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USNRC

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OFFICE OF SECRETARY
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ADJUDICATIONS STAFF

Dr. Brian W. Sheron
Associate Director for Project Licensing and Technical Analysis
U.S. Nuclear Regulatory Commission
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Rockville, MD 20852-2738

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

U.S. NUCLEAR REGULATORY COMMISSION
In the Matter of Entergy Nuclear Vermont Yankee LLC
Docket No. 50-271 Official Exhibit No. NEC-UW-15
OFFERED by: Applicant/Licensee Intervenor NEC
NRC Staff Other
IDENTIFIED on 7/23/08 Witness/Panel Wide
Action Taken: ADMITTED REJECTED WITHDRAWN
Reporter/Clerk MAC

Template Secy-028

DS-03

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.

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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.

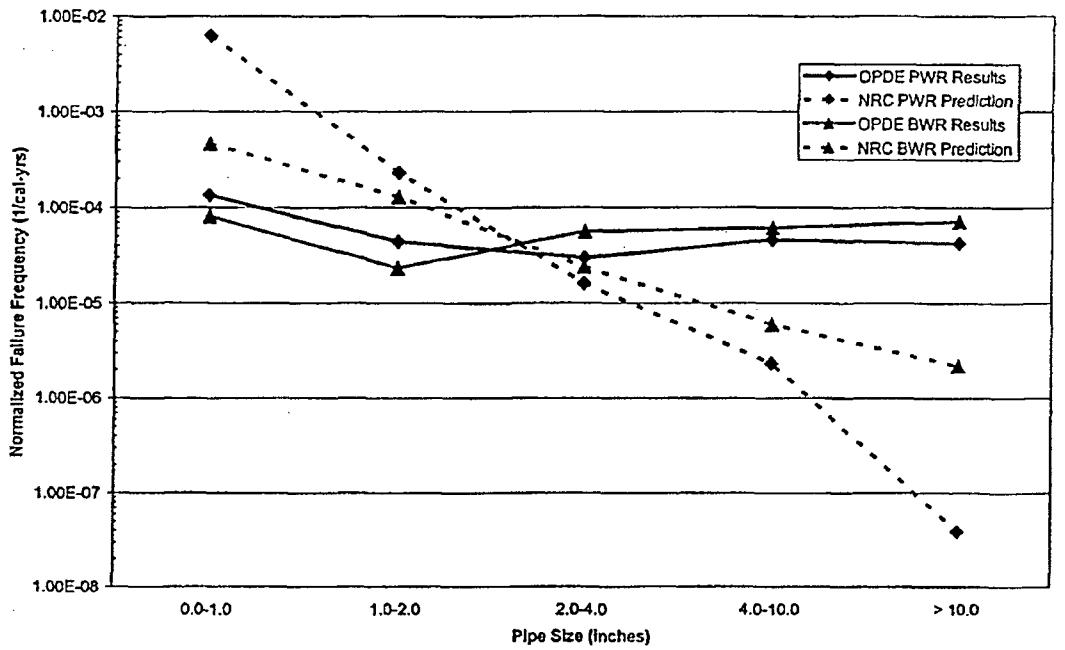

Figure 4.1-1. Normalized pipe failure frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants.

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.

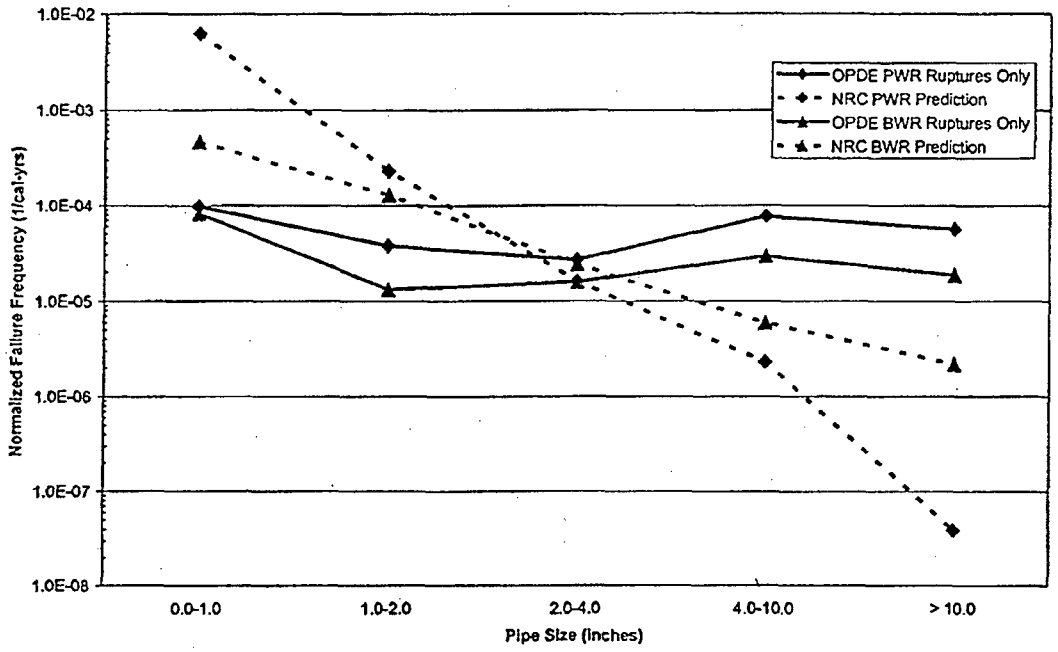

Figure 4.1-2 Normalized rupture frequencies as a function of pipe group size for both carbon and stainless steel pipe failures in both BWR and PWR plants.

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.

