browns Ferry	2	20	stainless steel	crack	IGSCC
9	BWR	Monticello		22	stainless steel	crack	IGSCC
10	BWR	Monticello		12	stainless steel	crack	IGSCC
11	BWR	Monticello		12	stainless steel	crack	IGSCC
12	BWR	Monticello		12	stainless steel	crack	IGSCC
13	BWR	Monticello		12	stainless steel	crack	IGSCC
14	BWR	Monticello		12	stainless steel	crack	IGSCC
15	BWR	Hatch	1	20	stainless steel	crack	IGSCC
16	BWR	Hatch	1	24in	stainless steel	crack	IGSCC
17	BWR	Hatch	1	22	stainless steel	crack	IGSCC
18	BWR	Hatch	1	22	stainless steel	crack	IGSCC
19	BWR	Hatch	1	22	stainless steel	crack	IGSCC
20	BWR	Hatch	1	22	stainless steel	crack	IGSCC
21	BWR	Hatch	1	22	stainless steel	crack	IGSCC
22				4	304H Stainless Steel	crack	stress corrosion
23				6	304H Stainless Steel	crack	stress corrosion
24				10	304H Stainless Steel	crack	stress corrosion

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 5: Stainless steel data subdivided by failure mechanism and size class.

Carbon steel Data					
28					
Leakage					Failure
24					1
ISCC			Defects/Construction Error		ISCC
22			2		1
Class 2	Class 3	Class 4	Class 1	Class 2	Class 4
3	10	15	1	1	1

Project Number: 1	
Analyst	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 6: Carbon steel data subdivided by failure mechanism and size class.

Stainless Steel Data												
27												
Leakage								Failure				
15								12				
Fatigue		Corrosion		Defects/ Construction error		MechDamage/ Vibration/ Loading		Corrosion	Hydrogen combustion	FAC		MechDamage/ Vibration/ Loading
5		6		3		5		4	2	2		1
cl2	cl3	cl2	cl3	cl2	cl3	cl2	cl3	cl4	cl3	cl3	cl4	cl4
3	2	4	2	1	1	3	1	4	2	1	1	1

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

Table 7: Frequency failure for carbon steel.

Plant Type	Class	Pipe Size (in)	# of Data	Fraction of Failures	Frequency per Cal. Year
BWR	1	0 to 1	0	0.000	1.000E-20
	2	1 to 4	3	0.500	1.475E-04
	3	4 to 12	3	0.500	1.475E-04
	4	12 to 24	0	0.000	1.000E-20
	5	24 to 30	0	0.000	1.000E-20
	6	> 30	0	0.000	1.000E-20
PWR	1	0 to 1	0	0.000	1.000E-20
	2	1 to 4	3	0.200	5.900E-05
	3	4 to 12	5	0.333	9.833E-05
	4	12 to 24	6	0.400	1.180E-04
	5	24 to 30	0	0.000	1.000E-20
	6	> 30	1	0.067	1.967E-05
Total	1	0 to 1	0	0.000	1.000E-20
	2	1 to 4	7	0.280	8.260E-05
	3	4 to 12	10	0.400	1.180E-04
	4	12 to 24	7	0.280	8.260E-05
	5	24 to 30	0	0.000	1.000E-20
	6	> 30	1	0.040	1.180E-05

*Carbon Steel

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 8: Frequency failure for stainless steel.

Plant Type	Class	Pipe Size (in)	# of Data	Fraction of Failures	Frequency per Cal. Year
BWR	1	0 to 1	1	0.045	1.341E-05
	2	1 to 4	0	0.000	1.000E-20
	3	4 to 12	5	0.227	6.704E-05
	4	12 to 24	15	0.682	2.011E-04
	5	24 to 30	1	0.045	1.341E-05
	6	> 30	0	0.000	1.000E-20
PWR	1	0 to 1	1	0.200	5.900E-05
	2	1 to 4	3	0.600	1.770E-04
	3	4 to 12	0	0.000	1.000E-20
	4	12 to 24	1	0.200	5.900E-05
	5	24 to 30	0	0.000	1.000E-20
	6	> 30	0	0.000	1.000E-20
Total	1	0 to 1	2	0.065	1.903E-05
	2	1 to 4	4	0.129	3.806E-05
	3	4 to 12	8	0.258	7.613E-05
	4	12 to 24	16	0.516	1.523E-04
	5	24 to 30	1	0.032	9.516E-06
	6	> 30	0	0.000	1.000E-20

**Stainless Steel

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 9: Frequency failure for combined sets.

Plant Type	Class	Pipe Size (in)	# of Data	Fraction of Failures	Frequency per Cal. Year
BWR	1	0 to 1	1	0.036	1.054E-05
	2	1 to 4	3	0.107	3.161E-05
	3	4 to 12	8	0.286	8.428E-05
	4	12 to 24	15	0.536	1.580E-04
	5	24 to 30	1	0.036	1.054E-05
	6	> 30	0	0.000	1.000E-20
PWR	1	0 to 1	1	0.050	1.475E-05
	2	1 to 4	6	0.300	8.850E-05
	3	4 to 12	5	0.250	7.375E-05
	4	12 to 24	7	0.350	1.032E-04
	5	24 to 30	0	0.000	1.000E-20
	6	> 30	1	0.050	1.475E-05
Total	1	0 to 1	2	0.036	1.054E-05
	2	1 to 4	11	0.196	5.794E-05
	3	4 to 12	18	0.321	9.482E-05
	4	12 to 24	23	0.411	1.212E-04
	5	24 to 30	1	0.018	5.268E-06
	6	> 30	1	0.018	5.268E-06

***Total

Project Number: 1	
Analyst: i	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

Table 10: NRC failure frequency results.

Plant Type	Class	Break Size (in)	Estimates (per cal. Year)		
			5%	Mean	95%
BWR	1	0.5	2.3E-05	5.1E-04	1.9E-03
	2	1.875	1.8E-06	1.2E-04	4.7E-04
	3	3.25	2.4E-07	2.1E-05	8.0E-05
	4	7	5.7E-08	6.6E-06	2.5E-05
	5	18	1.0E-08	2.4E-06	6.9E-06
	6	41	2.8E-11	2.5E-09	9.5E-09
PWR	1	0.5	3.0E-04	2.1E-03	7.5E-03
	2	1.875	4.9E-06	2.5E-04	9.3E-04
	3	3.25	3.1E-07	1.8E-05	7.0E-05
	4	7	6.0E-08	2.5E-06	9.6E-06
	5	18	9.3E-10	6.1E-08	2.4E-07
	6	41	1.0E-10	4.6E-08	1.7E-07

^NRC (Reference 1)

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

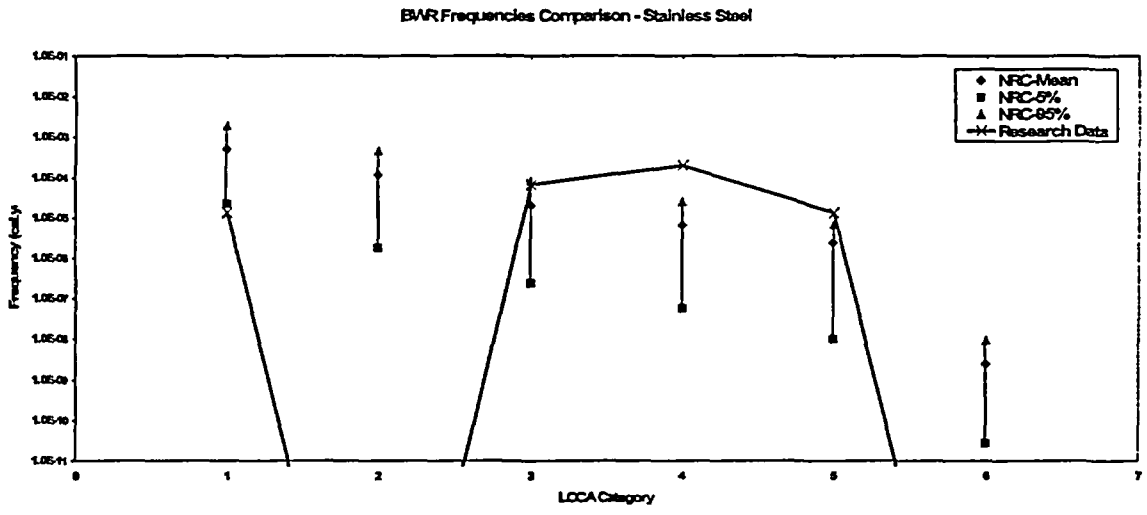

Figure 1: BWR frequencies comparison for stainless steel data.

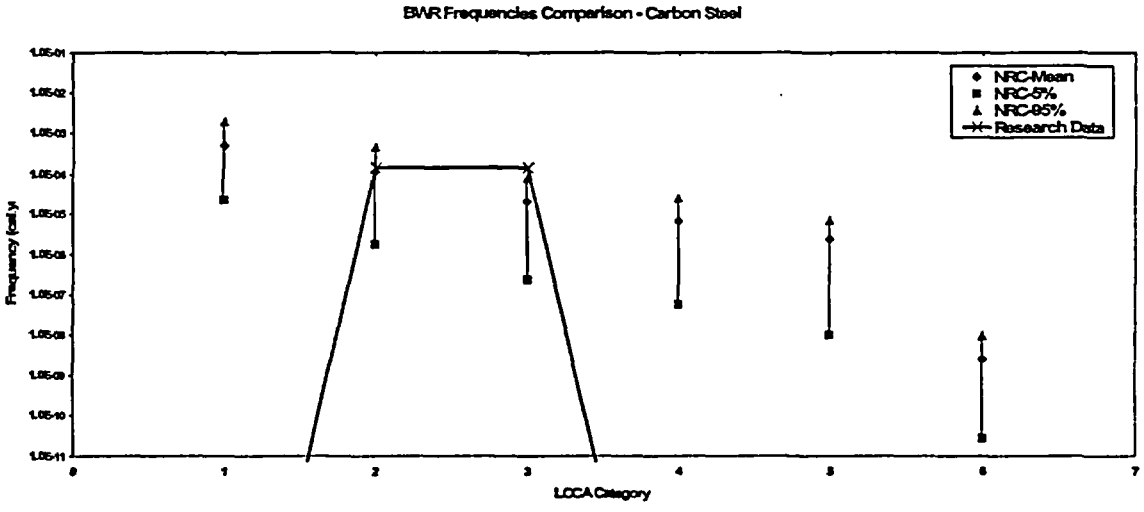

Figure 2: BWR frequencies comparison for carbon steel data.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

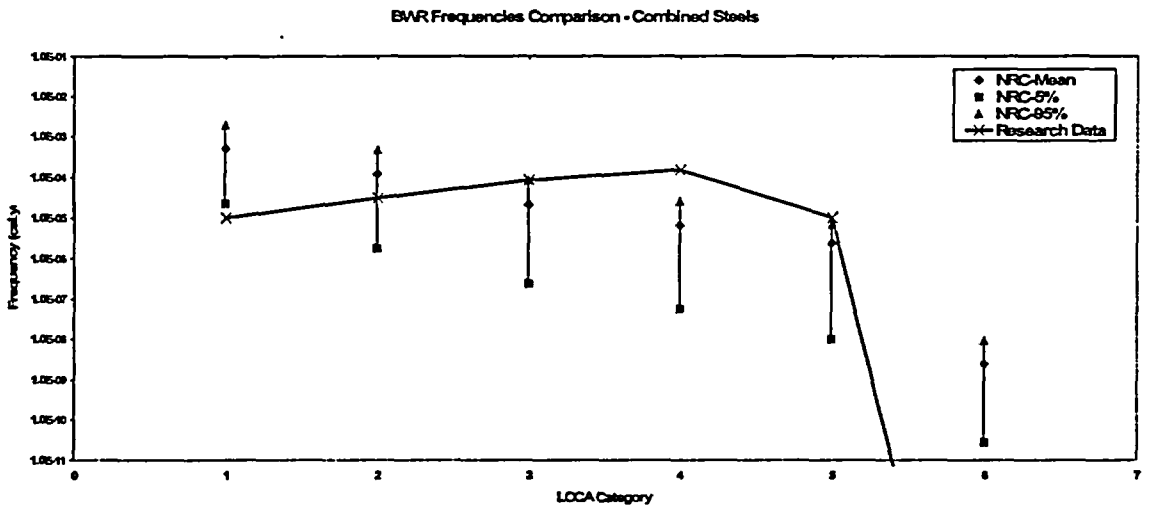

Figure 3: BWR frequencies comparison for combined data sets.

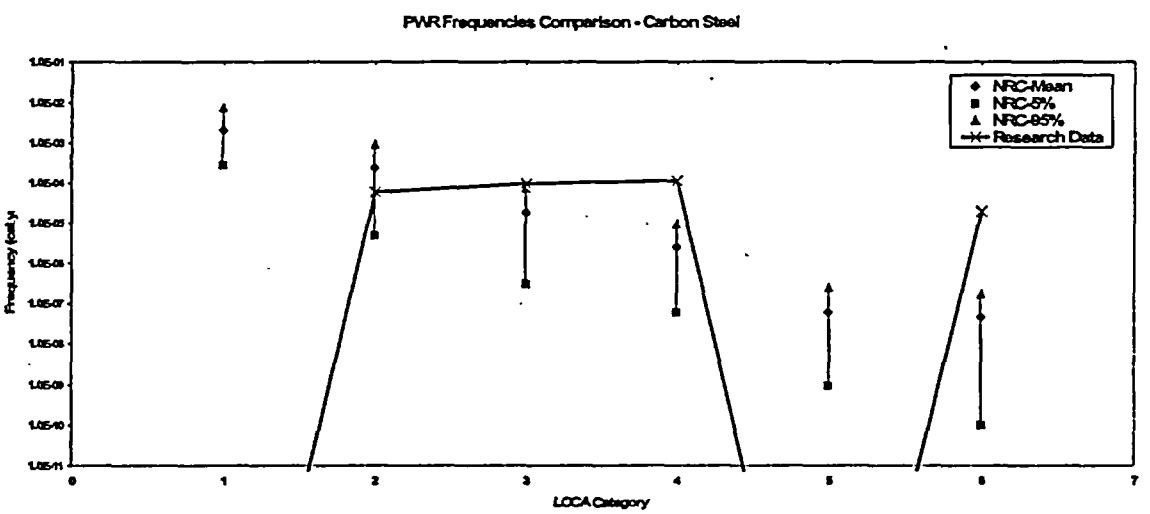

Figure 4: PWR frequencies comparison for carbon steel data.

Project Number: 1	
Analyst	
Instructor: L.E. Hochreiter	**Due Date:** 04/06/2005
Course: NucE 597-D Nuclear Reactor Safety	

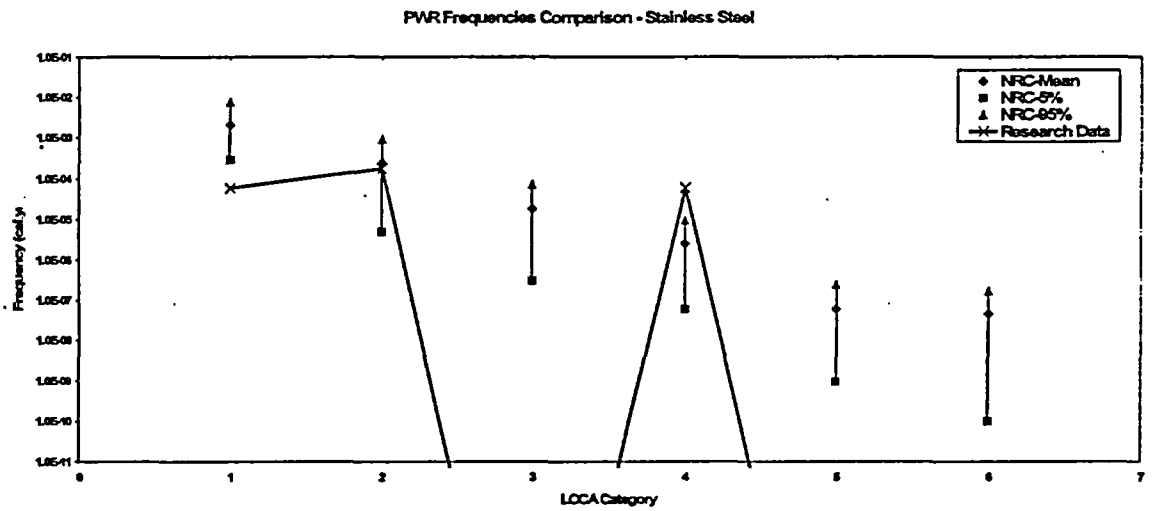

Figure 5: PWR frequencies comparison for stainless steel data.

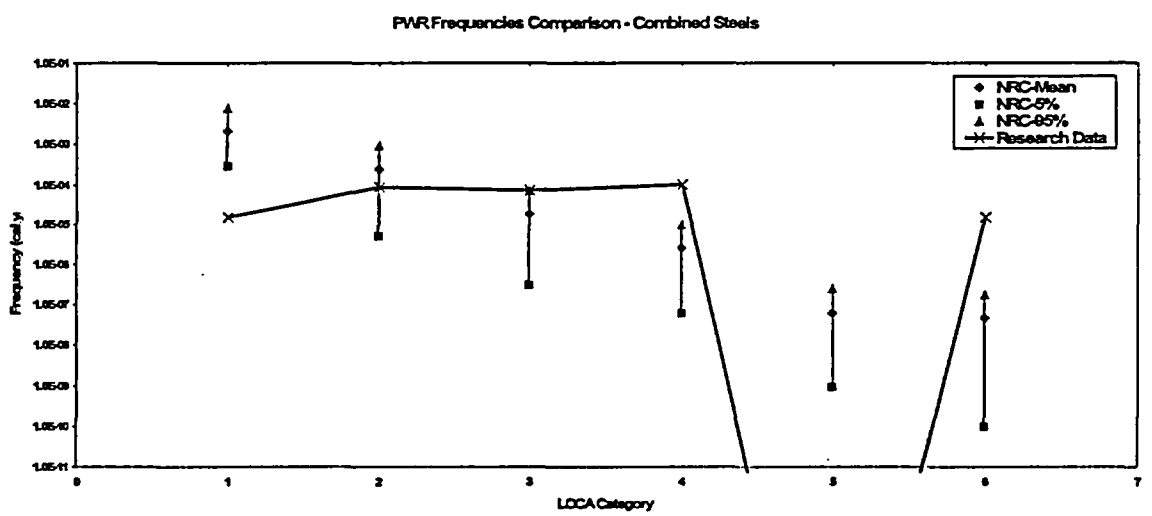

Figure 6: PWR frequencies comparison for combined data sets.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

5.0 Conclusions

It should be noted that a statistical approach was not used for processing the found pipe failure data.

The database documented in this report is composed by 55 data points. These data are not enough to fill with enough points all of the six different identified size classes ranging from less than 1in to greater than 30in. As a result the comparison against NRC data cannot be properly performed. However, some indication can be obtained from the obtained results mostly for the classes more populated.

In addition, the value of the analysis here documented remains. This database should be used in conjunction with other parallel database developed in the framework of the same project in order to create a database large enough to make the comparison against NRC failure frequencies more reliable.

Calculated trend are not fully consistent with NRS frequency trend versus LOCA category. The calculated trend do not show a clear decrease in frequency failure for going for lower to higher LOCA category classes. The results show similar trend for BWR and PWR (mostly when the combined material sets are considered for both reactors). However, calculated BWR frequencies are somewhat lower than PWR failure frequencies in the same class. This is consistent with NRC results.

Calculated frequencies are affected by the chosen value of reactor-years. May a worldwide value of reactor-years should be used for calculating the frequencies, since worldwide data were included in the database.

Most of the found data points are within the classes 2, 3, and 4, and mostly within pipe size ranges between 6 and 24 inches.

Most common failure mechanism found was ISCC for stainless steel. This was an expected result, since is a very well known problem of stainless steel in NPP technology and a lot of analyses are available in literature concerning this issue. For carbon steel there were found three mechanisms with almost the same number of failure data points: fatigue, corrosion/erosion, and mechanical damage/vibrations. These also were expected results since is well knows these are among the most common failure causes.

Interesting results are two failures due to hydrogen combustion or explosion in pipes.

Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

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Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

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Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

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Project Number: 1	
Analyst:	
Instructor: L.E. Hochreiter	**Due Date: 04/06/2005**
Course: NucE 597-D Nuclear Reactor Safety	

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Project #1

NucE 597D
Professor Hochreiter

Table of Contents

Abstract....2

Introduction....3

Analysis Approach....4

Discussion of Results....5

Conclusions....8

References....9

Appendicies

Appendix A – Pipeline Failure Database

Appendix B – Carbon Steel Pipe Failures – Table and Failure Frequency Graphs

Appendix C – Stainless Steel Pipe Failures – Table and Failure Frequency Graphs

Abstract

This project investigated the break frequency for large pipes in an attempt to determine the validity of a probabilistic approach to power plant requirements instead of a deterministic method. The investigation analyzed 34 different pipe failures throughout various industries, then applied the data to a frequency model to determine break frequencies if the same pipes and conditions were present in nuclear power plants. The largest breaks found for carbon steel were in pipes greater than 24 inches in diameter. When these were analyzed in the context of nuclear power plants (over their entire lifetimes), a frequency of 1.03×10^{-4} per year in all US plants. For stainless steel, the largest break found was between 12-24 inches in diameter. When this was analyzed in the context of nuclear power plants (over their entire lifetimes), a frequency of 2.95×10^{-5} per year in all US plants.

Introduction

At the present time, the Nuclear Regulatory Commission (NRC) is considering an amendment to Appendix K regarding requirements for nuclear power plants in the United States.

The current requirements represent a deterministic approach to potential power plant accidents. Under these requirements, a utility must show that the plant can undergo the worst possible transient under the worst possible conditions and still meet accepted guidelines concerning the safety of the core, the plant, and the environment/public around the plant.

A criticism of this approach is that the probability of a worst case scenario transient is very small. The transients that are more likely are smaller in nature. By focusing on the larger, worse transients, it is possible to overlook smaller, more frequent ones when doing analysis. In doing so, plants may not be prepared to adequately respond to smaller accidents.

As a result, the proposed amendment to Appendix K would shift the accident analysis requirements for a plant from a deterministic approach to a probabilistic one. This would give more attention to the more frequent accidents and focus less on the extremely rare worst case scenario incidents.

The purpose of this report is to analyze the inherent assumption in the proposed change that worst-case scenario transients are extremely unlikely. Since the worst case scenario involves a large break LOCA, research was done into the likelihood of such an event. Research was conducted to find cases of large pipe breaks throughout various industries. The data gained through this research was used to determine a pipe break frequency for various pipe sizes under various conditions. This calculated frequency was then used to determine how safe the assumption is that large break LOCA's are infrequent enough to move safety requirements away from them and instead to focus on smaller, more frequent breaks.

Analysis Approach

Once the data was found using the exhaustive internet search mentioned above, the data needed to be sorted, normalized, and a failure frequency calculated. The data was first sorted by either stainless or carbon steel. It was then sorted according to mechanism of failure and then finally by pipe size. Once the data was sorted by pipe size (as can be seen in Appendices B and C), the data was normalized by dividing the number of failures in each pipe size bin by the total number of failures for that type of pipe and reactor class. This is labeled as "Fraction of Total" in Appendices B and C. To find the frequency per calendar year, the normalized data was divided by 3390. The number 3390 represents the number of reactor years experience in the United States (2745 years) as of the end of 2003 divided by an assumed availability factor of the plants of 0.81 to get calendar years. This frequency is then used to produce the various graphs found in Appendices B and C. These graphs all have a logarithmic scale attributed to the y-axis in order to be able to compare the group's data with the data presented by the NRC.

Discussion of Results

From the data found, frequencies for pipe breaks were determined. These frequencies are in the form of number of breaks per year in the US (nuclear power plants only). These results are summarized in Table 1 for carbon steel pipes and Table 2 from stainless steel pipes (sorted by pipe size).

Carbon Steel Piping				
Plant Type	Pipe Size	# of Failures	Fraction of Total	Frequency per Cal. Yr.
BWR	<1"	Group found no data points for carbon steel piping failures in BWR plants		
	1-2"			
	2-4"			
	4-12"			
	12-24"			
	>24"			
PWR	<1"	0	0.00	0.00E+00
	1-2"	0	0.00	0.00E+00
	2-4"	2	0.09	2.57E-05
	4-12"	7	0.30	8.98E-05
	12-24"	7	0.30	8.98E-05
	>24"	8	0.35	1.03E-04
Both	<1"	0	0.00	0.00E+00
	1-2"	0	0.00	0.00E+00
	2-4"	2	0.09	2.57E-05
	4-12"	7	0.30	8.98E-05
	12-24"	7	0.30	8.98E-05
	>24"	8	0.35	1.03E-04

Table 1: Frequencies of breaks in carbon steel

Stainless Steel Piping				
Plant Type	Pipe Size	# of Failures	Fraction of Total	Frequency per Cal. Yr.
BWR	<1"	3	0.50	1.47E-04
	1-2"	0	0.00	0.00E+00
	2-4"	1	0.17	4.92E-05
	4-12"	1	0.17	4.92E-05
	12-24"	1	0.17	4.92E-05
	>24"	0	0.00	0.00E+00
PWR	<1"	0	0.00	0.00E+00
	1-2"	1	0.10	2.95E-05
	2-4"	1	0.10	2.95E-05
	4-12"	2	0.20	5.90E-05
	12-24"	0	0.00	0.00E+00
	>24"	0	0.00	0.00E+00
Both	<1"	3	0.30	8.85E-05
	1-2"	1	0.10	2.95E-05
	2-4"	2	0.20	5.90E-05
	4-12"	3	0.30	8.85E-05
	12-24"	1	0.10	2.95E-05
	>24"	0	0.00	0.00E+00

Table 2: Frequencies of breaks in stainless steel pipes

The frequencies of greatest concern are those for the largest pipes. For carbon steel, the largest breaks were in the >24" bin. When these breaks, which constituted 35% of the carbon steel breaks found, were analyzed to find a frequency applicable to US nuclear power plants, a frequency of 1.03×10^{-4} breaks per year over all us nuclear plants was found (assuming 81% availability).

For stainless steel, the largest break found was in the 12-24" bin and it constituted 10% of the stainless steel breaks found. When it was analyzed, it produced a frequency of 2.95×10^{-5} breaks per year across all US nuclear plants.

When these frequencies were compared with NRC data, the calculated values were several orders of magnitude higher than the NCR numbers. The largest breaks found (in the largest pipes) had break sizes as large as 4-5 feet. The frequencies for breaks per year in the US found by the NRC were on the magnitude of 10^{-8} in PWR's and 10^{-9} in BWR's. The largest cause for this discrepancy is the source of the data. The NRC numbers are based on nuclear data

and, as such, the pipes being analyzed have higher quality control. Pipes used in nuclear plants are manufactured, installed, and inspected under higher scrutiny and to smaller tolerances than pipes in other industries. The data used in this report used pipe breaks from a range of industries (including, but not limited to, nuclear power). Many of them are from the petrochemical industry, where pipes are not controlled as well in terms of quality. It is safe to assume that some of the breaks discovered in research for this report would not have occurred were the pipes in nuclear power plants instead. As a result, the number from the NRC is likely more correct.

Another source of error in the calculations done for this report is the small number of breaks considered. Only 34 total breaks were analyzed, 10 of which were stainless steel and 24 of which were carbon steel. There were difficulties in discovering occurrences of breaks in industry, and the small number found adds large uncertainty to the calculations. Carbon steel breaks that apply to BWR's in specific were hard to search for, since BWR's employ little to no carbon steel in the core loop.

Conclusions

While the breaks analyzed are rare, they are not non-existent. The numbers found for this report indicate that, in any given year, there is approximately a 0.01% chance of a large (>24" in diameter) carbon steel pipe break in a US nuclear power plant and a 0.003% chance of a large (12-24" in diameter) stainless steel pipe break in a US nuclear power plant. These numbers are several orders of magnitude higher than the frequencies determined by the NRC (for the above reasons), but even then it shows that, while small, such breaks are not impossible. It is still in the best interest for the industry to account for this small but real chance of a large break in a primary reactor system, given the ramifications of such an accident.

Another interesting determination made by this investigation is the abundance of corrosion-induced breaks (failure mechanism is listed for investigated breaks in Appendix A). Even in stainless steel, corrosion and stress-corrosion cracking account for a majority of all breaks found. Since this is a primary cause of pipe failures, it is advisable that the NRC and industry develop better models and inspection/detection methods for these failure mechanisms.

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Appendix A

Pipeline Failure Database

Appendix A

Date	Location / Plant	Type of Pipe	Break or Crack	Failure Type	Leak/Failure Mechanism	Pipe Diameter	Wall Thickness
April 7, 2000	Fuel Oil Pipeline near Chalk Point, Maryland	Carbon Steel	Break	buckled and ruptured	Fatigue	12.75"	0.203"
August 1999	Savannah River, Georgia	Carbon Steel	Break	fish mouth (split on seam)	Defects in pipe welds	2"	sch 40
August 9, 2004	Mihama-3, Japan	Carbon Steel	Break	rupture	Aging and Wear (pipe was 27 years old)	18"	0.4"
March 9, 1985	Trojan Nuclear Plant, Oregon	Carbon Steel	Break	rupture	Wear (pipe was 9 years old) / FAC	14"	0.375"
July 22, 1992	Maine Yankee, Maine	Carbon Steel	Break	rupture	Wear / Corrosion	12"	steam line ruptured on a moisture separator reheater
December 14, 2001	Brunsbuttel Nuclear Power Station, Germany	Carbon Steel	Break	rupture	Corrosion	4"	0.22"
February 27, 1996	Crude Oil Pipeline near Langbank, Saskatchewan	Carbon Steel	Break	rupture	Corrosion / FAC	34"	0.28"
June 10, 1999	Gasoline Pipeline near Bellingham, Washington	Carbon Steel	Break	rupture	Defects in Pipe Wall	16"	0.31"
July 4, 2002	Crude Oil Pipeline near Cohasset, Minnesota	Carbon Steel	Break	rupture	Fatigue along pipe weld	34"	0.312"
March 9, 2000	Gasoline Pipeline near Greenville, Texas	Carbon Steel	Break	rupture	Corrosion-Fatigue Caracking	28"	0.281"
January 27, 2000	Crude Oil Pipeline near Winchester, Kentucky	Carbon Steel	Break	rupture	Fatigue Cracking due to external defect	24"	0.25"
February 9, 1999	Diesel Oil Pipeline near Knoxville, Tennessee	Carbon Steel	Break	rupture	Corrosion / FAC	10"	0.25"
August 24, 1996	Liquified Petroleum Gas Pipeline near Lively, Texas	Carbon Steel	Break	rupture	Corrosion / FAC	8"	0.188"
June 26, 1996	Fuel Oil Pipeline near Fork Schoals, South Carolina	Carbon Steel	Break	rupture	Corrosion / FAC	36"	0.281"
April 21, 1997	Fort Calhoun Power Station	Carbon Steel	Break	rupture	Flow Accelerated Corrosion	12"	.375"
December 9, 1986	Surry Power Station, Virginia	Carbon Steel	Break	rupture (catastrophic, 360°)	Wear / FAC	18"	0.5"
September 2001	Japan	Carbon Steel	Break	rupture (double-ended break)	Radiolysis Gas Reaction	6"	0.4"
November 3, 1983	Heiss Damf Reactor, West Germany	Carbon Steel	Break	rupture (double-ended guillotine)	Fatigue	8"	
August 19, 2000	Natural Gas Pipeline near Carlsbad, New Mexico	Carbon Steel	Break	rupture and explosion	Corrosion / FAC	30"	0.335"
November 5, 1996	Diesel Oil Pipeline near Murfreesboro, Tennessee	Carbon Steel	Break	rupture due to overpressurization	Overpressurization	6"	0.188"
March 30, 1998	Gasoline Pipeline near Sandy Springs, Georgia	Carbon Steel	Crack	crack; circumferential buckle and subsequent crack	External Pressure	40"	0.344"
November 14, 2004	Ikata 1 Reactor, Japan	Carbon Steel	Crack	cracks found in welds joining a stainless steel pipe to a carbon steel nozzle	Defects in Pipe Welds	35"	3.15"
November 1999	Brunsbuttel Nuclear Power Station, Germany	Carbon Steel	Crack	cracks; 1 longitudinal and 2 circumferential	Internal Pressure	2"	sch 40
1992	Savannah River, Georgia	Carbon Steel	Crack	holes	Corrosion / FAC	8"	a hole in the discharge line of a pump
July 1, 1999	AlliedSignal Metropolis Works Facility	Stainless Steel	Break	Chemical Attack		.5"	
October 17th, 1989	San Jose	Stainless Steel	Break		Earthquake	3"	
October 17th, 1989	San Jose	Stainless Steel	Break		Earthquake	10"	
December 7, 1984	Pilgrim Nuclear Power Station	Stainless Steel	Crack	7 through-wall cracks	Chloride-Induced SCC	1"	
	Chernobyl 3, Leningrad 3, Ignalina Power Station	Stainless Steel	Crack	Several cracks, not all the way through pipe wall	SCC	11.8"	.60"
July 27, 1984	Peach Bottom 2	Stainless Steel	Crack	Several Indications of Cracks (1/8" deep, not all the way through wall)	SCC	12"	.83"
October 10, 1994	River Bend Power Station	Stainless Steel	Crack/Leak		Chloride Induced trans-granularSCC	4"	
February 9, 2005	South Texas Project, Unit 2	Stainless Steel	Leak	Weld Failure		<1"	
October 17th, 1989	San Jose	Stainless Steel	Leak		Earthquake	4"	
March 14, 1992	Palo Verde Unit 2	Stainless Steel	Break	Rupture		<1"	

Appendix A

Date	Location / Plant	Operating Pressure	Fluid Type	Length / Size	Wall Thickness at Failure
April 7, 2000	Fuel Oil Pipeline near Chalk Point, Maryland		Fuel Oil	6.5 inches	
August 1999	Savannah River, Georgia	3000 psi	Water	2.5 inches	1/2 of sch 40
August 9, 2004	Mihama-3, Japan	800 psi	Steam	24 inches	0.055 inches
March 9, 1985	Trojan Nuclear Plant, Oregon	450 psi	Water		0.1 inches
July 22, 1992	Maine Yankee, Maine		Steam		
December 14, 2001	Brunsbuttel Nuclear Power Station, Germany		Water	360°	
February 27, 1996	Crude Oil Pipeline near Langbank, Saskatchewan	650 psi	Crude Oil	5.8 ft	0.28 inches
June 10, 1999	Gasoline Pipeline near Bellingham, Washington	1433 psi	Gasoline	27 inches	0.24 inches
July 4, 2002	Crude Oil Pipeline near Cohasset, Minnesota	526 psi	Crude Oil	69 inches	0.312 inches
March 9, 2000	Gasoline Pipeline near Greenville, Texas	705 psi	Gasoline	50.5 inches	
January 27, 2000	Crude Oil Pipeline near Winchester, Kentucky	606 psi	Crude Oil	40 inches	0.025 inches
February 9, 1999	Diesel Oil Pipeline near Knoxville, Tennessee	91 psi	Diesel Oil	360°	0.13 inches
August 24, 1996	Liquified Petroleum Gas Pipeline near Lively, Texas	1448 psi	Liquid Butane	12.5 inches	0 inches
June 26, 1996	Fuel Oil Pipeline near Fork Schoals, South Carolina	374 psi	Fuel Oil	34 inches	0.069 inches
April 21, 1997	Fort Calhoun Power Station	300 psig	steam	6 sq ft	
December 9, 1986	Surry Power Station, Virginia	450 psi	Water	360°	0.05 inches
September 2001	Japan	800 psi	Steam		
November 3, 1983	Heiss Damf Reactor, West Germany		Water		1/4 original thickness
August 19, 2000	Natural Gas Pipeline near Carlsbad, New Mexico	675 psi	Natural Gas		
November 5, 1996	Diesel Oil Pipeline near Murfreesboro, Tennessee	1820 psi	Diesel Oil		
March 30, 1998	Gasoline Pipeline near Sandy Springs, Georgia	384 psi	Gasoline	6 inches	
November 14, 2004	Ikata 1 Reactor, Japan		Water	Crack A - 0.2 inches Crack B - 0.16 inches	3.15 inches
November 1999	Brunsbuttel Nuclear Power Station, Germany		Water		
1992	Savannah River, Georgia		Water		
July 1, 1999	AlliedSignal Metropolis Works Facility	3 psia	Flourine		
October 17th, 1989	San Jose		Water		
October 17th, 1989	San Jose		Water		
December 7, 1984	Pilgrim Nuclear Power Station	atm	Water		
	Chernobyl 3, Leningrad 3, Ignalina Power Station		Water	9.84" Long, .47" deep	.60"
July 27, 1984	Peach Bottom 2		Water	.25"-.7" long, 1/8" deep	.83"
October 10, 1994	River Bend Power Station				
February 9, 2005	South Texas Project, Unit 2				
October 17th, 1989	San Jose		Water		
March 14, 1992	Palo Verde Unit 2				

Appendix A

Date	Location / Plant	Website			
April 7, 2000	Fuel Oil Pipeline near Chalk Point, Maryland	http://www.ntsb.gov/publictn/2002/PAR0201.pdf			
August 1999	Savannah River, Georgia				
August 9, 2004	Mihama-3, Japan	www.eh.doe.gov/paa/oesummary/oesummary2004/oe2004-16.pdf and www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec3/139r1.html			
March 9, 1985	Trojan Nuclear Plant, Oregon	www.eh.doe.gov/paa/oesummary/oesummary2004/oe2004-16.pdf and www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec3/139r1.html			
July 22, 1992	Maine Yankee, Maine	www.eh.doe.gov/paa/oesummary/oesummary2004/oe2004-16.pdf			
December 14, 2001	Brunsbuttel Nuclear Power Station, Germany				
February 27, 1996	Crude Oil Pipeline near Langbank, Saskatchewan	http://www.tsb.gc.ca/en/reports/pipe/1996/p96h0008/p96h0008.asp			
June 10, 1999	Gasoline Pipeline near Bellingham, Washington	http://www.ntsb.gov/publictn/2002/PAR0202.pdf			
July 4, 2002	Crude Oil Pipeline near Cohasset, Minnesota	http://www.ntsb.gov/publictn/2004/PAR0401.pdf			
March 9, 2000	Gasoline Pipeline near Greenville, Texas	http://www.ntsb.gov/publictn/2001/PAB0103.pdf			
January 27, 2000	Crude Oil Pipeline near Winchester, Kentucky	http://www.ntsb.gov/publictn/2001/PAB0102.pdf			
February 9, 1999	Diesel Oil Pipeline near Knoxville, Tennessee	http://www.ntsb.gov/publictn/2001/PAB0101.pdf			
August 24, 1996	Liquified Petroleum Gas Pipeline near Lively, Texas	http://www.ntsb.gov/publictn/1998/PAR9802S.pdf			
June 26, 1996	Fuel Oil Pipeline near Fork Schoals, South Carolina	http://www.ntsb.gov/publictn/1998/PAR9801.pdf			
April 21, 1997	Fort Calhoun Power Station	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97084.html			
December 9, 1986	Surry Power Station, Virginia	www.eh.doe.gov/paa/oesummary/oesummary2004/oe2004-16.pdf and www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0933/sec3/139r1.html			
September 2001	Japan				
November 3, 1983	Heiss Damf Reactor, West Germany				
August 19, 2000	Natural Gas Pipeline near Carlsbad, New Mexico	www.ntsb.gov/publictn/2003/PAR0301.pdf			
November 5, 1996	Diesel Oil Pipeline near Murfreesboro, Tennessee	http://www.ntsb.gov/publictn/1999/PAB9903.pdf			
March 30, 1998	Gasoline Pipeline near Sandy Springs, Georgia	http://www.ntsb.gov/publictn/1999/PAB9901.pdf			
November 14, 2004	Ikata 1 Reactor, Japan	http://cnic.jp/english/newsletter/nit104/nit104articles/nit104ikata.html			
November 1999	Brunsbuttel Nuclear Power Station, Germany				
1992	Savannah River, Georgia	www.eh.doe.gov/paa/oesummary/oesummary2004/oe2004-16.pdf			
July 1, 1999	AlliedSignal Metropolis Works Facility	http://www.nrc.gov/reading-rm/doc-collections/event-status/morning/1999/19990702mr.html			
October 17th, 1989	San Jose	Loma Prieta Earthquake pipe database			
October 17th, 1989	San Jose	Loma Prieta Earthquake pipe database			
December 7, 1984	Pilgrim Nuclear Power Station	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1985/in85034.html			
	Chernobyl 3, Leningrad 3, Ignalina Power Station	http://64.233.179.104/search?q=cache:bc3fa-3NYSYJ:www.eurosafe-forum.org/ipsn/pdf/euro2_1_6_laea_programme_mitigation.pdf+stainless+steel+piping+fracture+accident			
July 27, 1984	Peach Bottom 2	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1984/in84089.html			
October 10, 1994	River Bend Power Station	http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/1995/1995012.html			
February 9, 2005	South Texas Project, Unit 2				
October 17th, 1989	San Jose	Loma Prieta Earthquake pipe database			
March 14, 1992	Palo Verde Unit 2	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1993/in93056.html			

