SKI Report 2008:01

Research

Reliability Data for Piping Components in Nordic Nuclear Power Plants "R-Book" Project Phase I

Rev 1

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SKI-perspective

SKI Report 2008:01 - “Reliability Data for Piping Components in Nordic Nuclear Power Plants - R-Book Project Phase I” – is a planning document for a new R&D project to develop a piping component reliability parameter handbook for use in probabilistic safety assessment (PSA) and related activities. Included in this handbook will be pipe leak failure rates and rupture frequencies that are derived from the service experience data that is stored in the “OECD Pipe Failure Data Exchange” (OPDE) database. This new R&D project is sponsored jointly by the Swedish Nuclear Power Inspectorate and the Swedish utility members of the Nordic PSA Group (NPSAG).

Established in 2002, OPDE is an international database on the service experience with piping in commercial nuclear power plants. The OPDE database captures information on damage and degradation mechanisms that result in repair or replacement of affected piping, including small-, medium- and large-diameter safety-related and non-safety-related piping systems. The “R-Book” project is one of a series of completed or ongoing OPDE application projects, including work by the Korea Institute of Nuclear Safety, Korea Atomic Energy Research Institute, and the Japan Nuclear Energy Safety Organization.

SKI Report 2008:1 describes the methods and techniques that are proposed for the derivation of piping reliability parameters. The report also outlines the technical scope of the analyses to be performed and the proposed detailed content of the R-Book.

Background

The history behind the current effort to produce a handbook of piping reliability parameters goes back to 1994 when SKI funded a 5-year R&D project to explore the viability of establishing an international database on the service experience with piping system components in commercial nuclear power plants. An underlying objective behind this 5-year program was to investigate the different options and possibilities for deriving pipe failure rates and rupture probabilities directly from service experience data as an alternative to probabilistic fracture mechanics. The R&D project culminated in an international piping reliability seminar held in the fall of 1997 in Sigtuna (Sweden) and a pilot project to demonstrate an application of the pipe failure database to the estimation of loss-of-coolant-accident (LOCA) frequency (SKI Report 98:30).

Scope

The scope of the research project which is described in SKI Report 2008:01 is to derive piping component failure rates and rupture probabilities from piping failure reports stored in the OECD Nuclear Energy Agency OPDE database.

Results

Since the completion of the original piping reliability R&D in 1998, a very large number of practical pipe failure database applications have been completed, some of which are referenced in this report. The insights and lessons learned from these applications, including the experience gained from the OPDE project, form the basis for developing the “R-Book.”. The results of the planning effort that are presented in this report are:

- Review of pipe failure databases and identification of technical features that are considered important to the statistical estimation processes that are considered for use in the R-Book development (Chapter 2: Existing Pipe Failure Databases).

- Review of methods for piping reliability parameter estimation (Chapter 3: Pipe Failure Parameter Estimation & Requirements on Data Sources).

- Development, distribution and evaluation of a questionnaire that addresses user requirements on the planned R-Book (content, including level of detail, and updating philosophy) (Chapter 4: Questionnaire – Database users).

During 2008, high-level presentations of the project, including technical progress reports will also be given at forthcoming international conferences.

Impact on the operation of SKI

The usefulness of any component failure data collection depends on the way by which a stated purpose is translated into database design specifications and requirements for data input and validation, access rules, support and maintenance, and QA. SKI sees it as an important step to verify the content and quality of the OPDE database, and that interested parties strive against harmonized ways of creating reliability data to be used in safety analyses.

Continuing work within the research area

During 2008 and 2009 the work continues in a phase 2, which is an implementation phase. Overall work strategy for the continuous work with the R-Book project in Phase 2 will be:

- Identification of already existing piping population databases, including those at Nordic nuclear power plants. These databases will provide critical input to exposure term definitions that are required for the calculation of pipe failure rates.

- For selected systems, qualitative and quantitative piping reliability information will be developed to demonstrate the R-Book document design and content.

- A seminar with representatives from the Nordic utilities and SKI will be held in the May-June 2008 timeframe. At this seminar the interim results will be presented. Comments and recommendations with respect to methodology and handbook content will be accounted for before the work continues to complete a first edition of the R-Book.

- Continued work to produce reliability data parameters for the R-Book.

Project information

SKI Project Manager:	Ralph Nyman
Project number:	2005 02 004
Dossier Number:	SKI 2005/500

Earlier published reports[1] related to the topic of this research project are:

SKI Report 95:58, Reliability of Piping System Components. Volume 1: Piping Reliability – A Resource Document for PSA Applications, December 1995

SKI Report 95:59, Reliability of Piping System Components. Volume 2: Review of Methods for LOCA Frequency Assessment, December 1995

SKI Report 95:60, Reliability of Piping System Components. Volume 3: A Bibliography of Technical Reports and Papers Related to Piping Reliability, December 1995

SKI Report 95:61, Reliability of Piping System Components. Volume 4: The Pipe Failure Event Database, December 1995

SKI Report 1996:20, Piping Failures in United States Nuclear Power Plants: 1961-1995, February 1996

SKI Report 1996:24, An Overview of Stress Corrosion in Nuclear Reactors from the Late 1950s to the 1990s, February 1996

SKI Report 1996:39, Failure Frequencies and Probabilities Applicable to BWR and PWR Piping, March 1996

SKI Report 1997:26, Reliability of Piping System Components, December 1997

SKI Report 1997:32, Proceedings of Seminar on Piping Reliability, October 1997

SKI Report 1998:30, Failure Rates in Barsebäck-1 Reactor Coolant Pressure Boundary Piping, May 1999

SKI Report 02:50, Skador i svenska kärnkraftanläggningars mekaniska anordningar (1972-2000), December 2002 (For the period 1972-2000, this report includes a detailed review of the piping service experience at the Swedish nuclear power plants. The report is available in Swedish language only).

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[1] For more information go to www.ski.se

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Sammanfattning

Föreliggande dokument utgör planering för ett F&U projekt med syfte att ta fram en handbok innehållande tillförlitlighetsdata för rörkomponenter (den svenska benämningen på handboken är ”R-boken”) för att använda i PSA (Probabilistiska säkerhetsanalyser) samt andra aktiviteter relaterade till PSA.

Målet med projektet är att använda den databas som går under benämningen OPDE (OECD Nuclear Energy Agency “OECD Pipe Failure Data Exchange Project”) för att ta fram felfrekvenser med tillhörande brottsannolikheter. Dessa data ska sedan kunna användas vid analys av översvämning, rörbrott i högenergisystem, framtagande av riskinformerade rörprovningsprogram samt andra PSA-relaterade aktiviteter. Detta F&U projekt finansieras av medlemmar från den Nordiska PSA-Gruppen (NPSAG), nämligen Forsmark AB, OKG AB, Ringhals AB samt SKI.

Historien som gett upphov till projektet om R-boken går tillbaka till 1994 när SKI finansierade ett 5-årigt F&U projekt som syftade att undersöka möjligheten att ta fram en internationell databas innehållande erfarenhetsdata på rörkomponenter i kommersiella kärnkraftverksanläggningar. Ett bakomliggande motiv till detta 5-årsprogram var att undersöka möjligheterna att ta fram tillförlitlighetsdata för rörkomponenter utifrån erfarenhetsdata som ett alternativ till data framtaget m.h.a. probabilistisk strukturmekanik. Detta F&U projekt kulminerade hösten 1997 med ett internationellt seminarium i Sigtuna (Sverige) samt ett pilotprojekt som syftade att demonstrera framtagande av LOCA-frekvenser från erfarenhetsdata (SKI Rapport 98:30).

Ett särskilt viktigt resultat från det 5-åriga F&U projektet var ett beslut från SKI att överföra erfarenhetsdatabasen som tagits fram till ett internationellt samarbetsprojekt under OECD Nuclear Energy Agency. Under år 2000 pågick informationsinsamling och planeringsmöten och år 2001 organiserade OECD Nuclear Energy Agency det projekt som kom att gå under namnet OECD Pipe Failure Data Exchange Project (OPDE). Projektet startades officiellt upp i maj år 2002. I dag (per januari 2008) så stöds OPDE av organisationer från tolv länder och i november 2007 beslutades om projektets tredje period som kommer att omfatta åren 2008-2011. Generell information om OPDE kan hittas på www.nea.fr.

Sedan det ursprungliga F&U projektet från 1998 har ett stort antal praktiska applikationer genomförts baserat på olika databaser för rörkomponenter, vissa av dem finns refererade i föreliggande dokument. Insikter och lärdomar från dessa applikationer tillsammans med den kunskap som har byggts upp i samband med OPDE utgör grunden för framtagande av ”R-boken”. En viktig lärdom från föregående applikationer är vikten av att de inträffade händelser som återfinns i databasen är verifierade och kvalitetssäkrade samt att det verifieras att de händelsepopulationer sökningar i databasen resulterar i är tillräckligt fullständiga för att relevanta slutsatser ska kunna dras.

Summary

This report constitutes a planning document for a new R&D project to develop a piping component reliability parameter handbook for use in probabilistic safety assessment (PSA) and related activities. The Swedish acronym for this handbook is “R-Book.”

The objective of the project is to utilize the OECD Nuclear Energy Agency “OECD Pipe Failure Data Exchange Project” (OPDE) database to derive piping component failure rates and rupture probabilities for input to internal flooding probabilistic safety assessment, high-energy line break” (HELB) analysis, risk-informed in-sevice inspection (RI-ISI) program development, and other activities related to PSA. This new R&D project is funded by member organizations of the Nordic PSA Group (NPSAG) – Forsmark AB, OKG AB, Ringhals AB, and the Swedish Nuclear Power Inspectorate (SKI).

The history behind the current effort to produce a handbook of piping reliability parameters goes back to 1994 when SKI funded a 5-year R&D project to explore the viability of establishing an international database on the service experience with piping system components in commercial nuclear power plants. An underlying objective behind this 5-year program was to investigate the different options and possibilities for deriving pipe failure rates and rupture probabilities directly from service experience data as an alternative to probabilistic fracture mechanics. The R&D project culminated in an international piping reliability seminar held in the fall of 1997 in Sigtuna (Sweden) and a pilot project to demonstrate an application of the pipe failure database to the estimation of loss-of-coolant-accident (LOCA) frequency (SKI Report 98:30).

A particularly important outcome of the 5-year project was a decision by SKI to transfer the pipe failure database including the lessons learned to an international cooperative effort under the auspices of the OECD Nuclear Energy Agency. Following on information exchange and planning meetings that were organized by the OECD Nuclear Energy Agency during 2000 – 2001, the “OECD Pipe Failure Data Exchange Project” (OPDE) was officially launched in May 2002. Today (January 2008) the OPDE is supported by organizations from twelve countries. The project’s third term (2008-2011) was approved in November 2007. General information about OPDE can be found at www.nea.fr.

Since the completion of the original piping reliability R&D in 1998, a very large number of practical pipe failure database applications have been completed, some of which are referenced in this report. The insights and lessons learned from these practical applications, including the experience gained from the OPDE project, form the basis for developing the “R-Book.” An important observation from prior applications is the need to ensure that reports on pipe degradation and failure as recorded in a database are fully validated and that the event populations that result from database queries are sufficiently complete.

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1 Introduction

This report constitutes a planning document for the development of a piping reliability parameter handbook (the “R-Book”), which will include tabulations of failure rates and conditional failure probabilities for the full range of piping system components found in the Nordic light water reactor plants. Specifically the document addresses the different types of reliability parameters to be derived and certain aspects of the methodology on which the parameter estimation will be based.

The scope of the handbook includes small-bore (DN[2] ≤ 25 mm), medium-bore ($25 <$ DN ≤ 250 mm), and large-bore piping (DN > 250 mm) within the containment/ drywell, auxiliary and reactor buildings, turbine buildings, and other service buildings within the controlled area of a nuclear power plant. Included in the scope are carbon steel, low alloy steel, nickel base steel, and stainless steel piping components. Any piping system, whose failure can have an impact on routine plant operations, is considered in the scope of the R-Book.

1.1 Planning Steps

Based on technical discussions and seminars within the framework of the Nordic PSA Group (NPSAG) planned activities during 2002-2005, a formal decision to launch the R-Book project was made in 2005. Funding for a planning phase was made available in December 2005. The results of the planning effort are presented in this report. The planning effort consisted of five technical elements:

1. Review of pipe failure databases and identification of technical features that are considered important to the statistical estimation processes that are considered for use in the R-Book development (Chapter 2).
2. Review of methods for piping reliability parameter estimation (Chapter 3).
3. Development, distribution and evaluation of a questionnaire that addresses user requirements on the planned R-Book (content, including level of detail, and updating philosophy) (Chapter 4).
4. Development, distribution and evaluation of a questionnaire that addresses the availability and access to piping exposure term data (piping system design information including weld counts and pipe length information organized by system, size, material, process medium, safety classification) (Chapter 5).
5. Detailed work plan for R-Book development, including cost, schedule, quality assurance, and analysis tools and techniques (Chapter 6).

1.2 Results of the Planning Phase

Following a review during 2006-2007 of working documents prepared for each of the five technical elements identified above and a comment resolution phase, a detailed work plan with associated budget and schedule was approved during the second half of 2007. Key elements of the work plan are documented in Chapter 6. High-level

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[2] DN is the German designator for nominal pipe diameter in [mm]. This designator is also used in the Nordic countries for nominal pipe diameter.

presentations of the R-Book project, including technical progress reports will be given at forthcoming international conferences, including:

- ICONE-16 – 16th International Conference on Nuclear Engineering, May 11-15, 2008.
- Ninth International Probabilistic Safety Assessment and Management Conference (PSAM-9), 18-23 May, 2008.
- JRC and CSNI Conference on Risk-Informed Structural Integrity Management, June 2-4, 2008.
- American Society of Mechanical Engineers 2008 Pressure Vessels and Piping (PVP) Conference, 27-31 July 2008.
- International Topical Meeting on Probabilistic Safety Assessment & Analysis (PSA 2008), September 7-11, 2008.

1.3 Technical Scope of R-Book

The R-Book will contain tabulations of piping reliability parameters that are organized by plant system, material (e.g., carbon steel, stainless steel) and nominal pipe diameter. In addition to the derived statistical parameters (e.g., mean, median, 5th and 95th percentiles) of pipe leak rates and rupture frequencies, the Handbook will also include qualitative information with respect to piping failure histories and the various structural integrity management programs that have been developed to address certain degradation mechanisms. The piping reliability parameters will be specialized in such a way that appropriate and reasonable account is taken of the Nordic design and inspection practices and service experience.

The R-Book is intended to be used in connection with practical PSA applications. Users of the Handbook values are responsible for how the applications are performed, including any data specialization beyond what is addressed by the Handbook.

1.4 Report Outline

The report consists of seven sections and ten attachments. In the main body of the report, one section is devoted to each of the five technical elements that address certain aspects of the R-Book scope and content. Chapter 7 includes a list of references.

The ten attachments include all the supporting documentation including the two questionnaires developed and evaluated as part of the R-Book scope definition. Attachment 7 includes the questionnaire prepared for the three Swedish utility organizations that are participating in and supporting the R-Book project. This questionnaire deals with the availability of and access to piping design information specific to the ten Swedish operating plants. Attachment 7 has not been translated into English.

2 Existing Pipe Failure Databases

2.1 Abstract

This chapter includes the results of a survey of existing pipe failure databases. It divides surveyed databases into three categories according to their fitness for use in risk-informed PSA applications: Category 0, 1 and 2. These categories relate to the ASME PSA Standard (ASME RA-Sb-2005) and the Nuclear Energy Institute's PSA Peer Review Guidelines NEI 00-02 as indicated below.

	ASME RA-Sb-2005 (November 2005) PSA Capability Category		
	I	**II**	**III**
NEI 00-02 PSA Peer Review Guidelines	Grade 1,2	Grade 3	Grade 4
R-Book Database Categorization	Cat0, Cat 1	(Cat1) Cat2	Cat2

Figure 2.1 *Pipe Failure Database Categorization*

At the highest level, a Category 2 (Cat2) database is expected to support Grade 3 or 4 PSA applications as defined in NEI-00-02. Associated with this database category are certain requirements for data processing, maintenance, validation and Quality Assurance. These requirements are tied to statistical data analysis tasks to obtain quantitative reliability parameters.

By contrast, a Category 0 (Cat0) database reflects a transitional phase in database development to establish updated perspectives on piping reliability and loss-of-coolant-accident frequencies relative to those developed by WASH-1400. These types of databases in general have not been subjected to independent validation and do not have any clearly stated quality objective.

Finally, a Category 1 (Cat1) database is intended for high-level evaluations of failure trends. It supports a multitude of qualitative and semi-quantitative evaluation tasks, and it usually has direct links to source data (for example, plant owners provide the input data directly to the database administrator). This type of database usually has a single user (person or organization), whereas a Category 2 database has (is intended to have) multiple users.

The survey is concerned with definitions of purpose (objectives and requirements for a database), piping component boundary definitions, validation, database management routines including quality assurance (QA), and fitness-for-use, including extent of demonstrated practical application and peer review. The survey also contrasts-and-compares databases that have found practical use.

Included in the survey are three examples of compilations of piping reliability parameters that have resulted from database applications: 1) BWR-specific weld failure rates extracted from Appendix D of NUREG-1829 [2.27], 2) raw water pipe failure rates and rupture frequencies extracted from EPRI Report No. 1012302 [2.9], and 3) pipe failure rates applicable to High Energy Line Break analysis [2.5].

2.2 Introduction

The usefulness of any component failure data collection depends on the way by which a stated purpose is translated into database design specifications and requirements for data input and validation, access rules, support and maintenance, and QA. In this chapter a survey is made of existing pipe failure data collections and their abilities to support risk informed PSA applications. Using insights and results from database development and application during 1995-2007, this survey also identifies database quality requirements against which conclusions are reached about past and current database development efforts and their relevance with respect to practical use by multiple users.

2.2.1 Database Categorization

In this survey, existing pipe failure databases are grouped in three categories according to their capability to support a particular risk-informed or risk-based application. Three database categories are defined - Cat0, Cat1 and Cat2 – and Figure 2.1 shows how these categories compare with the NEI "PSA Peer Review Guidelines" [2.17] grading and the "Capability Categories" of the ASME PRA Standard [2.26].

	ASME RA-Sb-2005 (November 2005) PSA Capability Category		
	I	**II**	**III**
NEI 00-02 PSA Peer Review Guidelines	Grade 1,2	Grade 3	Grade 4
R-Book Database Categorization	Cat0, Cat1	(Cat1) Cat2	Cat2

Figure 2.1 *Pipe Failure Database Categorization*

2.2.2 Pipe Failure Database Features & Requirements

Over the years many different types of pipe failure databases have been developed [2.18 and 2.19]. Relative to intended use, maintenance/updating routines and QA, a distinction is made between "failure event database" and "reliability database". The former is a collection of raw data (or field data) on specified types of piping components or piping systems with or without database QA program in place but with direct access to source data. Usually this type has a single user (can be a person or organization) with sporadic or periodic database maintenance, if any, to support high-level (possibly one-time or occasional) evaluations of failure trends. It is referred to as a Category 1 (Cat1) database in this survey. The latter type of database includes processed raw data, is continuously updated and subjected to validation for technical accuracy and completeness. Invariably this type of database has multiple users engaged in risk-informed applications or advanced applications (for example expanded risk-informed application to investigate certain correlations between degradation mitigation and failure rate). Some form of independent peer review normally precedes a release of such a database for routine application by multiple users. A QA program is (should) always be in place for reliability databases. It is referred to as a Category 2 (Cat2) database in this survey and should be viewed as an extension of a Category 1 database.

Industry guides and recommendations exist for Category 2 database development, structure and quality [2.16, 2.22 and 2.24]. Chapters 2 and 3 of SKIFS 2005:2 [2.25] address the need for quality assured failure data in the context of risk-informed in-service inspection (RI-ISI).

In risk-informed applications data quality is particularly important and necessitates considerations for traceability and reproducibility of derived reliability parameters: including the source data producing database query results and data processing and statistical analysis of query results. From a user perspective, a Category 2 database should include detailed and correct information on failure events so that database queries generate relevant and complete results. That is, detailed information with respect to reliability attributes and influence factors. Furthermore, provisions should exist for pooling of different but relevant subsets of failure data to strengthen the statistical significance of obtained parameters. In summary, a minimum set of requirements on a Category 2 database include:

- User-friendly and flexible structure, data input forms should be designed in such a way as to encourage continuous updating by multiple operators. The structure should be flexible so that new database fields can be added if so desired.
- Clear database field definitions that reflect the attributes and influence factors that are unique to pipe degradation and failure.
- Input of raw data supported by an extensive, all-inclusive set of roll-down menus with standardized and complete set of key words.
- “All-inclusive” structure in which free-format memo fields for narrative descriptions support codification and justifications for assumptions if needed.
- Support full traceability from field data to processed data so that database users and independent reviewers have full confidence in the completeness and accuracy of database field contents.
- Configuration control with strict user access rules.
- Use of recognized and proven computer program(s) so that the database structure and its content remain impervious to future program revisions and “upgrades.”
- Ease of transfer of database query results to external computer program (e.g., Microsoft® Excel or other approved statistical analysis program).
- Data security routines must be established to ensure that all relevant but potentially sensitive or proprietary failure information is captured in the database. Also routines must exist for proper sharing of information among multiple users.
- Detailed database documentation including coding guideline to ensure proper technology transfer. Reference [2.20] is an example of such documentation.
- Approved QA program. To be effective a QA program should reflect a consensus perspective on data quality. The prospective database users must have a common understanding of intended usage and steps that are required to ensure configuration control and validation of database records.
- Completeness of database should be ensured through continuous or at least periodic updating. Completeness is concerned with event populations and assurances that “all” relevant events are captured. It is also concerned with completeness of the

classification of each database record. Ultimately "completeness" has direct bearing on the statistical significance of derived reliability parameters.

This "requirements list" for a Category 2 database is not an all inclusive list. Depending on the number of database users and type of application additional requirements could be defined. Fundamentally a database for risk-informed applications must be robust in the sense that it must support a broad range of applications, including repeat applications, and provide analysts with a solid knowledgebase for database query definition. Ideally a reliability database should be self contained so that it includes all facts about the cause-and-consequence of any degraded condition recorded in it. Why was it recorded in the first place, what were the material specifications and operating conditions, and exactly where in a piping system did the failure occur?

The previous paragraphs described the defining features of Cat1 and Cat2 databases. There is a third type of database, which in this survey is referred to as **Category 0** (Cat0) database. It is a hybrid database, which includes some of the features found in Category 1 and 2 databases, but it is not intended to exist as a standalone, computerized database for practical use beyond an original relatively narrowly defined objective. This type of database is typically embedded as extensive tables in a technical report, sometimes as an appendix, and provides traceable or non-traceable background to derived piping reliability parameters included in the main body of a technical report. Historically these published Category 0 databases have found widespread use in risk-informed applications, however. A data user's parameter selections and justifications are rationalized by simply referencing a table in published report.

2.2.3 Reading guide

A pipe failure database needs to include information of certain type and content to support practical applications. Concentrating on risk-informed applications, Chapter 2.3 is an exposé of the types of piping reliability parameters that may be needed. This exposé gives a background to the analytical demands and requirements that may be imposed on a Category 2 database. Chapter 2.4 summarizes results and insights from the database survey. A list of references is found in Chapter 7. Attachment 1 includes a sample of database excerpts and Attachment 2 includes a high-level summary of the PIPExp-2007 database (it is the OPDE "parent database"). Attachment 3 includes information on the web based OPDE user interface. Attachment 4 includes examples of compilations of piping reliability parameters that have resulted from database application.