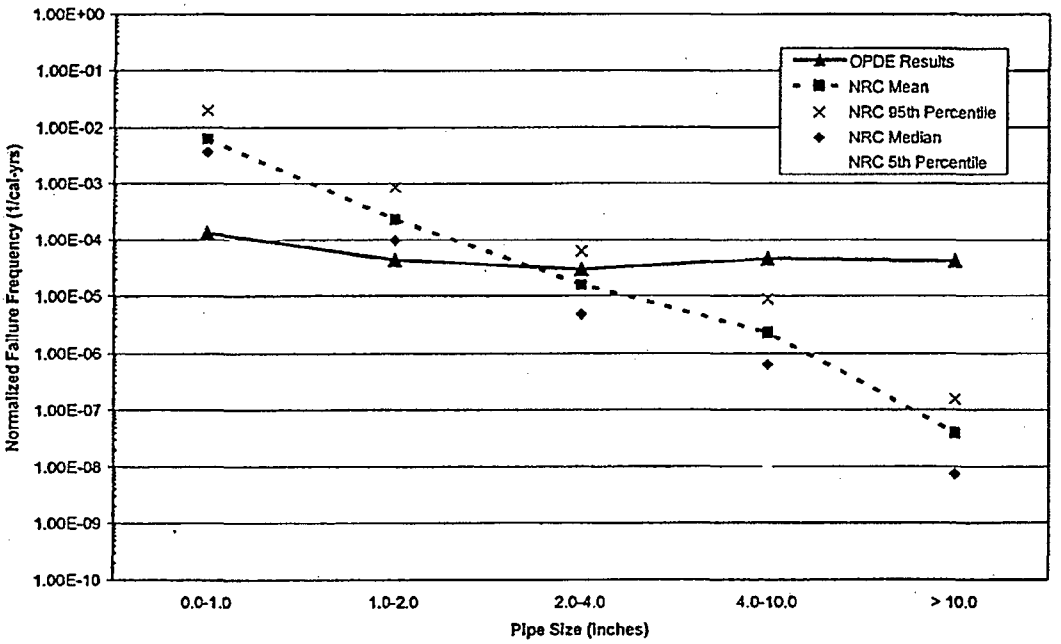

Figure 4.1-3. Normalized Failure Frequency Distribution for PWRs.

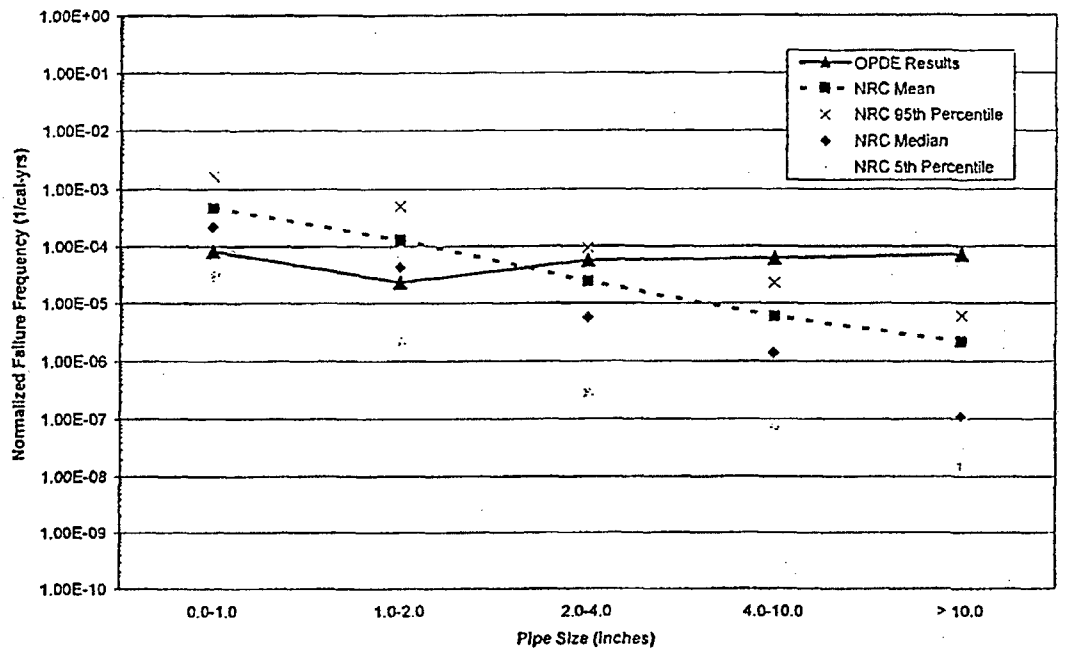

Figure 4.1-4. Normalized Failure Frequency Distribution for BWRs.

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.

