SKI Technical Report 95:59

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PSA LOCA Data base
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PSA LOCA Data base
Review of Methods for LOCA Evaluation since the WASH-1400

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Disclaimer: This report concerns a study which has been conducted for the Swedish Nuclear Power Inspectorate (SKI). The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the SKI.

SUMMARY

1. Background

Reflecting on older analysis practices, passive components failures seldom receive explicit treatment in PSA. to expand the usefulness of PSA and to raise the realism in plant and system models the Swedish Nuclear power Inspectorate has undertaken a multi-year research project to establish a comprehensive passive components database, validate failure rate parameter estimates and model framework for enhancement of integration passive components failures in existing PSAs. Phase 1 of the project (completed in Spring 1995) produced a relational data base on worldwide piping system failure events in nuclear and chemical industries. Approximately 2300 failure events allowed for data exploration in Phase 2 to develop a sound basis for PSA treatment of piping system failure. In addition, a comprehensive review of the current consideration of LOCA in PSA and a comprehensive review of all available literature in this area was undertaken.

2. Implementation

Available public and proprietary database and information sources on piping system failures were searched for relevant information. Specific utilities were asked to contribute their own experience with piping components. Using a relational database to identify groupings of piping failure modes and failure mechanisms, together with insights form extensive reviews of published PSAs, the project team attempt to determine how and why piping fail, and what is the expected frequency of failure.

3. Results

This Phase 2 report is devoted to identification of treatment of LOCA in PSAs. The report contains a detailed review of many programs and dozens of specific PSA studies for different reactor types. LOCA definitions and frequency determination form more that 100 PSA are contained in the data base. This collection and analyze of information together with information for the relational data base was used to develop a matrix approach on contribution to LOCA events from different components which are a part of the reactor coolant system pressure boundary. The overall conclusion of the work is that although there are some further development in this area, there is still no significant enhancement of ways how LOCA are considered in PSAs as compared to mid seventies(WASH 1400), only selected studies attempted (and succeeded) to address LOCAs in a more comprehensive way.

4 Conclusions

Emphasis on transient analysis in PSA studies, and generally lower importance of LOCA during eighties resulted in somewhat neglected of treatment of LOCA in PSAs. Many PSAs simply followed generic approaches and adopted categorization and frequency values for older sources. Such an approach may still be numerically correct, but minimize potential for use of PSA for tasks like optimization of in service inspection. Some newer studies attempted to bring new insights into the LOCA considerations. Together with insights gained from the review of more that 200 events stored into SLAP relational data base, later phases of this project are expected to contribute to enhancement of treatment of LOCA events in PSA studies.

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The overall project manager who also made a significant contribution to all 4 volumes is Mr. Ralph Nyman of the SKI’s Department of Plant Safety Assessment.

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1. INTRODUCTION

1.1 Overview of the SKI Project on Reliability of Piping

The Swedish Nuclear Power Inspectorate (SKI) in 1994 commissioned a multi-year, four-phase research project in piping system component reliability. That is, determination of reliability of passive components, such as pipe (elbow, straight, tee), tube, joint (weld), flange, valve body, pump casing, from operating experience data using statistical analysis methods compatible with today's probabilistic safety assessment (PSA) methodology. Directed at expanding the capability of PSA practices, the project scope includes development of a comprehensive pipe failure event data base, a structure for data interpretation and failure rate estimation, and an analysis structure to enhance existing PSA models to explicitly address piping system component failures.

Phase 1 of the research consisted of development a relational, worldwide database on piping failure events. This technical report documents Phase 2 results. *Interim piping failure data analysis insights are presented together with key piping reliability analysis considerations*. Phase 3 will be directed at detailed statistical evaluations of operating experience data, and development of a practical analysis guideline for the integration of passive component failures in PSA. Finally, Phase 4 will include pilot applications.

A fundamental aspect of PSA is access to validated, plant-specific data and models, and analysis insights on which to base safety management decisions. As an example, in 6,300 reactor-years of operating experience no large loss-of-coolant accident (LOCA) has been experienced. Interpretation and analysis of the available operating experience indicates the large LOCA frequency to be about $1.0 \cdot 10^{-4}$/year. Several probabilistic fracture mechanics studies indicate the large LOCA frequency to be $1.0 \cdot 10^{-8}$/year.

Decision makers should be able to confidently rely on PSA. By definition, PSA uses applicable operating experience and predictive techniques to identify event scenarios challenging the engineered safety barriers. *The usefulness of PSA is a function of how well operating experience (including actual failures and incident precursor information) is acknowledged during model (i.e., event tree and fault tree) development*.

The past twenty years have seen significant advances in PSA data, methodology, and application. *An inherent feature of PSA is systems and plant model development in presence of incomplete data*. The statistical theory of reliability includes methods that account for incompleteness of data. Expert judgment approaches are frequently (and successfully) applied in PSA. Legitimacy of expert judgment methods rests on validation of results by referring to the "best available" operating experience. Despite advances in PSA methodology, it remains a constant challenge to ensure models and results accurately reflect on what is currently known about component and system failures and their effects on plant response.

One technical aspect of PSA that has seen only modest R&D-activity is the integrated treatment of passive component failures. Most PSA projects have relied on data analysis and modeling concepts presented well over twenty years ago in WASH-1400. Piping failure rate estimates used by WASH-1400 to determine frequency of loss of coolant accidents (LOCAs) from pipe breaks were based on approximately 150 US reactor-years of operating experience combined with insights from reviews of pipe break experience in US fossil power plants.

In this context, the SKI-project is directed at enhancing the PSA "tool kit" through a structure for piping failure data interpretation and analysis. Phase 2 results are documented in four volumes:

- Volume 1 (SKI Report 95:58). Reliability of Piping System Components. Piping Reliability - A Resource Document for PSA Applications. This is a summary of piping reliability analysis topics, including PSA perspectives on passive component failures. Some fundamental data analysis considerations are addressed together with preliminary insights from exploring piping failure information contained in a relational data base developed by the project team. A conceptual structure is introduced for deeper analysis of passive component failures and their potential impacts on plant safety.

- Volume 2 (SKI Report 95:59).This report

- Volume 3 (SKI Report 95:60). Piping Reliability - A Bibliography. This bibliography includes over 800 technical reports, papers, and conference papers. Computerized literature searches were performed using the International Nuclear Information System (INIS), UN International Labor, Occupational Safety and Health data base (CISDOC), US National Institute of Occupational Safety and Health data base (NIOSHTIC), and UK Health and Safety Executive's Library Information data base (HSELINE). A variety of key words and other means of searches were used

- Volume 4 (SKI Report 95:61), SLAP-SKI’s Worldwide piping Failure Event Data Base. Includes printouts of failure reports classified as ‘public domain” information not undergoing additional investigation. A large portion of event reports remains subject to interpretation and classification by the project team. The report include graphical presentation of the worldwide operating experience with piping system components. The report also include an overview of fundamental data analysis considerations.

1.2 Need to Address Piping Failures in PSA

Plant risk is highly dynamic. Results from plant-specific PSAs change with advances in data, modeling, operating experience, and changes in system design. The significance of risk contributions from passive component failures tends to become more pronounced by each living PSA program iteration. Shifts in risk topography are caused by strengthened defense-in-depth and decreasing transient initiating event frequencies. As the relative worth of risk contributions from transient initiating events decreases, the relative worth of LOCAs caused by passive component failures increases. The relative contributions from LOCAs and transients identified by early PSA studies (i.e., 1975-1985) may no longer be universally applicable.

Directed at PSA practitioners, this project provides a consolidated perspective on passive component failures. This volume of the Phase 2 reports addresses fundamental issues related to the treatment of LOCA initiators in PSAs, by reviewing the historical development and explaining the logic behind the LOCA categorization and determination of frequency.

An important aspect of the Swedish Nuclear Power Inspectorate’s Research project on piping reliability is the consideration of the treatment of LOCAs in PSA studies. Since the time of first comprehensive PSA (WASH-1400, published in 1975), a tremendous amount of work was devoted to probabilistic approaches worldwide. Among other methodological issues, approaches to LOCA definition and determination of LOCA frequencies were often addressed.

One of the main aims of the SKI research project is to enhance the capability of PSA practices through assessment of operational practices and other insights. To enable the application of the collected knowledge directly in PSAs, an assessment of how PSAs have treated LOCAs was performed. An assessment of up to 100 PSA studies, including all the major international projects is documented in this report. At present, significant efforts are placed on determining the failure probabilities and related failure mechanisms on stainless steel and intergranular stress corrosions cracking, and not so much on the other frequent failure mechanisms like corrosion/erosion and similar. This is the other reason why this project stresses the “passive components” issues and the PSA categorization and treatment of those.

1.3 Structure of this Report

While the discussion in this report focuses on the historical development of the LOCA concept presented over the five (broadly chronological) categories, the discussion of possible LOCA cases (other than pipe breaks) resulted in a presentation of ‘ideal “ LOCA categorization from the PSA perspective. The historical discussion of LOCA categorization shall also be considered to reflect not only modeling capabilities but also the computing tools (both hardware and software) which made a more detailed modeling prohibitively time consuming until fast, integrated packages became available. A separate section is devoted to LOCA frequencies and their development over time. Clearly, some of the old practices established at the time of WASH-1400 is simply not relevant any more. [It shall be noted that the analysts involved in the WASH 1400 project were fully aware of the fact that a detailed, realistic analysis of LOCAs would require inclusion of hundreds of potential LOCA locations. However, it was recognized that such detailed analysis would entail development of a very detailed model structure which would be well beyond the capabilities of the computer code used (PREP-KITT).]

From the today’s perspective one of the deficiencies of (especially early) PSAs is to concentrate on the piping failures as the only source of LOCA. Piping failures are an important source of LOCA, but it is felt that many PSA studies put less emphasis on some, possibly equally important LOCA sources. By screening all the components which are a part of the pressure boundary of a reactor coolant system and through qualitative assessment of the likelihood of a LOCA on specific components/location, this report supports the cause-consequence “matrix “ approach to definition of LOCA and determination of LOCA frequency which is detailed in the Volume 1 of this project.

Section 2 presents the historical review of the LOCA concept. More that a dozen of programs and numerous specific studies are discussed with emphasis on how were the LOCAs defined and what was the basis for the determination of frequency. Section 3 approach the LOCA definition form the component side, by discussing which components could give rise to LOCA events, and what is the international operating experience in this area. Section 4 discuss the development of LOCA categorization, considering data driven categorization and plant design impact. Section 5 discuss ideal LOCA categorization, and section 6 compare currently used LOCA frequencies.

Finally, Section 7 of the report and the appendix present the LOCA data base which contains more than 600 individual entries taken from almost 100 PSA studies. This data base is to be used as a compendium of information on how the LOCAs were considered in various plant specific cases, and possibly serve and a background information against which modern approaches could be compared.

2. HISTORICAL REVIEW OF LOCA CONCEPT

2.1 LOCA Concept

The loss of coolant accident (LOCA) is an event caused by a pipe break or a leakage in the reactor coolant system. LOCA events are integral to the design philosophy of nuclear power plants.

Both deterministic and probabilistic approaches consider LOCA events, albeit is somewhat different manner. In the deterministic safety analysis LOCA events analyzed are those considered to be within the design basis envelope. The special category of events called “design basis events” are those which are not expected to occur during the lifetime of the reactor, but which are postulated as the basis for the design of safety systems. For example, the large LOCA type events, initiated by the double ended break of the largest main coolant pipe (and the most rapid loss of coolant) is the design basis event for emergency core cooling system and for the reactor containment. Considering the design basis events, the basic approach of the deterministic safety analysis is to specify bounding values of essential plant variables and to show by analysis that the criteria are met for a required spectrum of initiating events. As a result of that consideration the second level effects as dynamic loads/effects in all LOCA categories are not comprehensively treated. The consequence of that is that ‘multiple” pipe rupture/damages can occur, but have not been considered as important.

Plant’s safety systems and features are designed to cope with all postulated events within the design basis envelope. Events like catastrophic failures of reactor pressure vessel (RPV) and steam generators (SG) shell failure have not been considered as a design basis. Failure of RPV, SG or the pressurizer would therefore be beyond the capacity of engineered safety features and would lead to a serious accident with core melt.

The approach taken by the probabilistic analysis is fundamentally different, because in the probabilistic analysis all events are considered as possible events, although with varying probability of occurrence. Thus, the probabilistic analysis will consider effects of a whole spectrum of loss of coolant accidents, and comparable evaluation will be done for the more of less frequent events, and their consequences estimated. Consequently, the probabilistic approach would simultaneously address the high frequency events like very small LOCAs and the highly improbable events line failure of the reactor pressure vessel.

While the basic approach is similar, the specific of LOCA considerations for Pressurized water reactor (PWR) and Boiling water reactors (BWR) are somewhat different. In both cases there is a distinction between small and large breaks. With BWRs, an important distinction is between the breaks below and the above the core, as well as the distinction between breaks within and outside the containment. The difference is in possibilities to isolate the leak as well as in the timing (and the overall effects) of the actual accident sequences[1].

Especially for older BWRs, the break of recirculation piping is the most serious accident., whit the highest rate of loss of coolant with the initial break flow of up to

20.000 kg/s. The dryout of the parts of the core occurs in few seconds. For the newer reactors with internal recirculation, an assumed guillotine break of the main steam line represents the large LOCA. There is a rapid loss of the coolant inventory and the pressure in the containment and the reactor vessel equalize in few minutes. The difference between the two is primarily between the rate of loss of coolant, which is also related to the fact that the break occurred in the steam region vs. water region. In fact many probabilistic analysis recognizing that fact make the difference between steam and water breaks at BWRs.

With PWRs the processes are somewhat different. The blowdown phase during the large LOCA event last for up to 20 second, and the core is during that period reflooded from the accumulators. PWRs do not have the steam breaks, as the steam line break only results in a loss of secondary water. The most critical large break at PWRs is the guillotine break of the cold leg after the primary pump discharge which results in a double side flow.

Apart form difference in the philosophy between deterministic and probabilistic approaches which is described above, the probabilistic safety analysis adopted the basic LOCA categorization for the deterministic analysis. Those however, evolved with time. The first PSA study (WASH-1400)[2] considered a total of 6 LOCA events, and modeled further 4 of those. Modern PSAs distinguish between a dozen or more LOCA events. The selection of LOCA events is driven by both the safety philosophy and perceived plant response.

In the deterministic safety analysis, the selection of LOCA events and their analysis is driven by the safety philosophy and the plant response characteristics (i.e. to prove that the safety design is appropriate). The probabilistic approach adopted this, basically deterministic philosophy because the available resources and tools were such that a more extensive analysis would not be feasible (both the methods but even more the computer codes). Especially during eighties, the transients were considered more important. Finally, the lack of operational experience available to support the determination of frequency of LOCA (for most LOCA categories, apart form SGTR, and very small LOCAs) was also an important reason for adopting the deterministic approaches.

The principles of estimation of frequency of LOCA events has also changed over the time. WASH-1400 set a precedent in determination of LOCA frequency by combining the operating experience (including non-nuclear experience) available at that time with expert judgment. Many later studies simply adopted WASH-1400 values. During seventies, initial pipe break estimated using probabilistic studies (probabilistic fracture mechanics) were undertaken which considered the material properties of piping. Some studies claimed the Leak-before-break (LBB) concept to justify extremely low values of larger LOCA sizes, which was not always accepted by the reviewers. At least one study is known to have used innovative approaches like Thomas elemental model to generate LOCA frequencies. Despite of recognized attempts, the structural reliability considerations and the PSA have never fully merged, and the LOCA categorizations (and frequencies) that evolved for deterministic safety analysis and early PSA studies have prevailed in nineties.

The following paragraphs presents the historical development of the LOCA concept in PSA studies. The presentation is divided in 5 sections each broadly corresponding to a period in development of LOCA approaches.

2.2 Early PSA Studies

2.2.1 Reactor Safety Study “WASH-1400” USA 1975

2.2.1.1 Introduction

WASH-1400 was a first full scope PSA study. It pioneered the plant wide probabilistic safety analysis of nuclear reactors. The concept of fault tree and event trees has been adopted from other industries (aerospace) and for the first time applied to commercial nuclear power plants. While the reliability techniques including the fault tree methods were extensively used during sixties and seventies on the system level for a variety of activity including determination of the testing intervals, WASH 1400 pioneered an integrated plant model achieved by linking the fault trees and event trees. In part the WASH-1400 was commissioned to add to [at that time] heated discussion on effectiveness of the Emergency Core Cooling Systems (ECCS) in case of a large loss of coolant accident. While the WASH-1400 did not solve the problem, it helped to highlight small LOCA as an important safety issue. WASH-1400 was first published in 1975 and was extensively reviewed and commented on in the second half of seventies.

2.2.1.2 LOCA Concepts

Among other things, WASH-1400 pioneered the LOCA concept in the PSA sense (LOCAs being considered in 3 distinctive categories, each of which would have a different plant response). The WASH-1400 definition of LOCA is ‘... a break or opening large enough so that the coolant inventory cannot be maintained by the normally operating makeup system”. Moreover, the WASH-1400 went beyond of what has been considered the design basis events. Events like reactor vessel rupture or steam generator shell failure were also considered in order to ascertain the extent to which they can potentially affect the overall risk from NPP operation.

2.2.1.3 LOCA Categories

Following the above indicated definition of LOCA, the WASH-1400 considered a total of 6 specific LOCA categories, which are summarized in Table 2.1.

Conceptually, the LOCA categories were determined on the basis of analysis of plant response, and specific system actuation (or requirements for operation of specific systems, e.g. low and high pressure safety injection). Reactor vessel rupture is considered to lead directly to core melt. Interface LOCA was considered as a separate category because the coolant is irretrievably lost in that sequence. It is believed that such a sequence will always result in the core damage, and an open path to the environment, as the containment barrier is bypassed.

One of the important findings of WASH-1400 was the identification of the risk due to an interfacing system LOCA; i.e., failure of interfaces between the high-pressure primary system and the low-pressure injection system.

The categorization of LOCAs was driven by the thermal-hydraulic analysis (plant response characteristics) and a desire to keep the number of categories to a minimum (which was the artifact of the primitive computer codes available, which could not manage larger models). The LOCA categorization was also partially constrained by the availability of data. Originally, all the data available was grouped in 2 categories: one for the piping with equivalent diameter below 100 mm and another one with more than 100 mm diameter. The final categorization however, interpolates and expands the data to 3 (piping) LOCA categories.

Table 2.1: ***WASH-1400 LOCA Categories***

LOCA CATEGORY	DEFINITION
Large pipe break	Break of a pipe with more than 150 mm equivalent diameter
Small to medium pipe break	Break of pipe with equivalent diameter between 50 and 150 mm
Small pipe breaks	Break of pipe with equivalent diameter between 12 and 50 mm
RPV rupture	Large disruptive reactor vessel failure
SG failure	Gross steam generator ruptures
Interface LOCA	Ruptures between systems that interface with the RCS.

2.2.1.4 LOCA Frequency Estimation

The basis for the estimation of LOCA frequencies for WASH-1400 was a comprehensive collection of data from nuclear sources, industrial sources and numerous other sources. The pipe failure data gathered from all those sources was assessed to be”... quite rough and gave much freedom for interpretation.”(quote original text from WASH-1400) which consequently introduced a significant uncertainty in the LOCA frequencies. Another important characteristic is that the data collected included a spectrum of events like ruptures, leaks, severance etc. During the data qualification process, only breaks of severance-type size were considered. Minor leaks were not considered. Attempts were made to clarify specific failures.

To enable consideration of data sources where the piping failures were reported as per-plant value, an estimate was made on the percentage of plant piping susceptible to LOCA. It was concluded that about 10% of the total plant piping at a nuclear plant is the “LOCA susceptible piping”. The division between “small” and ”large” category (below and above 100 mm diameter) was estimated to be 47% vs. 53 % respectively.

The nuclear operating experience considered for estimating the LOCA frequency in WASH-1400 included about 150 reactor years of commercial nuclear power, about 40 years of experimental reactors and about 1200 years of military reactors. As no large bore piping failure had occurred in this period, an upper limit estimate was calculated to be 7.0E-7 per plant per year. If 10% of the piping is considered LOCA susceptible, another order of magnitude reduction is achieved. In addition, some process piping failures had been identified and used in determining the failure probability for small diameter piping.

Use was made of the US non nuclear industry experience, mostly of an extensive study commissioned by General Electric (GEAQP-574) [3] which summarizes power utilities experience. This data source was based on about 10000 plant years and 400 observed failures (5% were catastrophic). From the documentation of WASH 1400 is not fully clear to which extent those data were used in derivation of final frequency values.

DATA SOURCES USED

- Commercial reactor experience (150 yr.)
- Research reactors experience (40 yr.)
- Military reactors (1200 yr.)
- UK Vessel data (100000 yr.)
- US power industry (400 events)
- German Vessel data
- Other industrial sources (SRD etc.)

WASH-1400 assigned logarithmically distributed failure rates for 3 LOCA categories (small, medium and large LOCA). For every category, a median value and 5th and 95th percentile was determined.

WASH-1400 also pioneered the approach for determining the frequency of intersystem LOCA events. The frequency was estimated considering the probability that two isolation (check) valves in series would fail catastrophically, each one as an independent failure.

2.2.1.5 Conclusion

WASH-1400 established the basis for structured treatment of LOCAs in PSA. The approach to the LOCA categorization has been kept in many PSA studies up to the present. Within the framework of WASH-1400 an extensive review was performed of operational experience and literature data sources to estimate the frequencies of failure of piping. The values adopted represented a cross section of empirical and theoretical knowledge available at that time. Pipe failure frequencies established have been used for many years as a benchmark values

2.2.2 German Risk Study Phase A (Germany 1980)

2.2.2.1 Introduction

German Risk Study (DRS-A; „**D**eutsche **R**isiko **S**tudie Phase **A**“) [4] was commissioned by the German Ministry of Research and Technology in 1976 with the objective to identify if the risks from a commercial nuclear power plant in Germany are comparable with the risk identified by WASH-1400. The specific objective of the study was also to adopt the WASH 1400 methodology and to enhance the documentation of the approaches. Biblis B NPP was used as the reference plant. The study was performed in two phases. Relevant insights and results of Phase A which were published in 1980 are described here. Results of Phase B which was published in 1989 are described later. The study followed the approaches and methods adopted from WASH-1400.

2.2.2.2 LOCA Concept

As for WASH-1400 three major LOCA categories were defined; large, medium and small LOCA. The definition of LOCA sizes was based on system analysis (plant response), and adjusted to specific discrete success criteria taking into account the high pressure injection, accumulators, low pressure injection and recirculation as well as main and auxiliary feedwater supply. In addition to the three standard leak sizes, a very small leak was defined. However, this leak is fully manageable with plant’s makeup system. Since it does not contribute to the overall risk, it has not been analyzed in a greater detail. The purpose of addressing the small small LOCA without further analysis appears to be related to the frequency of event, i.e. if not considered, the frequency of the small LOCA would increase significantly.

2.2.2.3 LOCA Categories

Three standard LOCA categories were defined in German Risk Study Phase A. Unlike WASH-1400, where piping diameter was the basis for categorization, in the German Risk study LOCA categories are defined on the basis of an effective leak area. The categories are:

Table 2.2: ***Categorization of LOCAs in German Risk Study Phase A***

LOCA CATEGORY	DEFINITION
Large LOCA	Break with equivalent flow area larger than 40.000 MM
Medium LOCA	Break with equivalent flow area between 8.000 and 40.000 mm^2
Small LOCA	Break with equivalent flow area between 200 and 8.000 mm^2

The consideration was given on a small leak on the pressurizer (Inadvertent opening of the Relief Valve-IORV), which was found to be less probable on German designed plants than on the US plants (on the basis of operational experience). LOCA caused by the RPV failure was studied and on the basis of extensive evaluation of both operational experience of nuclear and non nuclear pressure vessels, it was concluded that from the risk perspective, the probability is extremely low. The intersystem LOCA sequence was also evaluated in the frame of the German Risk Study. The analysis has shown that the probability and the potential consequences of such an event are so low that this sequence does not contribute to the overall risk level.

2.2.2.4 LOCA Frequency Estimation

The frequency estimated for LOCAs in the German Risk Study was based on a thorough evaluation of:

- actual piping failure in non-nuclear industries with an assessment of the applicability to NPP
- analysis of reported operating experience with piping in light water reactors

The sources used to a certain extent replicate the WASH-1400 sources with some specific additions. German Risk Study also benefited from increased operating experience, compared to the time of WASH-1400.

The final values derived are mean values and are somewhat higher than the WASH-1400 median values. The distribution (uncertainty) is assessed to be rather high, as all the information collected showed a relatively high scatter.

Table 2.3: ***LOCA Frequencies in German Risk Study Phase A***

LOCA CATEGORY	FREQUENCY
Large LOCA	2.7E-4
Medium LOCA	8.0E-4
Small LOCA	2.7E-3

2.2.2.5 Conclusion

The German Risk Study followed the approaches and methodology delineated by WASH-1400. The approach to the definition of break sizes was redefined to meet specific German requirements. The data sources used were based on somewhat broader nuclear experience and review of some additional non-nuclear sources. The LOCA frequency remained generally similar to WASH-1400.

2.2.3 Early Swedish Studies (Sweden, mid eighties)

2.2.3.1 Introduction

The regulatory framework under which Swedish studies have been performed is called ASAR [5], which stands for the periodic safety evaluation performed in eighties. During early eighties, plant specific studies were completed for most of Swedish reactors. While some innovative PSA concepts, especially in the area of common cause failures were introduced, the studies largely followed the general approach to LOCA categorization and frequency determination delineated by WASH-1400.

Even before the ASAR program, the Swedish Safety Inspectorate (SKI) sponsored the first PSA for Barsebäck unit 2 in 1977 [6]. The aim of that study was to perform a comparison with WASH 1400 study for Peach Bottom. The front end of that study was not innovative, while the back end of it was the state-of-the-art of its time. About the same time, another team performed a study for Forsmark 3 NPP [7], which again did not contribute too much to the development of LOCA approach.

2.2.3.2 LOCA Concept

The general LOCA concept included definition of specific LOCA sizes relative to the plants` success criteria. The interesting characteristics is that, although all the plants divided LOCAs into small, medium and large, the actual break sizes and definitions varied. While most of the plants defined break sizes in terms of flow, some decided to keep the definition in terms of pipe sizes. Some of the plants addressed the reactor pressure vessel breaks and intersystem LOCA, others did not.

2.2.3.3 LOCA Categories

LOCA categories used in early Swedish PSA separated the small, medium, large distribution, but actual break sizes and definition vary. The table below summarizes the definitions used in PSAs which were performed as a part of the Swedish ASAR program in mid eighties. The reader's attention is drawn to the fact that the ASAR program is much broader that the PSA. An ASAR report on a plant include the summary of the overall plant safety program, quality assurance/quality control consideration, operator training and similar items. Every ASAR report include a 10-20 pages discussion on PSA, and some of PSAs referred to in ASAR were of limited scope.

Table 2.4: ***Definition of LOCA Sizes in Swedish ASAR PSAs [5]***

LOCA Size	**PLANT**				
	Barsebäck **Oskarsham 2**	**Oskarsham 1**	**Ringhals 1**	**Ringhals 2**	**Forsmark 3**
large LOCA	Flow above 2000 kg/s	Flow between 600 and 2000 kg/s	Flow above 1200 kg/s	Break on pipe with diameter above 150 mm	Flow area larger than 45.000 mm^2
medium LOCA	Flow between 30-2000 kg/s	Flow between 35-600 kg/s	Flow between 35-1200 kg/s	Break with diameter between 50 -150 mm	Flow area between 8.000 and 45.000 mm^2
small LOCA	Flow between 10-30 kg/s	Flow below 35 kg/s	Flow between 5-35 kg/s	Break with diameter less that 50 mm	Flow area less than 8.000 mm^2
RPV failure	-	-	Yes	Yes	Yes
IS LOCA	Yes	-	Yes	Yes	-

2.2.3.4 LOCA Frequency Estimation

All of the Swedish PSAs completed at that time (eighties) used published data to determine LOCA frequency. Some variations exist, which are apparent due to limited plant specific data.

It is worth to note the frequency of large LOCA used for the Oskarsham 1 and 2 PSAs. While most of the other PSAs used mean values around 1.0E-4 per reactor year which ultimately comes form WASH 1400 determination of frequency, Oskarsham used significantly lower frequencies in the 1.0E-7 range. Medium LOCAs were also considered to be less frequent, with values in 1.0E-5 and 1.0E-6 range for Oskarsham 1 and 2 , respectively. The justification for such a low values used was found on the basis of leak-before-break principles. Being concerned with the primary system integrity, the Regulatory body (SKI) actually never accepted the frequency values nor the justification. Small LOCA values used for Oskarsham plants are in 1.0E-2 range and therefore an order of magnitude higher than the values used at other plants.

The intersystem LOCA frequency used for Ringhals plants is rather low and it is in 1.0E-7 and 1.0E-8 range for Ringhals 1 and 2, respectively (Those values correspond to values used in US at that time). The Ringhals 2 value was below the value used for RPV rupture. The frequency for an intersystem LOCA is determined to be 1.0E-7 for Oskarsham 1.

Reactor vessel rupture was considered for Ringhals 1 and 2 and Forsmark 3 NPPs. In all 3 cases a 2.7E-7 value was used.

2.2.3.5 Conclusion

Early Swedish studies did not bring much new development to LOCA definitions and determination of frequency. Oskarsham studies which used LBB justification to warrant their very low LOCA frequency were among the first PSAs to do so. Although this approach has been repeated by some other PSAs internationally, it drew a lot of criticism and was often considered not fully justifiable.

