POLICY ISSUE
INFORMATION

April 13, 2004 SECY-04-0060

FOR: The Commissioners

FROM: William D. Travers
Executive Director for Operations

SUBJECT: LOSS-OF-COOLANT ACCIDENT BREAK FREQUENCIES FOR THE OPTION III RISK-INFORMED REEVALUATION OF 10 CFR 50.46, APPENDIX K TO 10 CFR PART 50, AND GENERAL DESIGN CRITERIA (GDC) 35

PURPOSE:

To inform the Commission of the updated preliminary loss-of-coolant accident (LOCA) frequency estimates for use in the Option III risk-informed reevaluation of 10 CFR 50.46, Appendix K to 10 CFR Part 50, and GDC 35 and to summarize the technical basis for these frequencies. These frequencies were required by the staff requirements memorandum (SRM) to SECY-02-0057, "Update to SECY-01-0133, Fourth Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria)," and provide one input for redefining the design basis break size in the 10 CFR Part 50. The other technical and policy issues associated with the break size redefinition are discussed in SECY-04-0037, "Issues Related to Proposed Rulemaking to Risk-Inform Requirements Related to Large Break Loss-of-Coolant Accident (LOCA) Break Size and Plans for Rulemaking on LOCA with Coincident Loss-of-Offsite Power."

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BACKGROUND:

The Commission issued a SRM in response to SECY-02-0057 on March 31, 2003. This SRM provided direction on the four major technical areas associated with the emergency core cooling system (ECCS) requirements: ECCS acceptance criteria, ECCS reliability, ECCS evaluation methods, and break size redefinition. The current design-basis break size requirements are used to demonstrate the acceptability of the ECCS by analyzing a failure in the worst possible location using the break size that results in the highest peak core cladding temperature. This analysis must consider break sizes up to and including a double-ended guillotine break (DEGB) of the largest pipe in the reactor coolant system. The SRM directed the staff to consider a risk-informed revision of this design-basis requirement.

The SRM also directed the staff to reevaluate the passive system LOCA frequencies and use these to form part of the technical basis supporting subsequent changes in the design basis break size. The SRM provided the following guidance to the staff with respect to this reevaluation:

1. Develop LOCA frequency distributions by combining relevant service history data with probabilistic fracture mechanics insights using expert judgment.

2. Provide a comprehensive LOCA failure analysis and frequency estimation for piping and nonpiping contributions.

3. Develop realistically conservative estimates, with appropriate margin for uncertainty.

4. Credit leak-before-break (LBB) considerations only in conjunction with the establishment by a licensee of reliable and comprehensive means to detect primary system leaks of the relevant size.

5. Use a 10-year period for the estimation of LOCA frequency distributions, with re-estimation every 10 years and a review of new types of failures every 5 years.

This Commission paper provides the staff's response to this direction.

DISCUSSION:

This section summarizes the process employed to develop the LOCA frequency estimates. The discussion includes the objective and scope of the effort, the general approach followed, and the results obtained from the elicitation process. Additional details of this process are provided in the attachment.

Objective and Scope

The objective of the study was to develop piping and nonpiping passive system BWR and PWR LOCA frequency distributions as a function of rupture size for the present and future operating periods. The study was solely focused on determining frequencies of LOCAs that initiate by unisolable primary system failures. This focus is consistent with current use of these frequencies in probabilistic risk assessment (PRA) analysis. Consequential failures of the primary side due to either secondary side failures or failures of other plant structures were not considered. Previous evaluations of seismic-induced large LOCA piping failures have shown them to not be significant. However, it should be noted that those evaluations have not explicitly addressed degradation. This study primarily considered normal plant operational cycles and loading histories consistent with current internal event PRAs. A complete assessment of risk from all sources is necessary when determining appropriate ECCS requirements.

The future plant operating characteristics were assumed to be essentially consistent with past operating experience. The effects of operating profile changes were not considered due to the uncertainties associated with particular changes and the potential ramifications with respect to degradation-related LOCA frequencies. For instance, changes in plant performance and operating characteristics (e.g., temperature, environment, flow rate) as a result of power uprate could impact future LOCA frequencies. The 5-year review of these LOCA frequency estimates will provide confirmation that neither operating condition changes nor the emergence of new degradation mechanisms undermine the technical basis of these current LOCA frequency estimates. The degradation-related LOCA frequency distribution will be updated, as necessary, every 10 years to account for any changes.

Approach

To develop these estimates, expert elicitation was used to evaluate service history data in light of probabilistic fracture mechanics insights. Expert elicitation is a formal process for providing quantitative estimates for the frequency of physical characteristics of phenomena when the required data is sparse and when the subject is too complex to adequately model. Formal elicitation is a well-established PRA tool. There is precedence for using formal elicitation as the basis for technical evaluation. Examples include NUREG-1150, “Reactor Risk Reference Document”; determination of flaw density and size distributions in reactor pressure vessels for the pressurized thermal shock rule revision; evaluation of the high-level waste repository; and probabilistic seismic hazard curve analysis. See the attachment for more detail.

The elicitation was structured to make present estimates of the degradation-related LOCA frequencies and assess how they could be affected in the future by continued plant aging. Past assessments have lacked either a suitable nuclear experience base or an accounting of possible service degradation. The present assessment extends relevant nuclear operating experience using expert opinion of service degradation effects pertaining specifically to nuclear power plants. Aging effects were evaluated by considering the synergistic interaction among material, geometry, loading history, environment, and degradation mechanisms for specific piping systems and nonpiping components. The effect of mitigation on curbing the effects of aging was also a principal consideration. Mitigation measures considered include inservice inspection, leak detection, water chemistry, and other specific practices. The likelihood that aging mechanisms will result in a precursor leak prior to failure (e.g., LBB) was also addressed.

The expert elicitation process consisted of a number of steps. To begin, the facilitation team identified the technical issues to be evaluated and selected a panel of 12 experts. Each panel member has at least 25 years of relevant technical expertise. The panel also represented a wide range of organizational affiliations. The attachment to this memorandum lists the panel members. At its initial meeting, the panel discussed the technical issues and developed a final approach to quantifying the effect of these issues. The facilitation team and panel then developed background technical information and prepared the elicitation questionnaire. A second meeting was held to review and refine the technical information and questionnaire. Each individual panel member then did a separate analysis to answer the questionnaire.

The facilitation team met separately with each panel member in a day-long elicitation session. At this session, each panel member answered the elicitation questionnaire by providing quantitative estimates and a qualitative rationale to support the judgments of the most important LOCA challenges. Each panel member also provided the uncertainty associated with these estimates. The project staff then compiled the panel's responses and developed preliminary estimates of the LOCA frequencies. Along with the rationales, the preliminary estimates were presented to the panel at a final meeting. Panel members were invited to fill in gaps in their questionnaire responses and, if desired, to modify their responses.

<u>Results</u>

The results of this elicitation provide a comprehensive assessment of degradation-related LOCA frequencies. The results reflect the inherent uncertainty in estimating rare events. Panel members provided their median responses and associated uncertainty bounds for each question. The median responses and uncertainty bounds were used to obtain mean LOCA frequency estimates. Individual uncertainty bounds are used to develop the 5th and 95th percentile estimates for the LOCA frequency distributions. Variability in the panel results is reflected in uncertainty bounds provided for each estimate in the attachment.

The degradation-related LOCA frequencies are estimated for six rupture size categories. The LOCA definitions are similar to historical small break (SB), medium break (MB), and large break (LB) flow rate definitions for the first three LOCA categories. Additionally, three larger LOCA categories were defined in the elicitation within the classical LB LOCA regime. The purpose of these additional categories was to examine trends with increasing break size, up to and including a DEGB of the largest reactor coolant system piping.

The important qualitative technical issues identified by the individual panel members were reasonably consistent. However, the quantitative estimates of the importance of these issues differed substantially among panel members. This is expected given the uncertainties in assessing degradation-related LOCA frequencies. The panel's mean and 95th percentile LOCA frequency estimates are presented in Table 1.

Table 1: Preliminary Degradation-Related LOCA Frequencies for Ensuing 10 Years

LOCA Size (gpm)	Effective Break Size (in)	BWR Plants		PWR Plants	
		Mean (cal-yr^{-1})	95th (cal-yr^{-1})	Mean (cal-yr^{-1})	95th (cal-yr^{-1})
100 - 1,500	½ - 2	3 E-04	1 E-03	6 E-03	2 E-02
1,500 - 5,000	2 - 3	1 E-04	4 E-04	2 E-04	8 E-04
5,000 - 25,000	3 - 7	2 E-05	7 E-05	1 E-05	5 E-05
25,000 - 100,000	7 - 18 (BWR) 7 -14 (PWR)	4 E-06	2 E-05	2 E-06	9 E-06
100,000 - 500,000	18 - 41 (BWR) 14 - 31 (PWR)	2 E-06	6 E-06	2 E-08	8 E-08
> 500,000	> 41 (BWR) > 31 (PWR)	2 E-09	9 E-09	2 E-08	7 E-08

Notes: 1: Final estimates subject to change resulting from peer review, stakeholder feedback, and sensitivity analysis.
2: Sensitivity analysis is ongoing to examine robustness of estimates due to analysis assumptions.

The frequencies are provided as a function of both the expected flow rate and corresponding effective break size ranges. These frequencies are applicable for the ensuing 10-year period. Additional results are discussed in the attachment. These frequency distributions represent generic BWR- and PWR-specific frequencies for the commercial fleet. The results are generally comparable to NUREG/CR-5750 estimates for SB, MB, and LB LOCAs.

