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The In-Plant Reliability Data Base for Nuclear Plant Components: Interim Report—The Valve Component

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Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Risk Analysis
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FOREWORD

During the preparation of WASH-1400 and subsequent to its publication, the nuclear community recognized the need for more comprehensive sources of reliability data. In response to that need several efforts were undertaken:

1. An American National Standards Institute (ANSI)/Edison Electric Institute (EEI)/Nuclear Regulatory Commission (NRC)-sponsored effort to collect safety component failure information was organized under the auspices of the then-designated N18-20 Committee of the American Nuclear Society (ANS). This effort was called the Nuclear Plant Reliability Data System (NPRDS).
2. An Institute of Electrical and Electronics Engineers Subcommittee 5 sponsored effort to collect electrical and electronic equipment failure rates led to the publication of IEEE Standard 500.
3. An NRC-sponsored program with EG&G Idaho was undertaken to supplement the failure-frequency information contained in the LERs. Estimates of population and exposure (time and demands) were made to permit failure rate estimates on major plant components (pumps, valves, diesels, etc.).

These efforts greatly expanded the base of available information although none of the data were extracted directly from records existing in the plants.

An effort was organized under the auspices of the ANSI/Failure and Incidents Reports Review (FIRR) Data Subcommittee to contact individual plant sites and arrange for visits by data collection teams to extract data from in-plant maintenance records, and to attempt to construct a base of reliability data from these collected records. Because of the magnitude of each plant effort, the scope was limited to a few sample plants. The initial data extraction, data encoding, and data analysis effort was directed at the components considered to be most significant (viz., pumps and valves). This effort was named the In-Plant Reliability Data System (IPRDS).

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The Institute of Electrical and Electronics Engineers (IEEE) Office of Standards provided assistance in data handling and storage, as secretariat to the American National Standards Institute/Failure and Incidents Reports Review (ANSI-FIRR) Committee. The IEEE Subcommittee on Reliability (SC-5) provided technical assistance as well as coordination of the data collection plant visits.

EXECUTIVE SUMMARY

This document details the data collection and preliminary analyses related to valves in the In-Plant Reliability Data System. The data base is developed primarily from historical records of corrective maintenance actions obtained directly from nuclear plant maintenance files. A comprehensive valve population is also included. The results in this report represent the data from one PWR and one BWR power plant in the data base.

The purpose of this report is to demonstrate the degree of distinction and refinement in the reliability statistics that is possible with data from the IPRD and to suggest a general format for disclosure of suitable reliability statistics to satisfy needs within the nuclear data community. The examples given in the various tables and figures are suggested methods of comparing valve data and are representative of the degree to which reliability statistics for any particular valve can be ascertained. The refinement of the summary data available from IPRD as to the precise valve (i.e., valve type, valve size, and operating parameters) is compared to the refinement found in WASH-1400[1] and from LER[2].

One objective of this report is to examine the improvement possible using IPRD in refining the statistics to ultimately focus on the reliability of specific valve types and operators in specific operating environments in the U.S. nuclear power plants. The second objective is to generate comments from members of the nuclear data community as to the efficacy of the suggested formats for documenting valve information and the various methods used for comparison in this report. These comments will be used to improve the reporting in a valve data manual which will cover information from an expanded data base in the IPRDS. The results presented here should be treated as preliminary, and therefore, only as examples of the statistics that could be made available in a valve data manual from an enlarged data base.

Failure rate calculations are shown graphically for selected valves and results are compared to failure rate estimates in WASH-1400 and LERs. Presented in this report are breakdowns of failure rates by failure modes and by failure causes showing calculated maintenance frequencies and repair times. IPRDS Repair time distributions, unavailable from LERs, are also presented and evaluated. A short study of safety relief valves is presented in the appendix.

The major observation in this report is that the preliminary results obtained from the pilot data base indicate WASH-1400 statistics may be nonconservative for reliability estimates for some valve types in certain failure modes. Conclusive results are not possible due to the size of this pilot data base.

THE IN-PLANT RELIABILITY DATA BASE FOR NUCLEAR PLANT COMPONENTS: INTERIM REPORT — THE VALVE COMPONENT

ABSTRACT

This report on valves in the IPRDS documents the type of reliability information that could be generated using the current IPRDS methodology on an expanded data base. Preliminary results and various methods for their documentation are presented as suggested methods for reporting results in a data manual. Comparison of preliminary results within a plant, between plants, and among other data sources are made to exemplify some of the alternate uses of the IPRDS information that would be possible with an expanded data base.

1. INTRODUCTION

1.1 Program Description and Objectives

The objective of the In-Plant Reliability Data (IPRD) program is to develop a comprehensive, component-specific data base for probabilistic risk assessment and for other statistical analyses relevant to component reliability evaluations. This objective is being attained through a cooperative effort with several utilities, wherein each utility provides access to the maintenance files and pertinent population information, and in return, receives computerized listings and tapes of their component populations (equipment lists) and the component maintenance records. This data base includes (1) a component population list for each plant including electromechanical and mechanical equipment and (2) comprehensive component failure and repair histories including corrective maintenance actions on each component, i.e., pumps (including drivers), valves (including operators), diesel generators, inverters, battery chargers and batteries.

This pilot study was undertaken to estimate the reliability characteristics of valves in two nuclear power generating stations, a PWR unit and a BWR unit. The data sources used to develop the data base and, therefore, the component failure rates and mean repair times are the plant valve equipment lists, plant drawings, and the maintenance work requests on these valves. The data were entered into a computer data management system developed for this project. Background information on the development of this data system is reported in "The In-Plant Reliability Data Base for Nuclear Power Plant Components: Data Collection and Methodology Report," NUREG/CR-2641,[3] and "The In-Plant Reliability Data Base for Nuclear Power Plant Components: Interim Data Report — The Pump Component," NUREG/CR-2886.[4]

1.2 Program Scope

Currently, the valve population, failure, and repair records from two PWR units and four BWR units have been entered into the data base (24 reactor years of information). Table 1 gives a breakdown of the maintenance records currently in the data base. Differences in plant-specific information are described in Appendices A and B.

This report examines the reliability characteristics of valves in both selected systems and entire plants. A sample of statistics on valves from one PWR (Plant 1) and one BWR are developed in this report to illustrate the degree of refinement possible when using the IPRD. Plant 2 data was not included because of the short time span which the collected data cover. Plant 3 data was not included because of significant incompatibilities between population and failure records.

Table 1. Data base status (September 1983)

	IPRDS Plant					
	PWR		BWR		Total	WASH-1400
	1[a]	2	3	4[a]		
Number of maintenance records collected	30,000	10,000	50,000	30,000	120,000	700
Number of corrective maintenance records	8,000	3,000	6,000	7,000	24,000	303
Number of valve maintenance records	3,067	980	992	773	5,812	102
Time span of valve maintenance records (years)	5.0	1.6	10.9	6.0	23.5	17
Number of valve population records	3,138	3,310	16,799	1,578	24,825	NA

NA – Not available.

[a]Identifies plant data used in this report.

2. METHODOLOGY

The procedure used for establishing the data base and calculating the component failure rate is as follows: From the plant equipment lists, piping and instrument diagrams, and process flow diagrams, a population card was formulated for each valve containing information such as the component identification number, system, valve type (gate, globe, check, etc.), type of operator, process fluid, and valve size in inches. System codes were assigned from descriptive information derived from plant equipment lists and piping & instrument drawings (P&ID's). The system codes, universal for all IPRD components, are designated in Table 2. In cases in which not all of the above information was readily available from the plant records, these data fields were left blank.

The failure rate estimate is calculated after determining the appropriate numerator (number of failures) and denominator (component hours or demands) from the data base. To determine the numerator of the failure rate estimate, the analysts reviewed all the corrective maintenance records collected from the plant visit for valve related failures. These records were separated, reviewed again, and classified. Analyzing the failure and repair text, the analysts assigned the following codes: failure cause(s), failure severity, and failure mode. The data reported on the maintenance record such as component name, failure date, failure and repair text, as well as the code assignments from the analyst were entered into the computer. A computer program then matched the individual failure and repair record with the population record on the basis of the component identification number. A population record/failure and repair record set was thus generated for each population record, containing the failure and repair history of each component. The total number of failures for a particular valve of interest was used as the numerator for the failure rate estimate. Information was gathered to determine the denominator of the failure rate estimate: the total number of service hours for a time-dependent failure rate or the total number of demands for a demand failure probability. For each valve IPRD analysts assigned the service hours (calendar hours in the system) and an estimated number of demands (12 actuations per year) to each valve. No valve specific estimates of the number of demands were attempted for this interim report.

2.1 Valve Boundary

The approach used to define the boundary around the valve component was to consider the valve body and all of its internal parts, the valve operator (motor, solenoid, pneumatic, etc.), and the limit and torque switches mounted on the valve or needed by the operator to make the valve function. Supply or auxiliary systems to the valve (e.g., electrical, air, or hydraulic) are considered outside the bounds of the components. This approach is consistent with the method used by plant maintenance personnel to create a valve maintenance work request action; typically, by the failure of the valve to function as designed.