Appendix B

Carbon Steel Pipe Failures - Table and Failure Frequency Graphs

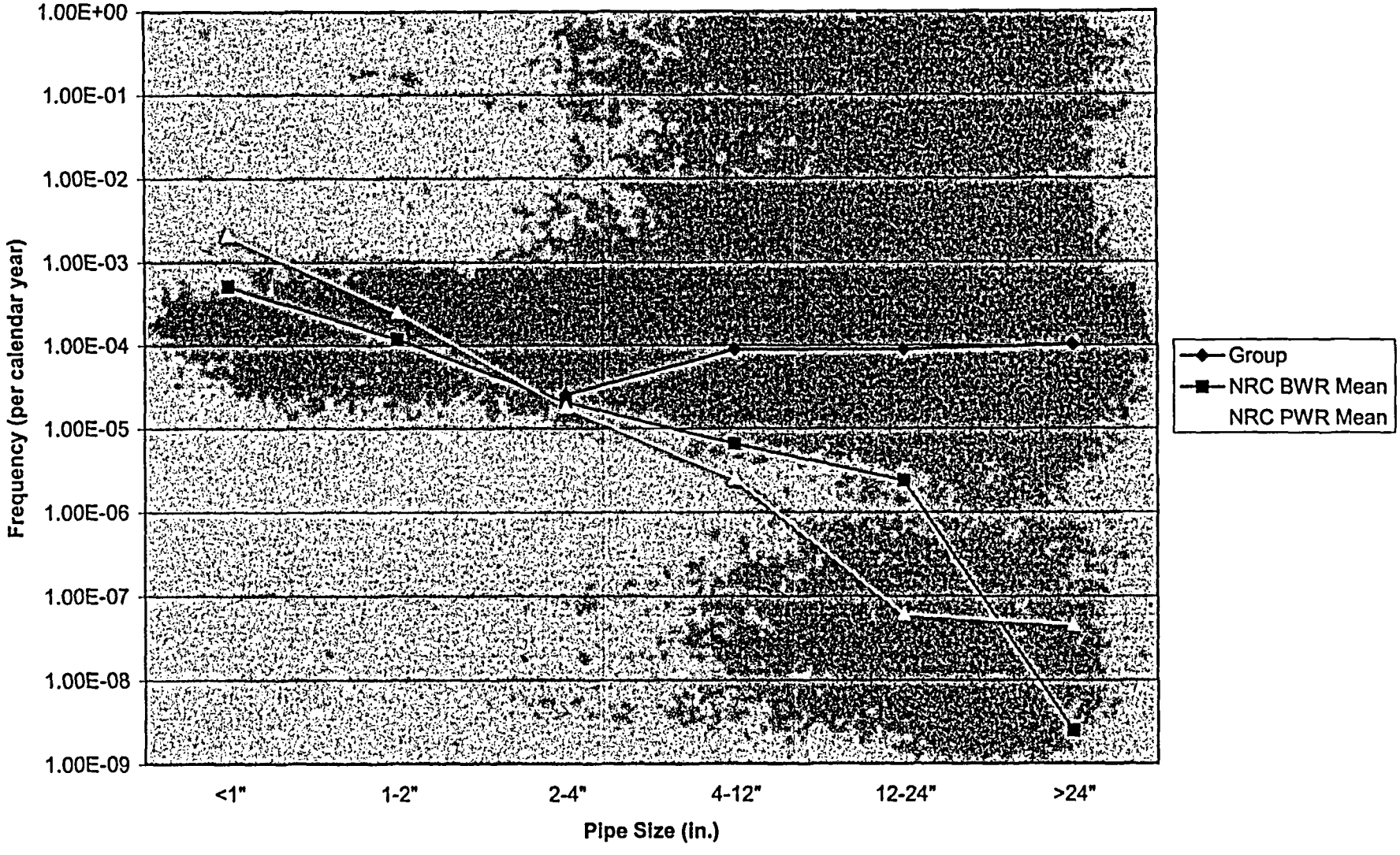
Appendix B

Plant Type	Pipe Size	# of Failures	Fraction of Total	Frequency per Cal. Yr.	Frequency per Cal. Yr. 5%	Frequency per Cal. Yr. Mean	Frequency per Cal. Yr. 95%	
BWR	<1"	Group found no data points for carbon steel piping failures in BWR plants			2.3E-05	5.1E-04	1.9E-03	10 CFR 50.46
	1-2"				1.8E-06	1.2E-04	4.7E-04	
	2-4"				2.4E-07	2.1E-05	8.0E-05	
	4-12"				5.7E-08	6.6E-06	2.5E-05	
	12-24"				1.0E-08	2.4E-06	6.9E-06	
	>24"				3.5E-11	2.5E-09	9.5E-09	
PWR	<1"	0	0.00	0.00E+00	3.0E-04	2.1E-03	7.5E-03	
	1-2"	0	0.00	0.00E+00	4.9E-06	2.5E-04	9.3E-04	
	2-4"	2	0.09	2.57E-05	3.1E-07	1.8E-05	7.0E-05	
	4-12"	7	0.30	8.98E-05	6.0E-08	2.5E-06	9.6E-06	
	12-24"	7	0.30	8.98E-05	9.3E-10	6.1E-08	2.4E-07	
	>24"	8	0.35	1.03E-04	1.0E-10	4.6E-08	1.7E-07	
Both	<1"	0	0.00	0.00E+00				
	1-2"	0	0.00	0.00E+00				
	2-4"	2	0.09	2.57E-05				
	4-12"	7	0.30	8.98E-05				
	12-24"	7	0.30	8.98E-05				
	>24"	8	0.35	1.03E-04				

Note: The data for pipeline failures in the database is included under PWR's

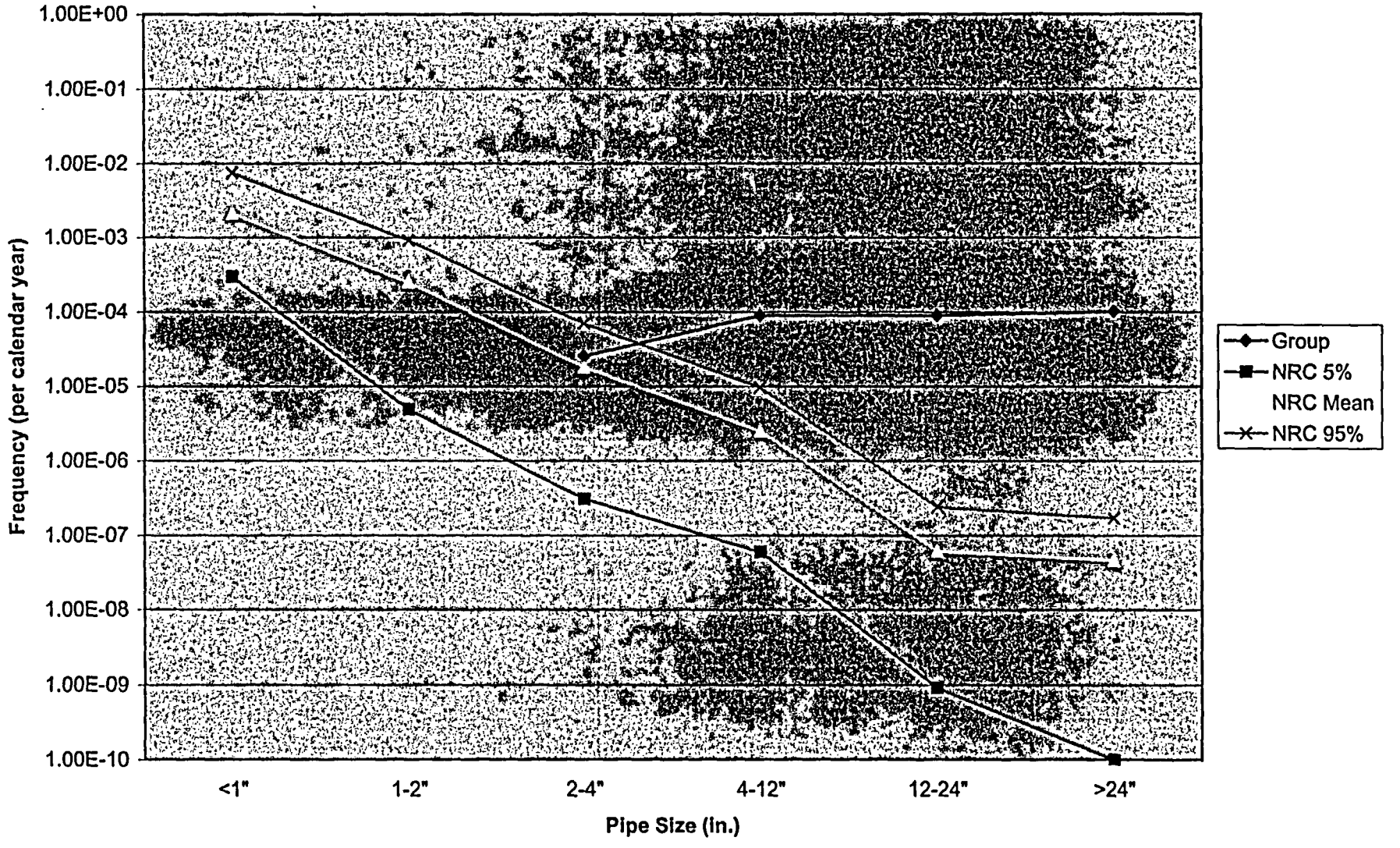
Appendix B

Failure Frequencies for BWR and PWR (Carbon Steel)



Appendix B

PWR Failure Frequencies (Carbon Steel)



Appendix C

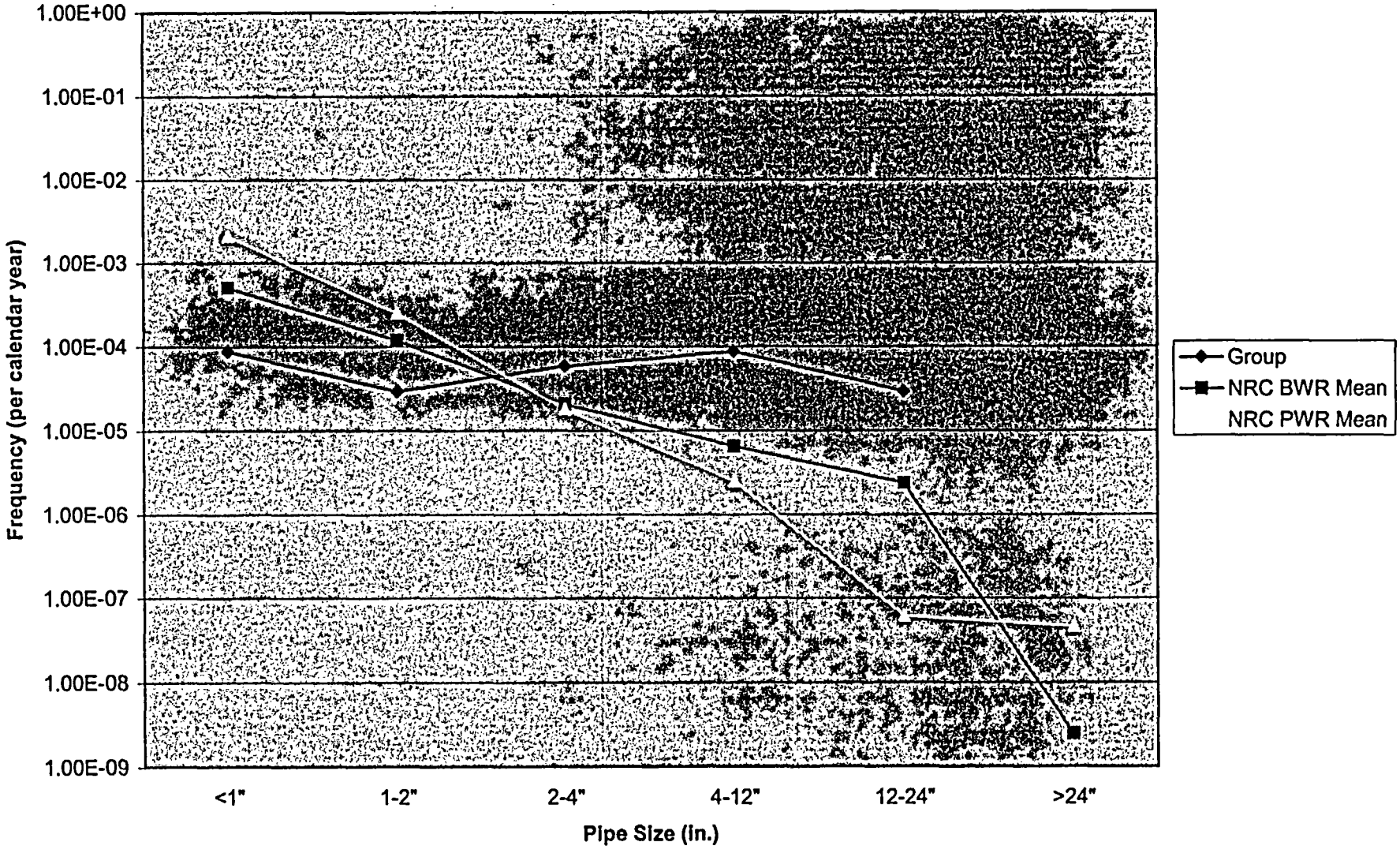
Stainless Steel Pipe Failures - Table and Failure Frequency Graphs

Appendix C

Plant Type	Pipe Size	# of Failures	Fraction of Total	Frequency per Cal Yrs	Frequency per Cal Yrs 5%	Frequency per Cal Yrs Mean	Frequency per Cal Yrs 95%	
BWR	<1"	3	0.50	1.47E-04	2.3E-05	5.1E-04	1.9E-03	10 CFR 50.46
	1-2"	0	0.00	0.00E+00	1.8E-06	1.2E-04	4.7E-04	
	2-4"	1	0.17	4.92E-05	2.4E-07	2.1E-05	8.0E-05	
	4-12"	1	0.17	4.92E-05	5.7E-08	6.6E-06	2.5E-05	
	12-24"	1	0.17	4.92E-05	1.0E-08	2.4E-06	6.9E-06	
	>24"	0	0.00	0.00E+00	3.5E-11	2.5E-09	9.5E-09	
PWR	<1"	0	0.00	0.00E+00	3.0E-04	2.1E-03	7.5E-03	
	1-2"	1	0.10	2.95E-05	4.9E-06	2.5E-04	9.3E-04	
	2-4"	1	0.10	2.95E-05	3.1E-07	1.8E-05	7.0E-05	
	4-12"	2	0.20	5.90E-05	6.0E-08	2.5E-06	9.6E-06	
	12-24"	0	0.00	0.00E+00	9.3E-10	6.1E-08	2.4E-07	
	>24"	0	0.00	0.00E+00	1.0E-10	4.6E-08	1.7E-07	
Both	<1"	3	0.30	8.85E-05				
	1-2"	1	0.10	2.95E-05				
	2-4"	2	0.20	5.90E-05				
	4-12"	3	0.30	8.85E-05				
	12-24"	1	0.10	2.95E-05				
	>24"	0	0.00	0.00E+00				

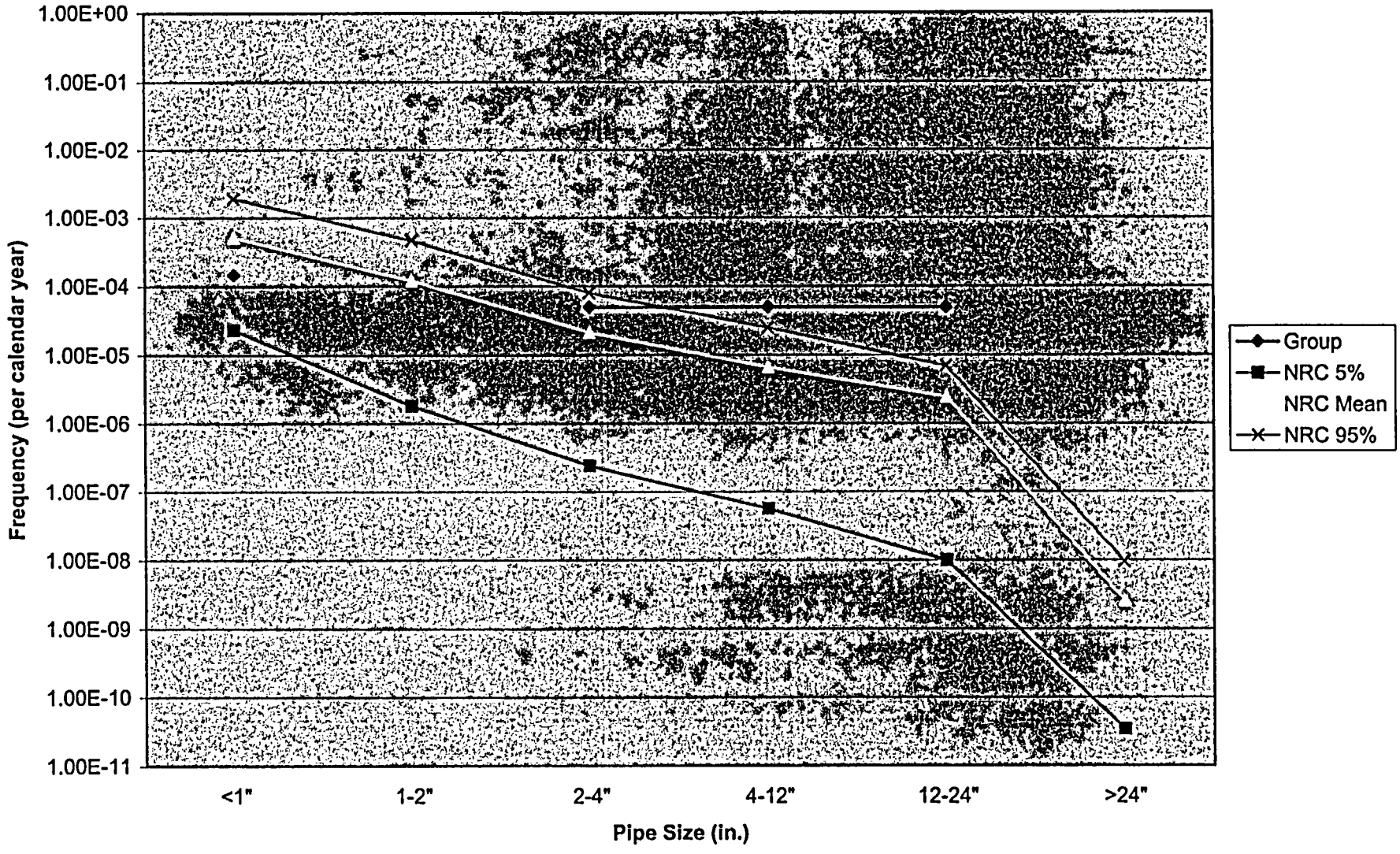
Appendix C

Failure Frequencies for BWR and PWR (Stainless Steel)



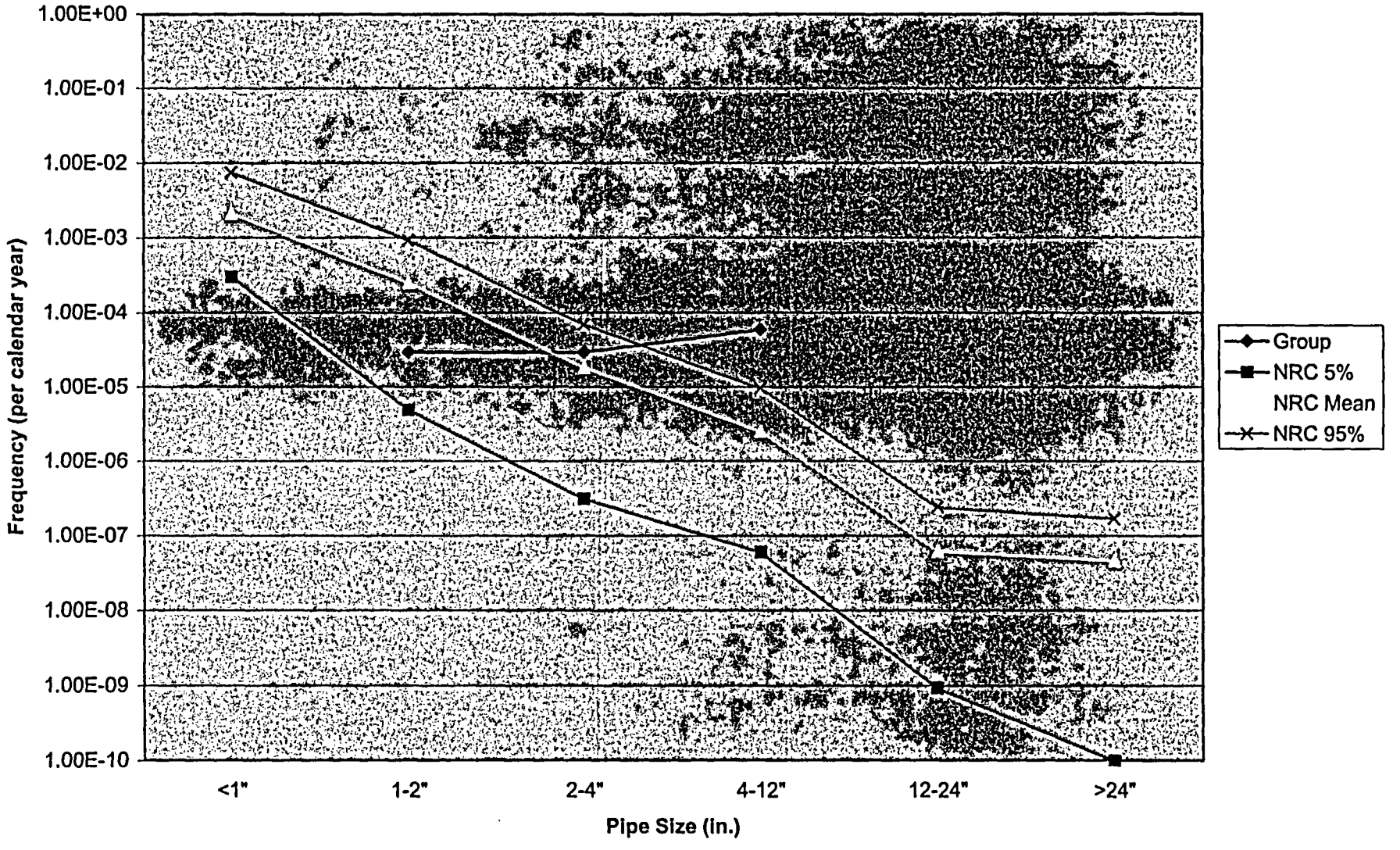
Appendix C

BWR Failure Frequencies (Stainless Steel)



Appendix C

PWR Failure Frequencies (Stainless Steel)



Frequency Failures for Carbon and Stainless Steel Pipes

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NucE 597D: Nuclear Safety

Dr. Lawrence Hochreiter

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Table of Contents

Abstract 3

1.0 Introduction.....4

2.0 Discussion.....5

3.0 Results 6

4.0 Conclusions.....11

References 14

Appendix .....Attached File, *Project_Data.xls*

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Abstract

This report was produced for the Pennsylvania State University (PSU) graduate course entitled "NucE 597D: Nuclear Safety.". Data for pipe leaks and failures were gathered from sources listed in the References Section. Each leak/failure was reviewed and categorized according to pipe size, material (stainless steel versus carbon steel), and mechanism for leaking or failure. The collected data was then normalized according to each category of carbon steel, stainless steel, and combined stainless/carbon steel data sets. This normalization was performed and compared against the NRC failure frequency estimates for Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) plants.

The conclusion reached by the comparison is that the NRC estimates may not necessarily be correct, and the results determined by this paper are questionable as well. Therefore, more data is needed to determine which failure frequency is more representative of reality.

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1.0 Introduction

This report is the product of a study conducted by a group of PSU students graduate course entitled "NucE 597D: Safety Analysis."

This report presents a pipe failure analysis for carbon steel and stainless steel pipes. The evaluation is based primarily on the data gathered by the group from various sources, which includes power plants and non power plant data. The objectives of the study are: (1) provide frequencies for the occurrence of pipe failure events in U.S. nuclear power plants; (2) compare these estimates to the NRC estimates; and (3) review the pipe failure frequencies from an engineering perspective to determine trends and patterns of plant performance on a plant-type [i.e., pressurized water reactor (PWR) or boiling water reactor (BWR)], and industry-wide basis.

The sources of data used in this study include the SKI Report (Reference 1), NUREG/CR-6861 (Reference 2), The NKS RAK-(97) Revision 10 Report (Reference 3), NUREG/CR-6582 (Reference 4), an article from *The Union Democrat Online* entitled "Sonora goes dry after pipe breaks" (Reference 5), an article from Spacewar.com entitled "Death toll from Japan's worst nuclear plant accident rises to five" (Reference 6), and 10 CFR50.46 (Reference 7).

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2.0 Discussion

Many sources were checked for pipe leak and failure events. The search engine, www.yahoo.com, was used to search for key words such as "pipe leak", "pipe failure", "pipe break", "carbon steel pipe", and "stainless steel pipe". Two specific events were found that were relevant. The first event that was found in Reference 5 was a carbon steel pipe that failed due to aging, in which the 6 inch underground water main ruptured and caused many homes to go dry in August of 2004. Although this was not a power plant event, it was deemed a relevant data point since the cause of the failure was due to aging. The other event was found in Reference 6. This carbon steel pipe failed due to flow assisted corrosion (FAC). The failure occurred in a 22-inch steam line in the condensate system, upstream of the feedwater pumps at the nuclear power plant in Mihama, Japan. This pipe failure event was deemed relevant due to it being a FAC failed pipe in a PWR.

In addition to using the internet, several publicly documented papers were reviewed for supporting information, such as the SKI Report, The NKS-RAK Report and NUREG-6582. These papers were mentioned as sources in Reference 7, therefore they were considered relevant to this study.

Several data points were collected and complied into an Excel 2003 Spreadsheet. Source by source, non-break failures were removed from the spreadsheet. Next, the remaining data was separated by pipe size and pipe material. The compilation resulted in 5 pipe size bins for each material type (carbon and stainless steel). The respective pipe size bins were divided into less than 1 inch, 1 inch to 2 inches, 2 inches to 4 inches, 4 inches to 10 inches, and greater than 10 inches.

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3.0 Analysis and Results

The next step following compilation and binning of the data was normalization. The data was normalized by determining a failure fraction for each bin size. This was determined by taking the number of failures for each bin and then dividing by the total number of failures in the pipe material. For example:

$$\text{Failure Fraction} = \frac{\#\text{Carbon Steel Failures in Bin 1}}{\text{Total Carbon Steel Failures}}$$

The next step was to calculate failure frequencies for stainless steel pipes only (see Table 3.2), carbon steel pipes only (see Table 3.4), and stainless and carbon steel pipes combined (see Table 3.5). This was determined by taking the failure fractions and dividing by 3390 calendar years, which represents the total time of reactor operation through 2003.

Once the failure frequencies were determined, they were then plotted against the failure frequencies determined by the NRC (Tables 3.3 and 3.6), which are listed in Reference 7. Figures 3.1 and 3.2 represent a comparison of the NRC PWR and BWR data to the Stainless Steel data and the Carbon Steel Data, respectively. Figure 3.3 represents a comparison of the NRC PWR and BWR data to the combined Stainless Steel and Carbon Steel data gathered from our sources. Note that the pipe sizes are listed by bin numbers in Figure 3 (i.e., Bin 1 encompasses all pipe sizes smaller than 1 inch in diameter). The bin numbers are defined as in Table 3.1:

Table 3.1: Legend for X-axis on Figures

Bin	Pipe Diameter
1	D < 1
2	1" < D < 2"
3	2" < D < 4"
4	4" < D < 10"
5	10" < D

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¶
The next step was to then normalize the data. The data was normalized by determining a failure fraction for each bin size. This was determined by taking the number of failures for each bin and then dividing by the total number of failures in the pipe material. ¶
Example: pipe bin 1 for carbon steel / CS failures = pipe bin 1 for CS failure fraction. ¶
¶
The next step was to calculate failure frequencies for carbon steel pipes only, stainless steel pipes only, and carbon and stainless steel pipes combined. This was determined by taking the failure fractions and dividing by 3390 calendar years. 3390 calendar years represents the total time of reactor operation through 2003.¶
¶
Once the failure frequencies were determined, they were then plotted against the failure frequencies determined by the NRC, which are listed in 10 CFR50.46. The resulting figure (Figure 3) is provided below. Note that the pipe sizes are listed by bin numbers in Figure 3 (i.e. bin 1 encompasses all pipe sizes smaller than 1 inch in diameter).¶
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Table 3.2: Stainless Steel Failure Frequencies vs. Pipe Size

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Stainless Steel Failures				
Pipe Size Ranges (in.)		No. of Failures	Failure Fraction	Failure Frequency
0	1	39	0.2422	7.146E-05
1	2	25	0.1553	4.581E-05
2	4	13	0.0807	2.382E-05
4	10	40	0.2484	7.329E-05
10	+	44	0.2733	8.062E-05

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Table 3.3: NRC Pipe Failure Frequencies by Reactor Type

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NRC Pipe Failure Frequencies	
BWR	PWR
4.7E-04	6.2E-03
1.3E-04	2.3E-04
2.4E-05	1.6E-05
6.0E-06	2.3E-06
2.2E-06	3.9E-08

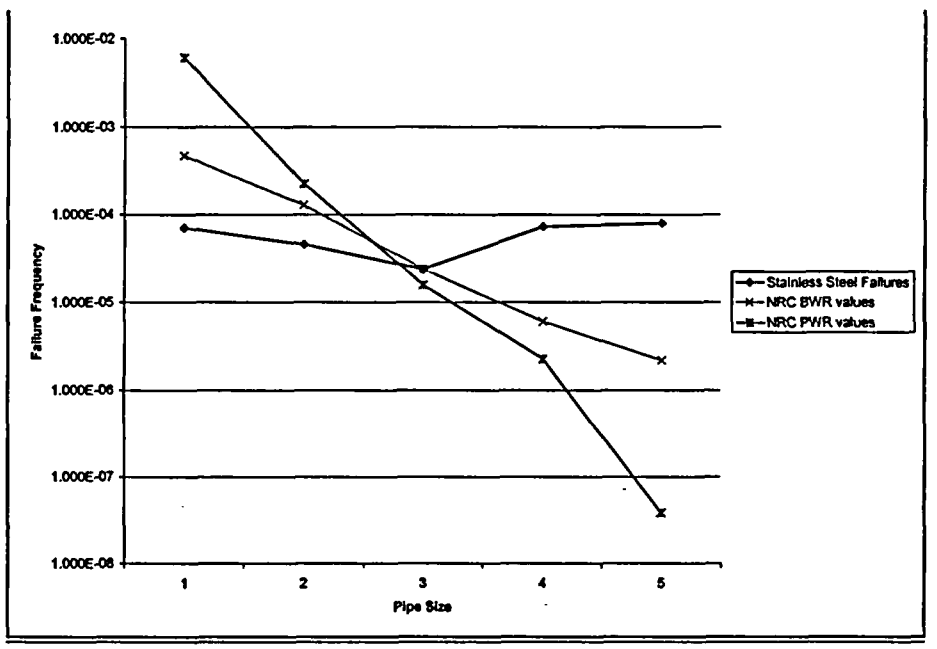

Figure 3.1: Stainless Steel Failure Frequencies vs. Pipe Size

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Table 3.4: Carbon Steel Failure Frequencies vs. Pipe Size

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Carbon Steel Failures				
Pipe Size Ranges (in.)		No. of Failures	Failure Fraction	Failure Frequency
0	1	32	0.5246	1.547E-04
1	2	4	0.0656	1.934E-05
2	4	4	0.0656	1.934E-05
4	10	8	0.1311	3.869E-05
10	+	13	0.2131	6.287E-05

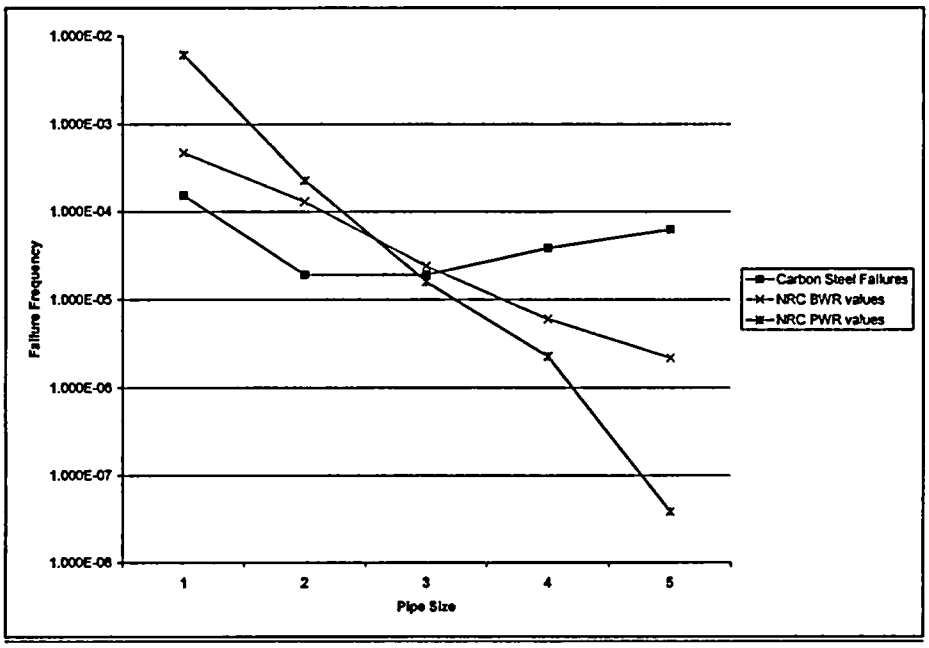

Figure 3.2: Carbon Steel Failure Frequencies vs. Pipe Size

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Table 3.5: Stainless Steel and Carbon Steel Failure Frequencies vs. Pipe Size

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SS + CS Failures				
Pipe Size Ranges (in.)		No. of Failures	Failure Fraction	Failure Frequency
0	1	71	0.3198	9.434E-05
1	2	29	0.1306	3.853E-05
2	4	17	0.0766	2.259E-05
4	10	48	0.2162	6.378E-05
10	+	57	0.2568	7.574E-05

Table 3.6: Combined NRC Pipe Failure Frequencies for BWR and PWR Reactor Type

NRC Pipe Failure Frequencies BWR + PWR
6.7E-03
3.6E-04
4.0E-05
8.3E-06
2.2E-06

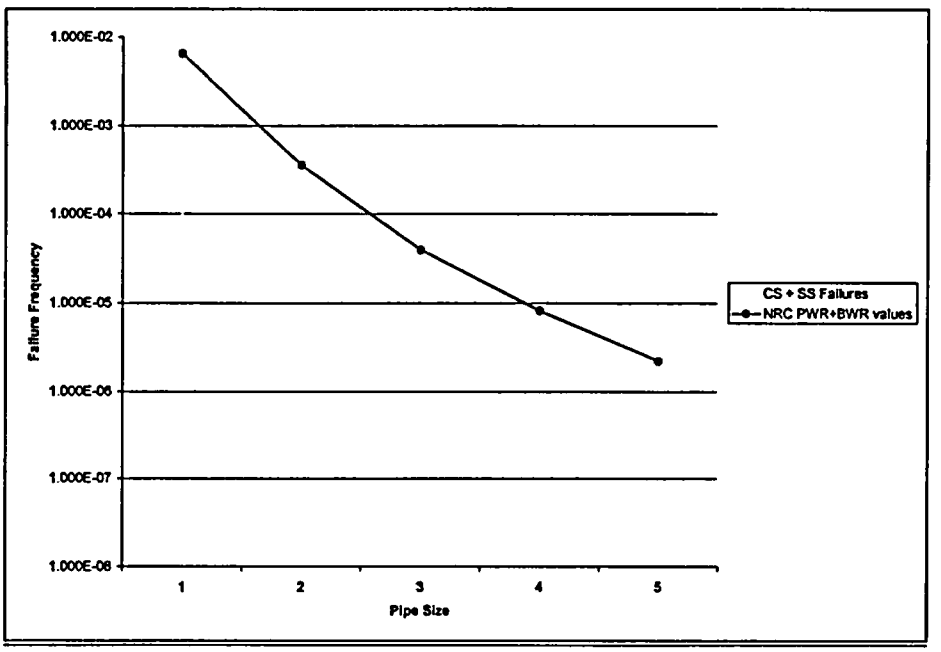

Figure 3.3: Combination of Stainless and Carbon Steel Failure Frequencies vs. Pipe Size

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4.0 Conclusions

At first glance, the figures in the previous section show that the NRC reported pipe failures for pipes with diameters less than 2 inches is conservative, based on the number of failures. For pipes with diameters that are larger than 4 inches, there is a disparity between the number of failures presented by the NRC data and the number of failures portrayed in the Figures in Section 3.0.