TECHNICAL ISSUES:

These degradation-related LOCA frequencies form a necessary, but not sufficient, component of the technical basis that will support the risk-informed revision of the ECCS regulation. There are additional steps required in order to select an alternative design-basis break size.

1. Frequencies associated with consequential LOCAs (e.g., seismic events) and other initiators (e.g., stuck open valves, transients) need to be assessed along with the degradation-related LOCA frequencies (Table 1), as discussed below.

2. Thermal-hydraulic analyses are necessary to investigate plant system response as a function of break size and location and develop appropriate success criteria, particularly for accident management.

3. The combined LOCA frequencies and success criteria need to be used as input to PRA models to understand risk and implications resulting from postulated events and plant operational changes.

A more thorough discussion of technical and policy issues associated with the development of revised design basis break size is contained in SECY-04-0037. The remaining technical work described above will be undertaken once additional Commission guidance is provided as requested in SECY-04-0037.

CONTINUING STAFF EFFORTS:

The formal elicitation of the experts has been completed. The remaining elicitation-related work will focus on project documentation, presentation of results to the ACRS and affected stakeholders, and peer review. This elicitation-related work will be completed by the end of 2004. In addition, probabilistic LOCA and fracture mechanics computer models are being developed to provide a technical basis for the next LOCA frequency estimation in 10 years as required by the SRM. Some initial results from these models will be available over the next 18 months. The evaluation of plant system response to postulated breaks, risk assessments of potential plant changes, and consideration of consequential LOCA frequency contributions are also currently ongoing in the Office of Nuclear Regulatory Research. A short-term scoping effort will be conducted to determine whether seismic LOCAs in degraded piping provide significant LOCA frequency contributions to those summarized in Table 1. The scope and schedule with remaining activities necessary to develop the technical basis will be determined after Comission guidance is provided for rulemaking options as described in SECY-04-0037.

RESOURCES:

There are resources in the budget to continue the staff activities necessary to complete the elicitation process and to continue confirmatory research supporting these degradation-related LOCA frequency estimates in FY2004. The principal resource allocation in subsequent years will be used for developing probabilistic LOCA and fracture mechanics computer models for planned use in reevaluating LOCA frequencies every 10 years. These computer models are needed for other applications as well. The estimated resources for the elicitation-related activities for FY2005 and FY2006 are 0.5 FTE and $500K each year for RES. Required resources to complete part of the technical basis and rulemaking efforts are discussed in SECY-04-0037. Resources to complete additional required technical basis work will be identified once Commission guidance is provided for SECY-04-0037. These resources will be budgeted through the PBPM process.

COORDINATION:

The Office of the General Counsel has reviewed this paper and has no legal objections. The Office of the Chief Financial Officer has reviewed this paper for resource implications and has no objections.

/RA Carl J. Paperiello Acting For/

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Attachment: 10 CFR 50.46 LOCA Frequency Development

10 CFR 50.46 LOCA Frequency Development

Attachment

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A. Background

Traditionally, two approaches have been used to assess LOCA frequencies: statistical analysis of service experience data and probabilistic fracture mechanics (PFM) analysis of specific postulated failure mechanisms. These approaches have different strengths. In fact, the two methods are complementary although a combined or comparative analysis utilizing both approaches is not typically performed. However, both approaches have several weaknesses with each technique which make them ill-suited to determine LOCA frequencies in isolation.

A.1 Service Based LOCA Estimates

One principal strength of the service experience data is that it can provide an indication of historical piping system precursor (e.g., a leak or crack) and failure rates. The service experience can also identify aging mechanisms which are the most important contributors to these failure rates and provide an indication of the effectiveness of historical mitigation techniques. One difficulty in using service experience-based analysis to determine LOCA frequencies is that precursor failure information comes from a variety of sources and it is difficult to construct a comprehensive database. Another deficiency of service data is that the effect of future aging mechanisms is not captured. Even when these mechanisms do emerge in service data, there is a lag before their effects are fully understood. Aging mechanisms can require significant incubation time before causing any actual piping failures. However, once the incubation period is over, crack growth can occur relatively rapidly and lead to rapidly increasing failure rates with time. These features are consistent with intergranular stress corrosion cracking (IGSCC) in the early 1980s [1] and primary water stress corrosion cracking (PWSCC) [2].

A.1.a WASH-1400

The first systematic study of piping failures in the nuclear industry was contained within WASH-1400, which was completed in 1975 [3]. At the time, the combined years of reactor service experience was less than 200. Therefore, the pipe LOCA frequencies were derived based on experience within other industries. WASH-1400 examined data from the naval nuclear reactor experience, experimental reactors, United Kingdom military information, commercial power plants, and the oil and gas transmission pipeline industry. The most comprehensive data was obtained from the oil and gas pipeline industry and formed the basis of the WASH-1400 LOCA frequency estimates after proper normalization to account for pipe length differences.

A.1.b NUREG/CR-5750

The next NRC-sponsored evaluation of pipe break LOCA frequencies occurred within Appendix J of NUREG/CR-5750, "Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 - 1995" [4]. The authors evaluated nuclear piping failures in this study and separate frequencies were determined for BWR and PWR reactors. For BWR plants, only U.S. experience was considered for a total of 710 reactor calendar years. The PWR database combined U.S. and "Western-style" LWR data from international experience for a total of 3,362 reactor calendar years. The authors utilized distinct methods to calculate pipe break frequencies as a function of break size. The SB LOCA estimates were actually calculated by a Bayesian update of the WASH-1400 SB LOCA estimates since no additional breaks occurred between the WASH-1400 and NUREG/CR- 5750, Appendix J studies.

The MB and LB LOCA frequencies were derived from precursor leak frequencies determined from service experience. The leak frequency was multiplied by the Beliczey and Schulz conditional pipe break probability (CBP) which is inversely related to pipe diameter [5]. The advantage of this precursor estimation approach is that there had been several reported leaks of class 1 piping, but no failures. Therefore, service history experience could be utilized directly to determine the pipe leak frequency and only the conditional break probability given a precursor leak needed to be estimated . A disadvantage of this precursor approach is that it ignores failure contributions from existing flaws or degradation that do not result in a leak. There are many potential initiating events which do not exhibit a precursor leak. Recent hydrogen combustion failures of residual heat removal piping at Hamaoka [6] and auxiliary coolant system piping at Brunsbuettal [7] represent one such mechanism. Flow accelerated corrosion (FAC), which induced a rupture of an 18" diameter feedwater suction pipe elbow at Surry 2 in 1986, [8] is another mechanism which can lead to rupture prior to precursor leaking.

A.2 PFM LOCA Estimates

The NRC and the nuclear industry have sponsored PFM-research over the last twenty years in an attempt to develop LOCA predictions from first principals. The international community (e.g. GRS in Germany and SKI in Sweden) has undertaken similar programs [9, 10]. Several of the more well-known US computer codes developed from this research include PRAISE [11], SRRA [12], PSQUIRT [13], and PROLBB [14]. The main attraction of the PFM models is their ability to predict future piping system performance for particular degradation mechanisms. However, PFM estimates have not typically been benchmarked by actual service experience. If PFM is used to predict performance over a 60 year period, it must adequately calculate measured failure rates for that particular degradation mechanism for the first 20 to 30 years of life. Only then is the prediction realistic. Additionally, it is not uncommon to see PFM-based LOCA frequency predictions vary by five orders of magnitude or more. These deficiencies which limit the ability of PFM to predict realistic, forward-looking LOCA estimates.

A.3 Expert Elicitation

Expert elicitation is designed to mitigate deficiencies in the service-experience and PFM based approaches, and was therefore a natural choice for these LOCA frequency estimations. Expert elicitation is a formal process for providing quantitative estimates for the frequency of physical characteristics of phenomena when the required data is sparse and when the subject is too complex to adequately model. On an informal basis, engineers and scientists do this routinely based on their experience and judgment. Formal elicitation is a well established PRA tool [15]. There is precedence for using formal elicitation as the basis for regulatory decisions. Examples include: NUREG-1150 [16], the determination of flaw density and size distributions in reactor pressure vessels [17], the evaluation of the high level waste repository [18, 19], and in probabilistic seismic hazard curve analysis [20].

Data sparseness and subject complexity are characteristic of pipe break LOCA frequencies. Sparseness is evident by the fact that no pipe break LOCA events have occurred. Existing NUREG/CR-5750, Appendix J pipe break LOCA estimates vary from $4x10^{-4}$ per calendar-year for SB LOCAs to $4x10^{-6}$ per calendar-year for PWR LB LOCAs. This translates into one expected SB LOCA every 2,500 years and one PWR LB LOCA every 250,000 years. Complexity is evident in the enormity of pipe system variables which must be considered to accurately model the full spectrum of pipe breaks using PFM and PRA analysis. Variables include piping design and layout; piping fabrication; materials; degradation mechanisms; stress; service environment; application of codes and standards; inspection type, quality and schedule; and the plant operating history.

B. Objective & Scope

The objective of the expert elicitation process is to develop piping and non-piping passive system LOCA frequency distributions as a function of rupture size and operating time from the current day up to the end of the license extension period. The elicitation was solely focused on determining event frequencies that initiate by unisolable primary system side failures that can be exacerbated by material degradation with age. Therefore, consequential failures of the primary side due to either secondary side failures or failures of other plant structures (e.g. heavy load drops) were not considered. Such frequency contributions are an important consideration when evaluating total plant risk and total LOCA frequency estimates. However, assessment of this risk contribution was outside the scope of the current elicitation and beyond the expertise of the assembled panel members.