2.3 Piping Reliability Models & Data Requirements

In this survey a "database" implies a collection of failure event information relating to a defined area of knowledge and application, organized so as to be available to analysts engaged in statistical analysis for the purpose of deriving equipment reliability parameters. To paraphrase the "Handbook on Quality of Reliability Data" [2.22], in applied risk and reliability analysis a database is a computerized "filing system" organized and constantly updated to contain data that describe degradation susceptibilities and failures of components as a function of time. As background to the survey of existing pipe failure databases, the types of piping reliability parameters needed for risk-informed applications are outlined below.

2.3.1 Reliability Parameters

A simple model of piping reliability components makes use of nuclear power plant reliability models originally developed to investigate alternative inspection strategies for different piping systems. Equation (1) is a representation of this model:

$$\rho_{ix} = \sum_{k=1}^{M_i} \rho_{ikx} = \sum_{k=1}^{M_i} \lambda_{ik} P_{ik} \{R_x | F\} I_{ik} \tag{1}$$

Where:

ρ_{ix} = Total “rupture” frequency for pipe component *i* for rupture mode *x*. A “rupture” corresponds to significant structural failure with through-wall flow rate well in excess of Technical Specification limits (see below for further details). The term “rupture” is nebulous: apart from implying a structural failure it does not convey information about its significance (for example, through-wall flow rate).

ρ_{ikx} = Rupture frequency of pipe component *i* due to damage mechanism k for failure mode *x*.

λ_{ik} = Failure rate of pipe component *i* due to damage mechanism *k*.

$P_{ik}\{R_x|F\}$ = Conditional probability of “rupture” mode *x* given failure for pipe component I and damage mechanism *k*.

M_i = Number of different damage mechanisms for component *i*.

I_{ik} = Integrity management factor for component *i* and damage or degradation mechanism *k*; this factor adjusts the rupture frequency to account for variable integrity management strategies such as leak detection, volumetric non-destructive examination (NDE), etc. that might be different than the components in a pipe failure database.

The term “failure” implies any degraded state requiring remedial action: from part through-wall crack, pinhole leak, leak, large leak to a significant, incapacitating structural failure. Types of remedial actions include repair (temporary or permanent), in-kind replacement or replacement using new, more resistant material. Depending on how this model of piping reliability is to be used, the precise definition of failure may be, and usually is, important. For example, it may be important to make distinction between different through-wall flaw sizes and their localized effects or global effects on plant operation. Localized effects include collateral damage (for example, damage to adjacent line or a jet stream causing damage to adjacent pipe insulation). Global effects include flooding of equipment areas or buildings. In recent risk-informed applications (as identified in Chapter 2.4, Table 2.4) the following definitions of pipe “rupture” modes defined in Table 2.1 have been used.

Table 2.1 *Example of Pipe "Rupture" Definitions*

"Rupture" Mode (x)	**Equivalent Pipe Break Diameter (EBD) [mm]**	**Peak Through-wall Flow Rate (FR) [kg/s]**
Large Leak	15 < EBD ≤ 50	0.5 < FR ≤ 5
Small Breach	50 < EBD ≤ 100	5 < FR ≤ 20
Breach	100 < EBD ≤ 250	20 < FR ≤ 100
Large Breach	250 < EBD ≤ 500	100 < FR ≤ 400
Major Breach	EBD > 500	FR > 400

PSA applications often require assessments of well differentiated pipe failure modes. For example, in internal flooding PSA it could be necessary to evaluate impacts of specific spray events on adjacent, safety-related equipment. Hence, initiating event frequency of a "large leak" could be required or any through-wall flaw of sufficient size to generate a spray effect. Another example could be the plant-specific assessment of a high-energy line break (HELB) initiating event of sufficient magnitude to activate fire protection sprinklers in a specific area of a Turbine Building.

In general, a point estimate of the frequency of pipe failure, λ_{ik}, is given by the following expression:

$$\lambda_{ik} = \frac{n_{ik}}{f_{ik} N_i T_i} \tag{2}$$

Where

n_{ik} = The number of failures (all modes including cracks, leaks and ruptures are included) events for pipe component *i* due to damage mechanism *k*.

T_i = The total exposure time over which failure events were collected for pipe component *i* normally expressed in terms of reactor years (or calendar years).

N_i = The number of components per reactor year that provided the observed pipe failures for component *i*.

f_{ik} = The fraction of number of components of type *i* that are susceptible to failure from degradation/damage mechanism (DM) "*k*" for conditional failure rates given susceptibility to DM "*k*", this parameter is set to 1 for unconditional failure rates.

When the parameter f_{ik} is applied the resulting failure rates and rupture frequencies are referred to as conditional failure rates as they are conditional on the susceptibility of the component to specific damage mechanisms. That is, for each component that these models are applied to, the damage mechanism susceptibility is known.

When the damage mechanism susceptibility is not known in advance the above equations are combined under the condition: $f_{ik} = 1$ to obtain the following expression for the point estimate of the rupture frequency:

$$\rho_{ix} = \sum_{k=1}^{M_i} \rho_{ikx} = \sum_{k=1}^{M_i} \lambda_{ik} P_{ik}\{R_x|F\} I_{ik} = \sum_{k=1}^{M_i} \frac{n_{ik}}{N_i T_i} P_{ik}\{R_x|F\} I_{ik} \tag{3}$$

Depending on the type of piping system under consideration, the conditional failure probability may be obtained by direct statistical estimation, or through probabilistic fracture mechanics (PFM), or expert judgment. Ultimately an estimated conditional failure probability needs to reflect existing service experience as well as structural integrity characteristics.

A Bayesian approach can be used to develop uncertainty distributions for the parameters in Equations (1) through (3). Prior distributions are developed for the parameters λ_{ik} and $P_{ik}\{R_x / F\}$ and these prior distributions are updated using the evidence from the failure and exposure data as in standard Bayes' updating. The resulting posterior distributions for each parameter on the right side of Equation (1) are then combined using Monte Carlo sampling to obtain uncertainty distributions for the pipe "rupture" frequency as illustrated in Figure 2.2, which is reproduced from Reference [2.7]

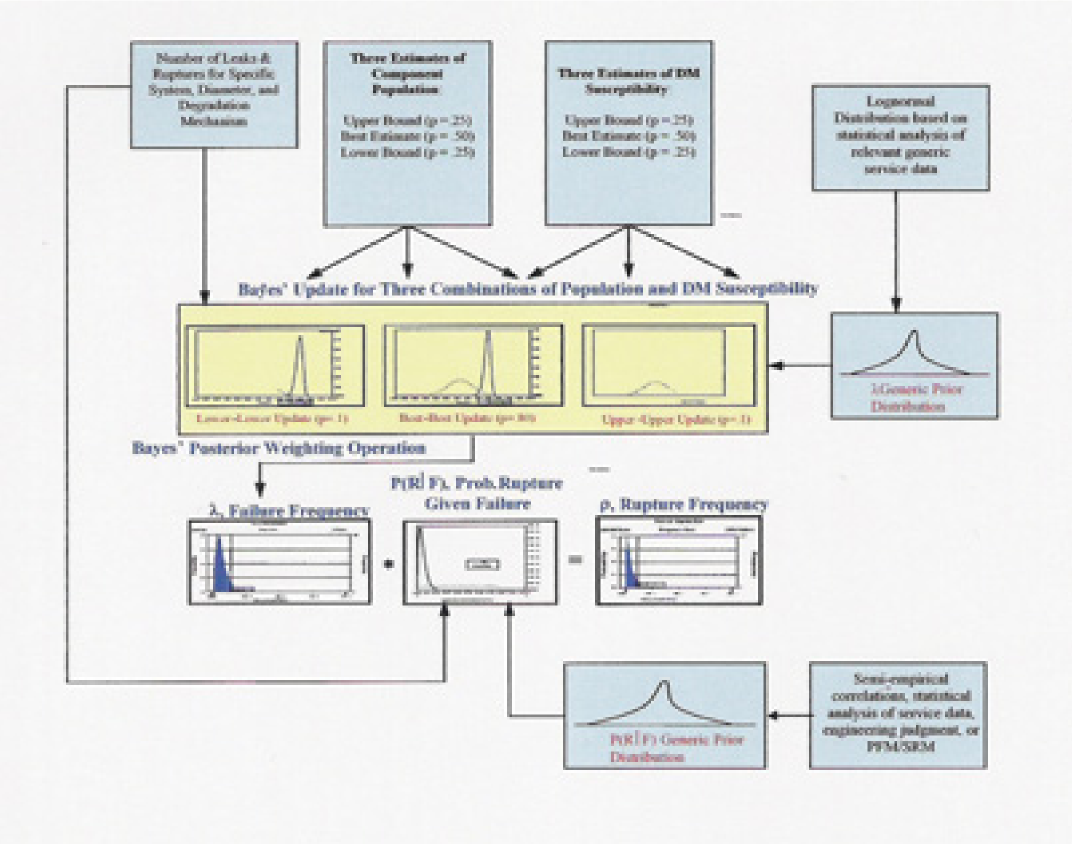


Figure 2.2 *Bayes' Estimates of Pipe Failure Rates and "Rupture" Frequencies*

For the conditional pipe failure probability, four approaches are used, 1) direct statistical estimation, 2) PFM, 3) expert judgment, or 4) combined approach using insights from data analysis, PFM and expert judgment. A limitation of the first approach is the dearth of data associated with major failure of piping that exhibits leak-before-break (LBB) characteristics. Different PFM algorithms have been developed and it is an area that continues to evolve. In general there are issues of dispute with respect to reconciliation of results obtained through direct statistical estimation versus PFM. A recent example of an application of expert judgment is documented in NUREG-1829 [2.27]

The chart in Figure 2.3 represents one perspective on conditional pipe failure probability. It includes plots of field experience data organized by observed through-wall peak leak or flow rate in kg/s. The given rates are threshold values. Given that a certain piping system is subject to degradation, what is the likelihood that a pipe flaw remains undetected and grows to produce a through-wall liquid or steam release of a certain magnitude? The ordinate of the chart shows the fraction of pipe failure of a certain class (ASME Code Class 1, 2, 3, or non-Code) and of certain magnitude (expressed as the peak leak/flow rate threshold value) to all failures in the class. It indicates how often a pipe failure of a certain magnitude has occurred according to existing historical data. The abscissa shows the observed through-wall liquid or steam peak flow rate threshold value.

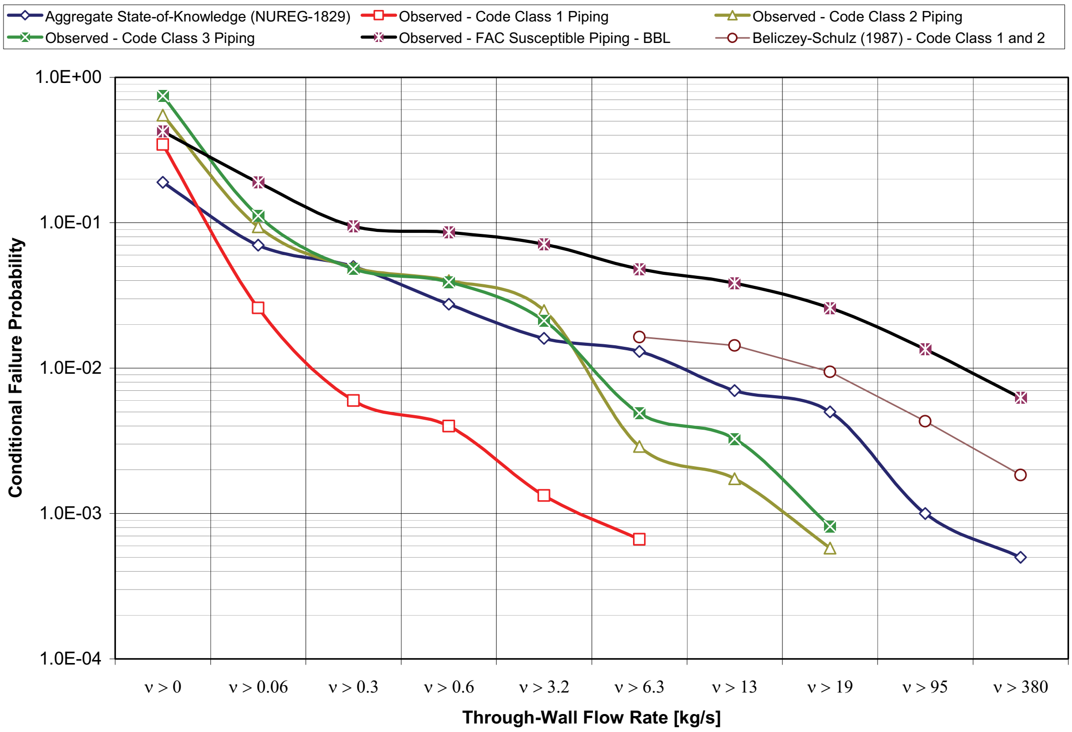


Figure 2.3 *Likelihood of Pipe Failure According to Service Data & Theoretical Studies*

According to the above figure, a Turbine Building ("FAC Susceptible") piping system failure is considerably more likely to produce a significant through-wall flaw than a safety-related piping system. Superimposed on the empirical data plots are the recent aggregate state-of-knowledge correlation from NUREG-1829 [2.27] and the "Beliczey-Schulz correlation" [2.2].

The empirical data used to construct the chart in Figure 2.3 represents 9,547 commercial react-years of operation as of 31-December-2005, including a total of 6,547 pipe failures as recorded in the PIPExp database. More details about this data source are found below and in Chapter 2.4, Table 2.4.

- For Code Class 1 piping the most severe failures to date have involved small-diameter piping. Of all failures involving through-wall flaws about 14% involve socket weld failures in DN20 and DN25 stainless steel lines. So far the largest observed through-wall flow rate is about 8 kg/s.
- Failure of large-diameter, thick walled Class 1 piping is unlikely. A primary reason for this is presence of mid-wall compressive residual stresses that tend to retard deep cracks.
- To date, there have been six Code Class 1 pipe failures involving > DN50 piping and > 6.3×10^{-2} kg/s peak leak/flow rate.
- For breaches in small-diameter, Class 1 piping observed flow rates are in general smaller or considerably smaller than the maximum theoretical possible flow rates. In part this explained by the flow restricting devices that are installed to minimize a through-wall flow rate given a severed pipe.
- The plots in Figure 2.3 are based on observed peak flow rates. In Class 1 piping and connecting Class 2 piping, the cracks that develop in the through-wall direction tend to be very tight producing only minor visible leakages, if any, while at full operating pressure. As the reactor is depressurized and shut down a through-wall crack tends to decompress so that a detectable leak develops and increases over time. As an example a thermal fatigue induced weld flaw at the U.S. PWR plant Oconee Unit 1 in April 1997 was initially diagnosed to be on the order of 0.16 kg/s at full reactor power. According to the event chronology, a manual reactor shutdown commenced on 21 April, 1997 at 2245 hours with through-wall leakage of 0.17 kg/s. On 22 April, 1997 at 1250 hours the reactor was tripped and at 1600 hours on the same day the through-wall leakage peaked at 0.75 kg/s
- The failures involving Code Class 2 and 3 and non-Code piping cover a significantly broader range of pipe sizes than does the Code Class 1 group.

The five data points in Figure 2.3 that represent the "Beliczey-Schulz" correlation correspond to a failed DN15, DN20, DN25, DN50 and DN100 pipe in a PWR, respectively. According to Table 2.2, reproduced from NUREG-1829 [2.27], at full primary pressure (about 15 MPa), a break in a DN100 pipe would generate a liquid peak through-wall flow rate of about 545 kg/s (or about 8,600 gpm).

Table 2.2 *Through-wall Flow Rate to Break Size Correlations for Code Class 1 Piping*

Equivalent Break Size		**BWR Liquid Release**		**PWR Liquid Release**	
Diameter [mm]	**Area [in^2]**	**Flow Rate [gpm]**	**Flow Rate Flux [gpm/in^2]**	**Flow Rate [gpm]**	**Flow Rate Flux [gpm/in^2]**
15	0.19635	116.8	595	134.9	687
25	0.78539	467.3	595	539.5	687
50	3.14159	1869.2	595	2158.2	687
75	7.06858	4205.8	595	4856.1	687
100	12.56637	7476.9	595	8633.1	687
150	28.27433	16823.2	595	19424.5	687
200	50.26548	29907.9	595	32220.2	641
250	78.53982	29452.4	375	50344.0	641

Table 2.2 *Through-wall Flow Rate to Break Size Correlations for Code Class 1 Piping*

Equivalent Break Size		**BWR Liquid Release**		**PWR Liquid Release**	
Diameter [mm]	**Area [in^2]**	**Flow Rate [gpm]**	**Flow Rate Flux [gpm/in^2]**	**Flow Rate [gpm]**	**Flow Rate Flux [gpm/in^2]**
300	113.0973	42411.5	375	72495.4	641
400	201.0619	75398.2	375	128880.7	641
750	706.8583	265071.9	375	453096.2	641

Based on:

- Moody, F.J., "Maximum Flow Rate of a Single Component, Two Phase Mixture," Trans. J. Heat Transfer, **86**:134-142, February 1965. Applies to medium-and large-diameter piping.
- Zaloudek, F.R., The Low Pressure Critical Discharge of Steam-Water Mixtures from Pipes, HW-68934, Hanford Works, Richland (WA), 1961. Applies to small-and medium-diameter piping.

1 gpm = 6.3 × 10^{-2} kg/s

According to Equation (4) [2.2], the conditional failure probability of a through-wall flaw producing a peak flow rate of about 545 kg/s is approximately 1.8E-3. Equation (4) reflects a German perspective on the conditional pipe failure probability based on service experience as of the mid-1980s, PFM and experimental fracture mechanics studies.

$$P_{ik}\{R_x|F\} = (9.6 \times \mathrm{DN}/2.5 + 0.4 \times \mathrm{DN}^2/25)^{-1} \quad (4)$$

Where

DN = nominal pipe diameter [mm]

The aggregate state-of-knowledge correlation from NUREG-1829 [2.27] represents the results of an expert elicitation process. It applies to BWR primary system piping and is derived from Figure 7.6 in NUREG-1829 using a total pipe failure rate (including all Class 1 systems, small-, medium- and large-diameter piping components) of 3.0×10^{-2} per reactor-year. Based on the information embedded in Figure 2.3 above it appears appropriate to use direct statistical estimation for non-Code piping when calculating conditional pipe failure probabilities of major structural failures. Unless PFM were to be used, some form of data extrapolation is required when using direct statistical estimation for safety-related piping, however. The question then becomes how to perform such extrapolations and how to characterize the state-of-knowledge uncertainty. In case PFM is used for estimating a conditional pipe failure probability it becomes important to reconcile the output against applicable service experience and known degradation and/or damage susceptibility.

Bayesian methodology is a practical way of defining a prior conditional failure probability uncertainty distribution that uses a bounding-type analysis where the uncertainty is expressed by a Beta Distribution. As an example, for Code Class 1 piping the prior A-parameter is fixed at 1 and the prior B-parameter is chosen so that the prior mean value corresponds to an appropriate mean value of the "aggregate state-of-knowledge" correlation in Figure 2.3.

The Beta Distribution takes on values between 0 and 1 and is defined by the two parameters “A” and “B” (some texts refer to these as “Alpha” and “Beta”). It is often used to express the uncertainty in the dimensionless probabilities such as MGL common cause failure parameters and failure rates per demand. The mean of the Beta Distribution is given by:

$$\text{Mean} = A/(A + B) \qquad (5)$$

If A = B + 1, the Beta Distribution takes on a flat distribution between 0 and 1. If A = B = ½, the distribution is referred to as Jeffrey’s non-informative prior and is a U-shaped distribution with peaks at 0 and 1. Expert opinion can be incorporated by selecting A and B to match up with an expert estimate of the mean probability. For example, to represent an expert estimate of 1×10^{-2}, A = 1 and B = 99 can be selected. These abstract parameters A and B can be associated with the number of failures and the number of successes in examining service data to estimate the failure probability on demand. The sum “A+B” represents the total number of trials.

The Beta Distribution has some convenient and useful properties for use in Bayes’ updating. A prior distribution can be assigned by selecting the initial parameters for A and B, denoted as A_{Prior} and B_{Prior}. Then when looking at the relevant service data, if there are “N” failures and “M” successes, the Bayes updated, or posterior distribution is also a Beta Distribution with the following parameters:

$$A_{Post} = A_{Prior} + N \qquad (6)$$
$$B_{Post} = B_{Prior} + M \qquad (7)$$

The above explains how the Beta Distribution can be used to estimate conditional pipe “rupture” probabilities. For piping exhibiting leak-before-break (LBB) characteristics the priors are selected to represent engineering estimates of the probabilities “prior” to the collection of evidence. Equations (6) and (7) are used to calculate the parameters of the Bayes’ updated (posterior) distribution after applying the results of a database query to determine N and M. N corresponds to the number of “ruptures” in some specialized combination of pipe size and material and M corresponds to the total number of failures that do not result in “rupture” in the corresponding pipe size/material combination. This model assumes that all pipe failures are precursors to pipe rupture.

Selecting appropriate “A” and “B” parameters is not a trivial task. Many different parameter combinations will produce the same mean value. Insights from probabilistic fracture mechanism could be utilized in defining application- and location-specific “A’ and “B” parameters. Another approach would be to utilize the empirical correlations in Figure 2.2. According to this figure a peak through-wall flow rate threshold value of $\nu > 380$ kg/s corresponds to a “Major Breach” with a mean conditional failure probability of about 5.0×10^{-4}, which would be our prior mean value given A = 1 and B = 1999. Assuming an analyst has access to a sufficiently complete and detailed pipe failure database, the shape of the posterior uncertainty distribution would be determined by the applicable service experience.

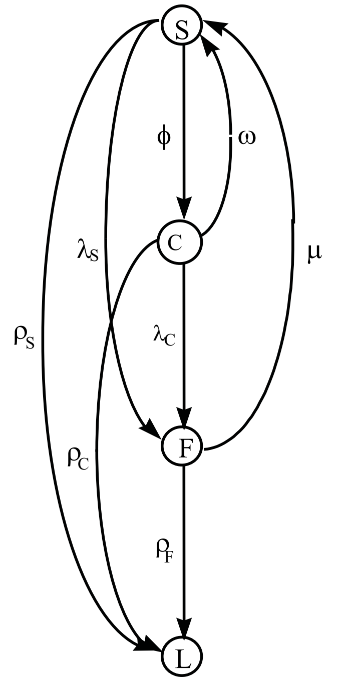
For piping that exhibits break-before-leak (BBL) characteristics, such as turbine building piping with susceptibility to FAC, it is proposed that the prior Beta Distribution parameters are derived directly from the empirical data. Consistent with the above, for a “Major Breach” the corresponding prior parameters would be A = 1 and B = 159, with a mean value of 6.3×10^{-3}.

2.3.2 Assessment of Inspection Effectiveness

Markov modeling enables the analysis of interactions between degradation and damage mechanisms that cause pipe failure, and the inspection, detection and repair strategies that can reduce the probability that failure occurs, or that cracks or leaks will progress to major structural failure before being detected and repaired [2.10].