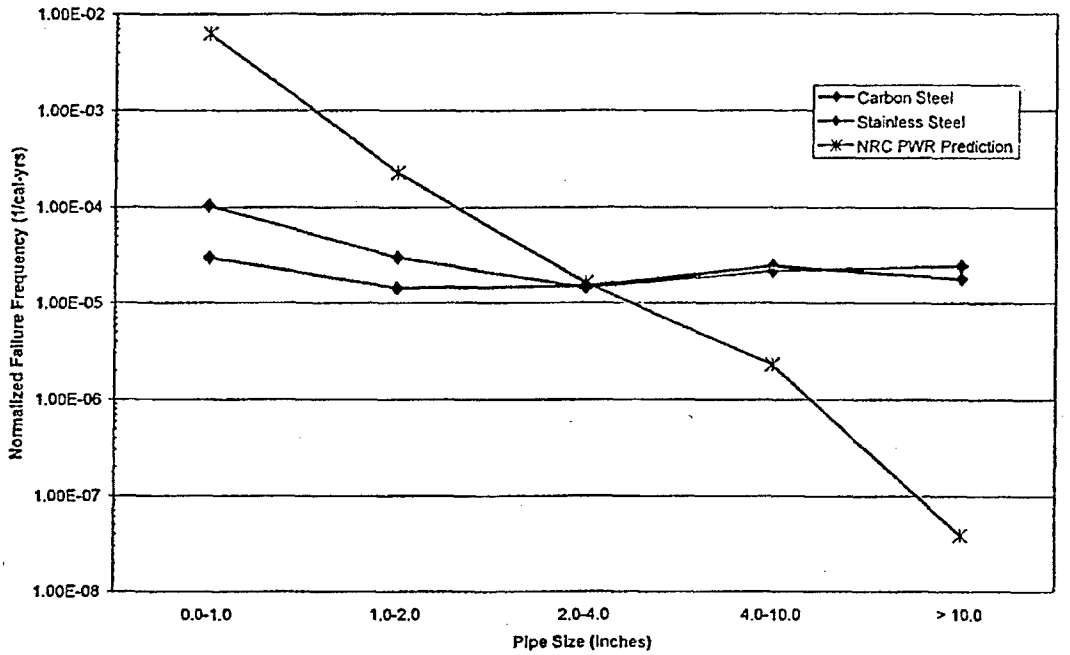

Figure 4.1-5. Normalized pipe failure frequencies as a function of pipe size for PWRs.

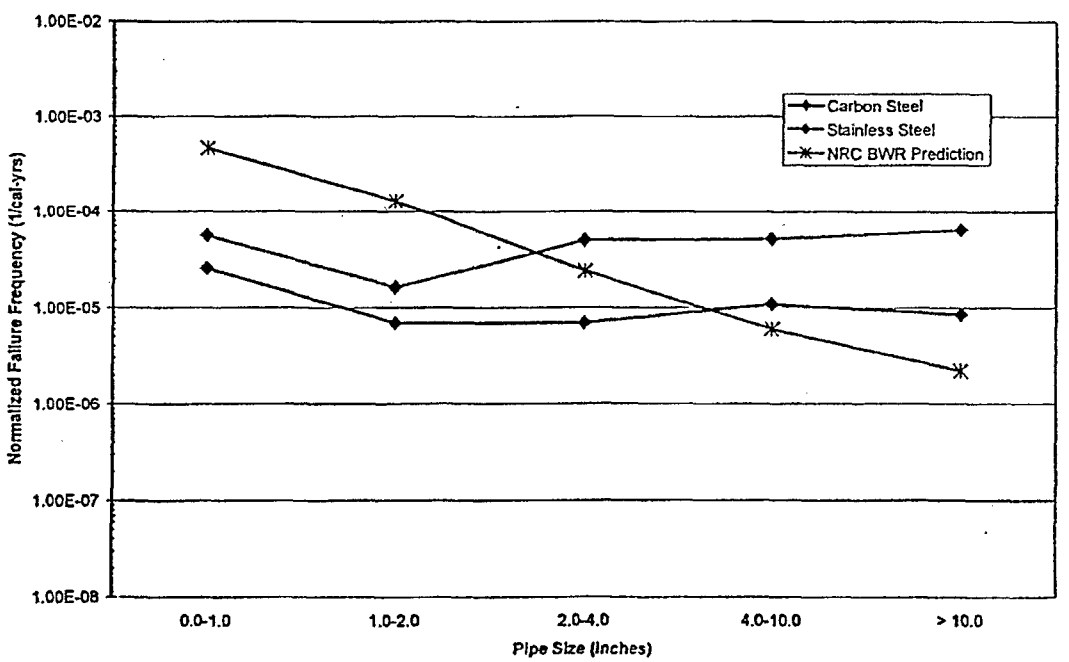

Figure 4.1-6. Normalized pipe failure frequencies as a function of pipe size for BWRs.

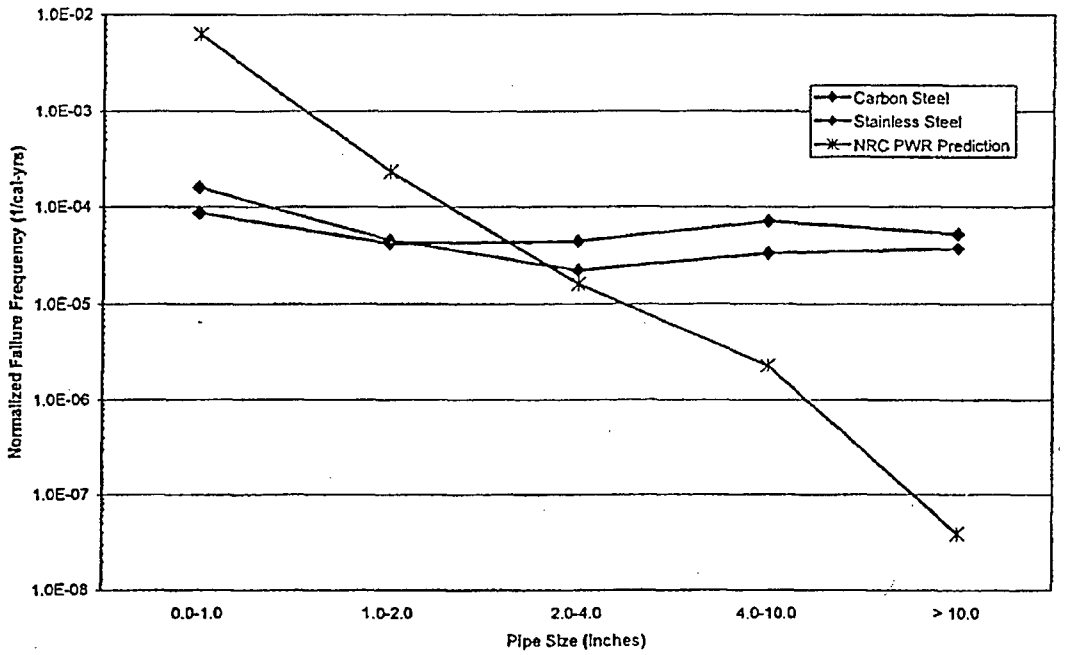

Figure 4.1-7. Normalized pipe failure frequencies as a function of pipe size for PWRs using the Modified Analysis Method.