It must be noted that the results of this data do not truly reflect the entire data set of pipe failures for several reasons. First, the data taken from the papers in the Reference section does not provide raw data for easy separation into the bins. Some of the bins have been combined in order to fit all of the data without altering the information reported in the referenced papers. Most notably, pipe sizes with diameters of 10 inches and greater, have been combined into one bin. Also, several valid data points were thrown out, due to the fact that the Reference papers did not provide the size or raw data to determine the size.

Second, the NRC failure frequencies are divided up by pipe size and by reactor type (PWR versus BWR), whereas most of the data collected from the referenced papers focused on pipe material (Stainless Steel versus Carbon Steel). Therefore, an error is introduced when combining the data for two different types of plants. This can be seen by reviewing the graph of SS with no breakdown of PWR versus BWR data as compared to NRC data, then the CS with no breakdown of PWR versus BWR as compared to NRC data.

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The third reason that the data is not adequately represented is due to the elimination of leak failure data from the sample set. Per instruction on this assignment, leaks are not viewed as catastrophic failures and should not be considered. After elimination of non-failure data points, this significantly reduces the sample set, thereby introducing error into the statistical calculations.

Finally, information in the figures of Section 3.0 was displayed not by plant type, but by material type. The NRC frequency failures were reported by pipe size and plant type. The reason for doing this is because the references reported the data by pipe size and material and not once did it mention the plant type that the accident occurred in.

The 5% / 95% confidence levels were also not reported since there are not enough data sources to perform a similar comparison. If one reads section E.3.a (page 14) of Reference 7, it can be determined that the resulting pipe failure frequencies were determined by taking an average of individual panel members' calculations. The 5% / 95% statistics was reported on the members' results. Since we only have our failure frequency for comparison, it is impossible to perform a similar statistical analysis.

In conclusion, even though the data shows that the NRC pipe failure frequency may not be entirely correct, it is determined that the results of this paper are not correct either and needs additional work in order to prove or disprove the NRC pipe failure frequency.

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References

1. R. Nyman, et al. "Reliability of Piping System Components – Framework for Estimating Failure Parameters from Service Data," SKI Report 97:26, December 1997. (ISSN 1104-1374).

2. D. S. Kupperman, et al., "Barrier Integrity Research Program," NUREG/CR-6861, December 2004.

3. B.O.Y. Lidell, "Strategies for Reactor Safety: Preventing Loss of Coolant Accidents," NKS RAK-(97)R10, December 1997. (ISBN: 87-7893-046-4).

4. D. A. Dahl, et al., "Assessment of Pressurized Water Reactor Primary System Leaks, NUREG/CR-6582, 1999. (INEEL/EXT-98-01068).

5. L. Rutherford, "Sonora goes dry after pipe breaks," *The Union Democrat Online*, [online] August 2004, Available: http://www.uniondemocrat.com/news/story.cfm?story_no=15018

6. "Death toll from Japan's worst nuclear plant accident rises to five". *SpaceWar.com*, [online] August 2004, Available: http://www.spacewar.com/2004/040825111301.12y5ikup.html

7. U.S. Nuclear Regulatory Commission, 10 CFR50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors."

Please note that The Appendix with supporting documentation of the report has been provided electronically, as Excel Spreadsheet Project_Data.xls.

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The data was compiled in an Excel 2003 spreadsheet by pipe size and pipe material. The compilation resulted in 5 different pipe size bins for each material type (carbon and stainless steel). The respective pipe size bins were divided into less than 1 inch, 1 inch to 2 inches, 2 inches to 4 inches, 4 inches to 10 inches, and greater than 10 inches.

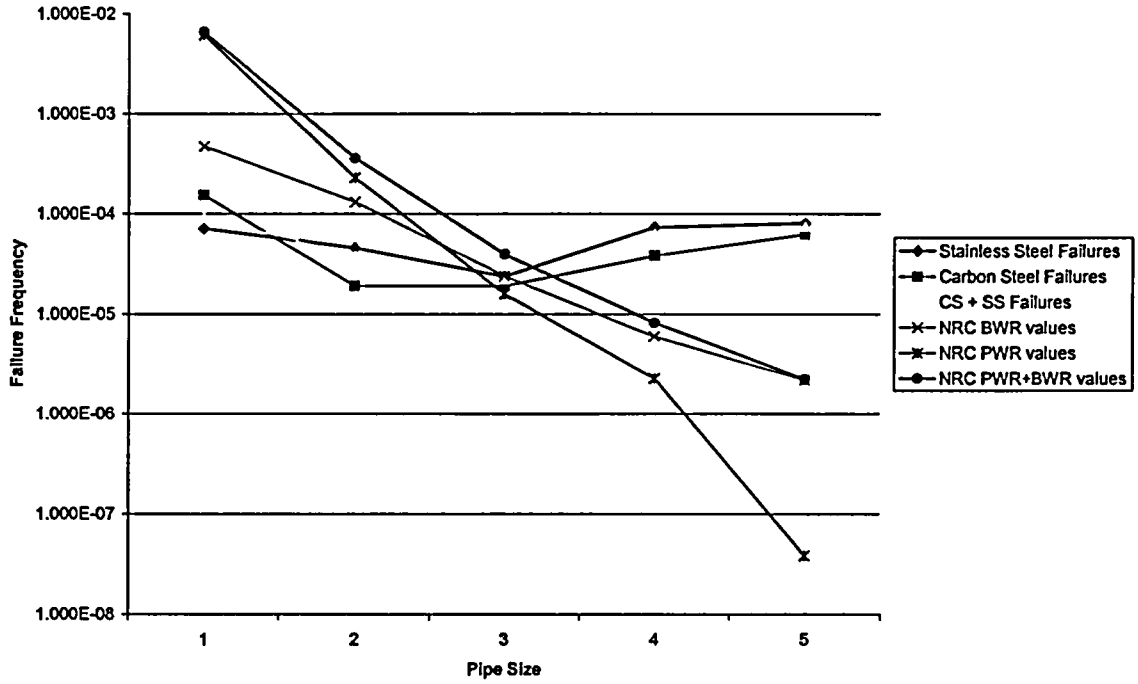
The next step was to then normalize the data. The data was normalized by determining a failure fraction for each bin size. This was determined by taking the number of failures for each bin and then dividing by the total number of failures in the pipe material.

Example: pipe bin 1 for carbon steel / CS failures = pipe bin 1 for CS failure fraction.

The next step was to calculate failure frequencies for carbon steel pipes only, stainless steel pipes only, and carbon and stainless steel pipes combined. This was determined by taking the failure fractions and dividing by 3390 calendar years. 3390 calendar years represents the total time of reactor operation through 2003.

Once the failure frequencies were determined, they were then plotted against the failure frequencies determined by the NRC, which are listed in 10 CFR50.46. The resulting figure (Figure 3) is provided below. Note that the pipe sizes are listed by bin numbers in Figure 3 (i.e. bin 1 encompasses all pipe sizes smaller than 1 inch in diameter).

Figure 3: Failure Frequencies vs. Pipe Size



Legend:

Pipe Size for Bin 1 - Diameter < 1 inch

Pipe Size for Bin 1 - 1 inch < Diameter < 2 inches

Pipe Size for Bin 1 - 2 inches < Diameter < 4 inches

Pipe Size for Bin 1 - 4 inches < Diameter < 10 inches

Pipe Size for Bin 1 - Diameter > 10 inches

NucE 597D - Project 1

DATA COLLECTION OF PIPE FAILURES OCCURING IN STAINLESS STEEL AND CARBON STEEL PIPING

Pennsylvania State University
Dr. L.E. Hochreiter
April 2005

Executive Summary

Currently the Nuclear Regulatory Commission (NRC) is contemplating changing the acceptance criteria for Emergency Core Cooling Systems (ECCS) for light-water nuclear power reactors contained in NRC Regulation 10 CFR 50.46. This regulation sets specific numerical acceptance criteria for peak cladding temperature, clad oxidation, total hydrogen generation, and core cooling under loss-of-coolant accident (LOCA) situations. Furthermore, the regulation requires that a spectrum of break sizes and locations be analyzed to determine the most severe case and to ensure the plant design can meet the acceptance criteria under such conditions.

Currently the regulation states that breaks of pipes in the reactor coolant pressure boundary up to, and including, a break equivalent in size to the double-ended rupture of the largest pipe in the reactor coolant system must be considered. While this restricts the design, it maintains a large safety margin ensuring the plant is covered under all LOCA situations. However, an impetus for change has resulted from materials research, analysis, and experience that indicate that the catastrophic rupture of a limiting size pipe at a nuclear power plant is a very low probability event.

If approved, the proposed change would divide the break spectrum into two categories based upon the likelihood of a break. Breaks of higher likelihood, breaks smaller than 10 inches, would need to meet the current requirements set forth in 10 CFR 50.46. Breaks of a lower likelihood, those larger than 10 inches, would only need to meet the requirements of maintaining a coolable geometry and having the capability for long term cooling.

The purpose of this project was to collect data on instances of pipe failures including cracks, leaks, and ruptures. For each instance of failure the plant type, pipe diameter, type of pipe, failure mechanism, and type of failure was recorded. The data was then collapsed based on plant type (PWR or BWR), type of pipe (carbon or stainless steel), pipe size, and failure mechanism. Then, normalized failure frequencies were calculated as a function of both pipe size and failure mechanism per reactor year. Plots of the frequency distributions were generated on a semi-log scale, and the frequency distributions as a function of pipe size were compared to the NRC predicted failure frequencies.

For this project our group collected two, independent sets of data. The first set was provided by the OECD Pipe Failure Data Exchange Project (OPDE), with a total of 2891 data points. The second set consists of 67 data points collected by our group from various sources. The two sets of data were not combined due to the lack of information accompanying the data presented in the OPDE database, such as plant name or exact failure size. This made it impossible to identify overlapping coverage and combine the information. Rather, within this report we have analyzed each data set individually in order to make an overall comparison of the trends observed for each data set and the NRC predictions.

The results from both the OPDE and the independent sets of data detailed in this report do not support the NRC's assertion that larger sized pipes do not break frequently enough to be used as design criteria. The overall trends of both sets of data show that the frequency of failures does not decrease as sharply with increasing pipe size as the NRC predicts.

Table of Contents

1.0 Detailed Introduction to the Problem 6

2.0 Data Collected 8

OECD Pipe Failure Data Exchange Project 8

Independently Collected Data 9

3.0 Collapsing and Analyzing the Collected Data 12

4.0 Results and comparisons 15

Failure Frequency as a function of Pipe Size 15

Failure Frequency as a function of Failure Mechanism 25

5.0 Conclusions 31

6.0 References 33

Appendix A – OPDE-Light Database

Appendix B – Independent Database

Appendix C – Collapsed OPDE Data

Appendix D – Copies of References

List of Figures

Figure 4.1-1. Normalized pipe failure frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants

Figure 4.1-2 Normalized rupture frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants

Figure 4.1-3. Normalized Failure Frequency Distribution for PWRs

Figure 4.1-4. Normalized Failure Frequency Distribution for BWRs

Figure 4.1-5. Normalized pipe failure frequencies as a function of pipe size for PWRs

Figure 4.1-6. Normalized pipe failure frequencies as a function of pipe size for BWRs

Figure 4.2-1. Normalized pipe failure frequency as a function of Pipe Group Size for PWRs

Figure 4.2-2. Normalized pipe failure frequency as a function of Pipe Group Size for BWRs

Figure 4.3-1. PWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

Figure 4.3-2. BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

Figure 4.3-3. PWR and BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

Figure 4.3-4. Pipe Failure by Corrosion as a Function of Pipe Size (PWR & BWR)

Figure 4.3-5. Pipe Failure by Fatigue as a Function of Pipe Size (PWR & BWR)

Figure 4.3-6. Pipe Failure by Mechanical Failures as a Function of Pipe Size (PWR & BWR)

Figure 4.3-7. Pipe Failure by Stress Corrosion Cracking as a Function of Pipe Size (PWR & BWR)

List of Tables

Table 1-1. NRC Total Preliminary BWR and PWR Frequencies

Table 2-1. Excerpt from "OPDE-Light" Database

Table 2-2. Description of Plant Systems and Type of Piping

Table 2-3. Definition of OPDE Pipe Size Groups

Table 2-4. OPDE Pipe Failure Definitions

Table 3-1. Definition of Pipe Size Groups

Table 3-2. Definition of NRC LOCA Groups

Table 4.1-1. OPDE Calculated, and NRC Predicted, Normalized Failure Frequencies (1/cal-yrs).

Table 4.1-2. Normalized Rupture Frequencies

Table 4.1-3. Summary of BWR Pipe Failures from the OPDE Database as of 2-24-05

Table 4.1-4. Summary of PWR Pipe Failures from OPDE Database as of 2-24-05

Table 4.2-1. OPDE Calculated, NRC Predicted, and Independent Database Calculated, Normalized Failure Frequencies (1/cal-yrs)

Table 4.3-1. Failure Frequencies of Pipes for each Failure Mechanism

1.0 Detailed Introduction of Problem

In order to ensure the safety of nuclear plants the cooling performance of the Emergency Core Cooling System (ECCS) must be calculated in accordance with an acceptable evaluation model, and must be calculated for a number of postulated loss-of-coolant accidents (LOCA) resulting from pipe breaks of different sizes, locations, and other properties. This is done to provide sufficient assurance that a plant can handle even the most severe postulated LOCA. LOCA's are hypothetical accidents that would result from the loss of reactor coolant, at a rate in excess of the capability of the reactor coolant makeup system. Currently, the evaluation criteria for these types of accidents state that pipe breaks in the reactor coolant pressure boundary up to and including a break equivalent in size to the double-ended rupture of the largest pipe in the reactor coolant system must be considered. In the case of such an event the NRC has set forth the following criteria that must be met for a design to be considered acceptable [37]:

a. Peak cladding temperature must not exceed 2200° F.

b. Maximum cladding oxidation must not exceed 0.17 times the total cladding thickness before oxidation.

c. Maximum hydrogen generation. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

d. A coolable geometry of the core must be maintained.

e. After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

While requiring that all plants be analyzed in the case of a double-ended guillotine break of the largest pipe restricts the design, it does maintain a large safety margin ensuring the plant is covered in all pipe break situations. However, an impetus for change has resulted from materials research, analysis, and experience which indicate that the catastrophic rupture of a large pipe at a nuclear power plant is a very low probability event. The hypothesis that is currently being set forth is that small pipes break more frequently than large pipes. The criteria would change so that the NRC would refocus their analysis efforts because they want to make sure that the appropriate amount of time and money are being invested in the areas of most concern.

Furthermore, risk analyses indicate that large break LOCA's are not significant contributors to plant risk. According to a presentation given by Dr. Brian Sheron of the NRC at Penn State in the Fall 2004, "using the double ended break of the largest pipe in the reactor coolant system as the design basis for the plant results in ECCS equipment requirements which are inconsistent with risk insights and places an unwarranted emphasis and resource expenditure on low risk

contributors. This also places constraints on operations which are unnecessary from a public health and safety perspective." Therefore, the proposed rule change would use the pipe size with the largest break frequency as the design basis for pipe rupture and accident analysis of the plant. A pipe size with a 10 inch diameter is currently being suggested. [37]

The proposed change would divide the break spectrum into two categories based upon the likelihood of a break. Breaks of higher likelihood, or those smaller than 10 inches, would need to meet the current requirements set forth in 10 CFR 50.46. These include criteria (a) through (e) above. On the other hand, breaks of a lower likelihood, or those larger than 10 inches up to and including a double-ended guillotine break of the largest pipe in the reactor coolant system, would only need to meet the requirements of maintaining a coolable geometry and having the capability for long term cooling. Thus, criteria (a), (b), and (c) would be eliminated for these cases. [37]

The purpose of this project was to collect data on instances of pipe breaks, leaks, and cracking. These failures included pipe failures from broken pipes either by splits, ruptures, or guillotines, and cracks in pipes, either circumferential or length wise. For each instance found the plant type, pipe diameter, type of pipe, failure mechanism, and type of failure was recorded. Only stainless steel and carbon steel pipes were considered. Then, normalized failure frequency distributions were developed and compared to NRC predictions.

The predicted NRC failure frequencies were taken from Table 3 on page 14 of 10 CFR 50.46, LOCA Frequency Development [38]. This table is replicated below.

Table 1-1. NRC Total Preliminary BWR and PWR Frequencies.

Plant Type	Effective Break Size (inches)	Current Day Estimates (per cal. yr)			
		5%	Median	Mean	95%
BWR	1/2	3.0E-05	2.2E-04	4.7E-04	1.7E-03
	1 7/8	2.2E-06	4.3E-05	1.3E-04	5.0E-04
	3 1/4	2.7E-07	5.7E-06	2.4E-05	9.4E-05
	7	6.6E-08	1.4E-06	6.0E-06	2.3E-05
	18	1.5E-08	1.1E-07	2.2E-06	6.3E-06
	41	3.5E-11	8.5E-10	2.3E-06	8.6E-09
PWR	1/2	7.3E-04	3.7E-03	6.3E-03	2.0E-02
	1 7/8	6.9E-06	9.9E-05	2.3E-04	8.5E-04
	3 1/4	1.6E-07	4.9E-06	1.6E-05	6.2E-05
	7	1.1E-08	6.3E-07	2.3E-06	8.8E-06
	18	5.7E-10	7.5E-09	3.9E-08	1.5E-07
	41	4.2E-11	1.4E-09	2.3E-08	7.0E-08

2.0 Data Collected

For this project our group collected two, independent sets of data. The first set was provided by the OECD Pipe Failure Data Exchange Project (OPDE), with a total of 2891 data points. The second set consists of 67 data points collected by our group from various sources listed as references in this report. The two sets of data were not combined due to the lack of information accompanying the data presented in the OPDE database, such as plant name and exact failure size, which made identifying overlapping coverage impossible. Rather, within this report each data set was individually analyzed in order to make an overall comparison of the trends observed for each data set and the NRC predictions.

OECD Pipe Failure Data Exchange Project [3]

OECD Pipe Failure Data Exchange Project (OPDE) was established in 2002 as an international forum for the exchange of pipe failure information. It is a 3-year project with participants from twelve countries, including Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Republic of Korea, Spain, Sweden, Switzerland and the United States. "The objective of OPDE is to establish a well structured, comprehensive database on pipe failure events and to make the database available to project member organizations that provide data." [3] The OPDE database evolved from what existed in the "SLAP database" at the end of 1998 [2].

OPDE covers piping in primary-side and secondary-side process systems, standby safety systems, auxiliary systems, containment systems, support systems and fire protection systems. Furthermore, ASME Code Class 1 through 3 and non-Code piping has been considered. At the end of 2003, the OPDE database included approximately 4,400 records on pipe failure. The database also includes an additional 450 records on water hammer events where the structural integrity of piping was challenged but did not fail.

Access to the actual OPDE database is restricted to organizations providing input data. However, a "OPDE-Light" version of the database will be made available later this year to non-member organizations contracted by a project member to perform work or which pipe failure data is needed. This version will not include proprietary data, such as the exact pipe diameter, where failure occurred, and preclude any plant identities or dates. Our group was fortunate enough to get a copy of this "light" version of the database for BWR and PWR pipe failures reported as of February 24, 2005. A total of 2891 failures (1536 for PWR plants and 1355 for BWR plants) were provided in this database, and considered for this project.

The database listed the plant type, reactor system, apparent cause of failure, pipe size group, number of total failures for each cause and pipe size group, and then a break down of the type of failure within the category. An excerpt from the OPDE-Light database has been provided for clarification in Table 2-1 on the following page. The database, in its entirety, has been included in Appendix A of this report.

However, there are a few problems with this database related to the purpose of this project. First, since the database did not provide the type of pipe (carbon or stainless) for each failure, a reasonable prediction of what type of pipe was involved in the failure based on the plant system, which was given, was made. The type of pipe assumed for each system is also given in the following page in Table 2-2.

Additionally, as previously mentioned, no explicit pipe diameters were given for each failure due to the proprietary nature of this information. Rather, the failures were collected into group sizes before it was sent out. A total of six group sizes were utilized by OPDE. The range of pipe diameters that comprise each group is given in Table 2-3. The main problem with these groupings, and the database in general, is that pipes larger than 10 inches in diameter are all grouped together and there is no way of determining how much larger than 10 inches they actually were. Finally, for the purpose of this analysis any crack, leak, or issue (i.e. wall thinning) with the pipe was considered to be a failure. However, the OPDE database lists the information by type of failure. The definitions of each failure type have been included in Table 2-4.

Independently Collected Data [5-36]

For the purpose of this project our group collected separate information on instances of piping failures and their causes. The information was collected primarily from Nuclear Regulatory Commission (NRC) bulletins, information notices, event reports, and generic letters. Our group was able to compile a total of 67 instances of piping failures. This database is provided in Appendix B. While our database is much smaller than the one compiled by the OECD Pipe Failure Exchange Project, it provides an independent check of the trends observed by that database.

A list of references is provided at the end of this report, and some of the actual references, printed from the NRC website, have been included in Appendix D.

Table 2-1. Excerpt from "OPDE-Light" Database

PLANT TYPE	PIPE TYPE	SYSTEM GROUP	APPARENT CAUSE	PIPE SIZE GROUP	TOTAL NO. OF RECORDS	Crack-Full	Crack-Part	Deformation	Large Leak	Leak	P/H-Leak	Rupture	Severance	Small Leak	Wall thinning
BWR	SS	RAS	Severe overloading	2	3			1				2			
BWR	SS	RCPB	external damage	3	1			1							
BWR	SS	RCPB	Severe Overloading	4	1			1							
BWR	SS	SIR	Severe overloading	6	1			1							
BWR	CS	STEAM	Water Hammer	6	1			1							
BWR	SS	RCPB	HF;Welding Error	3	7	1				1	1			4	
BWR	SS	RAS	TGSCC - Transgranular SCC	2	7	1	1				1			4	
BWR	SS	SIR	IGSCC - Intergranular SCC	4	4	1					2			1	
BWR	SS	RAS	IGSCC - Intergranular SCC	4	56	1	32				9		1	13	
BWR	SS	SIR		0	1	1									
BWR	SS	RCPB	TGSCC - Transgranular SCC	1	1	1									
BWR	SS	SIR	IGSCC - Intergranular SCC	2	3	1	1							1	
BWR	SS	RCPB	Overpressurization	4	2	1						1			
BWR	CS	AUXC	Vibration-Fatigue	5	1	1									

Table 2-2. Description of Plant Systems and Type of Piping.

Plant Group	Representative Plant System Names	Type of Piping
AUXC	Service Water Systems, Raw Water Cooling Systems	Carbon
CS	Containment Spray System	Stainless
EHC	Electro-Hydraulic Control System	Carbon
EPS	Emergency Diesel Generator System	Stainless
FPS	Fire Protection System	Carbon
FWC	Feedwater & Condensate Systems	Stainless
IA-SA	Instrument Air & Service Air Systems	Carbon
PCS	Power Conversion Systems (incl. Steam Extraction Lines, Heater Drain Lines, etc.)	Carbon
RAS	Reactor Auxiliary Systems (incl., CVCS, RWCU, CCWS, CRD)	Stainless
RCPB	Reactor Coolant Pressure Boundary	Stainless
SG	Steam Generator Systems (e.g., S/G Blowdown System)	Carbon
SIR	Safety Injection & Recirculation Systems	Stainless
STEAM	Main Steam (from nuclear boiler/steam generator up to turbine steam admission)	Carbon

Table 2-3. Definition of OPDE Pipe Size Groups.

Pipe Size Group	Corresponding Pipe Diameters (mm)	Corresponding Pipe Diameters (inches)
1	DN < 15	DN < 0.6
2	15 < DN < 25	0.6 < DN < 1.0
3	25 < DN < 50	1.0 < DN < 2.0
4	50 < DN < 100	2.0 < DN < 4.0
5	100 < DN < 250	4.0 < DN < 10.0
6	DN > 250	DN > 10.0

Table 2-4. OPDE Pipe Failure Definitions.

Type	Description
Crack - Part	Part through-wall crack (≥ 10% of wall thickness)
Crack - Full	Through-wall but no active leakage; leakage may be detected given a plant mode change involving cooldown and depressurization.
Wall Thinning	Internal pipe wall thinning due to flow accelerated corrosion - FAC
Small Leak	Leak rate within Technical Specification limits
Pinhole Leak	Differs from "small leak" only in terms of the geometry of the throughwall defect and the underlying degradation or damage mechanism
Large Leak	Leak rate in excess of Technical Specification limits but within the makeup capability of safety injection systems
Severance	Full circumferential crack – caused by external impact/force, including high-cycle mechanical fatigue – limited to small-diameter piping, typically
Rupture	Large flow rate and major, sudden loss of structural integrity. Invariably caused by influences of a degradation mechanism (e.g., FAC) in combination with a severe overload condition (e.g., water hammer)

3.0 Collapsing and Analyzing the Collected Data

The next important step in this analysis was collapsing the collected information into a usable form by specifying pipe size groups and failure mechanisms. The data was broken into separate bins based on plant type (PWR or BWR), pipe type (carbon or stainless), failure mechanism, and pipe size. Table 3-1 below lists the pipe diameters included in each bin for this analysis.

Table 3-1. Definition of Pipe Size Groups.

OPDE Pipe Size Groups	Corresponding Pipe Diameters (inches)
1+2	0.0-1.0
3	1.0-2.0
4	2.0-4.0
5	4.0-10.0
6	> 10.0

Note: This grouping of piping diameters includes one less bin than used by the OPDE database. Combination of the data from groups 1 and 2 of the OPDE database allowed the bin sizes to correspond more readily with those used by the NRC for listing predicted failure frequencies, taken from page 14 of 10 CFR 50.46, LOCA Frequency Development. The categories used for the NRC predicted failure frequencies are given in Table 3-2. [38]

Table 3-2. Definition of NRC LOCA Groups.

LOCA Category	Effective Break Size (inches)
1	1/2
2	1 7/8
3	3 1/4
4	7
5	18
6	41

It can be seen that for LOCA categories 1 though 5 the effective break sizes fall within the ranges listed for the pipe size groups, after pipe size groups 1 and 2 from the OPDE database were combined. LOCA category 6 was not considered in this analysis since the OPDE database did not provide specific information for pipes larger than 10 inches. The effect of this on the results will be discussed later in this report.

After collapsing the data based on pipe size, the data was then collapsed further by combining some of the failure mechanisms. The following is a list of the failure mechanisms that are used to group the data. Several items have been placed into general categories for simplification purposes.

1. Corrosion
2. Flow Accelerated Corrosion (FAC)
3. Microbiological Induced Corrosion (MIC)
4. Erosion
5. Fatigue
    a. Thermal Fatigue
    b. Vibration Fatigue
6. Human Factors (already combined in the OPDE database)
    a. Welding Error
    b. Fabrication Error
    c. Human Error
7. Mechanical Failures
    a. Excessive Vibration
    b. Overpressurization
    c. Overstressed
    d. Severe Overloading
8. Stress Corrosion Cracking
9. Water Hammer
10. Miscellaneous
    a. Brittle Fracture
    b. Cavitation
    c. External Damage
    d. Fretting
    e. Freezing
    f. Hot Cracking
    g. Hydrogen Embrittlement
    h. Unreported

After collapsing the data, it needed to be normalized so that failure frequency distributions could be calculated. Failure frequencies were calculated in for carbon steel pipes, stainless steel pipes, and a composite (both carbon and stainless) pipes as a function of both pipe group size and failure mechanism, separately for PWR and BWR plants.

The number of failures in each bin was normalized by dividing by the total number of failures. This gives the fraction of failures for each bin size. For example, when looking at carbon steel pipes in BWRs the number of failures in each pipe group size, regardless of failure mechanism, was divided by the total number of pipe failures (carbon + stainless) in BWRs. Similarly, the number of pipe failures in each failure mechanism bin, regardless of pipe size, was divided by the total number of pipe failures in BWRs.

Then, after normalizing the data, the fractional size in each bin was divided by 3390 calendar years of operation. This gives a failure frequency in 1/calander-years for each bin size. The number 3390 represents the number of reactor years experience in the US (2745 years) as of the end of 2003; divided by an assumed availability factor of 0.81 to get calendar years.

The normalization by pipe size (regardless of failure mechanism) and failure mechanism (regardless of pipe size) was repeated for BWR stainless steel failures, BWR composite failures, PWR carbon failures, PWR stainless steel failures, PWR composite failures, total carbon steel failures, total stainless steel failures, and total composite failures for a total of nine situations analyzed and a total of eighteen frequency distributions developed (nine as a function of pipe size and nine as a function of failure mechanism).

Finally, the frequency distributions developed were based both on pipe size and failure mechanisms for the different types of pipes had to be plotted against the NRC's predicted frequencies. Semi-log plots of failure frequency as a function of pipe group size were used.

OPDE Database

In order to use this database it had to be collapsed into a more useful form. First, after determining the type of pipe associated with each system, the plant system was no longer taken into consideration. Next, for the purpose of this project any type of failure (i.e. crack, rupture, wall thinning) was considered to be a pipe failure. Furthermore, as shown above several causes of failure were combined together into one failure mechanism category. The collapsed form of this database is provided in Appendix C.

Independent Database

There were 67 incidents recorded, which in the end did not provide enough data points in each bin to come up with a good normalized frequency distribution. When the data was sorted on plant type, then pipe material and finally on pipe size, various bins of pipe sizes had zero incidents. Appendix B is a listing of all of the incidents which were found. This listing is sorted on plant type, pipe material, and finally on pipe size. The highlighted incidents throughout the appendix represent incidents for which not enough information was given in the source to include this data in our analysis.

Failure mechanism plots were not made due to the lack of variety in failure mechanisms. The majority of the failure mechanisms were erosion/corrosion and stress corrosion cracking.

4.0 Results and Comparisons

4.1 Pipe Failures as a function of Pipe Size from OPDE Data

This section of the report examines the results of pipe failures as a function of pipe size. Normalized failure frequencies for carbon steel, stainless steel, and composite (carbon and stainless) pipes are presented individually for PWRs and BWRs. The NRC has developed their own failure frequencies for PWR and BWR plants as function of pipe size, but does not have separate frequencies for carbon and stainless steel pipes.

Table 4.1-1 lists the normalized failure frequencies for both PWR and BWR plants, regardless of pipe type, calculated from the OPDE database data and the NRC mean predictions [38].

Table 4.1-1. OPDE Calculated, and NRC Predicted, Normalized Failure Frequencies (1/cal-yrs).

Plant Type	Pipe Size Groups (inches)	OPDE Results	NRC Predictions
PWR	0.0-1.0	1.3E-04	6.3E-03
	1.0-2.0	4.4E-05	2.3E-04
	2.0-4.0	2.9E-05	1.6E-05
	4.0-10.0	4.6E-05	2.3E-06
	> 10.0	4.2E-05	3.9E-08
BWR	0.0-1.0	8.2E-05	4.7E-04
	1.0-2.0	2.3E-05	1.3E-04
	2.0-4.0	5.6E-05	2.4E-05
	4.0-10.0	6.2E-05	6.0E-06
	> 10.0	7.2E-05	2.2E-06

Figure 4.1-1 displays this information graphically on a semi-log plot with normalized failure frequencies on the y-axis and the pipe size groups on the x-axis. The figure shows that the results of the OPDE database underestimate the failure frequency for the smaller pipe size groups and overestimate the failure frequency for the larger pipe size groups compared to the NRC predictions for both PWRs and BWRs. However, there is less disparity in the two BWR predictions than the two PWR predictions.

The NRC predicts that PWR plants are much more likely to have pipe failures in smaller pipes than larger pipes. This trend remains the same in NRC prediction for BWR plants, but is not nearly as drastic. The OPDE results for both PWR and BWR plants show a much more consistent failure frequency both over the range of pipe sizes and between PWR and BWR plants.

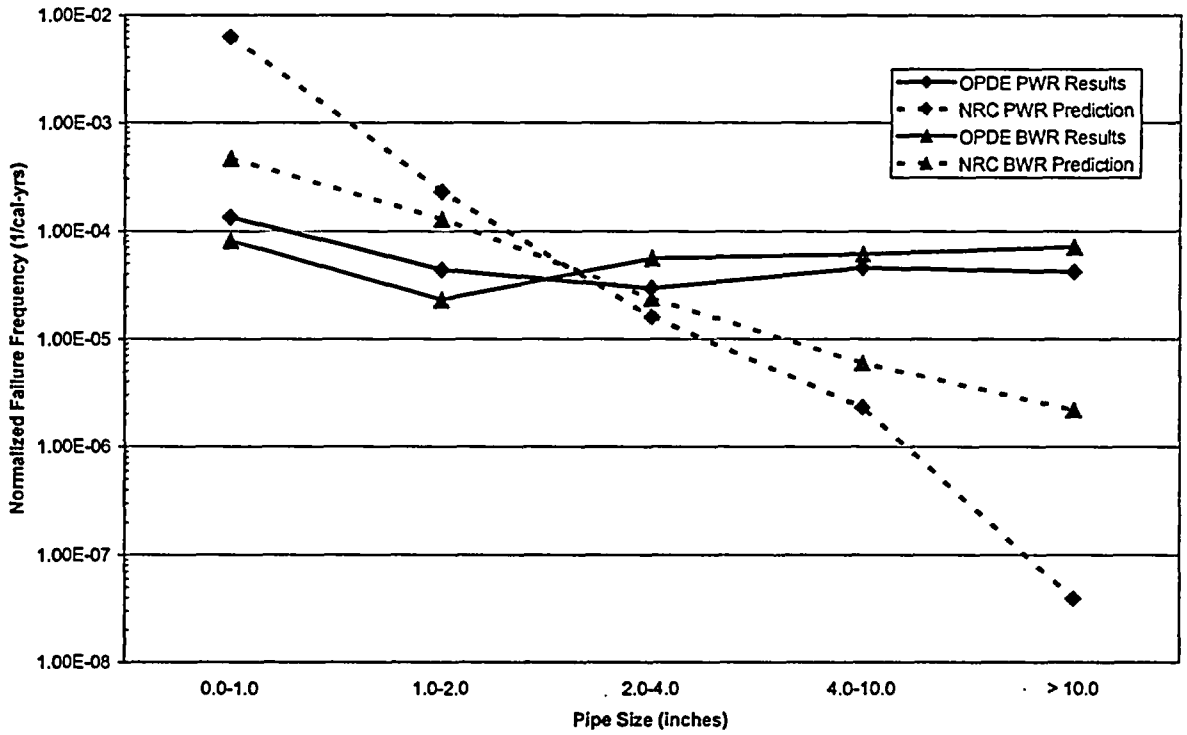


Figure 4.1-1. Normalized pipe failure frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants.

There were three issues in the data analysis that were initially thought to factor into the difference in results between the analyzed OPDE database and the NRC predictions. The first assumption was that all types of cracks, leaks, ruptures, or other issues were considered to be a complete failure in the pipe. In actuality this is not true since inspections or other indicators may catch a crack or leak before a complete failure occurs. As a result, a separate analysis considering only the pipe ruptures listed in the OPDE database was conducted. However, the calculated frequency distribution considering only ruptures did not change significantly, in either trend or magnitude, from the results obtained when considering all issues to be a failure. The results of this rupture only analysis are shown below in Figure 4.1-2.

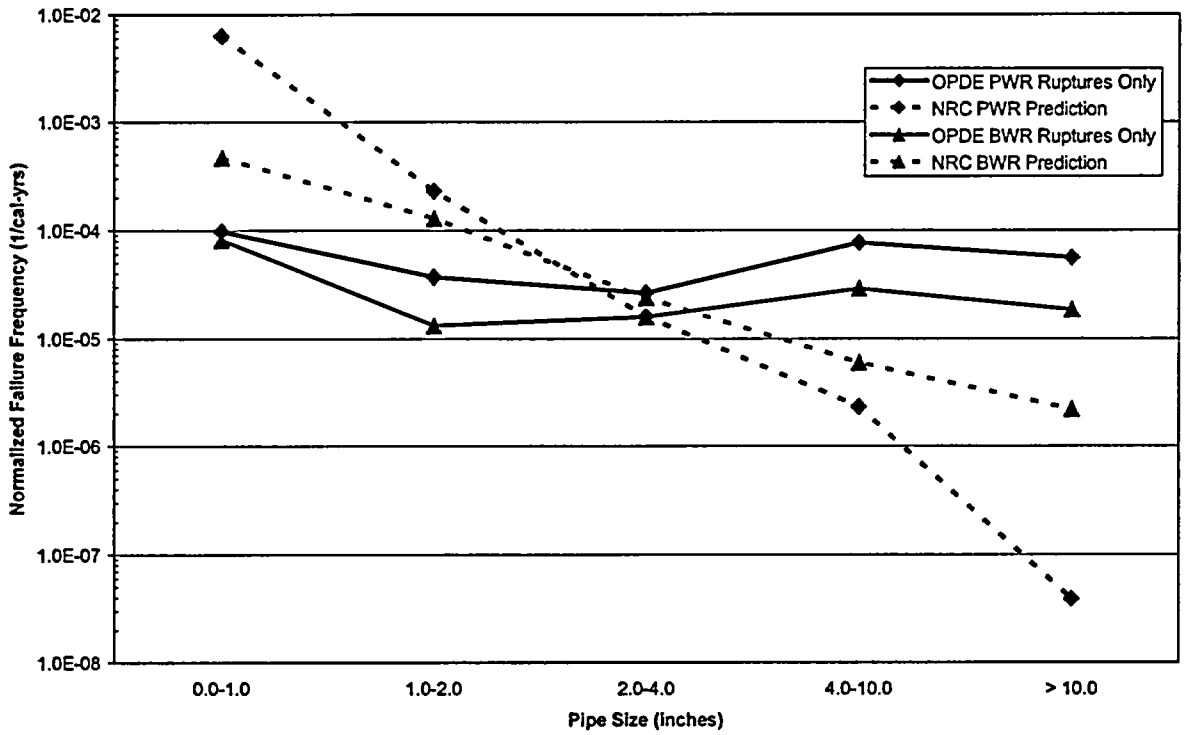


Figure 4.1-2 Normalized rupture frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants.

The data for this plot is shown in Table 4.1-2.

Table 4.1-2. Normalized Rupture Frequencies.

Plant Type	Pipe Size (inches)	Instances of Rupture	Normalized Failure Frequency (1/cal-yrs)
PWR	0.0-1.0	37	9.8E-05
	1.0-2.0	14	3.7E-05
	2.0-4.0	10	2.7E-05
	4.0-10.0	29	7.7E-05
	> 10.0	21	5.6E-05
	Total	111	---
BWR	0.0-1.0	31	8.2E-05
	1.0-2.0	5	1.3E-05
	2.0-4.0	6	1.6E-05
	4.0-10.0	11	2.9E-05
	> 10.0	7	1.9E-05
	Total	60	---

The second assumption of concern is the nature of the information contained in the OPDE database. Since the "light" version of the database did not specify the exact pipe size due to the proprietary nature of this information, all pipe failures greater than 10 inches were included in one bin for this analysis. However, for the NRC predictions there are two categories for pipes greater than 10 inches, LOCA categories 5 and 6. As a result, the OPDE calculated failure frequencies for the largest pipe group size would be expected to be larger in magnitude than the NRC's predictions since it covers a wider range of pipe sizes, and thereby a greater fraction of the total when normalized.

The final concern is the OPDE database excludes instances of steam generator tube rupture (SGTR) from consideration. By doing this the total number of failures in the smaller pipe size groups is reduced, and the calculated frequencies are lower for the smaller pipe size groups than if SGTR had been considered.