This Markov modeling technique starts with a representation of a “system” in a set of discrete and mutually exclusive states. The states refer to various degrees of piping system degradation; that is, the existence of flaws, leaks or major structural failure. The flaws can be pipe wall thinning or circumferential cracking of a weld heat affected zone. Figure 2.4 is a representation of a general four-state Markov model of piping reliability.

The state transition parameters of the Markov model can be estimated directly from service data. The model can be used to investigate the time dependence of pipe failure frequencies and the impact of alternative ISI and leak inspection strategies. Figure 2.5 shows an example of time-dependent piping reliability and how it is affected by ISI.



Piping Reliability States:

S = Success (or undamaged state);
C = Crack (non-through wall flaw);
F = Leaking through-wall flaw (leak rate is within Technical Specification limit);
L = Large leak (leak rate in excess, or well in excess of Technical Specification limit).

State Transitions:

ϕ	*Occurrence of non-through wall flaw*
λ_S	*Occurrence of small leak given an undamaged state (‘S’)*
λ_C	*Occurrence of small leak given a flaw (‘C’)*
ρ_S	*Occurrence of large leak given no flaw*
ρ_C	*Occurrence of large leak given a non-through wall flaw*
ρ_F	*Occurrence of large leak given a small leak*
μ	*Detect and repair a through-wall flaw*
ω	*Inspect and repair a non-through wall flaw*

Figure 2.4 *Four-State Markov Model of Piping Reliability*

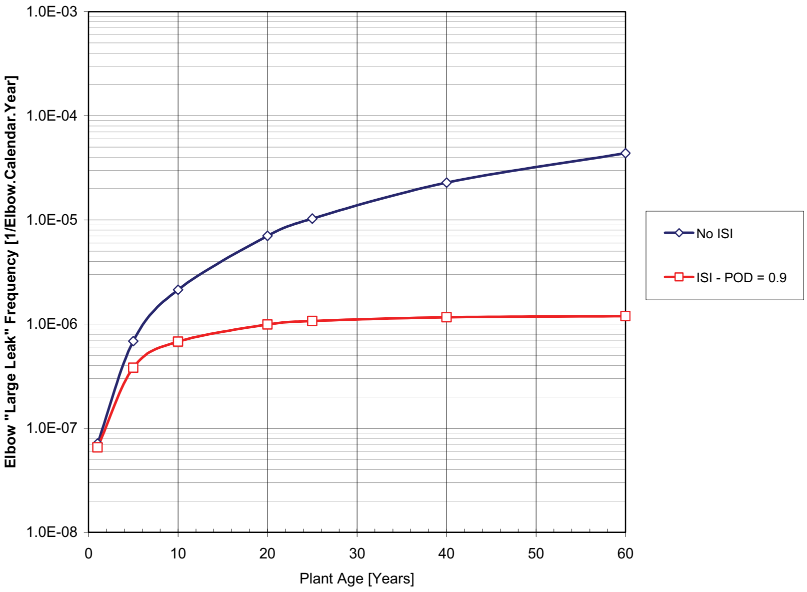


Figure 2.5 *Example of Time-Dependent Pressure Boundary Breach Frequency*

2.3.3 Data Specializations

Pipe failure is a function of interrelationships between pipe size (diameter and wall thickness), material, flow conditions, pressure & temperature, method of fabrication, loading conditions, weld residual stresses, etc. These relationships should be embedded in a reliability database and accessible for parametric evaluations. For circumferential welds their location within a piping system and residual stresses represent strong reliability influence factors. It is sometimes necessary to develop specialized weld failure rates to account for these influences. For a weld of type "*i*" and size "*j*" (defined by the nominal pipe diameter) the failure rate can be expressed as follows:

$$\lambda_{ij} = F_{ij}/(W_{ij} \times T) \tag{8}$$

and with

$$Sij = Fij \,/\, Fj \tag{9}$$
$$Aij = Wj/Wij \tag{10}$$

the failure rate of weld of type "*i*" and size "*j*" is expressed as

$$\lambda ij = (Fj \times Sij)/(Wij \times T) \tag{11}$$
$$\lambda ij = Sij \times Aij \times \lambda j \tag{12}$$

Where:

λ_{ij} = Failure rate of a susceptible weld of type "*i*", size "*j*".

λ_j = Failure rate of a susceptible weld of size '*j*'.

F_j = Number of size "*j*" weld failures.

F_{ij} = Number of type "*i*" and size "*j*" weld failures.

W_j = Size "*j*" weld count.

W_{ij} = Type “i” and size “j” weld count.

Susceptibility (S_{ij}) = The service experience shows the failure susceptibility to be correlated with the location of a weld relative to pipe fittings and other in-line components (flanges, pump casings, valve bodies). For a given pipe size and system, the susceptibility is expressed as the fraction of welds of type “ij” that failed due to a certain degradation mechanism). This fraction is established by querying the database.

Attribute (A_{ij}) = In the above expressions the attribute (A) is defined as the ratio of the total number of welds of size “j” to the number of welds of type “i”. A_{ij} is a correction factor and accounts for the fact that piping system design & layout constraints impose limits on the number of welds of a certain type. For example, in a given system there tends to be more elbow-to-pipe welds than, say, pipe-to-tee welds.

Combining a global (or averaged) failure rate with the weld configuration dependency provides failure rates that account for known or assumed residual stresses. Typically, a final weldment attaching a spool piece to, say, a heat exchanger nozzle or vessel nozzle tends to be the most vulnerable weld assembly in a piping system.

2.3.4 Summary

Pipe failure rate estimation involves querying a database for event populations (number of failures) and corresponding exposure terms or component populations (number of components from which the failure data are collected). Beyond these basic sets of information and depending on the specific type of risk-informed application, additional supporting and specialized information on pipe failure is needed. Database development must go hand-in-hand with practical applications to ensure that structure and content is sufficiently complete and compatible with the needs of analysts.

The next chapter summarizes the results of a survey of pipe failure databases. It provides insights about database structures, database content and the importance of data validation. Can the results of applications of existing databases be trusted?

2.4 Results of Survey

Results of the survey of selected pipe failure databases are summarized in this chapter. Included in the survey are Category 0 and Category 2 databases. Most of the identified databases have supported some level of risk-informed PSA application. Category 1 databases are not included in this survey. Several such databases are known to exist (see for example References [2.1 and 2.11]) but they are not normally available for independent reviews, however.

2.4.1 Survey Format

The survey results are summarized in Table 2.3 (older Category 0 databases) and Table 2.4 (Category 2 databases and recent Category 0 databases). Each database is reviewed against 22 attributes:

1. Software used to develop database.

2. Database category (Category 0 or Category 2).
3. Availability for use by practitioners.
4. Access control and data security.
5. Nuclear power plant population covered in database.
6. Data collection period.
7. Reactor critical years covered in database.
8. Component boundary and component types addressed by database.
9. Number of pipe failure records.
10. Number of “major” structural failures included in database.
11. Information on through-wall leak/flow rates, duration of event, and total amount of process medium released.
12. Flaw size data (for example, crack depth and length and crack orientation, size and shape of through-wall flaw).
13. Pipe dimensional data (diameter and wall thickness).
14. Pipe stress intensity data; for example, stress intensity factors (kI) for flawed pipe and critical stress intensity factors (kIc). The ratio kI/kIc is a measure of margin to significant structural failure given a degraded state. This type of information is included in relief requests for temporary repair of degraded piping.
15. Number of database fields.
16. Database updating and maintenance policy.
17. Source data archive (for independent verification of processed data).
18. Extent of verification and validation.
19. Component population data included in database.
20. Plant population data included in database.
21. Information on location of degradation/failure in a piping system; includes identification of plant building/area (for example, drywell, reactor building, auxiliary building, turbine building, as well as location identified by reference to isometric drawing coordinate or component identity).
22. In-service inspection information/history; this information provides an indication of ISI reliability (for example, did a previous inspection fail to identify a degraded state, and if so, why did it happen?).

Table 2.3 *Examples of Category 0 Pipe Failure Databases*

DATABASE ATTRIBUTE	**DATABASE**				
	AECL-Misc-204 (1981) [2.14]	**NUREG/CR-4407 (1987) [2.28]**	**EGG-SSRE-9639 (1991) [2.6]**	**EPRI TR-100380 (1992) [2.13]**	**NUREG/CR-5750 (1999) [2.23]**
Software	N/A (Not Applicable)	N/A	N/A	dBase III Plus The structure of the database is described in Chapter 3 of TR-100380	N/A
Availability	Restricted	Public domain	Public domain	For EPRI members only	Public domain
Access control & data security	N/A	N/A	N/A	Technical report is available for download via password protected EPRI website	N/A
Commercial Nuclear Power Plant (NPP) Population	U.S. BWR & PWR	U.S. BWR & PWR	U.S. BWR & PWR	U.S. BWR & PWR	U.S. BWR & PWR
Data Collection Period	1960-1981	1960-1984	1960-1990	1960-1986	1969-1997
Reactor Critical Years Experience covered	409	800	1,270	1,030	2,100
Component boundary and component types	Any passive, metallic and non-metallic (e.g., rubber expansion joint, PVC piping) piping and non-piping component	Any metallic piping component	Any metallic and non-metallic piping (e.g., rubber expansion joint, PVC pipe) and passive, non-piping component (e.g., valve body, H/X shell, H/X-tube, vessel)	Any metallic piping component	Any metallic piping component

Table 2.3 *Examples of Category 0 Pipe Failure Databases*

DATABASE ATTRIBUTE	**DATABASE**				
	AECL-Misc-204 (1981) [2.14]	**NUREG/CR-4407 (1987) [2.28]**	**EGG-SSRE-9639 (1991) [2.6]**	**EPRI TR-100380 (1992) [2.13]**	**NUREG/CR-5750 (1999) [2.23]**
Number of Failure Records	840 87 failures were interpreted to be "severances" No medium- or large-diameter pipe "severances"	19 Limited to "significant" through-wall flaws (leaks and "ruptures")	591 Limited to through-wall flaws (leaks and "ruptures") Includes safety-related and non safety-related piping	694 Class 1: 321 Class 2: 180 Class 3: 58 Non-Code: 135	54 Limited to "significant" through-wall flaws in Class 1 piping
Number of records on "major" structural failure [NOTE 1]	2 18-inch feedwater pipe break at Indian Point-2 8-inch expansion joint at Fort Calhoun	0	17	40 These are listed in the main body of the report	0
Information on through-wall leak/flow rate	No	Yes	Yes	Yes	Yes
Flaw size data	No	No	No	No	No
Pipe dimensional data	(Yes) [NOTE 2]	(Yes)	(Yes)	(Yes)	(Yes)
Stress intensity data	No	No	No	No	No
Number of database fields	13	4	11	51	8
Stated updating / maintenance policy and program	N/A	N/A	N/A	Yes See Reference [2.6] for details. An update was performed in 1993 to include pipe failure data for the period 1987-1991	Yes [NOTE 3]

Table 2.3 *Examples of Category 0 Pipe Failure Databases*

DATABASE ATTRIBUTE	DATABASE				
	AECL-Misc-204 (1981) [2.14]	**NUREG/CR-4407 (1987) [2.28]**	**EGG-SSRE-9639 (1991) [2.6]**	**EPRI TR-100380 (1992) [2.13]**	**NUREG/CR-5750 (1999) [2.23]**
Verification and Validation of Failure Data	Unknown	Unknown	Unknown	Unknown	Unknown
Component population data included?	No	Yes	Yes	Yes	No
Plant population data included	Yes	Yes	Yes	Yes	Yes
Information on location of degradation/failure in a piping system	Some indirect references (e.g., system name, inside/outside containment or drywell, weld-HAZ vs. base metal)	Some indirect references	Some indirect references	Some indirect references	Some indirect references
In-service inspection information/history	N/A	N/A	N/A	N/A	N/A
Presentation form for failure event data	Significant failures listed with brief narrative descriptions in Appendices A through C of AECL-Misc-204	Appendix D of NUREG/CR-4407 includes narratives of the pipe failure events	Appendices A through C of EGG-SSRE-9639 lists all events and identifies plant, event date and component	Significant failures listed in main body of TR-100380 together with brief narrative descriptions	Appendix J of NUREG/CR-5750 lists events and identifies plant, event date and component
Extent of application	Developed to support evaluation of failure trends as documented in AECL-Misc-204	Supports development of new LOCA frequency estimates as documented in NUREG/CR-4407	Used in several U.S. internal flooding PSA studies	Used in several U.S. PSA studies	Supports development of new LOCA frequency estimates as documented in NUREG/CR-5750

Notes:

1. Defined in this comparison as a through-wall flaw with flow rate > 3.2 kg/s (50 gpm)
2. Pipe diameter given for most records, no information on wall thickness.
3. Appendix E of NUREG-1829 [2.27]

Table 2.4 *Examples of Recent Category 0 and Category 2 Pipe Failure Databases*

DATABASE ATTRIBUTE	**D A T A B A S E**				
	SKI 96:20 (1996) [2.4]	**EPRI TR-110102 (1997) [2.3]**	**EPRI TR-111880 (1999) [2.15]** $^{\text{NOTE 1}}$	**PIPExp (2007)** $^{\text{NOTE 2}}$	**OPDE 2007:2 (2007) [2.20]**
Software	Microsoft® Access	Microsoft® Access	Microsoft® Access	Microsoft® Access	Microsoft® Access with Web based user interface (Appendix C includes further details)
Category	Category 0 (Appendix A includes further details)	Category 0 (Appendix A includes further details)	Category 0	Category 2	Category 2
Availability	EPRI members only $^{\text{NOTE 3}}$	EPRI members only $^{\text{NOTE 3}}$	N/A – see Note 4	Proprietary - OPDE "parent database"	Restricted to OPDE project members
Access control & data security	Unclear	Technical report is available for download via password protected EPRI website	N/A – see Note 4	Password protected, secure location	Data resides on Nuclear Energy Agency's secure server, access is password protected
Commercial Nuclear Power Plant (NPP) Population	U.S. BWR & PWR	U.S. BWR & PWR	U.S. BWR & PWR	NPPs worldwide: BWR, PWR, HWR/CANDU, RBMK	NPPs worldwide: BWR, PWR, HWR/CANDU, RBMK
Data Collection Period	1961-1995	1961-1997	1961-1995	1970 to date	1970 to date
Reactor Critical Years Experience covered	2,100	2,300	2,100	Ca. 10,300	Ca. 7,385
Component boundary and component types	Any metallic and non-metallic piping (e.g., rubber expansion joint, PVC pipe) and passive, non-piping component (e.g., valve body, H/X shell, H/X-tube, vessel)	Any metallic and non-metallic piping (e.g., rubber expansion joint, PVC pipe) and passive, non-piping component (e.g., valve body, H/X shell, H/X-tube, vessel)	Any metallic and non-metallic piping (e.g., rubber expansion joint, PVC pipe) and passive, non-piping component (e.g., valve body, H/X shell, H/X-tube, vessel)	Metallic piping components	Metallic piping components

Table 2.4 *Examples of Recent Category 0 and Category 2 Pipe Failure Databases*

DATABASE ATTRIBUTE	**DATABASE**				
	SKI 96:20 (1996) [2.4]	**EPRI TR-110102 (1997) [2.3]**	**EPRI TR-111880 (1999) [2.15]** [NOTE 1]	**PIPExp (2007)** [NOTE 2]	**OPDE 2007:2 (2007) [2.20]**
Number of Failure Records	1,511 Limited to leaks and "ruptures" Class 1: 137 Class 2: 497 Class 3: 548 (about 10% H/X tubes/coils) Non-Code: 329	4,064 Non through-wall and through-wall flaws Direct extension of SKI 96:20	1,145 Events classified by pipe size < DN50 and ≥ DN50, and by system group	7,347 (12-31-2007) Class 1: 1635 Class 2: 1854 Class 3: 1569 Non-Code: 2289 Plus an additional 465 records on water hammer events that challenged the integrity of, but did not fail, piping	3,755 (12-31-2007) Class 1: 1026 Class 2: 949 Class 3: 965 Non-Code: 865 Water hammer events not considered unless a pressure boundary failed
Number of records on "major" structural failure [NOTE 5]	119	179	69	252	205
Stated updating / maintenance policy and program	No	No	No	Continuous – Monthly Status Reports issued since January 1999 – Appendix B includes an example	Periodic updates by respective National Coordinator
Information on through-wall leak/flow rate	No	No	No	Yes	Yes
Flaw size data	No	No	No	Yes	Yes
Pipe dimensional data	(Yes) [NOTE 6]	Yes	Yes	Yes	Yes
Stress intensity data	No	No	No	Yes [NOTE 7]	No
Number of database fields	13	15	18	75	60

Table 2.4 *Examples of Recent Category 0 and Category 2 Pipe Failure Databases*

DATABASE ATTRIBUTE	**DATABASE**				
	SKI 96:20 (1996) [2.4]	**EPRI TR-110102 (1997) [2.3]**	**EPRI TR-111880 (1999) [2.15]** [NOTE 1]	**PIPExp (2007)** [NOTE 2]	**OPDE 2007:2 (2007) [2.20]**
Source data archive	No	No	No	Yes Hard copies or electronic copies of source information (licensee event reports, reportable occurrence reports, inspection summary reports, root cause analysis reports, maintenance work orders, etc.) kept on file for all records in database.	Yes Hard copies or electronic copies of source information (licensee event reports, reportable occurrence reports, inspection summary reports, root cause analysis reports, maintenance work orders, etc) kept on file for all records in database.
Verification and Validation of Data Records?	Unknown [NOTE 8]	Unknown [NOTE 9] (Appendix A includes further details)	Some non-piping events deleted from SKI 96:20. Most rupture events verified (note difference between this database and SKI 96:20) but most leaks and cracks not verified [NOTE 9]	Extensive verification and validation and follow-up of all database records. The source data of each record (work orders, inspection reports, root cause analysis reports, licensee event reports) kept in an archive	Coding Guideline & QA Program: Extensive verification and validation of all database records by National Coordinators and Clearinghouse.
Component population data included?	No	No	Generic estimates and actual data from 2 plants (Code Class 1 and 2) included in TR-111880	Yes, integral part of database, actual data from 21 plants: safety-related piping and non-Code piping	No Decision about developing population data taken at the national level
Plant population data included	Yes	Yes	Yes	Yes – built in as Access relationships	Yes – built in as Access relationships

Table 2.4 *Examples of Recent Category 0 and Category 2 Pipe Failure Databases*

DATABASE ATTRIBUTE	**DATABASE**				
	SKI 96:20 (1996) [2.4]	**EPRI TR-110102 (1997) [2.3]**	**EPRI TR-111880 (1999) [2.15]** $^{\text{NOTE 1}}$	**PIPExp (2007)** $^{\text{NOTE 2}}$	**OPDE 2007:2 (2007) [2.20]**
Details on location of degradation/failure in piping system	No	No	No	Yes Free-format memo field with description of flaw with reference to line number or weld number, and P&ID and/or isometric drawing number. Hyperlinks provides access to photographs, line drawings, and isometric drawings	Yes Location in plant and system defined using P&ID and isometric drawing identifiers. Electronic library of source information, including photographs, line drawings and isometric drawings.
In-service inspection (ISI) information / ISI history of failed piping components	No	No	No	Yes	Yes
Extent of application	Developed to support evaluation of failure trends as documented in SKI Report 96:20	Developed to support evaluation of failure trends as documented in TR-110102	Derived failure parameters used by several RI-ISI program development projects (2000-2005); e.g., all Exelon plants	Multiple, including Koeberg-1/2 RI-ISI project, EPRI internal flooding guide [2.8 and 2.9]. See also Reference [2.20] Appendix G and Reference [2.21]	Reference [2.21]

Table 2.4 *Examples of Recent Category 0 and Category 2 Pipe Failure Databases*

DATABASE ATTRIBUTE	DATABASE				
	SKI 96:20 (1996) [2.4]	**EPRI TR-110102 (1997) [2.3]**	**EPRI TR-111880 (1999) [2.15] NOTE 1**	**PIPExp (2007) NOTE 2**	**OPDE 2007:2 (2007) [2.20]**

Notes:

4. An application of SKI 96:20 database
5. Appendix B includes further details.
6. This work was sponsored jointly by EPRI and SKI under a Memorandum of Understanding
7. Because of data validity concerns raised by member organizations, this report has been withdrawn from the secure EPRI website and is no longer available for download. A non-proprietary version (no data tables) of TR-111880 remains available from the Nuclear Regulatory Commission's Public Document Room, however (NRC-ADAMS Accession Number ML003776638).
8. Defined in this comparison as a through-wall flaw with flow rate > 3.2 kg/s (50 gpm)
9. In many cases engineering judgment is used to assign pipe diameter as either < 1-inch or ≥ 1-inch
10. Information on Stress Intensity Allowance (ratio of critical to assessed stress intensity factor) given for selected Code Class 2 and 3 flawed moderate-energy piping.
11. The database records mainly relies on information extracted from Licensee Event report titles. An independent review performed in January 1996 identified on the order of 600 misclassified records.
12. An independent review performed in July 2005 identified on the order of 1,000 erroneous records (e.g., duplicate records, misclassified records, or non-piping failures). See Appendix A for further details.

2.4.2 Insights

Numerous pipe failure databases have been developed to support risk-informed applications. Beyond fulfilling a one-time objective, most databases have not been subjected to continuous or periodic updates, however. A lack of validation of data records influences the validity of derived reliability parameters; this topic is addressed further in Appendix A.

The survey includes examples of ongoing, ambitious programs to develop "autonomous" databases. Autonomous in the sense that embedded in these databases is all the original source information.

3 Pipe Failure Parameter Estimation & Requirements on Data Sources

3.1 Abstract

The ability of a pipe failure database to support different PSA applications requirements is a function of database depth, completeness and knowledge-base embedded within a data collection. This document identifies the different types of pipe failure parameters that are used – or can be derived for use – in risk-informed and risk-based PSA applications. It also includes recommendations for the types of parameters to be included in a proposed "R-Book." These recommendations are based on the requirements of ASME RA-Sb-2005 (The American Society of Mechanical Engineers "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications") [3.8] as well as insights from past pipe failure database applications.

3.2 Introduction

According to the ASME PRA Standard [3.8], the objectives of the data analysis elements are to provide estimates of the parameters used to determine the probabilities of the basic events representing equipment failures and unavailabilities modeled in PSA in such a way that:

1. Parameters, whether estimated on the basis of plant-specific or generic data, appropriately reflect design and operation of the plant. Relative to piping systems and components, derived parameters should adequately reflect design practices, material selections, and water chemistries.
2. Component or system unavailabilities due to maintenance or repair are accounted for. Relative to piping systems and components, derived parameters should account for inspection practices, including leak detection/inspection, non-destructive examination, pressure tests, and repair/replacement practices.
3. Uncertainties in the data are understood and appropriately accounted for.

3.2.1 High Level Requirements for Data Analysis

The ASME PRA Standard [3.8] "High Level Requirements" (HLRs) for data analysis (DA) are reproduced in Table 3.1. According to these requirements, for a proposed R-Book to support PSA applications it needs to include generic parameter estimates as well as a relevant selection of "seed values" to support the derivation of plant-specific pipe failure parameters.