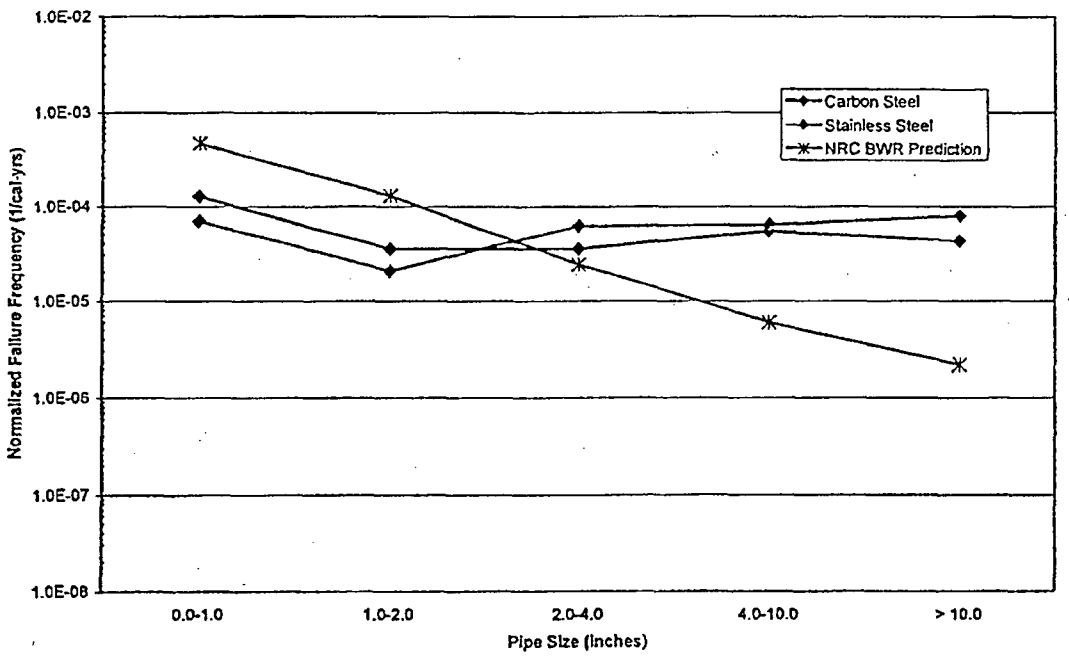

Figure 4.1-8. Normalized pipe failure frequencies as a function of pipe size for BWRs using the Modified Analysis Method.

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.

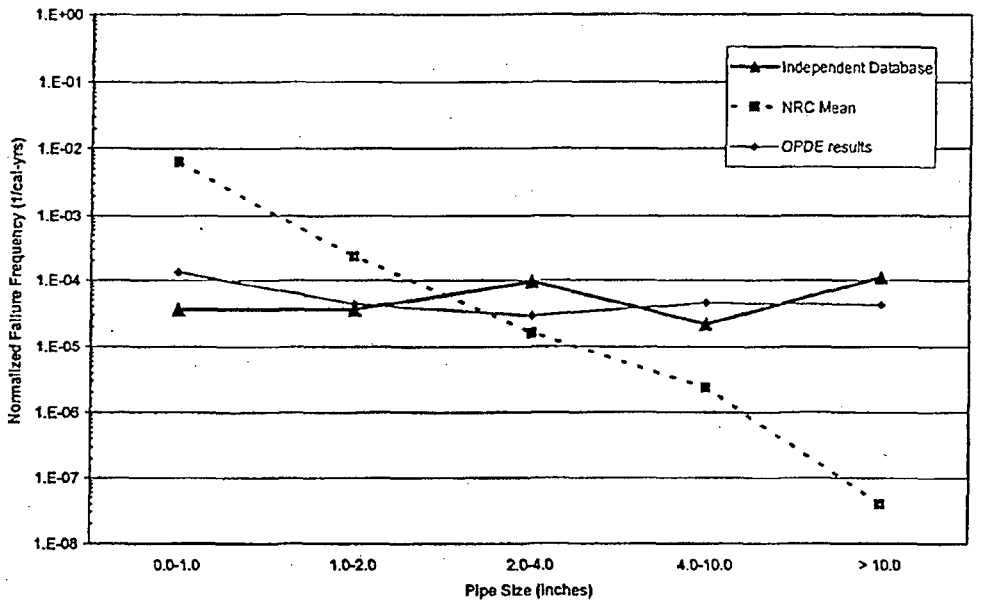

Figure 4.2-1. Normalized pipe failure frequency as a function of Pipe Group Size for PWRs.

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.