Table 2. IPRDS generic systems list

BWR		PWR	
	Nuclear Systems—N		
N01	Reactor core	N01	Reactor core
N02	Control rod drive system	N02	Control rod drive system
N02.A	Control rod drive hydraulic system		
N03	Reactor control system	N03	Reactor control system
N04	Reactor recirculation system	N04	Reactor coolant system
N05	Standby liquid control system	N05	Emergency boration system
N06	Reactor protection system	N06	Reactor protection system
N07	Neutron monitoring/nuclear instrumentation system	N07	Nuclear monitoring/nuclear instrumentation system
N08	Residual heat removal/low pressure safety injection system	N08	Residual heat removal/low pressure safety injection system
N09	Reactor water cleanup system	N09	Chemical and volume control system (CVCS)
	Engineered Safety Systems—S		
S01	Reactor core isolation cooling system		
		S02	Engineered safety features actuation system
S03	Engineered safety features	S03	Safety injection system
S03.A	High pressure coolant injection/core spray system	S03.A	High pressure safety injection subsystem
		S03.B	Safety injection tank/core flood subsystem
S03.C	Low pressure coolant injection	S03.C	Low pressure safety injection subsystem
S03.D	Low pressure core spray system		
S03.E	Automatic depressurization system		
S04	Remote shutdown system	S04	Remote shutdown system
		S05	Auxiliary feedwater system
	Containment Systems—C		
C01	Primary containment and penetrations		
C02	Reactor building	C02	Reactor building/containment and penetrations
C03	Containment heat removal	C03	Containment cooling system
		C03.A	Ice condenser system
C04	Containment isolation system	C04	Containment isolation system
C05	Containment purge system	C05	Containment purge system
C06	Standby gas treatment system		
C07	Combustible gas control system	C07	Combustible gas control system
C08	Containment ventilation system	C08	Containment ventilation system
C09	Reactor building ventilation system		
C10	Containment spray system	C10	Containment spray system
		C11	Penetration room ventilation system

Table 2 (continued)

BWR and PWR

Electrical systems—E

E01	Main power system
E01.A	Protective relaying and controls
E02	Plant AC distribution system
E02.A	Essential power system
E02.B	Non-essential power system
E02.C	HPCS power system
E02.D	Protective relaying and controls
E03	Instrumentation and control power systems
E03.A	DC power system • vital DC power subsystem • plant DC power subsystem
E03.B	Instrument AC power system • vital instrument AC power subsystem • plant instrument AC power subsystem
E04	Emergency power system
E04.A	Diesel-generator fuel oil subsystem
E04.B	Diesel-generator cooling water subsystem
E04.C	Diesel-generator air subsystem
E04.D	Diesel-generator lubrication oil subsystem
E05	Plant lighting system
E05.A	Essential lighting
E05.B	Non-essential lighting
E06	Plant computer
E07	Switchyard
E07.A	DC control power system
E07.B	Protective relaying

Power Conversion Systems—P

P01	Main steam system
P02	Turbine-generator system
P02.A	Electro-hydraulic control subsystem
P02.B	Turbine gland seal subsystem
P02.C	Turbine lubrication subsystem
P02.D	Stator (hydrogen) cooling subsystem
P02.E	Hydrogen seal oil subsystem
P03	Turbine bypass system
P04	Condenser and condensate system
P04.A	Condenser evacuation system
P04.B	Condensate cleanup/polishing system
P04.C	Condensate heater drain subsystem
P05	Feedwater system
P05.A	Feedwater heater drain subsystem
P06	Circulating water system
P07	Steam generator blowdown (PWR)
P08	Auxiliary steam system

Process Auxiliary Systems—W

W01	Radioactive waste system
W01.A	Gaseous radwaste system • offgas subsystem (BWR)
W01.B	Liquid radwaste system
W01.C	Solid radwaste system
W02	Radiation monitoring system
W02.A	Plant area radiation monitors
W02.B	Environmental radiation monitors
W02.C	Process radiation monitors
W03	Cooling water systems
W03.A	Reactor building cooling water system
W03.B	Turbine building cooling water system
W04	Service water systems
W04.A	Demineralized makeup water system
W04.B	Station service water system • Essential service water system • Non-essential service water system
W04.C	Chilled water system
W05	Refueling system
W06	Spent fuel storage system
W06.A	Fuel pool cooling and cleanup system
W07	Compressed air system
W07.A	Service air system
W07.B	Instrument air system
W08	Process sampling system
W09	Plant gas system
W09.A	Nitrogen system
W09.B	Hydrogen system

Table 2 (continued)

BWR and PWR			
	Plant Auxiliary Systems--X		
X01	Potable and sanitary water system	X05.C	Diesel building ventilation system
X02	Fire protection system	X05.D	Auxiliary building ventilation system
X02.A	Water system	X05.E	Fuel building ventilation system
X02.B	Carbon dioxide system	X06	Non-radioactive waste system
X03	Communications system	X06.A	Gaseous waste subsystem
X04	Security system	X06.B	Liquid waste subsystem
X05	Heating, ventilating, and air conditioning systems	X06.C	Solid waste subsystem
X05.A	Control room habitability system		
X05.B	Turbine building ventilation system		

2.2 Failure Mode Code Development Approach

The encoding efforts for the valve component have relied upon previous LER related work, specifically, coding schemes for cause codes and failure modes. The systematic development of these codes for the IPRD valve data base produces a more useful coded informational base. This is especially true in regard to the performance of reliability and risk analysis.

The selected failure modes encoded in the IPRD data represent the only intermediary link (i.e., the only link without resorting to review of the individual failure record text) between the fault tree analyst and the data analyst. For this reason it is imperative that the failure modes selected are consistent with the needs of the most commonly utilized fault tree basic events. Research and experience indicated that basic events for components are usually categorized according to a component type designation combined with a failure mode which indicated:

1. Loss of function of the component, or
2. Change of state without command, or
3. Failure to change state when commanded.

The significant valve component types identified in the risk assessment outputs and based upon experience were:

Valve type

1. Manual valves
2. Air operated valves
3. Motor operated valves
4. Solenoid valves
5. Check valves
6. Safety valves
7. Relief valves

When the generalized failure modes were applied to the specific case of valves, the following valve specific modes were systematically produced by generating exhaustive binary state transition failures as would be done in fault tree construction and applying these to a generic valve.

Mode 1. Loss of function of the component:
  a. Valve leaks through
  b. Valve plugged
Mode 2. Change of state without command:
  a. Valve closed — fails open
  b. Valve open — fails closed
Mode 3. Failure to change state when commanded:
  a. Valve open — fails open*
  b. Valve closed — fails closed

After generating the modes, they were applied to specific valve types and the developed modes were tailored to each specific type for the catastrophic failure category. This application caused the development of valve specific mode terminology in many cases. For example, when 3a is applied to safety valves it becomes: "Valve is open (due to a previous legitimate command); it is commanded to close (i.e., to reclose due to reduced system pressure), but it fails open (i.e., does not close)." This long description can be simplified and summarized by the statement: "Fails to Reclose," and this statement is just 3a tailored to safety valves.

When this tailoring was completed for all valve types, certain questionable specific modes were generated. For example, although modes 2 and 3 can be developed for check valves, they would only be useful if the correlation between a failure and an actual demand or the lack of a demand can be made (e.g., if the failure records indicate, "inlet check valve on pump A fails to open when pump A is activated"). This correlation is highly unlikely, and since the important system failures are contained within mode 1 (i.e., fails to check, and plugged), modes 2 and 3 were judged to be unnecessary for simple check valves (swing check valves are exceptions).

After the elimination of questionable types for specific valves was completed, the remaining types were expanded for the degraded and incipient. Again, conversion to type specific terminology was made where appropriate, and the elimination of questionable specific modes was carried out. In the next step, the surviving modes were divided into those primarily time related and those primarily demand related. Finally, the valve types and the valve specific mode categorizations were reviewed to determine if category similarities would allow grouping of types. This was attempted in order to reduce the final number of categories without sacrificing the required mode specialization. The results of this process are given in Table 3. In Table 3, each unique mode was assigned a unique alphabetic single digit identifier. These unique identifiers represent the suggested failure modes and their suggested encoding scheme.

---

*i.e., Valve is open, it is commanded to close, but does not close.

Table 3. Valve failure modes

I. <u>Manual, Operated Valves and Solenoid Valves</u>	
1 - <u>Catastrophic</u>	<u>Time/Demand Related</u>
A. Fails to operate	Demand
a) normally open - fails open b) normally closed - fails closed	
B. Spurious operation	Time
a) normally open - fails closed b) normally closed - fails open	
C. Plugged	Time
D. Leaks through (disabling internal leakage)	Time
2 - <u>Degraded</u>	
E. Improper operation (operates out of specification)	Time
F. Leaks through (debilitating internal leakage)	Time
I. Plugged (partial)	Time
3 - <u>Incipient</u>	
G. External leakage	Time
H. Faulty indication	Time
II. <u>Check Valves</u>	
1 - <u>Catastrophic</u>	<u>Time/Demand Related</u>
C. Plugged	Time
D. Leaks through (disabling internal leakage)	Time
2 - <u>Degraded</u>	
E. Improper operation (operates out of specification)	Time
F. Leaks through (debilitating internal leakage)	Time
I. Plugged (partial)	Time
3 - <u>Incipient</u>	
J. Chattering	Time
G. External leakage	Time
H. Faulty indication	Time

Table 3 (continued)

III. Safety and Relief Valves	
1 - Catastrophic	Time/Demand Related
A. Fails to operate (significant delayed operation)	Demand
B. Spurious operation	Time
D. Leaks through (significant internal leakage)	Time
K. Fails to reclose	Demand
2 - Degraded	
E. Improper operation	
1. Premature operation	Time
2. Delayed operation (operates out of spec)	Time
F. Leakage	Time
3 - Incipient	
L. Small external leakage	Time
H. Faulty indication	

Failure Mode Summary

Mode	Time/Demand Related
A. Fails to operate	Demand
B. Spurious operation	Time
C. Plugged	Time
D. Leaks through (significant internal leakage)	Time
E. Improper operation (operates out of spec)	Time
F. Leaks through (internal leakage)	Time
G. External leakage	Time
H. Faulty indication	Time
I. Plugged (partial)	Time
J. Chattering	Time
K. Fails to reclose	Demand
L. Weepage	Time

2.3 Cause Code Development Approach

A systematic attempt was made to develop the cause encoding scheme for valves. The thrust of the approach was to allow the maintenance record descriptions to specify the scheme. A sample (several hundred) of representative failure and repair records were reviewed by the data analysts. The analysts were instructed in each case to extract the essential cause description contained in each record. The analysts were trained to key on certain cause descriptors such as piece part failures, control failures, environmental failures, and installation failures. They were instructed to construct new cause descriptions from the data only when the essential cause of the description was not listed and was significantly different from those listed.

The resulting cause categories were reviewed in an attempt to restructure them so as to reduce their number without significantly affecting their cause content. Cause codes which were clearly outliers, (i.e., appeared only once) were eliminated and the remaining codes were grouped according to logical sets. Each of the codes within the sets were assigned unique, two digit, numerical identifiers. Blank entries were introduced between groups and also given identifiers. These blanks were reserved for cause codes which might be uncovered by further analysis of the data during the data encoding process. The suggested cause codes for valves which resulted from this analysis are given in Table 4.

2.4 Classification of Failure Severity

The failure severity of the component was classified in one of the following categories.

Catastrophic: The component is completely unable to perform its function.

Degraded: The component operates at less than its specified performance level.

Incipient: The component performs within its design envelope but exhibits characteristics that, if left unattended, will probably develop into a degraded or catastrophic failure.