Table 3.1 *High Level Requirements for Data Analysis*

Designator	Requirements
HLR-DA-A	Each parameter shall be clearly defined in terms of the logic model, basic event boundary, and the model used to evaluate event probability
HLR-DA-B	Grouping components into a homogeneous population for parameter estimation shall consider both design, environmental, and service conditions of the components in the as-built and as-operated plant

Table 3.1 *High Level Requirements for Data Analysis*

Designator	**Requirements**
HLR-DA-C	Generic parameter estimates shall be chosen and plant-specific data shall be collected consistent with the parameter definitions of HLR-DA-A and the grouping rationale of HLR-DA-B.
HLR-DA-D	The parameter estimates shall be based on relevant generic industry or plant-specific evidence. Where feasible, generic and plant-specific evidence shall be integrated using acceptable methods to obtain plant-specific parameter estimates. Each parameter estimate shall be accompanied by a characterization of the uncertainty.
HLR-DA-E	The data analysis shall be documented consistent with the applicable supporting requirements [of the standard].

3.2.2 Reading Guide

Building on previous Chapter 2.3, Chapter 3.3 of this report includes an overview of the different types of parameter estimates that are derived to support PSA applications of varying scope. Six different types of pipe failure parameters are identified, each type imposing certain minimum requirements on a pipe failure database design and use:

1 "Generic" pipe failure parameters that support PSA Capability Category I

2 Application-specific pipe failure parameters that support PSA Capability Category II or III, including

  2.1 Internal flooding initiating event frequency calculation

  2.2 High energy line break (HELB) frequency calculation

  2.3 Loss-of-coolant accident (LOCA) frequency calculation

3 Risk-informed in-service inspection (RI-ISI) risk impact evaluation

4 Advanced database applications that support PSA Capability Category III. This type includes any extension to the parameter estimation approaches used to support applications listed above.

The bases for the PSA Capability Categories are found in Reference [3.8] and are reproduced in Table 3.2. These capability categories refer to the extent of reliance on PSA results in supporting decisions, and the degree of resolution required of the factors (e.g., pipe failure data) that determine the risk significance of the proposed changes.

Under an assumption of using a Cat2 database as basis, recommendations for the types of parameters to be included in a proposed R-Book are summarized in Chapter 3.4. The characteristics of a Cat2 database are presented in Reference [3.1]. A list of references is found in Chapter 7.

Table 3.2 *Bases for PSA Capability Categories*

Attributes of PSA	I	II	III
1. **Scope and level of detail:** The degree to which the scope and level of detail of the plant design, operation, and maintenance are modeled.	Resolution and specificity sufficient to identify the relative importance of the contributors at the system or train level including associated human actions.	Resolution and specificity sufficient to identify the relative importance of the significant contributors at the component level including associated human actions, as necessary [Note (1)].	Resolution and specificity sufficient to identify the relative importance of the contributors at the component level including associated human actions, as necessary [Note (1)].
2. **Plant-specificity:** The degree to which plant-specific information is incorporated such that the as-built and as-operated plant is addressed.	Use of generic data/models acceptable except for the need to account for the unique design and operational features of the plant.	Use of plant-specific data/models for the significant contributors.	Use of plant-specific data/models for all contributors, where available.
3. **Realism:** The degree to which realism is incorporated such hat the expected response of the plant is addressed.	Departures from realism will have moderate impact on the conclusions and risk insights as supported by good practices [Note (2)].	Departures from realism will have small impact on the conclusions and risk insights as supported by good practices [Note (2)].	Departures from realism will have negligible impact on the conclusions and risk insights as supported by good practices [Note (2)].

NOTES:

(1) The definition for Capability Categories II and III is not meant to imply that the scope and level of detail includes identification of every component and human action, but only those needed for the function of the system being modeled.

(2) Differentiation between moderate, to small, to negligible is determined by the extent to which the impact on the conclusions and risk insights could affect a decision under consideration. This differentiation recognizes that the PSA would generally not be the sole input to a decision. A moderate impact implies that the impact (of the departure from realism) is of sufficient size that it is likely that a decision could be affected; a small impact implies that it is unlikely that a decision could be affected, and a negligible impact implies that a decision would not be affected.

3.3 Pipe Failure Parameter Types

This chapter identifies six different types of pipe failure data parameters for use in PSA applications. The objectives of a specific PSA application determine the piping component boundary definition(s) and how a pipe failure database is queried to obtain the necessary input to a statistical estimation process. And certainly, the depth and completeness of a pipe failure database determine whether the PSA application requirements can be fulfilled. Methods for estimating failure parameters and for quantifying the uncertainties in the estimates are addressed in Chapter 2. A comprehensive review of failure parameter estimation is included in NUREG/CR-6823 [3.1].

3.3.1 "Generic" Pipe Failure Parameters

A generic set of pipe failure parameters are derived from relevant service experience but usually at a low level of analytical discrimination. This means that while a parameter estimation process accounts for different system groups, failure types and pipe size groups it may not differentiate the source data by operating conditions, materials, method of fabrication, inspection program, plant design, failure locations, or degradation susceptibilities. A generic failure parameter represents a global average, which may or may not apply to a specific application beyond a PSA "Capability Category I" [3.8]. For a pipe failure database to be able to support estimation of generic failure parameters it must include at least the following information:

- System Group. Safety class must be identified together with information on type of system, for example Reactor Coolant System (RCS), Safety Injection & Recirculation (SIR), Reactor Auxiliary System (RAS), Auxiliary Cooling System (ACS), Feedwater & Condensate (FWC), Containment Spray (CS), Main & Auxiliary Steam (ST), Fire Protection (FP).
- Pipe Size. Differentiation according to "small-diameter", Medium-diameter", and "large-diameter."
- Plant Type. BWR, PHWR, PWR, RBMK.

Assuming that a data collection includes information as itemized above it must be processed and queried in such a way that a corresponding set of failure count and exposure term information is obtained. The analyst also must clearly define the failure type of interest (e.g., non-through wall, through-wall with a given leak/flow rate threshold value). It is quite straightforward to generate pipe failure parameters at a generic level.

3.3.2 Application-Specific Pipe Failure Parameters

There are at least four types of application-specific pipe failure parameters. Three of these types support the estimation of initiating event frequencies while a fourth type support risk-impact evaluation tasks in risk-informed in-service inspection (RI-ISI). In summary, the four types of application-specific pipe failure parameters are:

- Internal Flooding Initiating Event Frequencies. Internal flooding PSA includes consideration of flooding sources through pressure boundary failure. The way an initiating event is characterized and its frequency quantified is closely related to the definition of flooding "source terms." A flood source term is determined as the total amount or volume of passive components within a specified flood area that theoretically can generate a spray, flood or major flood event. Where a flood area includes a certain pipe run a corresponding flood source term can be characterized in terms of number of weld, linear meter of piping, or sections (or segments) of piping. The term "pipe run" means a length of piping between two reference points (can be wall penetration, valve, heat exchanger). Exactly how the piping boundary is defined is a function of material type and degradation susceptibility, but it is also a function of the analyst's preference and type of pipe failure parameters that are available for direct use. As an example, if a pipe run through a particular flood zone consists of Fire Protection water system piping with stagnant fire water it would be appropriate to use the corresponding linear foot of piping as the component boundary definition. In this case the entire length of piping would be susceptible to localized corrosion. The length of piping would be obtained from an isometric drawing. Table 3.3 [3.4] is an example of failure rates for Code Class 3 Service Water piping. It includes failure rates for two different piping component boundary definitions.

Table 3.3 *Frequency of Spray due to Service Water Pipe Failure (U.S. PWR Specific Service Experience – Salt Water)*

Component Boundary & Size		**SW Spray Frequency Uncertainty Distribution**			
Type	**Diameter [mm]**	**Mean**	**5th Percentile**	**Median**	**95th Percentile**
Base Metal [1/m.yr]	∅ ≤ 25	3.88E-05	2.07E-05	3.56E-05	7.12E-05
	25 < ∅ ≤ 50	4.23E-06	2.09E-06	3.83E-06	7.88E-06
	50 < ∅ ≤ 100	1.04E-05	5.33E-06	9.47E-06	1.94E-05
	100 < ∅ ≤ 150	2.93E-06	1.28E-06	2.59E-06	5.78E-06
	150 < ∅ ≤ 250	3.38E-06	1.68E-06	3.05E-06	6.30E-06
	∅ > 250	7.52E-07	3.93E-07	6.85E-07	1.40E-06
Weld [1/weld.yr]	∅ ≤ 25	4.99E-06	2.37E-06	4.47E-06	9.41E-06
	25 < ∅ ≤ 50	3.20E-07	1.04E-07	2.65E-07	7.12E-07
	50 < ∅ ≤ 100	1.91E-06	7.71E-07	1.67E-06	3.88E-06
	100 < ∅ ≤ 150	8.13E-07	2.17E-07	6.42E-07	1.98E-06
	150 < ∅ ≤ 250	1.52E-07	9.53E-09	7.05E-08	5.32E-07
	∅ > 250	6.59E-08	1.39E-08	4.88E-08	1.75E-07
In this example, "spray" is defined as the consequence of a through-wall flaw which produces a flow rate ≤ 6 kg/s					

In the above data summary the failure rates for "base metal" apply to carbon steel piping and "weld" apply to stainless steel piping.

- High Energy Line Break (HELB) Frequency. The pipe failure parameter estimation requirements for HELB frequency calculation are the same as for internal flooding PSA. However, the scope of the analysis is limited to high-energy piping such as Main Steam, Auxiliary Steam, Main Feedwater and Condensate piping. The piping component boundary definitions should reflect the degradation susceptibilities of the piping in the analysis scope. Normally the flow-accelerated corrosion (FAC) inspection plans include the piping component boundary definitions; an example is given in Table 3.4 [3.2].

Table 3.4 *Example of Exposure Data for HELB Frequency Calculation*

Plant Type	System Group	System	Avg. Inspection Locations According to FAC Program
BWR	FWC	Condensate	1184
		Feedwater Heater Drain, Vents, Relief	502
		Feedwater	252
	STEAM	Main Steam (incl. Moisture Separator Reheater System)	275
		Steam Extraction	68
		All:	2281
PWR	FWC	Condensate	522
		Feedwater Heater Drain, Vents, Relief	1550
		Feedwater	321
	STEAM	Main Steam (incl. Moisture Separator Reheater System)	625
		Steam Extraction	189
		All:	3207

Notes:

- The column "Inspection Locations" shows the mean of component counts based on a review of FAC Program Plans from 23 PWR plants and 29 BWR plants.
- The information for PWR is exclusive of Steam Generator Blowdown piping.
- The difference in population data between BWR and PWR is attributed to different water chemistries.
- "Inspection Location" is equal to piping component, which can be an elbow, straight pipe (typically downstream of an elbow, flow control valve, or orifice/venturi), reducer, tee

- Loss-of-Coolant Accident (LOCA) Frequency. The pipe failure parameter estimation requirements for LOCA frequency calculation are found in documents such as NUREG/CR-6224 [3.10] and NUREG-1829 [3.9]. In this type of application the failure counts and exposure terms should relate to specific in-service inspection (ISI) sites or weld configurations as documented on isometric drawings.
- RI-ISI Risk Impact Evaluation. In addition to the failure count and exposure term information, this task requires industry-wide and plant-specific service experience data organized in such a way that database queries produce results on damage or degradation susceptibilities associated with specific sites for non-destructive examinations (see Equation (2) in Chapter 2. The derived pipe failure rates are conditional on these susceptibilities. An example of pipe element susceptibility fractions are displayed in Table 3.5, which is adapted from Reference [3.9]. These fractions are input to the RI-ISI conditional pipe failure rate calculations. Note that these susceptibility fractions differentiate pipe failures according to base metal failure and weld failure.

*T**able 3.5*   *Example of Pipe Element Susceptibility Fractions for Input to RI-ISI Calculations*

System Group	**Confidence Level**	**Damage / Degradation Mechanism**						
		Fraction of Welds Susceptible				**Fraction of Pipe Length Susceptible**		
		CF	**E-C**	**SC**	**TF**	**D&C**	**COR**	**FAC**
RCS	low	0.01	0.01	0.01	0.05	1.00	N/A	N/A
	med	0.05	0.05	0.05	0.19	1.00	N/A	N/A
	high	0.25	0.25	0.25	0.80	1.00	N/A	N/A
SIR	low	0.01	0.01	0.01	0.01	1.00	N/A	N/A
	med	0.05	0.05	0.02	0.04	1.00	N/A	N/A
	high	0.25	0.25	0.08	0.20	1.00	N/A	N/A
CS	low	0.01	0.01	0.01	0.01	1.00	0.01	N/A
	med	0.05	0.05	0.05	0.05	1.00	0.05	N/A
	high	0.25	0.25	0.25	0.25	1.00	0.25	N/A
RAS	low	0.01	0.01	0.01	0.01	1.00	0.01	N/A
	med	0.05	0.05	0.05	0.05	1.00	0.05	N/A
	high	0.25	0.25	0.25	0.25	1.00	0.25	N/A
AUX	low	0.01	0.01	N/A	0.01	1.00	1.00	0.01
	med	0.05	0.05	N/A	0.05	1.00	1.00	0.05
	high	0.25	0.25	N/A	0.25	1.00	1.00	0.25
FWC	low	0.01	0.01	N/A	0.01	1.00	0.01	0.01
	med	0.05	0.05	N/A	0.05	1.00	0.03	0.05
	high	0.25	0.25	N/A	0.25	1.00	0.12	0.25
ST	low	0.01	0.01	N/A	0.01	1.00	0.01	0.10
	med	0.05	0.05	N/A	0.05	1.00	0.05	0.56
	high	0.25	0.25	N/A	0.25	1.00	0.25	0.90
FP	low	0.01	0.01	N/A	N/A	1.00	1.00	0.01
	med	0.05	0.05	N/A	N/A	1.00	1.00	0.05
	high	0.25	0.25	N/A	N/A	1.00	1.00	0.25

Legends:

CF	Corrosion Fatigue
E-C	Erosion-Cavitation
SC	Stress Corrosion Cracking
TF	Thermal Fatigue
D&C	Design & Construction
COR	Corrosion
FAC	Flow Accelerated Corrosion
N/A	not applicable

3.3.3 Advanced Database Applications

Embedded in a data collection on pipe failures are effects of in-service inspection, leak detection (remote and local), routine walkdown inspections, and other integrity management strategies. Using an appropriate reliability model it is feasible to “isolate” the effect of such strategy on structural reliability.

Advanced database applications are directed at parameter estimation in support of PSA applications other than those addressed in Chapter 3.3.2. Furthermore, the advanced applications could include more detailed consideration of the effects of different material types, leak detection strategies, repair strategies and/or inspection strategies on piping reliability. One example of the types of parameters needed to evaluate such influences using the Markov model of piping reliability is given in Table 3.6. It lists the Markov model parameters and the strategy to derive these from a Cat2 database.

***Table 3.6** Parameters of the Markov Model of Piping Reliability*

Symbol	Description	Data Source & Strategy for Parameter Estimation
λ_{ik}	Failure rate of pipe component "i" due to degradation or damage mechanism "k"	The failure rate is estimated directly by inputting TTF data to a hazard plotting routine (Weibull analysis) or indirectly via a database query to obtain a failure count over a certain observation period and for a certain piping component population
TTF	Time to Failure	Obtained directly via database query
$P_{ik}\{R_x\|F\}$	Conditional pipe failure probability. Index "x" refers to mode of failure as defined by through-wall peak flow rate threshold value	Obtained directly via database query, Bayesian estimation strategy, PFM (SRM), or expert elicitation
I_{ik}	Structural integrity management factor for component "i" and damage or degradation mechanism "k". This is an adjustment factor to account for variable integrity management strategies such as leak detection, volumetric NDE, etc, that might be different that the components included in a pipe failure database	Obtained through application of the Markov model of piping reliability (iterative analysis)
n_{ik}	Number of failures (all modes, including cracks, leaks and significant structural failures)	Obtained directly via database query
f_{ik}	The fraction of number of components or type "i" that are susceptible to failure from degradation or damage mechanism "k" for conditional failure rates given susceptibility to "k"; this parameter is set to 1 for unconditional failure rates	Obtained directly via database query, or from 'Degradation Mechanism Analysis" tasks of RI-ISI program development projects, or via engineering judgment
N_i	The number of components per reactor year (or calendar year) that provided the observed pipe failures for component "i"	Input from piping system design reviews (size, weld counts, pipe lengths, and material data) specific to an application. Required for estimation of λ_{ik}
T_i	Total exposure time over which failures were collected for pipe component "i"; normally expressed in terms of reactor years (or calendar years)	Obtained directly via database query. Required for estimation of λ_{ik}
ϕ	Occurrence rate of a flaw (non through-wall)	Obtained directly via database query, or can be estimated as a multiple of the rate of leaks based on ISI experience
λ_S	Occurrence rate of leak from a no-flaw state	Service data for leaks and reasoning that leaks without a pre-existing flaw are only possible for selected damage mechanism from severe loading
λ_C	Occurrence rate of a leak from a flaw state	Service data for leaks conditioned for existing conditions for selected degradation mechanisms
ρ_S	Occurrence rate of a "structural failure" from a no-flaw state	Service data for "structural failure" and reasoning that "structural flaws" without a pre-existing degradation is only possible for selected damage mechanisms and system-material combinations
ρ_C	Occurrence rate of a through-wall leak from a flaw (non through-wall) state	Service data for leaks conditioned for existing conditions for selected degradation and damage mechanisms

***Table 3.6** Parameters of the Markov Model of Piping Reliability*

ρ_F	Occurrence rate of "structural failure" from a through-wall flaw state	Estimates of physical degradation rates and times to failure converted to equivalent failure rates, or estimates of water hammer challenges to the system in degraded state.
μ	Repair rate via leak detection $\mu = \frac{P_{LD}}{(T_{LI} + T_R)}$	Model of equation for μ, and estimates of P_{LD}, T_{LI}, T_R
P_{LD}	Probability that a through-wall flaw is detected given leak detection or leak inspection	Estimate based on presence of leak detection system, technical specification requirements and frequency of leak inspection. Database generates qualitative insights. Reliability of leak detection systems is high. Quantitative estimate based on expert judgment
T_{LI}	Mean time between inspections for through-wall flaw	Estimate based on method of leak detection; ranges from immediate to frequency of routine inspections for leaks or ASME Section XI required system leak tests
ω	Repair rate via NDE $\omega = \frac{P_I P_{FD}}{(T_{FI} + T_R)}$	Model of equation for ω, and estimates of P_I, P_{FD}, T_{FI}, T_R
P_I	Probability that a flaw will be inspected (index "I") per inspection interval	Estimate based on specific inspection strategy; usually done separate for ASME Section XI (or equivalent) and RI-ISI programs
P_{FD}	Probability that a flaw will be detected given that the weld or pipe section is subjected to NDE. Also referred to as POD.	Estimate based on NDE reliability performance data and difficulty of inspection. A Cat2 database provides qualitative insights about NDE reliability
T_{FI}	Mean time between inspections	Based on applicable inspection program; can be "never" or 10 years for ASME XI piping
T_R	Mean time to repair once detected	Obtained directly via database query. The mean repair time includes time tag out, isolate, prepare, repair, leak test and tag-in

Another example of advanced database application involves parameter estimation to support benchmarking of probabilistic fracture mechanics (PFM) models. Reference [3.7] documents insights and results from a recent benchmarking exercise performed in support of a new computer code for the prediction of pipe break probabilities for LOCA frequency estimation [3.6]. Some results from the benchmarking are included in Table 3.7.

***Table 3.7** Comparison of Results for Different ISI Sites [3.7]*

Analysis Case	**Predicted Cumulative Probability of Through-Wall Flaw (Perceptible Leakage)**		
	PFM [Note 1]	**Service Data** [Note 2]	**Over-Prediction (PFM:Service Data)**
PWR Hot leg Bi-Metallic Weld (RPV Nozzle-to-Safe-end) @ 20 years	1.0×10^{-1}	2.9×10^{-3}	~ 100
PWR Pressurizer Surge Line Bi-Metallic Weld @ 6 years	5.0×10^{-1}	4.9×10^{-5}	~ 10000
PWR Pressurizer Spray Line Bi-Metallic Weld @ 6 years	5.0×10^{-1}	2.1×10^{-4}	~ 1000
BWR Reactor Recirculation Austenitic Stainless Steel Weld (12-inch) @ 15 years and no IGSCC mitigation	2.0×10^{-1}	3.4×10^{-3}	~ 60

Note 1: Average of PRAISE and PRO-LOCA results
Note 2: Estimation based on methodology as documented in Task 1 report (2005153-M-003)
Note 3: The term “perceptible leakage” implies a through-wall flaw but with very minor leakage or no active leakage during normal plant operation.

It is noted that these results reflect different assumptions about weld residual stresses as well as different assumptions about crack propagation. One insight from the benchmarking is that service data and associated parameter estimates can and should be used as one of several inputs to the calibration of the input to PFM models and validation of results.

3.4 Recommendations for R-Book Content

Ample experience exists with pipe failure database development and application. A plan for developing an “R-Book” for piping reliability analysis needs to account for an overall technical scope (systems, components, and operating environments to be accounted for) and end-user requirements. The end-user requirements should address intended applications as well as needs for data specializations. Three strategies for an “R-Book” are outlined below:

- Basic Approach. Tabulations of parameter values that are ready for use by PSA practitioners. It is expected of such an approach that piping component boundary conditions are clearly stated and that the techniques and tools for parameter estimation have been subjected to an accepted level of peer review. Any data tabulation needs to clearly acknowledge design and operating practices that are representative of the Nordic nuclear power plants. As an example, it would make no sense at all to develop failure parameters for, say, Service Water piping without first filtering out any service experience data for plants using fresh water or river water as the ultimate heat sink; all Nordic plants use brackish or sea water as the source of cooling water. Furthermore, any tabulation of failure parameters should reflect in-service inspection regulations and practices that apply to the Nordic plants. The overall scope of the data book could include all major plant systems, as identified in Table 3.8, or some subset thereof.

- Advanced Approach. This approach would be intended for an experienced data analyst requiring seed parameters for user-defined data applications or specializations. Rather than presenting parameter values ready for direct use in a

PSA model this version would include comprehensive tabulations of failure counts and the corresponding exposure data. For calibration purposes and for some pre-selected piping component types, parameter estimates could also be included based on a "pre-approved" method. Detailed user instructions would be included in an R-Book of this scope.

- Combined Approach. As implied, in this version some middle-ground would be established so that the data requirements at different user levels can be met. For example, in this approach the handbook could consist of proposed generic (or prior) failure rate distributions for selected systems. That is, for systems for which the available body of service experience is such that direct statistical estimation is feasible across the full range of failure modes (from degraded condition to major structural failure). These proposed generic failure rate distributions would include detailed user instructions, including guidelines for plant-specific data specializations. A second part of the handbook could consist of extensive database query results for all plant systems listed in Table 3.8. These queries would consist of pipe failure counts by pipe size, damage/degradation mechanism, material and failure location, and presented in such a way that input files exist for any chosen reliability parameter estimation approach. It is anticipated that the user guidance would include proposed, or recommended estimation tools.

Irrespective of the chosen approach it is expected that the experience with the T-Book [3] development and maintenance be applied to the R-Book development process. Methodology and presentation format must be transparent and reproducible.