The LOCA frequency estimates are summarized by the median, mean, 5^{th} and 95^{th} percentiles. Four separate LOCA frequencies have been determined: boiling water reactor (BWR) piping, BWR non-piping, pressurized water reactor (PWR) piping, and PWR non-piping. These piping and non-piping frequencies have been combined to estimate total passive system LOCA frequencies for BWR and PWR plants. Additionally, uncertainty bounds have been determined to reflect the variability of the panel members.

The frequency distributions represent generic values for the commercial fleet. The separate BWR and PWR frequencies have not been partitioned further to account for differences related to design class, vendor, or specific plant operating characteristics. These features can influence LOCA frequencies and it is expected that actual plant frequencies would be distributed about the mean or median values of these generic distributions. Specific plant/vendor differences and their possible effects on LOCA frequencies were considered during the elicitation. Each panel member was instructed to consider how plant specific factors influence the fleet average and the uncertainty bounds.

Three distinct time periods have been evaluated: current day, the average end of the original plant licensing period, and the average end of the license extension period. For the purposes of the elicitation, these time periods are represented by 25 (approximate current fleet average), 40, and 60 years, respectively, after plant operation commences. One important assumption is that the future plant operating characteristics are assumed to be essentially consistent with past operating practice. The effects of operating profile changes have not been considered due to the uncertainty surrounding particular changes and the potentially wide ranging ramifications with respect to LOCA frequencies. For instance, significant power uprate allowances may change plant performance and relevant operating characteristics (e.g. temperature, environment, flow rate, etc.) to a degree which significantly impacts the future LOCA frequencies.

The intent is that these LOCA frequencies will be amenable to future evaluation of core damage frequency (CDF) and large early release frequency (LERF) metrics using both current and advanced probabilistic risk assessment (PRA) tools. Therefore, the elicitation primarily considers normal plant operational cycles and loading histories consistent with current internal event PRAs. Separate frequencies for each unique mode of plant operation have not been determined. Rather, the frequencies developed implicitly consider all modes of operation per calendar year for the loading or operational history associated with each piping system or non-piping component.

Simple correlations were also developed to relate the rupture size to the expected flow rate required for the ECCS make-up system. The small break (SB), medium break (MB), and large break (LB) LOCA categories have historically been defined on the basis of flow rate. The correlations developed are different from those used in the past, but provide a mechanism to compare these current LOCA estimates with previous benchmarks. This exercise developed LOCA frequencies consistent with historical SB, MB, and LB flow rate definitions. Additionally, three larger LOCA categories were defined in the elicitation within the classical LB LOCA regime. The purpose of these additional categories was to examine trends with increasing break size, up to and including a DEGB of the largest piping in the plant.

While the primary focus of the elicitation was to develop frequencies associated with normal operational loading, a subset of the panel also estimated the conditional LOCA probability distributions for rare, emergency faulted load conditions. This question considers the impact of such rare events as large seismic loads and other large, unexpected internal and external loads (e.g. large water hammer, large thermal transients due to small pipe breaks, etc.). For the purposes of the elicitation, a rare event was defined as one with an expected frequency much less than one in 40 years, the original plant licensing period. The intent of this assessment was to develop generic conditional failure probabilities for degraded piping and non-piping plant components that can be combined with plant specific information about the rare event frequency and associated plant response characteristics to develop plant-specific LOCA frequencies for rare event loading. These frequencies could then be combined with the normal operational loading frequencies to develop a more comprehensive estimate of LOCA frequencies. The analysis of this portion of the study is still underway.

C. Approach

The expert elicitation process used for this project consisted of a number of steps. The first step was to conduct a pilot elicitation using NRC staff members. This served to identify important technical issues and provide feedback to design the approach for the formal elicitation. The formal elicitation began with evaluating and selecting a panel of twelve experts. The staff then gathered background material and prepared an initial formulation of the issues and provided these to the panel. At its initial meeting, the panel discussed the issues and, using the staff formulation as a starting point, developed a final formulation and decomposition of the issues. At this initial meeting, the panel was also trained in subjective elicitation of numerical values through exercises and discussion of biases. The staff then prepared a draft elicitation questionnaire and iterated with the panel to obtain a final questionnaire. A second meeting was held to review the base cases and discuss other issues. At their home institutions, the individual panel members performed analyses and computations to develop their answers to the questionnaire.

A facilitation team consisting of substantive experts, a normative expert and two recorders met separately with each panel member in a day-long elicitation session. At this session, each panel member provided answers to the elicitation questionnaire along with their rationales. The panel members then returned to their home institutions where they refined their responses based on feedback from the elicitation session. Upon receipt of the updated responses, the project staff compiled the panel's responses and developed preliminary estimates of the LOCA frequencies. Along with the rationales, the preliminary estimates were presented to the panel at a wrap-up meeting. Panel members were invited to fill in gaps in their questionnaire responses and, if desired, to modify any of their responses. Based on these updates, final estimates of the LOCA frequencies were calculated and provided to the panel members. More detail on several important steps is subsequently provided.

C.1 Pilot Elicitation

The study was initiated with a pilot elicitation conducted by NRC staff from RES and the Office of Nuclear Reactor Regulation (NRR). The primary purpose of this exercise was to identify technical issues for consideration during the subsequent formal elicitation. Additionally, interim LOCA frequency estimates were developed to support the study conducted by RES on the feasibility of risk-informing 10 CFR 50.46, Appendix K, and GDC 35. Specifically, estimates were sought to explore the potential of eliminating the design requirements to mitigate a simultaneous LOCA and loss-of-offsite-power (LOOP) event. The results of this feasibility study and the staff's pilot elicitation were reported on July 31, 2002 [21].

C.2 Panel Selection

Initially, a pool of 55 nominally qualified people was established by querying knowledgeable sources within the industry and NRC. Potential panel members were affiliated with industry, academia, national laboratories, contracting agencies, other government agencies, and international agencies. Twenty-five people were solicited for the panel from the pool. They were sent information about the objective, scope, and approach of the elicitation exercise as background and were asked to submit resumes and also evaluate their relevant technical areas of expertise for the exercise. Based on this feedback, the final panel of 12 was chosen to achieve both technical and organizational variety, and ensure a diversity of opinion, expertise, and backgrounds.

The elicitation panel members are listed in Table 1. The organizational diversity is apparent. Two of the panel members represent the European regulatory community; three of the panel members represent commercial vendors and owner's groups; four members are primarily NRC consultants; and three members have conducted extensive relevant research for both the commercial nuclear industry owner's groups and individual plants. Panel members were chosen to represent a range of relevant technical specialties: PFM, piping design, piping fabrication, operating experience, materials, degradation mechanisms, operating mitigation practices, stress analysis, nondestructive evaluation, etc. All panel members have at least twenty-five years of experience in these relevant technical areas pertaining to commercial nuclear power applications.

Table 1: LOCA Frequency Expert Panel

Panel Member	Organization
Dr Bruce Bishop	Westinghouse Electric Co LLC
Dr Vic Chapman	OJV Consultancy Lmtd
Mr Guy De Boo	Exelon Nuclear
Dr William Galyean	Idaho National Engineering Environmental Laboratory
Dr Karen Gott	Swedish Nuclear Power Inspectorate
Dr David Harris	Engineering Mechanics Technology, Inc.
Dr Bengt Lydell	ERIN Consulting
Dr Peter Riccardella	Structure Integrity Associates, Inc
Dr Helmut Schulz	Gesellschaft für Reaktorsicherheit (GRS) mbh
Dr Sampath Ranganath	GE Nuclear Energy/EXGEN Consulting
Dr Fredric Simonen	Pacific Northwest National Laboratory
Dr Gery Wilkowski	Engineering Mechanics Corporation of Columbus

C.3 Facilitation Team

A facilitation team was also assembled to guide the expert panel through the elicitation process. The team consisted of one normative expert, six substantive experts, and two recorders. All but two of the experts were NRC staff. The substantive experts were chosen to provide the same broad relevant technical knowledge and background required of the panel. The facilitation team role was to formulate the objectives and scope; coordinate and provide background technical information; develop the elicitation questions; guide and record the individual elicitation sessions; analyze and summarize the panel's findings; and develop the final LOCA frequency distributions from the panel's responses.

C.4 Technical Issue Formulation

The elicitation process continued in February 2003 with a three-day meeting of the expert panel and facilitation team. The five principal objectives of this meeting were to define the scope and objectives of the elicitation (Section D); provide background information about previous LOCA frequency estimates; construct an approach for determining LOCA frequencies, identify significant issues affecting LOCA frequencies, and conduct elicitation training.

The LOCA categories to be evaluated during the elicitation were defined by the panel (Table 2). They are largely consistent with historical definitions developed for SB, MB, and LB LOCAs during the WASH-1400 evaluation. These definitions were retained in subsequent exercises to characterize plant risk (NUREG-1150) and determine initiating event frequencies (NUREG/CR-5750). One distinction is that, historically, break size frequencies were defined over a range of flow rates for SB (100 to 1500 gpm) and MB (1500 to 5000 gpm) LOCAs. In this exercise, the panel chose to work with threshold values for each LOCA category. Additionally, three additional categories which fall within the classical LB LOCA regime were identified to reflect the different plant responses that are required to mitigate LB LOCA events of increasing size. LOCA category 6 was chosen to correspond to the flow rate which would result from rupture of the largest primary piping in the plant. LOCA categories 3 and 4 were determined so that the ratios between subsequent LB LOCA categories were approximately equivalent.

