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April 27, 2004

Attention: Document Control Center
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Project - 689

SUBJECT: Draft Revision 1 to NEI 94-01, *Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J,* and Final (pre-publication) EPRI Report, Product No. 1009325, *Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals*

This letter transmits the enclosed subject documents for NRC review. Our goal is to obtain NRC endorsement of NEI 94-01, Revision 1, through a revision Regulatory Guide 1.163.

NEI 94-01 was revised to support an industry effort to optimize Type A Integrated Leak Rate Test (ILRT) intervals for up to twenty years. The EPRI report will provide a basis for the revision to NEI 94-01. In conjunction with our ILRT Task Force, we additionally request the opportunity to meet with you and your staff to discuss this effort and related milestones.

We view the submittal of this document for NRC staff review and endorsement as a means of exchanging information that is intended to support generic regulatory improvements. Therefore we believe an exemption from any review fees is warranted based on the criteria in footnote 4 of 10 CFR 170.21.

We appreciate the opportunity to provide this document for your review and look forward to our meeting. Please contact me at 202 739-8081, arp@nei.org, or Rich Luckett at 202 739-8058, rml@nei.org if you desire further information.

Sincerely,

Anthony R. Pietrangelo

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Enclosures

c: Stephen Dembek, NRC

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NEI 94-01
Revision 1

NUCLEAR ENERGY INSTITUTE

INDUSTRY GUIDELINE FOR IMPLEMENTING PERFORMANCE-BASED OPTION OF 10 CFR PART 50, APPENDIX J

December 22, 2003

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REVISION 1 TO INDUSTRY GUIDELINE FOR IMPLEMENTING PERFORMANCE-BASED OPTION OF 10 CFR PART 50, APPENDIX J

December 22, 2003

DRAFT

ACKNOWLEDGMENTS

This guidance document, Industry Guideline for Implementing Performance-Based Option of 10 CFR 50, Appendix J, NEI 94-01, Revision 1, was developed by the Nuclear Energy Institute (NEI) Type A Integrated Leakage Rate Test Interval Extension Task Force. We appreciate the direct participation of the many licensees who contributed to the development of the guideline and the participation of the balance of the industry who reviewed and submitted comments to improve the document clarity and consistency. The dedicated and timely effort of the many Task Force participants, including their management's support of the effort, is greatly appreciated.

NEI also wishes to express its appreciation to the Electric Power Research Institute (EPRI) who devoted considerable time and resources to the development of this revised industry Appendix J guideline.

NOTICE

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FOREWORD

The purpose of this guidance is to assist licensees in implementing 10 CFR 50, Appendix J, Option B, "Performance-Based Requirements", and in extending Type A Integrated Leakage Rate Test (ILRT) surveillance intervals beyond the ten years permitted by NEI 94-01 (1995) and Regulatory Guide 1.163 (1995). To support this effort, in response to an NEI request many licensees provided pertinent leakage rate testing experience information covering the period from 1995 through 2001.

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EXECUTIVE SUMMARY

This document describes an acceptable approach for implementing the optional performance-based requirements of Option B to 10 CFR 50, Appendix J and for extending the Type A ILRT interval to up to twenty years. It delineates a performance-based approach for determining Type A, Type B, and Type C containment leakage rate surveillance testing frequencies. Justification of extending test intervals is based on the performance history and risk insights.

This guideline discusses the performance factors that licensees must consider in determining test intervals. It does not address how to perform the tests because these details can be found in existing documents (e.g., ANSI/ANS 56.8-[1994 or 2002 revision]). Both 1994 and 2002 revisions of ANSI/ANS 56.8 are referred to in this guideline. Both provide consistent information on how to perform tests, however, the 1994 revision conflicts in some cases with the performance-based aspects of this guideline. While the 2002 revision of ANSI/ANS 56.8 is performance-based, it conflicts in some cases with this document. In event of conflicting requirements, guidance provided in NEI 94-01, Revision 1 should be followed.

The performance criteria for Type A tests is a performance leak rate (as defined in Section 8.0 of this guideline) of less than 1.0 L_a. Extension of Type A test intervals are allowed based upon two consecutive successful Type A tests and other requirements stated in Sections 9.2.3 and 9.2.3.1 of this guideline. Type A testing shall be performed at a frequency of at least once per 20 years. If the Type A performance leak rate is not acceptable, the performance criteria is not met, and a determination should be performed to identify the cause of unacceptable performance and determine appropriate corrective actions. Once completed, acceptable performance should be reestablished by demonstrating an acceptable performance leak rate before resuming operation and by performing another successful Type A test within 48 months following the unsuccessful Type A test. Following these successful Type A tests, the surveillance frequency may be returned to at least once per 20 years.

If the As-found Type A results (for operability considerations as defined in Section 8.0 of this guideline) are not acceptable, a determination should be performed to identify the cause of unacceptable performance and determine appropriate corrective actions.