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[3] **T-Book** – Reliability Data of Components in Nordic Nuclear Power Plants.

Table 3.8 *Plant Systems in OPDE Database Scope [3.5]*

OPDE Generic (1)	**Description**	**Czech Republic**	**France**	**Germany** (7)		**Sweden**
				AKZ	**KKS**	
ADS	BWR Primary Depressurization System (BWR)	--	--	TK, RA		314
AFW	Auxiliary Feedwater System		ASG	RQ		327
CC	Component Cooling Water System	TF	RRI	TF	LA	711/712
COND	Condensate System			RM, RN	LC	414/430 (4)
CRD	Control Rod Drive (Insert/Removal/Crud Removal)	--	--			354
CS	Containment Spray System	TQ	EAS			322
CVC	Chemical & Volume Control System (PWR)		RCV	TA, TC, TD	KB	334
CW	Circulating Water System					443
EHC	Electro Hydraulic Control System					442
EXT	Steam Extraction System					419/423
FPS	Fire Protection System	C-52				762
FW	Main Feedwater System		ARE	RL	LA	312/415 (5)
HPCS	High Pressure Core Spray (BWR)	--	--	TJ		--
HPSI	High Pressure Safety Injection (PWR)	TJ	RIS	TH	JN	--
IA	Instrument Air System	US				484
LPCS	Low Pressure Core Spray (BWR)	--	--	TK, TM		323
LPSI	Low Pressure Safety Injection (PWR)	TH	RIS	TH	JN	--
MS	Main Steam System		VVP	RA	LB	311/411 (6)
MSR	Moisture Separator Reheater System			RB	LB	422
RCS	Reactor Coolant System (PWR)		RCP	YA, YB, YP	JA, JE	313
RHR	Residual Heat Removal System	(2)	RRA	TH	JN	321
RR	Reactor Recirculation System (BWR)	--	--			313
RPV-HC	RPV Head Cooling System (BWR)	--	--	TC		326
RVLIS	Reactor Vessel Level Indication System (BWR)	--	--			536
RWCU	Reactor Water Cleanup System (BWR)	--	--	TC	KB	331
SA	Service Air System	TL		TL	KL	753
SFC	Spent Fuel Pool Cooling System	TG	PTR	TG	FA	324
S/G Blowdown	Steam Generator Blowdown System (PWR)		APG	RS	LA	337
SLC	Standby Liquid Control System (BWR)	--	--			351

Table 3.8 *Plant Systems in OPDE Database Scope [3.5]*

OPDE Generic (1)	**Description**	**Czech Republic**	**France**	**Germany** (7)		**Sweden**
				AKZ	**KKS**	
SW	Service Water System (3)	VF	SEC	VE	PE	712/715

Notes:

1. See IEEE Std 805-1984 (IEEE Recommended Practice for System Identification in Nuclear Power Plants and Related Facilities) for information on system boundary definitions and system descriptions.
2. No dedicated RHR system in WWER-440 (decay heat removal is through natural circulation)
3. It is common practice in the U.S. to use different system ID for safety-related and non-safety related SW systems; e.g., ESW or SX for Code Class 3 piping and WS for non-Code piping
4. 414 for F1/F2/R1/R2/R3/R4 and 430 for O1/O2/O3
5. 312 for O1/O2/O3 and 415 for F1/F2/R1/R2/R3/R4. Also note that 312 is the designation for steam generators in Ringhals-2/3/4
6. 311 for O1/O2/O3 411 for F1/F2/R1/R2/R3/R4
7. AKZ = Anlagen Kennzeichnungs System, KKS = Kraftwerk Kennzeichnungs System

The method of data specialization entails re-scaling or re-baselining of a published pipe failure arte and then to factoring in new influence factors not accounted for by the original analyses. It also entails the application of Bayesian methods to update a prior failure rate with new and relevant information. With this in mind, a proposed R-Book should present information necessary for defining a prior failure rate. This then could be used to estimate a plant-specific failure rate. As an example, there is ample service experience data on rubber-lined, carbon steel piping in salt water service. The bulk of this experience – as recorded in OPDE and PIPExp – is for U.S. plants. However, the available data (failure counts and exposure) could be used in estimating, say, a pipe failure rate specialized to the three PWR units at the Ringhals site by updating the prior failure rate with the service experience data unique to Ringhals.

4 Questionnaire – Database users

As a part of the Phase 1 work with the R-book a questionnaire was developed that was sent to potential future R-Book users. The objective with the questionnaire was to establish user requirements of such a piping reliability data handbook.

4.1 Questionnaire distribution

This questionnaire was sent to the organizations listed below. Those that responded to the questionnaire are presented with **bold characters**.

Pacific Northwest National Laboratory	Institute for Energy, Nuclear Safety Unit, JRC-Petten	**Japan Nuclear Energy Safety Organization (JNES)**
Korea Atomic Energy Research Institute	U.S. Nuclear Regulatory Commission (Office of Nuclear Regulatory Research)	**Technology Insights, Inc.** (K.N. Fleming)
Oskarshamns Kraftgrupp AB, OKG	**Forsmarks Kraftgrupp AB, FKA**	**Ringhals AB, RAB**
Swedish Nuclear Inspectorate (SKI)		

4.2 Questionnaire

The questionnaire, which is presented in Attachment 5, contains questions within the following areas:

A Handbook applicability

B Level of detail

C Layout and updating

D Data background (traceability)

The answers by the respondents and the conclusions reached from evaluating the answers are given in [4.1]. The answers to the questionnaire have been used to establish high-level requirements for the R-Book technical scope the details of which are documented in Chapter 6.2.

5 Questionnaire - Piping Population Databases

As a part of the Phase 1 work with the R-book a questionnaire was developed that was sent to those Nuclear Power Plants that will be represented in the R-Book, at least in a first release.

The objective with this questionnaire was to determine availability of information regarding piping population (e.g., weld counts and pipe lengths).

5.1.1 Questionnaire distribution

This questionnaire was sent to the organizations listed below. Those that have answered that questionnaire are presented with **bold characters**.

Oskarshamns Kraftgrupp AB, OKG	**Forsmarks Kraftgrupp AB, FKA**	**Ringhals AB, RAB**

5.2 Questionnaire outline

The questionnaire, which is presented in Attachment 7 (given in Swedish only), contains questions within the following areas:

A Questions of general nature with respect to how information about piping components can be retrieved.

B Questions regarding information about piping component attribute i.e material data.

C Questions regarding piping component exposure term data, i.e. pressure, temperature etc.

D Questions regarding availability of information about piping components.

E Questions regarding operating experiences

Answers given on the questionnaire together with conclusions based upon the answers are given in [5.1]. The answers on the questionnaire have been used in order to establish requirements of the R-Book (Chapter 6.2).

6 R-Book project – Scope of Phase 2

This chapter documents the requirements for the first edition of the R-Book. These requirements reflect insights that have been gained from past practical piping reliability assessments that are based on service experience data, including the technical insights that are documented in Chapters 2 through 5 of this report, i.e.:

Chapter 2:	Database Survey
Chapter 3:	Data Needs
Chapter 4:	Database Users
Chapter 5:	Piping population databases

Important inputs are the conclusions that have been made based on the questionnaires presented in Chapter 4 and 5. The questionnaires together with all the answers and conclusions are given mainly in [6.4] but also in [6.5]. The conclusions from the questionnaires and their impact on the R-Book requirements are presented in Chapter 6.2.

6.1 Strategy for Phase 2

In [6.4] a compilation of the questionnaire on “User Requirements” sent to potential users of the R-Book is given together with answers and conclusions made based on the answers. Furthermore a set of “other issues” that was raised during the interviews is presented

Based on these user requirements as presented in [6.4] a strategy has been produced on what kind of information the R-Book will include in the first issue that will be produced during Phase 2 of the project.

The overall strategy for work with Phase 2 is listed below. The different subchapters in Chapter 6.2 gives more detailed information how the different user requirements in [6.4] will be met.

Overall work strategy for the continuous work with the R-Book project in Phase 2 will be:

A Identification of piping population data already existing for different NPPs that can be made available for the project.

B Based on the above a few systems will be selected and all quantitative and qualitative information that is to be found in the R-Book will be produced.

C A seminar with representatives from the utilities, the financiers NPSAG [4] *and SKI will be held. At this seminar the results produced for these first systems according to B will be presented. Any remarks with respect to content or methods will be taken into account before the work continues with producing data for other systems as well.*

D Continued work with producing data for the R-Book.

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[4] **NPSAG** – Nordic PSA Group

6.2 R-Book requirements

6.2.1 Applicability and level of detail

It is concluded that the main purpose of the R-Book will be to obtain data for PSA. The data presented will therefore be those necessary for PSA, any other possible application will be excluded, see also Chapter 6.2.6.

The R-Book will present a frequency of an initial defect, i.e. a defect of such magnitude that some kind of measure need to be taken (repair or replacement). However, this initial defect does not necessary mean that any kind of leakage occurred.

For each initial defect the conditional probability for a leakage will be calculated and by this a frequency for different levels of leakages can be presented. Conditional pipe failure probabilities will be developed for the uniquely defined consequences of structural failure using a technical approach as documented in PVP2007-26281 [6.1].

For different types of piping different levels of leakage will be presented. In Table 6.1, through-wall flow rates are presented at a pressure of approximately 15 MPa. This table is generated from NUREG-1829 [6.6] and it is also presented in Chapter 2.

Table 6.1 *Through-wall Flow Rate to Break Size Correlations for Code Class 1 Piping*

Equivalent Break Size		**BWR Liquid Release**		**PWR Liquid Release**	
Diameter [mm]	**Area [in^2]**	**Flow Rate [gpm]**	**Flow Rate Flux [gpm/in^2]**	**Flow Rate [gpm]**	**Flow Rate Flux [gpm/in^2]**
15	0.19635	116.8	595	134.9	687
25	0.78539	467.3	595	539.5	687
50	3.14159	1869.2	595	2158.2	687
75	7.06858	4205.8	595	4856.1	687
100	12.56637	7476.9	595	8633.1	687
150	28.27433	16823.2	595	19424.5	687
200	50.26548	29907.9	595	32220.2	641
250	78.53982	29452.4	375	50344.0	641
300	113.0973	42411.5	375	72495.4	641
400	201.0619	75398.2	375	128880.7	641
750	706.8583	265071.9	375	453096.2	641

Based on:

- Moody, F.J., "Maximum Flow Rate of a Single Component, Two Phase Mixture," Trans. J. Heat Transfer, **86**:134-142, February 1965. Applies to medium-and large-diameter piping.
- Zaloudek, F.R., The Low Pressure Critical Discharge of Steam-Water Mixtures from Pipes, HW-68934, Hanford Works, Richland (WA), 1961. Applies to small-and medium-diameter piping.

1 gpm = 6.3×10^{-2} kg/s

In order to make it possible to correlate a leak rate to a corresponding pipe break diameter the data tables in the R-Book will also contain a column with this information. Frequency of "structural failure" will be estimated on the basis of the resulting through-wall flow rate (kg/s). For Class 1 systems the correlations developed in NUREG-1829 [6.6] will be used. For other systems, leak rate calculations will be performed to establish realistic correlations between operating pressure and through-wall flaw size.

This work has already been completed, and, except for an independent review, no new development work is anticipated. Figure 6.1 shows through-wall flow rate as a function of flaw size for moderate-energy piping (e.g., SW piping).

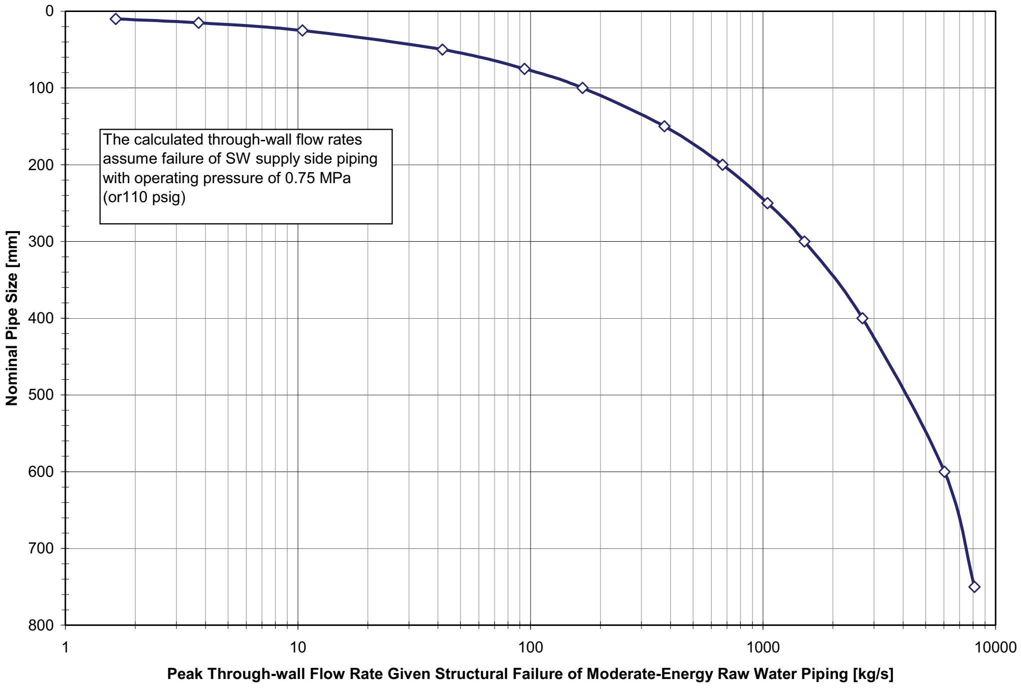

Figure 6.1 *Calculated Peak Through-wall Flow Rates for Failed SW Piping*

With respect to leak rates, it is important to note that the database OPDE in itself do not contain any explicit information whether a certain leak did exceed limits given by the Technical Specification or not. This kind of information is however used in the leak rate definition as explained the Coding Guideline of OPDE [6.2].

6.2.2 Site specific or generic data?

In order to have a sufficient statistical data material, i.e. that does not give rise to "unrealistic" uncertainties, failure data in the R-Book will be valid for NPPs in Nordic countries, i.e. Sweden and Finland. Also, data will be presented for the world wide plant population. The reason for the world wide population is that for some systems failure defects may not be reported in one country to the same level as it is in another country. By presenting data for a world wide population as well the R-Book user will be able to choose between using a more site specific data (Nordic Countries) or a more generic data (World Wide).

Besides distinguishing between Nordic and world wide data the failure data will be presented for PWR and BWR, and also for different kinds of materials, i.e. stainless steel, carbon steel and nickel based alloys.

In order to represent world wide data, already existing piping component population data will be utilized (Scandpower RM). Already existing piping population data sets are summarized below with additional details presented in Attachment 10.

- B1/B2 (Class 1 systems; refer to SKI 98:30 [6.6])

- Class 1 & 2; 11 different BWR design generations (US)
- Class 1 & 2; 7 different PWR plants (2-/3- & 4-loop, US)
- Class 3 & 4 (non-safety-related; FPS, SW, IA, FWC & Steam/EXT-Steam); 4 different PWR plants (US)
- Literature data (no QA)

This information will be augmented with information as supplied by NPSAG members for Swedish NPPs. The Finish plants OL1 and OL2 will then be treated as similar as F1 and F2 with respect to piping component population.

To conclude, the R-Book will not present any plant-specific information. The presentation will be limited to Median, Lower Bound and Upper Bound estimates of component counts as derived from available information.

6.2.3 Piping components to be represented

Failure data in the R-Book will be presented for different types of piping components, according to the information available in the OPDE database. The level of detail with respect to this is expected to be as follows:

- Welds in different material
- Base metal
- T-joints
- Bends

If a more detailed differentiation is needed it will be up to each user to proceed with this.

6.2.4 Piping population data requirements

For each system in the work scope the following information will need to be provided:

- Number of components, differentiated according to
- Component type (e.g., weld, bend, elbow, reducer, tee, pipe, expansion joint)
- Diameter
- Material (carbon steel, stainless steel, nickel-based, low-alloy steel)
- For welds, information about the configuration (e.g., pipe-to-pipe, pipe-to-elbow, pipe-to-tee, pipe-to-valve)
- Code class (safety class)
- Isometric drawing ID (preferred but not absolutely necessary)

In Attachment 8 an example of piping population data is given. A question has been sent to the NPSAG representatives about already existing piping population information (databases). Based on the answers received it will be decided what systems in different plants that will be represented in the first draft of the R-Book in phase 2.

6.2.5 Traceability

Data will be extracted from the OPDE database using queries in MS Access. Each query used will be given a unique ID and be saved, probably in appendices to the R-Book. Information about the queries and version of the OPDE database used will be sufficient in order to reproduce the input data. If needed, the queries can be expanded in order to also list the individual failure reports in OPDE that was the result of each query.

Recorded in OPDE is any degraded condition that requires some kind of corrective measure to be taken (repair or replacement). The database includes “precursor events” (non-through-wall flaws) as well a through-wall flaws that generate active leakage. OPDE is continually growing with approximately 200 events per year. A new version of OPDE is released every six month.

Not all events have undergone full validation with respect to flaw size data and cause of degradation/damage. However, each event in OPDE are marked with a Completeness Index (CI) from 1 to 3; where 1 means that the event has been completely verified, 2 means that it have been verified but some kind of (non-critical) background information is missing, 3 means that the event has not been verified. When a query is executed on the OPDE database all events with CI=1 or CI=2 will be included in the event count. Some events with CI=3 may also show as a result for the query. In such cases it must be judged whether that event shall be included or excluded from the result. In case the flaw has been verified together with a damage mechanism causing the flaw, the event may be included. When events with CI=3 are included this must therefore also be documented in the R-Book.

In order to simplify the queries used a sub database of OPDE will be extracted for each system, e.g. OPDE_v#_BWR-313.

6.2.6 Parameters to be presented

Parameters that will be presented in the first issue of the R-Book are listed below:

λ_{ik}	Frequency for an initial defect (calculated)
P_{ik}	Conditional probability for a leak consequence given the initial defect (calculated)
n_{ik}	Number of events (result from query)
f_{ik}	Portion of the total piping component population in a system that is susceptible to certain degradation or damage mechanism (based on OPDE and RI-ISI Degradation Mechanism Assessments)
N_i	Number of piping components in population (results from query)
T_i	Exposure time, based on number of reactor years (from plant population database)

The methodology is described in detail in Chapter 2. This methodology has been subjected to independent reviews by the Los Alamos National Laboratory (LANL), the University of Maryland (UoM), and Korea Energy Research Institute (KAERI). The reviews by LANL and UoM, respectively, are documented in TSA-1/99-164 (available from the U.S. NRC Public Document Room, Accession Number 9909300045) and EPRI TR-110161 (Appendix A). The methodology has been implemented in Microsoft® Excel with Crystal Ball® for uncertainty propagation. An advantage of this implementation is that all calculations will be traceable.

6.2.7 Systems to be presented

The proposed scope of the R-Book is given below in a list of systems for which pipe failure data parameters will be derived. Table 6.2 presents the proposed work scope, which reflects intended risk-informed PSA applications. The systems that are listed in Table 6.1 cover the full range of risk-informed PSA applications (LOCA frequency estimation, HELB evaluations, internal flood PSA, RI-ISI).

Table 6.2 *Scope of R-Book*

OPDE Generic (1)	**Description**	**Swedish Designations**
ADS	BWR Primary Depressurization System (BWR)	314
AFW	Auxiliary Feedwater System	327
CC	Component Cooling Water System	711/712
COND	Condensate System	414/430 (2)
CRD	Control Rod Drive (Insert/Removal/Crud Removal)	354
CS	Containment Spray System	322
CVC	Chemical & Volume Control System (PWR)	334
CW	Circulating Water System	443
EXT	Steam Extraction System	419/423
FPS	Fire Protection System	762
FW	Main Feedwater System	312/415 (3)
HPCS	High Pressure Core Spray (BWR)	--
HPSI	High Pressure Safety Injection (PWR)	--
LPCS	Low Pressure Core Spray (BWR)	323
LPSI	Low Pressure Safety Injection (PWR)	321 (LPSI)
MS	Main Steam System	311/411 (4)
MSR	Moisture Separator Reheater System	422
RCS	Reactor Coolant System (PWR)	313
RHR	Residual Heat Removal System	321
RR	Reactor Recirculation System (BWR)	313
RPV-HC	RPV Head Cooling System (BWR)	326
RVLIS	Reactor Vessel Level Indication System (BWR)	536
RWCU	Reactor Water Cleanup System (BWR)	331
SFC	Spent Fuel Pool Cooling System	324
S/G Blowdown	Steam Generator Blowdown System (PWR)	337
SLC	Standby Liquid Control System (BWR)	351
SW	Service Water System	712/715

Notes:

1. See IEEE Std 805-1984 (IEEE Recommended Practice for System Identification in Nuclear Power Plants and Related Facilities) for information on system boundary definitions and system descriptions.
2. 414 for F1/F2/R1/R2/R3/R4 and 430 for O1/O2/O3
3. 312 for O1/O2/O3 and 415 for F1/F2/R1/R2/R3/R4. Also note that 312 is the designation for steam generators in Ringhals-2/3/4
4. 311 for O1/O2/O3 411 for F1/F2/R1/R2/R3/R4

Figure 6.2 shows the types of systems that are considered as potential flood sources in a typical internal flooding PSA study.

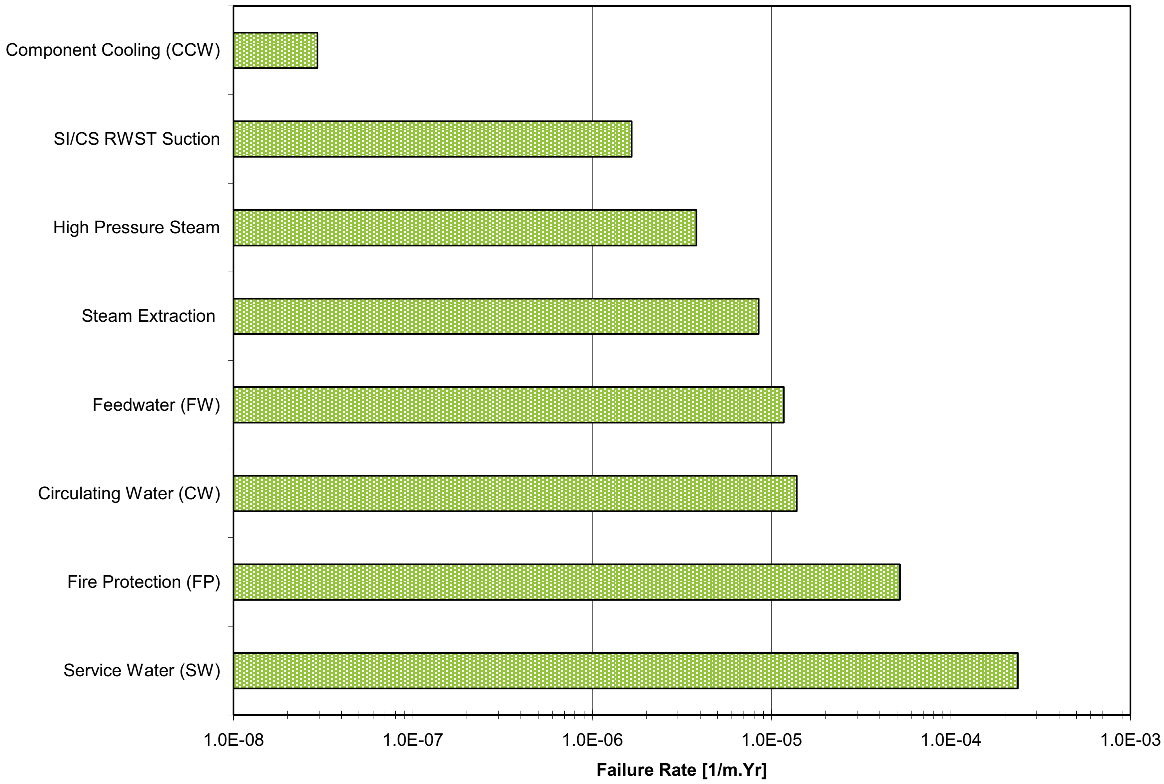

Figure 6.2 *Calculated Pipe Failure Rates for Systems Included in the Scope of a Typical Internal Flooding PSA*

6.2.8 Exposure term (pressure, temp, flow, chemistry etc.)

No special information regarding operating pressure and temperature, flow, water chemistry etc. will be included in the R-Book. Note, however, that in the qualitative and system-specific service history summaries there will be some general information given regarding the observed influence factors on damage and degradation mechanisms.