Table 2: LOCA Category Definitions

LOCA Category	Flow Rate Threshold (gpm)	LOCA Classification
1	> 100	SB
2	> 1500	MB
3	> 5000	LB
4	> 25,000	LB a
5	> 100,000	LB b
6	> 500,000	LB c

The panel members identified issues which affect both piping and non-piping passive system failures. Issues related to safety culture were often raised. While there are no organizational safety culture experts on the panel, the panel members have enough experience with both the industry and the NRC to judge possible effects of safety culture on LOCAs. It was decided to consider the effect of safety culture LOCA contributions separately from age-related contributions because the panel believes that safety-culture and age-related effects are only weakly correlated.

The panel developed a structure for considering passive system failures which contribute to LOCAs (Figure 1). The total passive system frequencies were divided by the panel into piping and non-piping contributions. The panel next agreed that the design and operating characteristics of each piping system and each major non-piping component (e.g. main coolant pumps, steam generators, pressurizer, and valves for PWR) could impact the underlying LOCA frequencies. Non-piping components were further subdivided into relevant subcomponents (e.g. valve bonnet, valve bonnet bolts, valve casing) that possess unique operating and design characteristics. For a given LOCA-sensitive piping system or non-piping subcomponent, the panel identified five variable classes (geometry, loading history, materials, aging mechanisms, and mitigation & maintenance) that contain the principal variables that affect LOCA frequencies.

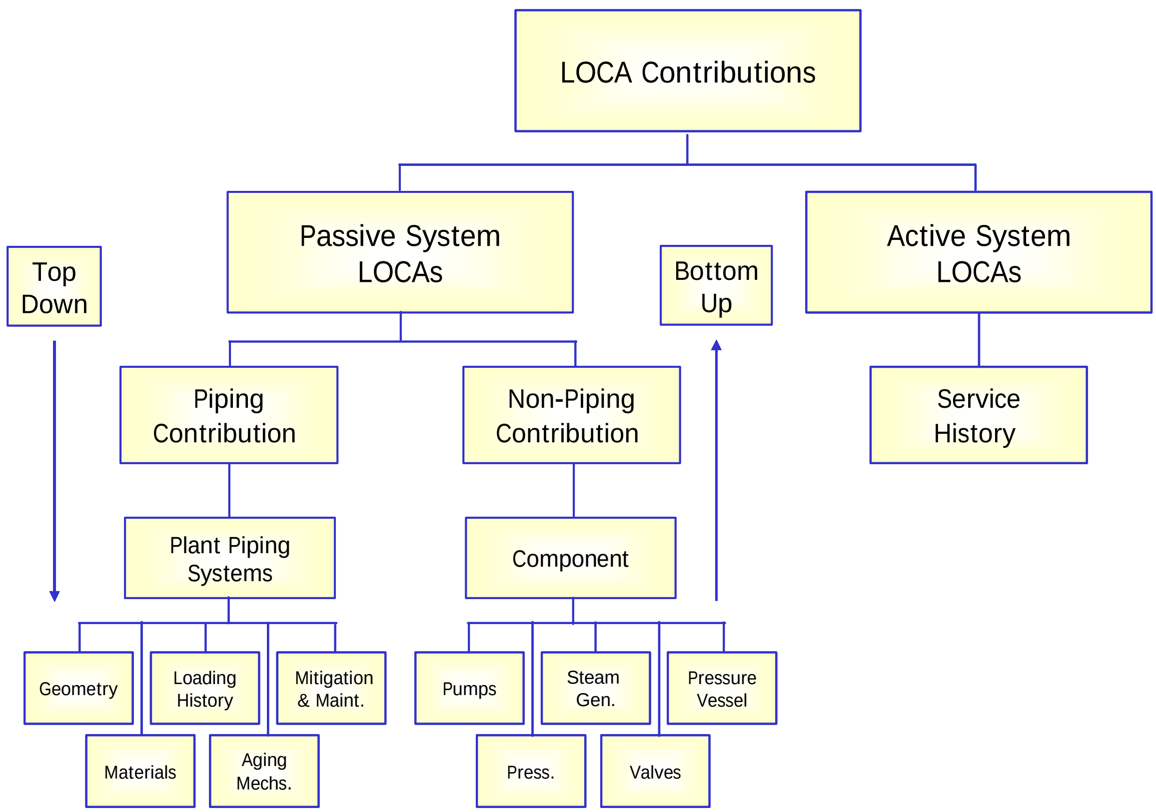

Figure 1: Elicitation Structure

C.5 Base Case Development

The elicitation structure provided the panel members with a way to assess and prioritize important contributing variables to the generic LOCA frequency distributions. However, the most challenging aspect for each member was quantifying the frequencies associated with the important contributing variables. Piping and non-piping base case frequencies were developed to provide the panel members with quantitative estimates for anchoring their responses. The piping and non-piping base case variables were clearly defined and then analyzed using both PFM and classical statistical or Bayesian assessment of service experience data. This analysis resulted in sets of frequencies associated with the defined variables. The base case conditions were defined in the initial meeting. A second meeting was held to present the various approaches used to estimate the associated frequencies to the entire panel.

C.6 Elicitation Question Development

Elicitation questions were posed in the following areas: base case evaluation, safety culture, PWR piping, BWR piping, PWR non-piping, and BWR non-piping. The base case evaluation questions required each panel member to address the accuracy and applicability of each of the four base case calculations to the conditions established by the entire panel. Each panel member also chose a specific set of calculations for anchoring all future responses.

The questions required each panel member to first identify the piping systems or non-piping components which provide the largest contribution to the LOCA frequency for each LOCA category and operating time period (25, 40, or 60 years). Then, each panel member chose appropriate base case conditions for anchoring. Finally, each question required a relative comparison between the chosen base case condition and the other condition being assessed. This decomposition allowed the estimates of absolute LOCA frequencies to be based on service history data and/or PFM models as embodied by the base case frequencies.

Each elicitation question required that a mid value, a lower bound, and an upper bound be provided. The mid value is defined such that, in the panel member's opinion, the unknown true value for that particular question has a 50% chance of falling above or below the mid value. Similarly, the lower and upper bounds are defined such that the true value has a 5% chance of falling below or above the bound, respectively. The medians of the LOCA frequency distributions obtained during this exercise were based on the mid value estimates while the 5^{th} and 95^{th} percentiles were derived from the lower and upper bounds, respectively.

C.7 Individual Elicitations

Individual elicitation sessions were conducted for each panel member and the facilitation team. There were several objectives of the elicitation sessions:

1. Obtain and discuss the qualitative and quantitative responses to elicitation questions.
2. Identify inconsistencies between the qualitative and quantitative responses.
3. Provide additional clarification to the elicitation questions, as necessary.
4. Identify necessary follow-on work for each panel member.
5. Solicit feedback about the process.

The most important objective was to obtain the quantitative responses to the questions and understand the rationale used to provide the basis for these responses. Each panel member used a different approach to obtain quantitative estimates and it was important to understand each so that results could be subsequently analyzed. There were weaknesses, inconsistencies, or incomplete areas for each panel member identified during these sessions. Each panel member then had another one to four months to revise his initial input to address any deficiencies.

C.8 Wrap-Up Meeting

After the individual elicitations were completed, and each panel member's results were analyzed, a third meeting was held with the entire panel. The purpose of this meeting was to summarize the important qualitative and quantitative results arising from the individual elicitations. The methodology used to calculate final results for each panel member and combine responses for the entire group was also presented along with the final estimates. Each panel member was then provided the opportunity to revise his estimates based on qualitative rationale from other experts and a more complete understanding of the analysis procedures. Each panel member was also asked to fill in gaps in his original responses as necessary.

D. Analysis of Elicitation Responses

The analysis estimates LOCA frequencies for four global system, plant-type combinations (BWR piping, BWR non-piping, PWR piping, PWR non-piping). The global systems estimates are all based on the individual panel members' responses. These individual estimates have the advantage of being self-consistent. The estimates are in the form of parameters of the LOCA frequency distributions implied by the panel members' responses. The parameters used are the mean, the median, the 95th percentile and the 5th percentile.

Each panel member estimated the contribution to LOCA frequency for each LOCA-susceptible piping system and non-piping component. First, each panel member chose base case conditions and associated frequencies to anchor the LOCA contributors. Next, the relative ratios were estimated to compare the LOCA contribution of each system to the relevant base case frequencies for each LOCA category and operating time (25, 40, and 60 years of operation). These responses constitute each panel member's raw input. Each panel member's piping and non-piping responses for a given plant type were combined to obtain individual LOCA estimates for that plant type. The total LOCA estimates for both BWR and PWR plants are the medians of the individual estimates.

It is important that the final LOCA estimates provided reflect both uncertainty and variability. Uncertainty stems from the uncertainties in each panel member's responses, as embodied in the upper and lower bound estimates for each elicited quantity. These individual uncertainties were propagated to obtain the 5th and 95th percentile LOCA frequency estimates (see Section E.3.c). Variability refers to the different responses from the various panel members. Because of the lack of data and the variety of approaches used by individual panel members, it is to be expected that there will be large differences in their responses. Uncertainty bounds were developed to reflect this variability (Section E.3.c).

E. Results

E.1 Safety Culture Effects on LOCA Frequencies

The panel members overwhelming expected the safety culture to either improve or remain constant over the next ten years and beyond. Several panel members did indicate however, that deficient safety culture at individual plants could lead to higher LOCA frequencies. The Davis-Besse experience was frequently cited as an example of this effect. The panel also overwhelmingly expressed the opinion that industry and regulatory safety culture are highly positively correlated. Therefore, regulatory and industry changes are expected to be virtually simultaneous. Improvements in safety culture are expected to be more beneficial to small piping failures because they constitute the bulk of the experience-base. Failures of larger pipes due to safety culture effects are expected to remain relatively constant in the future. Because of panel opinion, the LOCA frequencies developed during this exercise were not modified to account for the effects of safety culture. The only caveat to this general conclusion is that the LOCA frequencies developed by the elicitation could be significantly degraded by a safety-deficient plant operating philosophy.