The next two plots, Figure 4.1-3 and Figure 4.1-4, present the same data as is included in Figure 4.1-1, but these figures include the ranges for the NRC prediction. It can be seen that even when the range of validity is taken into consideration, a large portion of the distribution still falls outside the boundaries for both PWRs and BWRs.

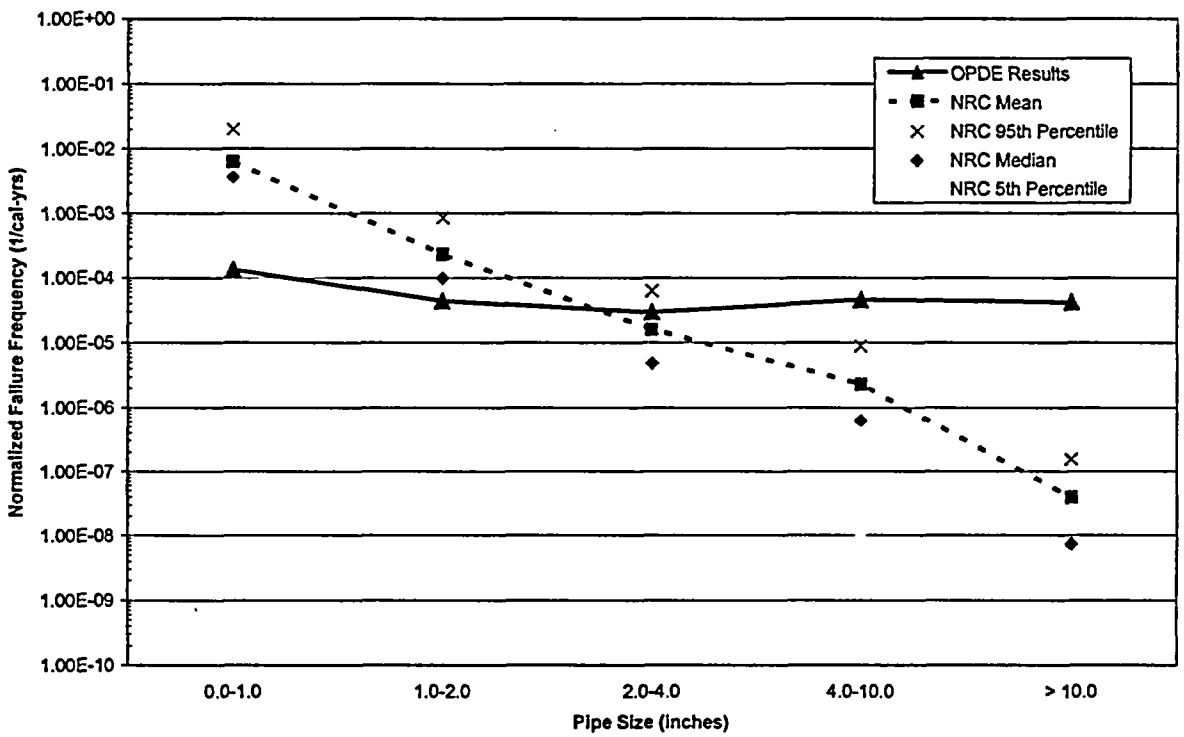


Figure 4.1-3. Normalized Failure Frequency Distribution for PWRs.

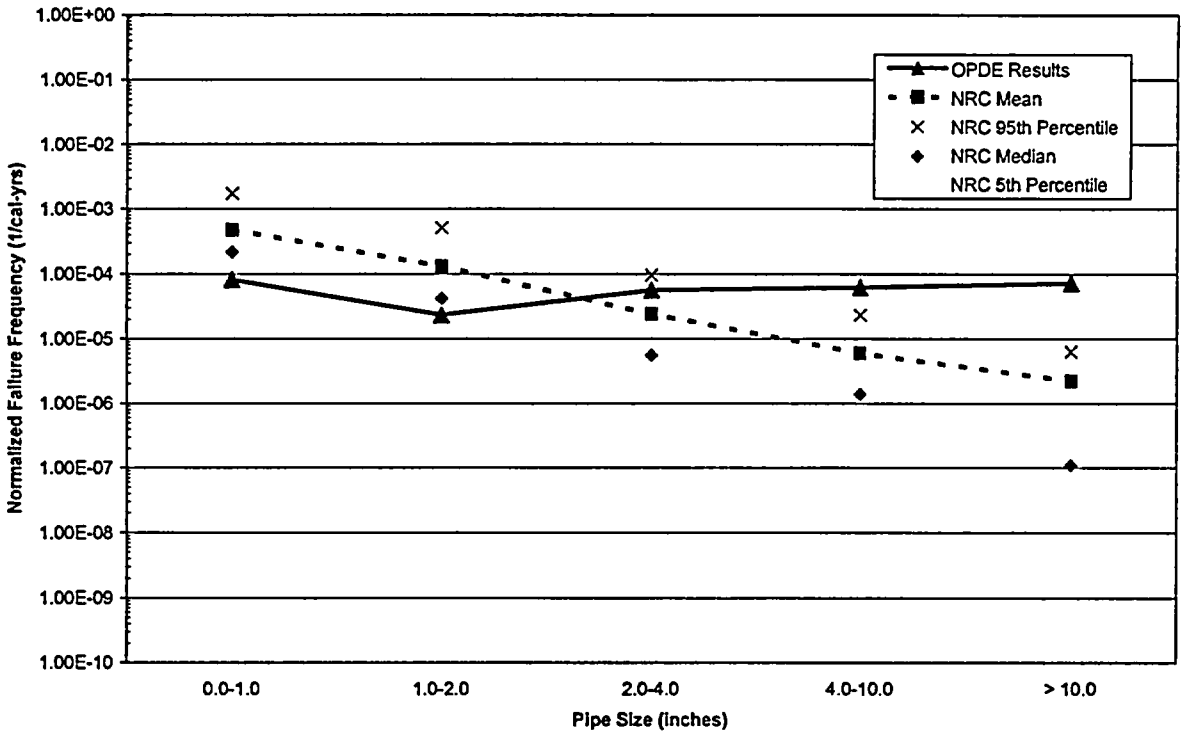


Figure 4.1-4. Normalized Failure Frequency Distribution for BWRs.

Table 4.1-3 and Table 4.1-4 serve as summaries of the information on pipe failure as a function of pipe size and pipe type from the OPDE database for BWRs and PWRs respectively.

Table 4.1-3. Summary of BWR Pipe Failures from the OPDE Database as of 2-24-05

Pipe Size (inches)	Both Carbon Steel and Stainless Steel Pipes		Carbon Steel Pipes Only		Stainless Steel Pipes Only	
	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)
0.0-1.0	375	8.2E-05	118	2.6E-05	257	5.6E-05
1.0-2.0	107	1.1E-05	32	7.0E-06	75	1.6E-05
2.0-4.0	259	2.6E-05	32	7.0E-06	227	4.9E-05
4.0-10.0	284	2.9E-05	50	1.1E-05	234	5.1E-05
> 10.0	330	3.4E-05	39	8.5E-06	291	6.3E-05
Total	1355	---	271	---	1084	---

Table 4.1-4. Summary of PWR Pipe Failures from OPDE Database as of 2-24-05

Pipe Size (inches)	Both Carbon Steel and Stainless Steel Pipes		Carbon Steel Pipes Only		Stainless Steel Pipes Only	
	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)	Number of Failures	Normalized Failure Frequency (1/cal-yrs)
0.0-1.0	698	1.3E-04	154	3.0E-05	544	1.0E-04
1.0-2.0	228	4.4E-05	74	1.4E-05	154	3.0E-05
2.0-4.0	153	2.9E-05	78	1.5E-05	75	1.4E-05
4.0-10.0	238	4.6E-05	126	2.4E-05	112	2.2E-05
> 10.0	219	4.2E-05	93	1.8E-05	126	2.4E-05
Total	**1536**	---	**525**	---	**1011**	---

There are a few important things to note from these tables. The first is that there have been a similar number of failures reported in BWRs as PWRs (1355 vs. 1536). Second, there were 4 times as many failures of stainless steel pipes as carbon steel pipes in BWRs (1084 vs. 271), and almost two times as many stainless steel failures than carbon steel failures in PWRs (1011 vs. 525). It was not expected to find more stainless steel failures than carbon steel failures. It should also be noted that while the number of stainless steel pipe failures is about the same for both BWRs and PWRs, but nearly twice as many carbon steel failures were observed in PWR plants than BWR plants (525 vs. 271).

Figure 4.1-5 and Figure 4.1-6 shows a more detailed representation of failure frequencies as a function of pipe size for PWR plants only, and BWR plants only, respectively. These figures present the separate failure frequency distributions for carbon steel and stainless steel pipes. Figure 4.1-5 shows that failures of stainless steel pipes are more frequent than carbon steel pipes only for smaller pipe sizes in PWRs. Figure 4.1-6 shows that stainless steel pipe failures are much more frequent than carbon steel pipe failures at all pipe sizes in BWRs.

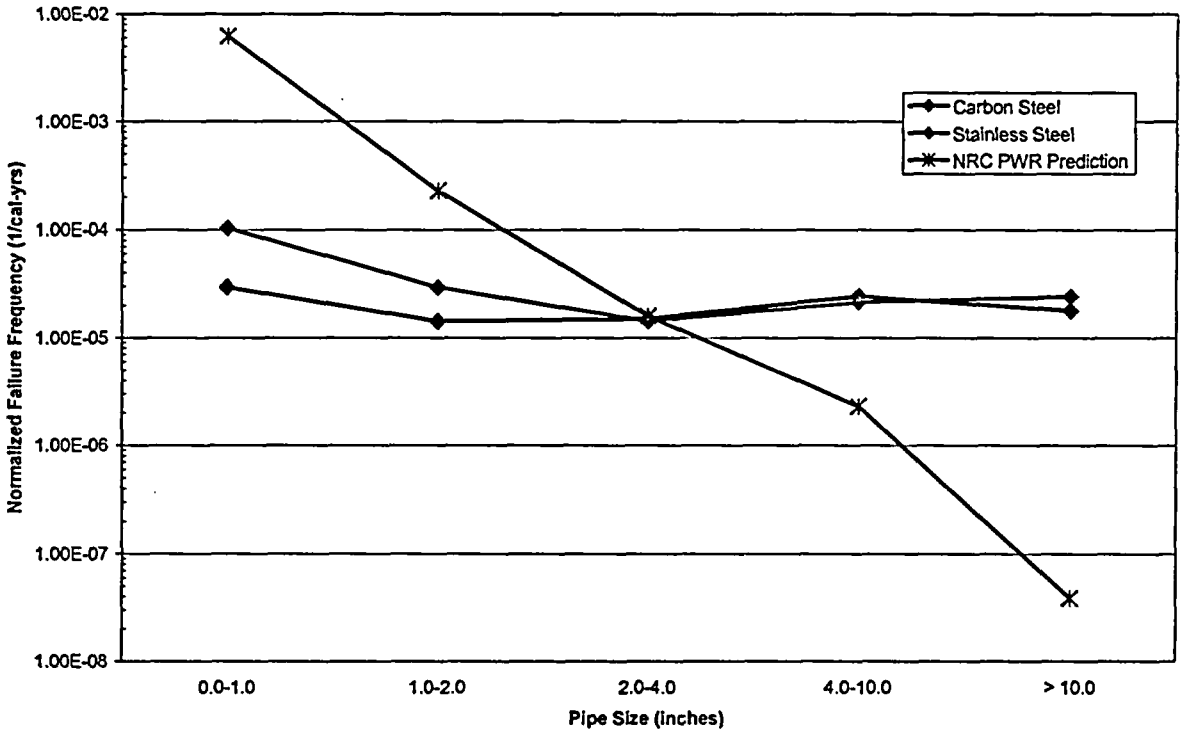


Figure 4.1-5. Normalized pipe failure frequencies as a function of pipe size for PWRs.

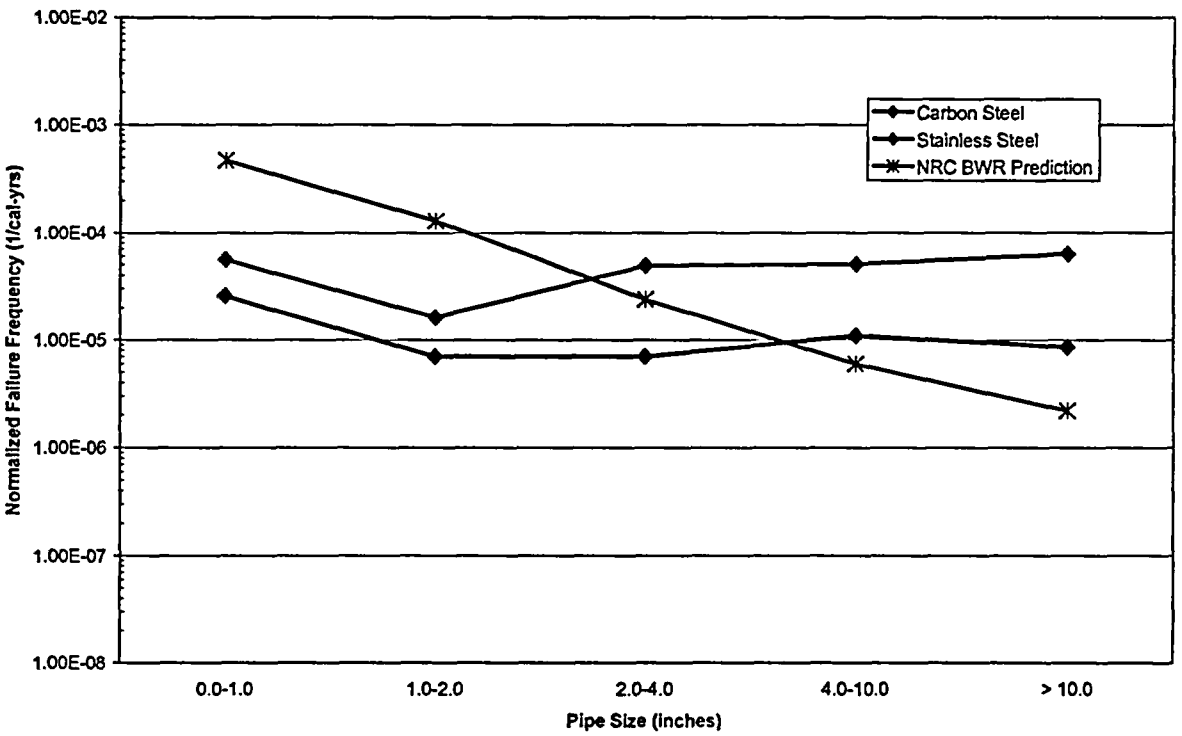


Figure 4.1-6. Normalized pipe failure frequencies as a function of pipe size for BWRs.

4.2 Pipe Failures as a function of Pipe Size from Independent Data

The independent database was used primarily to confirm the OPDE database predictions, along with comparing this set of data to the NRC data. Due to the small number of incidents found in this database, some of the pipe group size data groups had values of zero. When plotted on a semi-log scale, similar to the NRC and the OPDE plots, the points do not appear on the plot for that particular pipe size group. This occurs only once for the total normalized frequency plot for BWR data.

Table 4.2-1 shows the comparison of the OPDE, NRC and the independent database frequencies.

Table 4.2-1. OPDE Calculated, NRC Predicted, and Independent Database Calculated, Normalized Failure Frequencies (1/cal-yrs).

Plant Type	Pipe Size (inches)	OPDE Data	NRC Prediction	Independent Database
PWR	0.0-1.0	1.3E-04	6.3E-03	3.6E-05
	1.0-2.0	4.4E-05	2.3E-04	3.6E-05
	2.0-4.0	2.9E-05	1.6E-05	9.4E-05
	4.0-10.0	4.6E-05	2.3E-06	2.2E-05
	> 10.0	4.2E-05	3.9E-08	1.1E-04
BWR	0.0-1.0	8.2E-05	4.7E-04	2.3E-05
	1.0-2.0	2.3E-05	1.3E-04	0.0E+00
	2.0-4.0	5.6E-05	2.4E-05	3.4E-05
	4.0-10.0	6.2E-05	6.0E-06	2.3E-05
	> 10.0	7.2E-05	2.2E-06	2.2E-04

The Figure 4.2-1 presents the overall normalized frequencies of PWR plants in the United States, and roughly 10 foreign plants for the independent database, the entire OPDE-light, and the NRC mean data given in reports. As seen, the NRC mean values of frequency decrease as the pipe size increases. Although in the two other independent sets of data obtained, the frequencies remain relatively the same throughout the pipe size groups. Pipe sizes which were less than roughly two inches had a lower frequency for the two independent data sets compared to the NRC data, and the pipe sizes above the two to four inches group size show a higher frequency compared to what the NRC's expert elicitation has predicted. This figure shows that the two independent data sources follow similar trends compared to what the NRC's prediction. The PWR frequency shows a vast difference at the higher pipe size groups which in turn contradicts the thinking that larger the pipe size have a smaller break frequency.

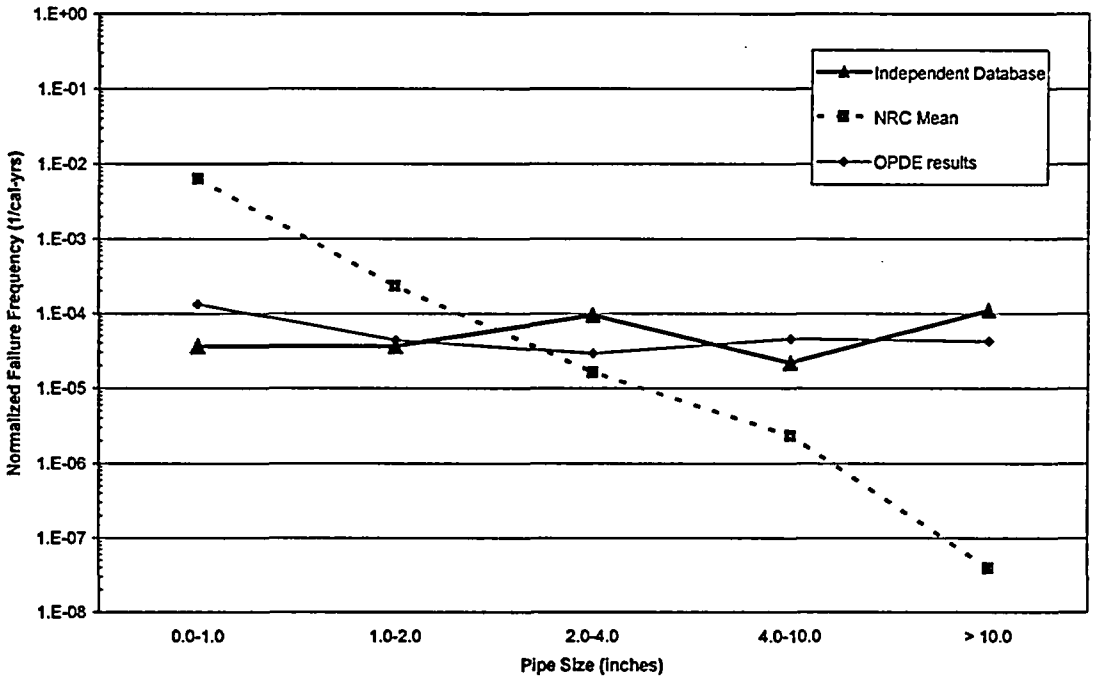


Figure 4.2-1. Normalized pipe failure frequency as a function of Pipe Group Size for PWRs.

Figure 4.2-2 presents the overall BWR data for the independent data, the OPDE-light, and the NRC data. A similar trend for each data set can be seen in BWR's as in PWR's, except that the frequency range is much smaller for BWR's than PWR's. The independent data provided no pipe failures in the pipe size group of one to two inches, and thus on a log-scale, no data point appears on the figure. Once again the independent data and the OPDE-light data coincide throughout the pipe size groups, and contradict the NRC prediction of pipe failure frequencies; except for the range of two to four inches again they are similar. Pipes which are larger than ten inches prove to have a higher frequency in the two independent data sets when compared to that of the NRC data set provided by expert elicitation.

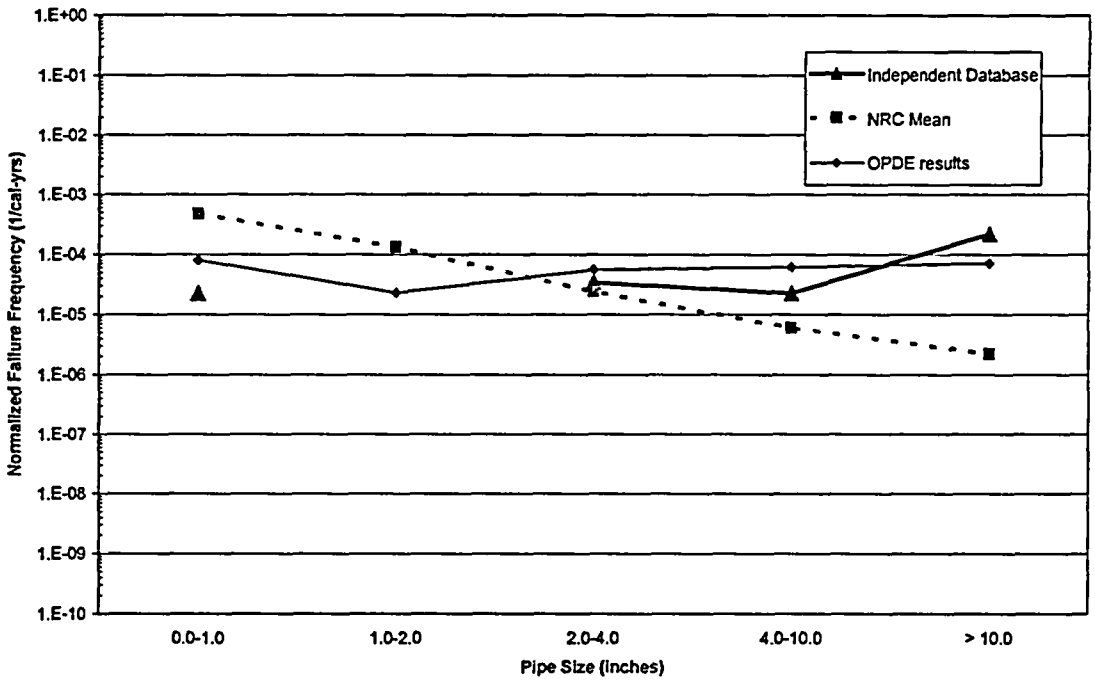


Figure 4.2-2. Normalized pipe failure frequency as a function of Pipe Group Size for BWRs.

Overall, the two independent data sets show contradicting trends when compared to the NRC normalized frequencies. Instead of the double-ended guillotine break being analyzed for every plant for the largest pipe in that plant, the NRC is trying to make the maximum break size which needs to be analyzed ten inches. The reasoning for this is due to low frequency of breaks in pipes of larger diameter than ten inches. This data above shows that the frequency from raw data does not agree with the current NRC predictions by expert elicitation. There is a high frequency of occurrence in pipe sizes greater than ten inches according to the independent data found.

4.3 Pipe Failures as a function of Failure Mechanism

This section of the report summarizes the frequency of failure mechanisms for carbon and stainless steel pipes. The information presented in figures 4.3-1 through 4.3-3 represents the normalized failure frequencies for each failure mechanism. This data is also presented in tabular form in table 4.3-1. The data was collapsed by pipe sizes and broken apart by steel type and plant type. The data was normalized for each type of steel based on the number of reactor years and the total amount of failures (carbon +stainless) for each plant.

Table 4.3-1. Failure Frequencies of Pipes for each Failure Mechanism.

Plant Type	Failure Mechanism	Carbon Steel Failure Frequency	Stainless Steel Failure Frequency	Total Failure Frequency
PWR	Corrosion	2.04E-05	5.38E-06	2.57E-05
PWR	FAC	2.29E-05	2.32E-05	4.61E-05
PWR	MIC	8.26E-06	1.92E-07	8.45E-06
PWR	Erosion	1.84E-05	2.30E-06	2.07E-05
PWR	Fatigue	1.77E-05	9.62E-05	1.14E-04
PWR	Human Factors	6.91E-06	2.42E-05	3.11E-05
PWR	Mechanical Failures	4.23E-06	7.11E-06	1.13E-05
PWR	SCC	9.60E-07	3.25E-05	3.34E-05
PWR	Water Hammer	0.00E+00	3.84E-07	3.84E-07
PWR	Misc	1.15E-06	2.69E-06	3.84E-06
BWR	Corrosion	6.31E-06	6.97E-06	1.33E-05
BWR	FAC	1.26E-05	1.37E-05	2.63E-05
BWR	MIC	1.31E-06	2.18E-07	1.52E-06
BWR	Erosion	8.71E-06	1.96E-06	1.07E-05
BWR	Fatigue	1.55E-05	4.90E-05	6.44E-05
BWR	Human Factors	5.22E-06	1.85E-05	2.37E-05
BWR	Mechanical Failures	3.92E-06	5.44E-06	9.36E-06
BWR	SCC	4.14E-06	1.36E-04	1.40E-04
BWR	Water Hammer	4.35E-07	2.18E-07	6.53E-07
BWR	Misc	8.71E-07	4.14E-06	5.01E-06

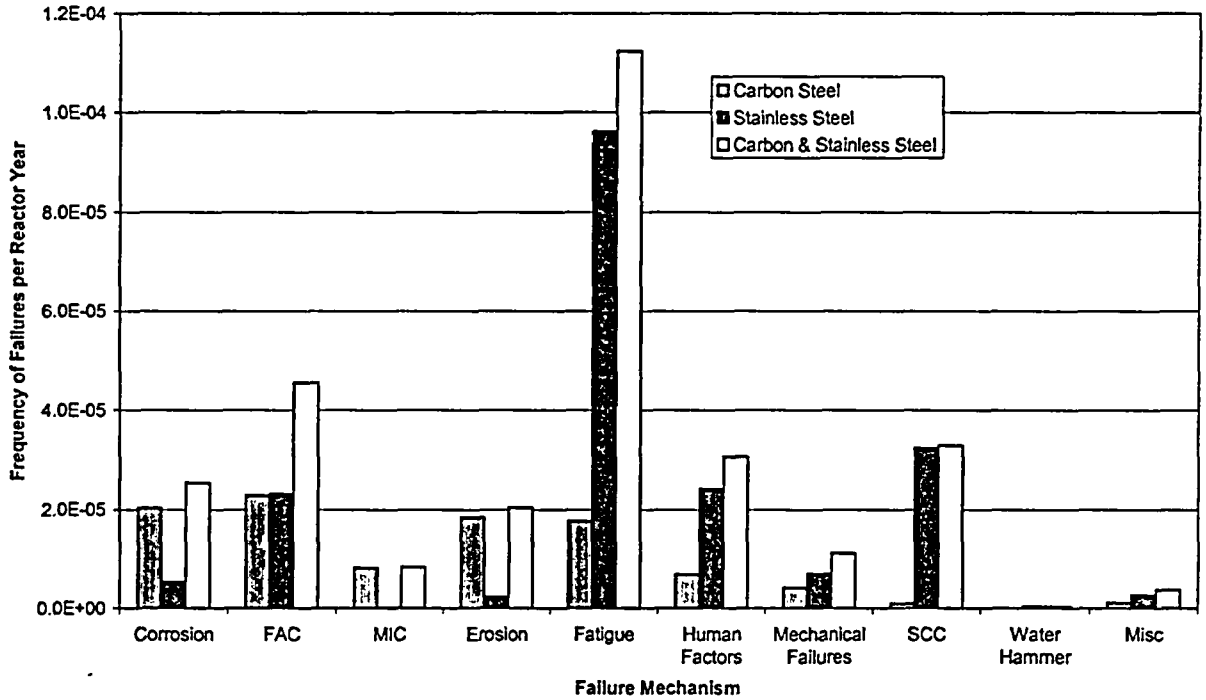


Figure 4.3-1. PWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

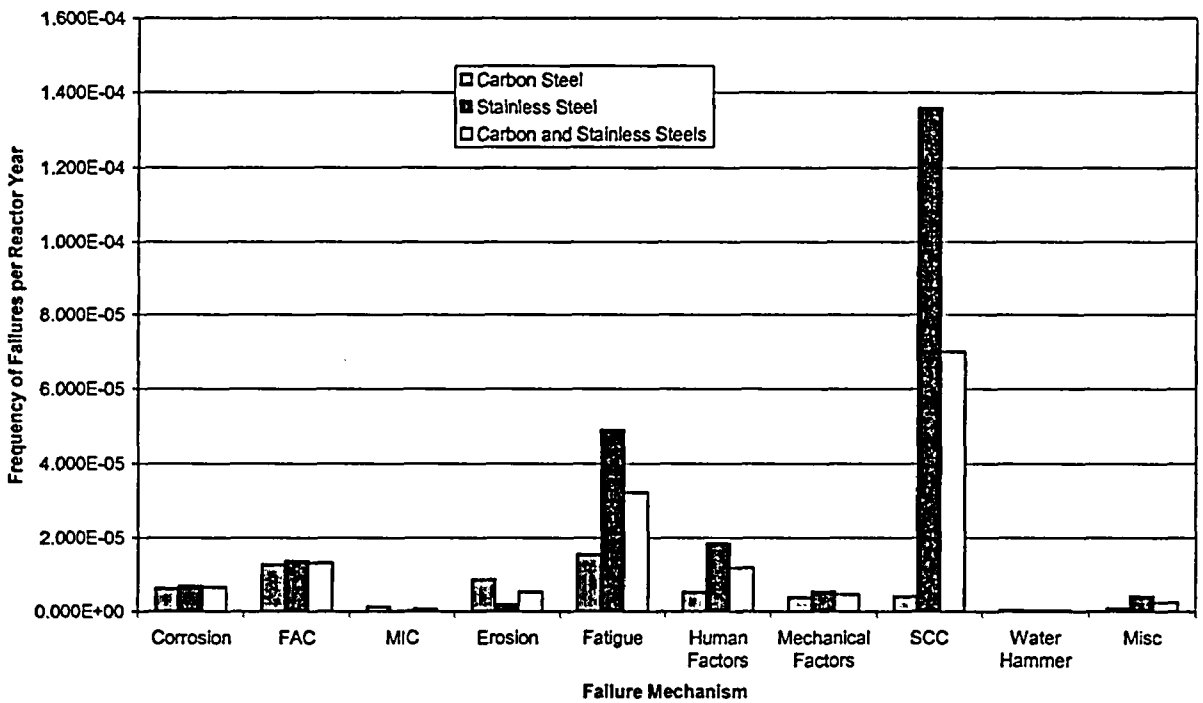


Figure 4.3-2. BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

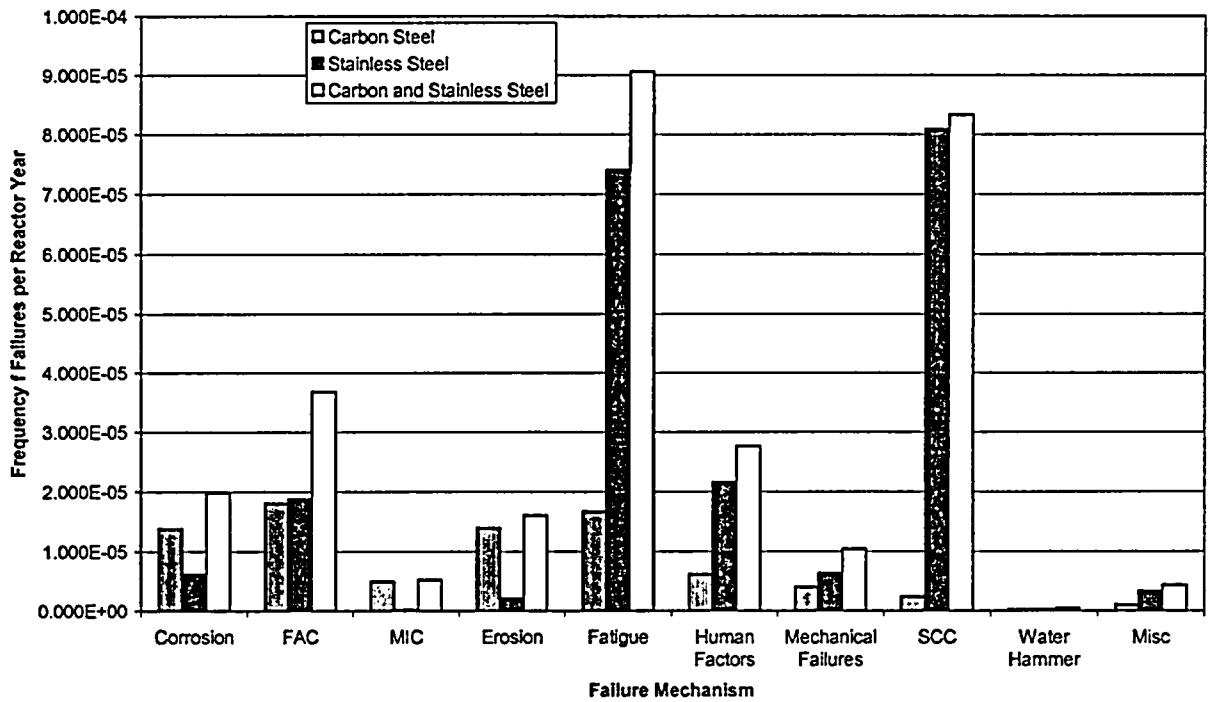


Figure 4.3-3. PWR and BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

From these plots it was determined that PWR plants are dominated by fatigue failures and BWR plants are dominated by stress corrosion cracking failures. However, in general the most frequent failure mechanisms for both plants are corrosion, fatigue, mechanical factors, and stress corrosion cracking. These four failure mechanisms were analyzed as a function of pipe size in figures 4.3-4 through 4.4-7.

For these plots corrosion includes general corrosion, flow accelerated corrosion, and microbiological corrosion. Stress corrosion cracking was not included with corrosion because the pipe failure method for stress corrosion cracking is different than the other corrosion types. Though mechanical failure frequency was not the highest, mechanical failures were chosen because they appear to be independent of pipe type and plant type. Human factors were ignored because they are a factor of quality assurance as opposed to the other failure mechanisms which are primarily a factor of operation. In regards to human factors it is not known if they have decreased with reactor operating experience because the dates of failures was not included with the OPDE data.