2.5 Application of Failure Modes and Cause Codes

The use of the valve cause codes in Table 4 in many instances is through a combination of two or more codes to specify both the part or subassembly of the valve and the cause of the failure. Therefore, codes 14 through 41 in Table 4 identify valve parts whose failure can be described by codes 53 through 60. For example, a binding or sticking valve stem that causes a sluggish valve stem movement would be assigned a "Degraded" failure severity, an E (improper operation) failure mode, with cause codes 33 and 55 to specify the cause and type of failure. In other cases, a failure may be described by assigning a single cause code with the failure severity/mode. For example, a common external leak through the valve packing can be encoded with an "Incipient" failure severity, a G

Component parts for Gall Table

Table 4. IPRD valve cause codes

00	Unknown	32	Seat
01	Design error	33	Stem
02	Personnel error	34	Spring
03	Fabrication error/construction	35	Bonnet
04	Procedural discrepancy	36	Collar
05	Blank	37	Orifice
06	Blank	38	Nipple
07	Blank	39	Damper
08	Leakage/general, unspecified	40	Pins/shear pin, Cotter pin, retainer pins
09	Leakage/air, gas, steam	41	Hoses/sample lines, sensing line, EH lines, air lines, flush lines, copper tubing
10	Leakage/liquid, hydraulic fluid	42	Blank
11	Leakage/lubricant, oil, grease	43	Blank
12	Seals/gaskets, O-rings, lantern ring	44	Control circuit failure (electrical)/position indicator, relay, positioner, lights, contracts, accumulator, dead band controls, alarm, loop controller, pilot valve
13	Damaged seal surface	45	Fuse failure
14	Coupling/shaft, reach rod, rocker arm, arm, universal joints	46	Switch failure/microswitch
15	Unions/connections, connecting pipe, elbows	47	Limit switch failure
16	Welds	48	Wire/leads
17	Fasteners, bolts, nuts, set screws, bonnet bolts, lugs, studs	49	Transducer/transformer
18	Packing	50	Faulty mechanical controls/regulator
19	Diaphragm	51	Blank
20	Cam	52	Blank
21	Solenoid	53	Corrosion/erosion
22	Motor	54	Foreign material contamination/plugged
23	Actuator	55	Binding/bound/seized/sticking
24	Valve operator	56	Cracked/pierced
25	Gear/pinion, bevel gear, gear box	57	Out of adjustment
26	Gate	58	Misaligned
27	Flange	59	Improper clearance
28	Bushing/bearing	60	Trips on overload
29	Handwheel/handle	61	Blank
30	Disc/bellows rupture	62	Blank
31	Linkage		

See Page 7 for list of effects

(external leakage) failure mode, and a single cause code at 18 to identify the location of the leakage.

2.6 Output Format

The data format presented in Table 5 is intended to be the means for documenting the valve reliability statistics of the IPRDS in a valve data manual. The rationale behind the format development is to allow hierarchical aggregation of the basic, valve-specific statistics to yield the more general valve statistics, e.g., the aggregation of basic statistics from all the tables on globe valves would yield general reliability statistics for globe valves with all operator types, valves sizes and in all process fluids. An example of the use of this format is given in Table 6. Terms shown in this format and other tables are defined as:

Annual demands:	Average number of annual demands per valve (estimated at 12 per valve/year for this report).
Component class:	Valve (includes operator)
Failure cause:	The principal failure causes as found in Table 4.
Failure demand probability:	The probability determined according to equations in Sect. 3.
Failure mode:	The IPRD mode classification found in Table 3.
Failure rate:	The rates calculated according to equations in Sect. 3.
Failure severity:	One of the three IPRD classes: catastrophic (D), degraded (D), incipient (I).
Maintenance frequency:	The total number of failures divided by the valve population divided by the population service hours.
Failure population (Pop.)	Total number of failures assigned to the valves.
Operating period:	Years between commercialization and date of last record collected from plant.
Plant:	IPRD identification number.
Plant type:	BWR or PWR.
Population:	Number of valves.
Population demands:	Average annual demands per valve times operating period (in years) times population.
Population service hours:	The period of observation (in hours) times population.
Primary class:	Valve operator.
Service hours:	Length of time covered by data multiplied by the number of valves.
Subclass:	Hierarchical information including operator type, system, type and size of valve, and process fluid.

Table 5. General format for reporting IPRDS valve population, failure and repair statistics

Population Information

Plant type ______	Primary Class: Operator type	Component population:	____
Plant no. ______	1st subclass: Valve type	Annual demands/valve:	____
Operating period ___ yrs.	2nd subclass: System	Population demands:	____
	3rd subclass: Size	Population service hours:	____
	4th subclass: Process fluid	Maintenance frequency:	____/h

Time-Related Failure and Repair Statistics

Failure mode	Failure severity	Failure population	Failures/10^6 h			Failure cause		Repair time (h)		
			Low	recommended	high	Code	(Failure Pop.)	low	median	high

Demand-Related Failure and Repair Statistics

Failure mode	Failure severity	Failure population	Failures/10^3 cycles			Failure cause		Repair time (h)		
			Low	recommended	high	Code	(Failure Pop.)	low	median	high

Table 6. Example of IPRDS valve population, failure and repair statistics

Plant no. 1	Primary Class: Pneumatic	Component population: 6
Plant type PWR	1st subclass: Globe	Annual demands/valve: 12
Operating period 5 yrs.	2nd subclass: Condensate - P04	Population demands: 360
	3rd subclass: Water	Population service hours: $2.62*10^5$ h
		Maintenance frequency: 1.26 E^{-4}/h
	4th subclass: 6 in.	(total failures all severities = 33)

Time-Related Failure and Repair Statistics (modes B, C, D, E, F, G, H, I)

Failure mode	Failure severity	Failure population	Failures/10^6 h Low	Recommended	High	Failure cause Codes (Failure Pop.)	Repair time (h) Low	Median	High
B (spurious operation)	C	1	0.20	3.8	18	48 (1)		3.0	
E (improper operation)	C	9	18	34	60	3, 57, 47(1); 57, 47(1); 57, 29(1); 14, 48(1); 44(1); 43(1); 24(1); 21(1); 17(1)	0	2.5	25
F (internal leakage)	D	3	3.1	11	30	33, 32(1); 12(1); 10(1)	0	40	52
G (external leakage)	I	2	1.4	7.6	24	17, 41(1); 41(1)	0		25
H (faulty indication)	I	7	12	27	50	3, 44, 48(1); 44, 58(1); 2, 48(1); 28, 29(1); 44(1); 59(1); 0(1)	0	2	6

Demand-Related Failure Statistics (mode A)

Failure mode	Failure severity	Failure population	Failures/10^3 cycles Low	Recommended	High	Failure cause Codes (Failure Pop.)	Repair time (h) Low	Median	High
A (fails to operate)	C	11	51	92	151	45(3); 47, 57(2); 45, 48(1); 3, 44(1); 17, 21(1); 48(1); 21(1); 0(1)	2	6	23

3. FAILURE RATE CALCULATIONS

3.1 Recommended Point Value Estimation

The equation used to estimate the probability of failure on demand (Q_d) is

$$Q_d = \frac{n}{D}$$

where

n = the number of failures observed and
D = the total number of demands experienced.

The equation used to estimate the failure rate (λ_t, per hour) is

$$\lambda_t = \frac{n}{T}$$

where

n = the number of failures observed and
T = the total operating time of the components.

In the data tables these values of Q_d and λ_t are listed under the column labeled "mean." When no failures were observed (n = 0), the point estimates Q_d and λ_t in this column were determined using the median of a chi-square variable with one degree of freedom

$$\lambda_t = \chi^2_{0.5}(1)/2T$$
$$= 0.227/T$$
$$Q_d = \chi^2_{0.50}(1)/2D$$
$$= 0.227/D\ .$$

For (D − n) < 40, the F-variate at the 50% point with one degree of freedom was used to calculate

$$Q_d^{50} = \frac{F_n}{2(D - n) + F_n + 1}\ ,$$

where $F_n = F_n(1,\ 2D + 1)$.

3.2 Interval Estimation

The confidence limits for the hourly failure rates were calculated on the assumption that the component times to failure are exponentially distributed. Although for Q_d the number of failures n is binomially distributed, the Poisson distribution may be used to approximate the distribution of this variable when the number of failures is small compared to the number of demands. The equations for estimating the 90% confidence bounds on the failure rates when $n > 0$ and $D - n \geq 40$ are:

$$\lambda_t^{5\%} = \frac{\chi^2_{0.05}\,(2n)}{2T} ,$$

$$\lambda_t^{95\%} = \frac{\chi^2_{0.95}\,(2n + 2)}{2T} ,$$

$$Q_d^{5\%} = \frac{\chi^2_{0.05}\,(2n)}{2D} , \text{ and}$$

$$Q_d^{95\%} = \frac{\chi^2_{0.95}\,(2n + 2)}{2D} ,$$

where

$\chi^2_{0.05}(2n)$ = the chi-square variate at the 0.05 level with 2n degrees of freedom and

$\chi^2_{0.95}(2n + 2)$ = the chi-square variate at the 0.95 level with (2n + 2) degrees of freedom.

For the cases where $D - n < 40$, the Poisson approximation to the binomial distribution is not adequate, and the following equations are used when $n > 0$:

$$\lambda_d^{5\%} = \frac{nF_i}{D - n + 1 + nF_i} \quad \text{and}$$

$$\lambda_d^{95\%} = \frac{(n + 1)\,F_u}{D - n + (n + 1)\,F_u} ,$$

where

$$F_i = F_{0.05}\ (2n,\ 2D - 2n + 2)\ ,$$

which is the F variate at the 0.05 level with 2n and 2D − 2n + 2 degrees of freedom, and

$$F_u = F_{0.05}\ (2n + 2,\ 2D - 2n)\ ,$$

which is the F variate at the 0.95 level with 2n + 2 and 2D − 2n degrees of freedom.

When n = 0, no estimates were made for the 5% values of λ_t or Q_d. The upper confidence level when n = 0 was calculated using

$$\lambda_t^{95} = \chi^2_{0.95}(2)/2T \quad \text{and}$$

$$Q_d^{95} = \chi^2_{0.95}(2)/2D\ .$$

4. DISCUSSION OF RESULTS

INTRODUCTION

This is a limited presentation of selected preliminary results derived from the data of two nuclear power plants. This only touches upon the numerous uses for the statistics and the various comparisons possible with IPRDS results. The tables and figures should be viewed as proposed methods or means for documenting future IPRDS information and are purposely noncomprehensive to inhibit direct use of the preliminary statistics. IPRDS results are compared with the overall catastrophic failure statistics of WASH-1400 and LERs. In addition there is a comparison of valve reliability and maintenance data for safety and nonsafety-related systems for various specific valve operator types. Failure statistics from one BWR plant (Plant 4) are contrasted with those of one PWR (Plant 1) for one specific system category. Repair times from Plant 1 are presented on the basis of three distributions. A cumulative distribution of repair times is shown and compared to the WASH-1400 results. The parameters of the lognormal repair time distribution are given as well as the maintenance frequencies and median repair times for valve types and valve operators.