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Extensions in Type B and Type C test intervals are allowed based upon completion of two consecutive periodic As-found tests where the results of each test are within a licensee's allowable administrative limits. Intervals for Type B tests may be increased from 30 months up to a maximum of 120 months (except for containment airlocks). Intervals for Type C tests may be increased from 30 months up to a maximum of 60 months. If the Type B and C test results are not acceptable, the test frequency should be set at the initial test intervals. Once the cause determination and corrective actions have been completed, acceptable performance may be reestablished and the testing frequency returned to the extended intervals as specified in this document.

Containment airlock(s) shall be tested at an internal pressure of not less than P_a prior to a preoperational Type A test. Subsequent periodic tests shall be performed at a frequency of at least once per 30 months. When containment integrity is required, airlock door seals should be tested within 7 days after each containment access. For periods of multiple containment entries where the airlock doors are routinely used for access more frequently than once every 7 days (e.g., shift or daily inspection tours of the containment), door seals may be tested once per 7 days during this time period.

The Performance Factors of Section 11.3.1 have been identified as important and should be considered in establishing testing intervals for Type B and C components. These factors include past performance, service, design, safety impact, and failure cause determination.

If a licensee considers extended test intervals of greater than 60 months or three refueling cycles for Type B tested components, the review should include the additional considerations of As-found tests, schedule and review as described in Section 11.3.2.

Finally, this document discusses the general requirements for recordkeeping for implementation of Option B to Appendix J.

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TABLE OF CONTENTS

1.0 INTRODUCTION 1
1.1 Background 1
1.2 Discussion 2
2.0 PURPOSE AND SCOPE 3
3.0 RESPONSIBILITY 4
4.0 APPLICABILITY 5
5.0 DEFINITIONS 5
6.0 GENERAL REQUIREMENTS 5
7.0 UTILIZATION OF EXISTING PROGRAMS 7
8.0 TESTING METHODOLOGIES FOR TYPE A, B AND C TESTS 7
9.0 DETERMINING PERFORMANCE-BASED TEST INTERVAL FOR TYPE A TESTS 9
9.1 Introduction 9
9.1.1 Performance Criteria 10
9.1.2 Test Interval 11
9.2 Type A Test 11
9.2.1 Pretest Inspection and Test Methodology 11
9.2.2 Initial Test Intervals 12
9.2.3 Extended Test Intervals 13
9.2.3.1 Requirements for ILRT Extensions Beyond Ten Years. 14
9.2.4 Containment Repairs and Modifications 15
9.2.5 Surveillance Acceptance Criteria 15
9.2.6 Corrective Action 15
10.0 DETERMINING PERFORMANCE-BASED TEST FREQUENCIES FOR TYPE B AND TYPE C TESTS 16
10.1 Introduction 16
10.2 Type B and Type C Testing Frequencies 17
10.2.1 Type B Test Intervals 18
10.2.2 Containment Airlocks 20
10.2.3 Type C Test Interval 21
11.0 BASIS FOR PERFORMANCE AND RISK-BASED TESTING FREQUENCIES FOR TYPE A, TYPE B, AND TYPE C TESTS 23
11.1 Introduction 23
11.2 Discussion 23
11.3 Plant-Specific Testing Program Factors 27
11.3.1 Performance Factors 29
11.3.2 Programmatic Controls 30
12.0 RECORDKEEPING 31
12.1 Report Requirements 31
12.2 Records 31

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APPENDICES

APPENDIX A

NRC Rule for Implementing Performance-Based Leakage Test Requirements, 10 CFR 50, Appendix J, Option B

APPENDIX B

Regulatory Guide 1.163, Revision 1, Performance-based Containment Leak-Test Program

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LIST OF ILLUSTRATIONS

		Page
Table 1	Risk Results for Type B, and Type C Testing Intervals from EPRI Research Project Report 4114-22	28

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1.0 INTRODUCTION

1.1 Background

Containment leakage rate testing is performed in accordance with 10 CFR 50, Appendix J, "Leakage Rate Testing of Containment of Light Water Cooled Nuclear Power Plants." Appendix J specifies containment leakage testing requirements, including the types of tests required. In addition, for each type of test, Appendix J discusses leakage rate acceptance criteria, test methodology, frequency of testing, and reporting requirements. The specific testing requirements are discussed in a variety of sources, including Technical Specifications, Final Safety Analysis Reports (FSARs), National Standards (e.g., ANSI/ANS 56.8-[1994 and/or 2002 revision], "Containment System Leakage Testing Requirements"), and licensee/NRC correspondence. These documents require that periodic testing be conducted to verify the leakage integrity of the containment and those containment systems and components which penetrate the containment.

The reactor containment leakage test program includes performance of an Integrated Leakage Rate Test (ILRT), also known as a Type A test; and performance of Local Leakage Rate Tests (LLRTs), also known as either Type B or Type C tests. The Type A test measures overall leakage rate of the primary reactor containment. Type B tests are intended to detect leakage paths and measure leakage for certain primary reactor containment penetrations. Type C tests are intended to measure containment isolation valve leakage rates.