E.2 Plant Aging Effects on LOCA Frequencies: Qualitative Rationale

Generally, the source of this rationale came from the individual elicitations although there were some opinions expressed during various panel meetings that were also included. For each of the individual elicitations, minutes were taken. In addition, the participants often provided a handout to lead the discussion. After each session, most of the participants provided formal written responses to the elicitation questions. In addition, each of the elicitations was audio taped and each meeting was video taped to provide a permanent record of the exercise.

Most of the participants believed that precursor events (e.g., cracks and leaks) were a good barometer of LOCA susceptibility. This is reflected by the fact that almost all of them anchored their response against some form of the available service history data. A distinct advantage of the service history data is its inclusion of all degradation mechanisms which have emerged to date, whereas the PFM approaches only address selected mechanisms. The advantage of the PFM approaches is that they are best suited for addressing LOCA size and operating time effects. A number of participants used the PFM results as a basis for adjusting the service history data in this manner.

For the most part, the participants did not see much of an effect of time on the aging-related component of the LOCA frequencies either. Obviously, any unabated aging mechanism would cause an increase in the LOCA frequency with time, but it was almost universally believe that the NRC and industry will aggressively respond to emerging mechanisms. Some concrete examples cited include IGSCC cracking in BWR plants in the late 1970s and PWSCC in PWR plants today. Overall, the participants generally believe that maintenance and mitigation will offset the tendency for LOCA frequencies to increase due to aging.

The panel members also expressed greater uncertainty as the LOCA size increases (i.e., the higher category LOCAs). This is natural because of the greater extrapolation required of service data. Uncertainty also increases with future operating time as one would expect. In addition, a number of the participants commented that the uncertainty and susceptibility of the PWR plants may be higher than BWR plants in the near future, because BWR plants have more experience dealing with aging-related degradation.

E.2.a. BWR Plants

The participants generally believe that the important degradation mechanisms for BWR plants are thermal fatigue, FAC, IGSCC, and mechanical fatigue. It was argued that BWR plants are more prone to thermal fatigue problems than the PWR plants because the temperature fluctuation during the operating cycle is higher. Only the feedwater piping system is highly susceptible to FAC. The main steam line is the other major carbon-steel piping system which experiences constant fluid flow. However, it is not as susceptible to FAC because the erosion rates associated with two-phase flow are less severe. The panel consensus is that the susceptibility to IGSCC is greatly reduced compared to the past. Measures such as improved hydrogen water chemistry, weld overlay repairs, and pipe replacement with more crack resistant materials had reduced the likelihood of IGSCC. However, there is still residual concern about the failure likelihood of the large recirculation piping material that has not been replaced. Mechanical fatigue is primarily a problem in smaller diameter piping, especially those with socket welds, and is caused by an adjacent vibration source.

E.2.b. PWR Plants

The primary aging mechanisms identified by the participants for PWR plants are thermal fatigue, PWSCC, and mechanical fatigue. The concerns associated with thermal and mechanical fatigue in PWR plants are similar to those in BWR plants. PWSCC has become more evident within the service experience over the last 5 years. It has many similar characteristics to the IGSCC problem experienced in BWR reactors. Many panel members believe that PWSCC problems will be resolved (i.e., mitigated) over the next 15 years. Therefore, its contribution to the overall LOCA frequencies may peak between the 25 and 40 year time period, but then decrease in the future.

E.2.c. Piping Contributions

As part of this elicitation exercise a total of 14 LOCA-susceptible piping systems were considered for the BWR plants and 12 for the PWR plants. Of these, however, most of the participants focused on a few common systems as being the important LOCA contributors. For the smaller category 1 and 2 LOCAs, the concern is with the smaller diameter lines, such as the instrument and drain lines. This was consistent for both BWR and PWR plants. Smaller diameter lines are typically fabricated with socket welds which have a history of mechanical fatigue damage from plant vibrations. These lines may also be susceptible to external failure mechanisms arising from human error (e.g. damaging with equipment). Finally, these smaller diameter welds are often subject to fabrication flaws and they are typically more difficult to inspect, if they are inspected at all. In-service inspection (ISI) is not routinely performed on these lines.

For the larger LOCA categories, the main contributor to the BWR LOCA frequencies was the recirculation system, followed by the feedwater, and residual heat removal (RHR) systems. Some panel members also identified the reactor water clean up (RWCU) system. The recirculation system is almost universally recognized as the primary contributor for both the large (category 3, 4) and very large (category 5) piping LOCA categories. Conversely, there is wide disagreement about the relative contributions of the other systems, e.g., the feedwater and RHR systems. The RHR system is deemed important by some panel members due to the relatively large number of precursor events reported and the relatively high number of welds.

For the PWR plants, the important contributors for the larger category LOCAs are the hot leg, surge line, safety injection system (direct volume injection [DVI] and accumulator), RHR, and chemical volume and control system (CVCS). For the category 3 and 4 LOCAs, the safety injection and CVCS lines are the most consistently identified contributors. The concern with these lines is thermal fatigue. For the very large category 5 and 6 LOCAs, the important systems are the hot leg, surge line, and RHR lines. PWSCC is the primary concern in the hot leg and surge line. Both systems have experienced PWSCC over the last few years, i.e., the V. C. Summer and Ringhals cracks in the hot legs and the Three Mile Island crack (as well as cracking in Belgium and Japan) in the surge lines. There is an additional concern with thermal fatigue in the surge line due to thermal stratification. The concern with the RHR lines is potential environmental attack and the large number of precursor events reported for these lines.

E.2.d. Non-Piping Contributions

It is almost universally accepted that steam generator tube ruptures are the dominant contributor to the PWR Cat 1 LOCA frequency. However, a number of the participants indicated that they believe that the steam generator tube contribution will decrease with time due to steam generator replacement programs and improvements made to the secondary side water chemistry. The major contributors for the BWR category 1 and 2 LOCA frequencies are the control rod drive mechanism (CRDM) stub tubes. However, the category 1 LOCA frequency for these penetrations is estimated to be almost two orders of magnitude less than the PWR steam generator tube frequency and one order of magnitude less than the PWR CRDM frequency due to the lower operating temperature. The CRDM nozzles and the pressurizer heater sleeves are the major contributors to the PWR category 2 LOCA frequencies. Some panel members believe that the CRDM contributions will decrease in the future with head replacement and better inspection techniques.

For the larger category LOCAs in both BWR and PWR plants, there was more disagreement among the panel members about the major contributing components. For some, pumps and valves are a primary concern because they are difficult to inspect, are made of material which is susceptible to thermal aging, and do not receive as much attention as the rest of the components. Others believe that the vessels (e.g.

pressurizer, steam generator, RPV) are the most susceptible due to postulated common cause bolting failures, larger transients, and the existence of multiple fabrication defects.

E.3. Plant Aging Effects on LOCA Frequencies: Quantitative Results

E.3.a. LOCA Frequencies

Nine panel members provided quantitative PWR information and eight panel members provided quantitative BWR information. The total BWR and PWR passive system LOCA frequencies are provided in Table 3. These frequencies are cumulative for each successive category. For example LOCA category 1 includes frequency LOCA categories 2 - 6 as well. These frequencies can also be presented in selected flow rate or break size ranges to agree with LOCA definitions used within PRAs. See Table 1 in the main paper.

Table 3: Total Preliminary BWR and PWR Frequencies

Plant Type	LOCA Size (GPM)	Eff. Break Size (in)	Current Day Estimates (per cal. yr) (25 yr fleet average operation)				Next 15 Year Estimates (per cal. yr) (End of original license)			
			5%	Median	Mean	95%	5%	Median	Mean	95%
BWR	> 100	1/2	3.0E-05	2.2E-04	4.7E-04	1.7E-03	2.3E-05	2.0E-04	5.1E-04	1.9E-03
	> 1,500	1 7/8	2.2E-06	4.3E-05	1.3E-04	5.0E-04	1.8E-06	3.8E-05	1.2E-04	4.7E-04
	> 5,000	3 1/4	2.7E-07	5.7E-06	2.4E-05	9.4E-05	2.4E-07	4.7E-06	2.1E-05	8.0E-05
	> 25,000	7	6.6E-08	1.4E-06	6.0E-06	2.3E-05	5.7E-08	1.2E-06	6.6E-06	2.5E-05
	> 100,000	18	1.5E-08	1.1E-07	2.2E-06	6.3E-06	1.0E-08	1.2E-07	2.4E-06	6.9E-06
	> 500,000	41	3.5E-11	8.5E-10	2.3E-09	8.6E-09	2.8E-11	9.7E-10	2.5E-09	9.5E-09
PWR	> 100	1/2	7.3E-04	3.7E-03	6.2E-03	2.0E-02	3.0E-04	1.1E-03	2.1E-03	7.5E-03
	> 1,500	1 5/8	6.9E-06	9.9E-05	2.3E-04	8.5E-04	4.9E-06	1.0E-04	2.5E-04	9.3E-04
	> 5,000	3	1.6E-07	4.9E-06	1.6E-05	6.2E-05	3.1E-07	6.6E-06	1.8E-05	7.0E-05
	> 25,000	7	1.1E-08	6.3E-07	2.3E-06	8.8E-06	6.0E-08	6.3E-07	2.5E-06	9.6E-06
	> 100,000	14	5.7E-10	7.5E-09	3.9E-08	1.5E-07	9.3E-10	1.2E-08	6.1E-08	2.4E-07
	> 500,000	31	4.2E-11	1.4E-09	2.3E-08	7.0E-08	1.0E-10	2.8E-09	4.6E-08	1.7E-07

Notes: 1. Final frequencies are subject to changes resulting from peer review, stakeholder feedback, and ongoing sensitivity analysis.