6.2.9 Language

The language of the R-Book will be English (US).

6.2.10 Treatment of "other issues" in [6.4]

This chapter deals with issues that were not initially listed in the questionnaire (Attachment 5) but was brought to the author's attention during the interviews and are therefore documented in [6.4]. A summary of each "issue" is given in italic and after that information on how this will be handled in the R-Book is presented.

Impact of power uprate and modernization projects

It is desired that the R-Book contains information on active damage mechanisms for different piping components/material during different operating condition. If such information can be provided it is possible to estimate effect of a future power increase or some other modernization, for instance change of material or water chemistry.

For each plant system that is addressed by the R-Book relevant qualitative information on the service experience will be presented. The qualitative information will be organized according to a template as given by Table 6.3.

Table 6.3 *Template for summarizing service experience history*

Plant System – e.g., BWR 313		**Event History (Failure Count)**			
Degradation Mechanism (DM#)		**1970-1979**	**1980-1989**	**1990-1999**	**2000-2007**
DM1	Worldwide				
	Nordic				
DM2	Worldwide				
	Nordic				
DM3	Worldwide				
	Nordic				
DM4	Worldwide				
	Nordic				

Notes:
- a – Mitigation program
- b – Water chemistry
- c - Material (e.g., typical types, material compositions)
- d - Ageing effects (including effects of power uprate projects)
- e - Non-destructive examination (NDE)

A set of notes (“a” through “e” in Table 6.3) addresses key piping reliability influence factors. These notes provide additional information on conditions that are judged to be of importance with respect to the number of observed defects. With this information the user of the R-Book can form conclusions about different conditions and their observed effects on the number of defects that are recorded in OPDE. These conditions might for instance be ageing effects, effects of change of material, but also change in NDE methods.

The influence factors on piping performance are interrelated. For example, a power uprate may cause increased wear effects on secondary system piping. But mitigation programs (e.g., replacement of original carbon steel piping with piping of low alloy steel) and improved NDE could offset a projected (or assumed) increase in observed failure rate.

Attachment 9 includes an example of service experience history for BWR Reactor Recirculation piping (System 313 according to the Nordic industry nomenclature).

Material designations

According to different standards, the same material may have different designations. It is therefore important to have a cross reference of different material standards.

OPDE has already produced such a cross reference matrix. This matrix will be included as an appendix to the R-Book.

Human Errors

A question was raised about how human errors will be treated in the R-Book, perhaps they should be excluded, or at least listed separately?

OPDE clearly identifies recordable/reportable flaw indications that are attributed to "Design & Construction Errors/Defects" (D&C). In the classification scheme that has been adopted by OPDE, "human error" is a subset of D&C and applies only to failures of small-bore piping (e.g., instrument sensing lines) that are attributed to maintenance personnel inadvertently making contact with the affected piping. In general, "D&C" can be contributing to the formation of a degraded condition (e.g., lack of weld fusion) but not a direct cause of failure. The format that will be adopted for presenting the event population data clearly documents the role, if any, of "human error."

References to other data sources

It would be good if some kind of reference can be made to other data sources that present similar data as the one presented in the R-Book.

The "R-Book" is intended as an autonomous current reference subject to quality control and restricted access in the same way as the current "T-Book" for active components. The "R-Book" will not reproduce any historical failure parameters. It is not the objective of the project to validate and verify any historical parameter estimates. It is noted that ample information on other data sources and historical parameter estimates already exists in published SKI Research Reports.

6.3 Prior distribution

One important step in the statistical calculations is the choice of prior distribution. The prior distribution will differ from system to system and the justifications for selected priors will be documented in the R-Book. The prior distributions to be used include non-informative priors and empirical prior distributions.

6.4 Quality Assurance

The overall approach to the statistical estimation process selected for the R-Book will utilize key elements of an approach that already has been subjected to an independent peer review by the Los Alamos National Laboratory – see also the methodology overview in Chapter 6.2.6. The R-Book will contain an appendix where the calculation methods will be described together with a reference to the independent review.

6.5 Software used for R-Book

The software used for the deriving the data in the R-Book will be:

- Microsoft® Excel
- Crystal Ball® (Monte Carlo simulations)
- R-DAT (Bayesian statistics/updating).

Data from OPDE will be exported to Excel together with the prior distributions. The updating of frequencies is then performed with R-DAT. In the last step the calculation of conditional probabilities will be performed using Excel, together with Crystal Ball for the Monte Carlo simulations. It is an "open" analysis format with full transparency of each calculation step.

6.5.1 Uncertainty distribution

Crystal Ball® produces percentiles for the uncertainty distributions. These will be presented in the R-Book in the same manner as they are presented in the T-Book. Even though it may be possible to let Crystal Ball® suggest a parametric distribution this possibility will not be used. The reason for this is that it is not certain that the parametric distribution will satisfy requirements of conservatism in all cases and therefore only percentiles in a discrete distribution will be presented.

In the main tables in the R-Book the 5th, 50th and 95th percentiles will be presented. In additional files extended distributions will be given in the same way as in the T-Book.

6.6 Overall time schedule for Phase 2

The overall time schedule for the R-Book phase 2 project will be as follows:

Winter – spring 2008

- Guidance on how statistical calculation shall be performed will be produced. This will be included as an appendix in the R-Book.
- Based on the response from each project member NPP regarding piping population counts, decision will be made on what systems to be included first in the R-Book.
- Historical qualitative summary and information for systems in the work scope.
- Perform first “trial calculations” with already existing piping populations.
- Description of calculation methodology will be included as an appendix in the R-Book.

Spring – summer 2008

- During the May – June 2008 timeframe a seminar will be held where the results for the first set of systems are presented. At this seminar presentation of data and other information will be discussed together with a practical demonstration of the calculation methodology used. Upon completion of the seminar decisions will be made relative to any changes regarding scope, methodology or data presentation format. Changes, if any, will be implemented before end of June 2008.

Autumn – winter 2008/2009

- During the autumn of 2008 calculations will commence for remaining systems provided that sufficient exposure data sets have been assembled.

6.7 Access to OPDE database

All Swedish nuclear plant operators have access to the complete version of OPDE database. The Terms & Conditions of the OPDE Project provide specific provisions for access and use of the database by contractors performing work for OPDE member organizations. Respective OPDE National Coordinator is responsible for upholding the OPDE Terms & Conditions. A protocol has been established for how to grant database user permissions.

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5 Chapter 5 Questionnaire – Piping Population Databases

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Attachment 1: Existing Pipe Failure Databases – Appendix A

Excerpts from selected databases

DATE	TYPE	PLANT	DATA SOURCE	EVENT	DESCRIPTION	SYSTEM	AGE [hrs]	SIZE	COMMENT
4/15/1973	BW-PWR	ANO-1	DL LTR 5/25/73	Leak	Stress corrosion	Containment spray	-11352	213mm	
2/28/1990	BW-PWR	ANO-1	90-001	Leak	Cooling coil leaks, corrosion pitting	Service water	136560	<25mm	Pipe size is judged to be less than 1 inch.
4/10/1985	BW-PWR	ANO-1	PNO-IV-85-015	Leak	Erosion/corrosion	Service water	93720	1,5	
9/6/1983	BW-PWR	ANO-1	83-019	Leak	Fatigue-vibration	Reactor coolant	79752	19mm	
8/28/1976	BW-PWR	ANO-1	RO 76-24	Leak	Leaked welds on valve, fatigue-vibration	RHRS	18192	12,7mm	
12/22/1990	BW-PWR	ANO-1	90-021	Leak	Stress corrosion cracking	Containment heat removal	143688	50mm	
4/15/1974	BW-PWR	ANO-1	Ltr DL 4/15/74	Leak	Fatigue-vibration	Makeup system	-2592	50mm	
2/16/1982	CE-PWR	ANO-2	82-007	Leak	Fatigue-vibration	Service water	28152	25mm	
4/4/1982	CE-PWR	ANO-2	82-007	Leak	Fatigue-vibration	Accumulators	29280	25mm	
5/5/1982	CE-PWR	ANO-2	82-017	Leak	Cracked weld	Reactor water cleanup	30024	25mm	
8/13/1985	CE-PWR	ANO-2	85-015, 016	Rupture/Leak	Water hammer	Condensate	58728	50mm	
6/23/1989	CE-PWR	ANO-2	PNO-IV-89-042	Leak	Fatigue-vibration at pressure sensing line sealant	Reactor coolant	92568	<25mm	Pipe size is judged to be less than 1 inch.
5/4/1994	WE-PWR	Beaver Valley-1	94-004	Leak	2 ft. section of pipe replaced, unknown cause	PRZ	157848		
1/19/1982	WE-PWR	Beaver Valley-1	82-002	Crack	Frozen pipe	Coolant recirculation	50136	<25mm	Pipe size is judged to be less than 1 inch.
5/14/1980	WE-PWR	Beaver Valley-1	80-036	Crack/Leak	Fatigue-vibration	Boric acid	35376	25mm	
9/25/1980	WE-PWR	Beaver Valley-1	RO	Rupture/Leak	Operator error	FPS	38592	>25mm	Pipe size is judged to be greater than 1 inch.
10/29/1981	WE-PWR	Beaver Valley-1	81-091R1	Rupture/Leak	Underground external corrosion	FPS	48168	304mm	
6/8/1975	WE-PWR	Beaver Valley-1	Problem report 6/20/75	Leak	Fatigue-vibration	SIS	-7872	19mm	

Table 1A-1 Excerpt from SKI 96:20 Database [2.4]

PLANT NAME	DATE	SYSTEM	DIAMETER [inch]	FAILURE TYPE	DATA SOURCE	CAUSE-1	CAUSE-2	CAUSE-3	COMMENT
Salem-2	1/17/90	Boron Injection	1	Leak	LER 90-005	Corrosion	Acid Corrosion	--	Leaked weld, corrosion, mode-3
Quad Cities-2	1/28/90	RHR	12	Leak	NPRDS	FAC	Single-Phase FAC	--	Schedule 40 (wall thickness)
ANO-1	2/28/90	Service Water	< 1	Leak	LER 90-001	Corrosion	Pitting	--	Cooling coil leaks, corrosion pitting
Brunswick-1 (NOTE 1)	3/2/90	Main Steam	6	Rupture / Severed	LER 90-003	FAC	Wet Steam Erosion	--	Erosion/corrosion
Clinton	3/3/90	Condensate Drain	8	Leak	NPRDS	FAC	Cavitation	--	Schedule 40, pinhole leak, shutdown
Three Mile Island-1	3/4/90	Feedwater	8 x 6	Leak	NPRDS	FAC	Single-Phase FAC	--	Schedule 80, 8 x 6 inch reducer, hole in pipe
Brunswick-1 (NOTE 2)	3/20/90	Unknown	> 1	Failed	LER 90-004	Construction / Fabrication Defect Error	Error	Installation Error	PVC lack of bond, 8 prior events LERs 86-6, 87-13, 87-22, 89-10, 89-22
As one perspective on the difference between a Cat0 and Cat2 database, two examples of the type of validation expected of a Cat2 database are included: This record is based on information in LER-title (LER 90-003-00: "*On 900302, HPCI sys declared inoperable to stop leak on steam supply drain line. Caused by severe steam erosion at 90-degree elbow. Involved section of piping replaced on Units 1 & 2).*" In creating this database record only the LER title information was utilized, however. For reference, the full-text LER is included on next page. The affected component was a 1-inch (DN25) 90-degree elbow, part of the High Pressure Coolant Injection (HPCI) System. This system utilizes a turbine-driven pump, which takes suction from a condensate storage tank. This record concerns PVC piping in the chlorination system for the circulating water system. The subject LER does not include details on the plastic piping (e.g., diameter or wall thickness).									

Table 1A-2 Excerpt from TR-110102 Database [2.3][7]

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[7] Annotations (in shaded cells) added by the authors of this report

Licensee Event Report (LER): 50-325/1990-003-00 (Brunswick-1, BWR)

TITLE: On 900302, HPCI sys declared inoperable to stop leak on steam supply drain line. Caused by severe steam erosion at 90-degree elbow. Involved section of piping replaced on Units 1 & 2).

ABSTRACT: At 1505 on March 2, 1990, the Unit 1 HPCI system steam supply isolation valves were manually closed to stop a steam leak located on the steam supply drain line. Attempts to isolate the leak from the steam supply without closing the isolation valves had been unsuccessful. A visual examination of the drain line revealed that severe steam erosion had resulted in a through wall failure. The failure was at a ninety degree elbow in a section of the drain line which had been installed since construction. Investigation revealed that a similar section of drain line existed on the Unit 2 HPCI system. The section of piping was replaced on both units. A work request has been initiated to investigate and repair the cause of the inability to isolate the leak without closing the steam supply isolation valves. Future monitoring of the piping will be in accordance with the Erosion/corrosion inspection Program. At the time of this event, Unit 1 was at 100% power with ECCS and RCIC systems operable in standby line up. Unit 2 reactor was shutdown in a refuel/maintenance outage. The safety significance of this event was minimal. This is considered an isolated event.

EVENT: Manual closure of the Steam supply isolation Valves to HPCI to isolate a steam leak on the steam supply drain pot line.

INITIAL CONDITIONS: The Unit 1 reactor was at 100% power. The HPCI, RCIC, ADS, CS and RHR/LPCI systems were operable in standby lineup. The Unit 2 reactor was shutdown in a refuel and maintenance outage.

EVENT DESCRIPTION: At 1505, on March 2, 1990, the Unit 1 CO received a report of a six to ten foot steam plume at the HPCI mezzanine from the reactor building AO. At 1510, the CO was informed that the leak was on the HPCI Steam Supply Drain Pot drain line. The CO closed the Supply Drain Pot Inboard and Outboard Drain valves, 1-E41-F028 and F029, in an attempt to isolate the leak. The leak appeared to increase. The CO reopened the referenced valves and instructed the AO to isolate the leak by closing the Supply Drain Pot Normal operating orifice upstream and Downstream Isolation valves, 1-E41-F036 and 1-E41-F037 and by failing closed the supply drain pot drain bypass valve, 1-E41-F054; but the leak continued. A second attempt to isolate the leak by closing 1-E41-F028 and F029 was not successful and, at 1539, the HPCI Steam Supply Inboard and Outboard Isolation Valves, 1-E41-F002 and 1-E41-F003 were closed. AOP 5.0, Radioactive Spills, High Radiation and Airborne Activity, was referenced to determine additional actions, Health Physics personnel were informed of the need to survey the area, a steam blanket was placed over the line break, additional room cooling was established and HPCI LCO A1-90-0295 and WR/JO 90-AEUM1 were initiated. The eroded section of piping was replaced and HPCI was returned to service at 1550, on March 4, 1990.

EVENT INVESTIGATION/CAUSE: A visual examination of the involved piping (1-inch, carbon steel) revealed that the through wall failure was caused by severe steam erosion at a ninety degree elbow which experiences continual discharge of high temperature, high pressure condensate to the lower pressure of the condenser. A review of plant documentation revealed that the elbow and an associated run of piping (approximately twenty feet) had been installed since plant construction. The remainder of the Unit 1 equipment drain line had been replaced by a plant modification (PM 82-137) installed in 1985.

As a result of this event, a review of the corresponding Unit 2 plant modification (PM 82-138), installed in 1984, revealed that it also had a section of piping that had not been replaced by plant modification. As part of the Erosion/corrosion inspection Program set forth in Engineering Procedure 51 (approved in January 1990 to address Generic Letter 89-08 concerns), an ultrasonic exam was performed, for the first time, during this Unit 2 outage

Licensee Event Report (LER): 50-325/1990-003-00 (Brunswick-1, BWR)

the first 45 degree elbow located downstream of the steam drain pot drain line and associated bypass line. The results were satisfactory. However, the elbow tested was upstream of the piping which had not been replaced. This elbow was chosen for inspection based on the belief that the entire run of line had been replaced by PM 82-138 and that it is expected to experience the greatest amount of turbulence and erosion. After reviewing the 1984 plant modification, it was decided to replace the same section of piping on Unit 2 which failed on Unit 1. The replacement was completed in accordance with WR/JO 90-AEXK1 prior to Unit 2 start-up. During replacement it was noted that this section of line had experienced erosion.

The Erosion/Corrosion inspection Program has scheduled an initial inspection on the Unit 1, HPCI steam pot drain line during its upcoming 1990 Refuel Outage.

The referenced plant modifications also involved replacement of the steam supply line drain pot line associated with the RCIC system. The modifications were reviewed to ensure that appropriate points were chosen for inspection under the Erosion/Corrosion Program. As a result, a 90 degree elbow was added as an additional inspection point on the RCIC steam pot drain line to assure the integrity of this piping. This 90-degree elbow on RCIC received an ultrasonic exam prior to Unit 2 start-up from the 1989/1990 outage and was found to be satisfactory.

While attempting to isolate the leak, closure of the 1-E41-F028 and P029

served to isolate the HPCI steam supply drain line from the common HPCI/RCIC steam supply drain line to the condenser. The removal of the flow path to the lower pressure of the condenser resulted in the observed increased leakage. Closing the 1-E41-F036, F037 and F054, which are upstream of the through wall, along with closure of the F028 and F029 should have stopped the steam leak. However, the leak appeared to be unchanged and it was necessary to close the HPCI steam supply isolation valves to stop the steam leakage. This indicates that the HPCI Steam Supply Drain Pot Drain Bypass valve may be leaking by its seat and WR/JO 90- AEUR1 has been initiated to investigate and repair the valve as required.

CORRECTIVE ACTIONS: The involved section of piping has been replaced on Unit 1 and on Unit 2. Future monitoring will be in accordance with the Erosion/corrosion Inspection Program.

WR/JO 90-AEUR1 has been initiated on the 1-E41-F054.[8]

EVENT ASSESSMENT: The safety significance of this event is minimal. The steam leak was discovered by plant personnel and was not of sufficient magnitude to initiate an automatic closure of the HPCI steam line valves. In addition, HPCI was available for its intended function until it was manually isolated. While HPCI was inoperable for repairs the other ECCS systems and RCIC were operable and no plant event occurred which required HPCI operation. This is considered an isolated event.

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[8] WR/JO = Work Request / Job Order

Attachment 2: Existing Pipe Failure Databases – Appendix B

PIPExp Database Summary for Month of February, 2006

Double click on icon to open file

To save file, double click on icon and "save copy as" in folder of choice

Embedded file: PIPExp-2006 Database Summary for Month of February 2006	PIPExp-2006-02.pdf

Attachment 3: Existing Pipe Failure Databases – Appendix C

Opde Web-Based User Interface

OPDE database resides on a secure server (HTTPS protocol) at NEA Headquarters

- Access to website requires user name and password
- Four security levels
    - NEA administrator
    - Clearinghouse (data input, upload/download, review, edit)
    - National Coordinator (input/edit national data, download data when new database version is available)
    - Plant operators (input national data); access restricted to owner's data
- Automated e-mail alerts when new records are available for review/validation
- Web browser sufficient for data manipulations – no need to install new software
- Independent of Access program version.