In 1995, the NRC amended the regulations to provide an Option B to 10 CFR 50, Appendix J. Option B is a performance-based approach to Appendix J leakage testing requirements. This option, in concert with Regulatory Guide 1.163, Revision 1 and NEI 94-01, Revision 1, allows licensees with good ILRT performance history to reduce the Type A integrated leakage rate test (ILRT) frequency from three tests in 10 years to at least one test in 20 years. The initial 1995 relaxation of ILRT intervals was based on the NRC risk assessment contained in "Performance-Based Containment Leak-Test Program (NUREG-1493) and EPRI Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals (TR-104285) both of which found that there was a very low increase in risk associated with increasing ILRT surveillance intervals to ten years. Furthermore, the NRC assessment stated that there was an imperceptible increase in risk associated with increasing ILRT intervals up to twenty years. In 2001, many licensees began to submit requests for one-time ILRT interval extensions beyond ten years, and it was deemed appropriate

to assess the risk involved in extending ILRT intervals beyond ten years. EPRI Product No. 1009325, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals" demonstrated that generically there is very little risk associated with extension of ILRT intervals of up to twenty years. This EPRI report provides the risk basis for extending ILRT intervals for up to twenty years.

For Type B and Type C tests, Option B, in concert with Regulatory Guide 1.163, Revision 1 and NEI 94-01, Revision 1 allows licensees to reduce testing frequency on a plant-specific basis based on experience history of each component, and established controls to ensure continued performance during the extended testing interval.

Generally, a FSAR describes plant testing requirements, including containment testing. In some cases, FSAR testing requirements differ from those of Appendix J. In many cases, Technical Specifications were approved that incorporated exemptions to provisions of Appendix J. Additionally, some licensees have requested and received exemptions after their Technical Specifications were issued. The alternate performance-based testing requirements contained in Option B of Appendix J will not invalidate such exemptions.

Plants that have elected to invoke 10 CFR 50, Appendix J, Option B in concert with NEI 94-01 (1995) and Regulatory Guide 1.163 (1995) and who do not wish to extend ILRT surveillance intervals beyond ten years are not required to comply with this current revision of NEI 94-01, Revision 1 and Regulatory Guide 1.163, Revision 1.

1.2 Discussion

This guideline describes an approach that may be used to meet the alternate testing requirements described in Option B to Appendix J. The performance history of containment, penetrations, and containment isolation valves is used as the means to justify extending test intervals for containment Type A, Type B, and Type C tests. This guideline provides a method for determining the extended test intervals based on performance.

Under Option B, test intervals for Type A, Type B, and Type C testing may be determined by using a performance-based approach. Performance-based test intervals are based on consideration of operating history of the component and resulting risk from its failure. Performance-based for Appendix J, refers to both performance history necessary to extend test intervals as well as criteria necessary

to meet the requirements of Option B. The performance-based approach to leakage rate testing discussed in NUREG-1493, "Performance-Based Leak-Test Program," concludes that the impact on public health and safety due to extended intervals is negligible. EPRI Product No. 1009325, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals" concludes that the risk impact is very small. The approach of the EPRI Risk Impact Assessment included compliance with appropriate current risk-informed guidance of Regulatory Guide 1.174 (1998), "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions in Plant-Specific Changes to the Licensing Basis."

Type A tests focus on verifying the leakage integrity of a passive containment structure. Type B and C testing focuses on assuring that containment penetrations are essentially leak tight. These tests collectively satisfy the requirements of 10 CFR 50, Appendix J, Option B summarized as follows: "These test requirements ensure that (a) leakage through these containments or systems and components penetrating these containments does not exceed allowable leakage rates specified in the Technical Specifications and (b) integrity of the containment structure is maintained during its service life."

2.0 PURPOSE AND SCOPE

This guideline describes an acceptable method for implementing the optional performance-based requirements of Appendix J. This method uses industry performance data, plant-specific performance data, and risk insights in determining the appropriate testing frequency. Licensees may elect to use other suitable methods or approaches to comply with Option B, but must obtain NRC approval prior to implementation.

The approach described in this guideline to implement Appendix J, Option B includes:

- Continued assurance of the leakage integrity of the containment without adversely affecting public health and safety;
- Licensee flexibility to implement cost-effective testing methods;
- A framework to acknowledge good performance;
- Utilization of risk and performance-based methods, and
- An awareness of and attention to supplemental means of assessing and maintaining containment integrity, particularly for ILRT interval extensions

beyond ten years. Specifically, this includes the Maintenance Rule, ASME Boiler and Pressure Vessel Code, Section XI, Subsections IWE/IWL inspections, and low pressure monitoring.

This guideline delineates the basis for a performance-based approach for determining Type A, Type B, and Type C containment leakage rate surveillance testing frequencies. It does not address how to perform the tests because these details can be found in existing documents (e.g., ANSI/ANS 56.8-[1994 or 2002 revision]). Both 1994 and 2002 revisions of ANSI/ANS 56.8 are referred to in this guideline. Both provide consistent information on how to perform tests, however, the 1994 revision conflicts in some cases with the performance-based aspects of this guideline. While the 2002 revision of ANSI/ANS 56.8 is performance-based, it conflicts in some cases with this document. In event of conflicting requirements, guidance provided in NEI 94-01, Revision 1 should be followed.