The value used for intersystem LOCA is very low and generally goes below what is warranted with common cause failure consideration. (Especially from today's perspective). Many other PSAs at that time have used values in the similar range. From the today's perspective, the Intersystem LOCA frequencies being lower than the RPV failure frequencies does not appear to be fully justified.

2.3 Early WASH-1400 Applications (USA, early-mid eighties)

2.3.1 Reactor Safety Study Methodology Application Program RSSMAP

The program called Reactor Safety Study Methodology Application Program [8]was the first attempt in US to have a wider application of approaches and methods developed in the framework of WASH-1400. The series of studies performed were intended to be a low-efforts scoping studies. Several studies were performed for NPPs constructed by various vendors. The lack of analysis depth was the biggest source of criticism for RSSMAP program.

As far as the LOCA categorization and frequency is concerned, RSSMAP program did not go too much further than the WASH-1400. Both the categorization of LOCA and the determination of frequency closely followed WASH-1400-developed approaches.

LOCAs were categorized in 3 standard categories: large, medium and small. Actual sizes of LOCAs in specific categories were adjusted to correspond with the plant specific success criteria.

Regarding the LOCA frequencies, efforts have been made to review the actual specific configuration (piping segments) and to establish a better basis for failures of specific piping segments. This approach only marginally modified original LOCA frequencies. Both intersystem LOCA and RPV rupture values used were directly adopted from WASH-1400.

2.3.2 IREP (USA early eighties)

2.3.2.1 Introduction

The program called Interim Reliability Evaluation Program (IREP) [9]was a follow-up on the RSSMAP program. Its original aim was to perform a comprehensive PSA Level 1 analysis on a number of operational plants in the US. The program developed its own methodology guide and a database.

In the area of LOCA methodology, considering both categorization and determination of frequency, IREP program was basically the continuation of the WASH-1400 approach. However, more efforts were placed on identifying the break sizes, which were fine tuned for specific plant responses. LOCA frequencies followed WASH-1400 values. The operational experience gained since WASH-1400 was not fully used, although lack of major LOCA events increased the credibility of some frequency values. In some of the IREP studies (for example IREP study for Arkansas Nuclear One-ANO), WASH-1400 data was actually used as a prior for Bayesian updating with plant specific or class specific operational experience.

2.3.2.2 LOCA Categories

With more attention paid to the plant specific responses, some of PSAs conducted under the IREP program redefined LOCA categories. IREP study for Arkansas 1 defined a large LOCA and two small LOCA categories. One of the small LOCA categories included the stuck open pressurizer safety valve which was a new event, not considered previously. The same study defined the small-small LOCA category which, in addition to breaks of very small pipes, included the stuck open pressurizer relief valve (smaller flow rate than pressurizer safety valve) and a leak on the reactor coolant pump seals.

Based on the methodology guide IREP study for a BWR plant distinguished between water and steam LOCA, recognizing that coolant loss rates and timing of respective sequences are different.

2.3.2.3 LOCA Frequency Categorization

While the basic frequency estimates mostly followed WASH-1400 values, more effort was put into assessing the configuration of the LOCA-susceptible piping. The actual frequency values used in specific studies consider the piping configuration issues. To an extent, the operating experience was used to update the generic data from WASH-1400. For new events (like pressurizer valve openings or primary pumps seal), operating experience was used along with specific engineering studies.

2.3.2.4 Conclusion

Although the basic concepts established by WASH-1400 were followed, IREP added to the definition of LOCA by refining LOCA categories to achieve a more structured plant response modeling. In that respect, IREP program began a trend towards specialization of LOCAs in PSA studies.

Another novel approach taken in some IREP studies was to specifically model spurious openings of relief valves. IORV is now considered in most modern PSAs. Although the plant response to IORV is generally similar to a LOCA of similar size, a frequency of such events sometimes warrant specific modeling of that sequence.

Some of IREP studies considered the small-small LOCA category which typically has at least an order of magnitude higher frequency than a small LOCA, mainly due to non-pipe-break events including leaks on primary pumps on PWRs.

2.3.3 PRA Procedure Guide NUREG 2300 (USA, early eighties)

The PRA procedure guide [10] was the first PSA guide which addressed the whole set of PSA approaches and methods from definition of initiators to off-site impact modeling. Prepared in early eighties by a group of PSA practitioners, the PRA procedure guide summarized all then available experience.

The PRA procedure guide treats LOCA categorization in a rather superficial manner. While it maintains the idea that all possible pathways for a loss-of-coolant shall be identified, the PRA procedure guide suggests that the LOCAs considered in a PSA study could be reduced to 3-4 groups (depending on the mitigation), each of which requires a separate event tree. The PRA Procedure Guide suggests that a “systematic search” is undertaken to identify any active elements which can either fail or be operated in such a manner to result in a loss of coolant. Emphasis is placed on the relief valves which can open or fail to reclose and initiate a loss of coolant.

2.4 Other Regulatory PSA Initiatives - Post IREP

2.4.1 NUREG 1150 (USA, late eighties)

2.4.1.1 Introduction

NUREG 1150 [11]was a USNRC initiative to ascertain that the streamlined PSA methodology can be successfully used to determine the vulnerability of a commercial NPP. NUREG 1150 program was developed over a period of several years and its results published in late eighties. The important characteristic of the program is its extensive use of previously collected insights and experience with various PSA studies. The experience from previous PSA was used to identify the areas of higher importance and methodological development related to NUREG 1150 concentrated on those. Described here is the approach delineated in NUREG 4550, Vol.1 (Methodology guide) which contains the methodological guidance which was followed by all NUREG 1150 PSAs.

Relative to the definition of LOCA categories and frequencies, NUREG 1150 program did not attempt to move beyond other PSAs at the time. However, it helped to consolidate the approach to LOCA definition and highlight the importance of events like small-small LOCA and SGTR which have previously not been treated consistently.

2.4.1.2 LOCA Categories

NUREG 1150 Methodology Guide suggests the definition of LOCA categories on the basis of plant response, established in terms of required operability of specific systems. The Guide suggest that a realistic plant response estimates are used as opposed to the (typically) conservative approach from FSAR (which was used for determining the plant response in several PSAs). A total of 5 LOCA groups were defined for each, PWR and BWR reactors. The groups for BWR are based on a concept of equivalent flow area, while for PWRs, the concept is based on the equivalent piping diameter. For BWRs the suggested LOCA groups include:

Table 2.5: ***Recommended LOCA Categories for BWRs according to NUREG 1150 Methodology Guide***

LOCA CATEGORY	DEFINITION
Large LOCA	Break with equivalent flow area larger than 9.300-to-27.910 mm^2
Medium LOCA	Break with equivalent flow area between 465 and 9-27.000 mm^2
Small LOCA	Break with equivalent flow area less than about 465 mm^2
Small-small LOCA	Break with the equivalent flow about 11 to 22 m^3/hr
Interface LOCA	Break on any high-to-low pressure boundary, with flow above small LOCA

PWR suggested LOCA groups include:

Table 2.6: ***Recommended LOCA Categories for PWRs according to NUREG 1150 Methodology Guide***

LOCA CATEGORY	DEFINITION
Large LOCA	Break of a pipe with equivalent diameter greater than 150 mm
Medium LOCA	Break of a pipe with equivalent diameter between 50 and 150 mm
Small LOCA	Break of a pipe with the equivalent diameter between 12.5 and 50 mm
Small-small LOCA	Break of a pipe with equivalent diameter less than 12,5 mm (or approximate flow about 11 to 22 m^3/hr)
Interface LOCA	Break on any high-to-low pressure boundary

The document also made a point that the specific grouping is highly dependent on the plant response, and may vary from the above indicated grouping. Additional LOCA groups can be differentiated by the break location, or the leaking medium (steam vs. water).

2.4.1.3 LOCA Frequencies

The frequency values suggested by NUREG 1150 are based on the review of PSA studies which have been completed prior to it. The values proposed to a large extent still follows the WASH-1400. In some case those were modified in specific PSAs, and adopted in NUREG 1150. No systematic effort was made as a part of NUREG 1150 to collect and review the operating experience. Values for small-small LOCA were partially based on related research activities.

NUREG 1150 offers a rather thorough discussion on determination of the interface LOCA. A description of suggested analysis steps is provided to determine ISLOCA for a typical US plant. The conclusion is that the probability of an interface LOCA event is small and thus the CDF as a result of this event is negligible.

An example of how to determine the SGTR was also developed in the Guide. From the perspective of the off-site release, the SGTR is relevant only when: 1) the core has been damaged and 2) an open path to the atmosphere exists through a SG relief valve. The probability of both of those happening simultaneously is assessed by the study to be extremely low. On that basis the Guide suggested that SGTR sequence does not warrant further evaluation. This conclusion is contrary to conclusions reached in some other studies, which found the SGTR events very important ones both from the perspective of the frequency of occurrence (about 8 SGTR events occurred worldwide) and from the perspective of the safety significance of it.

Table 2.7: ***LOCA Frequencies used in selected NUREG 1150 Studies[12], [13], [14], [15]***

LOCA TYPE	LOCA FREQUENCY	PLANT
IORV	1.40E-01	Grand Gulf 1
IS LOCA	1.00E-08	Grand Gulf 1
IS LOCA	1.00E-08	Peach Bottom 2
IS LOCA	1.00E-06	Surry 1
large LOCA	3.00E-04	Grand Gulf 1
large LOCA	2.70E-04	Peach Bottom 2
large LOCA	5.00E-04	Surry 1
large LOCA	3.00E-04	Zion
medium LOCA	8.00E-04	Grand Gulf 1
medium LOCA	8.00E-04	Peach Bottom 2
medium LOCA	1.00E-03	Surry 1
medium LOCA	1.10E-03	Zion
small LOCA	3.00E-03	Grand Gulf 1
small LOCA	2.70E-03	Peach Bottom 2
small LOCA	1.00E-03	Surry 1
small LOCA	6.80E-03	Zion
small small LOCA	3.00E-02	Grand Gulf 1
small small LOCA	2.70E-02	Peach Bottom 2
small small LOCA	2.00E-02	Surry 1

2.4.1.4 Conclusions

The methodological guidance of NUREG 1150 (NUREG 4550) has consolidated the level of knowledge on LOCA identification, categorization and determination of frequencies as far as it existed at that time. The methodology guidance suggest the SGTR and ISLOCA sequences are of less safety significance, which is different than some other studies found. In conclusion, while NUREG 1150 contribute to further consolidation of the methodology, it did not make a significant contribution to the development of LOCA categorization or frequencies.

2.4.1.5 NUREG 1150 Surry Unit 1 Analysis

The NUREG 1150 PSA study on Surry NPP followed the approach described in the methodology guidance (NUREG 4550 Vol.1). Four LOCA categories were identified (large, medium, small and very small) and their expected frequency of occurrences determined on the basis of a survey of values used in other PSAs. The interfacing LOCA event was treated in the same way as in the WASH-1400 study. A frequency of 1.0E-6 was identified for ISLOCA event. The SGTR induced release was found to have a very low frequency and therefore disregarded.

2.4.2 German Risk Study Phase B (Germany, late eighties)

The German Risk Study Phase B [16], [17] is a continuation and a specialization of the Phase A of the DRS. The same plant (Biblis B) was analyzed and while the same basic PSA approaches were used, specific aspects of methodology were reconsidered.

One of the items which was significantly modified as compared to the Phase A, is the definition and the determination of frequencies of LOCAs. Instead of previous 3 LOCA classes, the spectrum of LOCA events was divided into 6 classes, one category representing medium and large LOCA and 5 small LOCA categories. The differentiation between LOCA categories is based on the plant response including the timing of the event and the mitigating actions. Similarly to some other European studies, the break sizes are defined by their leak area (sq.cm.)

The way the LOCA frequencies were determined has been significantly modified as compared to the Phase A of the DRS. In addition to the operating experience accumulated in between the studies, extensive use has been made of the probabilistic fracture mechanic (PFM) analysis to justify some of the values, in particular large LOCA.

The most specific of the German Risk Study Phase B is, in particular, the fine differentiation among small LOCA categories to enable grouping of events in accordance to the specific plant response. Another interesting approach is the justification of (low) LOCA frequencies on the basis of the fracture mechanics arguments and extensive application of LBB criteria. That resulted in significantly lower frequencies of most events as if compared to DRS-A.

The LOCA classes and associated leak sizes are as listed in Table 2.8 and the frequencies used in DRS-B are summarized in table 2.9.

Table 2.8: *LOCA Categories in German Risk Study (Phase B)*

LOCA CATEGORY	DEFINITION
Large and medium LOCA	Break with equivalent leak area above 20.000 mm^2
Small LOCA 1	Break with equivalent leak area between 8.000 and 20.000 mm^2
Small LOCA 2	Break with equivalent leak area between 5.000 and 8.000 mm^2
Small LOCA 3	Break with equivalent leak area between 2.500 and 5.000 mm^2
Small LOCA 4	Break with equivalent leak area between 1.250 and 2.500 mm^2
Small LOCA 5	Break with equivalent leak area between 200 and 1.250 mm^2
IORV	Inadvertent opening of the PORV with a leak area of 4.000 mm^2
ISLOCA	Leak through high-to-low pressure boundary to annulus with equivalent flow area between 200 and 50.000 mm^2
SGTR Small leak #1	SG tube leak with equivalent leak area between 600 and 1.200 mm^2
SGTR Small leak #2	SG tube leak with equivalent leak area between 100 and 600 mm^2

Table 2.9: *LOCA Frequencies in German Risk Study (Phase B)*

LOCA CATEGORY	LOCA FREQUENCY
Large and medium LOCA	< 1.0E-7
Small LOCA 1	9.0E-5
Small LOCA 2	7.5E-5
Small LOCA 3	7.5E-5
Small LOCA 4	1.4E-4
Small LOCA 5	2.8E-3
IORV	8.5E-4
ISLOCA	< 1.0E-7
SGTR Small leak #1	1.0E-5.
SGTR Small leak #2	6.5E-3

2.5 Early Commercial PSA (eighties)

2.5.1 Early US Commercial Studies

The PSA approach and plant specific PSA studies were used to support various safety cases. Three plants (Limerick, Zion and Indian Point) [18], [19] were under a strong pressure because of their location in the vicinity of major population centers and their PSA studies were used to justify continued operation. Other plants performed plant specific PSA for various licensing reasons (Shoreham, Milstone 1, Yankee Rowe, Big Rock Point) [20], [21].

While these studies made numerous contributions to the PSA methodology, no significant advances in LOCA definition and determination of frequencies were made. Those PSAs maintain the LOCA division in small, medium and large categories. Similarly to IREP studies, the opening of single or multiple pressurizer safety valve was blended in respective LOCA categories. RCP seal failure and CRDM leak or rupture became a regular addition to the small LOCA category. A new LOCA category related to the steam generator tube rupture was added. Previously, this event was supposingly covered by the small LOCA category; it became a standard initiator for practically all later PSAs. The reason for that was a significantly different plant response in case of SGTR.

Although the increased amount of operational experience became available , early US commercial studies did not make extensive use of it. However, the small LOCA events (including TMI accident) and the SGTRs which occurred gave a better guidance for the modeling of those events and to a certain extent the basis for the estimation of frequency of occurrence. Nevertheless, the basis for determining the frequency of LOCAs still relied on values of the WASH-1400 study (or related IREP values) and only a limited operating experience is used to improve those. An interesting observation is that the frequencies assigned to specific LOCA categories are generally higher than those presented in WASH-1400. This in particular applies to the small LOCA categories and it is probably due to the sequence experienced at TMI in 1979.

Zion and Indian Point PSA studies were the benchmark studies of their time. These introduced for the LOCA definitions new specific events like SGTR and confirmed the need to address IORV and similar small leaks. On frequency determination, improvements by these studies were limited to the use of additional operating experience mainly for specific SGTR and small LOCA. Table 2.10 provides the overview and the comparison of frequency of LOCA as used in various US studies during eighties.

Table 2.10: ***LOCA Categories and Frequencies in selected US PSAs***

LOCA CATEGORY	PSA STUDY				
	Browns Ferry 1 IREP (1982)	Grand Gulf 1 ASEP (1986)	Millstone 1 (1985)	Peach Bottom ASEP (1986)	Shoreham (1986)
LOCAs:					
Large LOCA					
- Discharge Side	3.9E-5	-	-	-	-
- Suction Side	9.9E-6	-	-	-	-
- Steam Break	5.2E-5	-	-	-	-
Total:	1.0E-4	3.0E-4	1.0E-4	3.0E-4	7.0E-4
Medium LOCA	3.0E-4	8.0E-4	1.0E-3	8.0E-4	3.0E-3
Small LOCA	1.0E-3	3.0E-3	1.0E-2	3.0E-3	8.0E-3
RCP Seal LOCA	-	3.0E-2	-	2.7E-2	-
IS LOCAs:					
LPCI System	-	6.0E-9	1.6E-8	1.1E-8	9.6E-9
LPCS System	-	2.0E-9	1.1E-7	-	9.6E-8
RWCU System	-	-	1.4E-8	-	-
Isolation Condenser	-	-	1.5E-7	-	-
RHR System	-	-	-	-	1.6E-8
Total	-	8.0E-9	2.9E-7	1.1E-8	1.2E-7

2.5.2 Caorso PSA (Italy, mid eighties)

2.5.2.1 Introduction

Caorso NPP is a GE BWR which was operational in Italy in the eighties. A Level 1 and Level 2 PSA study was performed for this reactor in 1986 in response to public concerns arising from the Chernobyl accident. The study was developed by the utility with a US consultant. It was one of the earliest studies completely integrated on a PC. The whole study was completed on a very short time schedule with about 60 man-months of analysis efforts. In many characteristics it followed the PSA which has been performed for Alto Lazio NPP, and its results as well as insights gained were compared with Shoreham PSA because of relative similarity of designs.

2.5.2.2 LOCA Concept

The concept for defining LOCAs in the Caorso PSA[22] was based on identifying all the breaks and leaks which can lead to a loss of coolant either inside or outside the containment. The LOCA sizes are defined in terms of break area with a lower bound of 120 mm^2 (equivalent to the break of a pipe with the equivalent diameter of 12.5 mm) which is assessed to be the within the make-up capacity of a CRD pump. The break sizes were determined based on the number of systems/trains needed to maintain the RCS inventory or core cooling.

2.5.2.3 LOCA Categories

The whole spectrum of LOCAs was divided in 7 categories depending on the size and the location of the break:

Two large LOCAs were defined, one inside and one outside the containment
One medium LOCA inside containment was defined
One category of small break LOCA inside containment was defined
Two categories of Interface LOCA were defined, LPCI break and CS break
Several category ECCS break were defined (only one category was analyzed)
Reactor pressure vessel rupture was considered but not further analyzed due to negligible impact

Of interest in the LOCA categorization are definitions (and contributors) of large LOCAs, IS LOCAs and ECCS breaks, which are somewhat unique to this study.

Two large breaks defined differ in their location (inside and outside the drywell). Breaks inside the drywell include breaks of the recirculation line, which simultaneously disable parts the LPCI, and all other breaks which does not impact the operation of a front line system.

The breaks outside drywell include primary piping breaks at penetrations, main steam lines, main FW lines, and the HPCI/RCIC lines. The common characteristics to all those is that the break can be isolated.

An analysis to identify all possible breaks of piping, which can cause a loss of coolant without an automatic isolation (ISLOCA) was undertaken. Two systems were identified as potentially susceptible to ISLOCA. Those were the low pressure coolant injection and the core spray. Both systems operate at pressures which are significantly lower than reactor operating pressure. ISLOCA initiator would require either failure of both check valves and isolation MOVs, or erroneous signal to be applied and simultaneous failure of a check valve.

A specific LOCA event called ECCS break was considered in the Caorso PSA. ECCS breaks were defined as breaks in individual ECCS supply lines inside containment which would cause system failure. These were medium (LPCS) and large breaks. Not one but several ECCS breaks were defined. Explicitly only the LPCS breaks were considered at five different locations but with the same plant response.

2.5.2.4 LOCA Frequency Estimation

Frequencies of various LOCAs in the Caorso study were based on a combination of generic values and specific estimates. Generic data was used for large, medium and small LOCAs as well as for a reactor vessel rupture (IREP database and Shoreham PSA values were used).

Specific assessment was performed to determine expected frequencies of ECCS breaks and IS LOCAs. The ISLOCA frequency was determined using a fault-tree-type analysis. The ISLOCA frequency counts both CS and LPCI systems and is estimated to be 3.0E-7/yr.

The ECCS breaks are estimated using generic piping failure rates per piping section. The resulting ECCS LOCA IE frequency is 1.3E-5/yr.

2.5.2.5 Conclusion

Caorso PSA brought little new development to IE definition and frequencies. The general approach is similar to many other PSAs. Some specifics worth noting are related to the ECCS piping failures. Such LOCAs are rarely considered as an individual initiator in other PSAs. Interface LOCA analysis is interesting as it develop the possible locations for interface LOCA of larger diameters, although it does not consider other (possibly smaller diameter) piping connected to the RCS.

Another interesting characteristics of Caorso PSA is that different LOCA categories are not associated with specific break sizes or leak areas. LOCAs are simply called large, medium and small LOCA and they have been defined on the basis of systems needed for their mitigation which may be confusing to a user of the study.

2.5.3 CANDU PSA - Darlington (Canada, mid eighties)

2.5.3.1 Introduction

Darlington PSA [23] was one of the first comprehensive PSA studies for CANDU reactors. It was performed by Ontario Hydro using typical standard PSA tools. However, the sheer complexity of CANDU plants and somewhat different operating principles limit the applicability of the standard PSA approaches and required their modification to CANDU specific conditions. From the perspective of LOCAs, the CANDU reactor is very different from BWRs/PWRs since instead of a single pressure vessel, it consists of hundreds of pressure pipes which could fail. In addition, every pipe has an non-welded end (for the connection of the refueling machine) which could impact the frequency of coolant leaks.

2.5.3.2 LOCA Concept

The basic LOCA concept is similar to the light water reactors, although the assessment of locations of LOCAs is much more important. The “Loss of Heat Transport Inventory” (CANDU name for RCS leaks) is developed in quite a detail and divided in losses inside and outside containment. In total 8 initiators are identified as possible LOCAs inside containment, from pipe breaks and pressure tube breaks to refueling machine leakage and end-fitting failures. It is believed that 5 initiators can lead to a loss of coolant outside the containment, including shutdown cooling/make-up and other connected systems piping (ISLOCA), SGTRs and RCP seal leakage. Some specific initiators were identified using dedicated fault tree analysis approach. The objective of this analysis was to specifically develop the possible locations for LOCAs in relation to piping failures as well as to failure of components. An example is determination of LOCA on top of the pressurizer (break in primary piping on the top of pressurizer which results in a reduction of RCS pressure and closure of the make-up valves due to high pressurizer level).

Individual initiators were grouped in LOCA groups based on the plant response and the location of the leak/breaks, which is of relevance because of its impact on the safety systems. The timing of the sequences was also taken into account when defining the LOCA groups.

2.5.3.3 LOCA Categories

The LOCA categorization closely followed the mitigating system success criteria. Event trees were developed for four LOCA categories, pressure tube failures, SGTR and end fittings failures. The LOCA categories are as follows:

Table 2.11: ***LOCA Categories in Darlington PSA***

LOCA CATEGORY	DEFINITION
LOCA 4 (Large LOCA)	Break in the heat transport system with equivalent leak above 18.000m^3/hr
LOCA 3 (Medium LOCA)	Break in the heat transport system with equivalent leak between 3.600 and 18.000 m^3/hr
LOCA 2 (Small LOCA)	Break in the heat transport system with equivalent leak between 250 and 3.600 m^3/hr
LOCA 1 (Small-small LOCA)	Break in the heat transport system with equivalent leak below 250 m^3/hr
LOCA TOP (Small LOCA at pressurizer)	An equivalent leak between 250 and 3.600 m^3/hr at the top of the pressurizer
Pressure tube failure	An equivalent leak between 3.9 and 79 m^3/hr within calandria vessel
End fitting leakage	A leak in with an equivalent flow up to 3.600 m^3/hr (LOCA 1 or 2 category) at the end fitting or at the refueling machine
SGTR “1”	A leak on the SG tube(s) within the make up capacity (up to 250 m^3/hr)
SGTR “2”	A leak on the SG tube(s) outside the make up capacity (leak rate above 250 m^3/hr)

2.5.3.4 LOCA Frequency

The general principles to determine LOCA frequency was to use operating experience for LOCAs for which the operating experience existed (small LOCAs and similar) and generic values for large LOCAs. The generic values used were adopted from the light water applications. Bayesian updating method was used to specialize LOCA frequencies for CANDU applications.

2.5.3.5 Conclusion

The basic LOCA approach used in Darlington PSA is a fairly standard one from the standpoint of the application. The characteristic of the approach is that LOCAs are not defined in terms of pipe diameters but in terms of the volume loss. However, limited information on determination of frequency did not allow an assessment if the frequencies were based on the similar approach too.

2.6 Current Commercial PSAs (1990`s)

2.6.1 US IPE program

In 1988, after several years of preparation which entailed a comprehensive discussion between utility organizations and the regulatory body, the USNRC issued the Generic letter 88-20 “Individual plant examination (IPE)” [24]requiring all licensees to perform the analysis of their plants in order to identify the plant specific vulnerabilities which may have not been identified before. In addition, the purpose of the activity specified by the 88-20 was to enhance the comprehension of the utility staff of the overall plant risks as well as specific vulnerabilities. The Generic letter left a choice to the utilities to chose the methodology for the individual plant evaluation. The choice was either a standard PSA approach, an abbreviated probabilities approach developed through a utility initiative in early eighties or some other method which would then have to be confirmed by the USNRC to be acceptable. The actual documentation for the submittal was specified in topical regulatory documents. The IPE requirements were later expanded to include the identification of the vulnerabilities to external initiators. That program was abbreviated PIE (for External Events).

Most of the utilities have chosen to use a standard PSA approach. Some opted for the abbreviated approach. As of now almost all utilities submitted their IPEs, and many submitted their IPEEEs as well. Specific submittals are being reviewed by the USNRC for their completeness, and only a few selected ones were reviewed for their overall quality. In terms of front end analyze which include LOCA, the IPEs maintained the general approaches and few if any ventured into revolutionary new approaches.

For the purpose of this document, the approach taken at Ginna NPP IPE [25] is described in the following sections. It is felt that Ginna IPE provides a good insights into the approaches for defining LOCAs and their frequency as it follows a fairly standard approaches used in other IPE submittals.

2.6.1.1 Introduction

Ginna PSA is a project undertaken to comply with USNRC generic letter 88-20, requesting a performance of an individual plant evaluation (IPE) for every operating reactor in the US. Ginna study is interesting because it was performed almost entirely by the plant’s PSA team with some assistance from a consultant. The basic PSA methods and approaches used in Ginna are modern, but proven methods. Similarly to other IPEs, Ginna used a wealth of PSA knowledge and experience gained in the US.

2.6.1.2 LOCA Concept

In Ginna IPE, the definition of LOCA initiators was established through an iterative process where the literature sources and plant experience were considered. The information sources used primarily include other PSA studies (those were assessed for their applicability) and requirement by the generic letter 88-20 (It specifically required the following LOCA categories: small-small, small, medium, large LOCA, SGTR, ISLOCA). Specific break sizes were determined on the basis of plant response to specific events and the system success criteria. Break sizes are defined as an equivalent diameter of piping on which a LOCA is to occur.

2.6.1.3 LOCA Categories

A total of 8 LOCA categories was defined in Ginna IPE. Those are:

Table 2.12: ***LOCA Categories in Ginna PSA (IPE)***

LOCA CATEGORY	DEFINITION
Very large LOCA	RPV rupture (beyond capacity of ECCS)
Large LOCA	Break of a pipe with equivalent diameter above 140 mm
Medium LOCA	Break of a pipe with equivalent diameter between 38 mm and 140mm
Small LOCA	Break of a pipe with equivalent diameter between 25 mm and 38mm
Small-small LOCA	Break of a pipe with equivalent diameter below 25mm
SGTR “A”	Full SG tube rupture in Steam generator “A”
SGTR “B”	Full SG tube rupture in Steam generator “B”
ISLOCA	All events compromising high-to-low pressure boundary

While typical LOCA categories for piping breaks were adopted, a detailed, plant specific ISLOCA analysis was performed. The ISLOCA analysis addressed specific penetrations including those related to the SI, RHR, CVCS, and sampling systems. An interesting sequence was identified where the RCP seal rupture would lead to pressurization of CCW and an ISLOCA through CCW piping outside the containment. For every penetration, various scenarios and their consequences have been evaluated in a great detail. A total of 5 penetrations were identified which could lead to an ISLOCA.

2.6.1.4 LOCA Frequency

The frequency of LOCAs for Ginna PSA was based on the EPRI methodology (EPRI 1991 report on LOCA frequencies; section #3).

Some frequencies, like RPV rupture, were adopted from other PSA studies taking some specifics of Ginna reactor vessel into consideration. The frequencies for LOCAs used in the study are:

Table 2.13: *LOCA Frequencies in Ginna PSA (IPE)*

LOCA CATEGORY	LOCA FREQUENCY
RPV rupture	1.0E-8
Large LOCA	1.8E-4
Medium LOCA	4.0E-4
Small LOCA	3.7E-4
Small-small LOCA	7.3E-4
SGTR “A”	3.7E-3
SGTR “B”	8.2E-3
ISLOCA	7.7E-6

Ginna NPP is one of very few plants worldwide which experienced a full SGTR event. This event actually impacted the way how the SGTR frequency was determined. It has been calculated on the basis of operating experience on Westinghouse and CE plants in US. Five SGTRs occurred in more than 500 years of operation (up to the time of Ginna IPE study). One of those events occurred at Ginna plant. The SGTR frequency was determined using the Bayesian updating method. Ginna event was excluded from prior distribution to avoid double counting. To account for the event which took place on one of the steam generators, the SGTR frequency has been calculated separately for each of SGs. Apparently the data evaluation team felt that one of the SG is more susceptible to the SGTR type events that the other one, and therefore the difference in the frequency of initiator was maintained.