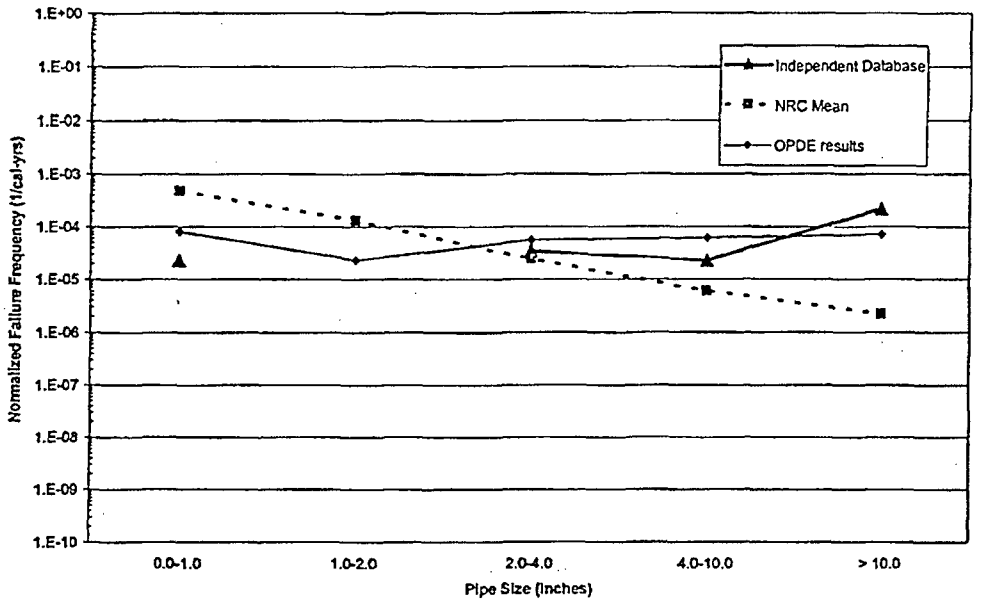

Figure 4.2-2. Normalized pipe failure frequency as a function of Pipe Group Size for BWRs.