It should be noted that other requirements that have been implemented since 1995 such as the Maintenance Rule and ASME Boiler and Pressure Vessel Code, Section XI, Subsections IWE/IWL inspections provide additional diverse means of maintaining and assessing containment integrity.

3.0 RESPONSIBILITY

Each licensee should determine if the requirements of the existing Appendix J (Option A) or the alternate requirements (Option B) are most appropriate for its facility. If a licensee elects to implement the Option B requirements, the guidance described in this document has been reviewed and endorsed by the NRC as an acceptable method of implementing the requirements.

In addition, if a licensee elects to adopt Option B, it may elect to adopt the requirements that apply to a specific category of tests (i.e., Type A, or Type B and Type C tests) only.

Plants that have elected to invoke 10 CFR 50, Appendix J, Option B in concert with NEI 94-01 (1995) and Regulatory Guide 1.163 (1995) and who do not wish to extend ILRT surveillance intervals beyond ten years are not required to comply with this current revision of NEI 94-01, Revision 1 and Regulatory Guide 1.163, Revision 1.

4.0 APPLICABILITY

This guideline is applicable to licensees holding an operating license issued in accordance with 10 CFR 50.21(b) and 50.22; and 10 CFR Part 52, Subpart C.

Industry operating experience and plant modifications that may affect Type A, Type B, and Type C testing program(s) should be reviewed to assure test and maintenance programs are appropriately adjusted to reflect these changes.

5.0 DEFINITIONS

Definitions of commonly accepted terms used in this guideline may be found in ANSI/ANS 56.8-[1994 or 2002 revision].

6.0 GENERAL REQUIREMENTS

Option B of 10 CFR 50, Appendix J states: "Type A tests to measure the containment system overall integrated leakage rate must be conducted under conditions representing design basis loss-of-coolant accident containment peak pressure. A Type A test must be conducted (1) after the containment system has been completed and is ready for operation and (2) at a periodic interval based on the historical performance of the overall containment system as a barrier to fission product releases to reduce the risk from reactor accidents. A general visual inspection of the accessible interior and exterior surfaces of the containment system for structural deterioration which may affect the containment leak-tight integrity must be conducted prior to each test, and at a periodic interval between tests based on the performance of the containment system. The leakage rate must not exceed the allowable leakage rate (L_a) with margin, as specified in the Technical Specifications. The test results must be compared with previous results to examine the performance history of the overall containment system to limit leakage."

A review of leakage rate testing experience indicates that only a small percentage of Type A tests have excessive leakage. Furthermore, the observed leakage rates for the few Type A test failures were only marginally above current limits. These observations, together with the insensitivity of public risk to containment leakage rate at these low levels, suggest that for Type A tests, intervals may be established based on performance. Type A test is the primary means to detect containment leakage that is not detectable by the Type B and Type C testing programs, and is also used to verify at periodic intervals the accident leakage (L_a) assumptions in the accident analysis. Specific details of Type A test requirements are discussed in ANSI/ANS 56.8-[1994 or 2002 revision].

An LLRT is a test performed on Type B and Type C components. An LLRT is not required for the following cases:

- Primary containment boundaries that do not constitute potential primary containment atmospheric pathways during and following a Design Basis Accident (DBA);

- Boundaries sealed with a qualified seal system; or,

- Test connection vents and drains between primary containment isolation valves which are one inch or less in size, administratively secured closed and consists of a double barrier.

For Type B and Type C tests, intervals shall be established based on the performance history of each component. Performance criterion for each component is determined by designating an administrative leakage limit for each component in the Type B and Type C testing program. The acceptance criteria for Type B and Type C tests is based upon demonstrating that the sum of leakage rates at DBA pressure for containment penetrations and valves that are testable, is less than the total allowable leakage rate specified in the plant Technical Specifications.

Primary containment barriers sealed with a qualified seal system shall be periodically tested to demonstrate their functionality in accordance with the plant Technical Specifications. Specific details of the testing methodology and requirements are contained in ANSI/ANS 56.8-[1994 or 2002 revision] and should be adopted by licensees with applicable systems. Test frequency may be set using a performance basis in a manner similar to that described in this guideline for Type B and Type C test intervals. Leakage from containment isolation valves that are sealed with a qualified seal system may be excluded when determining the combined leakage rate provided that:

- Such valves have been demonstrated to have fluid leakage rates that do not exceed those specified in the technical specifications or associated bases, and

- The installed isolation valve seal-water system fluid inventory is sufficient to assume the sealing function for at least 30 days at a pressure of 1.10 P_a.

7.0 UTILIZATION OF EXISTING PROGRAMS

Licensees should use existing industry programs, studies, initiatives and data bases, where possible.

8.0 TESTING METHODOLOGIES FOR TYPE A, B AND C TESTS

Type A, Type B and Type C tests should be performed using the technical methods and techniques specified in ANSI/ANS 56.8-[1994 or 2002 revision], or other alternative testing methods that have been approved by the NRC. However, because ANSI/ANS 56.8-1994 is not performance-based, certain exceptions and clarification to methods, techniques and definitions contained in that document are required. These are discussed in the following paragraphs.