The ISLOCA frequency was obtained by an estimate of the probability for a failure of specific configurations on relevant penetrations. A total of 4 penetrations are considered to be ISLOCA susceptible. The value in the table is an aggregate value for all penetrations.

2.6.1.5 Conclusion

Ginna PSA followed a standard US practice in defining LOCAs. While most of other LOCA events were based on the generic insights or adopted form other PSAs, significant efforts were put into identification of ISLOCA initiators. Similarly to other IPE studies, a combination of methods was used to identify possible ISLOCA locations and determine their frequencies. The frequencies of other LOCA initiators were determined using an EPRI-developed approach. The frequency of the SGTR considered Ginna specific operating experience.

2.6.2 French PSA 900 MWe

2.6.2.1 Introduction

A major PSA study for the French 900 MWe reactor series was developed by the Institute de Protection et Surete Nuclear(IPSN) in late eighties and published in 1990. The study made significant contributions to PSA methodology. One of the important issues was that it considered all plant operating modes and treated those in an integrated manner. While the basis for the approach to consider plant vulnerabilities in shutdown and low power operation had been developed in France and in US, the EPS 900 [26] (as well as EPS 1300 [27]) actually pioneered the integration of all operating modes in a single probabilistic study. Regarding the LOCA concept and development, the study followed the general practice but also introduced some specifics.

2.6.2.2 LOCA Concept

The LOCA concept basically follows the approach developed in US to define main LOCA categories. (French 900 MWe reactors have similar design concept as US three loop PWRs) The LOCA definition is based on functional response considerations. LOCAs have been considered in a total of five operating states, which include full power, intermediate shutdown, RHR cooling, mid loop operation and cavity filled. The sizing of different LOCAs is fully dependent on the operational parameters and on the thoroughly evaluated system success criteria.

In addition to standard LOCA categories, consideration has been given to various SGTRs, rupture of RPV, and intersystem LOCAs.

2.6.2.3 LOCA Categories

Standard LOCA categories basically followed the definition and even the sizes which are considered as a standard in US reactors. LOCAs are defined as for the equivalent diameter of the pipe namely:

Table 2.14: *LOCA Categories in French 900 MWe PSA Study*

LOCA CATEGORY	DEFINITION
Large LOCA	Break of a pipe with equivalent diameter larger than 150 mm
Medium LOCA	Break of a pipe with equivalent diameter between 50 and 150 mm
Small LOCA	Break of a pipe with equivalent diameter between 9,3 and 50 mm
Small-small LOCA	Break of a pipe with equivalent diameter below 9,3 mm
Pressurizer leaks	Failure of pressurizer safety valves causing a leak with equivalent diameter of 45 mm
RCP seal leak	failure of RCP seal, caused by the failure of CCW or SW systems
SGTR	Full rupture of one or two SG tubes
SGTL	Leaks of SG tubes below the automatic actuation of protection system
ISLOCA	Leak on any high-to low pressure interface point
RPV break	Catastrophic rupture of the reactor pressure vessel

All the above indicated events are defined for the operating mode which include power operation and hot shutdown. Most LOCAs are also defined for intermediate shutdown operating mode.

For the operating mode where the RHR connected and primary system closed, large, medium and small breaks are defined. Large break is specifically defined as any break with the equivalent diameter larger than 112,5 mm. During mid loop operation and with the reactor cavity flooded the only breaks considered were RHR breaks with a break size smaller than 50 mm.

SGTR of 1 or 2 tubes are considered for power operation, hot and intermediate shutdown and RHR operation with primary system closed. Small SG leaks are considered only during the power operation and hot shutdown.

2.6.2.4 LOCA Frequency Determination

The basis for the estimation of the frequency of initiating events was said to be the experience gained with the operation of nuclear power plants worldwide. For large and medium break LOCAs, the worldwide experience of “0” events has been used. For the small breaks, 2 reported events were used to determine the frequency. Very small break LOCA frequency was established on the basis of specific experience collected within the

EDF. The frequency for the opening and non-reclosure or spurious opening of the pressurizer valves were calculated using specific component operating experience.

While the frequency used for medium and large breaks are quite close to those used by other PSAs, small-small LOCA frequency which is determined on the basis of EDF experience has a rather high frequency (0.3 events per year). The probability of spurious opening of PORV or non-closing following a demand was estimated on the basis of probabilistic calculation and found to be extremely low (5.0E-5, which is lower than the large LOCA).

An interesting observation can be made when comparing the frequencies of various LOCAs in different operational states. The frequencies of all breaks are significantly reduced in operating mode B (for more than two orders of magnitude). While the break frequency is normalized per reactor year and the duration of the state B is about 1/200 of the state A, the actual frequency normalized on ‘units per hour’ basis remained the same. However, the frequency of PORV opening in operating mode B is significantly higher, actually almost 3 orders of magnitude when normalized per hour.

The failure probability for reactor vessel was based on engineering judgment taking into the consideration the results of the CEA/ Framatome/Euratom probabilistic study of propagation of flaws in RPV welds (estimated value of 3.0E-8/yr.) and frequencies of RPV rupture used in other PSAs. The value selected for RPV rupture was 1.0E-7/yr.

The only credible pathway found for the ISLOCA which would lead to loss of water outside the containment (some of IS LOCAs on RHR will end up as a break inside the containment) was the one through RHR and then PTR system. The calculated frequency of this event is about 1.0E-7/yr. A possibility of ISLOCA and simultaneous damage to SI system was also examined, but the frequency of this event is determined to be below 2E-9/yr.

2.6.2.5 Conclusions

French EPS for 900 MWe plants did not significantly improve the LOCA definitions and frequencies. A very specific characteristic of this PSA is the treatment of LOCAs in several operating modes of the plant.

2.6.3 EPS 1300 (French PSA for 1300 MWe Unit)

2.6.3.1 Introduction

The PSA for the standardized Framatome 1300 MWe unit was performed by EDF and completed in 1990. This study was performed in parallel with the 900 MWe study, so the methods and approaches used are quite similar. Although 1300 MWe units are practically identical to each other, Paluel NPP was used as a basis for modeling.

2.6.3.2 LOCA Concept

The LOCA concept in the EPS 1300 is similar to the concept employed in EPS 900. The LOCA sizes are given in pipe diameter and are adjusted for:

1) systems available to cope with a break
2) operating procedures available to operators to mitigate the sequence

Moreover, the location of the break and the possibility of isolating the break were also taken into account.

LOCAs were considered in all operating modes from full power to the n vessel. Relevant break sizes and frequencies were separately determined for different operating modes. Breaks smaller than 3/8 inches were not considered as LOCAs. They are considered to be compensable by the make-up system and therefore are not analyzed further (the frequency of these breaks is found to be 0.4/yr). Other breaks analyzed include a break of pressurizer on the steam side, which is isolable, and the accidental rod ejection which results in a break with equivalent diameter of 4.06 cm.

Similarly to EPS 900, this study considered IS LOCAs through RHR and PTR systems, safety injection systems and selected parts of make-up system.

2.6.3.3 LOCA Categories

Three basic categories of breaks were considered: small, medium and large breaks. The definition for a small break is between 9.3 and 50 mm inches, for medium between 50 and 125 mm and the large break LOCAs are defined by a break size greater than 125 mm up to the largest break size which is 900 mm.

An interesting approach taken in the EPS 1300 is that while LOCA categories have the frequency established for the entire category, every category is divided into several sub-categories. The small LOCA category is divided into break sizes below and above 25 mm, which in the accident sequence requires the use of one or the other procedure. From the plant response point of view, all breaks up to 350 mm are considered intermediate (large breaks above 350 mm have a specific plant response characteristics). This intermediate break category is subdivided into three categories, 50-75 mm, 75-125 mm and 125-350 mm. For the event of break sizes greater than 125 mm, the injection from the accumulators and the low pressure injection is automatically initiated. Breaks below and above 75 mm have a different operator response timing (20 and 10 minutes respectively).

Special attention has been placed on the SGTR initiator family. A total of 3 events has been considered. Small SGTR (leaks up to 36 m^3/hr), rupture of 1 tube (leak in the order of 110 m^3/hr) and rupture of 2 SG tubes are analyzed. Simultaneous rupture of more than two tubes was concluded to have such a low frequency that it can be neglected.

2.6.3.4 LOCA Frequencies

Similarly to EPS 900, the LOCA frequencies for this study were calculated on the basis of international operating experience and on the review of other PSA studies. The frequencies are given per reactor year and calculated separately for all five operating modes. The frequencies for power operation are similar to the EPS 900.

The frequency of control rod ejection with subsequent LOCA is estimated to be 1.0E-5/yr, and is in the same order of magnitude other PSAs have used.

Frequency of SGTR events has been determined mostly on the basis of operating experience of Westinghouse reactors worldwide. With consideration of a total of 6 separate SGTRs (single tube) which occurred worldwide, and other relevant information, the frequency of SGTR used in EPS 1300 are as follows:

Table 2.15: ***Frequency of SG related events used in French 1300 MWe PSA***

LOCA CATEGORY	FREQUENCY
SGTR (2 tubes)	1.0E-6
SGTR (1 tube)	6.0E-3
SGTL	1.0E-2

On the basis of some EDF analysis, it was demonstrated that the probability of 2 or more tube ruptures for EDF SGs is very low. (order of 1.0E-8/yr.) Therefore it was not analyzed further.

2.6.3.5 Conclusions

French EPS 1300 followed the main approaches and principles described for EPS 900.

The SGTR estimation is interesting and more comprehensive than most of the other studies conducted elsewhere. The frequency of occurrence, although said to be based on international experience, may not be applicable to all cases, as some of the SGTRs are too specific to be considered internationally.

2.6.4 Borssele PSA (The Netherlands, early nineties)

2.6.4.1 Introduction

Borssele NPP is a two loop KWU PWR reactor that began commercial operation in 1973. Its comprehensive PSA [28] program covers Level 1-3 PSA, shutdown analysis and external events. The Level 1 PSA was initially completed in 1991 and was reviewed and updated on several occasions. In its last revision a considerable time was spent developing and justifying LOCA categories and LOCA frequencies.

2.6.4.2 LOCA Concept

The standard LOCA categorization in large, medium and small exists and follows the system success criteria and the timing of the sequences. Initial Borssele LOCA categorization had 4 classes as a standard (large to very small). The later categorization added another category which is the lower part of the intermediate category.

The latest revision of Borssele PSA applied the Thomas elemental approach [29] to determine the frequency of LOCAs. The important characteristic of this technique, (which is discussed in a more detail in the LOCA frequency section), is that the LOCA frequencies are established not only on the basis of the pipe diameter but considering the range of other factors. In specific case, instead of associating the LOCA size with the diameter of a LOCA susceptible piping, the probability of leakage (up to the full diameter) of various LOCA categories was postulated on every pipe.

The whole analysis process is based on a detailed evaluation of the design and layout of the LOCA susceptible piping (including welds, connections etc.). Another very important characteristic of the LOCA concept in Borssele PSA the consideration of the possible leaks through components which are part of the RCS pressure boundary.

2.6.4.3 LOCA Categories

The basic LOCA categories used in the Borssele PSA correspond to those in other PSAs. The LOCA sizes are defined in terms of leak area, and specific LOCA categories are as follows:

Table 2.16: *LOCA Categories in Borssele PSA study*

LOCA CATEGORY	DEFINITION
Large LOCA	Loss of coolant with leak area greater than 20.000 mm^2
Medium LOCA #1	Loss of coolant with leak area between 10.000 and 20.000 mm^2
Medium LOCA #2	Loss of coolant with leak area between 2.500 and 10.000 mm^2
Small LOCA	Loss of coolant with leak area between 100 and 2.500 mm^2 This LOCA category include IORV and other relief valve related failures
Very small LOCA	Loss of coolant with leak area between 10 and 100 mm^2
SGTR (single)	Full rupture of one SG tube
SGTR (multiple)	Rupture of more than one SG tube
ISLOCA	Leak on any high-to low pressure interface point

2.6.4.4 LOCA Frequency Estimation

The classes of LOCAs considered in Borssele PSA include leaks and ruptures on piping, (including welds) leaks and ruptures of components and inadvertent opening of safety and relief valves. First presented in 1980, the Thomas model has not been widely used to establish LOCA frequencies for PSAs. Combined-technique-Thomas approach was used for piping leaks and breaks, generic data for components leaks and review of operating experience of KWU NPPs for SGTRs.

The Thomas technique used for determining the frequency of leaks and breaks on piping allowed the consideration of piping-specific parameters. When using this approach, a leak or rupture frequency for every pipe segment can be developed. As every segment of a pipe can either leak or break and thus contributes to various LOCA categories, probabilities were determined depending of the resulting leak size. The contribution of an individual pipe segment to a specific category was based on a formula which considered the diameter and the thickness of a pipe. Using this formula and the pre-assigned pipe failure probability, contributions to various LOCA categories were determined. For the leakage failures the general Thomas formula is:

$$P_L \sim 10^{-7}\, Q_e\, F$$

where P_L is the probability of leakage failure, Q_e is the total equivalent size and shape factor (which considers influence of pipe length, diameter, thickness etc. for both base metal and welds) and F is the plant age factor which could be read directly from the tables. The ratio P_C/P_L where P_C is the probability of catastrophic rupture may be determined using statistics of the fracture mechanics model.

As a basic estimator of pipe failure probability, a literature value has been used (1.0E-8/yr for general and 1.0E-9/yr for larger piping) and by using the Thomas equation, contributors to various LOCA categories were established for hundreds of piping segments.

Leaks and breaks at components were established as contributors to various categories of LOCAs. It was concluded that the rupture of most components (actually all except the pressurizer) has a very low frequency and therefore could be neglected. The leaks on components are more frequent, but those were assumed to contribute only to the category of very small LOCAs.

The resulting frequencies generated using the Thomas model are as follows (including both piping and components contribution):

Table 2.17: ***LOCA Frequencies in Borssele PSA***

LOCA CATEGORY	LOCA FREQUENCY
Large LOCA	1.4E-5
Medium LOCA #1	5.4E-6
Medium LOCA #2	3.0E-5r
Small LOCA	2.4E-3
Very small LOCA	7.9E-3
SGTR (one tube)	1.5E-3

2.6.4.5 Conclusion

Borssele PSA is a good example on how the determination of LOCA frequency using different methods may impact the overall results of PSA. The old values (determined by adopting the values from other PSAs) were in some categories significantly lower (large LOCA) or higher (medium LOCA) than those determined by the systematic application of the Thomas model.

Borssele PSA is one of the premier application of the Thomas approach in PSA. The resulting LOCA frequencies appear to be more realistic than otherwise. Borssele PSA is also the initial study to comprehensively analyze the impact of the components leakage or breaks and their contribution to the LOCA frequency. Borssele PSA LOCA analysis can, by many account, be seen as a pioneering work in defining of LOCAs and in determining more realistic LOCA frequencies.

2.6.5 Doel 1, 2 and Tihange 1 PSA (Belgium, mid nineties)

2.6.5.1 Introduction

The common PSA project Doel 1 and 2 and Tihange 1 [30] was the first major PSA in Belgium performed as a part of the periodic safety reevaluation. The study, which includes all operating modes, was completed in mid 1995. The LOCA approach covers an extensive range of possible breaks or leaks. The LOCA frequencies, however, are largely based on generic sources. The same approach is used for other Belgian PSAs (Doel 4 and Tihange 3).

2.6.5.2 LOCA Concept

As the general principle, the LOCA categories in Belgian PSAs are plant specific and are determined on the basis of the success criteria. The general principle is to determine an initiator which is representative for the whole IE category. The Doel - Tihange study addressed the whole spectrum of LOCAs other than pipe breaks, including pump seal LOCA, control rod ejection, IORV, SGTR and various IS LOCAs. The LOCAs categories related to pipe breaks are established in terms of equivalent pipe diameters. The very small breaks are defined by the equivalent leak area. The general approach for both LOCA identification and determination of frequency is a fairly standard one, but has some specifics which are discussed in subsequent sections.

2.6.5.3 LOCA Categories

Most of the PSA studies performed worldwide considered 3 LOCA classes (large, intermediate, small). Belgian PSAs defined only two classes, large and small LOCA with an equivalent pipe diameter of 75 mm defining the border between those (It has to be noted that the sizing of the large LOCA was based on an extensive thermal-hydraulic analysis which justified avoidance of the medium LOCA category). Each of these LOCA categories include several specific initiating events.

The large LOCA category includes the breaks of large piping and control rod ejection. The large piping break is a generic LOCA, defined as a break of the primary system above the midplane of the core. It includes all breaks on piping from 75 mm up to the double ended guillotine break of the largest primary pipe. A single control rod ejection during power operation will not result in a serious reactivity addition (because the rods are almost completely pulled out of the core) but will cause a rupture in the pressure boundary with equivalent diameter of about 100 mm.

Small break LOCA is any break between 7.5 and 75 mm. A break smaller than 7.5 mm is within the capacity of the make-up system, and therefore not analyzed further. All small LOCA initiators are considered. The plant response analysis is not sensitive enough to the break location to justify separating specific locations in unique categories. In addition to pipe breaks, the small LOCA category includes IORV, RCP seal LOCA and incore instrumentation thimble rupture. IORV is defined as a consequential event where a transient causes the relief valve to open. The relief valve then does not reclose nor the block valve closes. It results in an 38 mm LOCA. The RCP seal LOCA may be either an induced event or a real IE. The size of LOCA through RCP seals is up to 14 mm or 68,4 m^3 equivalent flow (per pump). The thimble LOCA is a rather unusual LOCA which, because of its location, may not be apparent to operators. The importance of this LOCA is high for the long term cooling mode. The size of break is estimated to be 38 mm.

Interfacing LOCA has been analyzed through an assessment of all possible pathways. Only one broad ISLOCA category was modeled, but many specific locations are included. The analysis of the ISLOCA is limited to power operation as in other modes different flow alignments preclude that LOCA. Failures of mechanical components and human errors which can cause IS LOCAs were considered together with the common cause failures.

Steam generators tube rupture category includes several individual initiators and it is bounded by a break of 2 SG tubes. The SG tube rupture is also considered as a consequential event to the steam or feedwater line break (conditional SGTR for SLB is 2.0E-2/yr).

2.6.5.4 LOCA Frequency

The LOCA frequency is to a large extent based on generic data, engineering judgment and previous PSAs.

The frequency of a break between 75 and 200 mm equivalent diameter is based on arithmetic averaging of values used in NUREG 1150 and EPS 1300. For breaks larger than 200 mm, the German Risk Study value was used. In this category the control rod ejection is also considered, frequency of which was adopted from French EPS. The total large LOCA frequency is thus 6E-4/yr.

The small break LOCA frequency was determined by an arithmetic averaging of the values for small LOCA found in NUREG 1150, German Risk Study and French EPS 1300 (Note: the sizes of breaks in those studies are different than in Belgian PSA) The value used was 2E-3/yr. (the small LOCA was divided into two subcategories below and above 38 mm.)

Other initiators in small LOCA category include rupture of RCP seal (which can be due to mechanical failures, pressure transients, degradation, maintenance induced errors and impurities in the coolant). The contribution to the small LOCA category from RCP seal leak is 1E-3 based on the engineering judgment.

A comprehensive analysis was performed on SEBIM PORVs and determined that the probability of the IORV is 2.3E-5 /yr. This takes into account the possibility to isolate the leak through closure of the block valves. The frequency of rupture of incore instrumentation thimble is found to be negligible.

The combined frequency of small LOCA in this study is 3E-3/yr.

The SGTR frequency is calculated using prior generic data and the operating experience from Doel NPP where a SG tube ruptured some time ago. The prior frequency was determined on the basis of the German Risk Study (6.5E-3/yr.) and EPS 1300 (6E-3/yr.). The resulting frequency used in the study is 8.6E-3/yr.

In summary, frequencies of specific LOCA events used in Doel 1 and 2 and Tihange 1 PSA are as follows:

Table 2.18: ***LOCA Frequencies in Doel 1,2 and Tihange 1 PSA***

LOCA CATEGORY	LOCA FREQUENCY
Large LOCA (75-200 mm)	5.8E-4
Large LOCA (above 200 mm)	1.0E-7
Large LOCA (Rod ejection-100 mm break)	5.8E-4
Small LOCA #1 (below 38 mm)	1.3E-3
Small LOCA #2 (above 38 mm)	7.6E-4
Small LOCA (RCP seal leak)	1.0E-3
Small LOCA (IORV)	2.3 E-5
Small LOCA (thimble tube leak)	negligible
SGTR	8.6E-3

2.6.5.5 Conclusion

Although the basic approach to LOCA definition is a standard one (especially for piping LOCA) Belgian studies attempted to define other LOCAs which may be of interest and of relevance from the PSA perspective. These include discussion on ISLOCA, RCP seal LOCA and incore instrumentation thimbles (the only known PSA which addressed those). The determination of frequency is rather conservative and mostly uses generic frequencies.

A specifics of the Belgian approach is the definition of only two LOCA categories (small and large LOCAs), and the neglecting of small-small LOCA (similar to French PSAs). Justification of only two LOCA classes was found in the plant specific thermal-hydraulic analysis.

2.6.6 Spanish PSA Studies (late eighties / early nineties)

In Spain PSAs are required for all operational reactors.

Almaraz and Zorita NPPs (Westinghouse PWR) defined standard small, medium and large LOCAs. ASCO and Vandellos 2 (also Westinghouse PWRs) in addition defined a very small LOCA (which in terms of sizes basically divided the small LOCA into two categories). In addition, Vandellos defined a very large LOCA which has a break size of the pipe with more than 187.5 mm diameter [31]. All the LOCA sizes in the mentioned studies are expressed in terms of pipe diameters.

For Trillo (KWU PWR) a total of 6 categories of LOCAs was defined. LOCA categories and equivalent sizes in Trillo PSA are as follows:

Table 2.19: ***LOCA Categories at Trillo NPP***

LOCA CATEGORY	BREAK SIZE
Large LOCA	beyond 220 mm. diameter
Medium LOCA	between 160 and 220 mm. diameter
Small LOCA	between 50 and 160 mm. diameter
Very Small LOCA	between 16 and 50 mm. diameter
RCS Leakage	between 11.3 and 16 mm. diameter
LOCA on Pressurizer	between 50 and 160 mm. diameter

Two BWR plants used a typical US definition for LOCA categories, which are defined in terms of leak area for either water or steam leaks. Small, medium and large LOCA were defined for Garona and Confrentes NPPs.

Determination of frequency of LOCAs has been performed on the basis of generic data and using the previous PSAs as sources. Some engineering judgment and some limited operating experience has also been used. As all studies are still undergoing a regulatory review, the frequencies of LOCAs are not available.

2.6.7 Sizewell B PSA (UK, early nineties)

Sizewell B PSA is one of the most comprehensive NPP PSA project ever undertaken. The project was performed in 3 phases: conceptual design, detailed design and construction phase of the plant. The PSA was used in the design phase to decide between possible design alternatives. As the outcome of this preliminary PSA (and some additional analysis), Sizewell B safety systems include added redundancy and diversity (e.g. redundant diesel driven charging pumps for RCP seals injection).

The LOCA concept, followed the typical approaches with some interesting adjustments.

The LOCA categories used in the Sizewell B PSA include 5 basic piping LOCAs, a set of SGTR events and a spectrum of IS LOCAs. Several LOCAs have subcategories depending on the size and location of the leak/break. The LOCA categorization is fully related to the plant response (success criteria) and to the location of the leak/break, especially in terms of the damage which may have been caused to other systems/components (CVCS, RHR etc.) The approach for the definition of LOCAs is somewhat unusual, as different LOCAs are defined in terms of the equivalent pipe diameter, flow area and sometimes in terms of mass leakage (kg/s or gpm). The LOCA categories and associated sizes are as follows:

Table 2.20: ***LOCA Categories in Sizewell B PSA***

LOCA CATEGORY	DEFINITION
Large LOCA	Loss of coolant with flow area greater than 46.500 mm^2.
Medium LOCA	Loss of coolant with an equivalent diameter greater than 125 mm and flow area less than 46.500 mm^2.
Intermediate LOCA	Break of piping with equivalent diameter between 25 mm and 125 mm
Small LOCA	Break of piping with equivalent diameter between 9,3 and 25 mm
Very small LOCA 4	Breaks within the capacity of make up system
RCP seal leak	Leak through an equivalent diameter of 9.3 mm
IORV	Loss of coolant with opening greater than 25 mm equivalent diameter
RCS leakages via sampling lines	equivalent flow between 1.8 and 4.3 m^3/hr
RCS leakages via CVCS#1	equivalent flow less than 1.8 m^3/hr
RCS leakages via CVCS#2	equivalent flow lebetween1.8 and 27 m^3/hr
ISLOCA	leakage on the high-to-low pressure boundary
SGTR	Full rupture of one SG tube

LOCA frequency determination for Sizewell B PSA was fully based on the literature sources. Sources reviewed include US and French sources and various databases. The exact values used in PSAs are not yet available as those are considered proprietary to the company.

3. LOCA VERSUS PIPE BREAK

3.1 Historical Definition

When initial commercial nuclear reactors were constructed, a limited experience with piping materials existed. This is especially true for piping material which is subject to specific pressures and temperatures as well as to radiation. The historical data on both piping and vessel subject to such conditions were limited. Nevertheless the operational experience appeared to indicate that the probability of piping failures is (much) higher than the probability of a vessel failure. Consequently, the LOCA accidents were mainly associated with ruptures of piping. The rupture of the reactor vessel (as well as the other vessels) was considered improbable, because of its design and the construction. [32], [33].

Breaks of other pipes being a part of or being connected to the reactor cooling system pressure boundary were also considered less important because in a standard accident analysis those would result in a less challenging accident sequence.

The overall safety importance of the large LOCA was challenged by PSA studies, WASH-1400 and the others, which showed that the core damage accident would more likely be caused by a small than a large LOCA event. This was further supported by the TMI accident in 1979. The probabilistic approaches, where all initiators are considered possible (although with varying probability) indicated the need form more emphasis on other LOCA sources. [34], [35], [36], [37], [38] [39], [40], [41], [42], [43], [44].

The purpose of this chapter is to discuss review the possible locations of LOCAs on a variety of components forming a pressure boundary of the reactor coolant system. The discussion in subsequent sections is aimed at establishing the basis for a more comprehensive identification of possible locations for LOCAs. In addition, the consideration of various locations/sources of LOCA in current PSAs is assessed in the last section of this chapter.

3.2 Other LOCA Cases

While LOCA caused by a break or a leak of piping still dominates the LOCA considerations, over the last years investigations were undertaken to identify possible loss of coolant accidents caused by breaks or malfunctions of a variety of components which are either part of the pressure boundary or which are connected to the RCS. The general approach and the current thinking tends to thoroughly assess a variety of possible LOCA initiators, from RCS piping and vessels, other piping connected to the RCS and a spectrum of components being a part of the RCS pressure boundary.

The following is the discussion of selected examples which includes specific events that could occur on different component types which form the pressure boundary. For each of the possible sources of LOCA, the importance in terms of number of components and their probability to fail in terms of reported events or experience, treatment of such initiators in PSAs and conclusions on the adequacy of treatment are discussed. For each specific component type, the impact on LOCA caused by different material, thermal processes and operating regimes is discussed. (The discussion here is limited to light water reactors)

3.2.1 LOCA on Vessels

3.2.1.1 Reactor Pressure Vessel

The failure of a reactor pressure vessel has never been considered as a design basis accident for commercial nuclear power plants. In fact, the failure of a pressure vessel is expected to lead directly to core damage, as the emergency core cooling systems are generally unable to cope with such an event. The reactor pressure vessel in NPP is designed and manufactured in a way to withstand the pressure, temperature and neutron bombardments throughout the lifetime of a plant. Stringent quality controls makes vessels failure highly unlikely.

COMPONENT TYPE	**REACTOR PRESSURE VESSEL**
Probability of failure	Low
Consequences of failure	High/not manageable
Operating experience	No critical failure experienced
Failure mechanisms	Some are known e.g. embrittlement
Treatment in PSAs	Addressed in some PSAs
LOCA category	RPV rupture

Older design RPVs for PWR type reactors were made of bend plates and had welds in the core region. Newer vessels are made of forged rings and do not have welds in the regions of the high neutron flux. It is believed (and it has been proved) that the material of welds is much more susceptible to failures than the base metal of the vessel. That is mostly due to the composition of weld material which, especially in the older vessels, has significant impurities.

The most important problem with the RPV is an increase in its brittleness with neutron bombardment. The Nill Ductility Temperature (NDT) where the metal changes from ductile to brittle, has been observed to be increasing with age and with the integrated neutron flux. At some RPVs it is believed to have reached values above hundred of degrees Celsius. The annealing is a process where by heating the vessel to the temperature above 400 ^{O}C, and keeping it at that temperature for several days, the accumulated stresses in the vessel material are relieved and the Nill ductility temperature reduced. The only commercially undertaken annealing activities were undertaken on the Soviet designed WWER reactors, mainly to reduce very high NDT points which were partially due to (relatively) high impurities in the vessel metal. The annealing has been completed on about half a dozen vessels. The reported results of the annealing process indicate significant reduction of the NDT, and though that is being disputed by some scientists.