4.1 <u>Comparison of IPRDS with WASH-1400 and LERs</u>

Upon initial review, the preliminary sampling of IPRDS results found in Table 7 tends to indicate that differences exist with WASH-1400 and LER values for the overall demand failure probabilities of valves. Although this may be implied by the results, certain caveats should be considered when evaluating this table, as well as other figures. First, the estimate of individual valve demands is one demand per month, or twelve per year for this report. This first order estimation is applied to all valves in all systems of the plant, and may be significantly different than the actual number of demands incurred by any particular valve. Also, the tables shown are meant to represent the results that are possible from analyses of data in the IPRDS and to present suggested formats for a computer-generated data manual. Finally, the general overall reliability statistics on valves as documented in Table 7 may not be considered as reasonable from an engineering standpoint. The reliability of valves can be affected by their operating and environmental conditions, and it likely varies for different valve types. Thus, combining data from different valve types (check, relief, gate, etc.) from all systems within the plant, gives results as in Table 7 that are comparable to WASH-1400 values; but based on engineering judgement, a more reasonable approach to valve failure data reporting would be Fig. 1.

Figure 1 graphically depicts a sample of preliminary reliability results for pneumatically operated valves by valve type from one PWR. Failure rates are depicted along with the population of valves and the number of failures that were used to calculate the failure statistics. The bounds of WASH-1400 estimates are shown by the dotted lines. The IPRDS

Table 7. Comparison of some preliminary PWR and BWR catastrophic failure statistics with WASH-1400 and LERs for one mode of failure

Valve operator	Failure mode	IPRDS PWR[a] Low	IPRDS PWR[a] Mean	IPRDS PWR[a] High	IPRDS BWR[b] Low	IPRDS BWR[b] Mean	IPRDS BWR[b] High	WASH-1400 Low	WASH-1400 Mean	WASH-1400 High	LERs Low	LERs Mean	LERs High
		Demand-related failure probabilities Q_d ($1/10^3$ d)											
Pneumatic	Failed to operate	2.5	4.8	8.4	1.8	2.8	4.3	0.1	0.3	0.9	0.19	0.7	1.8
Solenoid	Failed to operate	0.13	8.4	40	0.12	2.3	11	0.33	1.0	3			
Motor-driven	Failed to operate	3.5	6.4	11	1.9	3.7	6.4	0.33	1.0	3	3.6	4	4.4
Manual	Failed to operate	0.15	0.42	0.88	0.39	0.61	0.90				0.02	0.08	0.21

[a] Includes only valves in nuclear systems.

[b] Includes only valves in process auxiliary systems.

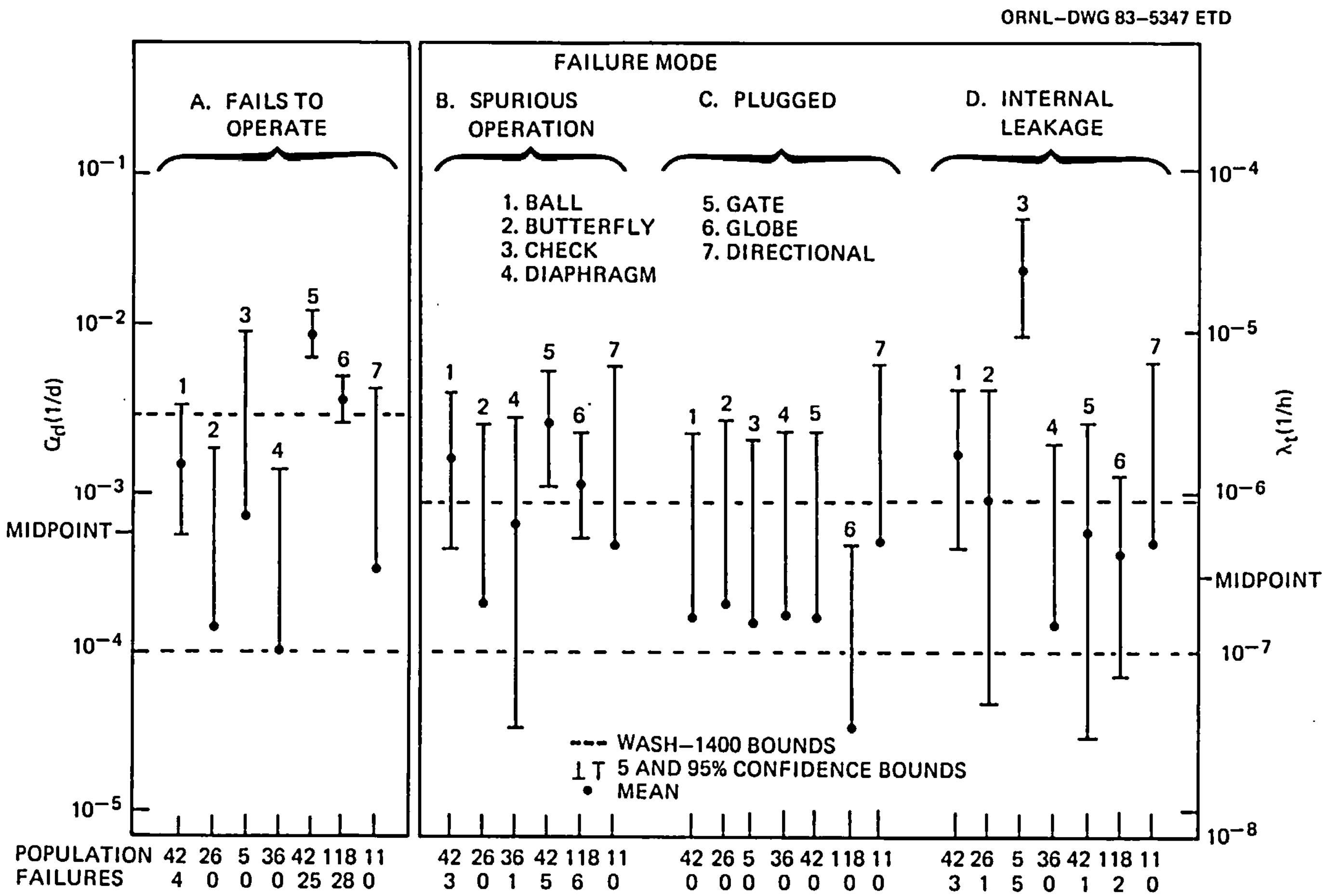

Fig. 1. Preliminary Catastrophic Failure Statistics of Plant 1 for: Pneumatically Operated Valves by Valve Type.

can further refine this figure for any particular system in the plant and any particular valve size, but unfortunately, the IPRDS pilot data base currently has an insufficient quantity of information to produce significant reliability information at this fine a level.

In comparing the IPRDS data with these sources, two points are evident. First, the IPRD system can offer more specialized failure rates for PRA in terms of valve type and mode of failure than either WASH-1400 or LERs. The IPRDS can distinguish among different valve types and operator types, as well as sizes and systems of application. Many of these distinctions are lost in the presentation of the WASH-1400 and LER data and as a result, their statistics are rather general. Secondly, the preliminary comparison of IPRDS results (Table 7) indicate that demand failure probabilites (Q_d) from WASH-1400 and LERs may be underestimated. Recognizing the aforementioned limited scope of the current IPRDS data, no direct challenges are made. However, sufficient cause exists to conclude that conclusive results could be attainable from an enlarged IPRDS data base.

4.2 Safety vs Non-Safety Related Systems

In Table 8 preliminary valve reliability and maintenance data are compared for a safety and a nonsafety related system in a PWR (Plant 1). This is done by comparing valves in the residual heat removal (RHR) system with those of the process auxiliary systems. The table is broken down by operator type giving the catastrophic failure statistics for demand and time-related failures and the maintenance frequencies. It is interesting to note that the maintenance frequency of safety-related valves is approximately twice that of nonsafety-related valves, yet in no case is there a substantial improvement in safety-related valve failure statistics over those of nonsafety-related valves. Further analysis on an enlarged data base may substantiate this and other preliminary observations.

4.3 BWR vs PWR Valve Maintenance and Reliability Statistics

A comparison of one major systems category (nuclear systems) in PWRs and BWRs is given in Table 9, broken down by valve operator type for each plant type. Given in the table are the preliminary catastrophic failure statistics, including failure rates and demand probabilities with the appropriate 90% confidence limits derived from chi-square distribution. Also a corrective maintenance frequency is calculated. Similarities exist between valve populations and catastrophic failure statistics in these systems for the two plant types. However, there is a sizable difference in the total number of failures (including degraded and incipient failures) and the related maintenance frequency. These preliminary results may be showing plant specific variability, and therefore, Table 9 only serves to illustrate a useful comparison for determining if significant differences exist between similar valves in the different plant types.

Table 8. Preliminary valve reliability and maintenance statistics for safety vs nonsafety related systems[a] in Plant 1

Safety	Nonsafety	Operator type	Valve population	Catastrophic failure statistics[b]: Fails to operate Q_d (1/10^3 d): No. of failures	Low	Mean	High	Spurious operation λ_t (1/10^6 h): No. of failures	Low	Mean	High	Internal leakage λ_t (1/10^6 h): No. of failures	Low	Mean	High	Maintenance frequency (1/10^6 h)
		Pneumatic														
X			3	0	-	1.3	16.0	0	-	1.7	22.0	0	-	1.7	22.2	45
	X		35	3	0.38	1.4	3.7	0	-	0.14	1.9	2	0.22	1.3	4.1	28
		Motor operated														
X			15	8	4.5	8.9	16.0	0	-	0.34	4.5	0	-	0.34	4.5	33
	X		37	14	5.1	8.6	13.0	0	0.21	1.2	3.9	0	-	0.14	3.9	18
		All (other?)														
X			40	7	1.4	2.9	5.5	0	-	0.12	1.7	0	-	0.12	1.7	27
	X		147	14	0.96	1.6	2.5	2	0.05	0.31	0.98	3	0.12	0.46	1.2	15

[a]The safety related valves of the RHR system are compared to the nonsafety related valves of the process auxiliary systems.

[b]No failures due to plugging were observed for either the safety or nonsafety valve. No failure rates were calculated.