Test intervals in ANSI/ANS 56.8-1994 are not performance-based and performance-based test intervals in ANSI/ANS 56.8-2002 may conflict with the requirements of this guideline. This guideline should be implemented when establishing test intervals for Type A, Type B and Type C testing.

All Appendix J pathways must be properly drained and vented during the performance of the ILRT, with the following exceptions:

- Pathways in systems which are required for proper conduct of the Type A test or to maintain the plant in a safe shutdown condition during the Type A test;

- Pathways in systems that are normally filled with fluid and operable under post-accident conditions;

- Portions of the pathways outside primary containment that are designed to Seismic Category I and at least Safety Class 2; or,

- For planning and scheduling purpose, or ALARA considerations, pathways which are Type B or C tested within the previous 30 calendar months or within the same outage as the Type A test need not be vented or drained during the Type A test.

The proper methods for draining and venting are specified in ANSI/ANS 56.8-[1994 or 2002 revision].

It should be noted that the Type B or C tests performed on those pathways must test all of its containment barriers. This includes bonnets, packings, flanged joints, threaded connections, and compression fittings. If the Type B or C test pressurizes any of the pathway's containment barriers in the reverse direction, it must be shown that test results are not affected in a nonconservative manner by directionality. The As-found and the As-left leakage rate for all pathways that are not drained and vented must be determined by Type B and Type C testing within the previous 30 calendar months of the time that the Type A test is performed and must be added to the Type A leakage rate UCL to determine the overall L_a surveillance acceptance criteria in accordance with the definition in ANSI/ANS 56.8-1994.

The As-found Type A test results described in ANSI/ANS 56.8-1994 are defined to include the positive differences between the As-found and As-left LLRT leakage rates for each pathway tested and adjusted prior to the performance of the Type A test (leakage savings). For purposes of determining an acceptable Type A test for operability considerations, the definitions and discussions found in ANSI/ANS 56.8-1994 for As-found Type A leakage rate should be followed.

However, because of the performance-based emphasis on Type A testing, criteria for Type A tests have been defined differently, and do not use the leakage savings value. The performance criteria use a calculated performance leakage rate, which is defined as the sum of the Type A test UCL and As-left MNPLR leakage rate for all Type B and Type C pathways that were in service, isolated or not lined up in their test position (i.e., drained and vented to containment atmosphere) prior to performing the Type A test. In addition, any leakage pathways that were isolated during performance of the test because of excessive leakage must be factored into the performance determination. If the leakage can be determined by a local leakage rate test, the As-left MNPLR for that leakage path must also be added to the Type A test UCL. If leakage cannot be determined by local leakage rate testing, the performance criteria for the Type A test were not met.

If an excessively leaking Appendix J barrier pathway is discovered during the Type A test, and the pathway is neither a Type B nor a Type C tested pathway, it shall still be tested to Type B or Type C test requirements after the Type A test and its As-left MNPLR added to the Type A test UCL. In this case, the Type A test performance criterion is not met unless that pathway is subsequently added to the Type B or Type C test program.

ANSI/ANS 56.8-[1994 or 2002 revision] also specifies surveillance acceptance criteria for Type B and Type C tests. The ANSI/ANS 56.8-[1994 or 2002 revision]

criteria is that the combined leakage rate for all penetrations subject to Type B or Type C tests is limited to less than or equal to $0.60L_a$, when determined on a MNPLR basis from As-found LLRT results; and limited to less than or equal to $0.60L_a$, as determined on a Maximum Pathway Leakage Rate (MXPLR) basis from the As-left LLRT results.

Due to the performance-based nature of Option B to Appendix J and this guideline, it is recommended that acceptance criteria for the combined As-found and As-left leakage rate for all penetrations subject to Type B or Type C testing be the same as that defined in ANSI/ANS 56.8-2002. E.g., the combined As-left leakage rates determined on a MXPLR basis for all penetrations shall be verified to be less than $0.60L_a$ prior to entering a mode where containment integrity is required following an outage or shutdown that included Type B and Type C testing. The combined As-found leakage rates determined on a MNPLR basis for all penetrations shall be less than $0.60L_a$ at all times when containment integrity is required. These combined leakage rate determinations shall be done with the latest leakage rate test data available, and shall be kept as a running summation of the leakage rates.

9.0 DETERMINING PERFORMANCE-BASED TEST INTERVAL FOR TYPE A TESTS

9.1 Introduction

Determination of the surveillance frequency of Type A tests is based upon satisfactory performance of leakage tests that meet the requirements of Appendix J. Performance in this context refers to both the performance history necessary to determine test intervals as well as overall criteria needed to demonstrate leakage integrity performance. Performance is also used as a basis for demonstrating negligible impact on public health and safety.