If the vessel failures due to undiscovered manufacturing errors are ignored (because of its low likelihood), the critical operating condition for RPVs is the cold over-pressurization, where because of elevated NDT, a vessel could become brittle under the high pressure. Although no vessel failure has occurred, cold over-pressurization have been experienced at several NPPs. Typically, a human error or a wrong test procedure could be the cause of such an event (an event with such characteristics occurred at Oskarsham 3 NPP in 1987). Another important event is the transient where the cold water injected into the vessel (due to operation of Emergency core cooling system) causes a local thermal stress. Additional scenario in which a RPV could fail catastrophically is the power surge from the hot shutdown or other non power mode. The analytical results indicate that during a power surge the maximum pressure reached (at least for German reactors) is below the maximum pressure the RPV is able to withstand.

The probability of a failure of the RPV is low.. The probability of a LOCA caused by RPV failing while the plant is in full power operating mode is generally very low. The consequences, however, are very serious and have probably off site effects, too. (because no protection is available) The probability of a failure due to cold over-pressurization or cold water injection is higher but still commonly considered lower than other sources of LOCA.

The treatment of RPV failures in PSA varies. Early PSAs considered the RPV failure with a rather low probability (probability RPV failure was equal to the probability of core damage), so it did not contribute visibly to the overall CDF. Many of newer PSAs simply ignored RPV sequence for full power operating mode because of its low importance.

Major low power and shutdown PSA studies considered the cold over-pressurization sequences, although the probability of the vessel rupture is not determined consistently. Some conservative results seem to indicate that the RPV failure in the described conditions can be a problem and can contribute to the overall CDF. A failure due to cold water injection is possible for the older vessels, but very few PSAs ever considered it. The power surge at standby/low power has been analyzed in at least one PSA but the results appear to indicate that there is no immediate problem.

The RPV failure is clearly not the highly important LOCA event from the perspective of the probability of event. However, the consequence (an obvious core damage) indicates that there is a need for a careful consideration. The RPV failure may be an important issue for plants with older vessels (with high NDT and core region welds) and for the specific operating modes like startup.

3.2.1.2 Other Vessels

In PWR reactors the pressurizer as a part of the RCS is another vessel of relevance for the LOCA considerations. Typically the pressurizer is of the same material as the primary piping and is relatively easy to inspect and maintain. Specific concerns regarding the integrity of the pressurizer is not usual. A pressurizer has several important connections, which may have an impact on its failure rate. Those include electric heaters and the spray connections as well as safety and relief valves at the top. There is also a surge line connection. Stresses may be present around those areas, because of temperature gradients and thermal expansion effects. The thermal as well as mechanical stresses are believed to occur during specific transients.

While the pressurizer contains a steam bubble which absorbs pressure surges, its critical state is the water solid condition before a steam bubble is formed. During this period (startup of a reactor), the pressurizer as well as the rest of the RCS is vulnerable to the over-pressure. Recently, severe cracks were found around sleeves of pressurizer heaters in some plants. Those, if unattended, may have results in through wall cracks with possible leaks or even major ruptures in the body of the pressurizer.

COMPONENT TYPE	PRESSURIZER
Probability of failure	Low
Consequences of failure	High/manageable
Operating experience	No failure; several precursors
Failure mechanisms	known; others possible
Treatment in PSAs	very few
LOCA category	large LOCA

Pressurizer failure is typically an accident which is comparable to a medium or large LOCA. In the case of a pressurizer failure, the surge line (typically 200 mm) limits the flow rate. Rupture of the pressurizer would actually cause a simultaneous leak from a cold leg and a hot leg and therefore complicates the accident mitigation.

The operational experience confirms that there were no catastrophic failures of the pressurizer vessel reported. There have been, however, lots of failures of components which are typically considered a part of the pressurizer boundary. Some of those failures would give a rise to LOCA events, and those usually contribute to the small LOCA category.

Only one PSA is known to have looked into the pressurizer failure. The results indicated that the failure of the pressurizer is a visible contributor to the LOCA family of core damage sequences.

3.2.2 LOCA through Piping

3.2.2.1 RCS Piping

The RCS piping is mostly of large diameter, and consists of numerous straight pieces, several bends and elbows and many welds. The RCS piping has numerous junctions and tees allowing the penetration of a variety of piping (from testing connections to safety and support systems’ connections).

COMPONENT TYPE	RCS PIPING
Probability of failure	Low
Consequences of failure	High/manageable
Operating experience	No failures; many precursors; some serious
Failure mechanisms	Many; known
Treatment in PSAs	included in all
LOCA category	Type dependent (large/medium LOCA)

The sensitive parts of the RCS piping are welds and junctions. Straight pieces and bends are typically fabricated in a manufacturing facility and thoroughly tested before installation. Typically the straight pipe runs and bends are not particularly susceptible to any specific failure mechanism (apart from those which are purely material related) and are generally believed to have a low failure probability.

Welds in the RCS piping, although being thoroughly controlled and inspected, have a significantly higher probability for failing than the base metal. Various literature sources indicate factors of 30-50 (the latter one is recommended by Thomas for his approach) and up to a factor of 90 increased probability of failure for the welds. The area of increased probability of failure also applies to the metal adjoining welds, which can be affected by heat during the welding process. Due to thermal as well as mechanical stress, nozzles on the reactor vessel are considered to be critical items for some reactor designs.

Another potentially problematic area in the RCS piping is the large bore junctions with ECCS and other piping. In addition to thermal and mechanical stresses experienced during the manufacturing processes, these areas are affected by the thermal stratification because of a stagnant and cold water in the ECCS piping. Moreover, this piping as well as the pressurizer surge line may be affected by the cracking caused by stagnant borated water and other corrosion related phenomena. The table below summarizes the failure mechanisms observed form the SLAP data base. [45].

Failure mechanisms relevant for piping in SLAP data base	Occurrence in %
Cavitation/Erosion	0.7 %
Corrosion	8.6 %
Corrosion/Fatigue	1.0 %
Erosion	3.5 %
Erosion/corrosion	19.9 %
Fatigue	2.2 %
Fretting	0.0 %
IGSCC	12.8 %
SCC	7.8 %
Vibration fatigue	35.0 %
Water hammer	4.6 %
Thermal fatigue	3.9 %

In the history of commercial nuclear reactors, no catastrophic failure of large RCS piping has ever been experienced. There were, however, numerous indications or failure precursors in form of cracks of various sizes and depths. Existence of those cracks indicate that there is a probability of failure. However, considering the operational experience and the overall quality control applied, a careful selection (and occasional replacement) of materials, as well as prompt repair of cracks and indications when those are identified, it appears that the probability for failure of piping in RCS is low. Nevertheless, depending on the design of the piping, there are sections of the piping systems that cannot be tested nor examined. From the PSA perspective, those segments are expected to be the risk dominant ones.

All PSAs considered the probability of RCS piping failure. The approach varies. Some PSAs developed a more detailed quantification counting the number of segments of piping. The majority simply assumed that the probability of a failure in the RCS piping is equal to a predetermined value in terms of events per year. PSAs like DRS-B used probabilistic fracture mechanics and LBB criteria to justify a rather low pipe rupture frequency.

The consequences of a LOCA on this type of components are in general low, as all plants are generally well protected for the case of rupture of RCS piping. The low frequency of event and the high probability of successful mitigation, makes the contribution caused by a RCS piping LOCA to the overall CDF low in most PSAs.

3.2.2.2 ECCS Piping

COMPONENT TYPE	ECCS PIPING
Probability of failure	low/moderate
Consequences of failure	Moderate/manageable
Operating experience	No ruptures, some major leaks, many precursors
Failure mechanisms	Many/known
Treatment in PSAs	Rarely explicitly
LOCA category	Type dependent/ small, medium, large LOCA

A typical light water reactor has a significant length of ECCS piping with an open connection to the RCS. This piping is connected to the RCS piping through tees or similar junctions at various points. The other end of the piping is closed by isolation valves which are either check valves or MOVs. The ECCS piping is typically of large diameter. Parts of it may be medium and in specific cases even a small bore piping (RPV head injection in some designs). In some cases, ECCS piping may have flow limiters.

The failure probability for straight segments and bends is lower than for welds and various junctions. Thermal or mechanically stressed parts may have an increased failure rate. Junctions with RCS suffer from thermal stratification and related phenomena. Corrosion caused by a stagnant borated water may be an important failure mechanism in selected ECCS piping, especially those related to accumulators. Specific failure mechanisms may be due to mechanical stress caused by thermal elongation and during the operation of ECCS pumps, valve scatter or flow induced vibration.

No event of a catastrophic failure of the ECCS piping has been reported internationally. Similarly to the RCS piping, numerous precursors in terms of cracks have been observed. Some major leaks from the ECCS have also been observed. Well publicized are the causes related to the thermal stratification at the junction between ECCS and RCS piping.

Few PSAs considered failure of ECCS piping as a separate initiator. Because of their diameter, ECCS piping usually contributes to large and medium LOCA categories (specific parts of those piping may contribute to Small LOCA). Some PSA studies took account of ECCS piping by counting its segments. Although the failure which is induced by valve vibration is an observed failure mechanism (though not on the ECCS piping) no PSA ever specifically considered this failure.

The general probability for a failure in the ECCS piping is comparable (possibly somewhat higher due to specific failure mechanisms) to the RCS piping. Although there are some specific failure modes which appear to affect only this piping, significantly higher values do not appear to be justified.

The consequences of the ECCS piping failures are somewhat more difficult than those of the RCS piping, because in addition to failing the pressure boundary, a break of the ECCS piping will disable one or more trains of the mitigation system making the event a typical Common Cause initiator (CCI).

3.2.2.3 CVCS Piping

COMPONENT TYPE	CVCS PIPING
Probability of failure	moderate
Consequences of failure	moderate/low and manageable
Operating experience	Some failures (isolable) leaks and precursors
Failure mechanisms	many known
Treatment in PSAs	not explicitly
LOCA category	Type dependent small/medium LOCA

The CVCS piping is less in quantify and usually also in size than ECCS piping. Usually there are about two letdown connections and two charging connections to the RCS. Typically the CVCS piping is of medium and often small diameter category. In some cases, these connections may be routed to same entry point to the RCS as the ECCS piping.

While many other characteristics of CVCS piping may be similar to ECCS (discussion on straight vs. welds and tees), this piping has a continuous flow of water through it. It is therefore not affected by the corrosion of stagnant borated water nor by thermal stratification. In the case of two CVCS connections with just one in operation, the other one may show the same characteristic/problems which have been discussed above for the ECCS piping. The operating connections may be more affected by stress and/or fatigue related to the vibration caused by CVCS pumps or vibrating valves. This is especially the case with plants using piston type or similar positive displacement pumps, which were observed to cause a significant vibration in the connected pipework. If the vibration is continuous, the aging phenomena related to a low frequency fatigue may become an important failure mechanism.

Orifices, heat exchangers and other components in the CVCS flow path may have additional problems related to the vibration, thermal and mechanical stresses. From the LOCA perspective those are of less interest since it is rather easy to isolate those by using isolation valves. Therefore, only the CVCS piping in between isolation valves and the RCS is of relevance.

No event of a catastrophic failure in the CVCS piping after the isolation valves has been reported on commercial reactors. Precursors in form of cracks with various sizes have been reported. Several events of damaged piping due to the vibration caused by pumps (in particular PDPs) have been reported, too.

The contribution to overall CDF from a LOCA out of this category is considered low because most of this piping is isolable and the catastrophic failure frequency is not expected to be significantly higher than for ECCS or RCS piping. Similarly to ECCS, the failure of this piping may be a CCI at some plants where CVCS is in function of high pressure injection system.

3.2.2.4 Instrumentation Lines

If considered their length, the instrumentation/testing/drainage and similar lines are the most of the RCS-connected piping. This piping is typically small bore, starting as low as 1 cm and up to 3-4 cm on most reactors. The instrumentation piping is connected to the primary circuit at various points. Some of the instrumentation lines have flow limiters and many of them also have manual valves installed, which are close to the primary circuit.

COMPONENT TYPE	INSTRUMENTATION LINES
Probability of failure	Medium/high
Consequences of failure	Low/moderate
Operating experience	Several failures, many leaks
Failure mechanisms	Many-known
Treatment in PSAs	Not explicitly
LOCA category	Small/Very small LOCA

The small bore piping like instrumentation lines usually has the diameter to thickness ratio which makes the piping rather strong. The small bore piping normally is not inspected as thoroughly as the RCS piping.

The dominant failure causes for some instrumentation lines appear to be the vibration and related mechanical impacts, stresses and fatigue. In some cases, the corrosion is also an important contributor. Most of the instrumentation lines do not have a flow through (except for temperature measurement) and inside those, the corrosion due to stagnant borated water and the accumulation of particles may be an important failure mode. Similarly, thermal stratification effects in the area where the instrumentation lines join the RCS are important.

With small bore instrumentation lines, it is expected that most of the failures will be sudden and complete. There may be, however, some leaks or incomplete breaks especially next to welds and connections of valves or flanges.

In commercial nuclear reactors several severance of instrumentation, test or drain lines have been observed which resulted in loss of coolant accidents. The small leaks from such piping actually happen quite often (in relative terms) and those are usually manageable by standard operating procedures.

Due to a high frequency of initiating events, small LOCAs could be a higher contributors to the core damage frequency than large or medium LOCAs. In fact some plants found that small LOCAs dominate the overall CDF results. The actual categorization varies considerably. Usually older PSAs consider just one small LOCA category which is a

LOCA beyond the normal make-up capacity. More recent PSAs also consider small-small (or very small) LOCA category which is considered to be within the make-up capacity but still can initiate a core damage sequence. Few PSAs define several categories of small LOCAs (e.g. DRS-B defined 5 small LOCA categories) to take into account the different timing of specific sequences.

3.2.2.5 Pressurizer Piping

In addition to the pressurizer surge line, (which is discussed as a part of the RCS piping), a pressurizer on PWRs is connected to the RCS through spray lines. Those lines as well as lines which some designs have in between the pressurizer vessel and the relief valve, are connected to the steam side of the pressurize. The pipes are usually small to medium size (between 3 and 10 cm diameter), and their length varies.

As with other piping, there is a possibility for these pipes to break or to leak, and therefore they can cause a LOCA (Steam LOCA). The failure mechanisms for this piping include mechanical stress and fatigue, as well as vibration in case of longer and/or poorly supported pipes. Another cause of vibration may be a malfunctioning valve on the pressurizer spray lines. Intermittent flow through the spray lines can eventually lead to a temperature caused fatigue.

COMPONENT TYPE	PRESSURIZER SPAY/RELIEF LINES
Probability of failure	Moderate
Consequences of failure	moderate/high
Operating experience	No full ruptures, some leaks, many precursors
Failure mechanisms	Many. known
Treatment in PSAs	Generally no, some PSA considered
LOCA category	Small LOCA (steam side)

No event with full severance of a pressurizer spray line has been reported. There have been some leaks on such lines; also cracks and similar precursors have been observed.

The consequences of this event are up to a certain extent similar to any other LOCA of the same size, except that the pressurizer will loose its function. Selected breaks on the pressurizer spray lines can be isolated by remote controlled isolation valves. The breaks of the piping to PORVs cannot be isolated.

PSAs seldom consider this type of breaks specifically. This LOCA type is usually lumped together with other breaks of the same LOCA category. Because of a different accident sequence and due to possibly increased failure probability of the pressurizer spray lines, at least one PSA found the pressurizer (steam space) LOCA to be the dominant LOCA contributor.

3.2.3 LOCA through Safety and Relief Valves

The inadvertent opening of a relief valve can result in a LOCA. Inadvertent opening of relief valves on the pressurizer for PWRs and on the depressurization system on BWRs directly causes a LOCA event.

COMPONENT TYPE	SAFETY/RELIEF VALVES
Probability of failure	High/Moderate
Consequences of failure	Low/moderate
Operating experience	Several IORV, several failures to reclose
Failure mechanisms	Known, many
Treatment in PSAs	mostly explicit
LOCA category	IORV

The opening of the relief valves can be caused by a malfunction of the valve itself, or by a break in the valve body. In addition, various leaks through the valve and to the outside are possible. Another important LOCA related to the relief valves is the failure to reclose after an opening during a transient. This is then an induced-LOCA sequence.

Typically reactors have a wide variety of relief valves connected to the primary circuit, from simple spring loaded to sophisticated pilot driven valves. Therefore, the failure mechanisms for those valves are as different as their designs and need to be investigated on a case by case basis. It is also important to account for a relief valve which has a remote controlled block valve to prevent from flow (a LOCA in this case) in case of an inadvertent opening or leakage from the main valve.

Numerous inadvertent openings of relief valves have been reported internationally. Some of those have been blocked by block valves, some smaller ones allowed a safe reactor shutdown, whereas the others have caused a reactor trip. Also several events have been reported with valves stuck opened or not reseated fully after the pressure relief, which has been caused by a transient. The well known case was the TMI accident in 1979 where a stuck open relief valve was the major contributor to the whole accident sequence. Another event of interest is a blown rupture disk at safety valves which occurred in Sweden in 1992.

Although the probability for inadvertent opening of an isolation valve is definitely higher than the probability for a catastrophic break of a pipe, for those valves where a block valve can isolate the leak, the contribution to overall CDF is relatively low. For plants where the flow cannot be blocked, the probability for opening is usually somewhat higher than the probability for a pipe break LOCA of the same size. The contribution of the sequence with IORV to the overall CDF is usually found to be comparable to those of a small LOCA.

Early PSAs did not model an inadvertent opening of relief valves as a separate event. As the flow area of relief valves typically corresponds to the upper end of the small LOCA category, many of the early PSAs consider this event as a contributor to the small LOCA category. Actually the leak size of the relief valve in some cases defines the upper limit of the small LOCAs. Later PSAs recognized that an inadvertent opening of a relief valve and the possibility to isolate a leak by using the block valve may be significantly different from a pipe rupture.

3.2.4 LOCA Related to RCP and the Recirculation Pumps

COMPONENT TYPE	RCP/RECIRC PUMPS
Probability of failure	Moderate
Consequences of failure	low
Operating experience	Leaks were experienced
Failure mechanisms	Known
Treatment in PSAs	Rarely explicit, often as a consequential failure
LOCA category	Small LOCA/RCP seal LOCA

The forced circulation of a coolant in the core is maintained by the reactor coolant pumps at PWRs and by the recirculation pumps at BWRs. PWRs typically have one pump per loop. The pump housing is part of the primary pressure boundary and its failure is considered to be less probable than the failure of the primary piping. The effect on the RCS is similar. However, this does not include a possibility of disintegration of the impeller or the pump shaft, which is an infrequent but possible event. A pump shaft has been broken and reported on a rather new PWR some years ago, and because the break was outside the pump housing, no primary leak has occurred. No other major failures related to the pump housing are known internationally.

The most probable LOCA mechanism on a RCP is a leak through the pump seals. The probability for a leak and its ultimate size depends on the specific design of a pump. Some like canned rotor designed pumps cannot have a leak on the seals. Other standard PWR pumps with 3 stage pressure seals can have leak sizes which are typically on the upper boundary of the small LOCA category.

The leaks in the RCP of a PWR can be induced by a loss of cooling to the seals or a loss of seal injection (those are typically caused by loss of component cooling system or loss of CVCS system). This LOCA type is an induced (secondary) event and not an initiator. Another possibility is the mechanical or thermal damage of the seals, which can cause a seal LOCA irrespective to the availability of cooling or seal injection. The seal leaks may be of different sizes, from a very small one, which is more probable, to a very large leak (equivalent to small LOCA) which is less probable. The large leak usually occurs with the destruction of seals as a consequence of loss of seal cooling/injection.

Several RCP seal damages and consequential leaks have been reported internationally, many more precursors in form of damaged seals have been observed (usually the seals are of a multistage design, so the damage of one stage does not result in a leak). The development of new sealing material make the seal leaks less likely.

Some PSAs, especially newer ones consider seal leaks as a separate LOCA category. Other PSAs consider the seal LOCAs as one contributor to the small LOCAs. Many PSAs consider a seal LOCA as a consequential event to the loss of seal coolant.

There are two types of recirculation pumps for BWR reactors. Older reactors have external recirculation pumps whereas the newer ones have internal pumps. There is a possibility of a LOCA event on both shaft seals and major rupture of pump housing. During the refueling at reactors with the internal RCP, one or more of those are removed for overhaul. The RCP locations are secured by cover clips. Inadvertent removal of those will result in an immediate loss of water for the reactor vessel and the fuel pools into the drywell area.

Recent assessment of Oskarsham 1 plant is Sweden performed within the project Fenix found high incidence of cracks in pumps and valves housings within the reactor coolant systems. During summer 1995 at Biblis NPP cracks were found in the forged stainless steel casting of the reactor coolant pumps. While cracks at Oskarsham 1 were judged not serious enough to preclude the restart of the plant, this issue could become a big issue in the future.

3.2.5 In-core Monitoring Thimble Tubes

COMPONENT TYPE	THIMBLE TUBES
Probability of failure	Low
Consequences of failure	Moderate
Operating experience	Some failures reported internationally
Failure mechanisms	Unknown
Treatment in PSAs	Usually not considered
LOCA category	Small LOCA

In PWR reactors, the in-core monitoring system is installed beneath the reactor vessel. The in-core monitoring equipment enters the vessel from the bottom and the probes are guided through thimble tubes which are a part of the reactor coolant pressure boundary. Those thimble tubes can break or leak and cause a LOCA.

Thimble tubes are manufactured to be small in diameter (< 2 cm) with even smaller flow rates due to resistors and fastenings. Therefore, break of a single tube can cause a very small LOCA which should be compensated by the CVCS. Simultaneous breakage of more tubes could lead to larger leaks. Another important element of the thimble tube LOCA is the specific location at the bottom of the vessel which can limit any efficient flow through the vessel and actually drain the water below the core, which effectively can have an impact on the long term core cooling as well.

Some problems related with the in-core monitoring thimble tubes were reported at selected meetings. [46] It is however, not known, if any plant experienced a thimble tube rupture. Only selected PSAs have considered the possibility of this LOCA path and concluded that the probability of an event and a consequential core damage is too low for any further assessment.

3.2.6 Control Rod Drives

The control rods of a PWR reactor enter the core from the top. During power operation the rods are withdrawn from the core and they are in the upper internals of the reactor vessel. An ejection of a control rod (or a control assembly) is an event which is considered as a design basis for PWRs. A control rod can be ejected with such an energy to allow a break through its housing (which is a part of the pressure boundary) and therefore cause a LOCA on top of the reactor vessel. In addition, the control rod housing itself can develop leaks of various sizes.

COMPONENT TYPE	CONTROL RODS
Probability of failure	Low/moderate
Consequences of failure	Moderate
Operating experience	Full rupture not known, precursors (cracks) identified
Failure mechanisms	Known
Treatment in PSAs	Sometimes explicit, usually implicit
LOCA category	Medium/large LOCA

The control rod ejection is considered as a design basis accident primarily from the perspective of a rapid increase of reactivity. The LOCA caused by a control rod ejection is a secondary effect since the ejection is a consequence of a catastrophic failure of the control rod drive. Because of the relatively high energy which is needed for the control rod to break through its housing, the rod must be released from a position fully or almost fully inserted in the core. As those conditions generally do not exist during full power operation, the probability of a LOCA caused by rod ejection during power operating mode is low. The probability of such an event in a hot standby or in the shutdown mode is somewhat higher.

Although rod ejection accidents have been reported, none of them has resulted in a major break of the control rod housing and a LOCA. Some PSAs (especially older) modeled the control rod ejection accidents explicitly, but the calculations never showed a high contribution to the CDF. Recently, a major precursor (significant cracks) which could ultimately develop and cause a major LOCA on reactor vessel head has been found in some plants.

Events with much higher frequency and related to the control rods are leaks at the control rod housing not caused by an ejection. Indeed many plants have found minor leaks mainly in the undiscovered area as a result of an operation far below the Technical Specification Limits (few liters per hour). In some cases, especially if those leaks are related to through wall cracks, those should be regarded as precursors to more serious leaks. Nuclear power plants in at least two countries identified problems related to the reactor vessel head penetrations and a variety of cracks in that region. Problems related with the reactor vessel head were identified in France and in Sweden ,and had lead to the extensive repair and even replacement of the vessel head. There is a Swedish Licensee Event report available on the topic. Other problems related to the core internals and pressure vessels are reported in ref. [46]

3.2.7 Control Rod Drives on BWRs

The control rods at BWRs are located below the core and if needed they are pushed into the core by either hydraulic or electro-mechanical force. In some BWRs, the DCRD nozzles are treated as belonging to the reactor vessel itself, and are not treated as a separate item.

3.2.8 LOCAs on Steam Generators

PWR steam generators consist of thousands of tubes and for many reasons they are the most sensitive equipment in a NPP. Typically the a SG tube is about 1-2 cm diameter, and subject to a differential pressure (up to 80 bars) between primary and secondary side. A break or a leak of one or more SG tubes (or even a tube sheet or collector) will cause a loss of primary water into the secondary side and in case the secondary side of the steam generator is not isolated, possible unrecoverable loss of water into the environment (including a radioactivity release).

To enable efficient heat transfer, the SG tubes are designed and manufactured in a specific way and made of specific materials. The SG tubes are subject to a variety of degradation mechanisms which sometimes result in tube leaks or even complete failures. The failure mechanisms include various secondary side chemical reactions (corrosion) and mechanical impacts (fretting, erosion) caused by vibration and other phenomena.

COMPONENT TYPE	**SG TUBES**
Probability of failure	Moderate
Consequences of failure	Moderate
Operating experience	At least 8 full failures, many leaks
Failure mechanisms	Many known
Treatment in PSAs	Explicit in all newer
LOCA category	SGTR

Due to the importance of the integrity of SG tubes to prevent from radioactive releases into the environment, most NPPs inspect all tubes in yearly intervals. In many cases precursors in form of cracks are found, and in specific cases those tubes are plugged.

Many plants experienced through wall cracks of SG tubes producing primary to secondary leak below or above the Technical Specification Limits. In the history of commercial nuclear power there have been at least 8 complete SG tube ruptures. For all of those, except one, just one single tube was affected. A cause which becomes more and more important, because it may cause the simultaneous failure of more than one SG tube, is a mechanical tube damage by a loose tube plug. The probability of such an event increases with many tubes plugged.

PSAs considered various SG tube related events. While old PSAs basically ignored SG tube related events, all newer PSAs take them into account. Some PSAs consider just one category (usually this is a single tube rupture), others differentiate between tube leak (above the Tech. Spec. Limit, but below the full tube rupture), a single tube rupture and multiple tube rupture (usually a simultaneous rupture of two SG tubes is considered). Examples also exist where some NPPs operated the reactor for years with all time increasing leakage from a SG tubes without performing an increased testing, or modifying test procedure (see SLAP data base).

The probability of SG tube sheet rupture on western SG design is extremely low (the tube sheet is made of a very thick metal). In some specific design (like Russian horizontal type SG) rupture of so called “collector” or its cover is a probable event, which actually occurred at one plant. For those type of plants, it is an event which is regularly considered in PSAs and often dominates the CDF.

The conditional probability of core damage may be higher in some cases than for a LOCA of the same flow size. Another difficulty is the radioactive release into the environment in case of an unsuccessful isolation of the affected SG and an unrecoverable loss of primary water.

3.2.9 Isolation Valves

All piping which is connected to the reactor coolant system is at one point isolated by an isolation device. This applies to the safety system connections like the safety injection or the residual heat removal and also to many test lines, drains etc. Of the main interest here are the isolation devices (valves) at the large bore piping like SI, RHR, CVCS or other systems connected with the RCS.

COMPONENT TYPE	ISOLATION VALVES (CHECK/MOV)
Probability of failure	low
Consequences of failure	moderate/high
Operating experience	Failures, several leaks, precursors
Failure mechanisms	Many known, include. human interactions
Treatment in PSAs	Sometimes explicit, often bounding treatment
LOCA category	Small LOCA/ISLOCA

The typical arrangement is that every pipe connected to the RCS is isolated by a series of two or more isolation valves. If those valves fail, the full pressure of the RCS would be applied to the piping downstream of the valves, which is typically not designed for that pressure. This can cause a catastrophic rupture of piping and lead to an unrecoverable loss of water outside the containment, bypassing two safety barrier. Such an event is typically beyond the design basis, but is has been considered in many PSA studies.

The operating experience with isolation valves, which form the pressure boundary of the RCS, shows no event where a major over-pressurization with the distraction of the low pressure piping and subsequent rupture has occurred during power operation. There are several events reported worldwide of over-pressurization of low pressure piping during startup/shutdown modes. However, there have been numerous precursors, from leaks through the first isolation valve and failures of vent piping, to opening of various isolation valves and subsequent leaks of reactor coolant. The failure mechanism on isolation valves is highly valve specific and can be assessed only on a case by case basis.

In SLAP data base there are several ISLOCA cases (mostly precursors). Important event occurred in 1969 at Agesta reactor in Stockholm, when a check valve ruptured and about 4 cm^2 piece of metal loosened form the valve housing. A major leak occurred with about 400 m^3 of cooling water flooding the turbine hall and caused major problems with electrical distribution and control systems.

Other possibilities of LOCAs related to the isolation valves are ruptures of the valve body and various external leaks of packing etc. The valve body rupture is typically a low frequency event (although not impossible). No event of this kind is known to have occurred on isolation valves (but has occurred on other valves), whereas leaks on valves of various categories and design are relatively frequent occurrence at NPPs. Most of those leaks are small. It is known that small leaks have occurred at isolation valves but few, if any, beyond the Tech. Spec. Limits. Those may be considered precursors.