2. Sensitivity analysis is ongoing to examine the robustness of estimates.

The 5%, median, and 95% values are the medians of the panel members' total BWR and PWR estimates calculated from their responses. The mean values are calculated based on the assumption of a lognormal distribution with the corresponding median and 95th percentile values listed in Table 3. The LOCA size for each category is also provided along with the correlation between this flow rate and the minimum effective break size. It is again worth stressing that while each LOCA category is defined in terms of its flow rate, most panel members considered effective break size in assessing failure rates for each LOCA category. Values in this table are provided to two significant figures, but only one significant figure should be assumed in practice given the relatively large uncertainties associated with these estimates.

Estimates are provided for the current day (corresponding to the 25 year fleet average) and at the end of the next fifteen years (corresponding to the end of the original plant license). As indicated earlier, the results are relatively insensitive to time over this period. For all LOCA categories, the frequencies vary by less than a factor of two over the next fifteen years. Factors less than three are considered statistically insignificant given the uncertainty associated with each estimate.

The current day means and 95th percentiles from Table 3 are graphed in Figure 2. Therefore, these are cumulative frequencies. The higher PWR frequencies for category 1 – 2 estimates are a function of steam generator tube rupture and concerns about pressurizer heater sleeve and CRDM penetration failures. The category 3 estimates are similar in both BWR and PWR plants. However, BWR frequencies are higher for LOCA categories 4 and 5 due to remaining concerns about IGSCC susceptibility in the largest, 28" diameter, recirculation system lines. For both BWR and PWR plants, the 95th percentiles are generally between a factor of 3 and 4 higher than the mean values.

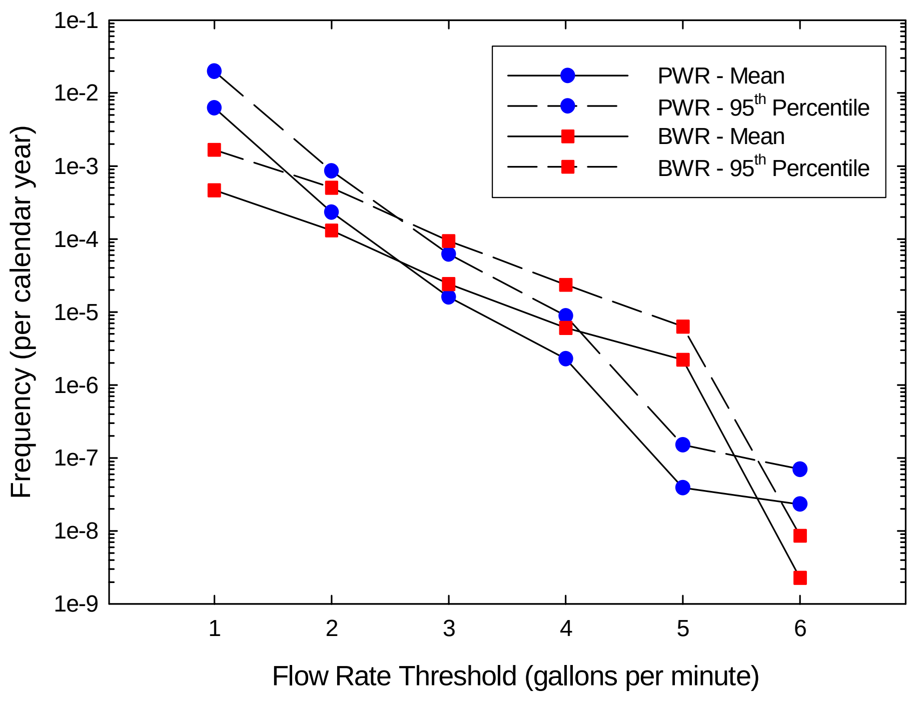

Figure 2: Total BWR and PWR Frequencies (Current Day Estimates)

Estimates were also developed for the time period between the next 15 and 35 years of plant operation (corresponding to the end of the license extension). These results are generally consistent with the previous estimates, although the uncertainty is higher. These results are not presented because of the increased uncertainty associated with the end-of-license-extension estimates. They are also outside the scope of the SRM requirements.

E.3.b. Non-Piping Contributions

The BWR non-piping contributions are a significant percentage of the piping contributions through LOCA category 3. This is largely a result of the current PWSCC concern for vessel penetrations, such as the lower head control rod drive housings. Above LOCA category 4, however, the BWR non-piping relative contributions diminish substantially. This trend reflects the expected robustness of the vessel, pump, and valve passive system failures compared to the piping contributions.

The PWR frequencies are dominated by non-piping contributions for LOCA categories 1 and 2. The domination of non-piping at smaller LOCA categories reflects the prevalence of steam generator tube ruptures, CRDM penetrations, and pressurizer heater sleeve failures for LOCA category 1. For LOCA category 2, the principal concerns are SCC in CRDM penetrations and heater sleeve failures. For LOCA category 3 and beyond, failure of these components is not expected to substantially contribute to the LOCA frequencies.

E.3.c. Uncertainties and Variability

There are significant uncertainties and variability associated with these cumulative frequency results. These are presented in Figures 3 and 4 for the current day BWR and PWR estimates, respectively, for the median and 95th percentile frequencies from Table 3. The uncertainties are expressed by the 95th percentiles. Panel variability is expressed by the first and third quartiles (vertical bars below and above, respectively, each value in Figures 3 and 4). The first and third quartiles are the 25th and 75th percentiles, respectively, of the individual panel members' responses. Therefore, about half of the individual estimates fall within this range. The difference between the third and first quartile is known as the interquartile range (IQR).

The BWR uncertainty bounds are generally narrower than the PWR bounds, especially for LOCA categories 3 - 5. The tighter BWR bounds are attributable to the fact that the experts were in better agreement about the important LOCA contributing factors for the BWR plants. However, in general, the magnitudes of the IQR are not surprising given the magnitudes of the frequency estimates provided and the diversity of opinion of the panel members for PWR plants.

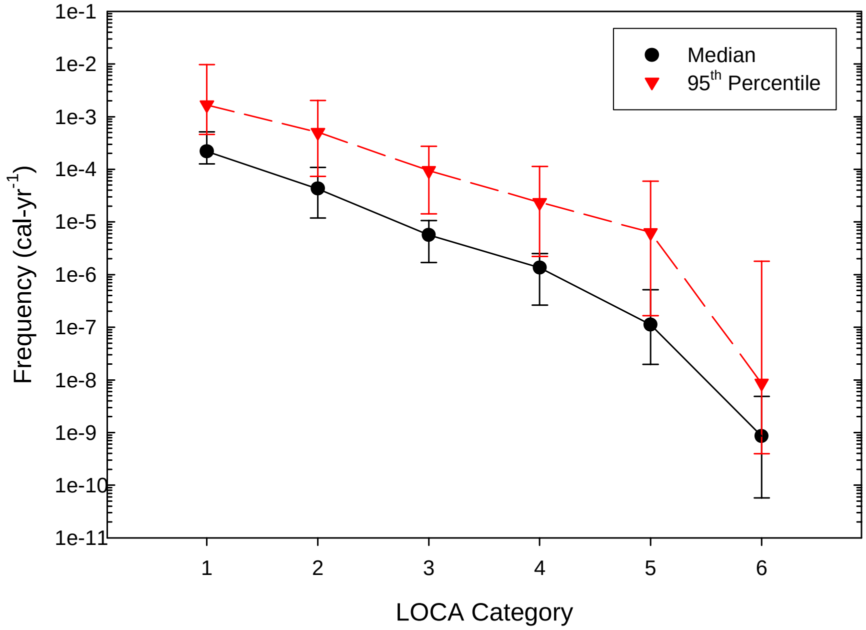

Figure 3: BWR Frequencies with Uncertainty Bounds (Current Day Estimates)

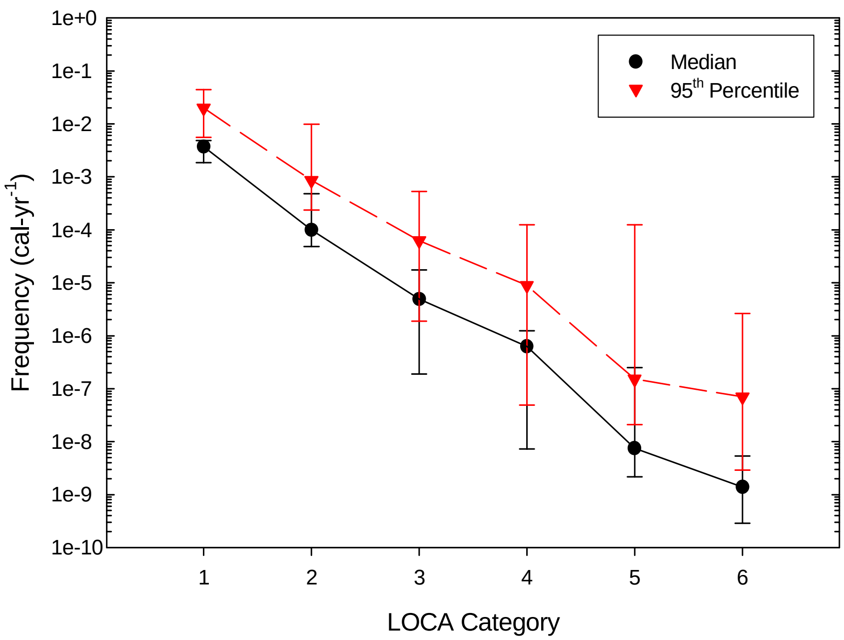

Figure 4: PWR Frequencies with Uncertainty Bounds (Current Day Estimates)

E.3.d Comparison with Prior Studies

It is of interest to compare the current estimates with previous WASH-1400 and NUREG/CR-5750 results. However, there are a few important distinctions between these earlier studies and the current estimates which must be emphasized. First, these earlier estimates defined the LOCA range of 100 to 1500 gpm for SB LOCA and 1500 – 5000 gpm for MB LOCA while the current study defined flow rate thresholds for each LOCA category. For the purposes of the comparison, the current estimates were recalculated to conform to the historical definitions. A more important distinction is that the WASH-1400 and NUREG/CR-5750 definitions distinguished between MB and LB LOCAs at approximately a 6" effective pipe break diameter. In this study, category 3 and 4 LOCAs have minimum effective break diameters of 3 and 7", respectively.