Table 9. A comparison of preliminary BWR and PWR selected valve maintenance and reliability statistics for one major category of systems – nuclear systems

Valve operator	Plant type	Valve population	Catastrophic failure statistics: Fails to operate Q_d (1/10^3 d)				Spurious operation λ_t (1/10^6 h)				Plugged λ_t (1/10^6 h)				Internal leakage λ_t (1/10^6 h)				Total[a] number of failures	Corrective maintenance frequency (1/10^6 h)
			No. of failures	Low	Mean	High	No. of failures	Low	Mean	High	No. of failures	Low	Mean	High	No. of failures	Low	Mean	High		
Pneumatic	BWR	29	3	0.39	1.4	3.7	1	0.03	0.66	3.1	0	–	0.07	2.0	0	–	0.07	2.0	6	3.9
	PWR	31	9	2.5	4.8	8.4	3	0.59	2.2	5.7	0	–	0.17	2.2	0	–	0.17	2.2	96	70
Motor operated	BWR	26	1	0.03	0.53	2.5	2	0.26	1.5	4.6	0	–			0	–			33	24
	PWR	26	10	3.5	6.4	11.0	2	0.31	1.7	5.5	0	–	0.20	2.6	0	–	0.20	2.6	40	35
Manual[b]	BWR	69	3	0.17	0.6	1.6	0	–	0.06	0.83	0	–	0.06	0.83	0	–	0.06	0.83	1.0	2.8
	PWR	199	5	0.16	0.42	0.88	2	0.15	0.23	1.0	0	–	0.03	0.34	1	0.01	0.11	0.54	68	7.8

[a]Total of incipient and degraded failures as well as catastrophic.

[b]Contains valves designated as manual in the plant equipment lists and valves having no operator designated in the lists.

4.4 Repair Times

Presented in this section are repair times for all types of valves and valve operators in all nuclear plant systems. Repair times on valves are available from only one plant of the four plants in the IPRDS. The cumulative distribution of repair times is plotted in Fig. 2 along with the results found in WASH-1400. A noticeable shift to the left occurred with the IPRDS data (i.e., shorter repair times). Probability plots are presented for three frequently used distributions. Note that the repair times from Plant 1 are actually the man-hours required of the maintenance personnel and may not be the actual hours the component was out for repair. Additional research is necessary to relate man-hours with actual component downtimes.

Probability plots of repair times from Plant 1 are compared to three distributions: exponential, log normal, and Weibull. Such plots are useful when looking for suitable probability density functions.

First the repair times are ordered from smallest (= 0.5 h) to largest (= 880 h), assigning rank 1 to the smallest and rank N (= 2809) to the largest. If the ranks alone are plotted against time (or log time for log normal and Weibull), the familiar "S"-shaped cumulative distribution function of Fig. 2 is generated. The "S"-shaped curve is "straightened" by making an appropriate transformation of the ranks for each of the three

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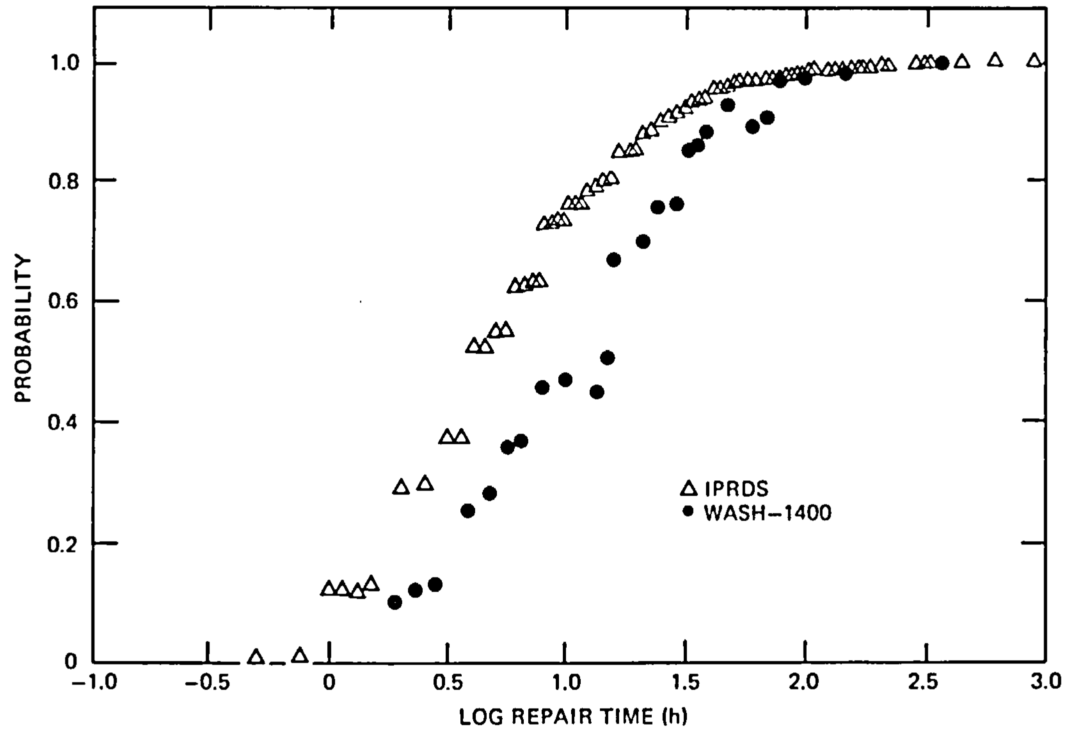

Fig. 2. Cumulative Distribution Function of Observed Repair Times for Valves in Plant 1.

distributions so that the plotted points can be compared to a straight line. These plots are given in Figs. 3–5. Of the three, the log normal most closely resembles a straight line. Note that not all of the points are plotted; only the 99 different repair times. The first 39 repair times that are equal to 0.5 h are represented by the middle rank of 20 (= 39/2 + 1/2). The mode of 2 h (most frequently occurring repair time) is represented by the middle rank of 598.5. At least one-half of the observed repair times are less than or equal to 4 h (median value).

Exponential Distribution (Fig. 3)

The density is given by

$$f(t) = \lambda e^{-\lambda t} \text{ for } t \geq 0$$

where parameter λ is the failure rate. An estimate of λ, denoted $\hat{\lambda}$, is obtained from the mean time to failure by

$$\hat{\lambda} = (\text{mean time to failure})^{-1} = \left(\frac{1}{N} \sum_{i=1}^{N} t_i\right)^{-1} = 0.0767$$

where

t_i = i^{th} repair time, and
N = total number of repair times = 2809.

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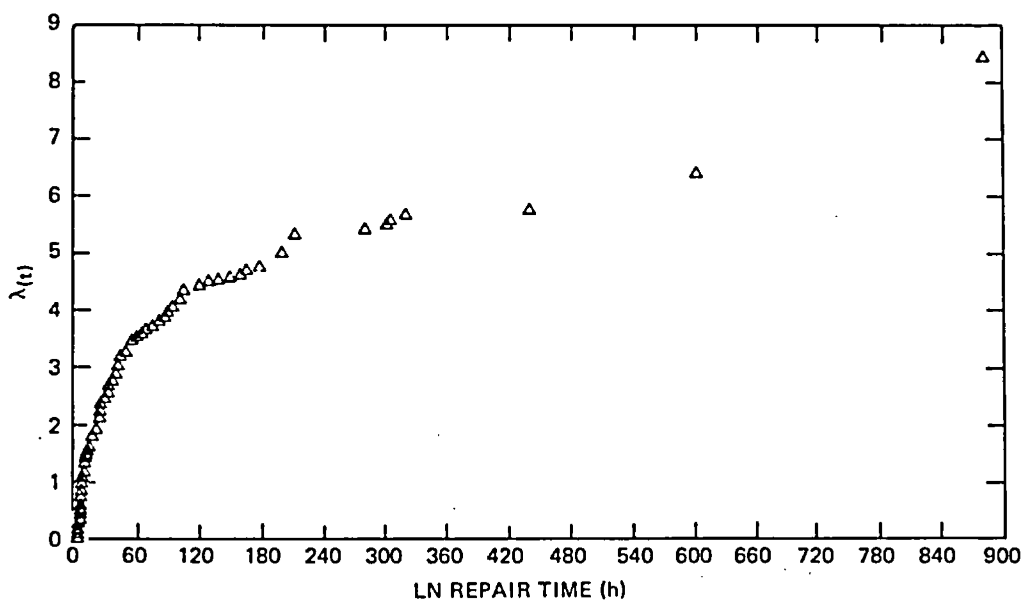

Fig. 3. Exponential Plot of Repair Times of Plant 1.

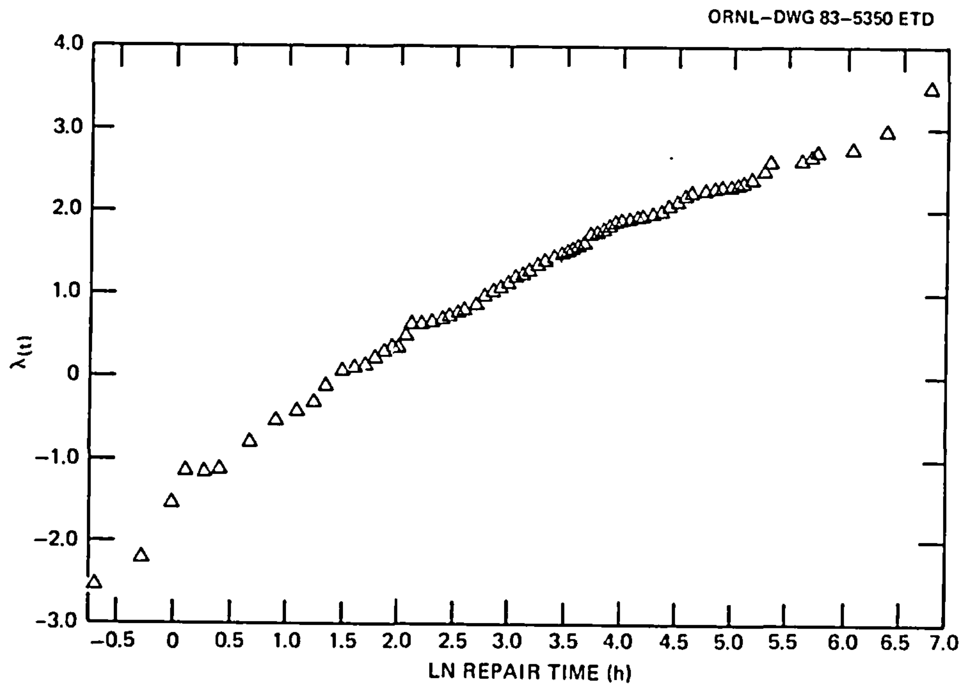

Fig. 4. Log-Normal Plot of Repair Times of Plant 1.