The sequence where a failure of an isolation valve causes over-pressurization and rupture of the low pressure piping was initially considered in the WASH-1400 study (ISLOCA). The modeling of this sequence (which was conservatively estimated to lead directly to the core damage) was based on the assessment of the failure probability of two isolation valves. Later PSA studies followed the same principle with some additional sophistication (i.e. test intervals on valves). Many new studies take the approach to evaluate every single containment penetration to identify a possible ISLOCA sequence. Most of the PSA studies identified the sequence to be a less important contributor to the overall CDF. Some attempts were made to estimate the common cause failures of isolation devices which could simultaneously fail several valves. The Common Cause Failures of isolation valves can be very important element for the level 2 PSA studies, where the source term of the radioactive release to the environment is evaluated.

Only one PSA is known to considers the probability for various LOCA categories through leaking valves etc. This study identified numerous valves and flanges as contributors to the small LOCA category. Because a very optimistic failure rate was used for the leaks, those do not visibly contribute to the overall small LOCA frequency.

3.3 Current Understanding of LOCA Initiators in PSAs

The consideration and treatment of LOCA initiators in PSAs evolved over the years. While older PSAs considered only 3 categories of LOCAs (small, medium and large) and associated those mainly with the piping failures, recent PSAs fine tuned the LOCA sizes and added numerous other possible LOCA initiators.

Even today, the coverage of LOCAs in PSA varies. The following paragraphs summarize the treatment of various LOCAs in PSA studies.

3.3.1 RPV Failure

Early PSAs considered typically RPV failure as a LOCA initiator. The basic consideration of this initiator is simple: If the RPV breaks, the core damage occurs. Efforts have been taken to justify the low frequency of RPV failure. On the basis of experience with pressure vessels from other industries (which have a comparable operating and manufacturing characteristic), the failure frequency for the RPV rupture was determined to be in the order of 1E-7/yr. This frequency has been used by most of the PSAs. Several PSAs do not consider the RPV failure at all. It became obvious that a small value of 1E-7/yr. is a negligible contribution to the overall CDF. However, the reactor vessel failure is of major importance for the level 2 and 3 PSA, as it shape the accident sequence in a specific way.

The UK and German pressure vessel data collected in sixties-seventies estimated that the reactor vessel failure probability is about 1.0E-5.By making the vessel ticker, and using stricter manufacturing rules, this probability is believed to be lowered by a factor of about 100. No evidence exists that 1.0E-7/yr is an appropriate frequency figure for the catastrophic RPV rupture.

3.3.2 Large LOCA

All PSAs consider large LOCAs. In the majority of cases, those are related to the break of the large piping in the RCS. In some cases, the large LOCA category includes structural breaks within the RCS and RPV rupture as well. In other cases the large LOCA category has been considered to include everything what is above the small LOCA category.

The frequency of large LOCAs used in PSAs is still dominated by the values used in WASH-1400. Those have been adopted by most US studies later. In recent years some studies (mostly European and Japanese) have using significantly lower values, which have been justified by the probabilistic fracture mechanics and LBB criteria. As no events occurred in this LOCA category, and all the values used are below the frequency which could be obtained by using zero events statistic, there is an uncertainty associated with large LOCA.

3.3.3 Medium LOCA

The medium LOCA category has been used by many PSAs to cover a variety of break sizes between large and small LOCA category. Again, mostly piping failures contribute to this LOCA category. ECCS and similar piping connected to the RCS mostly fall into the medium LOCA category. In some cases, medium LOCAs have been joined with large LOCAs into one category to streamline the modeling. Some PSAs define medium and intermediate categories as two separate categories. Some PSAs include CR ejection in the medium LOCA category

In this category no pipe failure has been reported on NPPs internationally. Consequently, the frequencies are mostly generic and the probabilistic fracture mechanics arguments were used to a lesser extent than in the large LOCA category.

3.3.4 Small LOCA

In many PSAs the small LOCA category is actually the first LOCA category and it includes every break or leak which cannot be compensated by the operational make-up system. The sizes used for this category varies. While older studies defined a single small LOCA category, many newer PSAs defined several subcategories depending also on the location and the plant response.

Small LOCAs have occurred at several plants. The frequency of small LOCAs used in PSAs vary considerably. Some used a rather sophisticated model to calculate detailed contributions, whereas others simply took the values from other PSAs. Some PSAs include events like IORV, RCP leak and others in the small LOCA category.

3.3.5 Small-Small LOCA

While early PSAs did not consider this LOCA category, it has been proven that the small-small LOCA (or very small LOCA) can indeed be quite difficult to cope with and can initiate a sequence leading to the core damage. Therefore many newer PSAs consider this LOCA category.

The frequency is usually determined by taking into account some plant/utility specific or the worldwide operational experience. In some cases, events like leaking components etc. are also included in this LOCA category.

3.3.6 Inadvertent Opening of a Relief Valve

Similarly to small-small LOCAs, IORV was not considered within the scope of an early PSAs. In fact, this event has been grouped together with either small LOCA category or similar.

Later PSAs found that the IORV may have a significantly different sequence than a LOCA caused by a break (because of the possibility to isolate and some other specific characteristics). Therefore a separate category for IORV has been defined for many cases.

The frequency of the initiator in this category is established in many different ways, mostly by taking into account some of the plant specific operating experience. Several PSAs considered the possibility of a IORV only as a failure not to reclose after an opening of the relief valve, which is caused by a transient or similar.

3.3.7 Steam Generator Tube Rupture

Early PSAs mostly ignored SGTRs or grouped this LOCA type together with the small LOCAs. Later PSAs found the sequence to be significantly different and concluded that this sequence can end up with an open path to the environment. Therefore in modern PSAs SGTR is modeled as a separate event.

As there have been at more than half of a dozen of SGTRs worldwide, the frequency of this event is basically determined using either worldwide or reactor type specific operating experience.

3.3.8 Intersystem LOCA

Most of the PSAs, even from the early times, considered the intersystem LOCA sequence. The initiating event is usually modeled as a simultaneous failure of two or more isolation devices.

The frequency is always determined on a plant specific basis. Recent PSAs have a somewhat more sophisticated approach and evaluate the interface system LOCAs as per penetration of the containment.

3.3.9 Components LOCA

Early PSAs and many of the modern PSAs completely ignore LOCAs, which occurred as a consequences of leaks or breaks of components which are a part of the pressure boundary. Some more sophisticated PSAs analyzed those and concluded that the components contributed mostly to the small LOCA category. This categorization as well as the frequency of this event is mostly dependent on the initial assumptions undertaken.

4. LOCA CATEGORIES DEVELOPMENT

In a NPP, the LOCA sizes can vary from few liters per hour type of loss of coolant accident up to a massive rupture where the whole inventory of reactor cooling system is lost in seconds. Actually, LOCA sizes could be seen as an almost continuous distribution between two extremes. From the PSA perspective, such a consideration is not just impracticable, it is not necessary as the systems response comes in several discrete categories.

Consequently, LOCAs are being categorized in a manageable number of categories. The purpose of categorization of LOCA is to reduce the number of categories to a controllable set (for the modeling perspective), by grouping together various events which would ultimately lead to similar or reasonably similar consequences.

The following sections discuss the issues relevant for categorization of LOCAs, with some critical comments to highlight the logic behind specific categorization. Also discussed are the advantages and drawbacks of specific approaches. The assessment of currently used LOCA definitions as contained in the LOCA database is presented in the attached tables. A table is produced for every major LOCA category (very small, small, medium and large) compares the definition of the categories of LOCA with the actual parameter used.

4.1 Plant Design Driven Definition

Categorization of LOCAs depends on several parameters many of which belongs to a “plant response” arguments. In essence, LOCAs are categorized with consideration to systems (or trains) which are needed to accomplish the safety function, approximate timing of critical points in a sequence, or the ability of an operator or the automatics to initiate the mitigation actions.

Such the approach is generally logical and have been used in most of PSAs and other studies of LOCA accidents. Typically, a small LOCA is an event where the high pressure safety injection system (or similar) will be needed to maintain the inventory, but the heat removal through the break (leak) would not be sufficient to remove the decay heat. Therefore, the secondary side cooling is still needed, placing the additional requirements on both safety and support systems. Typically, the event is terminated before the need for recalculation of water from the containment sump is required.

As a subcategory of small LOCA (in most newer PSAs it is also a category on its own) a small-small (or very small) LOCA is defined as an event where a regular (non-safety) make-up system could cope with the loss of coolant and maintain the inventory. Plant is shut down and cooled using secondary side cooling.

Medium LOCA category is typically the one where the high pressure systems are needed early into the sequence, but to assure cooling of the core, low pressure systems are needed later on. The energy release through the break may be sufficient to remove the heat from the core, thus minimizing the need for the secondary side cooling. There will be a need for a recirculation of the water later in the event.

Large LOCA is the event where the inventory loss is so rapid that the low pressure systems, both passive and active, need to be initiated immediately to prevent the overheating of the core. If successful, injection of water from those systems and its loss through the break area will be more that enough to remove the decay heat and to prevent the overheating of the core. In addition, there will be a need for recirculation shortly in the sequence.

The above indicated categories are the most basic LOCA categories developed early into the probabilistic safety assessment of commercial nuclear power. In fact, many PSAs just adopted the 3 LOCA categories without any further distinction.

Both operators and the designers know that within each of the basic LOCA categories, there may be a number of distinct subcategorizes, which are not necessarily only dependent on the size of the leak, than also on the specific location of the leak/break, possibilities to isolate it, as well as the detection or consequential effect of a leak/break.

Some newer PSAs also attempted to make a fine tuning of LOCA categories, often considering the time window in which an operator action is needed before the sequence developed in an accident. One example is the German Risk Study’s or CANDU PSAs specialization of small LOCA into 3-5 categories, each of which result in a significantly different operator response characteristics (both detection and the mitigation). Other PSAs have taken a credit to the possibility to isolate the leak either with the primary isolation valves or by a variety of remotely operated isolation devices. Finally, the criteria for categorization is also the location of the break, which may simultaneously disable one or more safety systems or trains. Some PSAs consider this characteristics separately. Others took a conservative judgment, considering that every LOCA in a certain category will occur at the location which will disable a part of the mitigation system. Such an approach is typically a highly conservative one.

One of the basic reasons which preclude a finer categorization of LOCAs is the lack of more precise thermal-hydraulic analysis. Many PSA use the FSAR-type conservative criteria to establish the plant response. In some cases a superficial (or “scoping”) thermal-hydraulic calculation is used, which again may be too conservative. This conservatism may have a negative impact on a finer resolution of LOCA categories.

On the other side, finer categorization of LOCAs imply the need for additional analysis, which is not always justified. In many PSAs, the contribution of LOCA categories is low, that finer tuning would just result in the fractionating of an already low contributor.

In conclusion, the categorization of LOCAs in most PSAs is generally rudimentary and does not allow for fine tuning specific to the accident sequence. Finer categorization allows the introduction of specific modeling of human interaction or timing of sequences. The increased amount of work needed for modeling cannot always be justified by the results as those are not necessarily of a high safety significance.

The main problem for finer categorization of LOCA events lays in the unavailability of more detailed thermal hydraulic analysis. Most of the standard PSA projects used existing analysis and did not attempt to perform additional ones within the scope of the project. Without specific and focused thermal-hydraulic analysis specialization of LOCA categories is often not feasible.

4.2 Data Driven Categorization

While in essence, the categorization of LOCAs into discrete classes generally follows the plant success criteria, in many studies the actual logic behind the categorization was availability of data. If the data on LOCA frequencies available to project team were grouped into the 3 basic categories, those were used, even in cases where the basic plant design would not fully correspond to those categories. Therefore, one can observe different definition of categories (say large LOCA above 100, 150 or 200 mm diameter) all having similar failure rate. Typically in such cases, a generic value for specific LOCA category will be selected, and sizes of the LOCA susceptible piping at a specific plant identified. Then the categories will be defined to be limited to the largest pipe in a specific category.

4.3 Definition of LOCA Categories

The definition of LOCA categories appears to be a combination of a variety of concepts. Early PSA studies, still under the influence of the approach to nuclear safety at that time, where the guillotine break of the largest pipe was the dominant event, defined the LOCA categories as the diameter of a pipe on which the LOCA was to occur.

Such the approach imply that every failure event on a particular pipe would be a complete break of the pipe with at least single side unrestricted flow. Depending on the plant designer, the pipe diameters used to define LOCA categories were defined either in inches or centimeters. Typical categorization would be that the small LOCAs lower bound will be piping with about 12.5 mm diameter and the upper bound about 50 mm (is some cases the upper bound of small LOCA is defined with the diameter of the PORV). Medium LOCA will cover all piping up to 150 mm diameter, and the large LOCA being anything above that.

Defining LOCA categories on the basis of diameter of a pipe which is susceptible to LOCA is a straight forward process. In addition, generic data are widely available to support such a definitions. In reality, however, the sudden and complete severance of piping occurs with a much lower frequency than partial failures or leaks. When partial failures are taken into account (by assuming that every pipe failure is a complete severance), there is a significant conservatism involved. Still, because of the clarity and the simplicity of the approach, many PSA projects stick to such definitions.

Another basis for defining LOCA categories is the flow area. The flow area is defined as the area through which the reactor coolant will be lost. In fact, the definition of flow area instead of pipe diameters was initiated by early BWR PSA studies because at that reactor type, LOCA could mean a loss of water or a loss of steam, which makes significant difference in terms of loss of inventory and the development of accident sequence. In US or for the US designed reactors, the flow area is usually defined in units of square feet. Some European studies adopted that approach and defined the flow area in square centimeters.

The approach to define the flow area instead of diameter of the pipe is much more logical one because it allows for gradation of pipe failures. Such an approach is actually ideally suited to be used with probabilistic estimates of various categories of pipe severance. Such an approach is also better suited for modeling of the valve leaks, where the valve diameter is not an adequate measure of the leak size.

The majority of PSAs using a “flow area” approach determined the flow area by simply calculating it from the pipe diameter, thus disregarding the gradation of pipe failures. At least one PSA made a fully use of the potential of this approach. The Borssele PSA defined a total of 5 LOCA categories. Every pipe or component which is a part of the RCS boundary was analyzed to estimate what is the maximum size of the loss of coolant through that components. The probabilistic estimate of the leak size was based on a variety of parameters including the diameter and the thickness of the pipe. As a result, the failure of every component contributes to every LOCA category (up to a maximum size). This is more appropriate for treatment of LOCA categories than any other.

Some PSAs defined LOCA categories in terms of leak rate. The leak rate is defined either in gallons per minute (gpm), liters per second (or cubic meters per hour) or in kilograms per second (kg/s) depending on the location of the plant and its vendor. This is the most logical definition of LOCA because the loss of inventory is the actual parameter of interest in defining LOCA categories. The leak rate calculation does not only take into the account the leak (failure) area, it also take into the account the pressure differential, flow restrictions etc. The leak rate definition is also much more appropriate from the plant response standpoint. However, the difficulties associated with leak rate estimates, precluded wider use of such definition.

Figure 4.1 presents a summary on various LOCA sizes as taken from the LOCA data base. The figure contains the information on the very small LOCA, small, medium and large LOCA categories. For each LOCA category, the minimal and maximal values are taken from the data base and plotted. The following tables (table 4.1- 4.4) give an overview on the actually used sizes for every LOCA category as taken from the database. In these tables the break sizes, leak-areas or flow rates for each specific LOCA category are presented. (Note: all sizes are given in units which have been used in the original study; in addition the number of studies which made use of the same size definition is given next to it)

Table 4.1: *Large LOCA Category Definitions*

	unit inch	No	*unit* mm	No	*unit* cm^2	No	*unit* ft^2	No	*unit* kg/s	No
LARGE LOCA	> 4	3	> 150	1	> 300	4	> 0.1	1	> 1200	1
	> 4.3	1	> 300	1	> 400	1	> 0.3	3	>2000	2
	> 5	1	200 - 500	1	> 450	1	0.1 - 0.3	1	> 3000	2
	> 5.5	1	300 - 500	1	> 1000	1			600-2000	1
	> 6	5								
	> 8	1								
	> 13.5	1								
	6 - 29	1								
	10 - 13.5	1								
			175 (Guillotine)	2			0.3 - 4.3 (liquid)	2		
			650 (Guillotine)	1			1.4 - 4.1 (steam)	1		

Table 4.2: *Medium LOCA Category Definitions*

	unit inch	No	*unit* mm	No	*unit* cm^2	No	liquid ft^2	No	steam ft^2	No
MEDIUM LOCA	1 - 4	2	20-200	2	50-300	1	0.004-0.1	1	0.004-0.1	1
	1.5 - 5.5	1	50-150	1	80-400	1	0.004-0.2	1	0.1-0.3	3
	1.9 - 4.3	1	125-300	1	80-450	1	0.004-0.3	1	0.12-1.4	1
	2 - 5	1	175	2	100-1000	1	0.005-0.3	1		
	2 - 6	6	200-300	1	150-300	1	0.12-0.3	1		
	3 - 8	1								
	4 - 10	1								
	2.5 - 8.5 (liquid)	1								
	4.7 - 6 (steam)	1								

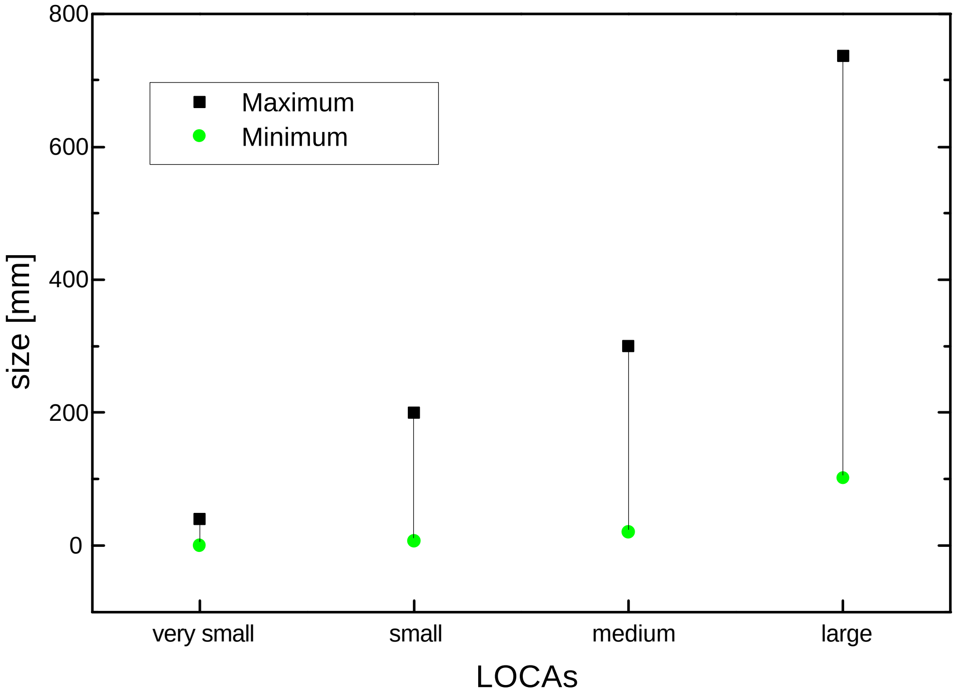
Table 4.3: *Small LOCA Category Definitions*

SMALL LOCA	*unit* inch	No	*unit* mm	No	*unit* cm^2	No	liquid ft^2	No	steam kg/s	No
	0.3 - 1.9	1	7 - 20	3	2 - 12	1	< 0.004	2	< 0.01	1
	0.375 - 2	1	10 - 70	1	2 - 80	1	< 0.005	2	< 0.1	3
	0.5 - 2	4	20 - 60	1	5 - 50	2				
	0.5 - 4	1	30 - 125	2	5 - 150	2				
	< 1	2	< 32	1	5 - 100	1				
	1 - 1.5	1	32 - 60	1	12 - 25	1				
	1.2 - 1.66	1	60 - 100	1	25 - 50	1				
	1.55 - 3	1	175	2	50 - 80	1				
	1.66 - 4	1			< 80	1				
	< 2	2			80 - 200	1				
	0.6 - 2.6 (liquid)	1								
	1 - 4.7 (steam)	1								

Table 4.4: *Very small LOCA Category Definitions*

VERY SMALL	*unit* inch	No	*unit* mm	No	*unit* cm^2	No	*unit* gpm	No
	0 - 1	1	0 - 7	3	1 - 5	1	0.5 - 100	1
	0.3 - 1.55	1	0 - 10	1			50 - 100	3
	0.38 - 1.2	1	< 30	1				
	< 0.5	1						

Figure 4.1: ***Sizes used for different LOCA Categories***



5. IDEAL LOCA CATEGORIES

Ideal LOCA categories are underpinned by the need to be logical from the standpoint of the plant response. This implies a discrete category which depends primarily on the interplay of plant thermal-hydraulics and safety injection systems. As a result, decisions on LOCA categorization are very much plant specific. It should be remembered, as discussed earlier, that there are important differences in the requirements placed on LOCA categorization for probabilistic studies compared to deterministic studies.

Based on contemporary PSA experience, the definition of between 4 and 10 different LOCA categories appears appropriate. Specific issues that may influence the choice of LOCA categories are:

- Safety or operational systems required.
- Capacity of safety systems.
- Sequence timing issues: detectability, response time, human interactions (for example, manual switch to recirculation).
- Availability of specific procedures and decision supports.
- Issues related to break/leak location: impact on safety systems, support systems, or instrumentation.

The last point, the specific location of the LOCA initiator, is often ignored in the definition of LOCA categories, but may have a major influence on the development of accident sequences. Thus, some LOCAs that are similar from the leak-rate point-of-view may differ from the plant-response point-of-view. To account for the influence of break location, event tree models are sometimes be backed up by elaborate fault tree or spreadsheet models. Analysts may elect to carry specific initiating event cutsets throughout the sequences. A drawback of such an approach is a considerable increase in the complexity of the analysis.

In order to define LOCA categories and their frequencies, it is important, but has been disregarded in many PSA studies, to relate possible leak rates to piping/component size and other relevant parameters:

- For piping, the diameter and the wall thickness are important parameters in determining the probability of leak or break. In addition, the design of the pipe segment (straight, bend, heat affected area) and its location (supported or unsupported, junction with safety systems) may have a very large impact on the probability of failure. In addition, different classes of piping which form the RCS pressure boundary may have different manufacturing and inspection practice, and sometimes different quality standards.
- Components, other than piping, which are part of the RCS pressure boundary could also contribute to certain LOCA categories. In some of these, the design of a component limits the possible leak rate. For example, an RCP seal leak is equivalent to a small LOCA, at most. As for piping, components need to be assessed taking into account a variety of factors which may influence the leak rate.

An appropriate approach to LOCA categorization and frequency calculation would be an iterative process with an initial categorization following plant response criteria and taking into account the parameters indicated previously. Following this process, together with a careful analysis of the parameters influencing piping and component failures (applying specific formulas such as, for example, the Thomas Elemental Method), a contribution to the initially defined LOCA categories from every segment of the RCS pressure boundary could be determined. If, during that process, it is found that failures belonging to the same LOCA category from the leak rate standpoint have a significantly different plant response (for example, due to location, breaks that fail a safety injection train, etc), categories may be redefined.

The specific items which are a part of the reactor pressure boundary and which could be considered to give rise to LOCA events are tabulated below.

Table 5.1 ***LOCA Susceptible Items***

PIPING	VESSELS	COMPONENTS	OTHER
Straight piece	**RPV**	**Pump housing**	**Gaskets**
Elbow, bellow	**SG shell**	**Valve housing**	
Tee	**Pressurizer**	**Isolation valves**	
Flange	**SG/Pressurizer manholes**	**CRD**	
Nozzle		**Thimble tubes**	
Expander		**Instrument penetrations**	
Weld		**Reducers**	

6. CURRENTLY USED LOCA FREQUENCIES - A COMPARISON

In order to support the determination of optimal categories of LOCA and determination of its frequencies, and attempt was made to develop a data base which would contain the values used by various PSA projects internationally. The review of the data base shows a relatively high deviation (up to several orders of magnitude) for all LOCA categories. All the entries for large LOCA, medium LOCA, Small LOCA, Small-small LOCA and RPV rupture were extracted from the data base bad compared in their respective groups. The following characteristic were identified:

- **large LOCA:**
  118 records exist in the database. The minimum frequency of 1.0E-9/yr. has been used for a Japanese 1100 MWe BWR (January 1990), whereas the maximum value of 2.0E-3/yr. was used at Forsmark NPP. There is a good indication that values used in contemporary PSA studies (at least in Western Europe) tend to be lower. The mean average value for the frequencies contained in the data base is about 2.4E-4/yr. This value is dominated by studies performed during eighties (which represent the highest proportion of the data base entries) More recent studies have their values grouped around 1.0E-5/yr.

- **medium LOCA:**
  A total of 98 records exist in this category. The frequencies varies between the minimum of 7.4E-7/yr, used at Mühlheim Kärlich PSA in October 1994, and the maximum of 3.0E-3/yr which was used for Shoreham PSA in January 1983. Again, there seems to be a trend towards lower frequencies over the past ten years. The mean value for the medium LOCA category is 6.4E-4/yr.

- **small LOCA:**
  125 records exist for small LOCA frequencies. The lowest frequency for the small LOCA category is 4.0E-5/yr used in Bohunice 1,2 PSA in February 1994 for a small isolable LOCA. The maximum value is 3.0E-1/yr used in Paks PSA in January 1994. The mean frequency of 8.8E-3/yr is representative for the current status. No trend over the time could be identified in this LOCA category.

- **Very small LOCA:**
  32 records exist in the database. The arithmetic mean value is 2.3E-2/yr, which is in good agreement with the values used in studies completed in US in late eighties (NUREG 1150, Surry 1, Peach Bottom 2 and Grand Gulf). The lowest value in this category is 1.6E-5/yr used in Mühlheim Kärlich PSA, followed by Ginna PSA (7.3E-4). The highest frequency value is the one used in French 900 MWe PSA in Jan. 1990, (3.0E-1/yr)

- **RPV rupture:**
  14 records exist in the data base. All frequencies are within three orders of magnitude with a mean value of 1.0E-6/yr. The minimum of 1.0E-8/yr. has been used in Ginna PSA and the maximum of 5.5E-6/yr was used for Loviisa PSA.

- **Other LOCA categories:**
  Other LOCA categories which are presently included in the database, have significantly less records so the comparison of values in not providing any additional insights.
  The only two LOCA categories which still have the number of records which would allow for comparison are IORV and IS LOCA. However, the variety of definitions used in PSAs to describe those initiator categories makes the comparison meaningless.

- **Statistical evaluation**
  Limited statistical analysis has been applied to the above indicated LOCA categories to illustrate the spread of values as well as to attempt to correlate the values with the specific period when the PSA study was performed. The following table contains the arithmetic mean value, the standard deviation, maximum and minimum frequency, the plant name for the max./min. value, date of the study as well as the number of records which have been used as a basis for calculating the mean and standard deviation values. The reader is, however cautioned that there might be differences in the definitions which are used to describe one or another frequency category so that those are not necessarily fully compatible. It is however felt that for the illustrative purposes, the values contained in the table are useful for PSA practitioners.

Table 6.1: ***Comparison of Frequency Values used for different LOCA Categories***

LOCA CATEGORY	No. of Records evaluated	Mean	SD	Max	Plant/Date (Max)	Min	Plant/Date (Min)
large LOCA	118	2.4E-4	2.7E-4	2.0E-3	Forsmark	1.0E-9	Japan 1100 Jan. 90
medium LOCA	98	6.4E-4	5.5E-4	3.0E-3	Shoreham 1 Jan. 83	7.4E-7	Mühlheim Kärlich
small LOCA	125	8.8E-3	2.8E-2	3.0E-1	Paks Jan. 94	4.0E-5	Bohunice1,2 Feb. 94
very small LOCA	32	2.3E-2	5.4E-2	3.0E-1	French 900 Jan. 90	1.6E-5	Mühlheim Kärlich
IS LOCA	10	7.8E-5	2.5E-4	1.0E-3	Paks Jan. 94	1.0E-8	Grand Gulf Jan. 87
SGTR	18	6.9E-3	8.5E-3	3.7E-2	Angra Jan. 88	1.0E-5	Biblis B Jan, 80
RPV rupture	14	1.0E-6	1.82E-6	5.5E-6	Ginna	1.0E-8	Loviisa
IORV	17	4.8E-2	5.7E-2	1.4E-1	NUREG 1150	2.3E-5	Doel 1,2 Aug. 95

Figures 6.1 - 6.8 have been prepared to provide a graphical representation of the distribution of LOCA frequencies as used by PSAs included in the data base. Each plot shows values for BWRs and PWRs separately and for all reactor types (BWRs, PWRs and others). The plots therefore give an indication of the dependency of LOCA frequency on reactor type.

Separate figures are presented for very small, small, medium and large LOCA categories, there being two types of figures for every LOCA category.

One type of figure (figures 6.2; 6.4; 6.6 and 6.8) gives an indication of the spread of frequency values found in the original sources. The mean, median value and 10 and 90% of the distribution of all sources have been calculated and shown.

The other type of figure (figures 6.1; 6.3; 6.5 and 6.7) is usually known as a cumulative distribution plot. For each point on the curve, the value on the y-axis shows the fraction of studies that used a frequency lower than the corresponding x-axis.

Theses plots are considered to give an overview of the values for LOCA frequency in the database.