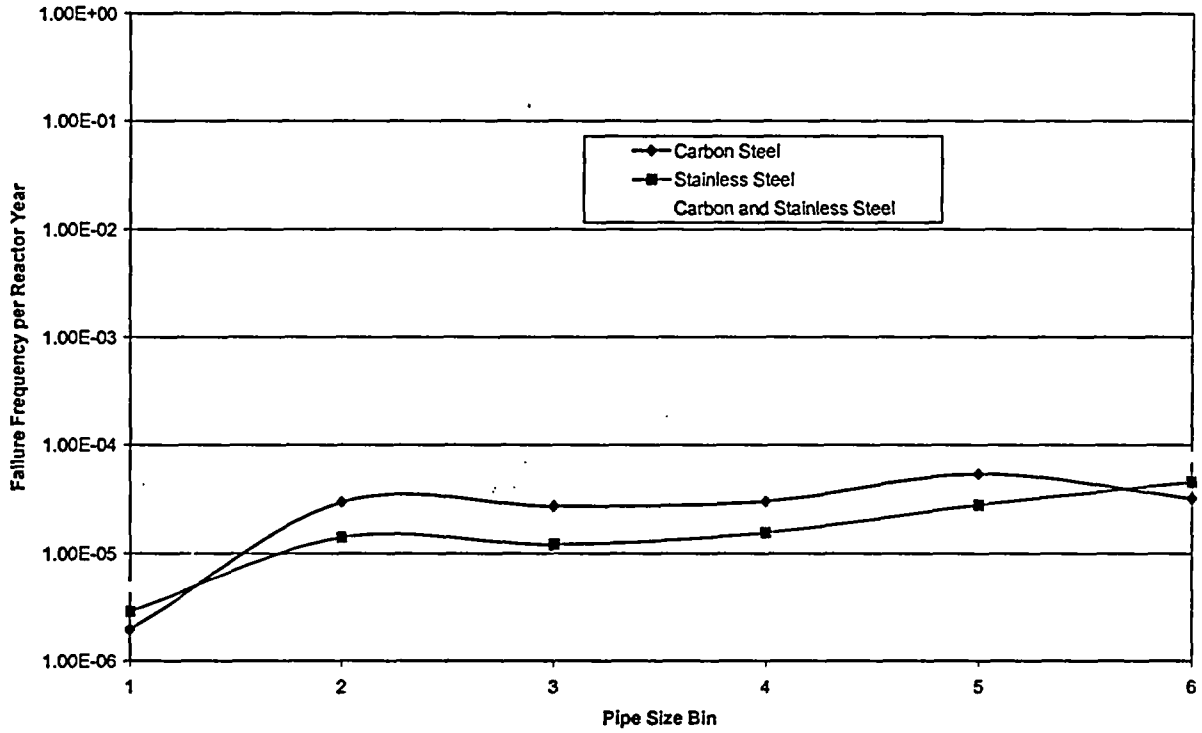


Figure 4.3-4. Pipe Failure by Corrosion as a Function of Pipe Size (PWR & BWR)

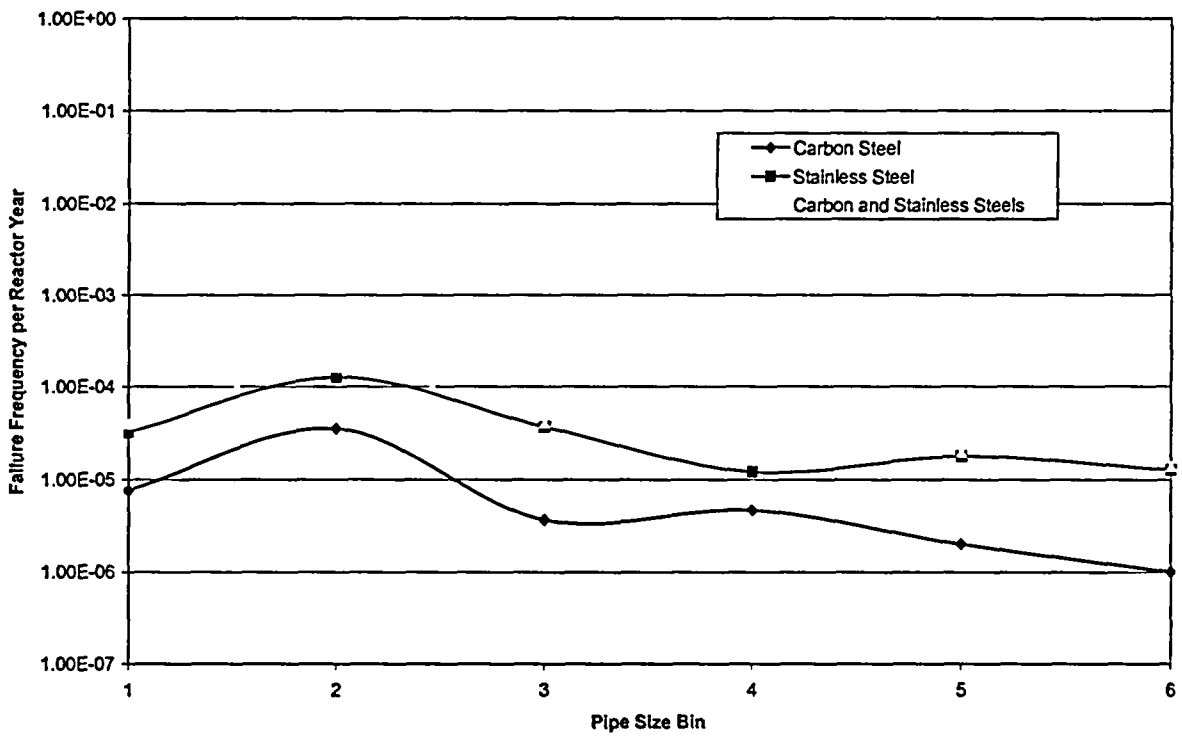


Figure 4.3-5. Pipe Failure by Fatigue as a Function of Pipe Size (PWR & BWR)

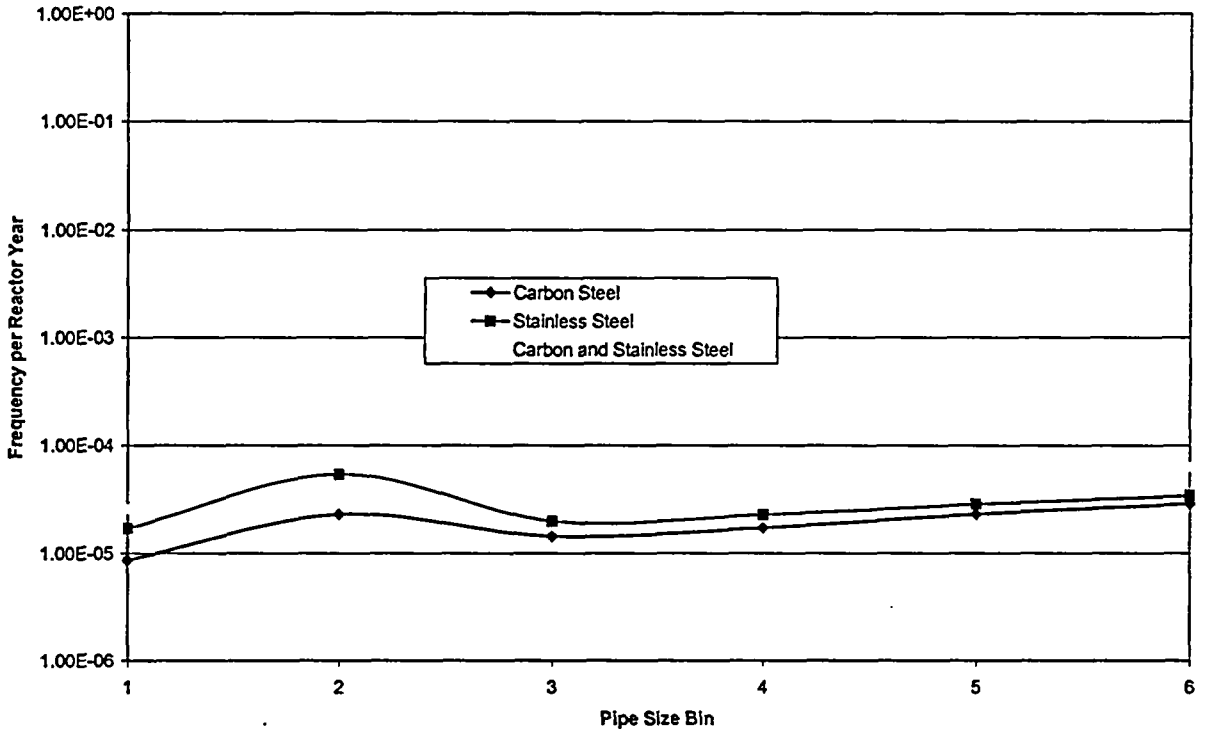


Figure 4.3-6. Pipe Failure by Mechanical Failures as a Function of Pipe Size (PWR & BWR)

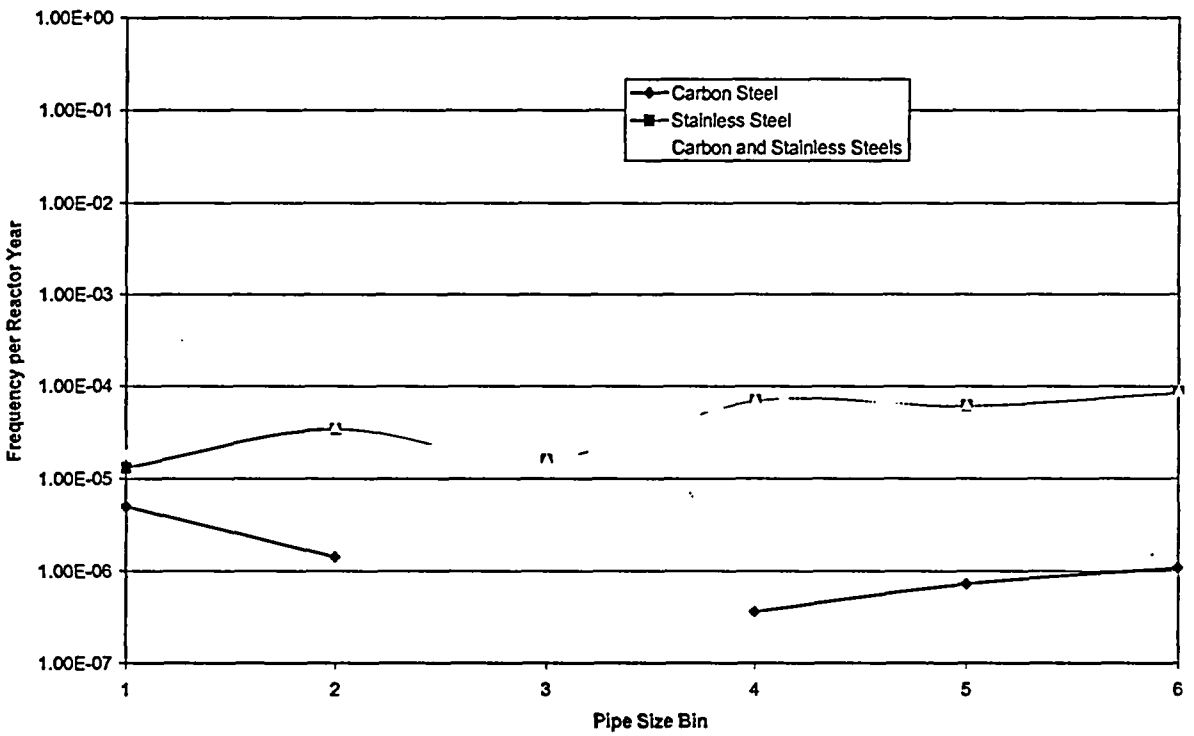


Figure 4.3-7. Pipe Failure by Stress Corrosion Cracking as a Function of Pipe Size (PWR & BWR)

The frequencies of pipe failures by corrosion shown in Figure 4.3-4 are nearly independent of pipe size. With the exception of the smallest of pipe sizes (< 1.0 inches) the frequency of failure for each type of steel is relatively constant. Stainless steel has a lower frequency of failure due to corrosion than carbon steel, which is expected because stainless steel is meant to be corrosion resistant.

Figure 4.3-5 shows that carbon steel is less likely to fail by fatigue than stainless steel for all pipe sizes. The figure also shows that as the pipes increase in size they fail less frequently by fatigue. This is more than likely due to greater movement of the pipes as they decrease in size. The amount of force required to fatigue a larger pipe is greater than that of a smaller pipe.

Figure 4.3-6 supports the information from figure 4.3-3 that shows mechanical failures being relatively equal for all pipe sizes and types. The frequencies of the different pipes in each bin are roughly the same and they stay relatively constant across the spectrum of pipe sizes. The different failures that were grouped into mechanical failures as listed in the section 3.0 are excessive vibration, overpressurization, overstressed, and severe overloading. Though the instances of these failures are low they seem to affect all pipes relatively equally.

Stress corrosion cracking appears to be much more prevalent in stainless steel pipes as opposed to carbon steel pipes as shown in Figure 4.3-7. The discontinuity in the carbon steel data is due to plotting a frequency of zero on a log scale. For both stainless and carbon pipes the frequency of failure increases for the largest pipe size (> 10 inches).

5.0 Conclusions from Data

5.1 Pipe Failures as a function of Pipe Size from OPDE Data

1. The main problem with the OPDE database is it does not have any resolution beyond pipe sizes greater than 10 inches.

2. For both PWRs and BWRs the results of the OPDE database underestimate the failure frequency for the smaller pipe size groups, and overestimate the failure frequency for the larger pipe size groups, compared to the NRC predictions. In both cases the OPDE data does not predict as drastic of a difference in the frequencies for small pipes and large pipes as the NRC does.

3. The OPDE database excludes instances of steam generator tube rupture (SGTR) from consideration. By doing this the total number of failures in the smaller pipe size groups are reduced, and the calculated frequencies are lower at smaller pipe sizes than if SGTR had been considered. This may be one source of difference in the OPDE results and NRC prediction.

4. The OPDE database reports failures of stainless steel pipes are more frequent than carbon steel pipes for smaller pipe sizes in PWRs and stainless steel pipe failures are much more frequent than carbon steel pipe failures at all pipe sizes in BWRs.

5.2 Pipe Failures as a function of Pipe Size from Independent Data

1. The data set collected independently by our group compares very well with the trends observed in the OPDE data, but does not match the results predicted by the NRC.

2. The main problem with this data set is the limited amount of data points.

3. Failure mechanism plots were not made due to the lack of variety in failure mechanisms. The majority of the failure mechanisms were erosion/corrosion and stress corrosion cracking.

5.3 Pipe Failures as a function of Failure Mechanism

1. The failure mechanism that appears to dominate PWR plants is fatigue failure, and BWR plants are dominated by stress corrosion cracking failures. In general both plants are limited by corrosion, fatigue, and stress corrosion cracking.

2. For some failure mechanisms the frequency of failure increases as pipe size increases. Stress corrosion cracking is one failure mechanism where this trend is seen. It should be noted that this does not necessarily contradict the NRC's assertion that larger pipes break less frequently. This conclusion only states that for some failure mechanisms large pipes fail more frequently.

3. Although the OPDE data does not show water hammer to be a significant failure mechanism, it should be noted that the OPDE database listed 450 separate water hammer events where structural pipe integrity was challenged but not failed. Had this data points been included as probable failures, water hammer would have become one of the leading failure mechanisms.

6.0 References

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PLANT TYPE	PIPE TYPE	SYSTEM GROUP	APPARENT CAUSE	PIPE SIZE GROUP	TOTAL NO. OF RECORDS	Crack-Full	Crack-Part	Deformation	Large Leak	Leak	P/H-Leak	Rupture	Severance	Small Leak	Wall thinning
PWR	CS	AUXC	Cavitation	5	1						1				
PWR	CS	AUXC	Cavitation-erosion	5	1									1	
PWR	CS	AUXC	Cavitation-erosion	6	1						1				
PWR	CS	AUXC	Corrosion	2	15				1		2		1	10	1
PWR	CS	AUXC	Corrosion	3	17		1				3			10	3
PWR	CS	AUXC	Corrosion	4	15	1					3			11	
PWR	CS	AUXC	Corrosion	5	20	1				1	9			8	1
PWR	CS	AUXC	Corrosion	6	18	1				1	5			10	1
PWR	CS	AUXC	Erosion-cavitation	6	2									1	1
PWR	CS	AUXC	Erosion-corrosion	1	4						1			3	
PWR	CS	AUXC	Erosion-corrosion	2	17					1	2			14	
PWR	CS	AUXC	Erosion-corrosion	3	15						5			10	
PWR	CS	AUXC	Erosion-corrosion	4	13	1	1			1	4			5	1
PWR	CS	AUXC	Erosion-corrosion	5	20	1				3	5	1		10	
PWR	CS	AUXC	Erosion-corrosion	6	20				3	1	9			7	
PWR	CS	AUXC	External Impact	5	1									1	
PWR	CS	AUXC	FAC - Flow Accelerated Corrosion	6	1									1	
PWR	CS	AUXC	Galvanic Corrosion	2	1									1	
PWR	CS	AUXC	HF.CONSTANST	1	1									1	
PWR	CS	AUXC	HF.CONSTANST	2	4									4	
PWR	CS	AUXC	HF.CONSTANST	4	2						1			1	
PWR	CS	AUXC	HF.CONSTANST	6	2		1		1						
PWR	CS	AUXC	HF.Human Error	2	1									1	
PWR	CS	AUXC	HF.Human Error	5	1						1				
PWR	CS	AUXC	HF.Welding Error	3	5									5	
PWR	CS	AUXC	HF.Welding Error	6	1						1				
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	2	2						1			1	
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	3	4						3				1
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	4	11						7			1	3
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	5	12	1	1			1	3			5	1
PWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	6	3					1	1			1	
PWR	CS	AUXC	Severe overloading	1	1									1	
PWR	CS	AUXC	Severe overloading	4	2								2		
PWR	CS	AUXC	Thermal fatigue	4	1									1	
PWR	CS	AUXC	Unreported	3	1									1	
PWR	CS	AUXC	Vibration-Fatigue	2	17									17	
PWR	CS	AUXC	Vibration-fatigue	4	7	5								2	
PWR	SS	CS	HF.CONSTANST	2	1									1	
PWR	SS	CS	HF.Welding Error	3	1						1				
PWR	SS	CS	IGSCC - Intergranular SCC	5	3						3				
PWR	SS	CS	TGSCC - Transgranular SCC	5	3									3	
PWR	SS	CS	Unreported	5	1									1	
PWR	SS	CS	Vibration-fatigue	2	6		1							5	
PWR	SS	CS	Vibration-fatigue	6	1		1								
PWR	CS	EHC	Severe Overloading	2	2								2		
PWR	CS	EHC	Vibration-Fatigue	1	3					1			1	1	
PWR	CS	EHC	Vibration-Fatigue	2	9							1	1	7	
PWR	CS	EHC	Vibration-fatigue	4	1									1	
PWR	SS	EPS	Vibration-fatigue	1	11		2					2		7	
PWR	SS	EPS	Vibration-fatigue	2	3							1		2	
PWR	CS	FPS	Corrosion	2	4						1			3	
PWR	CS	FPS	Corrosion	3	3						1			2	
PWR	CS	FPS	Corrosion	4	3									3	
PWR	CS	FPS	Corrosion	5	4				1		1	1		1	
PWR	CS	FPS	Corrosion	6	2						1	1			
PWR	CS	FPS	HF.CONSTANST	5	2								1	1	
PWR	CS	FPS	HF.Human error	3	1								1		
PWR	CS	FPS	HF REPAIR/MAINT	6	1							1			
PWR	CS	FPS	HF.Welding Error	6	1						1				
PWR	CS	FPS	MIC - Microbiologically Induced Corrosion	5	7				1	1	2			1	2
PWR	CS	FPS	MIC - Microbiologically Induced Corrosion	6	4										4
PWR	CS	FPS	Severe overloading	3	1							1			
PWR	CS	FPS	Severe overloading	4	1							1			
PWR	CS	FPS	Severe overloading	5	2							2			
PWR	CS	FPS	Severe overloading	6	1							1			

PWR	SS	FWC	Corrosion	3	3							1		2	
PWR	SS	FWC	Corrosion	4	1					1					
PWR	SS	FWC	Corrosion	6	3		1				1			1	
PWR	SS	FWC	Corrosion-fatigue	4	1		1								
PWR	SS	FWC	Corrosion-fatigue	6	3		2							1	
PWR	SS	FWC	Erosion	2	2									2	
PWR	SS	FWC	Erosion	5	1									1	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	1	2						1			1	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	2	4					1	1	1		1	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	3	7				1		3	1		2	
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	4	11		1			1	2	3		2	2
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	5	27				1	2	1	11		4	8
PWR	SS	FWC	FAC - Flow Accelerated Corrosion	6	67				1	1		7		8	50
PWR	SS	FWC	Fatigue	2	3								1	2	
PWR	SS	FWC	Fatigue	3	1									1	
PWR	SS	FWC	Fatigue	4	1									1	
PWR	SS	FWC	Galvanic Corrosion	3	2					2					
PWR	SS	FWC	HF:CONST/INST	2	2					1				1	
PWR	SS	FWC	HF:CONST/INST	4	2									2	
PWR	SS	FWC	HF.CONST/INST	6	1										1
PWR	SS	FWC	HF:Design error	1	1									1	
PWR	SS	FWC	HF Fabrication Error	4	1										1
PWR	SS	FWC	HF.REPAIR/MAINT	4	1						1				
PWR	SS	FWC	HF REPAIR/MAINT	6	1									1	
PWR	SS	FWC	HF Welding Error	1	1									1	
PWR	SS	FWC	HF.Welding Error	2	2						2				
PWR	SS	FWC	HF:Welding error	3	2						1			1	
PWR	SS	FWC	HF:Welding error	5	1									1	
PWR	SS	FWC	HF.Welding Error	6	3		1				1			1	
PWR	SS	FWC	Severe overloading	2	5		1							4	
PWR	SS	FWC	Severe overloading	3	1							1			
PWR	SS	FWC	Severe overloading	4	2			1						1	
PWR	SS	FWC	Severe overloading	5	2		1					1			
PWR	SS	FWC	Severe overloading	6	6		1					4		1	
PWR	SS	FWC	Thermal Fatigue	2	2							1		1	
PWR	SS	FWC	Thermal Fatigue	3	2							1		1	
PWR	SS	FWC	Thermal Fatigue	6	13		9			1				3	
PWR	SS	FWC	Thermal Fatigue - Cycling	6	1									1	
PWR	SS	FWC	Thermal Fatigue - Stratification	6	5		5								
PWR	SS	FWC	Vibration-fatigue	1	5							3		2	
PWR	SS	FWC	Vibration-Fatigue	2	23					1		2	2	18	
PWR	SS	FWC	Vibration-fatigue	3	5	1						3		1	
PWR	SS	FWC	Vibration-Fatigue	4	2					1				1	
PWR	SS	FWC	Vibration-Fatigue	5	4	1	1							2	
PWR	SS	FWC	Vibration-fatigue	6	5		4							1	
PWR	SS	FWC	Water Hammer	5	1							1			
PWR	SS	FWC	Water Hammer	6	1					1					
PWR	CS	IA-SA	Fatigue	2	1								1		
PWR	CS	IA-SA	HF.Human error	1	2							1	1		
PWR	CS	IA-SA	HF Human error	2	2								2		
PWR	CS	IA-SA	Severe overloading	2	1									1	
PWR	CS	IA-SA	Severe overloading	3	1								1		
PWR	CS	IA-SA	Vibration-fatigue	1	4							1	2	1	
PWR	CS	IA-SA	Vibration-fatigue	2	11							6	4	2	
PWR	CS	PCS	Corrosion	2	1									1	
PWR	CS	PCS	Erosion	5	2									2	
PWR	CS	PCS	Erosion	6	1		1								
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	2	4							1		3	
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	3	7							2		5	
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	4	9					1		4		3	1
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	5	28					3		6		20	
PWR	CS	PCS	FAC - Flow Accelerated Corrosion	6	12					2		3		7	
PWR	CS	PCS	Fatigue	5	1									1	
PWR	CS	PCS	Fretting	3	1									1	
PWR	CS	PCS	HF:Welding error	5	1					1					
PWR	CS	PCS	PWSCC	4	1									1	
PWR	CS	PCS	Severe overloading	2	1							1			

PWR	CS	PCS	Severe overloading	6	2							2			
PWR	CS	PCS	Thermal fatigue	3	1									1	
PWR	CS	PCS	Vibration-Fatigue	1	2								1	1	
PWR	CS	PCS	Vibration-fatigue	2	10								1	9	
PWR	CS	PCS	Vibration-fatigue	3	1									1	
PWR	CS	PCS	Vibration-fatigue	5	4									4	
PWR	SS	RAS	B/A-SCC	2	2						1			1	
PWR	SS	RAS	B/A-SCC	3	5		1							4	
PWR	SS	RAS	Brittle-Fracture	1	1				1						
PWR	SS	RAS	Cavitation-erosion	5	1									1	
PWR	SS	RAS	Corrosion	1	1									1	
PWR	SS	RAS	Corrosion	2	2						1			1	
PWR	SS	RAS	Corrosion	4	5					1	3			1	
PWR	SS	RAS	Corrosion	5	2						1			1	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	1	6						4			2	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	2	1									1	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	3	1									1	
PWR	SS	RAS	ECSCC - External Chloride Induced SCC	4	2									2	
PWR	SS	RAS	Erosion-cavitation	4	2									2	
PWR	SS	RAS	Excessive Vibration	3	1									1	
PWR	SS	RAS	FAC - Flow Accelerated Corrosion	2	1									1	
PWR	SS	RAS	FAC - Flow Accelerated Corrosion	3	1					-				1	
PWR	SS	RAS	Fretting	1	1									1	
PWR	SS	RAS	Fretting	3	1									1	
PWR	SS	RAS	HF.CONST/INST	1	3				1		1			1	
PWR	SS	RAS	HF.CONST/INST	2	6				1					5	
PWR	SS	RAS	HF.CONST/INST	3	5						1			4	
PWR	SS	RAS	HF.CONST/INST	4	3									3	
PWR	SS	RAS	HF.Fabrication Error	2	1									1	
PWR	SS	RAS	HF.Human error	2	1									1	
PWR	SS	RAS	HF.Human error	3	1						1				
PWR	SS	RAS	HF.REPAIR/MAINT	1	1									1	
PWR	SS	RAS	HF.Welding Error	1	4						1			3	
PWR	SS	RAS	HF.Welding Error	2	7					1	2			4	
PWR	SS	RAS	HF.Welding Error	3	4	2					1			1	
PWR	SS	RAS	HF.Welding error	4	2						1			1	
PWR	SS	RAS	IGSCC - Intergranular SCC	4	1					1					
PWR	SS	RAS	MIC - Microbiologically Induced Corrosion	2	1									1	
PWR	SS	RAS	Overpressurization	5	1							1			
PWR	SS	RAS	PWSCC	2	2					1				1	
PWR	SS	RAS	PWSCC	3	7						1			6	
PWR	SS	RAS	PWSCC	4	5					1				4	
PWR	SS	RAS	PWSCC	5	3						1			2	
PWR	SS	RAS	Severe overloading	2	1									1	
PWR	SS	RAS	Severe overloading	3	3		3								
PWR	SS	RAS	TGSCC - Transgranular SCC	1	5									5	
PWR	SS	RAS	TGSCC - Transgranular SCC	2	1	1									
PWR	SS	RAS	TGSCC - Transgranular SCC	3	3						1			2	
PWR	SS	RAS	TGSCC - Transgranular SCC	4	1									1	
PWR	SS	RAS	Thermal Fatigue	3	5				1	1				3	
PWR	SS	RAS	Thermal Fatigue	4	2				1					1	
PWR	SS	RAS	Thermal Fatigue - Cycling	3	1		1								
PWR	SS	RAS	Unreported	4	1									1	
PWR	SS	RAS	Unreported	5	1						1				
PWR	SS	RAS	Vibration-fatigue	1	10		1					1		8	
PWR	SS	RAS	Vibration-fatigue	2	105		2		7	3	12	2	3	76	
PWR	SS	RAS	Vibration-fatigue	3	44	1	2		2	7	7			25	
PWR	SS	RAS	Vibration-fatigue	4	10				1		2			7	
PWR	SS	RAS	Vibration-fatigue	5	4		1							3	
PWR	SS	RAS	Vibration-fatigue	6	1									1	
PWR	SS	RCPB	B/A-SCC	1	1									1	
PWR	SS	RCPB	B/A-SCC	2	1									1	
PWR	SS	RCPB	Corrosion	2	2		1			1					
PWR	SS	RCPB	Corrosion-fatigue	2	1				1						
PWR	SS	RCPB	Corrosion-fatigue	4	1							1			
PWR	SS	RCPB	ECSCC - External Chloride Induced SCC	1	1	1									
PWR	SS	RCPB	Fretting	1	1		1								

PWR	SS	RCPB	HF:CONST/INST	1	5				2					3	
PWR	SS	RCPB	HF:CONST/INST	2	12	4			1					7	
PWR	SS	RCPB	HF:CONST/INST	3	2									2	
PWR	SS	RCPB	HF:CONST/INST	4	1									1	
PWR	SS	RCPB	HF:CONST/INST	5	1									1	
PWR	SS	RCPB	HF:Design Error	1	1									1	
PWR	SS	RCPB	HF:Design error	2	1							1			
PWR	SS	RCPB	HF:REPAIR/MAINT	1	1							1			
PWR	SS	RCPB	HF:Welding Error	1	3						2			1	
PWR	SS	RCPB	HF:Welding Error	2	11					1			1	9	
PWR	SS	RCPB	HF:Welding Error	3	2									2	
PWR	SS	RCPB	HF:Welding error	6	1		1								
PWR	SS	RCPB	Hydrogen embrittlement	1	1				1						
PWR	SS	RCPB	IGSCC - Intergranular SCC	5	1		1								
PWR	SS	RCPB	PWSCC	1	2						1			1	
PWR	SS	RCPB	PWSCC	2	44	26	2			1	4		1	10	
PWR	SS	RCPB	PWSCC	3	6		1							5	
PWR	SS	RCPB	PWSCC	4	3		1							2	
PWR	SS	RCPB	PWSCC	5	2		1							1	
PWR	SS	RCPB	PWSCC	6	7		2				2			3	
PWR	SS	RCPB	Severe overloading	2	3									3	
PWR	SS	RCPB	Severe overloading	3	1							1			
PWR	SS	RCPB	TGSCC - Transgranular SCC	1	7	1	1				1			4	
PWR	SS	RCPB	TGSCC - Transgranular SCC	2	5						1			4	
PWR	SS	RCPB	TGSCC - Transgranular SCC	5	1					1					
PWR	SS	RCPB	Thermal fatigue	1	4									4	
PWR	SS	RCPB	Thermal fatigue	2	1									1	
PWR	SS	RCPB	Thermal fatigue	3	4		1			1	1			1	
PWR	SS	RCPB	Thermal fatigue	6	1		1								
PWR	SS	RCPB	Thermal Fatigue - Cycling	3	1									1	
PWR	SS	RCPB	Thermal Fatigue - Cycling	6	1		1								
PWR	SS	RCPB	Vibration-Fatigue	1	31				1	5			1	24	
PWR	SS	RCPB	Vibration-Fatigue	2	82	2			3	10	1			66	
PWR	SS	RCPB	Vibration-fatigue	3	11					4				7	
PWR	SS	RCPB	Vibration-fatigue	4	2					1				1	
PWR	SS	RCPB	Vibration-Fatigue	5	2									2	
PWR	SS	RCS-INSTR	Fatigue	1	1									1	
PWR	SS	RCS-INSTR	HF:CONST/INST	1	1					1					
PWR	SS	RCS-INSTR	HF:CONST/INST	2	1				1						
PWR	SS	RCS-INSTR	Vibration-Fatigue	1	1									1	
PWR	SS	RCS-INSTR	Vibration-fatigue	2	1									1	
PWR	CS	SG	Corrosion	1	1									1	
PWR	CS	SG	Deformation/Thermal Fatigue	2	1									1	
PWR	CS	SG	FAC - Flow Accelerated Corrosion	3	3							1		2	
PWR	CS	SG	HF:Welding Error	6	1						1				
PWR	CS	SG	PWSCC	1	3	3									
PWR	CS	SG	TGSCC - Transgranular SCC	2	1									1	
PWR	CS	SG	Vibration-Fatigue	2	2									2	
PWR	CS	SG	Vibration-fatigue	4	1									1	
PWR	SS	SIR	B/A-SCC	3	1									1	
PWR	SS	SIR	B/A-SCC	5	3		1							2	
PWR	SS	SIR	Cavitation-erosion	3	1							1			
PWR	SS	SIR	Cavitation-erosion	5	2									2	
PWR	SS	SIR	Corrosion	2	1									1	
PWR	SS	SIR	ECSCC - External Chloride Induced SCC	5	3		2				1				
PWR	SS	SIR	ECSCC - External Chloride Induced SCC	6	1						1				
PWR	SS	SIR	Erosion-cavitation	2	3						1			2	
PWR	SS	SIR	FAC - Flow Accelerated Corrosion	2	1						1				
PWR	SS	SIR	Freezing	1	1	1									
PWR	SS	SIR	Fretting	5	1										1
PWR	SS	SIR	HF:CONST/INST	1	1									1	
PWR	SS	SIR	HF:CONST/INST	2	4						1			3	
PWR	SS	SIR	HF:CONST/INST	5	2					1				1	
PWR	SS	SIR	HF:Human error	2	1									1	
PWR	SS	SIR	HF:REPAIR/MAINT	5	1									1	
PWR	SS	SIR	HF:Welding Error	1	3						2			1	
PWR	SS	SIR	HF:Welding error	2	7					1	1	1		4	

PWR	SS	SIR	HF.Welding Error	3	1									1	
PWR	SS	SIR	HF.Welding Error	4	2						1			1	
PWR	SS	SIR	HF.Welding Error	5	2	1	1								
PWR	SS	SIR	HF.Welding Error	6	1		1								
PWR	SS	SIR	Overstressed	1	3									3	
PWR	SS	SIR	PWSCC	2	1						1				
PWR	SS	SIR	PWSCC	3	5									5	
PWR	SS	SIR	PWSCC	4	2		2								
PWR	SS	SIR	PWSCC	5	17		2			2	3			10	
PWR	SS	SIR	Severe Overloading	1	1									1	
PWR	SS	SIR	Severe overloading	2	3							2		1	
PWR	SS	SIR	Severe overloading	5	2		1							1	
PWR	SS	SIR	Severe overloading	6	2		1	1							
PWR	SS	SIR	TGSCC - Transgranular SCC	1	1	1									
PWR	SS	SIR	TGSCC - Transgranular SCC	2	1									1	
PWR	SS	SIR	TGSCC - Transgranular SCC	4	1						1				
PWR	SS	SIR	TGSCC - Transgranular SCC	5	1		1								
PWR	SS	SIR	Thermal fatigue	3	1		1								
PWR	SS	SIR	Thermal fatigue	4	3		2		1						
PWR	SS	SIR	Thermal fatigue	5	8		2		2	4					
PWR	SS	SIR	Thermal Fatigue - Cycling	3	1		1								
PWR	SS	SIR	Thermal Fatigue - Cycling	4	1									1	
PWR	SS	SIR	Unreported	3	2									2	
PWR	SS	SIR	Unreported	5	1		1								
PWR	SS	SIR	Unreported	6	1						1				
PWR	SS	SIR	Vibration-fatigue	0	3					1		1		1	
PWR	SS	SIR	Vibration-fatigue	1	8							2		6	
PWR	SS	SIR	Vibration-fatigue	2	42		2		1	3	3	2		31	
PWR	SS	SIR	Vibration-fatigue	3	9		1						1	7	
PWR	SS	SIR	Vibration-fatigue	4	3									3	
PWR	SS	SIR	Vibration-fatigue	5	7	1	1			1				4	
PWR	CS	STEAM	Corrosion	3	1					1					
PWR	CS	STEAM	Corrosion-fatigue	6	1									1	
PWR	CS	STEAM	Erosion	4	1									1	
PWR	CS	STEAM	Erosion	5	1						1				
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	2	10							1		9	
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	3	9									9	
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	4	8					1	1	1		5	
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	5	14					1		3		9	1
PWR	CS	STEAM	FAC - Flow Accelerated Corrosion	6	14					1		1		10	2
PWR	CS	STEAM	Fretting	3	1						1				
PWR	CS	STEAM	HF.CONSTANST	2	3							1		2	
PWR	CS	STEAM	HF:Human Error	2	1							1			
PWR	CS	STEAM	HF:Human error	6	1									1	
PWR	CS	STEAM	HF.Welding Error		1						1				
PWR	CS	STEAM	HF.Welding Error	3	1						1				
PWR	CS	STEAM	HF.Welding error	6	2		2								
PWR	CS	STEAM	Overstressed	1	1					1					
PWR	CS	STEAM	Severe overloading	4	1									1	
PWR	CS	STEAM	Severe overloading	5	2							2			
PWR	CS	STEAM	Severe overloading	6	3		2					1			
PWR	CS	STEAM	Vibration-fatigue	1	2							1		1	
PWR	CS	STEAM	Vibration-fatigue	2	9		1					1	1	6	
PWR	CS	STEAM	Vibration-fatigue	3	2							1		1	
PWR	CS	STEAM	Vibration-fatigue	4	1									1	
PWR	CS	STEAM	Vibration-fatigue	6	1									1	

PLANT TYPE	PIPE TYPE	SYSTEM GROUP	APPARENT CAUSE	PIPE SIZE GROUP	TOTAL NO. OF RECORDS	Crack-Full	Crack-Part	Deformation	Large Leak	Leak	P/H-Leak	Rupture	Severance	Small Leak	Wall thinning
BWR	CS	AUXC	Corrosion	1	1				1						
BWR	CS	AUXC	Corrosion	2	4						1			3	
BWR	CS	AUXC	Corrosion	3	2					1				1	
BWR	CS	AUXC	Corrosion	4	3					1	1			1	
BWR	CS	AUXC	Corrosion	5	4					1	1			1	1
BWR	CS	AUXC	Corrosion	6	7				2		2			2	1
BWR	CS	AUXC	Erosion-cavitation	3	1						1				
BWR	CS	AUXC	Erosion-cavitation	6	1						1				
BWR	CS	AUXC	Erosion-corrosion	3	4						2			2	
BWR	CS	AUXC	Erosion-corrosion	4	7				1	2	1			3	
BWR	CS	AUXC	Erosion-corrosion	5	9						3			5	1
BWR	CS	AUXC	Erosion-corrosion	6	15					2	8			2	3
BWR	CS	AUXC	HF.CONST/INST	2	1									1	
BWR	CS	AUXC	HF:CONST/INST	5	1						1				
BWR	CS	AUXC	HF:Fabrication Error	5	1		1								
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	2	1					1					
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	4	2						2				
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	5	1						1				
BWR	CS	AUXC	MIC - Microbiologically Induced Corrosion	6	1									1	
BWR	CS	AUXC	Severe overloading	3	3									3	
BWR	CS	AUXC	Severe overloading	5	2							1		1	
BWR	CS	AUXC	Severe overloading	6	2								2		
BWR	CS	AUXC	Unreported	5	1									1	
BWR	CS	AUXC	Vibration-fatigue	2	11					1			2	8	
BWR	CS	AUXC	Vibration-Fatigue	3	1									1	
BWR	CS	AUXC	Vibration-Fatigue	4	1									1	
BWR	CS	AUXC	Vibration-Fatigue	5	1	1									
BWR	SS	Containment System	Brittle fracture	5	1		1								
BWR	SS	Containment System	Corrosion	2	1									1	
BWR	SS	Containment System	HF:CONST/INST	5	1		1								
BWR	SS	Containment System	IGSCC - Intergranular SCC	5	1		1								
BWR	SS	Containment System	Severe overloading	5	1								1		
BWR	SS	Containment System	Severe overloading	6	2	1								1	
BWR	SS	Containment System	Vibration-Fatigue	1	1								1		
BWR	SS	CS	Fatigue	1	1							1			
BWR	SS	CS	HF.Welding Error	0	1										1
BWR	SS	CS	IGSCC - Intergranular SCC	4	1						1				
BWR	SS	CS	TGSCC - Transgranular SCC	5	1									1	
BWR	CS	EHC		2	1					1					
BWR	CS	EHC	Fretting	1	2					1	1				
BWR	CS	EHC	HF:CONST/INST	1	1									1	
BWR	CS	EHC	HF:Human error	1	1									1	
BWR	CS	EHC	HF:Human error	4	1									1	
BWR	CS	EHC	HF Welding Error	2	1							1			
BWR	CS	EHC	Vibration-Fatigue	1	3							3			
BWR	CS	EHC	Vibration-fatigue	2	7				1	2		2		2	
BWR	CS	EHC	Vibration-fatigue	3	1									1	
BWR	SS	EPS	Fatigue	1	1								1		
BWR	SS	EPS	Vibration-fatigue	1	7							1	2	4	
BWR	SS	EPS	Vibration-fatigue	2	2									2	
BWR	CS	FPS	Corrosion	1	1						1				
BWR	CS	FPS	Corrosion	4	1						1				
BWR	CS	FPS	Corrosion	5	2					1	1				
BWR	CS	FPS	FAC - Flow Accelerated Corrosion	4	1						1				
BWR	CS	FPS	Fretting	5	1									1	
BWR	CS	FPS	HF.CONST/INST	5	1								1		
BWR	CS	FPS	HF:Human error	3	1							1			
BWR	CS	FPS	HF Human Error	6	1				1						
BWR	CS	FPS	HF INST/CONST	5	1									1	
BWR	CS	FPS	HF.Welding Error	4	1						1				
BWR	CS	FPS	MIC - Microbiologically Induced Corrosion	3	1						1				
BWR	CS	FPS	Severe overloading	4	1							1			
BWR	CS	FPS	Severe Overloading	5	2									2	
BWR	CS	FPS	Vibration-fatigue	1	1									1	
BWR	CS	FPS	Vibration-fatigue	3	1								1		