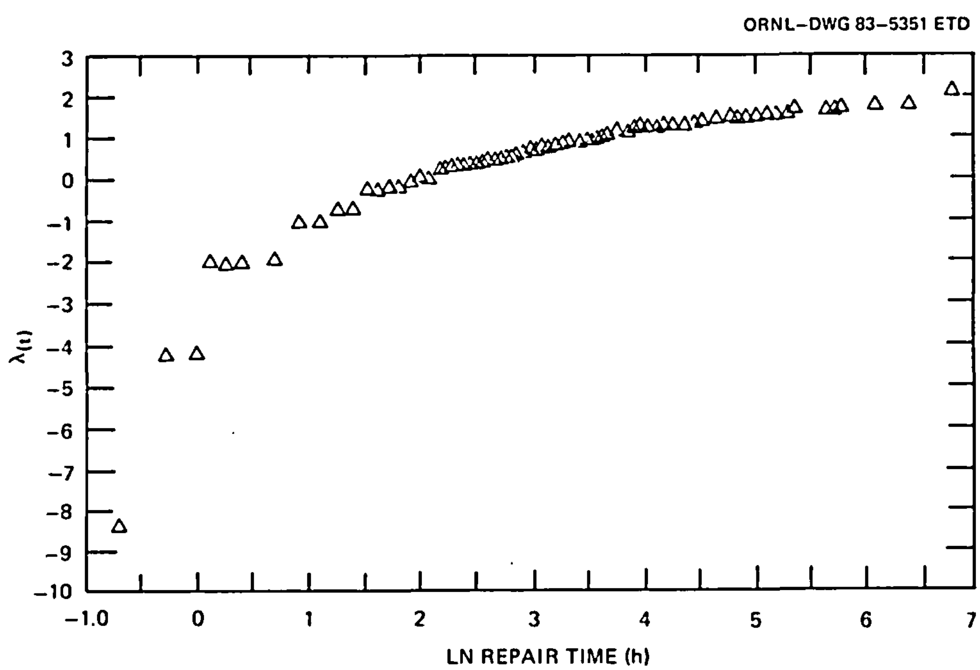

Fig. 5. Weibull Probability Plot of Repair Times of Plant 1.

Figure 3 plots the pairs

$$\left[\ln\left(\frac{N + 0.25}{N - r_i + 0.625}\right),\ t_i\right]$$

where

r_i = rank of i^{th} ordered repair time.

Log Normal Distribution (Fig. 4)

When the logarithm of a random variable has a normal distribution, the random variable is distributed log normal. The density is

$$f(t) = \frac{1}{\alpha t\sqrt{2\pi}} \exp\left[-\frac{(\ln t/\beta)^2}{2\alpha^2}\right],\ 0 \leq t < \infty,\ -\infty < \beta < \infty,\ \alpha^2 > 0,$$

where the parameters β and α are measures of the location and spread, respectively. Estimates are given by

$\hat{\beta} = 3.91$ h

$\hat{\alpha} = 1.55.$

Figure 4 plots the pairs

$$G^{-1}\left(\frac{r_i - 0.375}{N + 0.25}\right),\ \ln(t_i)$$

where

$G^{-1}\left(\frac{r_i - 0.375}{N + 0.25}\right)$ is the $\left(\frac{r_i - 0.375}{N + 0.25}\right)^{th}$ percentile value from the normal distribution

Weibull Distribution (Fig. 5)

The Weibull density for two parameters is given by:

$$f(t) = \beta\left(\frac{t}{\alpha}\right)^{\beta-1}\left[\exp -\left(\frac{t}{\alpha}\right)^{\beta}\right],\ \alpha,\ \beta > 0,\ t \geq 0$$

with parameters α and β. No estimates are given.

Figure 5 plots the pairs

$$\left\{ \ln\left[\ln \frac{100}{100 - (r_i/N)\ 100}\right],\ \ln\,(t_i) \right\}$$

The parameter estimates for the log normal distribution of repair times and other statistics are given in Table 10. Of particular interest is the range of valves (0.5 to 880 h) and the median for all valves (4 h). Table 11 further breaks down the repair times and maintenance freqencies by valve type for each operator. Again of interest is the range of median repair times (2 to 10 h) with the majority of valve types requiring between 4 and 6 h for repair.

Table 10. IPRDS and WASH-1400 parameters of the log-normal distribution of repair times

	IPRDS	WASH-1400
Number of observations	2809	28
Mean, h	5.2	24
Median, h	4.0	NA
Mode, h	2.0	NA
Standard deviation, h	3.2	NA
Maximum, h	880	350
Minimum, h	0.5	1

NA - not available.

NOTE: These preliminary and most general IPRDS parameters have been determined using all valve types, all failure severities and modes, and all valve sizes.

4.5 A Technique for Studying Maintenance Histories — Corrective Maintenance Signatures

The technique of corrective maintenance (C. M.) signatures is to portray the entire corrective maintenance history of a particular component on a time line and graphically represent the failure and its corresponding severity as shown in Fig. 6. To complete the failure history, the causes of each failure can be associated with the corresponding line.

Table 11. Maintenance frequency and median repair times by valve type for Plant 1

Valve type	Operator type	Maintenance frequency (No. of failures/10^6 h)	Median repair time (h)
Ball	All	7.36	8
	- pneumatic	7.61	8
	- others	6.76	3
Butterfly	All	9.64	4
	- pneumatic	35.1	4
	- motor-driven	28.2	4
	- others	3.40	3
Check	All	9.65	6
Diaphragm	All	4.52	5
Gate	All	17.6	6
	- pneumatic	97.8	8
	- motor-driven	62.0	4
	- hand	28.5	4
	- others	4.42	3
Globe	All	17.2	4
	- pneumatic	43.1	4
	- solenoid	182.0	4
	- motor-driven	48.0	2
	- hand	25.1	10
	- others	4.19	2
Relief/Safety	All	14.5	6
Directional Control	All	14.6	3
	- pneumatic	18.7	3
	- solenoid	4.15	5
	- motor-driven	68.2	2
	- others	5.71	3

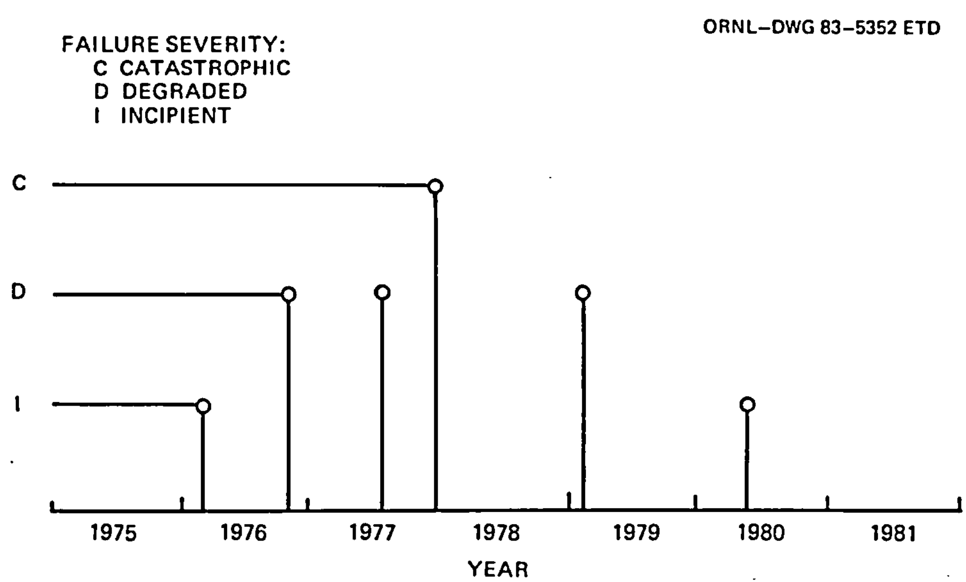

Fig. 6. Corrective Maintenance Signature of a Steam Generator Dump Valve.

This technique enables the relationships between time-variant factors affecting component reliability (i.e., plant status, component environment, preventative maintenance) and component failures to be evaluated by overlaying the C. M. signature with the history of the appropriate factor. Changes in preventative maintenance policies and their effects on component reliability are particularly evident using this technique.

4.6 Plant Specific Information

The majority of plant specific information can be found in the Appendices A and B, representing Plants 1 and 4 respectively. The first table (i.e., Table A-1 and B-1) in both appendices gives the valve population, the estimated demands, and service hours for each type of valve and specific operator in the plant. Tables A-2 and B-2 provide background information that was used to develop the failure statistics for Plants 1 and 4, respectively. They provide the number of failures for each mode by valve type and operator type.

4.7 Safety Valve and Power-Operated Relief Valves

A ministudy on safety valves and power operated relief valves is included in Appendix C.

5. DATA BASE LIMITATION AND RECOMMENDATIONS

The data and calculated values in this pilot study must be considered preliminary in nature and should be used only as screening values. The calculated values may be subject to substantive changes as the data base expands.

5.1 Relatively Short Time Span and Limited Number of Plants

The IPRD system currently has valve population data from four nuclear power plant stations (six units). Although the maintenance records from these six units (four BWR and two PWRs) span almost 24 reactor-years of commercial operation, the number of reactor-years of data from each unit is relatively small (1.6 to 6 years). The failure rates and mean repair times calculated in this report are from two of the six units and should therefore be considered preliminary values. In many cases, the time span of the data collected and the number of failures, most importantly catastrophic failures, were small.

It is recommended that (1) data from additional plants be collected and (2) updating of the four plants currently in the data base continue.

5.2 Differing Maintenance Policies Affect Component Failure Rates

The differing maintenance policies of these two particular plants may not reflect the overall population of nuclear power plants in the United States. This could lead to plant-specific component failure rates and maintenance frequencies which are not representative of the nuclear industry. Until data from additional plants are available, it should not be assumed that these preliminary results are applicable to the general population of nuclear valve components.

5.3 Underestimation of the Number of Annual Demands

It is recommended that for selected valves, the operator logs should be reviewed to ascertain the actual number of demands.

5.4 Plant 2 and 3 Records

Plant 2 equipment lists were insufficient in documenting the valve type and size. Additional information from the plant P&ID's is necessary for developing the necessary hierarchical structure for each valve to enable proper statistical analysis.