Figure 6.1: ***Cumulative Distribution of Frequencies used for large LOCA***

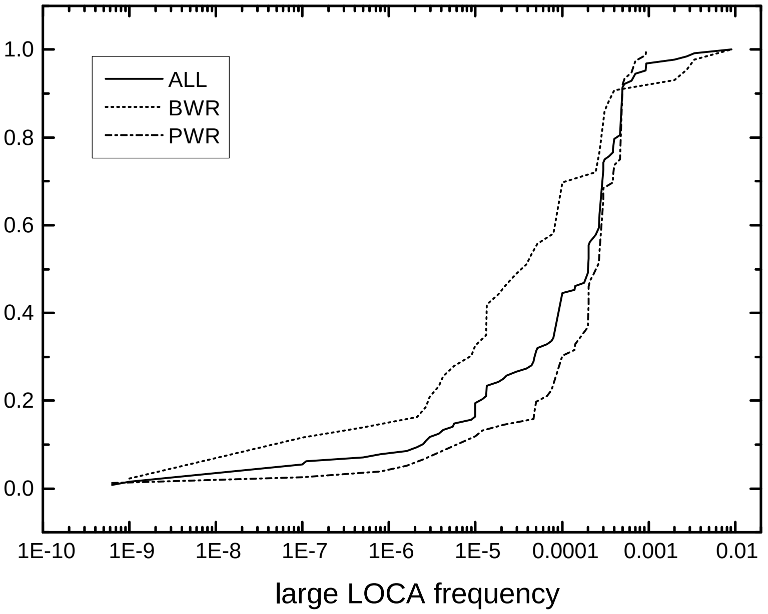


Figure 6.2: ***Mean and Median Values for Frequencies in large LOCA Category***

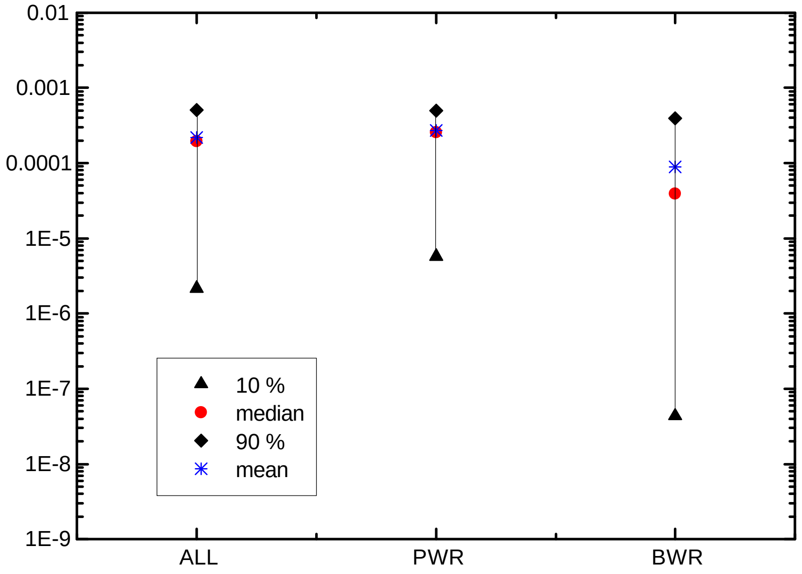


Figure 6.3: ***Cumulative Distribution of Frequencies used for medium LOCA***

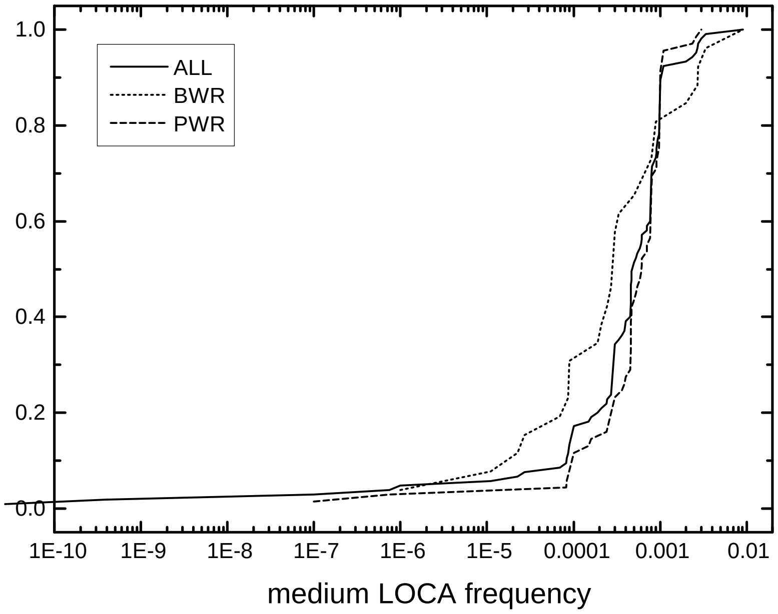


Figure 6.4: ***Mean and Median Values for Frequencies in medium LOCA Category***

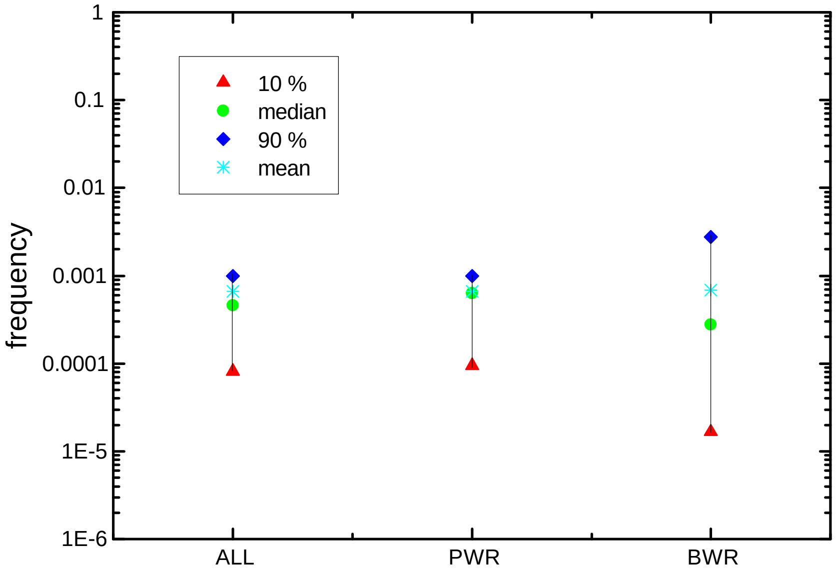


Figure 6.5: ***Cumulative Distribution of Frequencies used for small LOCA***

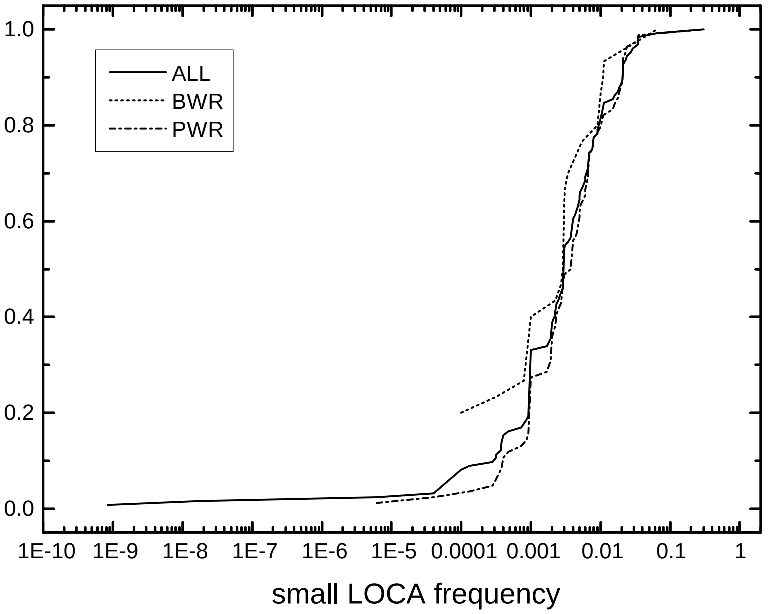


Figure 6.6: ***Mean and Median Values for Frequencies in small LOCA Category***

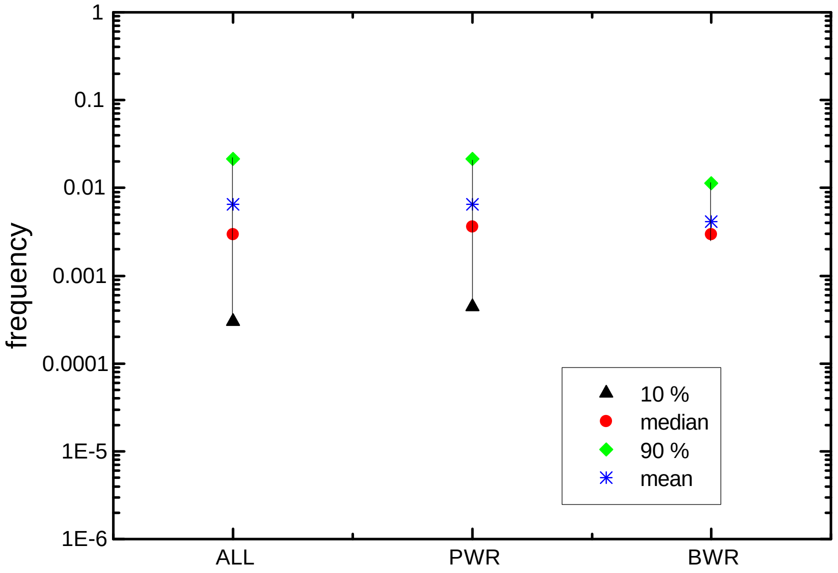


Figure 6.7: ***Cumulative Distribution of Frequencies used for very small LOCA***

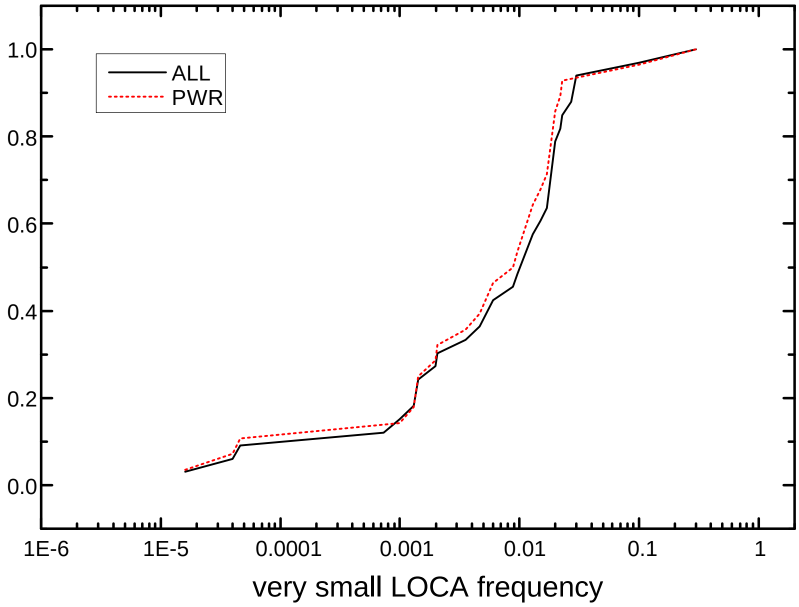
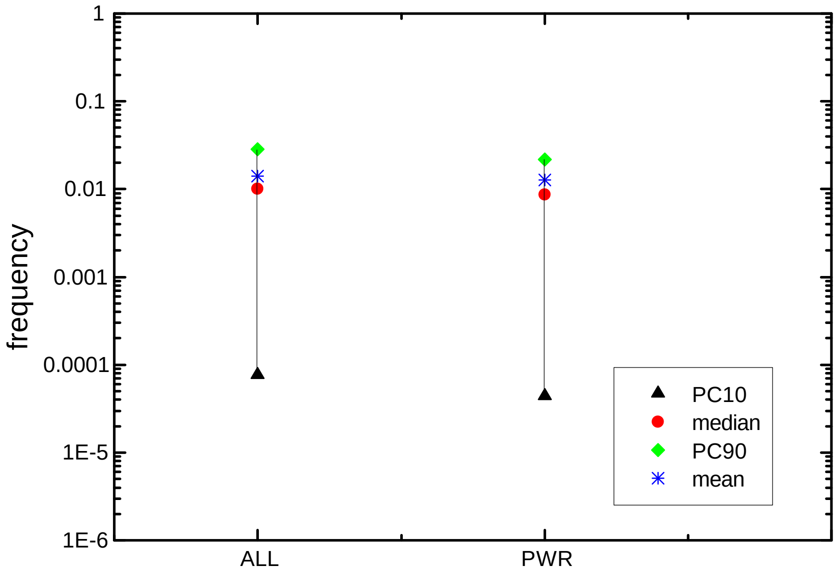


Figure 6.8: ***Mean and Median Values for Frequencies in very small LOCA Category***



7. DESCRIPTION OF THE LOCA DATABASE

7.1 Description of the LOCA Database and Sources

A wide variety of PSA studies was screened to extract data for the LOCA database, which at present contains about 505 records. The PSA studies in the data base go from the first comprehensive NPP PSA (WASH-1400) to the most recent Doel 1,2 NPP PSA, (published in August 1995), and the Oskarshamn 1 PSA (published in January 1995).[references not mentioned previously and used for the data base are Nos. 47-54].

The LOCA database has been developed with MS Access database manager, one of the most powerful software packages currently available for such purposes. The philosophy behind the structure of the LOCA database is to enable fast retrieval of all data stored in the database. Each record consists of one number field, scientific notation is used to store the LOCA frequency value, and ten textual data fields. For these text fields it was identified that they cover most of the technical aspects and all the areas of interest in accordance to the purpose of this study.

To make available storage from all relevant information which may not necessarily fit into the one of the above described fields, an additional field of internal type memo for comments was designed.

Altogether the records contained in the LOCA database at the current status cover data from about 75 NPP sites worldwide. Some of the sites has different PSAs for different units. In addition for some plants there is more than one PSA performed (usually under a different program),. Some of the studies used specific data from a single unit, others made use of all accumulated data from several units which are similar and operated at the same site.

Table 7.1 lists the number of records for the different LOCA categories which are currently included in the database.

Table 7.1: ***Number of Records in the Database for each LOCA Category***

LOCA CATEGORY	No. of RECORDS	LOCA CATEGORY	No. of RECORDS
small LOCA	129	RPV - rupture	14
large LOCA	123	IORV	10
medium LOCA	100	small-small LOCA	7
IS LOCA	24	large/medium LOCA	5
very small LOCA	26	pressurizer system LOCA	3
SGTR	20	other categories	17

7.2 Database Structure

The database consists of eleven main fields for each record. Those fields are as follows:

Table 7.2: ***Field Names used in the Database***

FIELD NAME	DESCRIPTION
LOCA TYPE	Categorization of LOCA
LOCA SIZE	Definition of the break size or break area
SIZE DEFINITION	Description of the LOCA size
FREQUENCY	Value presented in the study
FREQ. DISTRIBUTION	Description of the value, upper and lower bounds, frequency distribution
FREQ. SOURCE	The ultimate source of LOCA frequency
PLANT NAME	Name of the plant where the study was conducted
COMM. OP. DATE	Commercial operation date according to the IAEA source
PSA TITLE	Title of the PSA study
PSA DATE	Date of the PSA results
COMMENTS	Additional important facts

Besides the fields listed above, an extra field labeled `**COUNTER**` is added to each record, which automatically assigns consecutive numbers to all of the records from 1 to 505. There is no relevance for the specific number of an individual record, which means that all the numbers assigned to a record are completely arbitrary. The `**COUNTER**` field is used only for fast identification of the records and easy handling of the records within the database.

`**LOCA TYPE**` is the main categorization field, which allows grouping and/or sorting of the stored records by several classes of LOCAs at different classification levels according to the terminology which was used in the study. In the `**LOCA TYPE**` field the LOCAs are categorized and current records include IORV, IS LOCA, SGTR, RPV - rupture, very small LOCA, small LOCA, medium LOCA, medium/large LOCA, large LOCA as well as some other very specific types, each of which do not have a significant number of entries in the database (i.e. less than five records per LOCA type).

The `**LOCA SIZE**` field stores information about the definition of individual break size, break area or quantity of leaking fluid/steam which was used to define the LOCA category. As discussed in the previous sections of this report, few of the studies defined the LOCA size precisely, therefore at current status the `**LOCA SIZE**` field contains information for about the precise definition of LOCA size for all records stored in the database. As discussed the definitions are different among almost all of them with respect to the units and the specific values.

In the `**FREQUENCY**` field the value for the LOCA frequency is stored, which was derived as the result from the study for the specified LOCA category. Scientific notation is used for these values.

The `**FREQ. DISTRIBUTION**` field contains a description about the frequency value and the distribution. In case upper and/or lower bounds have been calculated, those values are included in the `**FREQ. DISTRIBUTION**` field as well.

Whenever the source(s) about how a certain LOCA frequency has been derived (i.e. which data sources or generic data have been used) were given in the documents used to update the LOCA database, those sources are summarized in the `**FREQ. SOURCE**` field.

PLANT NAME` and `**COMM. OPERATION DATE**` fields contain the information regarding the plant (for most of the records plant and details about the modeled unit are given) and the date for the beginning of commercial operation at the specific plant/unit according to the IAEA source. This information about the plant is considered to be of high interest for further evaluations, because it allows to quickly identify possible differences in the results among older and newer plants. This data can be used also to easily retrieve the maximum of plant specific data, which was available during the time the study was performed. (operating data and experience gained from earliest commercial operation until the date the PSA was performed/continued).

The `**PSA TITLE**` and the `**PSA DATE**` fields contain the title of the study and the date when the PSA study has been completed/published.

Additionally a `**COMMENTS**` field is included to allow storing of all the interesting information for every record within the LOCA database. This field mainly contains information, which does not fit into any of the above mentioned basic database entries, but nevertheless appears to be important for further analysis. As an example for some records information about the isolability of the LOCA flow path as well as the location of the LOCA (inside or outside containment) is stored in the `**COMMENTS**` field. The internal structure of this `**COMMENTS**` field is a database memo field, which unfortunately does not allow automatic sorting by running queries/creating indexes on the different entries in the memo field.

Therefore the flexibility and usability of the information stored in this field may be limited up to a certain extent.

7.3 Presentation of the Database

All records from the LOCA database are presented in two distinctive sets.

- The first set, provided in **APPENDIX A** presents information on LOCA type, plant name, LOCA frequency, and PSA date. All the records are sorted and grouped by

LOCA type. Within one LOCA type category the frequency values are used for an additional ascending sort. This means that all frequencies, which have been identified for a specific LOCA class are sorted and therefore the listing allows a fast retrieval for all currently used LOCA frequencies within a specific LOCA type category. The fraction among the number of records for each of the categories can also be seen immediately and shows mainly the characteristics which are discussed in greater detail in the previous sections. - There is a clear trend to define more LOCA categories and to develop a more sophisticated model for the LOCA concept throughout all the newer PSAs whereas older PSAs defined large, medium and small LOCA categories. (very few records for categories like IS LOCA, IORV, RPV rupture, very small LOCA and others reflect this situation, which is due to a lack of those categories in the older studies)

- **APPENDIX B** provides a full listing of the database. The records are grouped by LOCA type category and sorted in the following order:
    - *IORV*
    - *IS LOCA*
    - *large LOCA*
    - *large/medium LOCA*
    - *medium LOCA*
    - *PORV inadvertent opening or leakage*
    - *Pressurizer System LOCA*
    - *RPV rupture*
    - *SGTR*
    - *small LOCA*
    - *small-small LOCA*
    - *very small LOCA*

  Within one LOCA category the records are sorted according to their LOCA frequency values in an ascending order as they are sorted in APPENDIX A All the information which is available in a record is presented. If there are missing entries for instance for the LOCA size, those records have been extracted from studies which did not publish any definition for either break size or break area of the used LOCA type.

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ABBREVIATIONS & ACRONYMS

Abbreviations & Acronyms - Engineering Terms

AFW	Auxiliary Feedwater
ANOVA	Analysis of Variance
ATWS	Auxiliary Feedwater System
BoP	Balance of Plant
BW/CR	Cracking in Stagnant Borated Water
C/F	Corrosion-Fatigue
CC	Component Cooling
CCW	Component Cooling Water
CRD	Control Rod Drive
CRDM	Control Rod Drive Mechanism
CVCS	Chemical and Volume Control System
CW	Circulating Water
DEGB	Double-Ended Guillotine Break
DHR	Decay Heat Removal
DN	Nominal Diameter (in mm)
E/C	Erosion/Corrosion
EBFT	Energy Balance Fault Tree
ECCS	Emergency Core Cooling System
EHC	Electro-Hydraulic Control
FW	Field Weld
FW	Feedwater
GPM	Gallon per Minute
HAZ	Heat-Affected Zone
HIC	Hydrogen Induced Cracking
HPCI	High Pressure Core Injection
HPCS	High Pressure Core Spray
HPI	High Pressure Injection
HSCC	Hydrogen Stress Corrosion Cracking
IC	Inspection Class
ID	Inside Diameter
IGSCC	Intergranular Stress Corrosion Cracking
IORV	Inadvertent Open Relief Valve
ISI	In-service Inspection
ISLOCA	Interfacing System LOCA
LBB	Leak-Before-Break
LOCA	Loss of Coolant Accident
LOFW	Loss of Feedwater
LOOP	Loss of Off-site Power

LOSP	Loss of Station Power
LSP	LOCA Sensitive Piping
MFW	Main Feedwater
MFWS	Main Feedwater System
MHIDAS	Major Hazard Incident Analysis System
MOV	Motor Operated Valve
MSIV	Main Steam Isolation Valve
NLSP	Non-LOCA Sensitive Piping
NSSS	Nuclear Steam Supply System
PCS	Power Conversion System
PFM	Probabilistic Fracture Mechanics
PNL	Pacific Northwest Laboratories
PORV	Power Operated Relief Valve
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR	Residual Heat Removal
RPS	Reactor Protection System
RPV	Reactor Pressure Vessel
RSS	Reactor Safety Study
RT	Radiographic Test
RV	Relief Valve
SCC	Stress Corrosion Cracking
SCC	Stress Corrosion Cracking
SFD	Safety Function Disabled
SG	Steam Generator
SGTL	Steam Generator Tube Leak
SGTR	Steam Generator Tube Rupture
SICC	Stress-induced Corrosion Cracking
SIS	Safety Injection Signal
SN	Schedule Number
SRV	Safety Relief Valve
SSCC	Sulfide Stress Corrosion Cracking
SW	Shop Weld
SWS	Service Water System
TC	Thermal Cracking
TFITS	Thermal Fatigue by Thermal Stratification
UT	Ultrasonic Test
WD	Weld Defect
WH	Water Hammer

Abbreviations & Acronyms - Organizations

AECL	Atomic Energy of Canada Limited
ANO	Arkansas Nuclear One

APS	Arizona Public Service
ASME	American Sociat6y of Mechanical Engineers
BMFT	Bundesministerium für Forschung und Technologie
BMU	Bundesminister für Umwelt, Naturschutz und Reaktorsicherheit
CEA	Commissariat de Energy Atomique
CSNI	Committee on the Safety of Nuclear Installations
EPRI	Electric Power Research Institute
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit
IAEA	International Atomic Energy Agency
INPO	Institute of Nuclear Power Operations
IVO	Imatran Voima Oy
KSU	Kärnkraftsäkerhet och Utbildning AB
MPA	Staatl. Materialprüfungsanstalt (MPA), Universität Stuttgart
NEA	Nuclear Energy Agency
NKS	Nordic Nuclear Safety Research
OECD	Organization for Economic Cooperation and Development
PNL	(Battelle) Pacific Northwest Laboratories
SKI	Statens Kärnkraftinspektion
TÜV	Technischer Überwachungsverein
USNRC	United Statens Nuclear Regulatory Commission

Abbreviations & Acronyms - General

BWR	Boiling Water Reactor
CCF	Common Cause Failure
CCI	Common Cause Initiator
CDF	Core Damage Frequency
FMEA	Failure Mode and Effect Analysis
FSAR	Failure Safety Analysis Report
FTA	Fault Tree Analysis
IE	Initiating Event
INES	International Nuclear Event Scale (IAEA)
INES	International Nuclear Event Scale (IAEA)
IREP	Interim Reliability Evaluation Program
LER	Licensee Event Report
MLD	Master Logic Diagram
NDE	Non-Destructive Examination
NEA-IRS	(OECD) Nuclear Energy Agency - Incident Reporting System
NPE	Nuclear Power Experience
NPP	Nuclear Power Plant
NPRDS	Nuclear Plant Reliability Data System
PRA	Probabilistic Risk Assessment
PRAISE	Probabilistic Reliability Analysis Including Seismic Events
PSA	Probabilistic Safety Assessment
PSI	Pre-service Inspection
PWR	Pressurized Water Reactor
QA	Quality Assurance
QC	Quality Control
SLAP	SKI's LOCA Affected Piping Database
WWER	Soviet Designed PWR (Water moderated, Water cooled reactor)

Appendix A:

Listing of LOCA Type, Plant Name, Frequency and PSA Date Sorted by LOCA Category

Appendix B:

Full Listing of the LOCA Database

LOCA type: large LOCA **LOCA Size:** break with equivalent area greater than 400 sq.cm
LOCA freq: 2,70E-04 **Freq.distr:** mean value/r.yr.; EF 10 **Source:** generic data sources
Plant name: Biblis B **Com.op:** 1/1/77 **Ref:**
PSA title: German risk study, table F1, 4-5 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent area 80 to 400 sq.cm
LOCA freq: 8,00E-04 **Freq.distr:** mean value/r. yr.; EF 10 **Source:** generic data sources
Plant name: Biblis B **Com.op:** 1/1/77 **Ref:**
PSA title: German risk study, table F1, 4-5 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent area 2 to 80 sq.cm
LOCA freq: 2,70E-03 **Freq.distr:** mean value/r.yr.; EF 10 **Source:** generic data sources
Plant name: Biblis B **Com.op:** 1/1/77 **Ref:**
PSA title: German risk study, table F1, 4-5 **PSA date:**
Comments:

LOCA type: small leak on pressurizer **LOCA Size:** stuck open relief of safety valve
LOCA freq: 1,30E-03 **Freq.distr:** mean value/r.yr.; EF 6 **Source:** operating experience and engineering analzsis
Plant name: Biblis B **Com.op:** 1/1/77 **Ref:**
PSA title: German risk study, table F1, 4-5 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 13.5 inches
LOCA freq: 7,50E-05 **Freq.distr:** mean value/r.yr. **Source:** RSS study combined with ANO-1 break ranges
Plant name: Arkansas One-1 **Com.op:** 12/1/74 **Ref:**
PSA title: IREP-ANO1, table 4-7 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size 10 to 13.5 inches
LOCA freq: 1,20E-05 **Freq.distr:** mean value/r.yr. **Source:** RSS study combined with ANO-1 break ranges
Plant name: Arkansas One-1 **Com.op:** 12/1/74 **Ref:**
PSA title: IREP-ANO1, table 4-7 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 4 to 10 inches
LOCA freq: 1,60E-04 **Freq.distr:** mean value/r.yr. **Source:** RSS study combined with ANO-1 break ranges
Plant name: Arkansas One-1 **Com.op:** 12/1/74 **Ref:**
PSA title: IREP-ANO1, table 4-7 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size 1.66 to 4 inches
LOCA freq: 3,80E-04 **Freq.distr:** mean value/r.yr. **Source:** RSS study combined with ANO-1 break ranges
Plant name: Arkansas One-1 **Com.op:** 12/1/74 **Ref:**
PSA title: IREP-ANO1, table 4-7 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size 1.2 to 1.66 inches; stuck open prszr safety valve
LOCA freq: 3,10E-04 **Freq.distr:** mean value/r.yr. **Source:** RSS study combined with ANO-1 break ranges
Plant name: Arkansas One-1 **Com.op:** 12/1/74 **Ref:**

PSA title: IREP-ANO1, table 4-7 **PSA date:**

Comments:

LOCA type: small small LOCA **LOCA Size:** break with equivalent size 0.38 to 1.2 inches; stuck open relief valve; RCP seal failure

LOCA freq: 2,00E-02 **Freq.distr:** mean value/r.yr. **Source:** RSS study combined with ANO-1 break ranges

Plant name: Arkansas One-1 **Com.op:** 12/1/74 **Ref:**

PSA title: IREP-ANO1, table 4-7 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 4 inches

LOCA freq: 4,00E-04 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation and different data sources

Plant name: Limerick -1 **Com.op:** 2/1/86 **Ref:**

PSA title: Limeric PRA, table A.1.6 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 1 to 4 inches

LOCA freq: 2,00E-03 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation and different data sources

Plant name: Limerick -1 **Com.op:** 2/1/86 **Ref:**

PSA title: Limeric PRA, table A.1.6 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size up to 1 inch

LOCA freq: 1,00E-02 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation and different data sources

Plant name: Limerick -1 **Com.op:** 2/1/86 **Ref:**

PSA title: Limeric PRA, table A.1.6 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 6 inches

LOCA freq: 5,00E-04 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** average of past PRAs

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent area greater than .1-.3 sq.ft

LOCA freq: 1,00E-04 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** RSS value

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2 to 6 inches

LOCA freq: 1,00E-03 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** average of past PRAs

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent area .004-.3 sq.ft liquid; .1-.3 sq.ft steam

LOCA freq: 3,00E-04 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** assessed from nuclear, industrial and other datasources

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .5 to 2 inches

LOCA freq: 1,00E-03 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** average of past PRAs

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent area less than .005 sq.ft liquid or less than .1 sq.ft steam