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

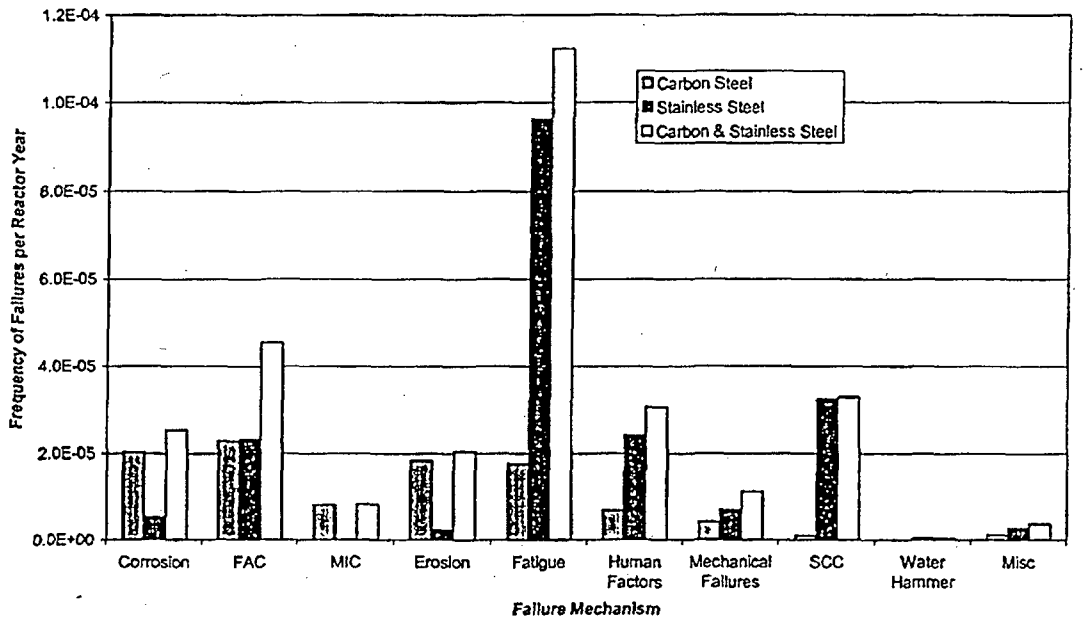

Figure 4.3-1. PWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

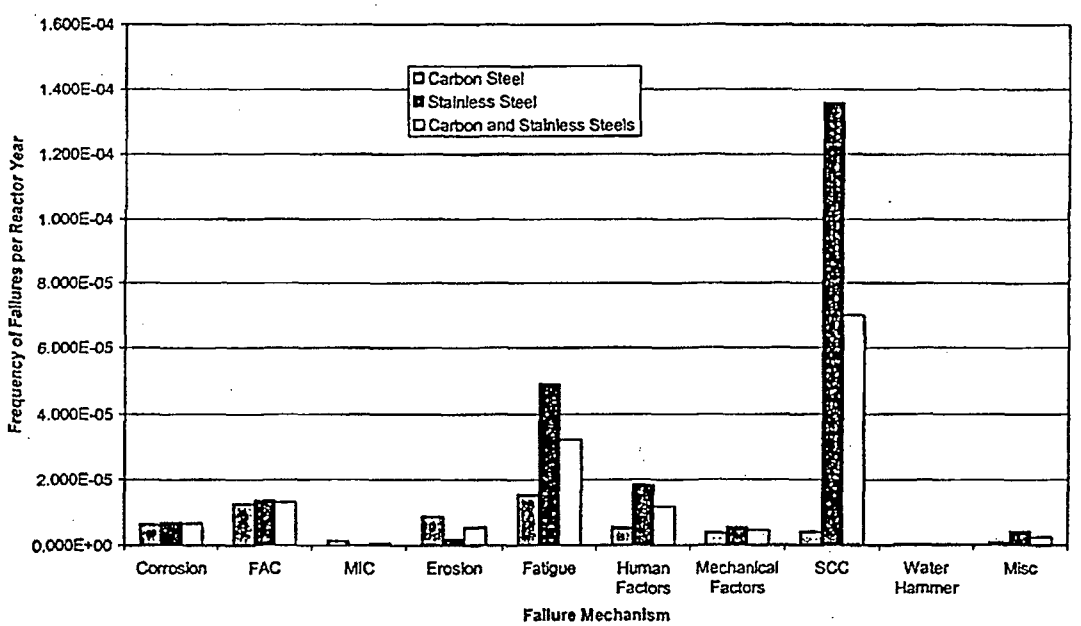

Figure 4.3-2. BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

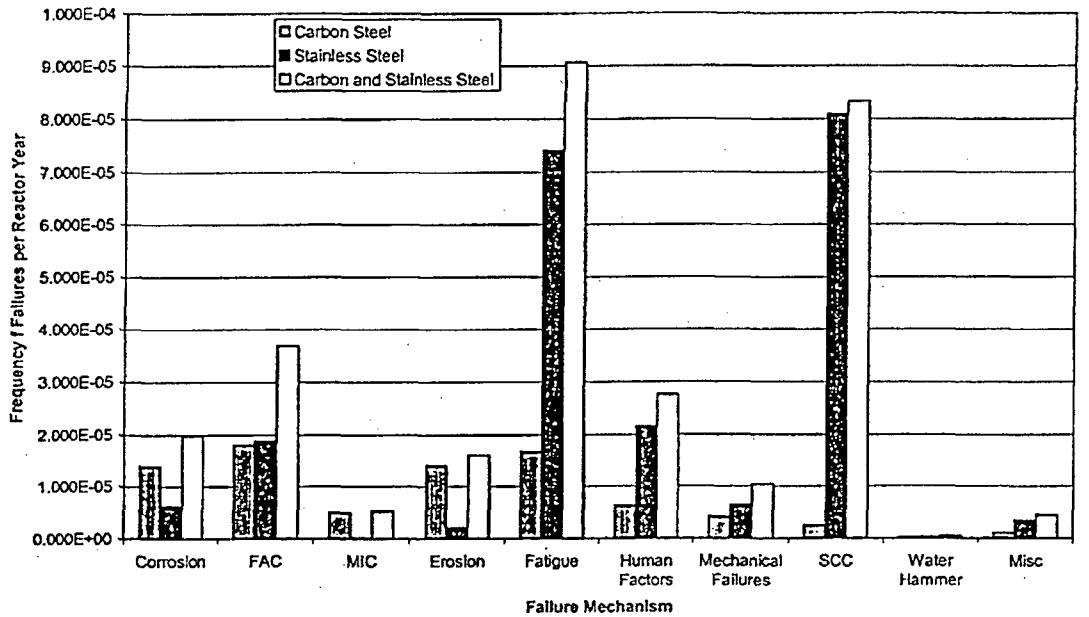

Figure 4.3-3. PWR and BWR Failure Frequency for Carbon and Stainless Steel Pipes as a Function of Failure Mechanism

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.

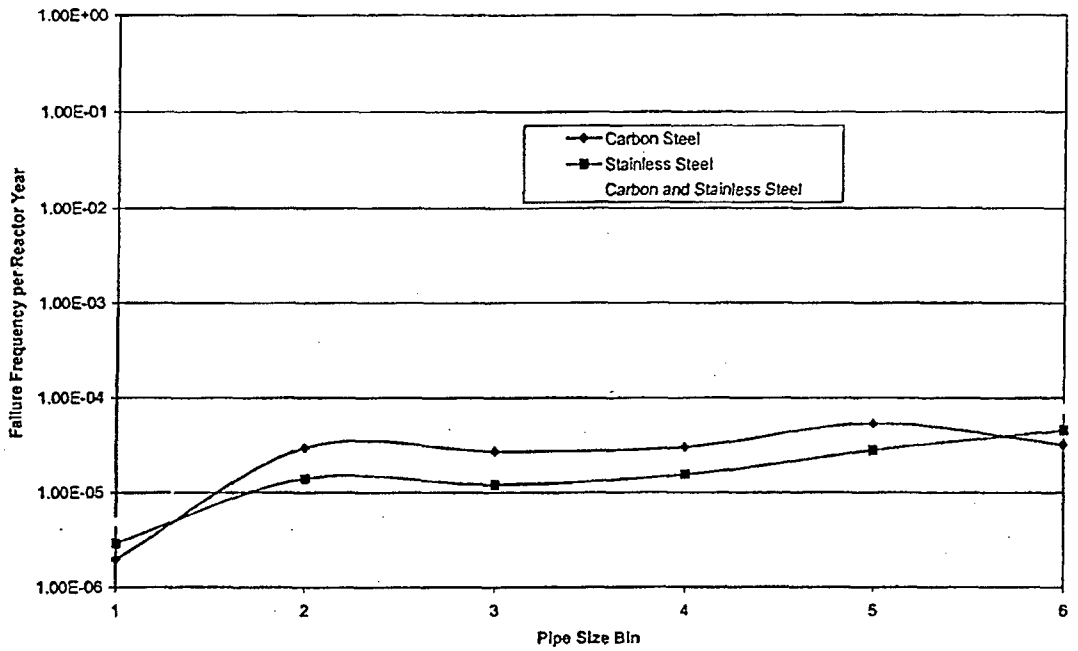

Figure 4.3-4. Pipe Failure by Corrosion as a Function of Pipe Size (PWR & BWR)