Plant 3 failure and repair records were extracted from the monthly maintenance summary reports. As such, the component identification numbers were frequently omitted or recorded erroneously. This made matching with Plant 3 population records a difficult task. Ultimately it became evident that less than one third of the failure and repair records could be matched. This did not yield a suitable sample to perform statistical analysis upon. The original failure and repair records are necessary for proper data base development.

5.5 Information Documented in the Maintenance Work Requests

In reviewing and classifying the maintenance work request (MWR) records of the four nuclear stations, additional information on the MWR about the components' failure mode, failure severity, and repair or unavailable time would be helpful in using the failure and repair document for data base development.

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APPENDIX A

SUMMARY OF PLANT 1 DATA

APPENDIX A (PLANT 1)

Plant 1

Population data. Equipment lists containing: component identification number, valve location, type and size of valve, operator type, the number (population) of such valves, and the operating mode (normal valve position). This information was available on 1051 of 3138 (33%) population records.

Maintenance work request data. The plant component and system summary cards of the individual work requests were the input to IPRD. Each summary card contains the component identification number, an abbreviated description of the failure, repair actions, repair time derived from the original maintenance work request, dates of the failure and repair action, and report number. Of 3078 total failure and repair records, 2942 matched with 1347 population records.

Table A-1. Valve populations, demands, and service hours for Plant 1

Valve type	Operator type	Population	Total demands	Total service hours (10^6 h)	Maintenance frequency (No. of failures/10^6h)
Ball	All	59	3,540	2.58	7.36
	– pneumatic	42	2,520	1.84	7.61
	– others*	17	1,020	0.740	6.76
Butterfly	All	251	15,100	11.0	9.64
	– pneumatic	26	1,560	1.14	35.1
	– motor-driven	30	1,800	1.31	28.2
	– others*	195	11,700	8.54	3.40
Check	All	116	6,960	5.08	9.65
Diaphragm	All	353	21,200	15.5	4.52
Gate	All	752	45,100	32.9	17.6
	– pneumatic	42	2,520	1.840	97.8
	– solenoid	1	60	0.044	NC
	– motor-driven	95	5,700	4.16	62.0
	– hand	20	1,200	0.876	28.5
	– others*	594	35,600	26.0	4.42
Globe	All	496	29,800	21.70	17.2
	– pneumatic	118	7,080	5.17	43.1
	– solenoid	2	120	0.088	182.0
	– motor-driven	29	1,740	1.27	48.0
	– hand	10	600	0.438	25.1
	– others*	337	20,200	14.8	4.19
Needle	All	1	60	0.044	NC
Plug	All	53	3,180	2.326	NC
	– pneumatic	2	120	0.088	NC
	– others*	51	3,060	2.23	NC
Safety/Relief	All	131	7,860	5.74	14.5
Directional control	All	28	1,680	1.23	14.6
	– pneumatic	11	660	0.482	18.7
	– solenoid	11	660	0.482	4.15
	– motor-driven	2	120	0.088	68.2
	– others*	4	240	0.175	5.71

*Indicates that valve equipment list did not specify operator type. This includes the majority of manually operated valves.

NC – not calculated.

Table A-2. Valve failures by mode and severity for each valve type in Plant 1

Valve type	Operator type	Number of failures												
		Severity												
		Catastrophic					Degraded Mode			Incipient				
		A	B	C	D	K	E	F	I	G	H	J	L	
Ball	All				3	N/A	4	2	N/A	6	4	N/A	N/A	19
	– pneumatic				3		3	2		3	3			
	– others*						1			3	1			
Butterfly	All	22	5		1	N/A	38	12	N/A	23	5	N/A	N/A	106
	– pneumatic	4	3		1		9	9		11	3			
	– motor-driven	13	2				16	1		4	1			
	– others*	5					13	2		8	1			
Check	All	N/A	N/A		5	N/A	4	7		27	N/A	6	N/A	49
Diaphragm	All	7	2	1	3	N/A	17	20	N/A	16	4	N/A	N/A	70
Gate	All	106	16		2	N/A	155	55	N/A	215	28	N/A	N/A	577 45%
	– pneumatic	25	5		1		62	19		54	14			
20%	– motor-driven	61	10				58	12		106	10			
	– hand	3	1				8	3		10				
	– others*	17			1		27	21		45	4			
Globe	All	55	9		5	N/A	71	49	N/A	141	43	N/A	N/A	373
	– pneumatic	28	6		2		44	32		79	32			
	– solenoid	2	1				3			8	2			
	– motor-driven	16	2				9	2		26	6			
	– hand	2					1	5		3				
	– others*	7			3		14	10		25	3			
Relief/Safety	All	6	N/A	N/A	N/A	4	11	30	N/A	N/A	2	N/A	30	83
Directional Control	All					N/A	3	2	N/A	11	2	N/A	N/A	18
	– pneumatic						2	1		4	2			
	– solenoid						1	1						
	– motor-driven									6				
	– others*									1				
		196	32	1	19	4	303	177		439	88	6	30	1295 total

Mode Codes:
(A) – Fails to Operate
(B) – Spurious Operation
(C) – Plugged
(D) – Significant Internal Leakage
(K) – Fails to reclose/reseat
(E) – Improper Operation
(F) – Internal Leakage
(I) – Partial Plugging
(G) – External Leakage
(H) – Faulty Indication
(J) – Chattering
(L) – Weepage

*Indicates valve equipment list did not specify operator type. Includes majority of manually operated valves.

N/A – Not applicable.

APPENDIX B

SUMMARY OF PLANT 4 DATA

APPENDIX B (PLANT 4)

Plant 4

Population data. An equipment list and plant manual containing: component name and identification number, valve type and size, operator type, and system. These data were available for 523 out of 1578 (33%) population records.

Maintenance work request data. Copies of the original maintenance records were obtained. Each record contains the component identification number, failure description, repair action, dates of failure report and repair, and report number. All 547 total failure and repair records were matched with 263 population records.

Table B-1. Valve population, demands, and service hours for Plant 4

Valve type	Operator type	Population	Total demands	Total service hours (10^6 h)	Maintenance frequency $\left(\frac{\text{no. of failure}}{10^6\ \text{h}}\right)$
Ball	All	3	216	0.158	12.7
	- pneumatic	3	216	0.158	12.7
Butterfly	All	230	16,600	12.1	14.8
	- pneumatic	98	7,060	5.15	29.1
	- motor-driven	30	2,160	1.58	12.0
	- chain	18	1,300	0.946	0
	- others*	84	6,050	4.42	2.26
Check	All	194	14,000	10.2	3.43
	- pneumatic	170	12,200	8.94	2.58
	- others*	24	1,730	1.26	2.38
Diaphragm	All	79	5,690	4.15	0.962
	- pneumatic	1	72	0.053	0
	- solenoid	1	72	0.053	0
	- others*	77	5,540	4.05	0.988
Gate	All	547	39,400	28.8	5.82
	- pneumatic	8	576	0.420	0
	- solenoid	3	216	0.158	0
	- motor-driven	93	6,700	4.89	26.2
	- chain	1	72	0.053	0
	- hand	8	576	0.420	9.52
	- others*	434	31,200	22.8	1.54
Globe	All	118	8,500	6.20	8.23
	- pneumatic	20	1,440	1.05	1.90
	- motor-driven	17	1,220	0.894	39.1
	- others*	81	5,830	4.26	3.29
Plug	All	18	1,300	0.946	8.47
	- pneumatic	8	576	0.420	14.3
	- hand	2	144	0.105	9.52
	- others*	8	576	0.420	2.38
Safety/Relief	All	49	3,530	2.58	9.69
	- pneumatic	41	2,950	2.15	6.94
	- others*	8	576	0.420	23.8
Angle	All	10	720	0.526	7.60
	- Motor-driven	7	504	0.368	10.9
	- others*	3	216	0.158	0

*Indicates that valve equipment list did not specify operator type. This includes the majority of manually operated valves.

Table B-2. Valve failures by mode and severity
for each valve type in Plant 4

Valve type	Operator type	Number of failures											
		Severity											
		Catastrophic					Degraded Mode			Incipient			
		A	B	C	D	K	E	F	I	G	H	J	L
Ball	All												
	- pneumatic					N/A				2		N/A	N/A
Butterfly	All	32	2		2	N/A	38	22	2	14	73	N/A	N/A
	- pneumatic	19	1		2		28	17	2	11	70		
	- motor-driven	9	1				4	2		1	2		
	- chain												
	- others*	4					2	1		2	1		
Check	All	N/A	N/A			N/A	11	3		18	12		N/A
Diaphragm	All					N/A				3		N/A	N/A
Gate	All	12	7			N/A	26	10		95	17	N/A	N/A
	- pneumatic												
	- motor-driven	7	7				21	10		74	9		
	- hand												
	- others*	5					5			18	7		
Globe	All	2				N/A	2	4		40	3	N/A	N/A
	- pneumatic	1								1			
	- motor-driven						2	3		28	2		
	- others*	1						1		11	1		
Plug	All					N/A		1			7	N/A	N/A
	- pneumatic										6		
	- hand										1		
	- other							1					
Relief/Safety	All		1	N/A	1		7	5	1	N/A	1	N/A	
	- pneumatic		1		1		6	4	1		1		
	- other						1	1					
Angle	All	1				N/A				3		N/A	N/A
	- motor-driven	1								3			
	- others												
Unknown	All	50	15				57	10	6	54	73	3	2
	- penumatic	3					8		2	3	15		
	- solenoid	1								1	1		
	- hand												
	- others	46	15				49	10	4	50	57	3	2

Mode Codes:
(A) - Fails to Operate
(B) - Spurious Operation
(C) - Plugged
(D) - Significant Internal Leakage
(K) - Fails to reclose/reseat
(E) - Improper Operation
(F) - Internal Leakage
(I) - Partial Plugging
(G) - External Leakage
(H) - Faulty Indication
(J) - Chattering
(L) - Weepage

*Indicates valve equipment list did not specify operator type. Includes majority of manually operated valves.

N/A - Not applicable.

APPENDIX C

SAFETY AND POWER OPERATED RELIEF VALVES

APPENDIX C

SAFETY VALVES AND POWER OPERATED RELIEF VALVES

1. Purpose and Scope

The purpose of this task was to review and categorize maintenance records of the two PWR plants participating in the In-Plant Reliability Data program for failures of the ASME code safety valves and the power-operated relief valves (PORV) located at the pressurizer. Emphasis was on the failure mode, "Failure to close given the valve is open." Summaries of the failure and repair actions from the maintenance records are provided.