The purpose of Type A testing is to verify the leakage integrity of the containment structure. The primary performance objective of the Type A test is not to quantify an overall containment system leakage rate. The Type A testing methodology as described in ANSI/ANS 56.8-[1994 or 2002 revision], and the modified testing frequencies recommended by this guideline, serves to ensure continued leakage integrity of the containment structure. Type B and Type C testing assures that individual penetrations are essentially leak tight. In addition, aggregate Type B and Type C leakage rates support the leakage tightness of primary containment by minimizing potential leakage paths. A review of

performance history has concluded that almost all containment leakage is identified by local leakage rate testing.

This section discusses a method to determine a testing frequency for Type A testing based on performance. The extended test interval is based upon industry performance data that was compiled to support development of Option B to Appendix J, and is intended for use by any licensee. In adopting extended test intervals recommended in this guideline, a licensee should perform Type A testing in accordance with recommended industry practices. Additional technical information concerning data analysis may be found in NUREG-1493 and EPRI Product No. 1009325, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals".

Consistent with standard scheduling practices for Technical Specifications Required Surveillances, intervals for recommended Type A testing given in this section may be extended by up to 15 months for ILRT intervals up to eighteen years. For ILRT intervals beyond eighteen years, Type A testing intervals may be extended by up to three months. This option should be used only in cases where refueling schedules have been changed to accommodate other factors.

9.1.1 Performance Criteria

Performance criteria for establishing Type A test intervals should provide both the standard against which performance is to be measured and basis for determining that performance is acceptable. Because of the performance-based emphasis on Type A testing, the criteria to determine extended Type A test intervals have been defined differently than the surveillance acceptance criteria discussed in ANSI/ANS 56.8-1994, but is consistent with that discussed in ANSI/ANS 56.8-2002. This is to make the performance leakage rate more of an indicator of the overall condition of containment leakage integrity.

The performance criteria for Type A test allowable leakage is less than $1.0L_a$. This allowable performance leakage rate is calculated as the sum of the Type A UCL and As-left MNPLR leakage rate for all Type B and Type C pathways that were in service, isolated, or not lined up in their test position (i.e., drained and vented to containment atmosphere) prior to performing the Type A test. In addition, leakage pathways that were isolated during performance of the test because of excessive leakage must be factored into the performance determination. If the leakage can be determined by a local leakage rate test, the As-left MNPLR for that leakage path must also be added to the Type A test UCL. If the leakage cannot be determined by local leakage rate testing, the performance criteria are not met.

If an excessively leaking Appendix J barrier pathway is discovered during the Type A test, and the pathway is neither a Type B nor a Type C tested pathway, it shall still be tested to Type B or Type C test requirements after the Type A test and its As-left MNPLR added to the Type A test UCL. In this case, the Type A test performance criterion is not met unless that pathway is subsequently added to the Type B or Type C test program.

Performance criteria do not include addition of the positive differences between the As-found MNPLR and the As-left MNPLR for each pathway tested and adjusted prior to Type A testing (total leakage savings). Total leakage savings are identified through performance of Type B and Type C testing and do not contribute to performance of a Type A test. Failure of Type B and Type C test components found during performance of a Type A test should be reviewed for cause determination and corrective actions. However, if the component leakage cannot be determined by local leakage rate testing, the Type A performance criteria are not met.

9.1.2 Test Interval

Extensions in test intervals are allowed based upon two consecutive, periodic successful Type A tests and requirements stated in Sections 9.2.3 and 9.2.3.1 of this guideline. The elapsed time between the first and the last tests in a series of consecutive passing tests used to determine performance shall be at least 24 months.

9.2 Type A Test

9.2.1 Pretest Inspection and Test Methodology

Prior to initiating a Type A test, a visual examination shall be conducted of accessible interior and exterior surfaces of the containment system for structural problems which may affect either the containment structure leakage integrity or the performance of the Type A test. This inspection should be a general visual inspection of accessible interior and exterior surfaces of the primary containment and components. It is recommended that these inspections be performed in conjunction with or coordinated with the ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWE/IWL required examinations.

ANSI/ANS 56.8-[1994 or 2002 revision] testing methodology states that pathways open to the primary containment atmosphere under post-DBA conditions

shall be drained and vented to the primary containment atmosphere during a Type A test. There are four exceptions discussed in ANSI/ANS 56.8-2002 that allow penetrations to be tested under the LLRT program and the results added to the Type A leakage rate Upper Confidence Limit (UCL). One exception states that pathways in systems which are required for proper conduct of the Type A test or to maintain the plant in a safe condition during the Type A test may be operable in their normal mode. Proper outage planning should identify systems that are important to shutdown safety. A sufficient number of systems should be available so as to minimize the risk during the performance of the Type A test.

For planning and scheduling purposes, or ALARA considerations, licensees may want to consider not venting and draining additional penetrations that are capable of local leakage rate testing. It should be noted that the Type B or C tests performed on those pathways must test all of its containment barriers. This includes bonnets, packings, flanged joints, threaded connections, and compression fittings. If the Type B or C test pressurizes any of the pathway's containment barriers in the reverse direction, it must be shown that test results are not affected in a nonconservative manner by directionality. The As-found and the As-left leakage rate for all pathways that are not drained and vented must be determined by Type B and Type C testing within the previous 30 calendar months of the time that the Type A test is performed and must be added to the Type A leakage rate UCL to determine the overall L_a surveillance acceptance criteria in accordance with the definition in ANSI/ANS 56.8-1994.