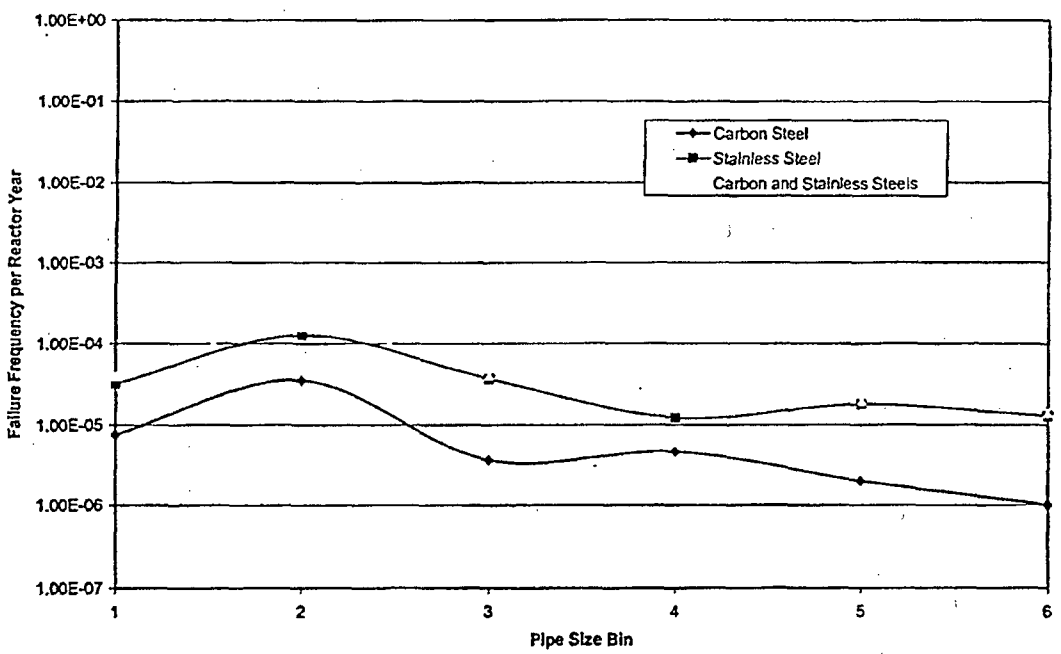

Figure 4.3-5. Pipe Failure by Fatigue as a Function of Pipe Size (PWR & BWR)

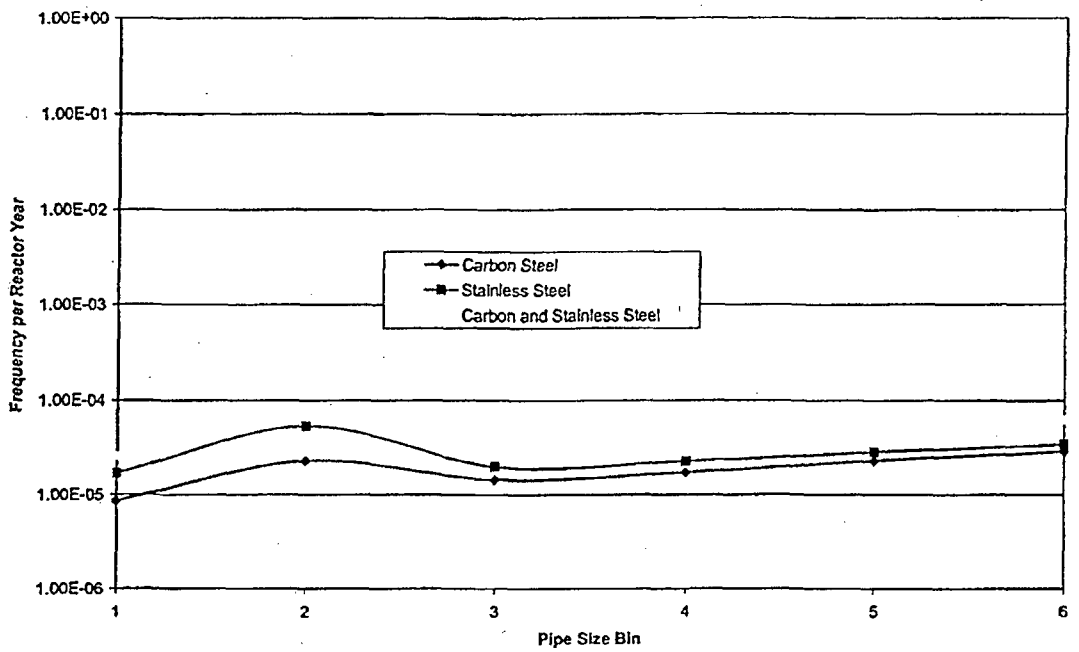

Figure 4.3-6. Pipe Failure by Mechanical Failures as a Function of Pipe Size (PWR & BWR)

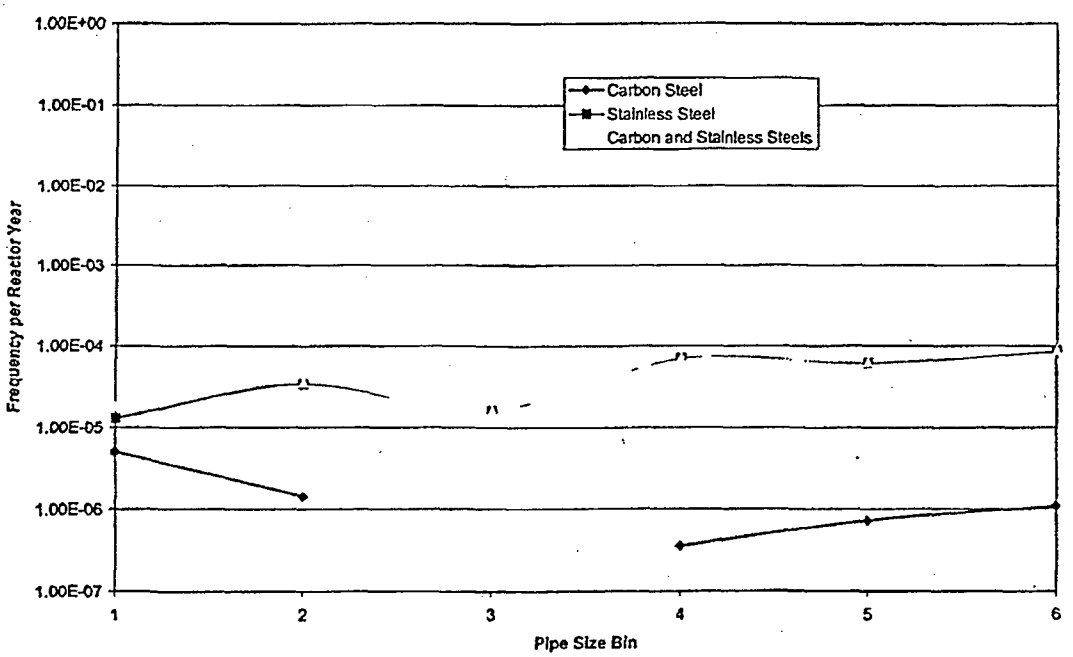

Figure 4.3-7. Pipe Failure by Stress Corrosion Cracking as a Function of Pipe Size (PWR & BWR)

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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16) Rossi, Charles E., Information Notice 91-18: HIGH-ENERGY PIPING FAILURES CAUSED BY WALL THINNING, March 12, 1991.