LOCA freq: 3,00E-03 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** assessed from nuclear, industrial and other data sources

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: small small LOCA **LOCA Size:** break with equivalent size greater than .5 inch or flow .5 to 100 qpm

LOCA freq: 2,00E-02 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** NPP operating experience

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: small small LOCA **LOCA Size:** break with flow 50 to 100 qpm

LOCA freq: 3,00E-02 **Freq.distr:** mean value/r.yr.; EF 3 **Source:** review of past PRAs

Plant name: n/a **Com.op:** n/a **Ref:**

PSA title: NUREG/CR 4550, Vol.1, Methodology...,table VIII.1-1 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size 6 to 29 inches

LOCA freq: 5,00E-04 **Freq.distr:** mean value/r.yr. **Source:** based on NUREG/CR 4550 Vol. 1

Plant name: Surry 1 **Com.op:** 12/1/72 **Ref:**

PSA title: NUREG/CR 4550, Vol. 3,Surry Unit 1, table IV.3-1 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2 to 6 inches

LOCA freq: 1,00E-03 **Freq.distr:** mean value/r.yr. **Source:** based on NUREG/CR 4550 Vol. 1

Plant name: Surry 1 **Com.op:** 12/1/72 **Ref:**

PSA title: NUREG/CR 4550, Vol. 3,Surry Unit 1, table IV.3-1 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with the equivalent size .5 to 2 inches

LOCA freq: 1,00E-03 **Freq.distr:** mean value/r.yr. **Source:** based on NUREG/CR 4550 Vol. 1

Plant name: Surry 1 **Com.op:** 12/1/72 **Ref:**

PSA title: NUREG/CR 4550, Vol. 3,Surry Unit 1, table IV.3-1 **PSA date:**

Comments:

LOCA type: small small LOCA **LOCA Size:** break with the equivalent size less than .5 inches

LOCA freq: 2,00E-02 **Freq.distr:** mean value/r.yr. **Source:** based on NUREG/CR 4550 Vol. 1

Plant name: Surry 1 **Com.op:** 12/1/72 **Ref:**

PSA title: NUREG/CR 4550, Vol. 3,Surry Unit 1, table IV.3-1 **PSA date:**

Comments:

LOCA type: IS LOCA **LOCA Size:**

LOCA freq: 1,00E-06 **Freq.distr:** mean value/r.yr. **Source:** RSS data

Plant name: Surry 1 **Com.op:** 12/1/72 **Ref:**

PSA title: NUREG/CR 4550, Vol. 3,Surry Unit 1, table IV.3-1 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent area gretaer than .1 sq.ft

LOCA freq: 2,70E-04 **Freq.distr:** mean value/r.yr. **Source:** past PRAs and other sources

Plant name: Peach Botom-2 **Com.op:** 7/1/74 **Ref:**

PSA title: NUREG/CR 4550, Vol. 4, Peach Bottom, table IV.3-1 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent area .004 to .1 sq.ft
LOCA freq: 8,00E-04 **Freq.distr:** mean value/r.yr. **Source:** past PRAs and other sources
Plant name: Peach Botom-2 **Com.op:** 7/1/74 **Ref:**
PSA title: NUREG/CR 4550, Vol. 4, Peach Bottom, table IV.3-1 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent area less than .004 sq.ft liquid or .01 steam
LOCA freq: 2,70E-03 **Freq.distr:** mean value/r.yr. **Source:** past PRAs and other sources
Plant name: Peach Botom-2 **Com.op:** 7/1/74 **Ref:**
PSA title: NUREG/CR 4550, Vol. 4, Peach Bottom, table IV.3-1 **PSA date:**
Comments:

LOCA type: small small LOCA **LOCA Size:** leaks with 50 to 100 gpm flow recirculation pump steal
LOCA freq: 2,70E-02 **Freq.distr:** mean value/r.yr. **Source:** past PRAs and other sources
Plant name: Peach Botom-2 **Com.op:** 7/1/74 **Ref:**
PSA title: NUREG/CR 4550, Vol. 4, Peach Bottom, table IV.3-1 **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 1,00E-08 **Freq.distr:** mean value/r.yr. **Source:** analysis of the system interfaces using generic failure data
Plant name: Peach Botom-2 **Com.op:** 7/1/74 **Ref:**
PSA title: NUREG/CR 4550, Vol. 4, Peach Bottom, table IV.3-1 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break withequivalent size greater than .3 sq.ft
LOCA freq: 3,00E-04 **Freq.distr:** mean value/r.yr. **Source:**
Plant name: Grand Gulf-1 **Com.op:** 7/1/85 **Ref:**
PSA title: NUREG/CR 4550, Vol. 6, Grand Gulf 1, table IV.3-1 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent area .005 to .3 sq. ft liquid and .1 to .3 sq.ft steam
LOCA freq: 8,00E-04 **Freq.distr:** mean value/r.yr. **Source:**
Plant name: Grand Gulf-1 **Com.op:** 7/1/85 **Ref:**
PSA title: NUREG/CR 4550, Vol. 6, Grand Gulf 1, table IV.3-1 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent area less than .005 sq.ft liquid and less than .1 sq.ft steam
LOCA freq: 3,00E-03 **Freq.distr:** mean value/r.yr. **Source:**
Plant name: Grand Gulf-1 **Com.op:** 7/1/85 **Ref:**
PSA title: NUREG/CR 4550, Vol. 6, Grand Gulf 1, table IV.3-1 **PSA date:**
Comments:

LOCA type: small small LOCA **LOCA Size:** leaks with 50 to 100 gpm flow recirculation pump
LOCA freq: 3,00E-02 **Freq.distr:** mean value/r.yr. **Source:**
Plant name: Grand Gulf-1 **Com.op:** 7/1/85 **Ref:**
PSA title: NUREG/CR 4550, Vol. 6, Grand Gulf 1, table IV.3-1 **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 1,00E-08 **Freq.distr:** mean value/r.yr. **Source:** analysis of the system interfaces using generic failure data
Plant name: Grand Gulf-1 **Com.op:** 7/1/85 **Ref:**

PSA title: NUREG/CR 4550, Vol. 6, Grand Gulf 1, table IV.3-1 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with effective diameter greater than 4 inches
LOCA freq: 9,30E-04 **Freq.distr:** mean value/r.yr.; 95%,5%; 2.8E-3/yr; 9.4E-7/yr **Source:** generic rpior updated with plant specific operating experience
Plant name: Oconee-1 **Com.op:** 7/1/73 **Ref:**
PSA title: Oconee PRA, table 5.9 **PSA date:**
Comments:

LOCA type: RPV rupture **LOCA Size:**
LOCA freq: 1,10E-06 **Freq.distr:** mean value/r.yr.; 95%,5%; 4.1E-6/yr; 6.0E-8/yr **Source:** various sources
Plant name: Oconee-1 **Com.op:** 7/1/73 **Ref:**
PSA title: Oconee PRA, table 5.9 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .5 to 4 inches; inadvertant PORV or safety valve opening; RCP seal failure; control rod drive seal leakage
LOCA freq: 3,00E-03 **Freq.distr:** mean value/r.yr.; 95%,5%; 1.2E-2/yr; 1.0E-6/yr **Source:** update of generic prior
Plant name: Oconee-1 **Com.op:** 7/1/73 **Ref:**
PSA title: Oconee PRA, table 5.9 **PSA date:**
Comments:

LOCA type: STGR **LOCA Size:** tube rupture with leak greater than 100 gpm
LOCA freq: 8,60E-03 **Freq.distr:** mean value/r.yr.; 95%,5%; 2.7E-2/yr; 2.6E-5/yr **Source:** generic data updated with plant specific operating experience
Plant name: Oconee-1 **Com.op:** 7/1/73 **Ref:**
PSA title: Oconee PRA, table 5.9 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 6 inches
LOCA freq: 4,70E-05 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation using generic data
Plant name: Sequoyah-1 **Com.op:** 7/1/81 **Ref:**
PSA title: Sequoyah NPP RSSMAP, table 7-4 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2 to 6 inches
LOCA freq: 9,80E-04 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation using generic data
Plant name: Sequoyah-1 **Com.op:** 7/1/81 **Ref:**
PSA title: Sequoyah NPP RSSMAP, table 7-4 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .5 to 2 inches
LOCA freq: 1,80E-03 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation using generic data
Plant name: Sequoyah-1 **Com.op:** 7/1/81 **Ref:**
PSA title: Sequoyah NPP RSSMAP, table 7-4 **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 4,60E-06 **Freq.distr:** mean value/r.yr. **Source:** engineering evaluation using generic data
Plant name: Sequoyah-1 **Com.op:** 7/1/81 **Ref:**
PSA title: Sequoyah NPP RSSMAP, table 7-4 **PSA date:**
Comments:

LOCA type: RPV rupture **LOCA Size:**

LOCA freq: 1,00E-07 **Freq.distr:** mean value/r.yr. **Source:** generic data
Plant name: Sequoyah-1 **Com.op:** 7/1/81 **Ref:**
PSA title: Sequoyah NPP RSSMAP, table 7-4 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivaelnt size greater than 4 inches
LOCA freq: 7,00E-04 **Freq.distr:** point estimate/r.yr.; EF 10 **Source:** generic data based on collection of operating experience
Plant name: Shoreham-1 **Com.op:** n/a **Ref:**
PSA title: Shoreham PRA, Appendix A.1 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 1 to 4 inches
LOCA freq: 3,00E-03 **Freq.distr:** point estimate/r.yr.; EF 3 **Source:** generic data based on actual reactor operating experience
Plant name: Shoreham-1 **Com.op:** n/a **Ref:**
PSA title: Shoreham PRA, Appendix A.1 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size less than 1 inch
LOCA freq: 8,00E-03 **Freq.distr:** point estimate/r.yr.; EF 3 **Source:** generic data based on reactor operating experience
Plant name: Shoreham-1 **Com.op:** n/a **Ref:**
PSA title: Shoreham PRA, Appendix A.1 **PSA date:**
Comments:

LOCA type: RPV rupture **LOCA Size:**
LOCA freq: 3,00E-07 **Freq.distr:** point estimate/r.yr.; EF 10 **Source:** generic data sources
Plant name: Shoreham-1 **Com.op:** n/a **Ref:**
PSA title: Shoreham PRA, Appendix A.1 **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 1,20E-07 **Freq.distr:** point estimate/r.yr. **Source:** system evaluation
Plant name: Shoreham-1 **Com.op:** n/a **Ref:**
PSA title: Shoreham PRA, Appendix A.1 **PSA date:**
Comments:

LOCA type: RPV rupture **LOCA Size:**
LOCA freq: 1,00E-07 **Freq.distr:** median, event/r.yr.; 90% lognormal distr.; 1.0E-6/yr.; 1.0E-8/yr. **Source:** based on non/nuclear experience
Plant name: **Com.op:** **Ref:**
PSA title: WASH 1400, Reactor Safety Study, Appendix V, Chapter 4.5 **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 6 inches
LOCA freq: 1,00E-04 **Freq.distr:** median, event/r.yr.; 90% lognormal distr.; 1.0E-3/yr.; 1.0E-5/yr. **Source:** based on number of nuclear, industrial and other sources
Plant name: **Com.op:** **Ref:**
PSA title: WASH 1400, Reactor Safety Study, Appendix III, table III 6-9 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2.5 to 8.5 inches liquid and 4.7 to 6 inches steam
LOCA freq: 3,00E-04 **Freq.distr:** median, event/r.yr.; 90% lognormal distr.; 3.0E-3/yr.; 3.0E-5/yr. **Source:** assessment based on nuclear, industrial and other data sources
Plant name: **Com.op:** **Ref:**

PSA title: WASH 1400, Reactor Safety Study, Appendix III, table III 6-9 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivaalent size 2 to 6 inches

LOCA freq: 3,00E-04 **Freq.distr:** median, event/r.yr.; 90% lognormal distr.; 3.0E-3/yr.; 3.0E-5/yr. **Source:** assessment based on nuclear, industrial and other data sources

Plant name: **Com.op:** **Ref:**

PSA title: WASH 1400, Reactor Safety Study, Appendix III, table III 6-9 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size 0.6 to 2.6 inches liquid and 1 to 4.7 inches steam

LOCA freq: 1,00E-03 **Freq.distr:** median, event/r.yr.; 90% lognormal distr.; 1.0E-2/yr.; 1.0E-4/yr. **Source:** assessment based on nuclear, industrial and other data sources

Plant name: **Com.op:** **Ref:**

PSA title: WASH 1400, Reactor Safety Study, Appendix III, table III 6-9 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .5 to 2 inches

LOCA freq: 1,00E-03 **Freq.distr:** median, event/r.yr.; 90% lognormal distr.; 1.0E-2/yr.; 1.0E-4/yr. **Source:** assessment based on nuclear, industrial and other data sources

Plant name: **Com.op:** **Ref:**

PSA title: WASH 1400, Reactor Safety Study, Appendix III, table III 6-9 **PSA date:**

Comments:

LOCA type: IS LOCA **LOCA Size:**

LOCA freq: 4,00E-06 **Freq.distr:** median, event/r.yr.; EF 10 **Source:** analysis of the system interface using generic failure rates

Plant name: **Com.op:** **Ref:**

PSA title: WASH 1400, Reactor Safety Study, Appendix V, Chapter 4.4 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** brek with equivalent size greater than 4.3 inches

LOCA freq: 2,30E-04 **Freq.distr:** mean value/r.yr. **Source:** generic data

Plant name: Calvert Cliffs Unit 1 **Com.op:** 5/1/75 **Ref:**

PSA title: Calvert Cliffs Unit 1 IREP, table 4.2 **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 1.9 to 4.3 inches

LOCA freq: 2,40E-04 **Freq.distr:** mean value/r.yr. **Source:** generic data

Plant name: Calvert Cliffs Unit 1 **Com.op:** 5/1/75 **Ref:**

PSA title: Calvert Cliffs Unit 1 IREP, table 4.2 **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .3 to 1.9 inches; reactor coolant pump seal rupture

LOCA freq: 2,10E-02 **Freq.distr:** mean value/r.yr. **Source:** generic data

Plant name: Calvert Cliffs Unit 1 **Com.op:** 5/1/75 **Ref:**

PSA title: Calvert Cliffs Unit 1 IREP, table 4.2 **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent area .3 to 4.3 sq.ft liquid suction fluid

LOCA freq: 9,90E-06 **Freq.distr:** mean value/r.yr. **Source:** generic data

Plant name:	Browns Ferry Unit 1	**Com.op:**	8/1/74	**Ref:**	
PSA title:	Browns Ferry Unit 1 IREP, table 5			**PSA date:**	
Comments:					

LOCA type:	large LOCA	**LOCA Size:**	break with equivalent area .3 to 4.3 sq.ft liquid discharge side		
LOCA freq:	3,90E-05	**Freq.distr:**	mean value/r.yr.	**Source:**	generic data
Plant name:	Browns Ferry Unit 1	**Com.op:**	8/1/74	**Ref:**	
PSA title:	Browns Ferry Unit 1 IREP, table 5			**PSA date:**	
Comments:					

LOCA type:	large LOCA	**LOCA Size:**	break with equivalent area 1.4 to 4.1 sq.ft steam		
LOCA freq:	5,20E-05	**Freq.distr:**	mean value/r.yr.	**Source:**	generic data
Plant name:	Browns Ferry Unit 1	**Com.op:**	8/1/74	**Ref:**	
PSA title:	Browns Ferry Unit 1 IREP, table 5			**PSA date:**	
Comments:					

LOCA type:	medium LOCA	**LOCA Size:**	break with equivalent size.12 to .3 sq.ft liquid		
LOCA freq:	9,00E-05	**Freq.distr:**	mean value/r.yr.	**Source:**	generic data
Plant name:	Browns Ferry Unit 1	**Com.op:**	8/1/74	**Ref:**	
PSA title:	Browns Ferry Unit 1 IREP, table 5			**PSA date:**	
Comments:					

LOCA type:	medium LOCA	**LOCA Size:**	break with equivalent area .12 to 1.4 sq.ft steam		
LOCA freq:	2,10E-04	**Freq.distr:**	mean value/r.yr.	**Source:**	generic data
Plant name:	Browns Ferry Unit 1	**Com.op:**	8/1/74	**Ref:**	
PSA title:	Browns Ferry Unit 1 IREP, table 5			**PSA date:**	
Comments:					

LOCA type:	small LOCA	**LOCA Size:**	break with equivalent area less than .12 sq.ft		
LOCA freq:	1,00E-03	**Freq.distr:**	mean value/r.yr.	**Source:**	generic data
Plant name:	Browns Ferry Unit 1	**Com.op:**	8/1/74	**Ref:**	
PSA title:	Browns Ferry Unit 1 IREP, table 5			**PSA date:**	
Comments:					

LOCA type:	large LOCA	**LOCA Size:**			
LOCA freq:	2,00E-04	**Freq.distr:**	mean value/r.yr.; 95%, 5% of distribution; 5.2E-4/yr.; 7.6E-6/yr.	**Source:**	generic data updated with plant specific operating experience
Plant name:	Beznau	**Com.op:**	1969 - 09	**Ref:**	
PSA title:				**PSA date:**	1983
Comments:					

LOCA type:	medium LOCA	**LOCA Size:**			
LOCA freq:	4,60E-04	**Freq.distr:**	mean value/r.yr.; 95%, 5% of distribution; 1.2E-3/yr.; 2.3E-5/yr.	**Source:**	generic data updated with plant specific operating experience
Plant name:	Beznau	**Com.op:**	1969 - 09	**Ref:**	
PSA title:				**PSA date:**	1983
Comments:					

LOCA type:	small LOCA nonisolable	**LOCA Size:**			
LOCA freq:	4,00E-03	**Freq.distr:**	mean value/r.yr.; 95%, 5% of distribution; 1.4E-2/yr.; 1.2E-4/yr.	**Source:**	generic data updated with plant specific operating experience
Plant name:	Beznau	**Com.op:**	1969 - 09	**Ref:**	
PSA title:				**PSA date:**	1983

Comments:

LOCA type: small LOCA isolable
LOCA Size:
LOCA freq: 2,30E-02
Freq.distr: mean value/r.yr.; 95%, 5% of distribution; 5.0E-2/yr.; 3.3E-3/yr.
Source: generic data updated with plant specific operating experience
Plant name: Beznau
Com.op: 1969 - 09
Ref:
PSA title:
PSA date: 1983
Comments:

LOCA type: STGR
LOCA Size:
LOCA freq: 8,20E-03
Freq.distr: mean value/r.yr.; 95%, 5% of distribution; 2.1E-2/yr.; 3.1E-4/yr.
Source: generic data updated with plant specific operating experience
Plant name: Beznau
Com.op: 1969 - 09
Ref:
PSA title:
PSA date: 1983
Comments:

LOCA type: large LOCA
LOCA Size: break with equivalent flow greater than 2000 kg/s
LOCA freq: 3,00E-04
Freq.distr: mean value/r.yr.
Source: generic sources
Plant name: Barseback 1&2
Com.op: 1975 - 07
Ref:
PSA title:
PSA date:
Comments:

LOCA type: medium LOCA
LOCA Size: break with equivalent flow 30 to 2000 kg/s
LOCA freq: 9,00E-04
Freq.distr: mean value/r.yr.
Source: literature sources
Plant name: Barseback 1&2
Com.op: 1975 - 07
Ref:
PSA title:
PSA date:
Comments:

LOCA type: small LOCA
LOCA Size: break with equivalent flow 10 to 30 kg/s
LOCA freq: 3,00E-03
Freq.distr: mean value/r.yr.
Source: literature data
Plant name: Barseback 1&2
Com.op: 1975 - 07
Ref:
PSA title:
PSA date:
Comments:

LOCA type: RPV rupture
LOCA Size:
LOCA freq: 2,70E-07
Freq.distr: mean value/r.yr.
Source: literature sources
Plant name: Forsmark 3
Com.op: 1985 - 08
Ref:
PSA title:
PSA date:
Comments:

LOCA type: large LOCA
LOCA Size: break with the equivalent area greater than 450 sq.cm
LOCA freq: 1,00E-04
Freq.distr: mean value/r.yr.
Source: literature sources
Plant name: Forsmark 3
Com.op: 1985 - 08
Ref:
PSA title:
PSA date:
Comments:

LOCA type: medium LOCA
LOCA Size: break with the equivalent area 80 to 450 sq.cm
LOCA freq: 3,00E-04
Freq.distr: mean value/r.yr.
Source: literature sources
Plant name: Forsmark 3
Com.op: 1985 - 08
Ref:
PSA title:
PSA date:
Comments:

LOCA type: small LOCA
LOCA Size: break with the equivalent area less than 80 sq.cm
LOCA freq: 1,00E-03
Freq.distr: mean value/r.yr.
Source: literature sources
Plant name: Forsmark 3
Com.op: 1985 - 08
Ref:
PSA title:
PSA date:

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent flow 600 to 2000 kg/s
LOCA freq: 1,00E-07 **Freq.distr:** mean value/r.yr. **Source:** literature sources application of LBB criteria
Plant name: Oskarshamn 1 **Com.op:** 1972 - 02 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent flow 35 to 600 kg/s
LOCA freq: 1,10E-05 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 1 **Com.op:** 1972 - 02 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent flow less than 35 kg/s
LOCA freq: 1,10E-02 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 1 **Com.op:** 1972 - 02 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 1,00E-07 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 1 **Com.op:** 1972 - 02 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent flow greater than 2000 kg/s
LOCA freq: 1,00E-07 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 2 **Com.op:** 1975 - 01 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent flow 30 to 2000 kg/s
LOCA freq: 1,00E-06 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 2 **Com.op:** 1975 - 01 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent flow 10 to 30 kg/s
LOCA freq: 1,00E-02 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 2 **Com.op:** 1975 - 01 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent flow greater than 3000 kg/s
LOCA freq: 1,00E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 3 **Com.op:** 1985 - 08 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Oskarshamn 3 **Com.op:** 1985 - 08 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,00E-03 **Freq.distr:** mean value/r.yr. **Source:** literature sources

Plant name: Oskarshamn 3 **Com.op:** 1985 - 08 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent flow greater than 1200 kg/s

LOCA freq: 3,00E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources

Plant name: Ringhals 1 **Com.op:** 1976 - 01 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent flow 35 to 1200 kg/s

LOCA freq: 9,00E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources

Plant name: Ringhals 1 **Com.op:** 1976 - 01 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent flow 5 to 35 kg/s

LOCA freq: 3,00E-03 **Freq.distr:** mean value/r.yr. **Source:** literature sources

Plant name: Ringhals 1 **Com.op:** 1976 - 01 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: IS LOCA **LOCA Size:**

LOCA freq: 1,90E-07 **Freq.distr:** mean value/r.yr. **Source:** literature sources

Plant name: Ringhals 1 **Com.op:** 1976 - 01 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: RPV rupture **LOCA Size:**

LOCA freq: 2,70E-07 **Freq.distr:** mean value/r.yr. **Source:** literature data

Plant name: Ringhals 1 **Com.op:** 1976 - 01 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent diameter greater than 15cm

LOCA freq: 4,00E-04 **Freq.distr:** mean value/r.yr.; 95%; 1.2E-3/yr. **Source:** literature sources

Plant name: Ringhals 2 **Com.op:** 1975 - 05 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent diameter between 5 and 15 cm

LOCA freq: 8,10E-04 **Freq.distr:** mean value/r.yr.; 95%; 3.0E-3/yr. **Source:** literature sources

Plant name: Ringhals 2 **Com.op:** 1975 - 05 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,10E-02 **Freq.distr:** mean value/r.yr.; 95%; 2.5E-2/yr. **Source:** literature sources

Plant name: Ringhals 2 **Com.op:** 1975 - 05 **Ref:**

PSA title: **PSA date:**

Comments:

LOCA type: RPV rupture **LOCA Size:**

LOCA freq: 2,70E-07 **Freq.distr:** mean value/r.yr.; 95%; 1.0E-6/yr. **Source:** literature sources
Plant name: Ringhals 2 **Com.op:** 1975 - 05 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 4,20E-08 **Freq.distr:** mean value/r.yr. **Source:**
Plant name: Ringhals 2 **Com.op:** 1975 - 05 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: STGR **LOCA Size:**
LOCA freq: 9,70E-03 **Freq.distr:** mean value/r.yr.; 95%; 2.0E-2/yr. **Source:** literature sources
Plant name: Ringhals 2 **Com.op:** 1975 - 05 **Ref:**
PSA title: **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent diameter greater than 6 inches; RPV failure
LOCA freq: 9,40E-04 **Freq.distr:** mean value/r.yr.; 95%, 5%; 3.6E-3/yr.; 3.3E-5/yr. **Source:** literature sources and plant operating experiences
Plant name: Zion **Com.op:** 1973 - 12 **Ref:**
PSA title: Zion NPP PSS table 1.1.1-2 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent sizes between 2 and 6 inches; multiple pressurizer safety and relief valve failure
LOCA freq: 9,40E-04 **Freq.distr:** mean value/r.yr.; 95%, 5%; 3.6E-3/yr.; 3.3E-5/yr. **Source:** literature sources and plant operating experiences
Plant name: Zion **Com.op:** 1973 - 12 **Ref:**
PSA title: Zion NPP PSS table 1.1.1-2 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent diameter smaller than 2 inches; pressurizer and relief valve failure; CRDM failures; RCP seal failure
LOCA freq: 3,50E-02 **Freq.distr:** mean value/r.yr.; 95%, 5%; 7.2E-2/yr.; 1.3E-2/yr. **Source:** literature sources and plant operating experiences
Plant name: Zion **Com.op:** 1973 - 12 **Ref:**
PSA title: Zion NPP PSS table 1.1.1-2 **PSA date:**
Comments:

LOCA type: STGR **LOCA Size:**
LOCA freq: 2,40E-02 **Freq.distr:** mean value/r.yr.; 95%, 5%; 7.7E-2/yr.; 2.8E-3/yr. **Source:** literature sources and plant operating experiences
Plant name: Zion **Com.op:** 1973 - 12 **Ref:**
PSA title: Zion NPP PSS table 1.1.1-2 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 3,50E-02 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Angra **Com.op:** 1984 - 12 **Ref:**
PSA title: Angra NPP PSA summary report **PSA date:**
Comments:

LOCA type: STGR **LOCA Size:**
LOCA freq: 3,70E-02 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Angra **Com.op:** 1984 - 12 **Ref:**
PSA title: Angra NPP PSA summary report **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 9,40E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Angra **Com.op:** 1984 - 12 **Ref:**
PSA title: Angra NPP PSA summary report **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 9,40E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Angra **Com.op:** 1984 - 12 **Ref:**
PSA title: Angra NPP PSA summary report **PSA date:**
Comments:

LOCA type: IS LOCA **LOCA Size:**
LOCA freq: 4,00E-07 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Angra **Com.op:** 1984 - 12 **Ref:**
PSA title: Angra NPP PSA summary report **PSA date:**
Comments:

LOCA type: large LOCA inside drywell **LOCA Size:** break size greater than .3 sq.ft
LOCA freq: 2,70E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type: large LOCA outside drywell **LOCA Size:** break size greater than .3 sq.ft
LOCA freq: 1,00E-04 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break sizes between .1 and .3 sq.ft steam and .004 and .2 liquid
LOCA freq: 2,70E-03 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break size up to .1 sq.ft steam or .004 sq.ft liquid
LOCA freq: 2,70E-02 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type: IS LOCA LPCI break **LOCA Size:**
LOCA freq: 7,30E-08 **Freq.distr:** mean value/r.yr. **Source:** literature data
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type: IS LOCA CS break **LOCA Size:**
LOCA freq: 2,30E-07 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type: ECCS breaks **LOCA Size:**
LOCA freq: 1,30E-05 **Freq.distr:** mean value/r.yr. **Source:** literature sources
Plant name: Caorso **Com.op:** 1981 - 12 **Ref:**
PSA title: Caorso NPP PSS table A-2 **PSA date:**
Comments:

LOCA type:	RPV rupture	**LOCA Size:**			
LOCA freq:	3,00E-07	**Freq.distr:**	mean value/r.yr.	**Source:**	literature sources
Plant name:	Caorso	**Com.op:**	1981 - 12	**Ref:**	
PSA title:	Caorso NPP PSS table A-2			**PSA date:**	
Comments:					

LOCA type:	IORV	**LOCA Size:**			
LOCA freq:	6,00E-02	**Freq.distr:**	mean value/r.yr.	**Source:**	BWR operating experience
Plant name:		**Com.op:**		**Ref:**	
PSA title:	Limeric PRA, table A.1.3			**PSA date:**	
Comments:					

LOCA type:	IORV	**LOCA Size:**			
LOCA freq:	1,40E-01	**Freq.distr:**	mean value/r.yr.; EF 3	**Source:**	based on NUREG/CR 3862
Plant name:		**Com.op:**		**Ref:**	
PSA title:	NUREG/CR 4550, Vol. 1, Methodology...,table VIII.1-1			**PSA date:**	
Comments:					

LOCA type:	IORV	**LOCA Size:**			
LOCA freq:	1,40E-01	**Freq.distr:**	mean value/r.yr.	**Source:**	different nuclear sources and plant operating experiences
Plant name:	Grand Gulf-1	**Com.op:**	7/1/85	**Ref:**	
PSA title:	NUREG/CR 4550, Vol. 6, Grand Gulf 1...,table IV.3-1			**PSA date:**	
Comments:					