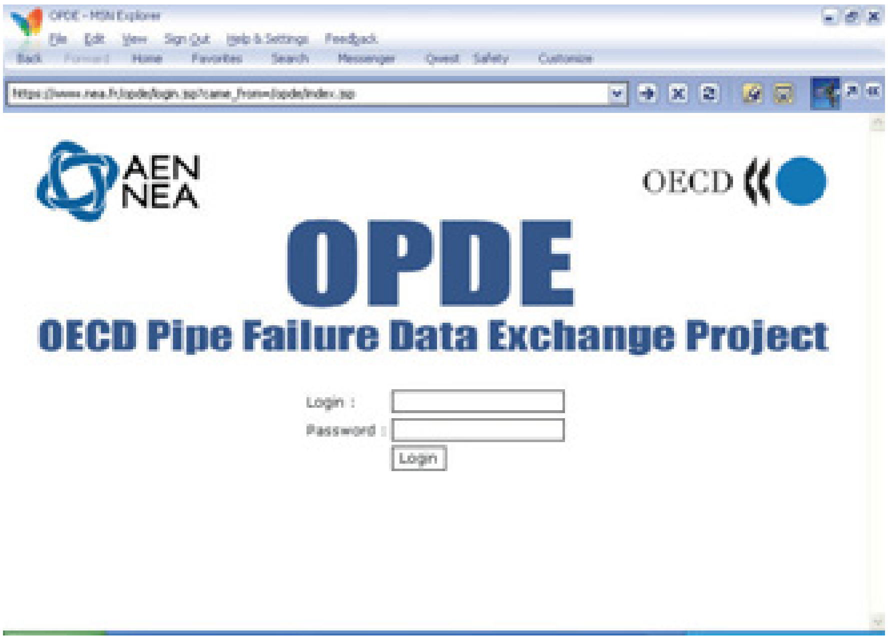
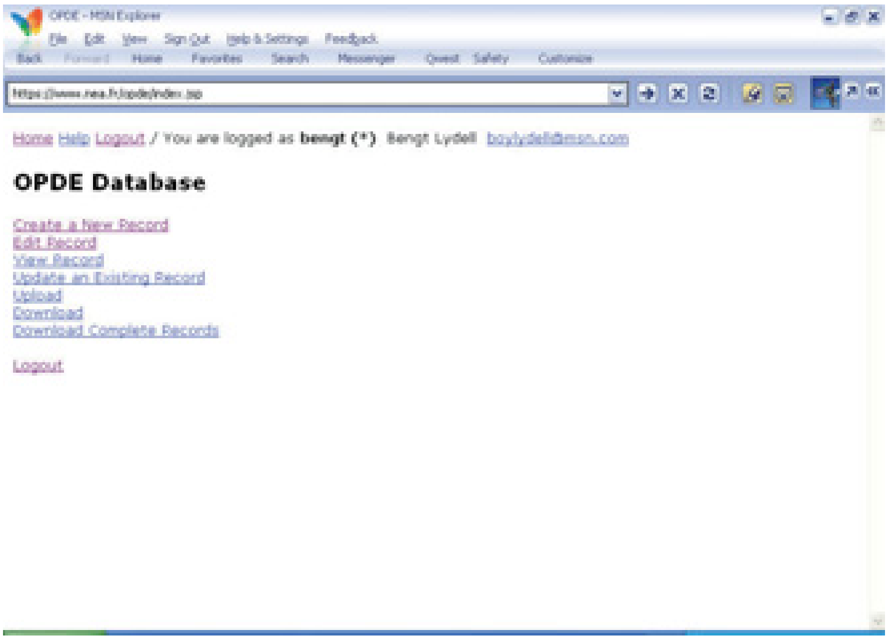


Figure 3C-1 OPDE Database Web-access



https://www.nea.fr/opde/index.jsp

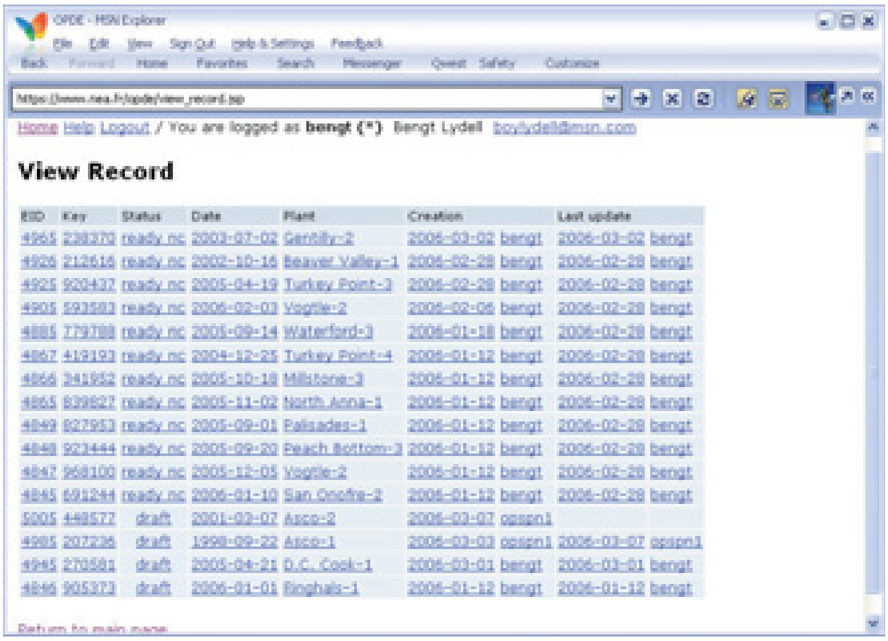
Home Help Logout / You are logged as **bengt (*)** Bengt Lydell boylydell@msn.com

OPDE Database

Create a New Record
Edit Record
View Record
Update an Existing Record
Upload
Download
Download Complete Records

Logout

Figure 3C-2 OPDE Menu



https://www.nea.fr/opde/view_record.jsp

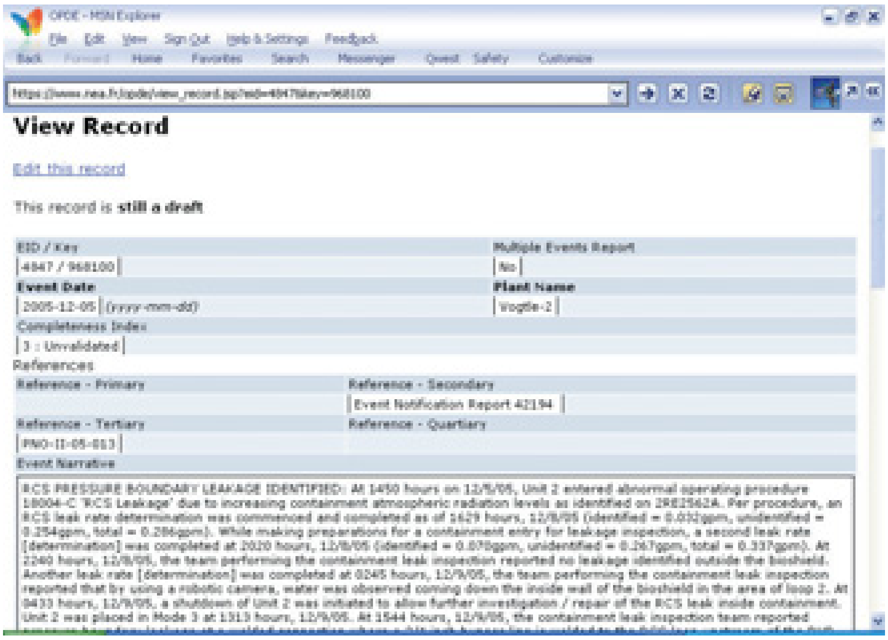
Home Help Logout / You are logged as **bengt (*)** Bengt Lydell boylydell@msn.com

View Record

EID	Key	Status	Date	Plant	Creation		Last update	
4965	238370	ready nc	2003-07-02	Gentilly-2	2006-03-02	bengt	2006-03-02	bengt
4926	212616	ready nc	2002-10-16	Beaver Valley-1	2006-02-28	bengt	2006-02-28	bengt
4925	920437	ready nc	2005-04-19	Turkey Point-3	2006-02-28	bengt	2006-02-28	bengt
4905	593583	ready nc	2006-02-03	Vogtle-2	2006-02-06	bengt	2006-02-28	bengt
4885	779788	ready nc	2005-09-14	Waterford-3	2006-01-18	bengt	2006-02-28	bengt
4867	419193	ready nc	2004-12-25	Turkey Point-4	2006-01-12	bengt	2006-02-28	bengt
4866	241952	ready nc	2005-10-18	Millstone-3	2006-01-12	bengt	2006-02-28	bengt
4865	839827	ready nc	2005-11-02	North Anna-1	2006-01-12	bengt	2006-02-28	bengt
4849	827953	ready nc	2005-09-01	Palisades-1	2006-01-12	bengt	2006-02-28	bengt
4848	923444	ready nc	2005-09-20	Peach Bottom-3	2006-01-12	bengt	2006-02-28	bengt
4847	968100	ready nc	2005-12-05	Vogtle-2	2006-01-12	bengt	2006-02-28	bengt
4845	691244	ready nc	2006-01-10	San Onofre-2	2006-01-12	bengt	2006-02-28	bengt
5005	448577	draft	2001-03-07	Asco-2	2006-03-07	opspn1		
4985	207236	draft	1998-09-22	Asco-1	2006-03-03	opspn1	2006-03-07	opspn1
4945	270581	draft	2005-04-21	D.C. Cook-1	2006-03-01	bengt	2006-03-01	bengt
4846	905373	draft	2006-01-01	Ringhals-1	2006-01-12	bengt	2006-01-12	bengt

Return to main page

Figure 3C-3 New Database Records



View Record

Edit this record

This record is **still a draft**

EID / Key	Multiple Events Report
4847 / 968100	No
Event Date	**Plant Name**
2005-12-05 (yyyy-mm-dd)	Vogtle-2
Completeness Index	
3 : Unvalidated	

References

Reference - Primary	Reference - Secondary
	Event Notification Report 42194
Reference - Tertiary	Reference - Quartiary
PNO-II-05-013	

Event Narrative

RCS PRESSURE BOUNDARY LEAKAGE IDENTIFIED: At 1450 hours on 12/5/05, Unit 2 entered abnormal operating procedure 18004-C 'RCS Leakage' due to increasing containment atmospheric radiation levels as identified on 2RE2562A. Per procedure, an RCS leak rate determination was commenced and completed as of 1629 hours, 12/5/05 (identified = 0.032gpm, unidentified = 0.254gpm, total = 0.286gpm). While making preparations for a containment entry for leakage inspection, a second leak rate [determination] was completed at 2020 hours, 12/5/05 (identified = 0.070gpm, unidentified = 0.267gpm, total = 0.337gpm). At 2240 hours, 12/5/05, the team performing the containment leak inspection reported no leakage identified outside the bioshield. Another leak rate [determination] was completed at 0245 hours, 12/6/05, the team performing the containment leak inspection reported that by using a robotic camera, water was observed coming down the inside wall of the bioshield in the area of loop 2. At 0433 hours, 12/6/05, a shutdown of Unit 2 was initiated to allow further investigation / repair of the RCS leak inside containment. Unit 2 was placed in Mode 3 at 1313 hours, 12/6/05. At 1544 hours, 12/6/05, the containment leak inspection team reported

Figure 3C-4 OPDE Data Input Form

Attachment 4: Existing Pipe Failure Databases – Appendix D
Examples of Compilations of Piping Reliability Parameters

Examples of Compilations of Piping Reliability Parameters

This appendix presents examples of how piping reliability parameters may be presented in a “Pipe Failure Data Handbook”:

Example 1 is reproduced from NUREG-1829, Appendix D [2.27]. It represents the type of parameters used in LOCA frequency assessment or RI-ISI program development. The derived failure rates are conditional on location within a Reactor Recirculation System (313). These location-dependencies are implicitly representative of different weld residual stresses.

Example 2 is adapted from EPRI 1012302 [2.9]. It represents the type of parameters used in internal flooding PSA. The derived failure rates are for carbon steel raw water piping and are conditional on water quality.

Example 3 is reproduced from Appendix A, Attachment 3 of the October 2005 “Kewaunee Power Station Flooding Significance Determination Process Risk Assessment Report.” This document includes reliability parameters for use in High Energy Line Break (HELB) analysis.

Example 1
Posterior BWR-Specific Weld Failure Rate Distributions [2.27]

System	Pipe Size	Weld Configuration	Failure Rate Uncertainty Distribution Parameters [(≤TS Leak)/Weld-yr]			
			Mean	5%-tile	50%-tile	95%-tile
RR (313)	DN300	Elbow-to-pipe	4.32E-05	8.48E-06	3.17E-05	1.16E-04
		Nozzle-to-safe-end	4.38E-05	5.52E-06	2.72E-05	1.36E-04
		Pipe-to-safe-end	2.99E-05	2.98E-06	1.70E-05	9.64E-05
		Pipe-to-sweepolet	3.14E-05	2.80E-06	1.71E-05	1.06E-04
		Pipe-to-reducer	7.82E-05	5.71E-06	3.97E-05	2.77E-04
RR (313)	DN550	Pipe-to-end-cap	1.54E-04	2.28E-05	1.01E-04	4.52E-04
		Pipe-to-cross	4.24E-05	4.38E-06	2.47E-05	1.37E-04
		Pipe-to-sweepolet	7.37E-05	7.02E-06	4.09E-05	2.40E-04
RR (313)	DN700	Pipe-to-elbow	8.52E-05	1.59E-05	6.07E-05	2.33E-04
		Nozzle-to-safe-end	6.55E-05	5.95E-06	3.61E-05	2.15E-04
		Pipe-to-safe-end	1.44E-04	2.11E-05	9.36E-05	4.28E-04
		Pipe-to-valve	5.96E-05	7.68E-06	3.75E-05	1.84E-04
		Pipe-to-pump	8.36E-05	8.68E-06	4.85E-05	2.71E-04
		Pipe-to-tee	5.78E-05	5.06E-06	3.13E-05	1.96E-04
		Pipe-to-pipe	1.29E-05	5.74E-07	5.25E-06	4.78E-05
		Pipe-to-cross	3.86E-05	7.89E-07	1.08E-05	1.50E-04
		Reducer-to-cross	3.86E-05	7.89E-07	1.08E-05	1.50E-04

Example 2
PWR-Specific Service Water Pipe Failure Parameters
Lake Water Service Environment [2.3]

Component Boundary & Size		Failure Rate Uncertainty Distribution			
Type	Diameter [inch]	Mean	5th Percentile	Median	95th Percentile
Base Metal [1/ft.yr]	∅ ≤ 2”	1.15E-04	7.15E-05	1.07E-04	2.14E-04
	2” < ∅ ≤ 4”	1.83E-04	1.12E-04	1.70E-04	3.38E-04
	4” < ∅ ≤ 10”	3.20E-05	1.94E-05	2.96E-05	5.89E-05
	∅ > 10”	5.56E-06	3.30E-06	5.14E-06	1.02E-05

Component Boundary & Size		Spray Frequency Uncertainty Distribution			
Type	Diameter [inch]	Mean	5th Percentile	Median	95th Percentile
Base Metal [1/ft.yr]	∅ ≤ 2”	4.40E-06	2.51E-06	4.04E-06	8.21E-06
	2” < ∅ ≤ 4”	7.01E-06	3.90E-06	6.46E-06	1.29E-05
	4” < ∅ ≤ 10”	1.22E-06	6.65E-07	1.13E-06	2.23E-06
	∅ > 10”	2.13E-07	1.13E-07	1.95E-07	3.94E-07

Example 3
Reliability Parameters Applicable to Non-Code High Pressure Steam Line Piping

Analysis Case	Description	Uncertainty Distribution			
		Mean [1/ft.yr]	5th Percentile	Median	95th Percentile
KNPP19	EBS1: HP Steam Pipe Failure Rate given post 1988 data	3.25E-06	1.62E-06	2.94E-06	6.01E-06
	EBS1: HP Steam Pipe Rupture Frequency given post 1988 data	3.03E-08	1.16E-08	2.64E-08	6.28E-08
KNPP20	EBS2: HP Steam Pipe Failure Rate given post 1988 data	1.16E-06	3.33E-07	9.37E-07	2.75E-06
	EBS2: HP Steam Pipe Rupture Frequency given post 1988 data	8.90E-09	2.01E-09	6.78E-09	2.26E-08
KNPP21	EBS1: HP Steam Pipe Failure Rate given 1970-1988 data	1.60E-05	9.34E-06	1.47E-05	2.94E-05
	EBS1: HP Steam Pipe Rupture Frequency given 1970-1988 data	1.49E-07	6.40E-08	1.34E-07	2.90E-07
KNPP22	EBS2: HP Steam Pipe Failure Rate given 1970-1988 data	2.50E-05	1.47E-05	2.30E-05	4.60E-05
	EBS2: HP Steam Pipe Rupture Frequency given 1970-1988 data	1.91E-07	7.72E-08	1.70E-07	3.78E-07
KNPP23	EBS1: HP Steam Pipe Failure Rate with FAC events screened out	1.74E-07	1.23E-08	8.44E-08	5.93E-07
	EBS1: HP Steam Pipe Rupture Frequency with FAC events screened out	1.64E-09	9.98E-11	7.52E-10	5.71E-09
KNPP24	EBS2: HP Steam Pipe Failure Rate with FAC events screened out	2.36E-07	1.53E-08	1.12E-07	8.29E-07
	EBS2: HP Steam Pipe Rupture Frequency with FAC events screened out	1.80E-09	9.99E-11	8.01E-10	6.49E-09

Notes:

- EBS = Equivalent Break Size
- EBS1: 50 < DN ≤ 150 mm
- EBS 2: DN > 150 mm
- KNPP19 & KNPP20 assumes augmented FAC inspections and implementation of EPRI-CHECWORKS program for predicting and monitoring pipe wall wear rates
- KNPP21 & 22 assumes no FAC inspections
- KNPP23 & 24 assumes all FAC-susceptible piping replaced with FAC-resistant material (e.g., stainless steel.
- Appendix A, Attachment 3 of the October 2005 "Kewaunee Power Station Flooding Significance Determination Process Risk Assessment Report" is available from NRC-ADAMS (Accession Number ML053180483) at www.nrc.gov

Attachment 5: Database Users – Appendix A

Instructions for the questionnaire

A set of questions is given below regarding the piping reliability handbook (R-book). For each question it is expected that as detailed answer as possible is given and that the answer is motivated as much as possible.

If a question is considered to be of no or minor importance in your field of expertise, then please give that as an answer instead of leaving a question blank.

It is important to have in mind when the questionnaire is answered that the handbook is focused on giving reliability data for piping components, e.g. failure rate and failure probability.

When responding, please use the designated space below or provide a separate Word file with your response.

A. Questions regarding handbook applicability

- In what area in your field of expertise do you see that handbook can be useful, i.e. what are you expectations in a piping component reliability handbook?

- Role of handbook in validation of PFM results. It is often proposed that service data should be used as one form of validation. In what form should service data be presented to support validation and what particular evaluation steps are involved a validation?

- What specific sets of parameters are required to support your application(s)? Please refer to Appendix 2 for a list of proposed parameters that may be included. In Appendix 2 a separate column is given for you where you can make remarks for each parameter.

B. Questions regarding level of detail

- Is it necessary that the handbook contains failure data for different leak rates and if so what leak rates?

- Does the handbook need to contain failure data for initial defects, i.e. cracks, that does not give any leakage and if so is it possible to define a crack size for different materials?

- Does the handbook need to include uncertainty distributions?

- How much information about active failure mechanisms does the handbook need to include (no information, summary information for each system or detailed information for each component)?

- How site specific should the data in the handbook be in order to fulfill your needs?

- What kind of piping components is most important to be included in the handbook (welds in piping, valves, pumps, T-joints, bends, straight piping without welds, tanks (high/low pressure), etc.)?

C. Questions regarding layout and updating

- What format should the handbook be published in (printed on paper, database on CD, software that is used on the OPDE database, other)?

- If the handbook is delivered in paper format or as a database, how often is it necessary to update the handbook with new data for it to be useful in your field of expertise?

- In your opinion, what structure should the handbook have with respect to its contents? Should it be divided according to systems or according to material data and operating conditions. Perhaps a completely different “classification system” shall be used in order to fulfill your requirements (e.g. Safety Class).

D. Questions regarding data background

- How much information about the data background is necessary to be included in the handbook (having in mind that no more information than what exist in the OPDE database can be included and that is not meaningful or possible to repeat all information already in the OPDE database)?

Data background can be information about material type and grade, operating conditions, residual stresses etc.

- In defining component and system boundaries, should the handbook include line drawings, or other type of graphical representations?

Attachment 6: Database Users – Appendix B

Scope of Data Handbook

The table below summarizes the types of input parameters to piping reliability analysis. The listed parameters have been used extensively in PSA applications and RI-ISI program development efforts. The proposed Handbook may address all of the listed parameters or any subset of listed parameters.

TABLE 6B-1

EXAMPLES OF PIPING RELIABILITY PARAMETERS TO BE INCLUDED IN PROPOSED DATA HANDBOOK

SYMBOL	**DESCRIPTION**	**DATA SOURCE & STRATEGY FOR ESTIMATION**	**INTENDED APPLICATION & EXTENT OF DEMONSTRATED DB APPLICATION**	**REMARK WHEN ANSWERING QUESTIONNAIRE**
λ_{ik}	*Failure rate of pipe component "i" due to degradation or damage mechanism "k"*	*The failure rate is estimated directly using TTF data or indirectly via an OPDE database query to obtain a failure count over a certain observation period and for a certain piping component population*	*PSA (LOCA frequency, internal flooding, HELB frequency) and risk-informed applications (RI-ISI). Extensive insights available from past DB applications*	
TTF	*Time to Failure*	*Obtained directly via OPDE database query*	*Can be used in predictive reliability analysis to determine pipe replacement intervals. Hazard plotting techniques (or Weibull analysis) use TTF data directly to estimate reliability parameters. This analysis approach has been used extensively to analyze IGSCC data and raw water pipe failure data*	
$P_{ik}\{R_x\|F\}$	*Conditional pipe failure probability. Index "x" refers to mode (or magnitude) of failure as defined by through-wall peak flow rate threshold value*	*Obtained directly via OPDE database query, Bayesian estimation strategy, PFM (SRM), or expert elicitation*	*PSA (LOCA frequency, internal flooding, HELB frequency) and risk-informed applications (RI-ISI). Extensive insights available from past DB applications*	

TABLE 6B-1
EXAMPLES OF PIPING RELIABILITY PARAMETERS TO BE INCLUDED IN PROPOSED DATA HANDBOOK

SYMBOL	**DESCRIPTION**	**DATA SOURCE & STRATEGY FOR ESTIMATION**	**INTENDED APPLICATION & EXTENT OF DEMONSTRATED DB APPLICATION**	**REMARK WHEN ANSWERING QUESTIONNAIRE**
I_{ik}	*Structural integrity management factor for component "i" and damage or degradation mechanism "k". This is an adjustment factor to account for variable integrity management strategies such as leak detection, volumetric NDE, etc, that might be different than the components included in a pipe failure database*	*Obtained through application of the Markov model of piping reliability (iterative analysis)*	*Extensive insights from past application of the Markov model*	
n_{ik}	*Number of failures (all modes, including cracks, leaks and significant structural failures)*	*Obtained directly via OPDE database query*	*PSA (LOCA frequency, internal flooding, HELB frequency) and risk-informed applications (RI-ISI).* *Extensive insights available from past DB applications*	
f_{ik}	*The fraction of number of components or type "i" that are susceptible to failure from degradation or damage mechanism "k" for conditional failure rates given susceptibility to "k"; this parameter is set to 1 for unconditional failure rates*	*Obtained directly via OPDE database query, or from 'Degradation Mechanism Analysis" tasks of RI-ISI program development projects, or via engineering judgment*	*RI-ISI program development (e.g., Δ-risk evaluations)*	

TABLE 6B-1
EXAMPLES OF PIPING RELIABILITY PARAMETERS TO BE INCLUDED IN PROPOSED DATA HANDBOOK

SYMBOL	**DESCRIPTION**	**DATA SOURCE & STRATEGY FOR ESTIMATION**	**INTENDED APPLICATION & EXTENT OF DEMONSTRATED DB APPLICATION**	**REMARK WHEN ANSWERING QUESTIONNAIRE**
N_i	*The number of components per reactor year (or calendar year) that provided the observed pipe failures for component "i"*	*Input from piping system design reviews (size, weld counts, pipe lengths, and material data) specific to an application. Required for estimation of* λ_{ik}	*Application-specific piping population databases already exist but most of these are not in the public domain, however.*	
T_i	*Total exposure time over which failures were collected for pipe component "i"; normally expressed in terms of reactor years (or calendar years)*	*Obtained directly via OPDE database query. Required for estimation of* λ_{ik}		
ϕ	*Occurrence rate of a flaw (non through-wall)*	*Obtained directly via OPDE database query, or can be estimated as a multiple of the rate of leaks based on ISI experience*	*Input to Markov model of piping reliability*	
λ_S	*Occurrence rate of leak from a no-flaw state*	*Service data for leaks and reasoning that leaks without a pre-existing flaw are only possible for selected damage mechanism from severe loading*	*Input to Markov model of piping reliability*	
λ_C	*Occurrence rate of a leak from a flaw state*	*Service data for leaks conditioned for existing conditions for selected degradation mechanisms*	*Input to Markov model of piping reliability*	

TABLE 6B-1

EXAMPLES OF PIPING RELIABILITY PARAMETERS TO BE INCLUDED IN PROPOSED DATA HANDBOOK

SYMBOL	**DESCRIPTION**	**DATA SOURCE & STRATEGY FOR ESTIMATION**	**INTENDED APPLICATION & EXTENT OF DEMONSTRATED DB APPLICATION**	**REMARK WHEN ANSWERING QUESTIONNAIRE**
ρ_S	*Occurrence rate of a "structural failure" from a no-flaw state*	*Service data for "structural failure" and reasoning that "structural flaws" without a pre-existing degradation is only possible for selected damage mechanisms and system-material combinations*	*Input to Markov model of piping reliability*	
ρ_C	*Occurrence rate of a through-wall leak from a flaw (non through-wall) state*	*Service data for leaks conditioned for existing conditions for selected degradation and damage mechanisms*	*Input to Markov model of piping reliability*	
ρ_F	*Occurrence rate of "structural failure" from a through-wall flaw state*	*Estimates of physical degradation rates and times to failure converted to equivalent failure rates, or estimates of water hammer challenges to the system in degraded state.*	*Input to Markov model of piping reliability*	
μ	*Repair rate via leak detection* $\mu = \frac{P_{LD}}{(T_{LI} + T_R)}$	*Model of equation for* μ*, and estimates of* P_{LD}, T_{LI}, T_R	*Input to Markov model of piping reliability*	

TABLE 6B-1
EXAMPLES OF PIPING RELIABILITY PARAMETERS TO BE INCLUDED IN PROPOSED DATA HANDBOOK

SYMBOL	**DESCRIPTION**	**DATA SOURCE & STRATEGY FOR ESTIMATION**	**INTENDED APPLICATION & EXTENT OF DEMONSTRATED DB APPLICATION**	**REMARK WHEN ANSWERING QUESTIONNAIRE**
P_{LD}	*Probability that a through-wall flaw is detected given leak detection or leak inspection*	*Estimate based on presence of leak detection system, technical specification requirements and frequency of leak inspection. DB generates qualitative insights. Reliability of leak detection systems is high. Quantitative estimate based on expert judgment*	*Input to Markov model of piping reliability; supports sensitivity analyses to address impact of different assumptions on piping reliability*	
T_{LI}	*Mean time between inspections for through-wall flaw*	*Estimate based on method of leak detection; ranges from immediate to frequency of routine inspections for leaks or ASME Section XI required system leak tests*	*Input to Markov model of piping reliability*	
ω	*Repair rate via NDE* $\omega = \frac{P_I P_{FD}}{(T_{FI} + T_R)}$	*Model of equation for* ω*, and estimates of* P_I, P_{FD}, T_{FI}, T_R	*Input to Markov model of piping reliability*	
P_I	*Probability that a flaw will be inspected (index “I”) per inspection interval*	*Estimate based on specific inspection strategy; usually done separate for ASME Section XI (or equivalent) and RI-ISI programs*	*Input to Markov model of piping reliability*	
P_{FD}	*Probability that a flaw will be detected given that the weld or pipe section is subjected to NDE. Also referred to as POD.*	*Estimate based on NDE reliability performance data and difficulty of inspection for particular inspection site. OPDE provides qualitative insights about NDE reliability*	*Input to Markov model of piping reliability*	

TABLE 6B-1
EXAMPLES OF PIPING RELIABILITY PARAMETERS TO BE INCLUDED IN PROPOSED DATA HANDBOOK

SYMBOL	**DESCRIPTION**	**DATA SOURCE & STRATEGY FOR ESTIMATION**	**INTENDED APPLICATION & EXTENT OF DEMONSTRATED DB APPLICATION**	**REMARK WHEN ANSWERING QUESTIONNAIRE**
T_{FI}	*Mean time between inspections*	*Based on applicable inspection program; can be "never" or 10 years for ASME XI piping*	*Input to Markov model of piping reliability*	
T_R	*Mean time to repair once detected*	*Obtained directly via OPDE query. The mean repair time includes time tag out, isolate, prepare, repair, leak test and tag-in*	*Input to Markov model of piping reliability*	

Attachment 7: Piping Population Database – Appendix A

Instruktioner för frågeformuläret

En uppsättning frågor ges i formuläret vars syfte är att utreda på vilket sätt som information om rörkomponenter är lagrade hos respektive kraftbolag. För varje fråga förväntas att svar ges så detaljerat som möjligt.