BWR	SS	FWC	Corrosion	2	2									2	
BWR	SS	FWC	Corrosion	3	1				1						
BWR	SS	FWC	Corrosion	4	2									2	
BWR	SS	FWC	Corrosion	5	2									2	
BWR	SS	FWC	Corrosion	6	1									1	
BWR	SS	FWC	Corrosion-fatigue	2	1		1								
BWR	SS	FWC	Corrosion-fatigue	3	1									1	
BWR	SS	FWC	ECSCC - External Chloride Induced SCC	1	1						1				
BWR	SS	FWC	Erosion	2	2									2	
BWR	SS	FWC	Erosion	3	1						1				
BWR	SS	FWC	Erosion	4	1									1	
BWR	SS	FWC	Erosion	5	1									1	
BWR	SS	FWC	Erosion-cavitation	4	2		1				1				
BWR	SS	FWC	Erosion-cavitation	5	2						2				
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	1	1									1	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	2	4					1				3	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	3	2				1					1	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	4	3						1			2	
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	5	22		1			1	1	1		10	8
BWR	SS	FWC	FAC - Flow Accelerated Corrosion	6	20							2		1	17
BWR	SS	FWC	Fatigue	6	1									1	
BWR	SS	FWC	HF:CONST/INST	4	1									1	
BWR	SS	FWC	HF:CONST/INST	5	1									1	
BWR	SS	FWC	HF:CONST/INST	6	1		1								
BWR	SS	FWC	HF:Human error	1	1								1		
BWR	SS	FWC	HF Welding Error	2	2									2	
BWR	SS	FWC	HF:Welding error	5	1									1	
BWR	SS	FWC	IGSCC - Intergranular SCC	4	1						1				
BWR	SS	FWC	Severe overloading	1	1								1		
BWR	SS	FWC	Severe overloading	3	1							1			
BWR	SS	FWC	Severe overloading	4	1							1			
BWR	SS	FWC	Severe overloading	5	3							2		1	
BWR	SS	FWC	Severe overloading	6	1							1			
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	2	1									1	
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	4	1									1	
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	5	3		1							2	
BWR	SS	FWC	SICC - Strain-rate Induced Corrosion Cracking	6	4		3							1	
BWR	SS	FWC	Thermal fatigue	2	3									3	
BWR	SS	FWC	Thermal Fatigue	3	3		1			1		1			
BWR	SS	FWC	Thermal fatigue	5	5		5								
BWR	SS	FWC	Thermal fatigue	6	5		4							1	
BWR	SS	FWC	Unreported	3	1									1	
BWR	SS	FWC	Unreported	4	1									1	
BWR	SS	FWC	Unreported	6	2		1					1			
BWR	SS	FWC	Vibration-fatigue	1	2				1					1	
BWR	SS	FWC	Vibration-fatigue	2	21					1		3	2	15	
BWR	SS	FWC	Vibration-fatigue	3	8		1				1	1		6	
BWR	SS	FWC	Vibration-fatigue	4	3							1		2	
BWR	SS	FWC	Vibration-fatigue	5	5					1		1	1	2	
BWR	SS	FWC	Vibration-fatigue	6	1		1								
BWR	CS	IA-SA		2	1					1					
BWR	CS	IA-SA	Corrosion	2	1							1			
BWR	CS	IA-SA	Fretting	2	1					1					
BWR	CS	IA-SA	HF:Human error	1	1								1		
BWR	CS	IA-SA	IGSCC - Intergranular SCC	2	1									1	
BWR	CS	IA-SA	Severe Overloading	1	1								1		
BWR	CS	IA-SA	Severe Overloading	2	1									1	
BWR	CS	IA-SA	Vibration-fatigue	1	5					1		1	3		
BWR	CS	IA-SA	Vibration-Fatigue	2	4					1		1	1	1	
BWR	CS	PCS			1					1					
BWR	CS	PCS	Corrosion	1	1									1	
BWR	CS	PCS	Corrosion	3	1									1	
BWR	CS	PCS	Erosion	5	1									1	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	2	2				1					1	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	3	1									1	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	4	6									6	
BWR	CS	PCS	FAC - Flow Accelerated Corrosion	5	12							4		8	

BWR	CS	PCS	FAC - Flow Accelerated Corrosion	6	2							1		1	
BWR	CS	PCS	HF.Welding error	2	1									1	
BWR	CS	PCS	Severe overloading	2	2					1				1	
BWR	CS	PCS	Severe overloading	6	2							1		1	
BWR	CS	PCS	Thermal fatigue	2	1							1			
BWR	CS	PCS	Vibration-fatigue	1	1							1			
BWR	CS	PCS	Vibration-fatigue	2	7							4		3	
BWR	CS	PCS	Vibration-fatigue	3	1							1			
BWR	CS	PCS	Vibration-fatigue	4	2									2	
BWR	SS	RAS	Cavitation-erosion	5	1						1				
BWR	SS	RAS	Corrosion	2	3					2			1		
BWR	SS	RAS	Corrosion	3	4									4	
BWR	SS	RAS	Corrosion	4	6									6	
BWR	SS	RAS	Corrosion	5	3									3	
BWR	SS	RAS	Corrosion-fatigue	1	1									1	
BWR	SS	RAS	ECSCC - External Chloride Induced SCC	1	1									1	
BWR	SS	RAS	ECSCC - External Chloride Induced SCC	2	17		8							9	
BWR	SS	RAS	ECSCC - External Chloride Induced SCC	3	2	2									
BWR	SS	RAS	FAC - Flow Accelerated Corrosion	3	1						1				
BWR	SS	RAS	Fatigue	4	1		1								
BWR	SS	RAS	HF:CONST/INST	2	1									1	
BWR	SS	RAS	HF.CONST/INST	3	1						1				
BWR	SS	RAS	HF.CONST/INST	4	1									1	
BWR	SS	RAS	HF CONST/INST	5	1									1	
BWR	SS	RAS	HF:Human error	1	1								1		
BWR	SS	RAS	HF.Human error	2	2				1				1		
BWR	SS	RAS	HF REPAIR/MAINT	1	1								1		
BWR	SS	RAS	HF REPAIR/MAINT	2	1									1	
BWR	SS	RAS	HF:REPAIR/MAINT	4	1		1								
BWR	SS	RAS	HF Welding error	2	2						2				
BWR	SS	RAS	HF.Welding error	3	2						1			1	
BWR	SS	RAS	HF.Welding error	4	1									1	
BWR	SS	RAS	HF.Welding Error	5	4		1				1			2	
BWR	SS	RAS	IDSCC - Interdendritic SCC	4	1					1					
BWR	SS	RAS	IGSCC - Intergranular SCC	2	5						1			4	
BWR	SS	RAS	IGSCC - Intergranular SCC	3	4						2			2	
BWR	SS	RAS	IGSCC - Intergranular SCC	4	56	1	32				9		1	13	
BWR	SS	RAS	IGSCC - Intergranular SCC	5	56	2	35			4	8			7	
BWR	SS	RAS	IGSCC - Intergranular SCC	6	2		1				1				
BWR	SS	RAS	Severe overloading	1	1							1			
BWR	SS	RAS	Severe overloading	2	3			1				2			
BWR	SS	RAS	Severe overloading	4	1							1			
BWR	SS	RAS	TGSCC - Transgranular SCC	1	1									1	
BWR	SS	RAS	TGSCC - Transgranular SCC	2	7	1	1				1			4	
BWR	SS	RAS	TGSCC - Transgranular SCC	3	7		6							1	
BWR	SS	RAS	TGSCC - Transgranular SCC	4	96		96								
BWR	SS	RAS	TGSCC - Transgranular SCC	5	1					1					
BWR	SS	RAS	Thermal fatigue	1	1									1	
BWR	SS	RAS	Thermal fatigue	2	2						1			1	
BWR	SS	RAS	Thermal fatigue	3	1		1								
BWR	SS	RAS	Thermal Fatigue	4	1									1	
BWR	SS	RAS	Thermal fatigue	5	10		5							5	
BWR	SS	RAS	Thermal Fatigue - Cycling	4	3									3	
BWR	SS	RAS	Thermal Fatigue - Cycling	5	1		1								
BWR	SS	RAS	Thermal Fatigue - Cycling	6	1		1								
BWR	SS	RAS	Unreported	3	1		1								
BWR	SS	RAS	Unreported	5	1									1	
BWR	SS	RAS	Vibration-fatigue	1	4		1							3	
BWR	SS	RAS	Vibration-fatigue	2	15				1		1	1	1	11	
BWR	SS	RAS	Vibration-fatigue	3	7		1		1	1				4	
BWR	SS	RAS	Vibration-fatigue	4	2		1							1	
BWR	SS	RAS	Vibration-fatigue	5	1									1	
BWR	SS	RAS	Water Hammer	1	1				1						
BWR	SS	RCPB		2	1										1
BWR	SS	RCPB	Corrosion	1	1									1	
BWR	SS	RCPB	Corrosion	2	1						1				
BWR	SS	RCPB	ECSCC - External Chloride Induced SCC	1	3	2								1	

BWR	SS	RCPB	ECSCC - External Chloride Induced SCC	4	1		1								
BWR	SS	RCPB	Erosion	2	1					1					
BWR	SS	RCPB	external damage	3	1			1							
BWR	SS	RCPB	HF.CONST/INST	1	1						1				
BWR	SS	RCPB	HF.CONST/INST	6	2		2								
BWR	SS	RCPB	HF.Fabrication Error	2	1						1				
BWR	SS	RCPB	HF:Fabrication Error	3	1									1	
BWR	SS	RCPB	HF.Fabrication Error	6	1		1								
BWR	SS	RCPB	HF:REPAIR/MAINT	2	1									1	
BWR	SS	RCPB	HF:Welding error	1	1						1				
BWR	SS	RCPB	HF.Welding error	2	2									2	
BWR	SS	RCPB	HF.Welding Error	3	7	1				1	1			4	
BWR	SS	RCPB	HF.Welding error	5	1									1	
BWR	SS	RCPB	HF:Welding error	6	8		8								
BWR	SS	RCPB	Hot cracking	4	1									1	
BWR	SS	RCPB	IGSCC - Intergranular SCC	1	4		2			1				1	
BWR	SS	RCPB	IGSCC - Intergranular SCC	2	3						2			1	
BWR	SS	RCPB	IGSCC - Intergranular SCC	3	2						2				
BWR	SS	RCPB	IGSCC - Intergranular SCC	4	20	2	5			2	7			4	
BWR	SS	RCPB	IGSCC - Intergranular SCC	5	10		7			1	2				
BWR	SS	RCPB	IGSCC - Intergranular SCC	6	203	3	174			1	22			3	
BWR	SS	RCPB	Overpressurization	4	2	1						1			
BWR	SS	RCPB	Severe Overloading	4	1			1							
BWR	SS	RCPB	SICC - Strain-rate Induced Corrosion Cracking	6	1		1								
BWR	SS	RCPB	TGSCC - Transgranular SCC	1	1	1									
BWR	SS	RCPB	TGSCC - Transgranular SCC	2	1		1								
BWR	SS	RCPB	TGSCC - Transgranular SCC	3	1									1	
BWR	SS	RCPB	Thermal Fatigue	2	2									2	
BWR	SS	RCPB	Thermal Fatigue	3	1									1	
BWR	SS	RCPB	Vibration-fatigue	1	3									3	
BWR	SS	RCPB	Vibration-Fatigue	2	42	2	1			4	2			33	
BWR	SS	RCPB	Vibration-Fatigue	3	4									4	
BWR	SS	RCPB	Vibration-fatigue	4	1									1	
BWR	SS	RCS-INSTR	ECSCC - External Chloride Induced SCC	2	1		1								
BWR	SS	RCS-INSTR	ECSCC - External Chloride Induced SCC	3	1		1								
BWR	SS	RCS-INSTR	HF:Welding error	2	2					1				1	
BWR	SS	RCS-INSTR	IGSCC - Intergranular SCC	4	2						1			1	
BWR	SS	RCS-INSTR	TGSCC - Transgranular SCC	1	2					1				1	
BWR	SS	RCS-INSTR	TGSCC - Transgranular SCC	2	1									1	
BWR	SS	SIR		0	1	1									
BWR	SS	SIR	Brittle fracture	5	4		4								
BWR	SS	SIR	Corrosion	3	1									1	
BWR	SS	SIR	Corrosion-fatigue	5	1									1	
BWR	SS	SIR	ECSCC - External Chloride Induced SCC	1	1									1	
BWR	SS	SIR	ECSCC - External Chloride Induced SCC	6	1		1								
BWR	SS	SIR	Erosion	2	2						1			1	
BWR	SS	SIR	Erosion	5	1										1
BWR	SS	SIR	FAC - Flow Accelerated Corrosion	2	4									4	
BWR	SS	SIR	FAC - Flow Accelerated Corrosion	3	4				1					2	1
BWR	SS	SIR	FAC - Flow Accelerated Corrosion	4	2						1				1
BWR	SS	SIR	Fatigue	1	1									1	
BWR	SS	SIR	Fatigue	2	1					1					
BWR	SS	SIR	Fatigue	5	1									1	
BWR	SS	SIR	Fatigue	6	1									1	
BWR	SS	SIR	HF.CONST/INST	2	2									2	
BWR	SS	SIR	HF.CONST/INST	3	1									1	
BWR	SS	SIR	HF.CONST/INST	4	1										1
BWR	SS	SIR	HF:CONST/INST	5	1									1	
BWR	SS	SIR	HF.Fabrication Error	5	2		2								
BWR	SS	SIR	HF:Fabrication Error	6	1		1								
BWR	SS	SIR	HF.Human error	1	1									1	
BWR	SS	SIR	HF:Human error	2	1									1	
BWR	SS	SIR	HF:Welding Error	2	2									2	
BWR	SS	SIR	HF.Welding Error	4	1								1		
BWR	SS	SIR	HF.Welding Error	5	10		9			1					
BWR	SS	SIR	HF:Welding Error	6	6	1	2					1		2	
BWR	SS	SIR	IGSCC - Intergranular SCC	2	3	1	1							1	

BWR	SS	SIR	IGSCC - Intergranular SCC	4	4	1					2			1	
BWR	SS	SIR	IGSCC - Intergranular SCC	5	64	2	51				6			5	
BWR	SS	SIR	IGSCC - Intergranular SCC	6	22		18				4				
BWR	SS	SIR	MIC - Microbiologically Induced Corrosion	5	1							1			
BWR	SS	SIR	Overpressurization	5	1							1			
BWR	SS	SIR	Overstressed	2	2									2	
BWR	SS	SIR	Severe overloading	2	2								1	1	
BWR	SS	SIR	Severe overloading	4	1									1	
BWR	SS	SIR	Severe overloading	6	1			1							
BWR	SS	SIR	TGSCC - Transgranular SCC	5	1					1					
BWR	SS	SIR	TGSCC - Transgranular SCC	6	1		1								
BWR	SS	SIR	Thermal fatigue	2	3									3	
BWR	SS	SIR	Thermal fatigue	5	3		3								
BWR	SS	SIR	Thermal fatigue	6	1		1								
BWR	SS	SIR	Thermal Fatigue - Cycling	5	2		1							1	
BWR	SS	SIR	Unreported	5	1									1	
BWR	SS	SIR	Vibration-Fatigue	0	2					2					
BWR	SS	SIR	Vibration-fatigue	1	6		1							5	
BWR	SS	SIR	Vibration-fatigue	2	27		2			1	1	1	1	21	
BWR	SS	SIR	Vibration-fatigue	3	3		1							2	
BWR	SS	SIR	Vibration-fatigue	4	2									2	
BWR	SS	SIR	Vibration-fatigue	5	1									1	
BWR	SS	SIR	Vibration-fatigue	6	1				1						
BWR	CS	STEAM	Corrosion	2	1									1	
BWR	CS	STEAM	ECSCC - External Chloride Induced SCC	1	1							1			
BWR	CS	STEAM	Erosion	3	1									1	
BWR	CS	STEAM	Erosion	4	1									1	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	2	16						3	1		12	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	3	7									6	1
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	4	3									3	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	5	7									7	
BWR	CS	STEAM	FAC - Flow Accelerated Corrosion	6	1									1	
BWR	CS	STEAM	Fatigue	2	3					1			1	1	
BWR	CS	STEAM	HF:CONST/INST	2	1									1	
BWR	CS	STEAM	HF.CONST/INST	3	1									1	
BWR	CS	STEAM	HF:CONST/INST	4	1					1					
BWR	CS	STEAM	HF.REPAIR/MAINT	1	1								1		
BWR	CS	STEAM	HF.Welding error	2	2									2	
BWR	CS	STEAM	HF:Welding error	3	2									2	
BWR	CS	STEAM	HF.Welding error	5	1					1					
BWR	CS	STEAM	HF.Welding Error	6	1		1								
BWR	CS	STEAM	IGSCC - Intergranular SCC	5	1		1								
BWR	CS	STEAM	Overpressurization	2	1							1			
BWR	CS	STEAM	Severe overloading	4	1							1			
BWR	CS	STEAM	SICC - Strain-rate Induced Corrosion Cracking	5	1		1								
BWR	CS	STEAM	SICC - Strain-rate Induced Corrosion Cracking	6	3		3								
BWR	CS	STEAM	TGSCC - Transgranular SCC	1	10		4			2				4	
BWR	CS	STEAM	TGSCC - Transgranular SCC	2	2		1							1	
BWR	CS	STEAM	Thermal fatigue	2	1									1	
BWR	CS	STEAM	Thermal fatigue	3	1									1	
BWR	CS	STEAM	Thermal fatigue	6	1									1	
BWR	CS	STEAM	Vibration-Fatigue	1	2							1		1	
BWR	CS	STEAM	Vibration-fatigue	2	12					1	1	2	2	6	
BWR	CS	STEAM	Vibration-fatigue	3	2									2	
BWR	CS	STEAM	Vibration-Fatigue	6	1									1	
BWR	CS	STEAM	Water Hammer	5	1		1								
BWR	CS	STEAM	Water Hammer	6	1			1							

Appendix B

Haddam Neck	PWR	CS	2.25	4	Erosion	GL 89-08
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
CANDU	PWR	CS	4	4	Thermal Fatigue	Korean
Millstone Unit 3	PWR	CS	6	5	Erosion/Corrosion	IN 91-18
Arkansas Nuclear One Unit 2	PWR	CS	14	6	Erosion	IN 89-53
DC Cook Unit 2	PWR	CS	16	6	Erosion	Bulletin 79-13
DC Cook Unit 2	PWR	CS	16	6	Erosion	Bulletin 79-13
Fort Calhoun Station	PWR	CS	12	6	FAC	IN 97-84
Surry Unit 1	PWR	CS	30	6	Not yet determined	IN 81-04
Surry Unit 2	PWR	CS	18	6	Erosion/Corrosion	IN 86-106
Trojan 1	PWR	CS	14	6	Erosion	IN 87-36
Zion 1	PWR	CS	24	6	Human Factor	IN 82-25
FR (Framatome Reactors)	PWR	CS	10	6	Corrosion	Korean
FR (Framatome Reactors)	PWR	CS	28	6	Corrosion	Korean
Diablo Canyon Unit	PWR	CS			Thermal Fatigue	IN 92-20
Loviisa Unit 1	PWR	CS			Erosion/Corrosion	IN 91-18
Sequoyah Unit 1	PWR	CS			Thermal Fatigue	IN 92-20
Surry Unit 1	PWR	CS			Erosion/Corrosion	IN 91-18
Wolf Creek	PWR	SS	0.25	1	Vibration	IN 89-07
KSNP Korean Standard Nuclear Power Plant	PWR	SS	0.375	1	Thermal Fatigue	Korean
Oconee Unit 3	PWR	SS	0.75	1	Mechanical Failure	IN 92-15
WH-3	PWR	SS	0.75	1	Flow Induced Vibration	Korean
WH-3	PWR	SS	0.75	1	Flow Induced Vibration	Korean
H.B. Robinson Unit 2	PWR	SS	2	3	SCC	IN 91-05
Oconee Unit 2	PWR	SS	2	3	Vibration	IN 97-46
Prairie Island Unit 2	PWR	SS	2	3	SCC	IN 91-05
WH-3	PWR	SS	2	3	Flow Induced Vibration	Korean
WH-3	PWR	SS	2	3	Flow Induced Vibration	Korean
WH-3	PWR	SS	2	3	Flow Induced Vibration	Korean
Crystal River Unit 3	PWR	SS	2.5	4	Fatigue	IN 82-09
Fort Calhoun Station	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Maine Yankee	PWR	SS	3.5	4	SCC	IN 82-02
Ginna	PWR	SS	8	5	SCC	IE Circular76-06
Foreign	PWR	SS	8	5	Thermal Stress	Bulletin 88-08
Arkansas Nuclear One Unit 1	PWR	SS	10	6	SCC	IE Circular76-06
Oconee Unit 2	PWR	SS	24	6	Erosion	IN 82-22
Sequoyah Unit 1	PWR	SS	16	6	Fatigue	IN 95-11
Sequoyah Unit 2	PWR	SS	10	6	Human Factor	IN 97-19
Surry Unit 2	PWR	SS	10	6	SCC	IE Circular76-06
Palo Verde	PWR	SS	Var		Human Factor	Bulletin 79-03
San Onofre Unit 2	PWR	SS	Var		Human Factor	Bulletin 79-03
San Onofre Unit 3	PWR	SS	Var		Human Factor	Bulletin 79-03
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
TMI unit 1	PWR	SS			SCC	IN 79-19
Farley Unit 2	PWR					IN 88-01
Point Beach Unit 1	PWR					IN 99-19

Appendix B (cont.)

Plant	Type	Material	Diameter	Pipe Size Group	Failure Mechanism	Reference
Dresden Unit 2	BWR	CS	4	4	Human Factor	Bulletin 74-10
Nine Mile Point Unit 2	BWR	CS	8	5	Fatigue	Event 36016
Vermont Yankee	BWR	CS	12	6	SCC	IN 82-22
Cooper Station	BWR	SS	0.25	1	Vibration	IN 89-07
Pilgrim	BWR	SS	1	2	Corrosion	IN 85-34
Browns Ferry 3	BWR	SS	4	4	SCC	IN 84-41
Browns Ferry 3	BWR	SS	4	4	SCC	IN 84-41
Nine Mile Point Unit 1	BWR	SS	6	5	SCC	Bulletin 76-04
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Dreseden Unit 2	BWR	SS	10	6	Thermal Fatigue	IN 75-01
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	22	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	20	6	SCC	IN 83-02
Hatch Unit 1	BWR	SS	24	6	SCC	IN 83-02
Montecello	BWR	SS	22	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Montecello	BWR	SS	12	6	SCC	IN 83-02
Browns Ferry 1	BWR					IN 82-24
Dresden Unit 1	BWR				Freezing	IN 94-38

Highlighted plants were not used in the data analysis due to missing information.

Appendix C. Collapsed OPDE Database

Collapsed OPDE Raw Data as function of Pipe Size

Plant Type	Pipe Size Group (inches)	Resulting Number of Failures		
		CS	SS	CS+SS
PWR	0.0-1.0	154	544	698
	1.0-2.0	74	154	228
	2.0-4.0	78	75	153
	4.0-10.0	126	112	238
	> 10.0	93	126	219
	Total	*525*	*1011*	*1536*
BWR	0.0-1.0	118	257	375
	1.0-2.0	32	75	107
	2.0-4.0	32	227	259
	4.0-10.0	50	234	284
	> 10.0	39	291	330
	Total	*271*	*1084*	*1355*
PWR+BWR	0.0-1.0	272	801	1073
	1.0-2.0	106	229	335
	2.0-4.0	110	302	412
	4.0-10.0	176	346	522
	> 10.0	132	417	549
	Total	*796*	*2095*	*2891*

Collapsed OPDE Raw Data as function of Failure Mechanism

Plant Type	Failure Mechanism	Resulting Number of Failures		
		CS	SS	CS+SS
PWR	Corrosion	106	28	134
	FAC	119	121	240
	MIC	43	1	44
	Erosion	96	12	108
	Fatigue	92	501	593
	Human Factors	36	126	162
	Mechanical Failures	22	37	59
	SCC	5	169	174
	Water Hammer	0	2	2
	Misc	6	14	20
	Total	*525*	*1011*	*1536*
BWR	Corrosion	29	32	61
	FAC	58	63	121
	MIC	6	1	7
	Erosion	40	9	49
	Fatigue	71	225	296
	Human Factors	24	85	109
	Mechanical Failures	18	25	43
	SCC	19	624	643
	Water Hammer	2	1	3
	Misc	4	19	23
	Total	*271*	*1084*	*1355*
PWR+BWR	Corrosion	135	60	195
	FAC	177	184	361
	MIC	49	2	51
	Erosion	136	21	157
	Fatigue	163	726	889
	Human Factors	60	211	271
	Mechanical Failures	40	62	102
	SCC	24	793	817
	Water Hammer	2	3	5
	Misc	10	33	43
	Total	*796*	*2095*	*2891*

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Do Small Pipes and Large Pipes Fail at the Same Frequency?

A Report on the Evaluation of Pipe Failures

Nuclear Engineering 597D
Spring 2005

Submitted to
Dr. L. E. Hochreiter

6 April 2005

EXECUTIVE SUMMARY

As part of the curriculum for Nuclear Engineering 597D at Penn State University, students examined the issue of pipe failures for stainless and carbon steels. Using several sources, data was collected on pipes of these materials. Using the pipe size as a source of division, the data could be normalized and turned into a value that would suggest the failure frequency per calendar year. The results were compared with previously gathered Nuclear Regulatory Commission (NRC) results of failure frequency of pipes of pressurized water reactors (PWRs) and boiling water reactors (BWRs). The goals of this project were a) to determine what information is readily available concerning pipe failures, b) to present this information as clearly as possible, c) to generate failure frequencies, d) to come to some conclusions on the correlation of failure frequency and pipe size. The results herein show little deviation in failure frequency for increasing pipe size, suggesting that large pipes fail nearly as often as small pipes and/or more data is necessary to come to more robust conclusions.

INTRODUCTION

The NRC has proposed changes to 10CR50.46 that are based on the idea that small pipes break and large pipes do not break as often. The scope of this project is to determine whether of not that this is true. The U.S. has established a number of reactor operating years gaining valuable experience and information. This has lead to an industry mentality that is turning away from a risk-based analysis and regulation system and moving more towards a risk-informed, probabilistic system. Consequently there has been discussion of changing the definition of a large break LOCA, and the acceptance criteria for the ECCS has come into question.

Can this lead to a relaxation of safety culture in light of the obvious fact that the US nuclear fleet is aging? The data collected by the NRC is obtained from nuclear plant operations. This information is based off of a half century of operation, and even less is from modern light water plants that have come of age. In addition, equipment, operating procedures, and inspection processes have been altered over the history of nuclear power. From the history of pipe failure reports, the NRC has established pipe failure rates with respect to effective break size. With the data collected for this project a new graph of failure rates will be compiled and compared to the previously established NRC failure rates. It is possible that a failure mechanism that may have been overlooked or simply forgotten by the NRC can be located.

Compiled is a list of data that includes piping failures of various sizes and various modes of failure. The following items are be key to every data point collected; diameter, pressure, fluid type, material (stainless steel or carbon steel), and type of failure. Unfortunately not all data can be used or is not applicable for a variety of reasons that are documented below.

As the data is collected it must be separated primarily by size of pipe. The pipe sizes will be placed into "bins" that generalize several piping systems inside a nuclear power plant. These bin sizes are similar for both PWR and BWR, but for each type the data will be plotted separately. The concern is with PWR and BRW plants because 10CFR50.46 states "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors".

The overall goals of this project include:

a) to determine what information is readily available concerning pipe failures,
b) to present this information as clearly as possible,
c) to generate failure frequencies,
d) to conclude on the correlation of failure frequency and pipe size.

DATA COLLECTION

The first major under taking in this project was to compile a database of usable pipe failure points. When working on compiling a database a wide range of sources were used to gather points. During process the main focus was to find as many pipe failures as possible and eliminate the non-applicable points later.

Several sources were used to find pipe failures. Internet based search engines were used to find several sources. Google, LexisNexis, Compendex, Penn State LIAS, ANS Online, the NRC Web site, and Science Direct were all used for searches on pipe failure references. Furthermore, *Nuclear News* periodicals were scanned for news briefs of pipe failures. This resulted in two recent pipe failure examples. The search engines used above all provided some sources of information including the Corrosion Testing Laboratories Web site and some brief articles about pipe failures. A majority of the data points came from a single article about piping damage at German nuclear plants. The article was found with Compendex and comes from the *Nuclear Engineering and* Design journal. Penn State LIAS did not yield as many results as anticipated. LIAS has a compilation of ASME and engineering papers, books, and theses. After rigorous searching on LIAS only one point was found, which was discouraging since a search yielded 30,000 hits. It was determined that most of the LIAS data was on papers or reports where the author had conducted experiments to failure, not on actual data collected on pipe failures that occurred unintentionally.

For much of the early search for pipe failure data, many properties were sought: the diameter of the pipe, what the pipe was transporting, the failure mechanism, and the material the pipe. With an increased understanding of how the data should ultimately be organized and plotted, the desired information was the pipe diameter, material, and failure mechanism.

Several data points were discarded because the diameter of the pipe was not reported. Also several pipe failures were not applicable since the pipes were used in the chemical industry and transported substances that lead to their failure; this prompted the consideration of only the failures that could be found in light water reactors. For example, a failure mechanism found was chloride induced stress corrosion cracking, not a failure mechanism found in light water reactors. After ruling out any failures that that could not occur in a light water reactor our number of points were reduced even more. Finally, some points were removed because the material was not stainless or carbon steel.

While gathering data the pressure in the pipes the pressure of the pipes was not typically documented and thus left out of this analysis. In an ideal situation the pipe diameter, failure mechanism, pipe material, crack size, temperature of the fluid, and the pressure would all be given and entered into the data base. These factors would increase the accuracy of the plots and make them relate more to the nuclear industry.

ANALYSIS METHODOLOGY

Once the data was collected, several steps needed to be taken to generate results that could be both analyzed to determine the frequency of pipe breaks and to compare with NRC results. For each data point obtained, the material and failure mechanism were used as starting points for separation. The failures needed to be divided by size and normalized. Further, the data was divided by a value that represented the sum years of United States nuclear operation for each plant. The results were thus turned into frequencies for comparison with the numbers for pipe failure frequency according to the NRC. The comparisons were done separately for BWRs and PWRs

When the data was collected, all cracks and breaks were considered failures. This comes from an assumption that the crack would become a leak or break if the issue had not been resolved. Therefore, the data presented in this report represents all the found pipes with cracks, breaks, leaks, and ruptures that are usable—material and geometry specified—and were caused by failure mechanisms that can be seen at a nuclear power plant.

For each type of plant, all the data was applied. However, one division was made to account for the pipe material. This project has a focus on stainless and carbon steels. The data was divided into three categories to later be normalized and plotted as a frequency: stainless steel, carbon steel, and both.

The pipes were then divided by the size of the nominal bore, or inner (flow) diameter. Because this project has a goal to determine some correlation between pipe size and failure frequency, the pipe size was a main source of division among all the collected points. Six different bin sizes were used to match the NRC report. The six bins, or categories, were normalized by the total number of failures.

Because PWR systems differ from BWR systems in pipe sizes, the bins were arranged more accurately to reflect different plants' pipes. The NRC data made available had six categories of different sizes for PWRs and BWRs. The data herein was thus separated differently for independent comparisons with NRC PWR results and BWR results.

The next step taken was to make the normalized data reflect a frequency. For proper comparison with the NRC data, the overall, normalized points, one for each bin or category, needed to be in units of per calendar year. It was assumed that the U.S. nuclear fleet had produced a total of 2745 reactor years at the end of 2003. An availability factor of 0.81 was also assumed for the entire U.S. fleet for all years; the availability factor is the fraction of a calendar year a plant was operating. Therefore,

Calendar Years = Reactor years / Availability factor
Calendar Years = 2745 ~~reactor years~~ / (0.81 ~~reactor years~~/calendar year)
Calendar Years = 3390 years

Once the value of each bin was divided by 3390, the data points could be plotted as failure frequency per calendar year versus pipe diameter separated into bins by size. This could then be plotted on a graph with NRC results. The NRC results had four points for each category, the 5th percentile, median, mean, and 95th percentile. The points provide estimates of where the data should be. In other words, the mean and median give estimates of standard failure frequency data. The two percentiles provide bounds of statistical variation and of confidence. The final generated plots are displayed on the following pages.

While this analysis is assumed to be the best available, it has a few key differences with the work completed by the NRC. First the NRC had the information available to use only BWR failures in their BWR analysis and PWR failures in their PWR analysis. For this project, all failures were included and the bins' pipe size ranges were adjusted for the different plant types. Moreover, their data comes from U.S. nuclear plant reports only. This report includes data from all applicable fields, regardless of country of origin. Lastly, the division of bins is based on pipe diameter, while the NRC data seems to be based on the effective break size. Because break sizes were often not documented and not documented in a single fashion, the diameters were chosen for the bins.

RESULTS

The following table provides a summary of the points included in this analysis and some background of the failure from a journal article (*Nuclear Engineering and Design*) discussing the history of piping damage at German plants.

Table 1: Summary of Data from Journal Article of Piping Damage at German Nuclear Plants

German Report	All Pipes Stainless Steel	0 - 15 mm = 0 - 0.59 in	0.59 in - 0.98 in	0.98 in - 1.97 in	1.97 in - 3.94 in	3.94 in - 9.84 in
Failure Mechanism	Manufacturing Defect	9	6	5	5	4
	Corrosion/Erosion	15	10	4	4	4
	Fatigue	13	14	4	3	1
	Fatigue-Manufacturing Defect	1	1	1	2	0
	Corrosion-Manufacturing Defect	1	0	0	2	11
Totals		39	31	14	16	20

The next tables provide a summary of the information that was found with various Internet sites. These points were found independently of one another, rather than as part of a single database. Those shown in red represent the points that were ultimately removed from the pool of data for the rest of the analysis. This table is followed by data recovered from the American Society of Civil Engineers (ASCE) about pipes exposed to seismic activity.

Table 2: Summary of Failures Found Individually

Number	Material	Cause	Break type: Crack vs. Rupture	Pipe Inner Diameter (in)	Break Size (if available)	Break depth (where applicable)
1	Carbon Steel	Thermal Fatigue	Cracks (varying lengths)	42		3/4 wall thickness (max)
2	Carbon Steel	Oxygen Corrosion	Grooves then cracks (vary)	2.23	1.5 inch grooves	
3	Stainless Steel	Stress Corrosion Cracking	Through wall Crack from OD to ID	10		wall thickness
4	Stainless Steel	Chloride Stress Corrosion Cracking	Through wall Crack from OD to ID	28		wall thickness
5	Stainless Steel	Chloride Induced Stress Corrosion Cracking	Several small cracks on shell	48		through wall
6	Stainless Steel	Polythionic Stress Corrosion Cracking	Several cracks that leaked that began at the ID	6.1		
7	Carbon Steel	Mismatch between deformation rates of base metal and weld	Longitudinal Crack at pipe weld	30		
8	Carbon Steel	Erosion/corrosion	Rupture of FW suction line elbow	18	2 ft x 4 ft	rupture
9	Carbon Steel	Erosion	180 degree fishmouth rupture	14	3 inches	rupture
10	Carbon Steel	FAC	6 ft^2 rupture at elbow	12	6 ft^2	rupture
11		Thermal Stress	Crack of varying depth 75% circumferential	56	75% circumferential	varying up 100%
12			Spiral Fracture in water distribution main for NYC	60		through wall of 5/8 inch
13			Small Leak in SG tube	CE design tube		
14	Carbon Steel	Erosion--turbulent flows	Rupture of steam pipe	21.26 (54 cm)	rupture	rupture
15	Stainless Steel	Intergranular Stress Corrosion Cracking	Several small cracks on shell	Unknown	8.1 inches	0.14 in

Table 2 (continued): Summary of Failures Found Individually

Number	Fluid	Notes	NSSS system (where applicable)	Reference
1	Steam	From Oil Refinery	May apply to steamlines	Corrosion Testing Laboratories
2	Water	Grooves develop into cracks at bands of tube ends	Steam generator tubes	CTL
3	Steam	Sensitized metal (unknown environment)	Primary system	CTL
4	Carbon Dioxide	Buried 4 feet but near roadway frequently salted		CTL
5	Distilled Water	humid environment		CTL
6		cracks developed under coke deposits		CTL
7	Steam	Crack was along weld	Steam lines	Kevin Kennedy and Associates
8	Water	Rupture did not occur at welds	FW suction lines	NRC
9	Steam	Significant wearing from 3/8" to 1/32" of wall thickness	High pressure steam extraction line	NRC
10	92% steam	4th stage extraction steam piping preheats FW heaters	4th stage extraction steam pipe	NRC
11		Plant specific Hatch-2 1984; nitrogen injector malfunction had N too hot	Vent Header	Lexis Nexis -- Nuclear News
12	Water	NYC water main, very large pipe		Lexis Nexis -- Engineering News
13	Water	Single tube leak was plugged	SG tubes	Nuclear News
14	Steam	Recent pipe burst at Japanese Plant	Steam pipes	Nuclear News
15	Water	RHR system, small cracks summed together, welding	RHR	NE&D

Table 3: Summary of Data from Earthquake ASCE Database

MEDIUM	SIZE (IN)	THICKNESS (IN)	MATERIAL	BREAK	LEAK	CORROSION	PIPE_OTHER	CRACK	PULL
WATER	0.75	0.12	CS	X					X
WATER	1.00	0.15	CS	X					X
WATER	1.00	0.15	CS	X					X
WATER	1.00	0.15	CS	X					X
WATER	1.50	0.00	CS	X			BROKEN PIPE		
WATER	2.00	0.19	CS		X	X			
WATER	2.00	0.19	CS	X					X
WATER	2.00	0.19	CS		X	X			
WATER	2.00	0.19	CS	X					X
WATER	2.00	0.19	CS		X	X			
WATER	2.00	0.19	CS		X			X	
WATER	2.00	0.19	CS		X			X	
WATER	2.00	0.19	CS		X	X			
WATER	2.00	0.19	CS	X				X	
WATER	2.00	0.19	CS	X					X
WATER	2.00	0.19	CS	X		X			X
WATER	2.00	0.19	CS	X					X
WATER	2.00	0.19	CS	X		X			
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X				
WATER	2.00	0.00	CS		X				
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X	X			
WATER	2.00	0.00	CS		X	X			
WATER	3.00	0.25	CS	X					X

MEDIUM	SIZE (IN)	THICKNESS (IN)	MATERIAL	BREAK	LEAK	CORROSION	PIPE_OTHER	CRACK	PULL
WATER	3.00	0.25	CS	X					X
WATER	3.00	0.25	CS		X	X			
WATER	3.00	0.00	CS		X	X			
WATER	4.00	0.00	CS		X				
WATER	4.00	0.00	CS	X					
WATER	4.00	0.00	CS						
WATER	6.00	0.00	CS	X				X	
WATER	6.00	0.06	CS		X	X			
WATER	8.00	0.00	CS	X					
WATER	8.00	0.12	CS		X		SERVICE BREAK AT MAIN		
WATER	12.00	0.00	CS		X				X
WATER	14.00	0.12	CS	X		X			
WATER	2.00	0.00	SS						
WATER	2.00	0.00	SS						
WATER	2.00	0.00	SS						
WATER	3.00	0.00	SS	X					X
WATER	4.00	0.00	SS		X				
WATER	4.00	0.00	SS						X
WATER	4.00	0.00	SS						
WATER	4.00	0.00	SS						
WATER	4.00	0.00	SS						
WATER	4.00	0.00	SS						
WATER	4.00	0.00	SS						
WATER	6.00	0.00	SS						
WATER	6.00	0.00	SS						
WATER	10.00	0.00	SS	X					X

Once the data was gathered, the points were separated and manipulated in the procedure described above. This returned the following summary of points used in the analysis and frequencies found that were compared with the NRC data.

Table 4: Summation of All Data Points Used to Generate Failure Frequency Plots

BWR Bin Sizes							
Category	**1**	**2**	**3**	**4**	**5**	**6**	
Bin Size (inches)	0 - 0.98	0.98 - 1.97	1.97 - 3.94	3.94 - 9.84	9.84 - 26	above 26	**Total**
Stainless	70	14	20	29	2	0	135
Normalized	0.519	0.104	0.148	0.215	0.015	0.000	1
Carbon	1	4	28	7	6	2	48
Normalized	0.021	0.083	0.583	0.146	0.125	0.042	1
Both	71	18	48	36	8	2	183
Normalized	0.388	0.098	0.262	0.197	0.044	0.011	1
PWR Bin Sizes							
Category	**1**	**2**	**3**	**4**	**5**	**6**	
Bin Size (inches)	0 - 0.98	0.98 - 1.97	1.97 - 3.94	3.94 - 9.84	9.84 - 18	above 18	**Total**
Stainless	70	14	20	29	2	0	135
Normalized	0.519	0.104	0.148	0.215	0.015	0.000	1
Carbon	1	4	28	7	5	3	48
Normalized	0.021	0.083	0.583	0.146	0.104	0.063	1
Both	71	18	48	36	7	3	183
Normalized	0.388	0.098	0.262	0.197	0.038	0.016	1

The normalized values above are then converted to frequencies per calendar year by dividing by 3390. The table below shows the values of the frequencies and compares them to the NRC data.