LOCA type:	IORV	**LOCA Size:**			
LOCA freq:	9,00E-02	**Freq.distr:**	mean value/r.yr.; EF 3	**Source:**	generic data and engineering evaluation
Plant name:		**Com.op:**		**Ref:**	
PSA title:	Shoreham PRA, Appendix A, table A.1-3			**PSA date:**	
Comments:					

LOCA type:	IORV	**LOCA Size:**			
LOCA freq:	1,30E-02	**Freq.distr:**	mean value/r.yr.	**Source:**	study for the plant with similar valves Alto Layio
Plant name:	Caorso	**Com.op:**	1981 - 12	**Ref:**	
PSA title:	Caorso NPP PSS table A-2			**PSA date:**	
Comments:					

LOCA type:	large LOCA	**LOCA Size:**			
LOCA freq:	1,00E-04	**Freq.distr:**		**Source:**	
Plant name:	Arkansas Nuclear 1	**Com.op:**	1974 - 12	**Ref:**	
PSA title:	IPE			**PSA date:**	
Comments:					

LOCA type:	small LOCA	**LOCA Size:**			
LOCA freq:	5,00E-03	**Freq.distr:**		**Source:**	
Plant name:	Arkansas Nuclear 1	**Com.op:**	1974 - 12	**Ref:**	
PSA title:	IPE			**PSA date:**	
Comments:					

LOCA type:	large LOCA	**LOCA Size:**			
LOCA freq:	1,00E-04	**Freq.distr:**		**Source:**	
Plant name:	Arkansas Nuclear 2	**Com.op:**	1980 - 03	**Ref:**	
PSA title:	IPE			**PSA date:**	
Comments:					

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Arkansas Nuclear 2 **Com.op:** 1980 - 03 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 5,00E-03 **Freq.distr:** **Source:**
Plant name: Arkansas Nuclear 2 **Com.op:** 1980 - 03 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,02E-04 **Freq.distr:** **Source:**
Plant name: Beaver Valley 1 **Com.op:** 1976 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,61E-04 **Freq.distr:** **Source:**
Plant name: Beaver Valley 1 **Com.op:** 1976 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,85E-02 **Freq.distr:** **Source:**
Plant name: Beaver Valley 1 **Com.op:** 1976 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes isolable and non isolable small LOCAs

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,03E-04 **Freq.distr:** **Source:**
Plant name: Beaver Valley 2 **Com.op:** 1987 - 11 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,64E-04 **Freq.distr:** **Source:**
Plant name: Beaver Valley 2 **Com.op:** 1987 - 11 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,37E-02 **Freq.distr:** **Source:**
Plant name: Beaver Valley 2 **Com.op:** 1987 - 11 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes isolable and nonisolable LOCAs

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Braidwood 1&2 **Com.op:** 1988 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Braidwood 1&2 **Com.op:** 1988 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,30E-03 **Freq.distr:** **Source:**
Plant name: Braidwood 1&2 **Com.op:** 1988 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Byron 1&2 **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Byron 1&2 **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,10E-03 **Freq.distr:** **Source:**
Plant name: Byron 1&2 **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Callaway **Com.op:** 1984 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RV rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Callaway **Com.op:** 1984 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Callaway **Com.op:** 1984 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 1,30E-02 **Freq.distr:** **Source:**
Plant name: Callaway **Com.op:** 1984 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,02E-04 **Freq.distr:** **Source:**

Plant name: Calvert Cliffs 1&2 **Com.op:** 1975 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,62E-04 **Freq.distr:** **Source:**
Plant name: Calvert Cliffs 1&2 **Com.op:** 1975 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 5,04E-03 **Freq.distr:** **Source:**
Plant name: Calvert Cliffs 1&2 **Com.op:** 1975 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 8,78E-03 **Freq.distr:** **Source:**
Plant name: Calvert Cliffs 1&2 **Com.op:** 1975 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes very very small LOCA

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,01E-04 **Freq.distr:** **Source:**
Plant name: Gatawba 1&2 **Com.op:** 1985 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes reactor pressure vessel rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Gatawba 1&2 **Com.op:** 1985 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 4,00E-03 **Freq.distr:** **Source:**
Plant name: Gatawba 1&2 **Com.op:** 1985 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-05 **Freq.distr:** **Source:**
Plant name: Crystal River **Com.op:** 1977 - 03 **Ref:**
PSA title: IPE **PSA date:**
Comments: RV rupture is not included

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Crystal River **Com.op:** 1977 - 03 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 2,00E-03 **Freq.distr:** **Source:**
Plant name: Crystal River **Com.op:** 1977 - 03 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: D.C. Cook 1&2 **Com.op:** 1975 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes break beyond ECCS capability

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 9,17E-04 **Freq.distr:** **Source:**
Plant name: D.C. Cook 1&2 **Com.op:** 1975 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,80E-03 **Freq.distr:** **Source:**
Plant name: D.C. Cook 1&2 **Com.op:** 1975 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 1,00E-04 **Freq.distr:** **Source:**
Plant name: Davis-Besse **Com.op:** 1978 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Davis-Besse **Com.op:** 1978 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,80E-03 **Freq.distr:** **Source:**
Plant name: Davis-Besse **Com.op:** 1978 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,00E-04 **Freq.distr:** **Source:**
Plant name: Diabolo Canyon 1&2 **Com.op:** 1985 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,60E-04 **Freq.distr:** **Source:**
Plant name: Diabolo Canyon 1&2 **Com.op:** 1985 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,93E-03 **Freq.distr:** **Source:**
Plant name: Diabolo Canyon 1&2 **Com.op:** 1985 - 05 **Ref:**
PSA title: IPE **PSA date:**
Comments: isolable and nonisolable

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Farley 1&2 **Com.op:** 1977 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA; reactor and vessel rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 7,70E-04 **Freq.distr:** **Source:**
Plant name: Farley 1&2 **Com.op:** 1977 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 4,70E-03 **Freq.distr:** **Source:**
Plant name: Farley 1&2 **Com.op:** 1977 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 1,00E-05 **Freq.distr:** **Source:**
Plant name: Fort Calhoun 1 **Com.op:** 1974 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments: reactor vessel failure not modeled

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-04 **Freq.distr:** **Source:**
Plant name: Fort Calhoun 1 **Com.op:** 1974 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Fort Calhoun 1 **Com.op:** 1974 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 1,80E-04 **Freq.distr:** **Source:**
Plant name: Ginna **Com.op:** 1970 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RV rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,00E-04 **Freq.distr:** **Source:**
Plant name: Ginna **Com.op:** 1970 - 07 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 3,70E-04 **Freq.distr:** **Source:**
Plant name: Ginna **Com.op:** 1970 - 07 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 7,30E-04 **Freq.distr:** **Source:**

Plant name: Ginna **Com.op:** 1970 - 07 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 5,00E-04 **Freq.distr:** **Source:**

Plant name: H. B. Robinson 2 **Com.op:** 1971 - 03 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes RV failure: 5.0E-7; tables 3.5 and 3.42, figures 1-1, 1-2

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 2,60E-03 **Freq.distr:** **Source:**

Plant name: H. B. Robinson 2 **Com.op:** 1971 - 03 **Ref:**

PSA title: IPE **PSA date:**

Comments: tables 3.5 and 3.42, figures 1-1, 1-2

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,50E-02 **Freq.distr:** **Source:**

Plant name: H. B. Robinson 2 **Com.op:** 1971 - 03 **Ref:**

PSA title: IPE **PSA date:**

Comments: tables 3.5 and 3.42, figures 1-1, 1-2

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 3,90E-04 **Freq.distr:** **Source:**

Plant name: Haddam Neck **Com.op:** 1968 - 01 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 6,10E-04 **Freq.distr:** **Source:**

Plant name: Haddam Neck **Com.op:** 1968 - 01 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 2,10E-03 **Freq.distr:** **Source:**

Plant name: Haddam Neck **Com.op:** 1968 - 01 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 9,60E-03 **Freq.distr:** **Source:**

Plant name: Haddam Neck **Com.op:** 1968 - 01 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 2,01E-04 **Freq.distr:** **Source:**

Plant name: Indian Point **Com.op:** 1974 - 08 **Ref:**

2

PSA title: IPE **PSA date:**

Comments: includes LOCA beyond ECCS

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 4,60E-04 **Freq.distr:** **Source:**

Plant name: Indian Point 2 **Com.op:** 1974 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,60E-02 **Freq.distr:** **Source:**

Plant name: Indian Point 2 **Com.op:** 1974 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 4,70E-04 **Freq.distr:** **Source:**

Plant name: Indian Point 3 **Com.op:** 1976 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes vessel failure: 1E-7

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 9,10E-04 **Freq.distr:** **Source:**

Plant name: Indian Point 3 **Com.op:** 1976 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA| **LOCA Size:**

LOCA freq: 9,10E-04 **Freq.distr:** **Source:**

Plant name: Indian Point 3 **Com.op:** 1976 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 6,00E-03 **Freq.distr:** **Source:**

Plant name: Indian Point 3 **Com.op:** 1976 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 5,00E-04 **Freq.distr:** **Source:**

Plant name: Kewaunee **Com.op:** 1974 - 06 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes reactor vessel failure

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 2,36E-03 **Freq.distr:** **Source:**

Plant name: Kewaunee **Com.op:** 1974 - 06 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 5,12E-03 **Freq.distr:** **Source:**

Plant name: Kewaunee **Com.op:** 1974 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,70E-04 **Freq.distr:** **Source:**
Plant name: Maine Yankee **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Maine Yankee **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Maine Yankee **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 6,00E-03 **Freq.distr:** **Source:**
Plant name: Maine Yankee **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes very very small LOCA accidents

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,01E-04 **Freq.distr:** **Source:**
Plant name: Mcguire 1&2 **Com.op:** 1981 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RPV rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Mcguire 1&2 **Com.op:** 1981 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 4,00E-03 **Freq.distr:** **Source:**
Plant name: Mcguire 1&2 **Com.op:** 1981 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 6,40E-04 **Freq.distr:** **Source:**
Plant name: Millstone 2 **Com.op:** 1975 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 7,10E-04 **Freq.distr:** **Source:**

Plant name: Millstone 2 **Com.op:** 1975 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,25E-03 **Freq.distr:** **Source:**
Plant name: Millstone 2 **Com.op:** 1975 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 4,65E-03 **Freq.distr:** **Source:**
Plant name: Millstone 2 **Com.op:** 1975 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,88E-04 **Freq.distr:** **Source:**
Plant name: Millstone 3 **Com.op:** 1986 - 04 **Ref:**
PSA title: IPE **PSA date:**
Comments: including RV rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 6,11E-04 **Freq.distr:** **Source:**
Plant name: Millstone 3 **Com.op:** 1986 - 04 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 9,07E-03 **Freq.distr:** **Source:**
Plant name: Millstone 3 **Com.op:** 1986 - 04 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: North Anna 1&2 **Com.op:** 1978 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RV rupture (EXC. LOCA)

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: North Anna 1&2 **Com.op:** 1978 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,10E-02 **Freq.distr:** **Source:**
Plant name: North Anna 1&2 **Com.op:** 1978 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 7,00E-04 **Freq.distr:** **Source:**
Plant name: Oconee 3 **Com.op:** 1974 - 12 **Ref:**
PSA title: IPE **PSA date:**

Comments: includes RPV rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 7,00E-04 **Freq.distr:** **Source:**
Plant name: Oconee 3 **Com.op:** 1974 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 4,00E-03 **Freq.distr:** **Source:**
Plant name: Oconee 3 **Com.op:** 1974 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,00E-04 **Freq.distr:** **Source:**
Plant name: Palisades **Com.op:** 1971 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: P. 2.2-82, figure 2.2-3

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,00E-04 **Freq.distr:** **Source:**
Plant name: Palisades **Com.op:** 1971 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: P. 2.2-83, figure 2.2-4

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,00E-03 **Freq.distr:** **Source:**
Plant name: Palisades **Com.op:** 1971 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: P. 2.2-84, figure 2.2-5

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,10E-04 **Freq.distr:** **Source:**
Plant name: Palo Verde 1&2&3 **Com.op:** 1986 - 01 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,50E-04 **Freq.distr:** **Source:**
Plant name: Palo Verde 1&2&3 **Com.op:** 1986 - 01 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 8,00E-03 **Freq.distr:** **Source:**
Plant name: Palo Verde 1&2&3 **Com.op:** 1986 - 01 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Point Beach 1&2 **Com.op:** 1970 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Point Beach 1&2 **Com.op:** 1970 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 3,00E-03 **Freq.distr:** **Source:**
Plant name: Point Beach 1&2 **Com.op:** 1970 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Prairie Island 1 **Com.op:** 1973 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Prairie Island 1 **Com.op:** 1973 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 3,00E-03 **Freq.distr:** **Source:**
Plant name: Prairie Island 1 **Com.op:** 1973 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Prairie Island 2 **Com.op:** 1974 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Prairie Island 2 **Com.op:** 1974 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 3,00E-03 **Freq.distr:** **Source:**
Plant name: Prairie Island 2 **Com.op:** 1974 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Salem 1 **Com.op:** 1977 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Salem 1 **Com.op:** 1977 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Salem 1 **Com.op:** 1977 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 2,00E-02 **Freq.distr:** **Source:**
Plant name: Salem 1 **Com.op:** 1977 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Salem 2 **Com.op:** 1981 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Salem 2 **Com.op:** 1981 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Salem 2 **Com.op:** 1981 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 2,00E-02 **Freq.distr:** **Source:**
Plant name: Salem 2 **Com.op:** 1981 - 10 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: San Onofre 2&3 **Com.op:** 1983 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RV rupture: 2.7E-4

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: San Onofre 2&3 **Com.op:** 1983 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCAS **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**

Plant name: San Onofre 2&3 **Com.op:** 1983 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 1,30E-02 **Freq.distr:** **Source:**

Plant name: San Onofre 2&3 **Com.op:** 1983 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 2,03E-04 **Freq.distr:** **Source:**

Plant name: Seabrook **Com.op:** 1990 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 4,65E-04 **Freq.distr:** **Source:**

Plant name: Seabrook **Com.op:** 1990 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,79E-02 **Freq.distr:** **Source:**

Plant name: Seabrook **Com.op:** 1990 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 2,02E-04 **Freq.distr:** **Source:**

Plant name: Sequoyah 1&2 **Com.op:** 1981 - 07 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 4,62E-04 **Freq.distr:** **Source:**

Plant name: Sequoyah 1&2 **Com.op:** 1981 - 07 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 1,98E-02 **Freq.distr:** **Source:**

Plant name: Sequoyah 1&2 **Com.op:** 1981 - 07 **Ref:**

PSA title: IPE **PSA date:**

Comments: isolable (1.5E-2) and nonisolable small LOCAs

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 5,00E-04 **Freq.distr:** **Source:**

Plant name: Shearon Harris 1 **Com.op:** 1987 - 05 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 6,00E-04 **Freq.distr:** **Source:**

Plant name: Shearon Harris 1 **Com.op:** 1987 - 05 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 2,00E-03 **Freq.distr:** **Source:**

Plant name: Shearon Harris 1 **Com.op:** 1987 - 05 **Ref:**

PSA title: IPE **PSA date:**

Comments: small 2 LOCA

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 1,50E-02 **Freq.distr:** **Source:**

Plant name: Shearon Harris 1 **Com.op:** 1987 - 05 **Ref:**

PSA title: IPE **PSA date:**

Comments: small 1 LOCA

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 2,02E-04 **Freq.distr:** **Source:**

Plant name: South Texas Project 1&2 **Com.op:** 1988 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments: includes excessive LOCA; 1.67E-7 lower limit from leading 54 sequences

LOCA type: medium LOCA **LOCA Size:**

LOCA freq: 4,63E-04 **Freq.distr:** **Source:**

Plant name: South Texas Project 1&2 **Com.op:** 1988 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 2,11E-02 **Freq.distr:** **Source:**

Plant name: South Texas Project 1&2 **Com.op:** 1988 - 08 **Ref:**

PSA title: IPE **PSA date:**

Comments: isolable, nonisolable together

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 2,66E-04 **Freq.distr:** **Source:**

Plant name: St. Lucie 1 **Com.op:** 1976 - 12 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: small LOCA **LOCA Size:**

LOCA freq: 4,06E-04 **Freq.distr:** **Source:**

Plant name: St. Lucie 1 **Com.op:** 1976 - 12 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 1,42E-03 **Freq.distr:** **Source:**

Plant name: St. Lucie 1 **Com.op:** 1976 - 12 **Ref:**

PSA title: IPE **PSA date:**

Comments:

LOCA type: large LOCA **LOCA Size:**

LOCA freq: 2,66E-04 **Freq.distr:** **Source:**

Plant name: St. Lucie 2 **Com.op:** 1983 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 4,06E-04 **Freq.distr:** **Source:**
Plant name: St. Lucie 2 **Com.op:** 1983 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 1,42E-03 **Freq.distr:** **Source:**
Plant name: St. Lucie 2 **Com.op:** 1983 - 08 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Summer **Com.op:** 1984 - 01 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RV rupture cor damage (1E-7)

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Summer **Com.op:** 1984 - 01 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 8,00E-03 **Freq.distr:** **Source:**
Plant name: Summer **Com.op:** 1984 - 01 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Surry 1&2 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: including RV rupture

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Surry 1&2 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,10E-02 **Freq.distr:** **Source:**
Plant name: Surry 1&2 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 1,43E-04 **Freq.distr:** **Source:**
Plant name: Three Misle Island 1 **Com.op:** 1974 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 3,61E-04 **Freq.distr:** **Source:**
Plant name: Three Misle Island 1 **Com.op:** 1974 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,32E-03 **Freq.distr:** **Source:**
Plant name: Three Misle Island 1 **Com.op:** 1974 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 3,56E-03 **Freq.distr:** **Source:**
Plant name: Three Misle Island 1 **Com.op:** 1974 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 1,00E-05 **Freq.distr:** **Source:**
Plant name: Turkey Point 3&4 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-04 **Freq.distr:** **Source:**
Plant name: Turkey Point 3&4 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Turkey Point 3&4 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Turkey Point 3&4 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Vogtl 1&2 **Com.op:** 1987 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 8,00E-04 **Freq.distr:** **Source:**
Plant name: Vogtl 1&2 **Com.op:** 1987 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,60E-03 **Freq.distr:** **Source:**
Plant name: Vogtl 1&2 **Com.op:** 1987 - 06 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-05 **Freq.distr:** **Source:**
Plant name: Waterford 3 **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,00E-03 **Freq.distr:** **Source:**
Plant name: Waterford 3 **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 4,47E-03 **Freq.distr:** **Source:**
Plant name: Waterford 3 **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 2,03E-04 **Freq.distr:** **Source:**
Plant name: Watts Bar 1&2 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes excessive LOCA

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 4,65E-04 **Freq.distr:** **Source:**
Plant name: Watts Bar 1&2 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,88E-02 **Freq.distr:** **Source:**
Plant name: Watts Bar 1&2 **Com.op:** 1972 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments: isolable and nonisolable

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 5,00E-04 **Freq.distr:** **Source:**
Plant name: Wolf Creek **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments: includes RV failure

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,10E-03 **Freq.distr:** **Source:**
Plant name: Wolf Creek **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 2,50E-03 **Freq.distr:** **Source:**

Plant name: Wolf Creek **Com.op:** 1985 - 09 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:**
LOCA freq: 3,00E-04 **Freq.distr:** **Source:**
Plant name: Zion 1&2 **Com.op:** 1973 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:**
LOCA freq: 1,10E-03 **Freq.distr:** **Source:**
Plant name: Zion 1&2 **Com.op:** 1973 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:**
LOCA freq: 6,80E-03 **Freq.distr:** **Source:**
Plant name: Zion 1&2 **Com.op:** 1973 - 12 **Ref:**
PSA title: IPE **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .375 to 2 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Almaraz **Com.op:** 1983 - 09 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2 to 6 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Almaraz **Com.op:** 1983 - 09 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 6 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Almaraz **Com.op:** 1983 - 09 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:** break with equivalent size .375 to 1 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Asco **Com.op:** 1984 - 12 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size 1 to 2 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Asco **Com.op:** 1984 - 12 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2 to 6 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Asco **Com.op:** 1984 - 12 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 6 inches

LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Asco **Com.op:** 1984 - 12 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:** break with equivalent size .375 to .7 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Vandellos 2 **Com.op:** 1988 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .7 to 1.5 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Vandellos 2 **Com.op:** 1988 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 1.5 to 4 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Vandellos 2 **Com.op:** 1988 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size 4 to 11.5 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Vandellos 2 **Com.op:** 1988 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: very large LOCA **LOCA Size:** break with equivalent size greater than 11.5 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Vandellos 2 **Com.op:** 1988 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size .2 to 2 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Zorita **Com.op:** 1969 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 2 to 6 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Zorita **Com.op:** 1969 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 6 inches
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Zorita **Com.op:** 1969 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent area 0.14 to 3.2 sq.ft liquid; 0.85 to 1.65 sq.ft steam
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Santa M Garona **Com.op:** 1971 - 05 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent area 0.07 to 0.14 sq.ft liquid; 0.08 to 0.85 sq.ft steam
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Santa M Garona **Com.op:** 1971 - 05 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent area less than 0.07 sq.ft liquid; less than 0.08 sq.ft steam
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Santa M Garona **Com.op:** 1971 - 05 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent size greater than 22 cm
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Trillo **Com.op:** 1988 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent size 16 to 22 cm
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Trillo **Com.op:** 1988 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent size 5 to 16 cm
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Trillo **Com.op:** 1988 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: very small LOCA **LOCA Size:** break with equivalent size 1.6 to 5 cm
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Trillo **Com.op:** 1988 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: RCS leakage **LOCA Size:** break with equivalent size 1.13 to 1.6 cm
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Trillo **Com.op:** 1988 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: LOCA at pressurizer **LOCA Size:** break with equivalent size 5 to 16 cm
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Trillo **Com.op:** 1988 - 08 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large LOCA **LOCA Size:** break with equivalent area greater than 0.5 sq.ft liquid; greater than 0.3 sq.ft steam
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Cofrentes **Com.op:** 1985 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: medium LOCA **LOCA Size:** break with equivalent area 0.01 to 0.5 sq.ft liquid; 0.1 to 0.3 sq.ft steam
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Cofrentes **Com.op:** 1985 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent area 0.003 to 0.1 sq.ft liquid; 0.003 to 0.1 sq.ft steam
LOCA freq: 0,00E+00 **Freq.distr:** **Source:**
Plant name: Cofrentes **Com.op:** 1985 - 03 **Ref:**
PSA title: Spanish **PSA date:**
Comments:

LOCA type: large and medium LOCA **LOCA Size:** break with equivalent area greater than 200 sq. cm
LOCA freq: 1,00E-07 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments:

LOCA type: small LOCA 1 **LOCA Size:** break with equivalent area 80 to 200 sq. cm
LOCA freq: 9,00E-05 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments:

LOCA type: small LOCA 2 **LOCA Size:** break with equivalent area 50 to 80 sq. cm
LOCA freq: 7,50E-05 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments:

LOCA type: small LOCA 3 **LOCA Size:** break with equivalent area 25 to 50 sq. cm
LOCA freq: 7,50E-05 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments: small leakage at the pressurizer with equivalent area of 40 sq.cm while inadvertant opening of securitz valve 8.5E-4

LOCA type: small LOCA 4 **LOCA Size:** break with equivalent area 12 to 25 sq. cm
LOCA freq: 1,40E-04 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments: small leakage at the pressurizer with equivalent area of 20 sq.cm: while the mainfeedwater is unavailable 3.2E-5; while the ultimate heat sink is unavailable 3.3E-5; while occuring of other transients 1.2E-4

LOCA type: small LOCA 5 **LOCA Size:** break with equivalent area 2 to 12 sq. cm
LOCA freq: 2,80E-03 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments:

LOCA type: STGR **LOCA Size:** break with equivalent area 6 to 12 sq.cm
LOCA freq: 1,00E-05 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS 72, table 4-4 **PSA date:** 1989
Comments:

LOCA type: STGR **LOCA Size:** breakwith equivalent area 1 to 6 sq. cm
LOCA freq: 6,50E-03 **Freq.distr:** estimated value/a **Source:**
Plant name: **Com.op:** **Ref:**

PSA title: GRS 72, table 4-4 **PSA date:** 1989

Comments:

LOCA type: small LOCA **LOCA Size:** break with equivalent diameter .375 to 2 inches

LOCA freq: 2,00E-03 **Freq.distr:** **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: Etude Probabiliste de Surete **PSA date:** 1990

Comments: LOCA frequency above for operating mode a, operating mode b: 1E-5; operating mode c: 7.1E-4; operating mode d: 1.2E-4; operating mode e: 5.8E-5

LOCA type: medium LOCA **LOCA Size:** break with equivalent diameter 2 to 5 inches

LOCA freq: 3,00E-04 **Freq.distr:** **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: Etude Probabiliste de Surete **PSA date:** 1990

Comments: LOCA frequency above for operating mode a, operating mode b: 1.5E-6; operating mode c: 1.1E-5; operating mode d: 1.8E-5; operating mode e: 8.7E-6

LOCA type: large LOCA **LOCA Size:** break with equivalent diameter greater than 5 inches

LOCA freq: 1,00E-04 **Freq.distr:** **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: Etude Probabiliste de Surete **PSA date:** 1990

Comments: LOCA frequency above for operating mode a, operating mode b: 5.1E-7; operating mode c: 3.5E-6

LOCA type: IORV **LOCA Size:**

LOCA freq: 1,00E-04 **Freq.distr:** **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: Etude Probabiliste de Surete **PSA date:** 1990

Comments: LOCA frequency above for operating mode a; operating mode b: 1.1E-4; operating mode c: 7.6E-4

LOCA type: large LOCA **LOCA Size:** break with equivalent diameter greater than 6 inches

LOCA freq: 1,00E-04 **Freq.distr:** mean value/r.yr. **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: A probabilistic safety assessment of the standard French 900MWe pressurized water reactor (EPS900) **PSA date:** 1990

Comments: LOCA frequncy above is for operation mode a; operation mode b: 5E-7

LOCA type: medium LOCA **LOCA Size:** break with equivalent diameter 2 to 6 inches

LOCA freq: 3,00E-04 **Freq.distr:** mean value/r.yr. **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: A probabilistic safety assessment of the standard French 900MWe pressurized water reactor (EPS900) **PSA date:** 1990

Comments: LOCA frequency above for operating mode a; operating mode b: 1.5E-6

LOCA type: small LOCA **LOCA Size:** break with euivalent diameter less than 2 inches

LOCA freq: 2,00E-03 **Freq.distr:** mean value/r.yr. **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: A probabilistic safety assessment of the standard French 900MWe pressurized water reactor (EPS900) **PSA date:** 1990

Comments: LOCA frequency above for operating mode a; operating mode b: 1E-5

LOCA type: break at pressurizer safety valve **LOCA Size:**

LOCA freq: 5,00E-05 **Freq.distr:** mean value/r.yr. **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: A probabilistic safety assessment of the standard French 900MWe pressurized water reactor (EPS900) **PSA date:** 1990

Comments: LOCA frequency above for operating mode a; operating mode b: 2.4E-4

LOCA type: very small LOCA **LOCA Size:**

LOCA freq: 3,00E-01 **Freq.distr:** mean value/r.yr. **Source:**

Plant name: **Com.op:** **Ref:**

PSA title: A probabilistic safety assessment of the standard French 900MWe pressurized water reactor (EPS900) **PSA date:** 1990
Comments: frequency above for operating mode a

LOCA type: small LOCA **LOCA Size:** break in feedwaterline with equivalent area 5 to 150 sq.cm
LOCA freq: 3,10E-03 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak inside containment

LOCA type: medium LOCA **LOCA Size:** break in feedwaterline with equivalent area 150 to 300 sq.cm
LOCA freq: 9,00E-05 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak inside containment

LOCA type: large LOCA **LOCA Size:** break in feedwaterline with equivalent area greater than 300 sq.cm
LOCA freq: 1,00E-07 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak inside containment; frequency less than exspected meanvalue !

LOCA type: small LOCA **LOCA Size:** break in mainsteamline with equivalent area 5 to 50 sq.cm
LOCA freq: 4,30E-03 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak inside containment

LOCA type: large LOCA **LOCA Size:** break in mainsteamline with equivalent area greater than 300 sq.cm
LOCA freq: 1,00E-07 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak inside containment; frequency less than exspected meanvalue !

LOCA type: small LOCA **LOCA Size:** break in feedwaterline with equivalent area 5 to 150 sq. cm
LOCA freq: 9,10E-03 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak outside containment

LOCA type: large LOCA **LOCA Size:** break in feedwaterline with equivalent area greater than 300 sq. cm
LOCA freq: 3,50E-04 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak outside containment;

LOCA type: small LOCA **LOCA Size:** break in mainsteamline with equivalent area 5 to 50 sq. cm
LOCA freq: 2,90E-03 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak outside containment

LOCA type: medium LOCA **LOCA Size:** break in mainsteamline with equivalent area 50 to 300 sq. cm
LOCA freq: 1,90E-04 **Freq.distr:** exspected meanvalue/yr. **Source:**
Plant name: **Com.op:** **Ref:**
PSA title: GRS - 98 **PSA date:** 1993
Comments: leak outside containment

LOCA type: large LOCA **LOCA Size:** break in mainsteamline with equivalent area greater than 300 sq.cm

LOCA freq:	5,00E-07	**Freq.distr:**	exspected meanvalue/yr.	**Source:**	
Plant name:		**Com.op:**		**Ref:**	
PSA title:	GRS - 98			**PSA date:**	1993
Comments:	leak outside containment; frequency less than exspected meanvalue !				