2. Observation and Conclusions

- Because of the short time span for which failure data are available (5 years of commercial operations for Plant 1 and 1.6 years for Plant 2) and the small population size, the conclusions drawn from reviewing the maintenance records should be considered preliminary.
- No failures of the ASME code pressurizer safety valves (PSV) either to open on demand or to reclose were found.
- Most of the failures of the PSVs, the power operated relief valves (PORV) and the motor operated isolation valves (MOV) were external leakage.
- No information was available from the maintenance records on the total number of actual demands on any of the three types of valves (PSV, PORV, and MOV) and therefore a failure rate for the failure mode "Fails to reclose" for the PSVs was not calculated.
- The PORVs are operated to relieve reactor coolant system pressure and limit the undesirable opening of the spring-loaded safety valves. Because of this design feature it is likely that the code safety valves have not been demanded to open during plant operation. Any demands on the PSVs were most probably due to the testing requirements of the ASME code. Because test interval is 5 years only one or two demands on the PSVs in 6.6 years of commercial operation are likely. This number of demands is insufficient to justify calculating a failure rate.

3. System Description

A simplified schematic of the pressurizer and the safety and relief valves for the two PWR plants are shown in Fig. C-1.

There are three pressurizer safety valves (PSV) at each plant. The PSVs are totally enclosed pop-type valves. The valves are spring-loaded, self-activated and with back-pressure compensation designed to prevent system pressure from exceeding the design pressure by more than 110%, in

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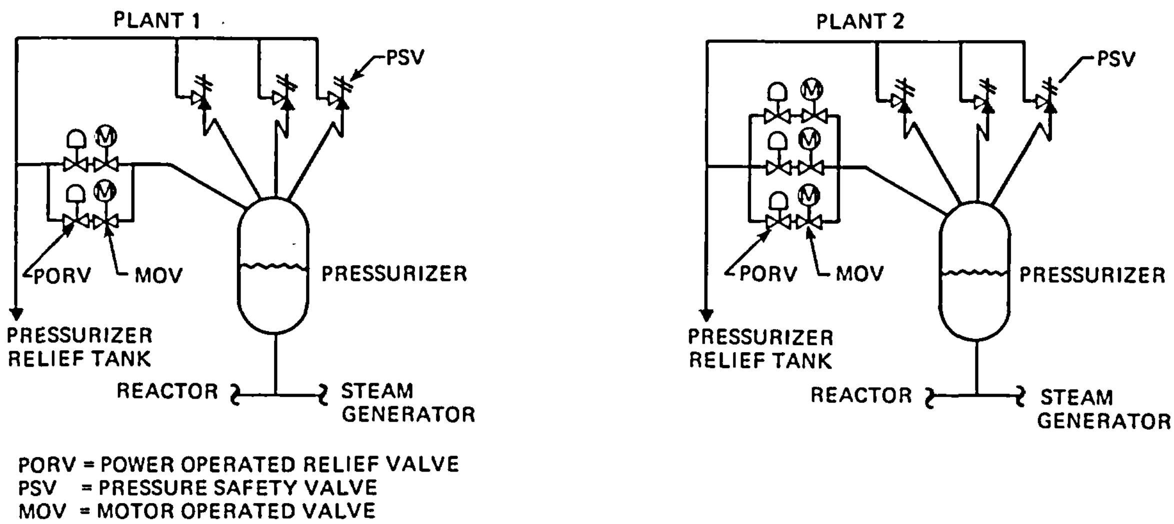

Fig. C-1. Pressurizer Safety and Relief Valves Arrangement.

accordance with the ASME Boiler and Pressure Code, Sect. III. The set pressure of the valves is 2485 psig.

The pressurizer is equipped with power-operated relief valves (PORV) which limit system pressure for a large power mismatch and thus prevent actuation of the fixed high-pressure reactor trip. The relief valves are operated automatically or by remote manual control. The operation of these valves also limits the undesirable opening of the spring-loaded safety valves. Remotely motor operated stop valves (MOVs) are provided to isolate the power-operated relief valves if excessive leakage occurs. The MOVs are normally in the open position and the PORVs are normally in the closed position.

The relief valves are designed to limit the pressurizer pressure to a value below the high-pressure trip set-point for all design transients up to and including the design percent step load decrease with steam dump but without reactor trip. The set pressure of the PORVs is 2335 psig. Plant 1 has two parallel lines of PORVs; Plant 2 has three parallel lines. The discharge ports of the PORVs and PSVs are routed to the pressurizer relief tank.

4. Plant Data

The time frame of the data from Plant 1 is 5 years of commercial operation; for Plant 2 is 1.6 years of commercial operation. Due to the relatively short time span of the collected data and the small population (2 plants), all conclusions drawn from reviewing these maintenance records should be considered preliminary.

The corrective maintenance actions for the PSVs, PORVs, and MOVs for Plants 1 and 2 are presented in Tables C-1 and C-2. A summary of the

Table C-1. Corrective maintenance actions of pressurizer valves in Plant 1
(time frame of data: 5 years of commercial operation)

Valve	Failure description	Repair description	Repair (h)
PSV-1	Leaks. (Failure occurred prior to commercialization date.)	(No documentation.)	
PSV-1	Leaks past seat. (Failure occurred prior to commercialization date.)	Replaced gasket and lapped seat.	48
PSV-1	Safety valve appears to leak thru seat. (Something under seat.)	Lifted seat and reset. OK now.	45
PSV-2	Possible leak past seat.	Removed plug.	3
PSV-3	Remove rust.	(No documentation.)	8
PORV-1	Valve leaks by (failure occurred prior to commercialization date.)	Replaced gasket and lapped seat.	30
PORV-1	Excessive leakage.	Beveled and lapped seat - replaced gasket.	38
PORV-1	Leaking.	Polished both seats and replaced gasket.	40
PORV-1	During test, cycled once but not twice.	Installed gaskets and one screen in regulator.	4
PORV-1	Regulators leak.	Renew gaskets and gages.	4
PORV-1	Limit switches need adjustment.	Adjusted limit switches.	4
PORV-1	Valve leaks through.	Adjusted spring tension-cycled.	80
PORV-1	Leaks through.	Loosened lock and adjusted valve.	8
PORV-1	Air leak in inlet to PORV nipple.	Installed solenoid, tested.	8
PORV-1	(No documentation.)	Changed diaphragm.	4
PORV-2	Leaks slightly.	No leaks at normal pressure.	
PORV-2	Leaks by.	Machined seat, straightened.	40
PORV-2	High temperature alarm indicating seat leakage.	Replaced stem and flex gasket.	34
PORV-2	Limit switches requires setting.	Adjusted limit switches.	4
PORV-2	Regulator leaks.	Renewed gaskets and gages.	4
PORV-2	Stem plug and cage assembly removed during shut down.	Machined stem plug face, and cage seat. Lapped plug and seat.	12
PORV-2	Limit switches out of adjustment.	Adjusted upper limit switch.	2.5
PORV-2	Valve leaks through.	Inspected and repaired valve.	80
PORV-2	Diaphragm on operators. Leaking.	Repair as instructed.	16
PORV-2	Air regulator for PORV.	Replaced regulator.	4
MOV-1	Small body to bonnet leak.	Retorqued and welded seal.	51
MOV-2	Small body to bonnet leak.	Retorqued and seal welded leak.	42

Table C-2. Corrective maintenance actions of pressurizer valves in Plant 2
(time frame of data: 1.6 years of commerical operation)

Valve	Failure description	Repair description	Repair (h)
PSV-1	(No failures reported.)		
PSV-2	(No failures reported.)		
PSV-3	(No failures reported.)		
PORV-1	Valve opened for preoperations test crew, it did not reset. Incorrect preload tension on valve spring. (Failure occurred prior to commercialization date.)	Adjusted pre-load tension on valve spring and functionally checked.	4
PORV-1	PORV-1, -2, -3 lift prematurely. (Failure occurred prior to commercialization date.)	Found bad solenoid valve on PORV-3. Replaced solenoid and calibrated.	3
PORV-1	Valve leaks thru. Seat and plug wire drawn.	Installed new seat and lapped plug to it. New gaskets, repacked, functionally checked.	20
PORV-2	Valve is leaking by. (Failure occurred prior to commercialization date.)	Valve not seated. Seat valve and stroked to insure properly seated.	2
PORV-2	Valve leaking by at normal pressure because disc is ruined.	Deterioration from service. Installed new stem and disc. Replaced seat ring gasket and bonnet gasket. Replaced packing.	12
PORV-3	Valve failed to open.	Solenoid valve no good. Replaced solenoid valve.	28
MOV-1	(Not documented.)	Retorqued packing gland per procedure spec.	12
MOV-1	Packing leak.	Natural end of packing life. Repacked valve.	16
MOV-1	(Not documented.)	Valve was jammed shut as clearance point.	4
MOV-1	Packing leak.	Natural end of packing life. Repacked valve.	6
MOV-2	(Not documented.)	Valve was jammed shut as clearance point.	4
MOV-3	Valve wedge jammed in seat. Over torqued by motor operator and by hand to effect isolation for another job.	Pulled bonnet and freed wedge. Stem reassembled and repacked.	52
MOV-3	Won't open electrically. Broken terminal on switch.	Broken terminal on benchboard switch repaired.	8

valve failure mechanisms is presented in Table C-3. Most of the valve failures are seat leakage. No maintenance records for the PSVs "Failing to close, given the valve is open" were found. A failure of a PORV to reset was observed in Plant 2 (PORV-1). However, this failure should not be considered as a random failure since it occurred in preoperation testing, that is prior to commercialization of the plant.

Table C-3. Summary of valve failure mechanisms

Valve type	Plant 1			Plant 2		
	PSV	PORV	MO	PSV	PORV	MO
Failure mechanism						
Valve seat leakage	4	10	2	0	3	3
Limit switch	0	3	0	0	0	0
Air/regulator leak	0	4	0	0	0	0
Operator failure	0	2	0	0	0	0
Failed to reset	0	0	0	0	1	0
Lifted prematurely	0	0	0	0	1	0
Solenoid failure	0	0	0	0	1	0
Other	1	1	0	0	0	4
Total	5	20	2	0	6	7

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16. ABSTRACT (200 words or less)

This report documents the methodology and some of the preliminary results attained from the valve data in the In-Plant Reliability Data System. The methodology used for data base development and failure rate calculation is described along with the present limitation of and recommendation for data system development.

A sampling of preliminary results is presented to exemplify the potential usefulness of an expanded data system.

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