Table 5: Failure Frequency Values (per calendar year) for Plant and Material Types with Corresponding NRC Data

	Collected Data			NRC Data			
Category	BWR Stainless	BWR Carbon	BWR Both	5%	Median	Mean	95%
1	1.53E-04	6.19E-06	1.14E-04	2.30E-05	2.00E-04	5.10E-04	1.90E-03
2	3.07E-05	2.45E-05	2.89E-05	1.80E-06	3.80E-05	1.20E-04	4.70E-04
3	4.37E-05	1.72E-04	7.73E-05	2.40E-07	4.70E-06	2.10E-05	8.00E-05
4	6.34E-05	4.31E-05	5.81E-05	5.70E-08	1.20E-06	6.60E-06	2.50E-05
5	4.42E-06	3.69E-05	1.30E-05	1.00E-08	1.20E-07	2.40E-06	6.90E-06
6	0.00E+00	1.24E-05	3.24E-06	2.80E-11	9.70E-10	2.50E-09	9.50E-09
	Collected Data			NRC Data			
Category	PWR Stainless	PWR Carbon	PWR Both	5%	Median	Mean	95%
1	1.53E-04	6.19E-06	1.14E-04	3.00E-04	1.10E-03	2.10E-03	7.50E-03
2	3.07E-05	2.45E-05	2.89E-05	4.90E-06	1.00E-04	2.50E-04	9.30E-04
3	4.37E-05	1.72E-04	7.73E-05	3.10E-07	6.60E-06	1.80E-05	7.00E-05
4	6.34E-05	4.31E-05	5.81E-05	6.00E-08	6.30E-07	2.50E-06	9.60E-06
5	4.42E-06	3.07E-05	1.12E-05	9.30E-10	1.20E-08	6.10E-08	2.40E-07
6	0.00E+00	1.86E-05	4.72E-06	1.00E-10	2.80E-09	4.60E-08	1.70E-07

The figures above are used to generate the six plots below. The lines are for the collected data corresponding to each plot. The other four points are the values of the NRC data.

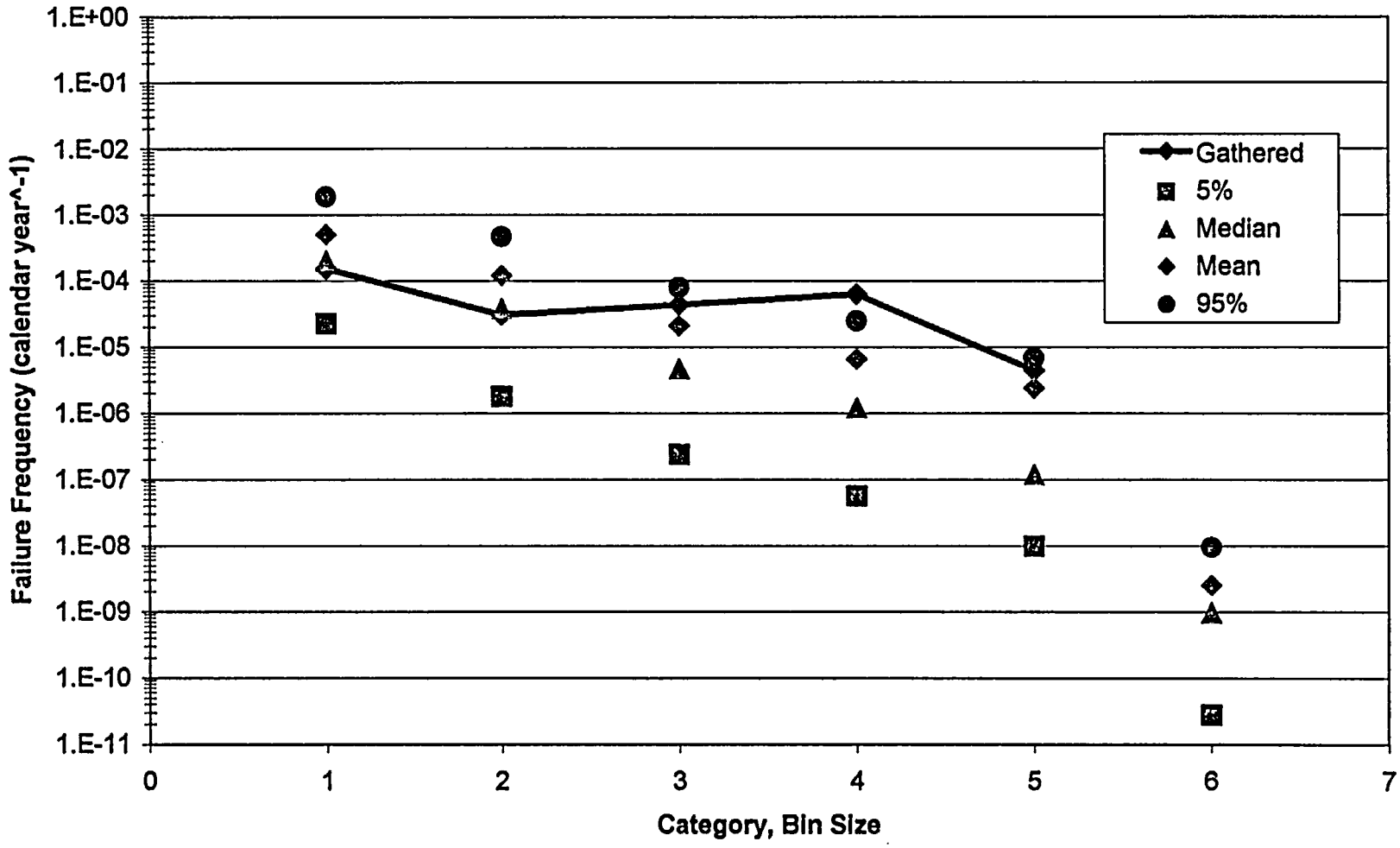

Figure 1: BWR Stainless Steel Failure Frequency and Comparison with NRC Data

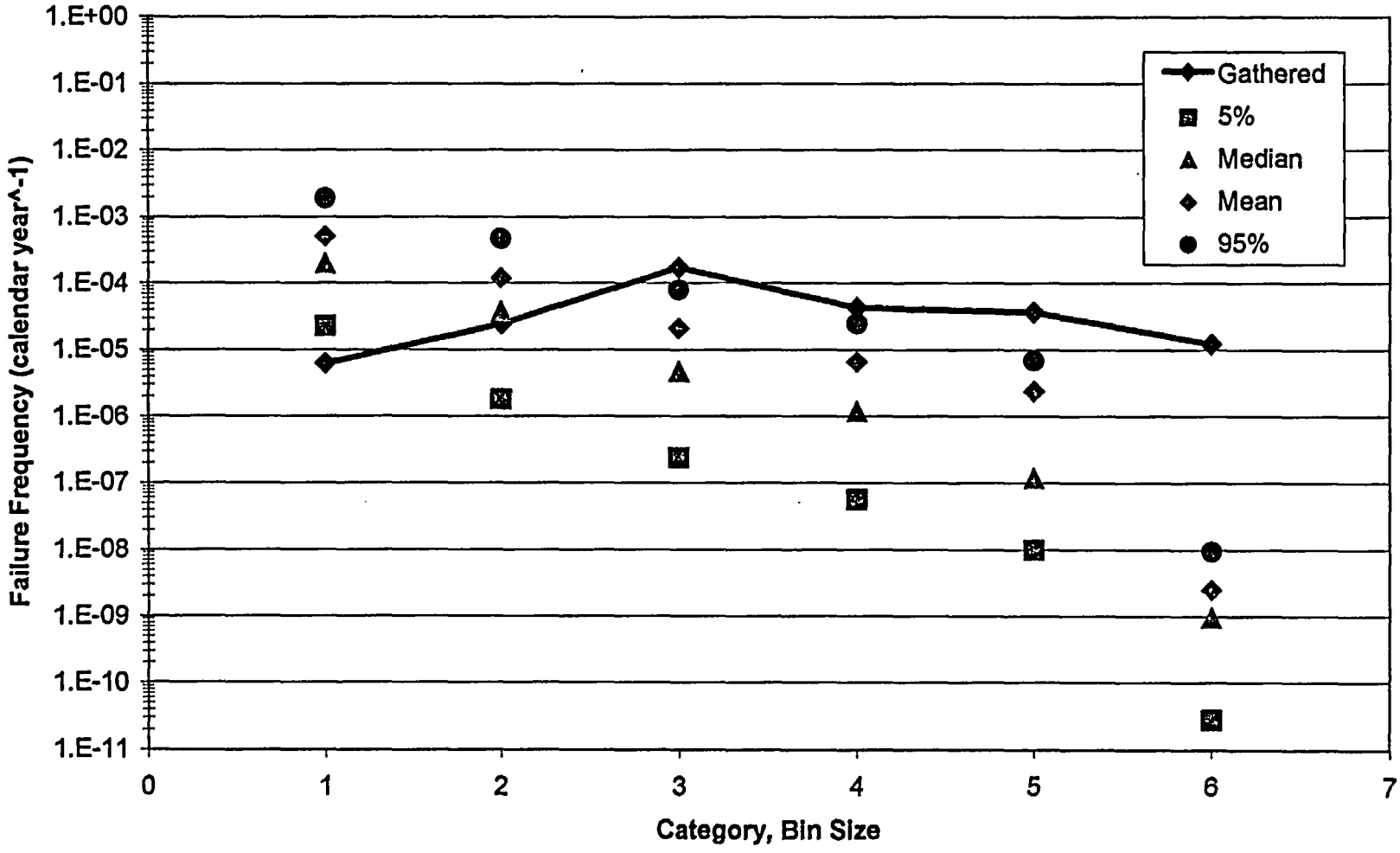

Figure 2: BWR Carbon Steel Failure Frequency and Comparison with NRC Data

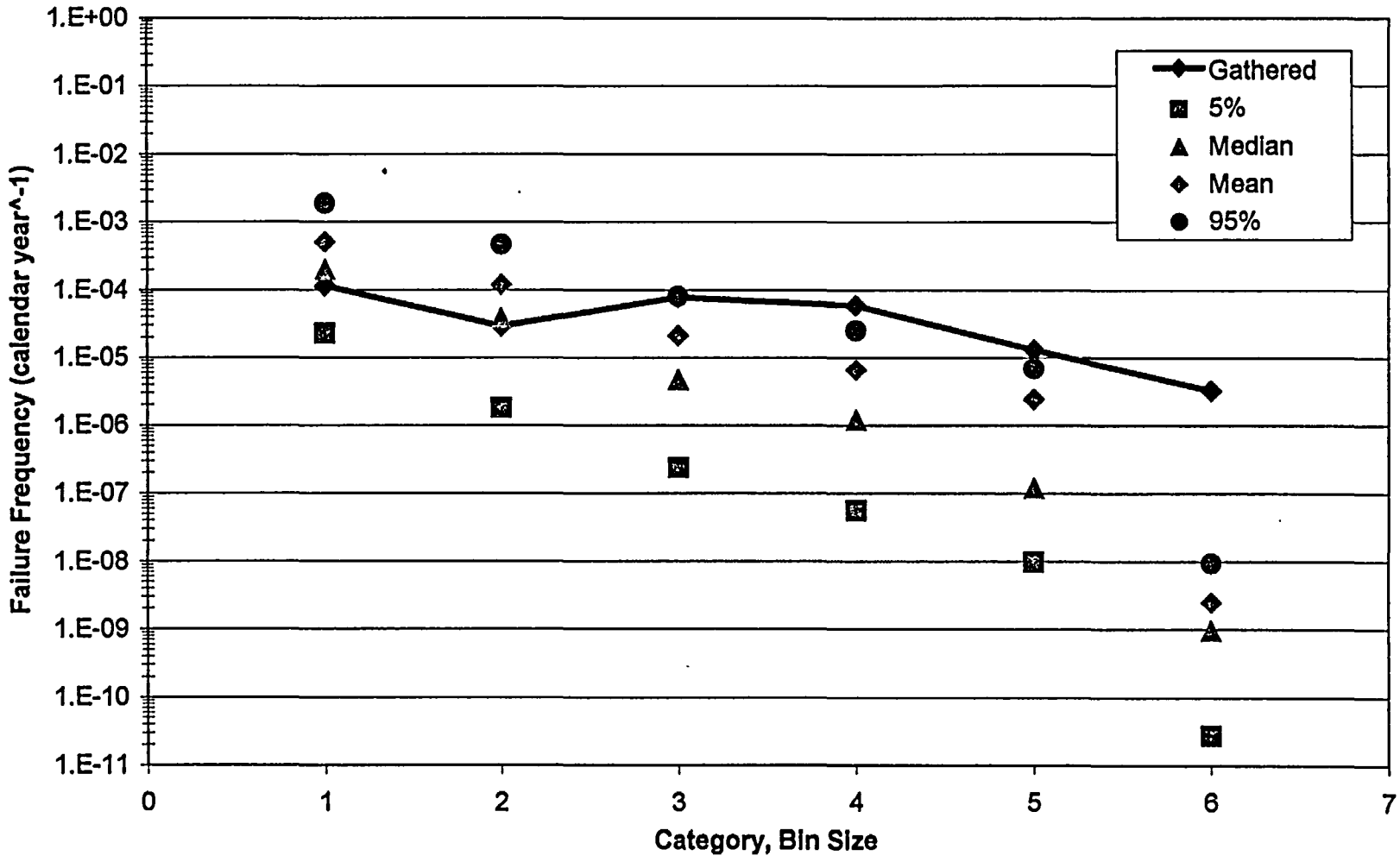

Figure 3: BWR Stainless and Carbon Steel Failure Frequency and Comparison with NRC Data

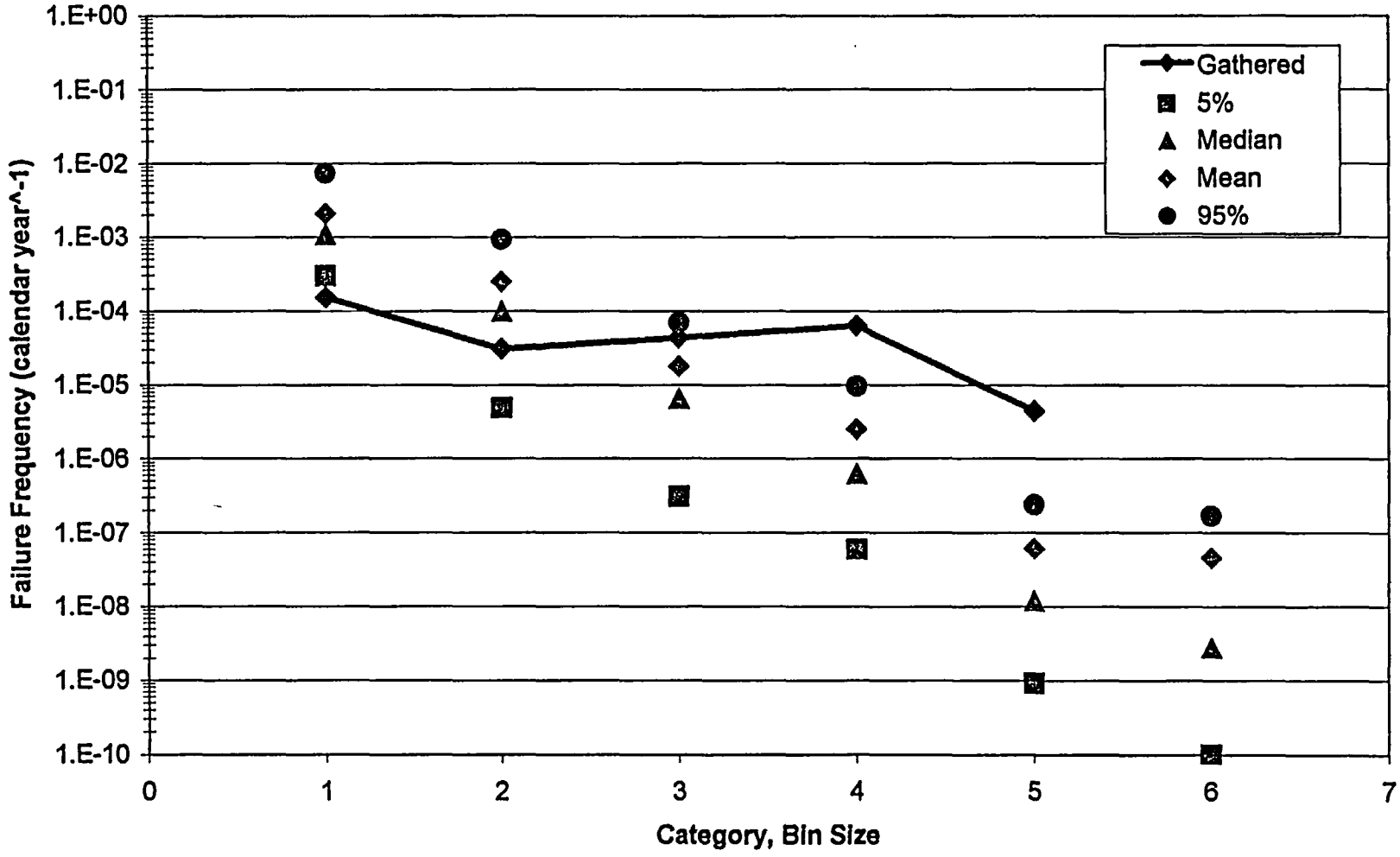

Figure 4: PWR Stainless Steel Failure Frequency and Comparison with NRC Data

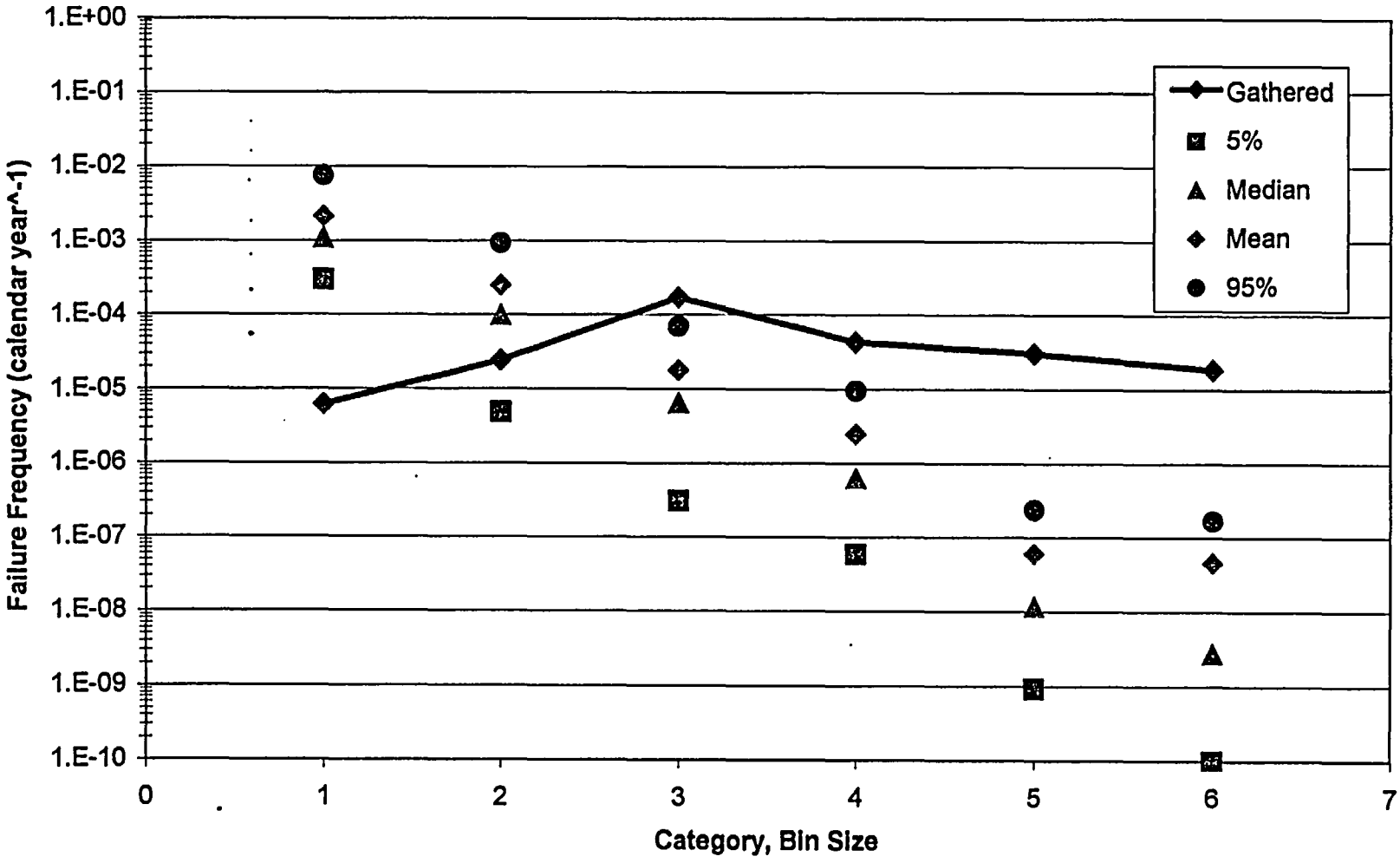

Figure 5: PWR Carbon Steel Failure Frequency and Comparison with NRC Data

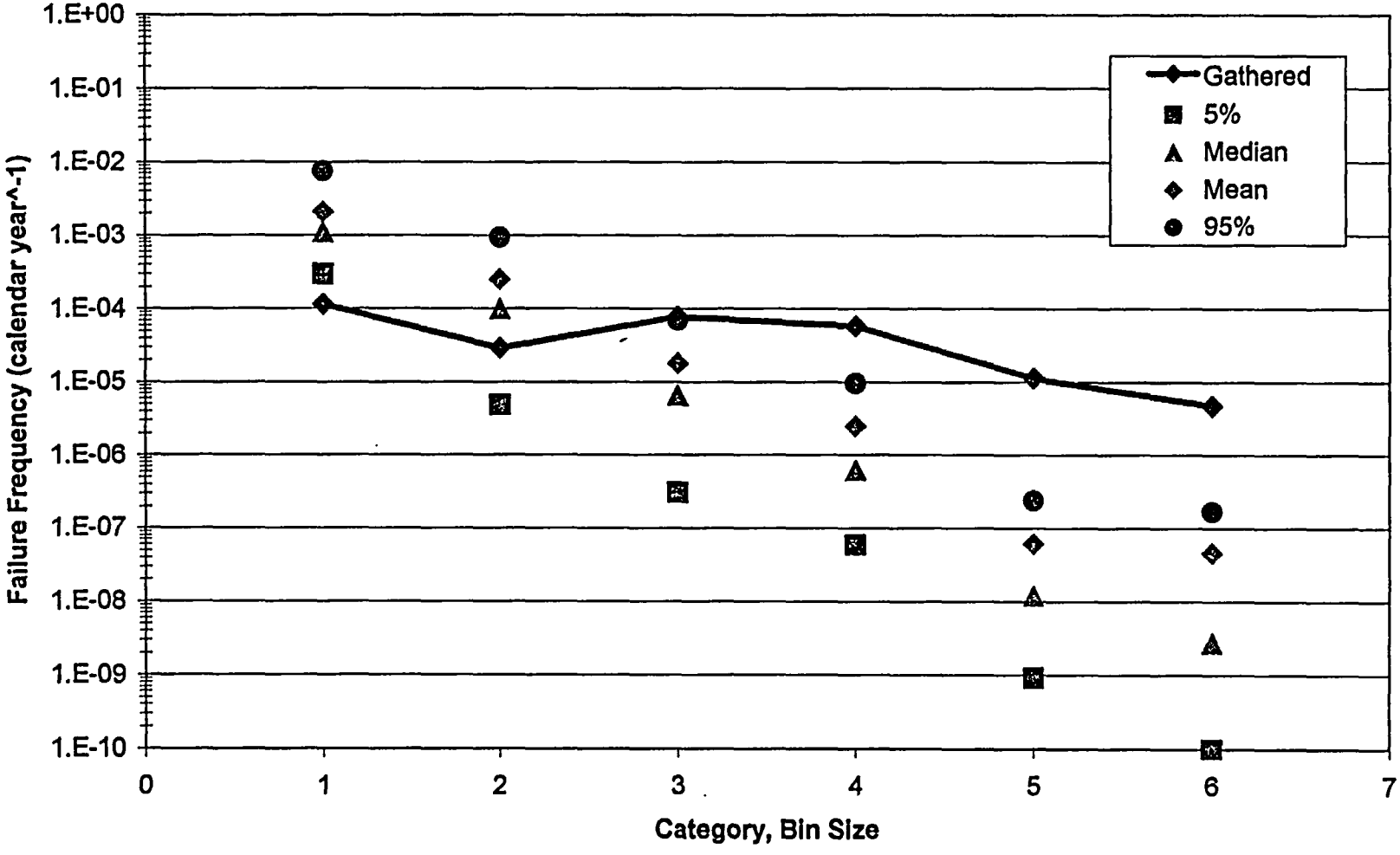

Figure 6: PWR Stainless and Carbon Steel Failure Frequency and Comparison with NRC Data

DISCUSSION

The primary goal of this project was to determine if there is a correlation with the failure frequency of pipes and their diameter. Moreover, there is an undeniable importance in the relation of the calculated results with those of the NRC. In addition, one can review the data to determine some ordinary causes of the pipe failures that were found. While the frequency plots show how often pipe failure occurs, just as important is the understanding of the common failure mechanisms.

When all usable points are put together, the database for the project was comprised of a total 183 pipe failures. This includes 135 points for stainless steel and 48 points for carbon steel. There is a wide range of data available to fit into all the categories or bins. In fact, the only bin empty of points was the largest bin for both BWR and PWR data sets of stainless steel.

While not many points were found for larger pipes, the frequency data was not terribly skewed to the smallest bin size. However, all results are limited by the data available. The three smallest bins have some of the highest frequencies because these pipes are likely more populous in reactor systems or coincidentally are the pipes most easily found from the sources reviewed.

The NRC has a more extensive database and different techniques to determine failure frequency than what was used for this project. For the six plots shown above, the NRC data is the same for the three BWR figures and the same for the three PWR figures. In each case, the NRC data shows a steady decrease in the failure frequency. However, NRC categories are divided by effective break sizes. It is unknown how closely the effective break size relates to the pipe diameter. This can be an explanation of why the NRC has such a low frequency with increasing size—large pipes may fail, but not with very large break sizes.

The data collected generated failure frequencies with far less variation of results with respect to increasing pipe size. In many cases, the category 1, category 3, and category 4 bins have the highest frequencies. The data collected had most points lying in these three bin sizes. Nevertheless, enough large pipes existed, that no significant drop-off existed for large pipes. In other words, the data does not support the notion that small pipes break while large pipes do not.

The carbon piping plots have peaks at category 3. This database had most points for carbon steel in the respective range, driving that frequency higher than the others. On the other hand, stainless steel data was largely dominated by the smallest bin size. This is perhaps a result of stainless steel being employed in small pipes with greater frequency than in large pipes.

In many cases, the collected data does not show any matching with the NRC results. The data may swing from 95th percentile through mean and median to 5th percentile between points. Also, for large pipe data, the collected results are

several orders of magnitude greater than the NRC results. Thus, this is further indication that the data makes little to no correlation between pipe size failure frequency.

The distribution of failure mechanisms largely depended on the sources of the data. A large database of seismic activity used in this report should not be used as an indication that earthquakes are the most likely failure mechanism of pipes in nuclear plants; however, this is certainly a concern. Moreover, the article of pipe damage at German plants dominated the stainless steel data set. This database documented several failure mechanisms. The most common failure mechanism was manufacturing defect. Further evidence is required to determine if the United States has a similar problem with the manufacturing of pipes.

Other common failure mechanisms that were found were fatigue, erosion/corrosion, and stress corrosion cracking. The results indicate that further work needs to be completed to have a better understanding of the reasons for pipe failure in this country. There is, however, a broad range of failure mechanisms for pipes in general that were found. Any organization that must deal with pipes must be aware of the various types of failure and be conscious of their possibility. Quality assurance programs at utilities should be familiar with all types of pipe failures such that a pipe crack or leak is handled with the appropriate level of attention.

Although the data shows little agreement with the NRC results, it should be understood that small pipes generally did fail more than large pipes according to these results. The difference between the databases in this respect is the amount of frequency decreased as the pipe size increased. This information may suggest that small pipes and large pipes fail with similar frequency, but it more importantly suggests that further research is needed to generate a more complete database.

CONCLUSIONS

This evaluation was conducted by gathering data from a large variety of sources and compiling a database. The database was divided into bins. Each bin was determined by pipe size, material, and ranges were set to better match with NRC information about PWRs and BWRs. The bins were normalized and converted into failure frequency. The frequencies calculated were then plotted against the NRC predicted frequencies.

When comparing the results between the NRC and the database generated as part of the work for this project, the plots suggest that both large and small pipes break at the nearly same frequency. Small pipes fit in best with the NRC data. Yet the curves shown in the figures above do not suggest much relation of the data found to the data the NRC has in its database.

These results reflect our ability to find data on pipe breaks. Given more time and access to proprietary information the accuracy of our plots would increase and could agree more with the NRC's information. Furthermore, for an even more accurate analysis and comparison with the NRC data, one should make greater effort in finding data from the nuclear industry only. This data can then be separated for BWRs and PWRs without overlap. An important variation of the results of this project and NRC data is the effective break size. The frequency variation developed here shows that large pipes fail, but the NRC data is based on break size. There is a likelihood that the data the NRC uses demonstrates only that small failures occur more likely than large failures.

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DOCUMENT TITLE:

Evaluation of Pipe Break Frequencies

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1 TABLE OF CONTENTS

EVALUATION OF PIPE BREAK FREQUENCIES 1
1 TABLE OF CONTENTS 3
2 INTRODUCTION 3
3 DATA ACQUISITION 3
4 DATA PRESENTATION 3
5 COMPARISON OF DATA 3
6 CONCLUSIONS 3
7 REFERENCES 3
8 ATTACHMENTS 17

2 INTRODUCTION

The purpose of this report is to document an independent evaluation of Nuclear Power Plant steel pipe break data in light of the recent push by the Nuclear Industry to change rules related to the consideration of extraordinary pipe break LOCAs in licensing basis of all U.S. commercial LWRs.

In the past, rigorous probablistic saftey assesments (PSAs) were not done to justify the need for inclusion of large pipe break analyses in nuclear plant licensing bases. Instead, it was simply assumed that the severity of the event was sufficient to justify the need for this type of event to be considered in a plant's design basis. On the other hand, extensive PSAs have been performed on active plant systems and components in order to determine which severe accidents needs be included in said design bases. Thus, the push by part of the nuclear industry today is for a rigorous analysis to be performed in order to determine if the very large pipe break scenarios considered in LOCA and steamline break analyses are prudent given the anticipated risk associated with such events.

The evaluations documented in this report thus represent an independent review of an internationally generated database of nuclear power plant pipe failures. This data represents a collection of reported pipe breaks at nuclear facilities as outlined below (Reference 1):

PLANT TYPE	# OF PLANTS SURVEYED	COVERAGE (REACTOR-YEARS)
BWR	71	1,398
LWGR	19	319
PHWR (CANDU)	20	354
PWR + VVER	164	2,670
TOTAL	274	4,741

Data from the above sources were queried to categorize pipe failures by: failure mode (i.e. leak or rupture), failure mechanism (i.e. IGSCC, fatigue, corrosion, etc), pipe material (i.e. carbon or stainless steel), and fluid type (i.e. de-mineralized / borated water, steam, gas, oil, etc.).

The collected and categorized data was used to generate statistics related to pipe failure frequency primarily as a function of pipe material and pipe diameter. The results of these evaluations are described in detail later in this report.

3 DATA ACQUISITION

In order to do an independent evaluation of pipe break frequencies at nuclear power facilities, a database of pipe failures needed to be generated from documented failure events at various nuclear facilities around the world. Ideally, this database would include all pipe failure events for all nuclear facilities since the advent of commercial nuclear power. However, this ideal is unrealistic, and such, the attempt was made to generate a database that was as comprehensive and representative of reality as is feasible.

The first database of pipe failures that was discovered during the initial data gathering process is documented in Reference 2. This reference includes a comprehensive database of over 2,000 pipe failures at nuclear power facilities. Unfortunately, this database does not contain sufficient information as to be used in the full evaluation of pipe break frequencies. Specifically, this report does NOT include data related to pipe materials. Thus, it is unknown as to whether pipes of other materials (i.e. copper, etc.) are included in the break statistics. An effort was made to gain information form industries outside of the nuclear field. However, too few details were provided (i.e. stainless vs. carbon steel piping) to make this data practical for use in this report.

The second database discovered is documented in Reference 1. This report includes pipe break data from nuclear power facilities around the world. This data did include all of the necessary data for collected pipe breaks such that it could be used in the evaluations documented in this report. Note, however, that this report is limited in that it does NOT include water hammer events in its analysis.

The Reference 1 data is a collection of failure data documented in licensee event reports from nuclear facilities around the world. Approximately 4,741 reactor-years of operation are included in the database. Assuming a gross capacity factor of about 81% (which is reasonable based on the known history of nuclear facility operations), this is equivalent to about 5,853 calendar years of plant operation.

The Reference 1 database was the sole source of pipe failure data used in the evaluations documented in this report. While additional pipe break data may be found in other sources, it was determined to be unwise to mix data from multiple sources for the following reasons:

- As mentioned earlier, the Reference 1 report includes failure data from licensee event reports for all nuclear facilities around the world for a broad span of time relative to the life of the nuclear power industry. As such, independent data sources would most likely include some if not all of the data already represented in Reference 1. As it is impossible to determine which data is or is not included in

the reference databases, it could be possible to double count certain events. In such case, the result may be to bias to the results of the evaluations performed from the reference data.

- Pipe failures for non-nuclear systems (i.e. piping failures at fossil fuel plants or other industrial complexes) were not considered for inclusion in this evaluation. This is because to the quality standard for both the manufacturing of pipe for these applications as well as the standards for use of said piping and reports of failure events are not the same in the non-nuclear industries. As such, the failure frequencies of piping in non-nuclear applications can not be said to represent those in nuclear applications.

4 DATA PRESENTATION

The data from Reference 1 was compiled and organized in order to present the pipe failure data in a format consistent with that provided in the guidance for this project assignment. Tables 1 through 6, present the data as requested. These tables present the pipe failure statistics for the following conditions:

- Table 1: Statistics for carbon steel pipe leaks. This data is subdivided into the type of media flowing through the pipe prior to failure.
- Table 2: Statistics for carbon steel pipe ruptures. This data is subdivided into the type of media flowing through the pipe prior to failure.
- Table 3: Statistics for stainless steel pipe leaks. This data is subdivided into the type of media flowing through the pipe prior to failure.
- Table 4: Statistics for stainless steel pipe ruptures. This data is subdivided into the type of media flowing through the pipe prior to failure.
- Table 5: Statistics for pipe leaks (carbon and stainless steam combined). This data is subdivided into the mechanism for pipe failure.
- Table 6: Statistics for pipe ruptures (carbon and stainless steam combined). This data is subdivided into the mechanism for pipe failure.

The data from these tables were used to calculate the pipe failure frequencies in Tables 7 and 8. These data were generated by taking the total number of failures in each pipe size category and normalizing these as follows:

$$\boxed{P_F^i = \frac{N_F^i}{T_{RX} \cdot \sum_i N_F^i}} \qquad (1)$$

In equation (1) above, N_F^i is the number of recorded failures in pipe size category *i*, and T_{RX} is the amount of time that the database of failures spans (in calendar years). From Section 3, it is known that the data spans about 5,853 calendar years.

Figure 1 presents the calculated pipe failure frequencies as a function of pipe break category. The data from Figure 1 is also presented in Table 7. Figure 2 presents the same data in a cumulative fashion (i.e. all lower catgories including failures from higher categories. This was done to present the data in a manner that is consistent with the evaluations in Reference 3. The data from Figure 2 is also presented in Table 8.