9.2.2 Initial Test Intervals

A preoperational Type A test shall be conducted prior to initial reactor operation. If initial reactor operation is delayed longer than 36 months after completion of the preoperational Type A test, a second preoperational Type A test shall be performed prior to initial reactor operations.

The first periodic Type A test shall be performed within 48 months after the successful completion of the last preoperational Type A test. Periodic Type A tests shall be performed at a frequency of at least once per 48 months, until acceptable performance is established in accordance with Section 9.2.3. The interval for testing should begin at initial reactor operation. Each test interval begins upon completion of a Type A test and ends at the start of the next test.

If the test interval ends while primary containment integrity is either not required or it is required solely for shutdown activities, the test interval may be extended indefinitely. However, a successful Type A test shall be completed prior to entering the operating mode requiring primary containment integrity.

9.2.3 Extended Test Intervals

Type A testing shall be performed during a period of reactor shutdown at a frequency of at least once per 20 years based on acceptable performance history. Acceptable performance history is defined as successful completion of two consecutive periodic Type A tests where the calculated performance leakage rate was less than 1.0 L_a. A preoperational Type A test may be used as one of the two Type A tests that must be successfully completed to extend the test interval, provided that an engineering analysis is performed to document why a preoperational Type A test can be treated as a periodic test. Elapsed time between the first and last tests in a series of consecutive satisfactory tests used to determine performance shall be at least 24 months.

For purposes of determining an extended test interval, the performance leakage rate is determined by summing the UCL (determined by containment leakage rate testing methodology described in ANSI/ANS 56.8-[1994 or 2002 revision]) with As-left MNPLR leakage rates for penetrations in service, isolated or not lined up in their accident position (i.e., drained and vented to containment atmosphere) prior to a Type A test. In addition, any leakage pathways that were isolated during performance of the test because of excessive leakage must be factored into the performance determination. If the leakage can be determined by a local leakage rate test, the As-left MNPLR for that leakage path must also be added to the Type A test UCL. If the leakage cannot be determined by local leakage rate testing, the performance criteria for the Type A test are not met.

If an excessively leaking Appendix J barrier pathway is discovered during the Type A test, and the pathway is neither a Type B nor a Type C tested pathway, it shall still be tested to Type B or Type C test requirements after the Type A test and its As-left MNPLR added to the Type A test UCL. In this case, the Type A test performance criterion is not met unless that pathway is subsequently added to the Type B or Type C test program.

In reviewing past performance history, Type A test results may have been calculated and reported using computational techniques other than the Mass Point method from ANSI/ANS 56.8-[1994 or 2002 revision] (e.g., Total Time or Point-to-Point). Reported test results from these previously acceptable Type A tests can be used to establish the performance history. Additionally, a licensee may recalculate past Type A test UCL (using the same test intervals as reported) in accordance with ANSI/ANS 56.8-[1994 or 2002 revision] Mass Point methodology and its adjoining Termination criteria in order to determine acceptable performance history. In the

event where previous Type A tests were performed at reduced pressure, at least one of the two consecutive periodic Type A tests shall be performed at peak accident pressure (P_a).

9.2.3.1 Requirements for ILRT Interval Extensions Beyond Ten Years

Type A ILRT intervals of up to twenty years are allowed by this guideline as endorsed by Regulatory Guide 1.163, Revision 1. Although the historical containment leak-tight performance has been very good, a few instances of degradation have occurred and have been detected by supplemental means other than Type A ILRTs. These means include ASME Boiler and Pressure Vessel Code Section XI, Subsection IWE/IWL examinations, Maintenance Rule inspections and low pressure monitoring. To provide continuing supplemental means of identifying potential containment degradation, the following should be performed:

- A general visual examination of accessible interior and exterior surfaces of the containment for structural problems should be performed at each 1/3 of a ten-year inspection interval. This examination may be performed in conjunction with or coordinated with the general visual examination of ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWE and IWL.

- Qualitative low pressure containment monitoring and trending should be performed to provide a gross indication of the potential existence of excessive containment to atmosphere leak path(s). Low pressure monitoring variables may include gas makeup rates for inerted containments and containment venting frequencies for containments with internal compressed air bleeds performed to maintain containment positive pressure within acceptable limits. It is recognized that containment pressure is affected by atmospheric pressure, internal temperature, heating, etc., and this monitoring is not intended to require licensees to attempt to calculate containment mass and/or mass leakage. Rather, establishing historical trends and comparing existing trends of gas makeup or venting frequency over a long period (several months) will provide a gross indication of containment to atmosphere leak-tightness. It is intended that this monitoring utilize existing equipment. The plant owner should establish criteria for monitoring and examination of trend results.

9.2.4 Containment Repairs and Modifications

Repairs and modifications that affect the containment leakage integrity require leakage rate testing (Type A testing or local leakage rate testing) prior to returning the containment to operation.