När svar ges så vänligen använd det utrymme som ges i samband med respektive fråga eller bifoga svar i separat dokument. Observera att Ni inte är begränsade till att svara på endast två rader, skriv så utförligt som möjligt på så många rader som Ni anser Er behöva.

Flera av frågorna kan vara snarlika och om Ni anser att Ni redan besvarat en fråga så vänligen hänvisa till det svar där informationen ges.

Sist i frågelistan ges några frågor som mer rör vilka drifterfarenheter som Ni har och hur informationen sparas – i databaser eller på annat sätt.

A. Generella frågor

Nedan ges frågor av generell natur angående lagring av data om rörkomponenter.

- Vänligen ge en övergripande beskrivning av hur data om rörkomponenter är hanterade/lagrade hos Ert kraftbolag (databas eller annat medium, t.ex. om man måste gå in i isometriritningar) och i vilken utsträckning som det är möjligt att få ut information om olika rörkomponenter, d.v.s. är det möjligt att extrahera data om olika svetsar, rörböjar, T-stycken etc. Antag t.ex. att man är intresserad av att få ut data om samtliga rörkomponenter som sitter i en viss del av ett system, är det i så fall möjligt att definiera en del av ett system och då få ut information om antal och typ av rörkomponenter?

- Är det skillnad på hur detaljerad informationen är baserat på vilken kvalitetsklass (säkerhetsklass) som komponenten i sig tillhör?

- Är det skillnad på hur detaljerad informationen är baserat på om komponenten sitter innanför eller utanför inneslutningen?

- Går det att få ut information om rörkomponenter och dess systemtillhörighet?

- Vilka är de största begränsningarna som Ni har i era databaser (enligt Er uppfattning) som gör att Ni tror att det blir svårt att sammanställa information om rörkomponenter (svetsar, rörböjar, T-stycken etc.) vid en eventuell kartläggning av olika system?

B. Attribut

Med ett attribut avses termer som beskriver en rörkomponents design/konstruktionsdata, t.ex. i form av kemisk sammansättning. Ett attribut kan inte ändras utan att rörkomponenten i fråga byts ut, t.ex. genom att byta ut kolstål mot rostfritt stål.

- I vilken utsträckning är det möjligt att få ut information om rörkomponenters design i form av kemisk sammansättning, dimension, godstjocklek, längd etc. Kan detta tas automatiskt ur någon databas eller måste det tas manuellt från ritningar.

- Vilka begränsningar finns det avseende tillgänglig information, d.v.s. är det någon i Er mening viktig parameter som är av betydelse för tillförlitligheten hos en komponent som inte är möjlig att få ut? Hur får man i så fall gå tillväga?

- Hur detaljerad kunskap finns dokumenterad när det gäller genomförda svetsingrepp och reparationer (när har ingrepp gjorts, av vilken orsak samt effekt av ingreppet)?

- Finns information lagrad om olika komponenters livslängder (när är eventuella rörbyten eller andra modifieringar genomförda)?

C. Exponeringsterm

Med exponeringsterm avses den “miljö” som en rörkomponent utsätts för, t.ex. i form av tryck, temperatur, flöde, innehållande medium (t.ex. vatten eller ånga), om vätgasdosering (HWC) nyttjas eller inte, etc.

- Vilken information avseende driftbetingelser enligt ovan går det att få ut om olika rörkomponenter?

- Vilka begränsningar finns det avseende tillgänglig information, d.v.s. är det någon i Er mening viktig parameter som är av betydelse för tillförlitligheten hos en komponent som inte är möjlig att få ut? Hur får man i så fall gå tillväga?

- Finns information lagrad avseende drifttid på olika system, såväl driftsatta system som system i standby avses?

D. Tillgänglighet på information

- I vilken utsträckning kan den information som eftersöks göras tillgänglig till tredje part för att eventuellt gå vidare med att ta fram tillförlitlighetsdata om rörkomponenter?

E. Drifterfarenheter

- Vad är Er erfarenhet avseende inverkan av och kunskaper om vibrationer och samverkan mellan olika degraderingsmekanismer?

- Finns information lagrad om tidigare genomförd provning och eventuell kunskap om provningseffektivitet. På vilket sätt lagras denna information i så fall?

Attachment 8: R-Book project – Scope of Phase 2 – Appendix A

Example of Piping Population Data

ID	Component ID	Line Number	Weld Number	Plant	System	Component	NPS	Iso Number	P&ID Number	Building	Location	Code Class	Category	Mat_spec1	Mat_spec2	Description	Pipe Schedule	Wall Thickness
1	1CS-01-01	1CS02AA-8"	01	A	CS - Containment Spray (PWR)	WELD	8	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA182 GR.F304	SA403 GR.WP304	PUMP 1CS01PA - ELBOW	40S	0.322"
2	1CS-01-02	1CS02AA-8"	02	A	CS - Containment Spray (PWR)	WELD	8	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW - 10"X8" REDUCER	40S	0.322"
3	1CS-01-03	1CS02AA-10"	03	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	10"X8" REDUCER - ELBOW	40S	0.365"
4	1CS-01-04	1CS02AA-10"	04	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW LONG SEAM	40S	0.365"
5	1CS-01-05	1CS02AA-10"	05	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW LONG SEAM	40S	0.365"
6	1CS-01-06	1CS02AA-10"	06	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA312 GR.TP304	ELBOW - PIPE	40S	0.365"
7	1CS-01-06A	1CS02AA-10"	06A	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
8	1CS-01-06B	1CS02AA-10"	06B	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
9	1CS-01-07	1CS02AA-10"	07	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA182 GR.F304	PIPE - VALVE 1CS003A FLANGE	40S	0.365"
10	1CS-01-08	1CS02AA-10"	08	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA182 GR.F304	SA351 GR.CF8	VLV 1CS003A FLNG - VLV 1CS004A	40S	0.365"
11	1CS-01-09	1CS02AA-10"	09	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA351 GR.CF8	SA403 GR.WP304	VALVE 1CS004A - ELBOW	40S	0.365"
12	1CS-01-10	1CS02AA-10"	10	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW LONG SEAM	40S	0.365"
13	1CS-01-11	1CS02AA-10"	11	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW LONG SEAM	40S	0.365"
14	1CS-01-12	1CS02AA-10"	12	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA312 GR.TP304	ELBOW - PIPE	40S	0.365"
15	1CS-01-13	1CS02AA-10"	13	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
16	1CS-01-14	1CS02AA-10"	14	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
17	1CS-01-15	1CS02AA-10"	15	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE - PIPE	40S	0.365"
18	1CS-01-16	1CS02AA-10"	16	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
19	1CS-01-17	1CS02AA-10"	17	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
20	1CS-01-18	1CS02AA-10"	18	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA403 GR.WP304	PIPE - ELBOW	40S	0.365"
21	1CS-01-19	1CS02AA-10"	19	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW LONG SEAM	40S	0.365"
22	1CS-01-20	1CS02AA-10"	20	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA403 GR.WP304	ELBOW LONG SEAM	40S	0.365"
23	1CS-01-21	1CS02AA-10"	21	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA403 GR.WP304	SA312 GR.TP304	ELBOW - PIPE	40S	0.365"
24	1CS-01-22	1CS02AA-10"	22	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"
25	1CS-01-23	1CS02AA-10"	23	A	CS - Containment Spray (PWR)	WELD	10	1CS-01	M-046 S01A	AUX BLD	CS PUMP ROOM 1A	2	C-F-1	SA312 GR.TP304	SA312 GR.TP304	PIPE LONG SEAM	40S	0.365"

Table 8A-1 Example of piping population data

Attachment 9: R-Book project – Scope of Phase 2 – Appendix B

R-Book form

System	***Event Population***	
	Peak Through-wall Leak/Flow Rate [kg/s]	***Event Count***
313 – Reactor Recirculation System	$0 < \nu \leq 6.3 \times 10^{-2}$	*130*
	$6.3 \times 10^{-2} < \nu \leq 3.2 \times 10^{-1}$	*11*
	$3.2 \times 10^{-1} < \nu \leq 6.3 \times 10^{-1}$	*0*
	$6.3 \times 10^{-1} < \nu \leq 3.2$	*0*
	$\nu > 3.2$	*1 (a)*
331 – Reactor Water Clean-up	$0 < \nu \leq 6.3 \times 10^{-2}$	*81*
	$6.3 \times 10^{-2} < \nu \leq 3.2 \times 10^{-1}$	*0*
	$3.2 \times 10^{-1} < \nu \leq 6.3 \times 10^{-1}$	*0*
	$6.3 \times 10^{-1} < \nu \leq 3.2$	*0*
	$\nu > 3.2$	*4 (b)*

Notes:

a. *EID #5172; severed, temporary instrument line (DN15). The event occurred during the commissioning of the plant in question.*
b. *Three of these events involved small-diameter piping (≤ DN25), one event (EID #1855) occurred in DN150 piping*

Table 9B-1 BWR-1 Observed Peak Through-wall Leak/Flow Rates

Abbreviations & Acronyms

DM	Dissimilar metal
NPS	Nominal Pipe Size [inch]
NTWC	Non-through-wall crack
RPV	Reactor Pressure vessel
TWC	Through-wall crack

Damage / Degradation Mechanisms

COR	Corrosion
D&C	Design & Construction Error
E-C	Erosion-cavitation
E/C	Erosion-corrosion
FAC	Flow-accelerated corrosion
SCC	Stress corrosion cracking
TF	Thermal fatigue

Attribute / Degradation Mechanism			*Event Population*										
			1970-79		*1980-89*		*1990-99*		*2000-07*		*1970-2007*		
			NTWC	*TWC*	*NTWC*	*TWC*	*NTWC*	*TWC*	*NTWC*	*TWC*	*NTWC*	*TWC*	*All*
Worldwide Data	*∅ > 250*	*COR*	--	--	--	--	--	--	--	--	--	--	--
		D&C	0	0	0	5	0	7	0	2	0	14	14
		E-C	--	--	--	--	--	--	--	--	--	--	--
		E/C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		FAC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		SCC	0	0	382	44	67	1	21	2	470	47	517
		TF	0	0	0	0	0	0	0	0	0	0	0
		VF	0	0	0	0	0	0	0	0	0	0	0
	50 < ∅ ≤ 250	*COR*	--	--	--	--	--	--	--	--	--	--	--
		D&C	1	0	0	3	0	1	0	0	1	4	5
		E-C	--	--	--	--	--	--	--	--	--	--	--
		E/C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		FAC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		SCC	16	11	35	6	59	2	0	0	110	19	129
		TF	--	--	--	--	--	--	--	--	--	--	--
		VF	0	0	0	1	0	1	0	1	0	3	3
	∅ ≤ 50	*COR*	--	--	--	--	--	--	--	--	--	--	--
		D&C	0	1	0	5	0	1	0	0	0	7	7
		E-C	--	--	--	--	--	--	--	--	--	--	--
		E/C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		FAC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		SCC	0	3	2	3	1	3	1	1	4	10	14
		TF	0	0	0	1	0	1	0	0	0	2	2
		VF	0	11	0	17	0	10	1	7	1	45	46
	All sizes	*All Mechanisms*	17	26	424	80	134	20	23	13	598	139	737
	Reactor-years		379		629		854		696		2558 (through 9/30/07)		

Pipe material (typical): Austenitic stainless steel or stabilized austenitic stainless steel (German BWR plants), DM RPV-nozzle-to-safe-end welds.

BWR water chemistry: All plants operate with a carefully monitored and controlled primary water chemistry program, the objective of which is to minimize presence of chemical impurities and to avoid chemical excursions. The details of the water chemistry program vary from plant-to-plant; some plants operate with hydrogen water chemistry (HWC) and others operate with HWC and noble metal chemical application (NMCA) to further the resistance to IGSCC. See BWRVIP-79 (EPRI TR-103515R2, or later editions) for further details.

Integrity management program: The Reactor Recirculation piping system is subject to periodic NDE as defined in the in-service inspection program (e.g., ASME Section XI or RI-ISI program). Various integrity management initiatives or programs were also implemented in the mid-1980s in response to IGSCC inspection findings. For further details, see the following documents: NUREG-0313 Rev. 2, U.S. NRC Generic Letter 88-01, and NUREG-1719.

Table 9B-2 BWR-2a Pipe Failure Data for System 313 (Reactor Recirculation System)

Attribute / Degradation Mechanism			***Event Population***										
			1970-79		***1980-89***		***1990-99***		***2000-07***		***1970-2007***		
			NTWC	***TWC***	***NTWC***	***TWC***	***NTWC***	***TWC***	***NTWC***	***TWC***	***NTWC***	***TWC***	***All***
Nordic Data	*∅ > 250*	*COR*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		D&C	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
		E-C	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		E/C	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		FAC	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		SCC	*0*	*0*	*0*	*0*	*11*	*0*	*0*	*0*	*11*	*0*	*11*
		TF	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
		VF	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	50 < ∅ ≤ 250	*COR*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		D&C	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
		E-C	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		E/C	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		FAC	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		SCC	*0*	*0*	*0*	*1*	*8*	*0*	*0*	*0*	*8*	*1*	*9*
		TF	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		VF	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	∅ ≤ 50	*COR*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		D&C	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
		E-C	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*	*--*
		E/C	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		FAC	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
		SCC	*0*	*0*	*0*	*0*	*0*	*2*	*0*	*0*	*0*	*2*	*2*
		TF	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
		VF	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	All sizes	*All Mechanisms*	*0*	*0*	*0*	*1*	*19*	*2*	*0*	*0*	*19*	*3*	*22*
	Reactor-years		*29*		*50*		*50*		*29*		*158 (through 9/30/07)*		

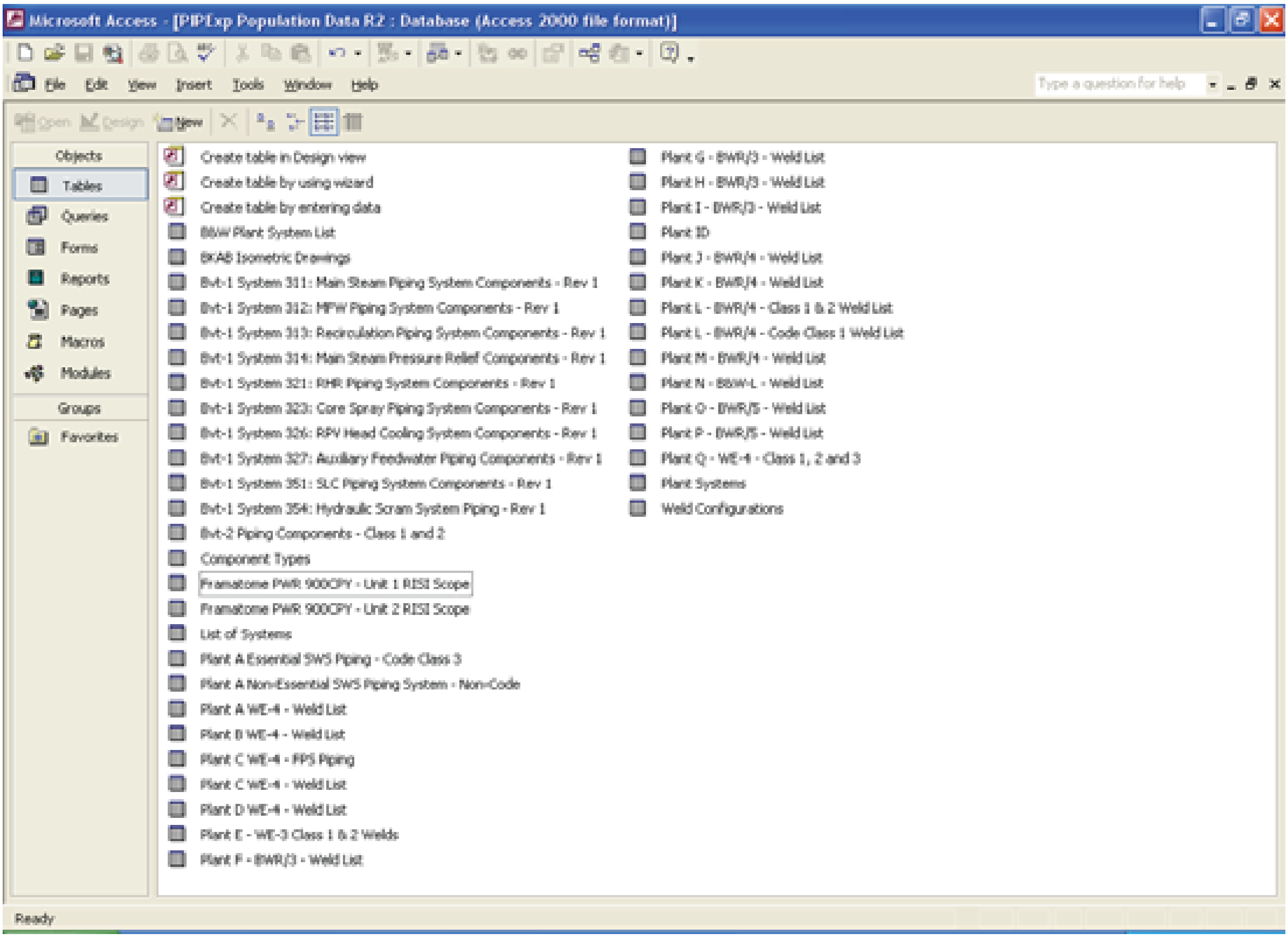
Notes:

- *This table applies to B1/B2, O1/O2, R1 (external Reactor Recirculation plants). The B1/B2 reactors have been permanently shutdown (30-Nov-99 and 05-May-05, respectively). Excluded from this table are F1/F2/F3 and Olk-1/Olk-2 (internal recirculation reactors)*

Table 9B-2 BWR-2a Pipe Failure Data for System 313 (Reactor Recirculation System)

Attachment 10: R-Book project – Scope of Phase 2 – Appendix C

Existing piping population data



Create table in Design view
Create table by using wizard
Create table by entering data
B&W Plant System List
BKAB Isometric Drawings
Bvt-1 System 311: Main Steam Piping System Components - Rev 1
Bvt-1 System 312: MFW Piping System Components - Rev 1
Bvt-1 System 313: Recirculation Piping System Components - Rev 1
Bvt-1 System 314: Main Steam Pressure Relief Components - Rev 1
Bvt-1 System 321: RHR Piping System Components - Rev 1
Bvt-1 System 323: Core Spray Piping System Components - Rev 1
Bvt-1 System 326: RPV Head Cooling System Components - Rev 1
Bvt-1 System 327: Auxiliary Feedwater Piping Components - Rev 1
Bvt-1 System 351: SLC Piping System Components - Rev 1
Bvt-1 System 354: Hydraulic Scram System Piping - Rev 1
Bvt-2 Piping Components - Class 1 and 2
Component Types
Framatome PWR 900CPY - Unit 1 RISI Scope
Framatome PWR 900CPY - Unit 2 RISI Scope
List of Systems
Plant A Essential SWS Piping - Code Class 3
Plant A Non-Essential SWS Piping System - Non-Code
Plant A WE-4 - Weld List
Plant B WE-4 - Weld List
Plant C WE-4 - FPS Piping
Plant C WE-4 - Weld List
Plant D WE-4 - Weld List
Plant E - WE-3 Class 1 & 2 Welds
Plant F - BWR/3 - Weld List
Plant G - BWR/3 - Weld List
Plant H - BWR/3 - Weld List
Plant I - BWR/3 - Weld List
Plant ID
Plant J - BWR/4 - Weld List
Plant K - BWR/4 - Weld List
Plant L - BWR/4 - Class 1 & 2 Weld List
Plant L - BWR/4 - Code Class 1 Weld List
Plant M - BWR/4 - Weld List
Plant N - B&W-L - Weld List
Plant O - BWR/5 - Weld List
Plant P - BWR/5 - Weld List
Plant Q - WE-4 - Class 1, 2 and 3
Plant Systems
Weld Configurations

Figure 10C-1 Piping Component Population Data www.ski.se

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