Table 1: Carbon Steel Pipe Statistics (Leak Failures Only)

Pipe Size (inches)	Pipe Content Material						
	Ins Air	Oil	Borated H_2O	Demin H_2O	Raw Water	D_20	Steam
< 1	3	2	0	7	4	0	2
4-12	19	11	0	84	132	0	74
12-24	1	0	0	30	48	0	36
24-30	0	1	0	20	36	0	9
> 30	0	0	4	58	65	0	58
total	**23**	**14**	**4**	**199**	**285**	**0**	**179**

Table 2: Carbon Steel Pipe Statistics (Rupture Failures Only)

Pipe Size (inches)	Pipe Content Material						
	Ins Air	Oil	Borated H_2O	Demin H_2O	Raw Water	D_20	Steam
< 1	1	2	0	2	0	0	0
4-12	5	4	0	9	3	0	10
12-24	0	0	0	6	6	0	9
24-30	0	0	0	3	2	0	6
> 30	0	0	0	22	14	1	27
total	**6**	**6**	**0**	**42**	**25**	**1**	**52**

Table 3: Stainless Steel Pipe Statistics (Leak Failures Only)

Pipe Size (inches)	Pipe Content Material							
	Ins Air	Oil	Borated H_2O	Demin H_2O	D_20	Raw Water	Gas (N_2)	Steam
< 1	2	12	68	25	3	2	0	2
4-12	14	3	227	118	10	9	0	9
12-24	1	0	97	41	1	1	0	1
24-30	0	0	27	75	0	1	0	3
> 30	0	0	83	130	1	0	8	3
Total	**17**	**15**	**502**	**389**	**15**	**13**	**8**	**18**

Table 4: Stainless Steel Pipe Statistics (Rupture Failures Only)

Pipe Size (inches)	Pipe Content Material							
	Ins Air	Oil	Borated H_2O	Demin H_2O	D_20	Raw Water	Gas (N_2)	Steam
< 1	0	3	4	4	0	0	0	0
4-12	5	1	8	6	0	0	0	1
12-24	0	0	3	0	0	0	0	1
24-30	0	0	2	1	1	0	0	0
> 30	0	0	0	4	1	0	0	1
total	**5**	**4**	**17**	**15**	**2**	**0**	**0**	**3**

Table 5: Pipe Leak Failure Statistics (Stainless and Carbon Steel)

Pipe Size (inches)	Pipe Content Material				
	Corrosion	Fatigue	IGSCC	Human	Other
< 1	4	69	26	17	22
4-12	176	303	40	100	96
12-24	23	49	0	0	0
24-30	50	28	59	17	24
> 30	127	82	117	41	62
total	**380**	**531**	**242**	**175**	**204**

Table 6: Pipe Rupture Failure Statistics (Stainless and Carbon Steel)

Pipe Size (inches)	Pipe Content Material				
	Corrosion	Fatigue	IGSCC	Human	Other
< 1	0	14	0	3	2
4-12	5	34	0	4	11
12-24	5	1	0	0	0
24-30	3	2	0	2	10
> 30	32	3	0	4	35
total	**45**	**54**	**0**	**13**	**58**

Table 7: Pipe Failure Frequencies by Pipe Category

Pipe	Pipe Failure Frequencies (1/rx-yr)							
Size	Carbon Steel		Stainless Steel		All			
(inches)	Leaks	Ruptures	Leaks	Ruptures	Leaks	Ruptures	Carbon Steel	Stainless Steel
< 1	4.37E-06	6.47E-06	1.99E-05	4.09E-05	1.34E-05	1.54E-05	4.70E-06	2.09E-05
4-12	7.77E-05	4.01E-05	6.82E-05	7.80E-05	7.22E-05	4.99E-05	7.17E-05	6.86E-05
12-24	2.79E-05	2.72E-05	2.48E-05	1.49E-05	2.61E-05	2.40E-05	2.78E-05	2.44E-05
24-30	1.60E-05	1.42E-05	1.85E-05	1.49E-05	1.75E-05	1.44E-05	1.57E-05	1.84E-05
> 30	4.49E-05	8.28E-05	3.93E-05	2.23E-05	4.17E-05	6.72E-05	5.09E-05	3.86E-05

Table 8: Pipe Failure Frequencies by Pipe Category (Cumulative)

Pipe	Pipe Failure Frequencies (1/rx-yr)							
Size	Carbon Steel		Stainless Steel		All			
(inches)	Leaks	Ruptures	Leaks	Ruptures	Leaks	Ruptures	Carbon Steel	Stainless Steel
>0	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04
>4	1.66E-04	1.64E-04	1.51E-04	1.30E-04	1.57E-04	1.55E-04	1.66E-04	1.50E-04
>12	8.88E-05	1.24E-04	8.27E-05	5.20E-05	8.53E-05	1.06E-04	9.44E-05	8.13E-05
>24	6.09E-05	9.71E-05	5.79E-05	3.71E-05	5.92E-05	8.16E-05	6.66E-05	5.70E-05
> 30	4.49E-05	8.28E-05	3.93E-05	2.23E-05	4.17E-05	6.72E-05	5.09E-05	3.86E-05

Figure 1: Pipe Failure Frequencies by Pipe Category

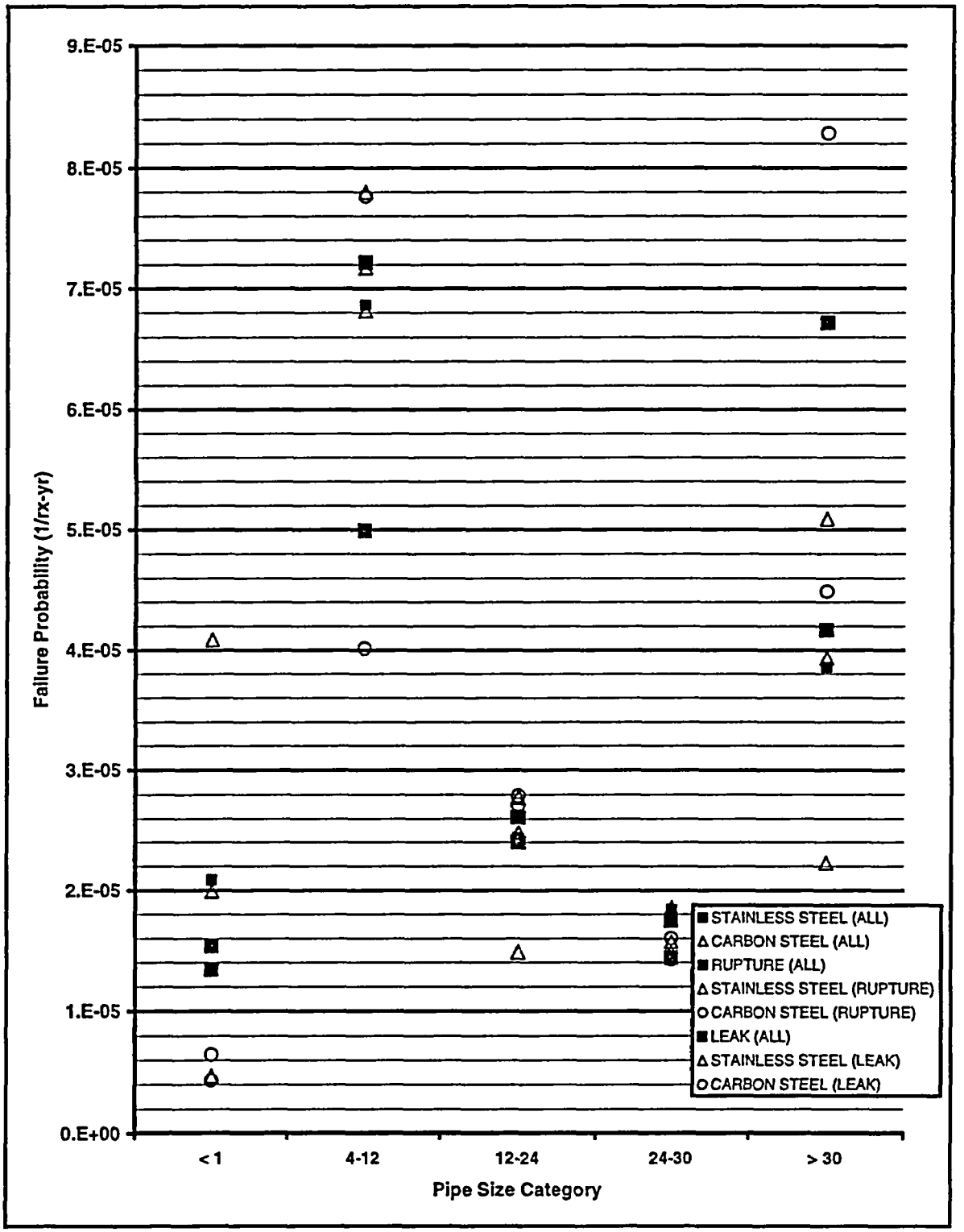
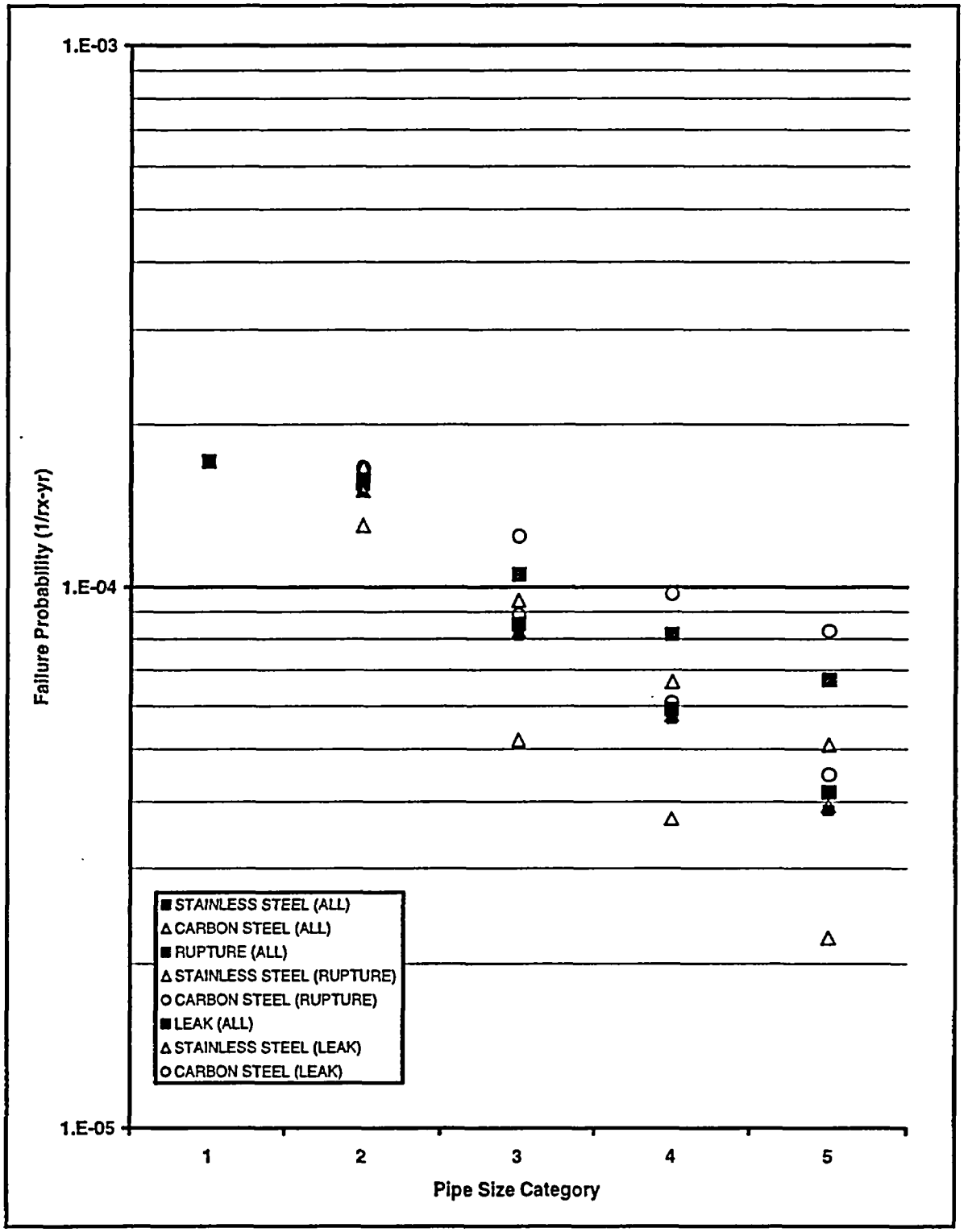


Figure 1: Pipe Failure Frequencies by Pipe Category (Cumulative)



5 COMPARISON OF DATA

The data generated in Section 4 of this report was compared to that from Reference 3 prior to drawing any conclusions from the data itself. This was done since the data from Reference 2 was compiled from an independent, reputable source and thus could be used to perform a preliminary check on the data used in this report.

The following is an excerpt of data taken from Reference 3 related to pipe break frequencies as a function of pipe size:

Table 9: Break Frequencies from Reference 3

Plant Type	LOCA Size (GPM)	Eff. Break Size (in)	Current Day Estimates (per cal. yr) (25 yr fleet average operation)				Next 15 Year Estimates (per cal. yr) (End of original license)			
			5%	Median	Mean	95%	5%	Median	Mean	95%
BWR	> 100	1/2	3.0E-05	2.2E-04	4.7E-04	1.7E-03	2.3E-05	2.0E-04	5.1E-04	1.9E-03
	> 1,500	1 7/8	2.2E-06	4.3E-05	1.3E-04	5.0E-04	1.8E-06	3.8E-05	1.2E-04	4.7E-04
	> 5,000	3 1/4	2.7E-07	5.7E-06	2.4E-05	9.4E-05	2.4E-07	4.7E-06	2.1E-05	8.0E-05
	> 25,000	7	6.6E-08	1.4E-06	6.0E-06	2.3E-05	5.7E-08	1.2E-06	6.6E-06	2.5E-05
	> 100,000	18	1.5E-08	1.1E-07	2.2E-06	6.3E-06	1.0E-08	1.2E-07	2.4E-06	6.9E-06
	> 500,000	41	3.5E-11	8.5E-10	2.3E-09	8.6E-09	2.8E-11	9.7E-10	2.5E-09	9.5E-09
PWR	> 100	1/2	7.3E-04	3.7E-03	6.2E-03	2.0E-02	3.0E-04	1.1E-03	2.1E-03	7.5E-03
	> 1,500	1 5/8	6.9E-06	9.9E-05	2.3E-04	8.5E-04	4.9E-06	1.0E-04	2.5E-04	9.3E-04
	> 5,000	3	1.6E-07	4.9E-06	1.6E-05	6.2E-05	3.1E-07	6.6E-06	1.8E-05	7.0E-05
	> 25,000	7	1.1E-08	6.3E-07	2.3E-06	8.8E-06	6.0E-08	6.3E-07	2.5E-06	9.6E-06
	> 100,000	14	5.7E-10	7.5E-09	3.9E-08	1.5E-07	9.3E-10	1.2E-08	6.1E-08	2.4E-07
	> 500,000	31	4.2E-11	1.4E-09	2.3E-08	7.0E-08	1.0E-10	2.8E-09	4.6E-08	1.7E-07

The data above, specifically the mean data, was compared with that from Section 4 of this report. Specifically, the calculated break frequencies from Table 8 were compared with those from Table 9 above.

The data in the above table shows a fall-off in the break frequency with increasing pipe size that is much faster than is shown in the Table 8 data. That is, while the low end of the pipe size shows good agreement between the two tables (i.e. 10^{-4}/rx-yr), the Table 9 data shows a decrease in frequency on the order of 10^{-5} at the high end of the break sizes. This is compared with the Table 8 data, which shows a decrease in frequency only on the order of 10^{-1}.

There is an obvious inconsistency in the frequency calculations between those in Table 8 and those in Table 9 (from Reference 3). This is most likely due to the sophisticated statistical approach that was used in the generation of the Reference 3 break frequencies. In this case, some statistical probability functions were probably used, based on empirical and theoretical data, in order to calculate break frequencies in light of the measured data available. For the purposes of this report the calculations are entirely based upon existing operation experience. Therefore, the probablity of failure is uniform across all break sizes as no statistical modifications or probabilities were used in calculations performed in this report.

As such a simplistic approach was taken in the generation of the data for this report, it is expected that the break frequencies calculated in this report are much too conservative. In this case, it is expected that the break frequencies calculated for this report will lead to conclusions about failures of large pipes that are biased to increase the risk of such failures by orders of magnitude.

Another possible cause for disagreement between Reference 1 and Reference 3 is that the data in Reference 3 takes into account the relative amounts of each pipe size in the plants at which each failure occurs. This approach was not taken in the generation of break frequencies in Reference 1.

6 CONCLUSIONS

The pipe failure frequency data generated in Section 4 of this report was evaluated, and conclusions were drawn based on these evaluations. The following are the major findings from the data.

1. **Pipe failure frequencies were found to not decrease significantly with increasing pipe diameter.** The data in Figure 1 (and Table 7) shows increasing failure frequencies with increasing pipe diameter in some cases. For instance, carbon steel pipe leakage and rupture frequencies were noted to reach their maximum in the largest pipe diameter group (>30 in). This would lead to the conclusion that steamline break (PWR) events could be quite probable, even though experience and common sense dictates otherwise.

   In the case of stainless steel pipe, the rupture frequency was noted to decrease slightly with decreasing pipe diameter. However, this decrease would be considered to be negligible since the frequencies are on the same order of magnitude. As stainless steel pipe is the material used in primary side components (i.e. the main coolant loops in a PWR) of nuclear reactors, this finding would lead to the conclusion that ruptures of the main coolant loops are as probable as rupture of much smaller pipes (i.e. on the order of 1" diameter). Again, this conclusion is contradicted by both experience and common sense (i.e. large break LOCAs are deemed to be hypothetical, limiting faults).

2. **Pipe failure frequencies were found to not agree well with the data from Reference 3.** This is discussed in more detail in Section 5 of this report.

As the data generated in this report seems to obviously contradict practical experience, sound engineering reason, and data documented independently from this report, it is concluded that no real conclusions can be drawn from the data in this report. That is, the reliability of the frequencies predicted by calculations is deemed to be very low, and thus it would be inappropriate to draw conclusions related to the risk of large pipe breaks from the evaluations documented in this report.

Based on the ratio of operational experience in reactor-years vs. actual number of documented piping breaks or leaks, it is also very difficult to determine that this is an adequite sample size to make global judgements concerning a particular break size or failure mechanisim. There may simply not be enough data points to get beyond the statistical noise associate with this investigation.

Other Thoughts

As the evaluations performed and documented in this report were not successful in leading to realistic conclusions related to break frequencies of large pipes in nuclear systems, some thought was given to the reasons why this exercise failed. The following are documented for consideration in future evaluations:

1. **Gather more data:** One of the major limitations in this exercise was the amount of failure data that was gathered prior to this evaluation. While a few databases of pipe failures do exist, the data available for public consumption is very limited. Specifically, the details of each recorded pipe failure (i.e. failure mechanism, type of pipe, use of pipe, age of pipe, etc) would be very valuable in the sorting and interpreting of the data.

2. **Use failure mechanics in interpretation of data:** In this report, it was assumed that all failures were equally probable. However, it is typically accepted that failure probability decreases with increasing pipe diameter. However, this is a function of many variables, including factors of safety employed, quality/manufacturing of materials, inspection and repair habits, etc. As much of this data that could be considered in the failure probability determination would be helpful in obtaining accurate failure frequencies.

3. **Obtain population sizes** for the catagories of pipe size used in Reference 1 and apply them to data from Reference 3.

7 REFERENCES

1. Nyman, R., et al. SKI Report 97:26, Reliability of Piping System Components, Framework for Estimating Failure Parameters from Service Data. December 1997, Swedish Nuclear Power Inspectorate.

2. Bush, Spencer. A Review of Nuclear Piping Failures and their use in Establishing the Reliability of Piping Systems. PVP Vol. 392 *Service Experience in Fossil and Nuclear Power Plants.* ASME 1999.

3. SECY-04-0060b, Attachment to 10 CFR 50.46, LOCA Frequency Development.

8 ATTACHMENTS

1. DrudyHahnMcgrewRobinsonPreliminaryData.xls – first complied database notcontaining information regarding pipe material from Reference 2.

2. DrudyHahnMcgrewRobinsonFinalData.xls – data compiled from Reference 1.

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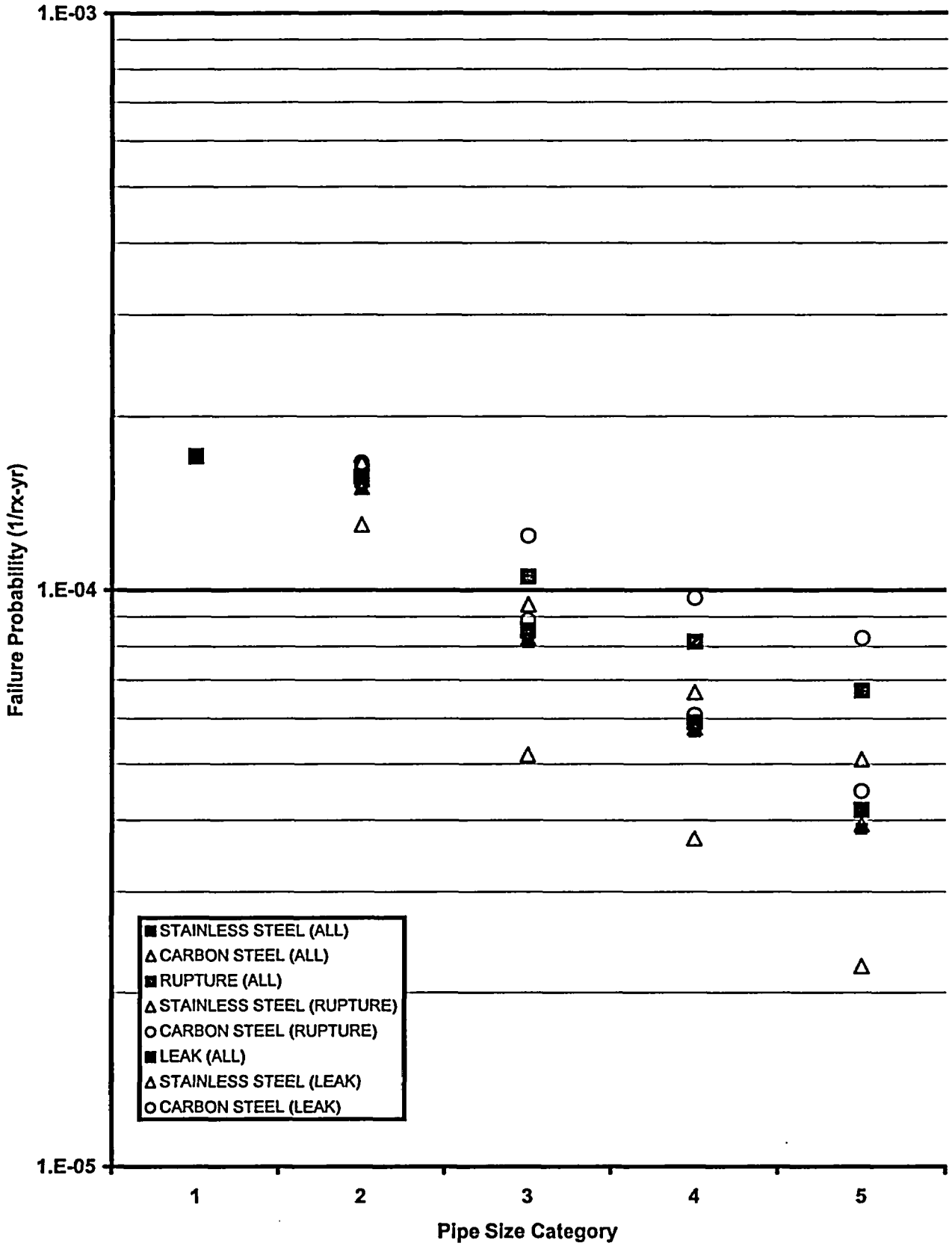
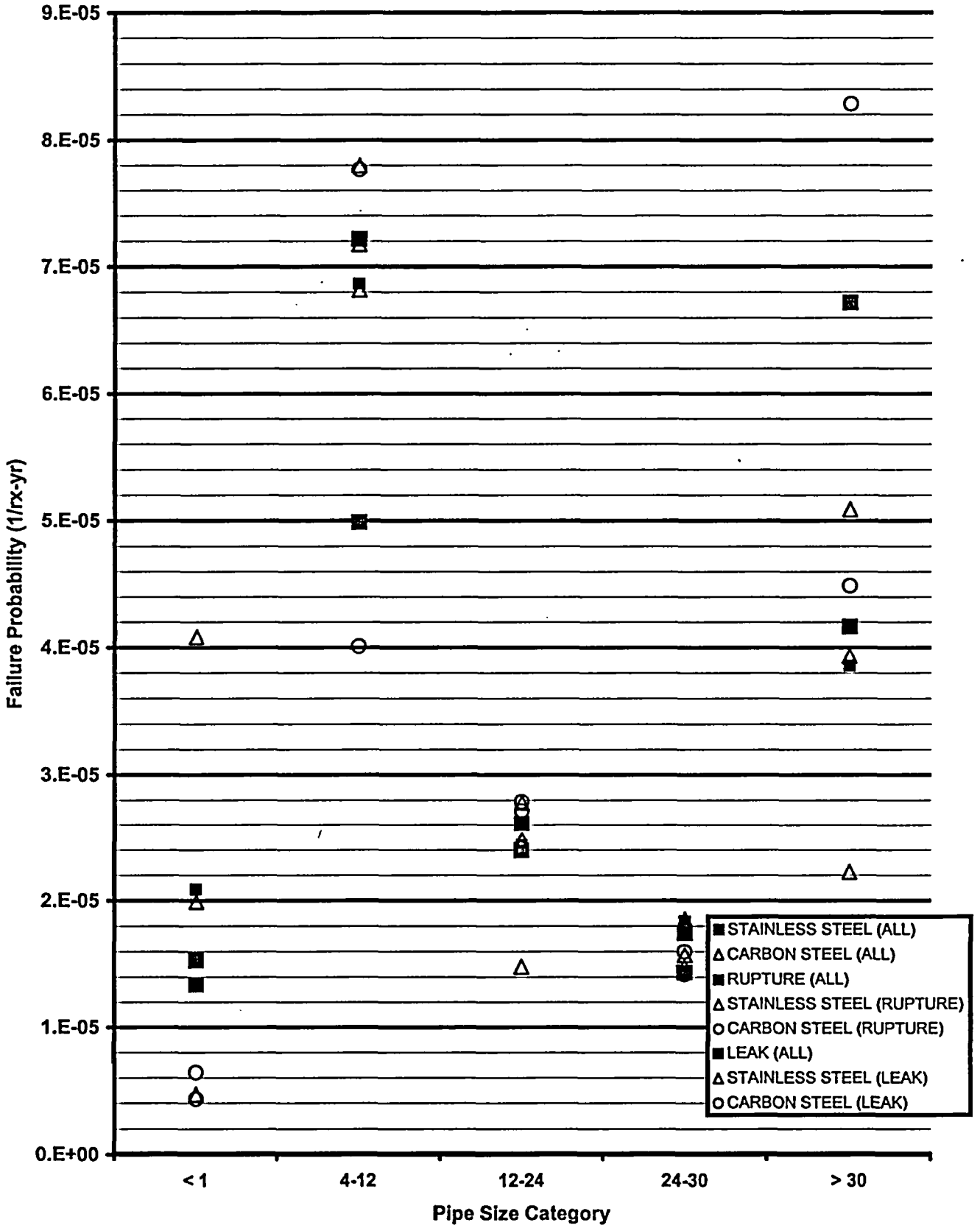
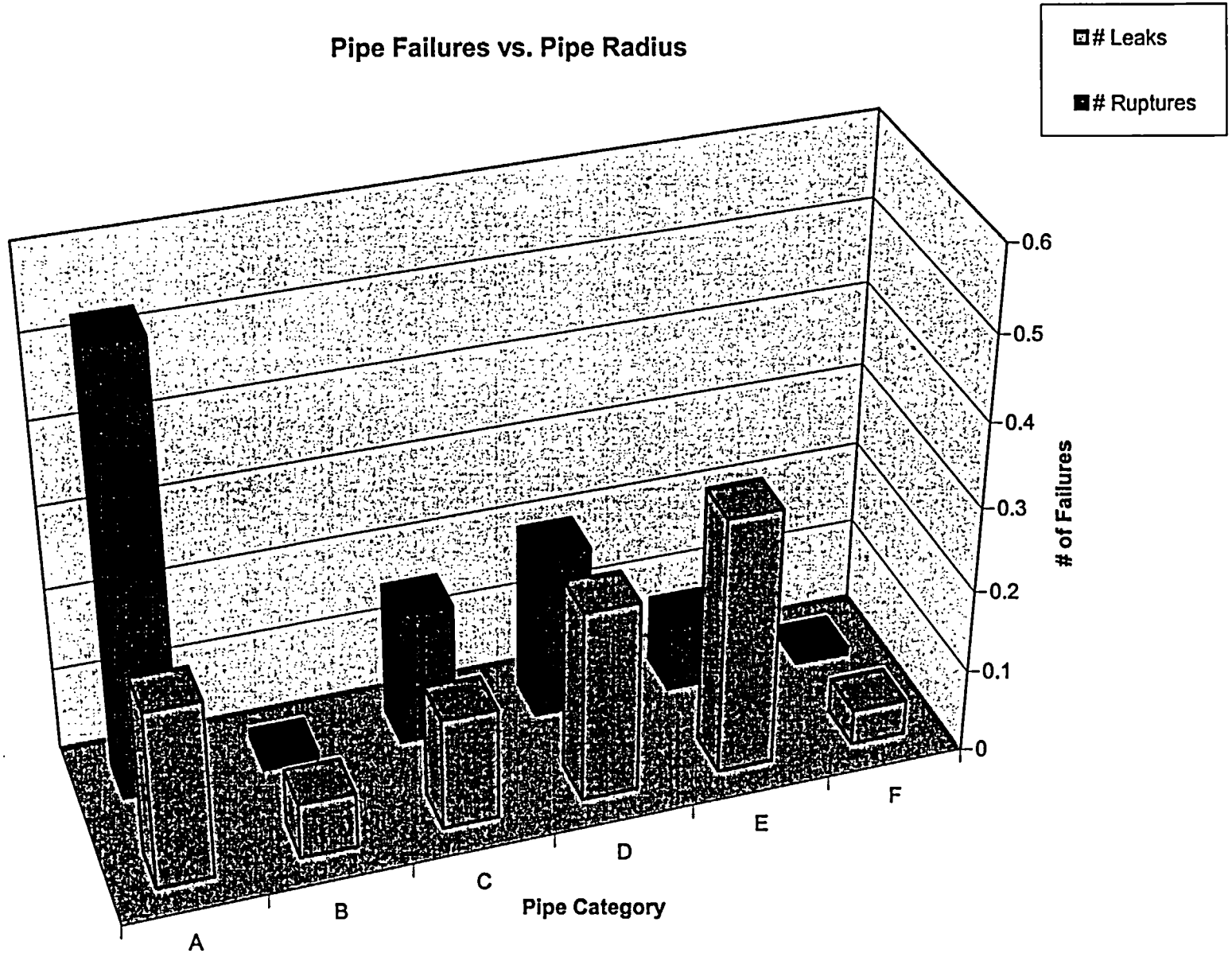

1.E-03
1.E-04
1.E-05
Failure Probability (1/rx-yr)
1
2
3
4
5
Pipe Size Category
STAINLESS STEEL (ALL)
CARBON STEEL (ALL)
RUPTURE (ALL)
STAINLESS STEEL (RUPTURE)
CARBON STEEL (RUPTURE)
LEAK (ALL)
STAINLESS STEEL (LEAK)
CARBON STEEL (LEAK)


9.E-05
8.E-05
7.E-05
6.E-05
5.E-05
4.E-05
3.E-05
2.E-05
1.E-05
0.E+00
Failure Probability (1/rx-yr)
< 1
4-12
12-24
24-30
> 30
Pipe Size Category
STAINLESS STEEL (ALL)
CARBON STEEL (ALL)
RUPTURE (ALL)
STAINLESS STEEL (RUPTURE)
CARBON STEEL (RUPTURE)
LEAK (ALL)
STAINLESS STEEL (LEAK)
CARBON STEEL (LEAK)

2500 psi
1005 F
18 inch OD
2.75 inch wall
carbon steel
rupture

Spencer Bush

Total Leaking		6500
Non-leaking and Leaking Events with most of data available		
number		4046
non-leaking		1817
	igscc	1331
	thinning	483
	delamination	2
	too thin	1
Leaking Events		
Number		2247
	small leak	1999
	large leak	65
	rupture	179
	separation	4


Pipe Failures vs. Pipe Radius
Leaks
Ruptures
0.6
0.5
0.4
0.3
0.2
0.1
0
# of Failures
A
B
C
D
E
F
Pipe Category

A	B	C	D	E	F
				1	
	51				
			9		
				4	
					1
	2				
		1			
			7		
				15	
					8

Plant Type	# plants surveyed	coverage (years)	Failure mode crack	leak	rupture
BWR	71	1398	114	648	63
LWGR	19	319	3	41	14
PHWR	20	354	11	75	14
CANDU	164	2670	55	1206	112
total	**274**	**4741**	**183**	**1970**	**203**

5853.0864 rx-years

1859 Points

Carbon Steel

pipe size (inches)	Leak ins air	oil	borated H2O	demin H2O	raw water	D20	Steam	total		
< 1	3	2	0	7	4	0	2		18	704
4--12	19	11	0	84	132	0	74		320	686
12--24	1	0	0	30	48	0	36		115	366
24--30	0	1	0	20	36	0	9		66	251
> 30	0	0	4	58	65	0	58		185	185
total	**23**	**14**	**4**	**199**	**285**	**0**	**179**		**704**	

pipe size (inches)	rupture ins air	oil	borated H2O	demin H2O	raw water	D20	Steam	total		
< 1	1	2	0	2	0	0	0		5	132
4--12	5	4	0	9	3	0	10		31	127
12--24	0	0	0	6	6	0	9		21	96
24--30	0	0	0	3	2	0	6		11	75
> 30	0	0	0	22	14	1	27		64	64
total	**6**	**6**	**0**	**42**	**25**	**1**	**52**		**132**	

Stainless Steel

pipe size (inches)	Leak ins air	oil	borated H2O	demin H2O	D2O	raw water	Gas (n2)	Steam	total		
< 1	2	12	68	25	3	2	0	2		114	977
4--12	14	3	227	118	10	9	0	9		390	863
12--24	1	0	97	41	1	1	0	1		142	473
24--30	0	0	27	75	0	1	0	3		106	331
> 30	0	0	83	130	1	0	8	3		225	225
total	**17**	**15**	**502**	**389**	**15**	**13**	**8**	**18**		**977**	

pipe size (inches)	rupture ins air	oil	borated H2O	demin H2O	D2O	raw water	Gas (n2)	Steam	total		
< 1	0	3	4	4	0	0	0	0		11	46
4--12	5	1	8	6	0	0	0	1		21	35
12--24	0	0	3	0	0	0	0	1		4	14
24--30	0	0	2	1	1	0	0	0		4	10
> 30	0	0	0	4	1	0	0	1		6	6
total	**5**	**4**	**17**	**15**	**2**	**0**	**0**	**3**		**46**	

Carbon Steel / Stainless Steel

pipe size (inches)	Leak corrosion	fatigue	IGSCC	human	other	total		rupture corrosion	fatigue	IGSCC	human	other	total
< 1	4	69	26	17	22	138		0	14	0	3	2	19
4--12	176	303	40	100	96	715		5	34	0	4	11	54
12--24	23	49	0	0	0	72		5	1	0	0	0	6
24--30	50	28	59	17	24	178		3	2	0	2	10	17
> 30	127	82	117	41	62	429		32	3	0	4	35	74
total	**380**	**531**	**242**	**175**	**204**			**45**	**54**	**0**	**13**	**58**	

Data Point Reference	Material SS or CS	Failure L or R	Failure Mechanism	Pipe Category	# Failures
1	CS	R	O - creep	D	1
2	?	L	FAT	A	294
2	?	L	FAT	B	29
2	?	L	FAT	C	54
2	?	L	FAT	D	9
2	?	L	FAT	E	2
2	?	R	FAT	A	51
2	?	R	FAT	C	9
2	?	R	FAT	D	4
2	?	R	FAT	F	1
2	?	L	ISCC	A	57
2	?	L	ISCC	B	72
2	?	L	ISCC	C	127
2	?	L	ISCC	D	441
2	?	L	ISCC	E	651
2	?	L	ISCC	F	1
2	?	L	FAC	A	136
2	?	L	FAC	B	50
2	?	L	FAC	C	124
2	?	L	FAC	D	76
2	?	L	FAC	E	54
2	?	L	FAC	F	94
2	?	R	FAC	A	2
2	?	R	FAC	B	1
2	?	R	FAC	C	7
2	?	R	FAC	D	15
2	?	R	FAC	E	8
		2370			

A - Aging
C - Corrosion
D - Defects, Construction Errors
MD - Mechanical Damage/Vibration/Loading
WR - Wear
WH - Water Hammer
FAC - Flow Assisted Corrosion (FAC)
FAT - Fatigue
SCC - Intergranular Stess Corrosion Cracking
O - Other

A - 0 to 1 inch
B - 1 to 4 inch
C - 4 to 12 inch
D - 12 to 18 inch
E - 18 to 30 inch
F - >28 inch

1 - MAIN STEAM LINK FAILURE KANSAS POWER & LIGHT PVP-Vol. 392 ASME 1999
2 - A Review of Nuclear Piping Failures and their use in Establishing the Reliability of Piping Systems PVP-392 ASME 1999
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10 -
11 -
12 -
13 -
14 -
15 -
16 -
17 -
18 -
19 -
20 -

Data Point Reference	Material SS or CS	Failure L or R	Failure Mechanism	Pipe Category	# Failures
1	CS	R	O - creep	D	1
2	?	L	FAT	A	294
2	?	L	FAT	B	29
2	?	L	FAT	C	54
2	?	L	FAT	D	9
2	?	L	FAT	E	2
2	?	R	FAT	A	51
2	?	R	FAT	C	9
2	?	R	FAT	D	4
2	?	R	FAT	F	1
2	?	L	ISCC	A	57
2	?	L	ISCC	B	72
2	?	L	ISCC	C	127
2	?	L	ISCC	D	441
2	?	L	ISCC	E	651
2	?	L	ISCC	F	1
2	?	L	FAC	A	136
2	?	L	FAC	B	50
2	?	L	FAC	C	124
2	?	L	FAC	D	76
2	?	L	FAC	E	54
2	?	L	FAC	F	94
2	?	R	FAC	A	2
2	?	R	FAC	B	1
2	?	R	FAC	C	7
2	?	R	FAC	D	15
2	?	R	FAC	E	8
		2370			

A - Aging
C - Corrosion
D - Defects, Construction Errors
MD - Mechanical Damage/Vibration/Loading
WR - Wear
WH - Water Hammer
FAC - Flow Assisted Corrosion (FAC)
FAT - Fatigue
SCC - Intergranular Stess Corrosion Cracking
O - Other

A - 0 to 1 inch
B - 1 to 4 inch
C - 4 to 12 inch
D - 12 to 18 inch
E - 18 to 30 inch
F - >28 inch

1 - MAIN STEAM LINK FAILURE KANSAS POWER & LIGHT PVP-Vol. 392 ASME 1999
2 - A Review of Nuclear Piping Failures and their use in Establishing the Reliability of Piping Systems PVP-392 ASME 1999
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11 -
12 -
13 -
14 -
15 -
16 -
17 -
18 -
19 -
20 -

A	B	C	D	E	F
	294				
		29			
			54		
				9	
					2

	57				
		72			
			127		
				441	
					651
						1
	136				
		50			
			124		
				76	
					54
						94

Pipe Category	# Leaks	# Ruptures
A	487	53
B	151	1
C	305	16
D	526	20
E	707	8
F	95	1
	2271	99

A	0.214443	0.535354
B	0.066491	0.010101
C	0.134302	0.161616
D	0.231616	0.20202
E	0.311317	0.080808
F	0.041832	0.010101

Pipe	Pipe Failure Frequences (1/rx-yr)							
Size	Carbon Steel		Stainless Steel		All	All	All	All
(inches)	Leaks	Ruptures	Leaks	Ruptures	Leaks	Ruptures	Carbon Steel	Stainless Steel
>0	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04
>4	1.66E-04	1.64E-04	1.51E-04	1.30E-04	1.57E-04	1.55E-04	1.66E-04	1.50E-04
>12	8.88E-05	1.24E-04	8.27E-05	5.20E-05	8.53E-05	1.06E-04	9.44E-05	8.13E-05
>24	6.09E-05	9.71E-05	5.79E-05	3.71E-05	5.92E-05	8.16E-05	6.66E-05	5.70E-05
> 30	4.49E-05	8.28E-05	3.93E-05	2.23E-05	4.17E-05	6.72E-05	5.09E-05	3.86E-05

Pipe	Pipe Failure Frequences (1/rx-yr)							
Size	Carbon Steel		Stainless Steel		All	All	All	All
(inches)	Leaks	Ruptures	Leaks	Ruptures	Leaks	Ruptures	Carbon Steel	Stainless Steel
< 1	4.37E-06	6.47E-06	1.99E-05	4.09E-05	1.34E-05	1.54E-05	4.70E-06	2.09E-05
4-12	7.77E-05	4.01E-05	6.82E-05	7.80E-05	7.22E-05	4.99E-05	7.17E-05	6.86E-05
12-24	2.79E-05	2.72E-05	2.48E-05	1.49E-05	2.61E-05	2.40E-05	2.78E-05	2.44E-05
24-30	1.60E-05	1.42E-05	1.85E-05	1.49E-05	1.75E-05	1.44E-05	1.57E-05	1.84E-05
> 30	4.49E-05	8.28E-05	3.93E-05	2.23E-05	4.17E-05	6.72E-05	5.09E-05	3.86E-05