Table 4 provides a comprehensive comparison of the means between the elicitation and NUREG/CR-5750 results. In this table, the mean results from the elicitation are replicated from Table 3. The ratios represent the ratio of the NUREG/CR-5750 estimates to the current elicitation results after adjusting the LOCA size definitions to be consistent. The LB estimates are compared with both the elicitation category 3 and 4 results because the break size definitions are not consistent. Figures 5 and 6 provide additional selected comparisons of the medians, means, and uncertainty bounds from Table 4.

Generally, the elicitation results yield frequency estimates that are less than the WASH-1400 estimates (Figures 5 and 6) and of the same order as the NUREG/CR-5750 estimates. The exception is for the current category 2 PWR estimates which are about an order of magnitude higher than the NUREG/CR-5750 PWR MB LOCA estimates (Figure 5, Table 4). The PWR LB LOCA estimate from NUREG/CR-5750 is approximately five times less than the category 3 estimate, but it is almost twice the category 4 estimate (Table 4).

Table 4: Comparison of Current Results with Selected Studies

Plant Type	Elicitation Results (Current Day)		NUREG/CR-5750 (Current Day)		
	LOCA Category	Mean Frequency (cal-yr^{-1})	LOCA Size	Mean Frequency (cal-yr^{-1})	Ratio
BWR	1	4.7E-04	SB	4.0E-04	0.8
	2	1.3E-04	MB	3.0E-05	0.2
	3	2.4E-05	LB	2.0E-05	0.8
	4	6.0E-06	LB	2.0E-05	3.3
PWR	1	6.2E-03	SB	7.4E-03	1.2
	2	2.3E-04	MB	3.0E-05	0.1
	3	1.6E-05	LB	4.0E-06	0.2
	4	2.3E-06	LB	4.0E-06	1.7

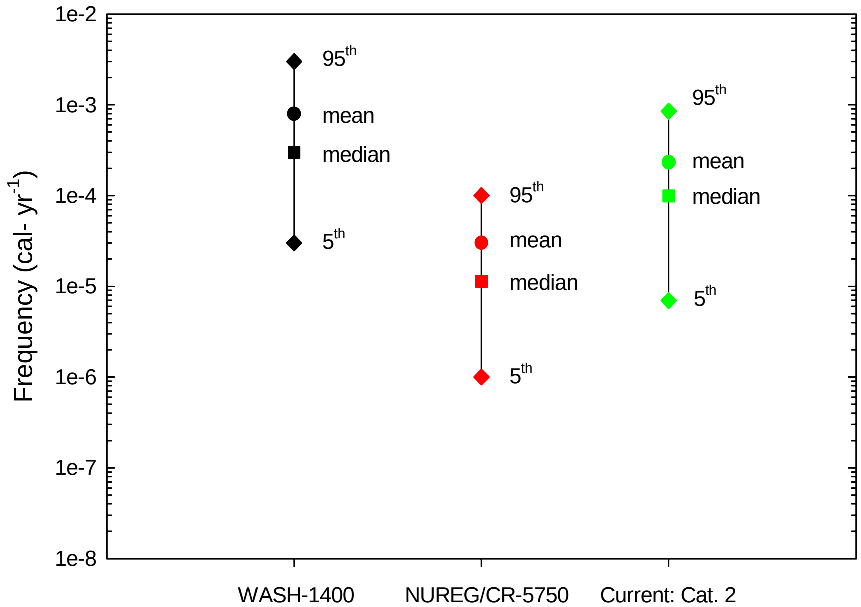

Figure 5: PWR MB LOCA Comparison (Current Day Estimates)

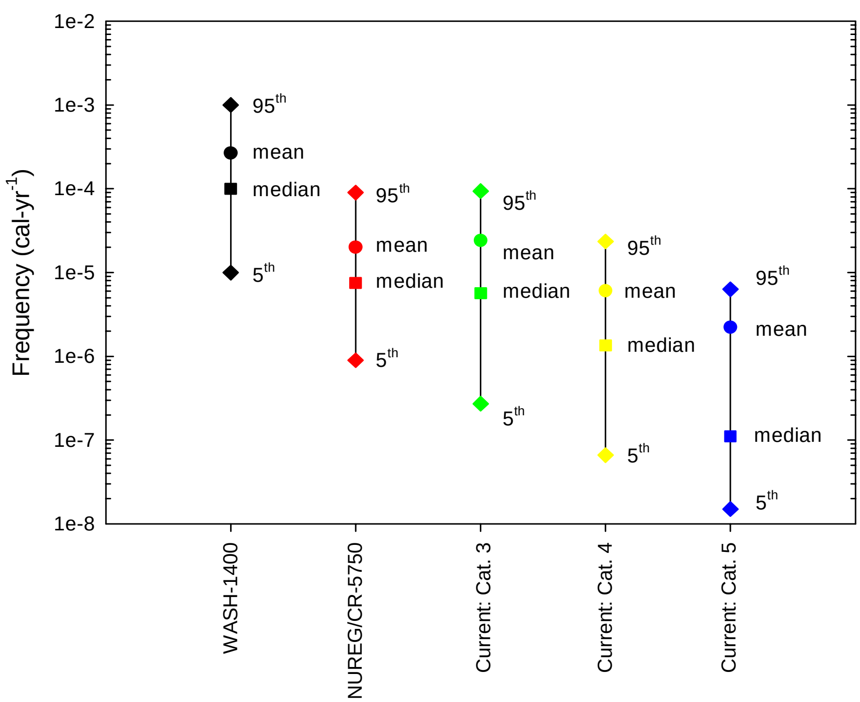

Figure 6: BWR LB LOCA Comparison (Current Day Estimates)

The BWR comparison between NUREG/CR-5750 and the current estimates are closer (Table 4). The difference between category 1 – 3 LOCAs and the corresponding NUREG/CR-5750 LOCA size is less than a factor of 2, except for category 2 which is five time higher in the current study. The NUREG/CR-5750 LB LOCA estimate is approximately 3 times greater than the category 4 estimate. The generally good agreement between the NUREG/CR-5750 and current estimates is a bit surprising given the markedly different methodology used to arrive at these results. This similarity may increase the confidence of these independent estimates.

F. Ongoing Work

Additional work is ongoing in an effort to finalize these frequency estimates. Sensitivity analysis is being conducted to confirm the robustness of the results. The objective is to ensure that the results will not be particularly sensitive to the analysis assumptions and techniques used to determine the estimates from the individual responses. A quality assurance program is also being implemented to ensure that the panel members' responses have been analyzed correctly.

A NUREG report is being developed to expand on the information provided in this summary document. The NUREG report will be developed by the facilitation team members and reviewed by the panel members to ensure that it fairly and accurately records the assumptions, approach, analysis, results, and conclusions from the elicitation. Also, individual and collective panel quantitative and qualitative responses will be provided to further buttress the final results that have been documented in this summary. This NUREG report will then receive internal NRC review and be presented to the ACRS for review and comment. The draft NUREG report is expected to be completed by May 28, 2004. After the internal and ACRS comments have been incorporated into the final report, it will be published and available for wider technical comment.

In addition a subgroup of the panel will attempt to estimate the LOCA frequency distributions given a conditional probability of a seismic event. The remaining steps in this effort include: (1) finalizing the analysis framework and analyzing the results, (2) iterating with the experts to ensure that the results are consistent with the analysis framework, (3) providing interim results to the experts and allowing for further revisions on their part, (4) documenting the process and results in a NUREG report and getting feedback from the experts on the NUREG, and (5) disseminating this information to the public.

As mentioned previously, confirmatory research to support these results through the development of probabilistic LOCA software is ongoing. Initially the effort is focused on conducting calculations for representative BWR and PWR piping systems undergoing stress corrosion cracking degradation. A PWR hot leg and a BWR main recirculation loop will be analyzed. The software is currently under development and initial frequencies for the SCC LOCA-susceptibility of these two systems are planned for the end of June 2004. Between June 2004 and September 2005, a more comprehensive estimate of LOCA initiating event frequencies will be conducted for all relevant aging mechanisms active in the important piping systems identified during the elicitation evaluation. At that time, a more comprehensive independent evaluation of the LOCA frequencies developed by formal elicitation should be possible.