17) Grimes, Brian K., Information Notice 95-11: FAILURE OF CONDENSATE PIPING BECAUSE OF EROSION/CORROSION AT A FLOW-STRAIGHTENING DEVICE, February 24, 1995.

18) Weaver, Brian, Event Notification Report 36016: MANUAL REACTOR TRIP DUE TO HEATER DRAIN LINE BREAK, August 12, 1999.

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20) Rossi, Charles E., Information Notice 89-07: FAILURES OF SMALL-DIAMETER TUBING IN CONTROL AIR, FUEL OIL, AND LUBE OIL SYSTEMS WHICH RENDER EMERGENCY DIESEL GENERATORS INOPERABLE, January 25, 1989.

21) Rossi, Charles E., Information Notice 88-08: THERMAL STESSES IN PIPING CONNECTED TO REACTOR COOLANT SYSTEMS, April 11,1989.

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23) Martin, Thomas T., Information Notice 97-19: SAFETY INJECTION SYSTEM WELD FLAW AT SEQUOYAH NUCLEAR POWER PLANT, UNIT 2, April 18, 1997.

24) Slosson, Marylee M., Information Notice 97-46: UNISOLABLE CRACK IN HIGH-PRESSURE INJECTION PIPING, July 9, 1997.

25) Rossi, Charles E., Information Notice 91-05: INTERGRANULAR STRESS CORROSION CRACKING IN PRESSURIZED WATER REACTOR SAFETY INJECTION ACCUMULATOR NOZZLES, January 30, 1991.

26) Rossi, Charles E., Information Notice 92-15: FAILURE OF PRIMARY SYSTEM COMPRESSION FITTING, February 24, 1992.

27) Grimes, Brian K., Information Notice 93-20: THERMAL FATIGUE CRACKING OF FEEDWATER PIPING TO STEAM GENERATORS, March 24, 1993.

28) Knapp, Malcolm R., Information Notice 94-38: RESULTS OF A SPECIAL NRC INSPECTION AT DRESDEN NUCLEAR POWER STATION UNIT 1 FOLLOWING A RUPTURE OF SERVICE WATER INSIDE CONTAINMENT, May 27, 1994.

29) NRC Bulletin 74-10A: FAILURES IN 4--INCH BYPASS PIPING AT DRESDEN-2, 12/17/74.

30) Davis, John G., Information Notice 75-01: THROUGH-WALL CRACKS IN CORE SPRAY PIPING AT DRESDEN-2, January 31, 1975.

31) NRC Bulletin 76-04: CRACKS IN COLD WORKED PIPING AT BWR'S, March 30, 1976.

32) Thompson, Dudley, Circular 76-06: STRESS CORROSION CRACKS IN STAGNANT, LOW PRESSURE STAINLESS PIPING CONTAINING BORIC ACID SOLUTION AT PWR's, November 22, 1976.

33) NRC Bulletin 79-03: LONGITUDINAL WELD DEFECTS IN ASME SA -312 TYPE 304 STAINLESS STEEL, March 12, 1979.

34) NRC Bulletin 79-13: CRACKING IN FEEDWATER SYSTEM PIPING, June 25, 1979.

35) Moseley, Norman C., Information Notice 79-19: PIPE CRACKS IN STAGNANT BORATED WATER SYSTEMS AT PWR PLANTS, July 17, 1979.

36) NRC Information Notice No. 81-04: CRACKING IN MAIN STEAM LINES, February 27, 1981.

37) Sheron, Dr. Brian, Proposed Modifications to ECCS Analysis Requirements, Presentation at Penn State University, September 23, 2004.

38) NRC Document, 10 CFR 50.46 LOCA Frequency Document (Attachment).

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	6	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			6	1
PWR	CS	AUXC	Erosion-corrosion	6	20	1				3	5	1		10	
PWR	CS	AUXC	Erosion-corrosion	6	20				3	1	9			7	
PWR	CS	AUXC	External impact	6	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	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			6	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	6	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	6	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	6	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	6							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	6	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	6	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	6	1									1	
PWR	CS	PCS	Fretting	3	1									1	
PWR	CS	PCS	HF:Welding error	6	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	6	4									4	
PWR	SS	RAS	B/A-SCC	2	2						1			1	
PWR	SS	RAS	B/A-SCC	3	6		1							4	
PWR	SS	RAS	Brittle-Fracture	1	1				1						
PWR	SS	RAS	Cavitation-erosion	6	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					6	
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	6	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.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	6	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	6	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	6	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	6	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	6	1						1				
BWR	CS	AUXC	HF:Fabrication Error	6	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	6	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	6	1		1								
BWR	SS	Containment System	Corrosion	2	1									1	
BWR	SS	Containment System	HF.CONST/INST	6	1		1								
BWR	SS	Containment System	IGSCC - Intergranular SCC	6	1		1								
BWR	SS	Containment System	Severe overloading	6	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	6	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	6	2					1	1				
BWR	CS	FPS	FAC - Flow Accelerated Corrosion	4	1						1				
BWR	CS	FPS	Fretting	6	1									1	
BWR	CS	FPS	HF.CONST/INST	6	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	6	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	6	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		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	6	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	6	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	6	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	6	4		1				1			2	
BWR	SS	RAS	IDSCC - Interdendritic SCC	4	1					1					
BWR	SS	RAS	IGSCC - Intergranular SCC	2	6						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	6	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	6	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	6	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	6	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	6	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	6	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	6	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:CONSTANST	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	6	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*

Appendix D - References

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