G. Public Interaction

The LOCA frequency distributions developed through the elicitation will be made available to stakeholders during the spring and early summer of 2004. A subcommittee meeting of the ACRS is scheduled to be presented the basis for this Commission paper on April 1, 2004. This will be followed by a main committee meeting on April 15, 2004. There are additional plans to conduct a number of public meetings with NEI, the owner's groups, licensees and other interested stakeholders between April and June to present the results and discuss the underlying technical basis. At this point, comments will be solicited from stakeholders. As mentioned previously, the NUREG report will be publicly available once it has been published. There are initial plans to hold one or more public meetings to discuss and present the NUREG report. Stakeholder comments and feedback concerning this document will be solicited as well. The timing of these efforts will be clearer once a publication date for the NUREG report has been established.

In June 2003, there was a joint CSNI/CNRA-sponsored workshop on "Redefining the Large Break LOCA: Technical Basis and its Implications". Over sixty five participants from fifteen countries in Europe, Asia, and North America participated in this two-day workshop. The objective was to understand the benefits of redefining the large break LOCA, explore the sufficiency of the supporting technical basis, and examine the ramifications for existing reactor operation and future reactor design. Each country presented research and/or licensing plans that are considering the ramifications of LOCA break size redefinition. There was much interest in the US plans to redefine the LB LOCA for existing plants and the supporting effort on reevaluating the LOCA frequency distributions. While there was general agreement that a technical basis could be developed, the international community requested that the US present the elicitation results and findings. It was agreed that the NRC would present the elicitation results and findings once they become finalized. Plans for such a presentation are pending, but will be scheduled after the NUREG report has been accepted.

H. Conclusions

While additional work remains to verify and finalize the LOCA frequencies herein, the completed effort is consistent with the intent and direction provided by the SRM in March 2003. Expert elicitation has been used to evaluate service history data and insights from PFM studies to develop LOCA frequency estimates. The elicitation panel was carefully chosen to provide the requisite technical expertise required for this analysis. Each panel member has at least twenty-five years of experience in relevant technical areas. Also, the panel is comprised of wide organizational affiliations.

The elicitation approach allowed the experts to decompose the complex issues which impact LOCA frequencies into fundamental pieces which are easier to assess. Quantitative estimates were provided to the experts for precursor events associated with piping and non-piping components. Additional quantification was conducted to develop frequencies associated with well-defined, or base case, conditions. All questions were framed in terms of relative comparisons between the base case and important contributing factors. Each panel member individually identified important contributing factors and chose appropriate base cases for anchoring.

The panel members provided quantitative estimates and reasoned qualitative rationale to support their judgments of the most important LOCA challenges. The elicitation was carefully defined to only consider issues based on normal operational loading and challenges that can be reasonably expected over the extended operating periods associated with plant life. Panel members were required to estimate future LOCA frequencies using the underlying service history and the base case frequencies as a basis. Frequency estimates were made for the current day, and for 15 and 35 years in the future. These future time periods were chosen because they correspond to the average end of the original operating license period and the average end of the extended operating license period. The intent was to use both the current-day and 15 year estimates as the basis for the LOCA frequencies associated with the next 10 year period required by SRM guidance.

The results reflect the inherent scientific uncertainty in estimating LOCA frequencies. In addition to providing responses to each question, panel members were also questioned about their uncertainty on their responses. The individual panel responses were propagated to obtain estimates of the means of the LOCA frequency distributions. Individual uncertainty bounds are reflected in the 5^{th} and 95^{th} percentile estimates of the LOCA frequency distributions. Panel variability is reflected in the uncertainty bounds provided for each estimate. It is intended that the uncertainty bounds will be used in concert with the mean estimates to form the technical basis of any future regulatory changes.

The important contributing issues identified by the panel are reasonably consistent. Frequency estimates are not expected to change dramatically over the next fifteen years. While aging will continue, the consensus is that procedures are in place, or will be implemented in a timely manner, to mitigate possible frequency increases. The panel also generally agrees that complete small pipe failure is more likely than partial rupture of bigger pipes for a given LOCA size. This is a primary reason why the biggest contributors in each LOCA category tend to be the smallest pipes which can lead to that size LOCA. The important piping systems and aging mechanisms of concern are also in general agreement by the panel, especially for the smallest (category 1, 2) and largest (category 5, 6) LOCA categories. There is substantially more disagreement for the middle (category 3, 4) LOCA categories because of the sheer number of possible contributing factors. Non-piping predictions are generally more difficult due to the range of possible failure scenarios and the lack of service history data available for these components.

While there is general qualitative agreement about important issues, the quantitative estimates of the importance of these issues differed substantially among panel members. This characteristic is expected given the scientific uncertainty and difficulty is assessing LOCA frequencies. This was the principal reason formal elicitation was chosen, and the basis for the approach developed in the exercise. The results generally compare well with NUREG/CR-5750 estimates for SB, MB, and LB LOCAs. Some care is required in making these comparisons because the historical break sizes associated with LB LOCAs falls between LOCA categories 3 and 4. However, the flow rate definitions for LOCA category 3 and historical LB LOCA breaks is consistent.

Work is ongoing to complete the supporting NUREG for this effort. Additionally, the findings will be provided to the ACRS for review and comment. Plans are in place for wider public dissemination of these results to garner stakeholder feedback and general comments about the process. Technical revisions based on this dissemination and comment may be necessary before the frequencies are finalized.

I. References

[1] "Investigation and Evaluation of Stress-Corrosion Cracking in Piping of Light Water Reactor Plants," NUREG-0531, U.S. Nuclear Regulatory Commission, February 1979.

[2] Rao, G.V., Seeger, D.E., Jr., Hoffman, J.A., DeFlitch, C., Rees, R.A., and Junker, W.R., "Metallurgical Investigation of Cracking in the Reactor Vessel Alpha Loop Hot Leg Nozzle to Pipe Weld at the V.C. Summer Nuclear Generating Station," WCAP-15616, Westinghouse Electric Company LLC, January 2001.

[3] "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400, U.S. Nuclear Regulatory Commission, October 1975.

[4] Poloski, J.P, Marksberry, D.G., Atwood, C.L., and Galyean, W.J., "Rates of Initiating Events at U.S. Nuclear Power Plants: 1987-1995," NUREG/CR-5750, U.S. Nuclear Regulatory Commission, February 1999.

[5] Beliczey, S., and Schulz, H., "Comments on Probabilities of Leaks and Breaks of Safety-Related Piping in PWR Plants," International Journal of Pressure Vessel and Piping, Vol. 43, pp. 219 – 227, (1990).

[6] "Manual Shutdown of Unit-1 of the Hamaoka Nuclear Power Station," Nuclear Power Safety Press Release Information, ANRE/MITI, Chubu Electric Power Company, November 8, 2001.

[7] "Unique Brunsbuettal Core Spray was Vulnerable to Gas Explosion," Nucleonic Week, Vol. 43, No. 10, March 7, 2002.

[8] Licensee Event Report (LER)-28186020, "Surry 2 Feedwater Failure," March 31, 1987.

[9] "Reliability of Piping System Components. Vol. 2: PSA LOCA Data Base Review of Methods for LOCA Evaluation Since the WASH-1400," SKI Report 95:59, Swedish Nuclear Power Inspectorate, 1996.

[10] Gesellschaft Für Anlagen und Reaktorsicherheit (GRS) mbh; German Risk Study Phase B, GRS-72, Verlag, TÜV; Cologne, 1989.

[11] Harris, D.O., and Dedhia, "A Probabilistic Fracture Mechanics Code for Piping Reliability Analysis (pcPRAISE code)," NUREG/CR-5864, U.S. Nuclear Regulatory Commission, 1992.

[12] Bishop, B.A., "Westinghouse Structural Reliability and Risk Assessment (SRRA) Model for Piping Risk Informed In-Service Inspection," WCAP-14572 Revision 1, Supplement 1, Westinghouse Electric Company LLC, October 1997.

[13] Paul, D.D., Ahmad, J., Scott, P.M., Flanigan, L.F., and Wilkowski, G.M., "Evaluation and Refinement of Leak-Rate Estimation Models," NUREG/CR-5128, Rev. 1, U.S. Nuclear Regulatory Commission, June 1994.

[14] Rahman, S., Ghadiali, N., Paul, D., and Wilkowski, G., "Probabilistic Pipe Fracture Evaluations for Leak-Rate Detection Applications," NUREG/CR-6004, U.S. Nuclear Regulatory Commission, April 1995.

[15] Meyer, M.A., and Booker, J.M., "Eliciting and Analyzing Expert Judgment: A Practical Guide," NUREG/CR-5424, U.S. Nuclear Regulatory Commission, January 1990.

[16] "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, U.S. Nuclear Regulatory Commission, December 1990.

[17] Simonen, F.A., Doctor, S.R., Schuster, G.J., and Heasler, P.G., "A Generalized Procedure for Generating Flaw-Related Inputs for FAVOR Code," NUREG/CR-6817, to be published (March 2004).

[18] Bonano, E.J., Hora, S.C., Keeney, R.L., and von Winterfeldt, D., "Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories," NUREG/CR-5411, U.S. Nuclear Regulatory Commission, May 1990.

[19] Kotra, J.P., Lee, M.P., Eisenberg, N.A., and DeWispelare, A.R., "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program, "NUREG/CR-1563, U.S. Nuclear Regulatory Commission, 1996.

[20] Budnitz, R.J., Apostolokis, G., Boore, D.M., Cluff, L.S., Coppersmith, K.J., Cornell, C.A., and Morris, P.A., "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on the Use of Experts," NUREG/CR-6372, U.S. Nuclear Regulatory Commission, 1997.

[21] Memorandum from A.C. Thadani to S.J. Collins, Transmittal of Technical Work to Support Possible Rulemaking on a Risk-Informed Alternative to 10 CFR 50.46/GDC 35, dated July 31, 2002.