Leakage tests for the following minor repairs or modifications may be deferred until the next scheduled leakage test or scheduled refueling outage (whichever comes first) provided nondestructive examination of the repairs or modifications is performed in accordance with the approved repair program.

- Welds of attachments to the surface of steel pressure-retaining boundary;
- Repair cavities, the depth of which does not penetrate required design steel wall by more than 10%, or
- Welds attaching to steel pressure-retaining boundary penetrations where the nominal diameter of the welds or penetrations do not exceed one inch.

9.2.5 Surveillance Acceptance Criteria

The As-found Type A test leakage rate must be less than the acceptance criterion of 1.0 L_a given in the plant Technical Specifications. Prior to entering a mode where containment integrity is required, the As-left Type A leakage rate shall not exceed 0.75 L_a. The As-left and As-found values are as determined by the appropriate testing methodology specifically described in ANSI/ANS 56.8-1994.

9.2.6 Corrective Action

If the Type A performance leak rate is not acceptable, the performance criteria is not met, and a determination should be performed to identify the cause of unacceptable performance and determine appropriate corrective actions. Once completed, acceptable performance should be reestablished by demonstrating an acceptable performance leak rate before resuming operation and by performing another successful Type A test within 48 months following the unsuccessful Type A test. Following these successful Type A tests, the surveillance frequency may be returned to at least once per 20 years.

Performance criteria do not include addition of the positive differences between the As-found MNPLR and the As-left MNPLR for each pathway tested and adjusted prior to Type A testing (total leakage savings). Total leakage savings are identified through performance of Type B and Type C testing and do not contribute to performance of a Type A test. As discussed in Section 9.2.3, leakage paths detected during a Type A test that are caused by failures of Type B and Type C test components are not required to be included in determination of adequate performance and Type A test intervals. However, if the component leakage cannot be determined by local leakage rate testing, the Type A performance criteria are not met. Corrective actions for Type B and Type C failures should be taken in accordance with Sections 10.2.1.4, 10.2.2.3, or 10.2.3.4 of this guideline.

If the As-found Type A results (for operability considerations as defined in Section 8.0) are not acceptable, a determination should be performed to identify the cause of unacceptable performance and determine appropriate corrective actions.

10.0 DETERMINING PERFORMANCE-BASED TEST FREQUENCIES FOR TYPE B AND TYPE C TESTS

10.1 Introduction

This section discusses the method to determine extended test intervals for Type B and Type C tests based on performance. It presents a range of acceptable intervals based upon industry data which have been analyzed through a process similar to that used by NRC in NUREG-1493, and have been reviewed for safety significance. Individual licensees may adopt a testing interval and approach as discussed in this guideline provided that certain performance factors and programmatic controls are reviewed and applied as appropriate. Programmatic controls may be necessary to ensure that assumptions utilized in analysis of the industry data are reasonably preserved at individual facilities.

The range of recommended frequencies for Type B and Type C tests are discussed in Section 11.0. The proposed frequencies are in part based upon industry performance data that was compiled to support the development of Option B to Appendix J, and a review of their safety significance. A licensee should develop bases for new frequencies based upon satisfactory performance of leakage tests that meet the requirements of Appendix J. Additional considerations used to determine appropriate frequencies may include service life, environment, past performance,

design, and safety impact. Additional technical information concerning the data may be found in NUREG-1493.

Consistent with standard scheduling practices for Technical Specifications Required Surveillances, intervals for the recommended surveillance frequency for Type B and Type C testing given in this section may be extended by up to 25 percent of the test interval, not to exceed 15 months for scheduling purposes only.

10.2 Type B and Type C Testing Frequencies

The testing interval for each component begins after its Type B or Type C test is completed and ends at the beginning of the next test. If the testing interval ends while primary containment integrity is not required or is required solely for cold shutdown or refueling activities, testing may be deferred; however, the test must be completed prior to the plant entering a mode requiring primary containment integrity.

Leakage rates less than the administrative leakage rate limits are considered acceptable. Administrative limits for leakage rates shall be established and documented for each Type B and Type C component prior to the performance of local leakage rate testing. The administrative limits assigned to each component should be specified such that they are an indicator of potential valve or penetration degradation. Administrative limits for airlocks may be equivalent to the surveillance acceptance criteria given for airlocks in Technical Specifications.

Administrative limits are specific to individual penetrations or valves, and are not the surveillance acceptance criteria for Type B and Type C tests. Due to the performance-based nature of Option B to Appendix J and this guideline, it is recommended that acceptance criteria for the combined leakage rate for all penetrations subject to Type B or Type C testing be defined as follows:

- The combined As-left leakage rates determined on a MXPLR basis for all penetrations shall be verified to be less than $0.60L_a$ prior to entering a mode where containment integrity is required following an outage or shutdown that included Type B and Type C testing. These combined leakage rate determinations shall be done with the latest leakage rate test data available, and shall be kept as a running summation of the leakage rates.

- The As-found leakage rates, determined on a MNPLR basis, for all newly tested penetrations when summed with the As-left MNPLR leakage rates for all other penetrations shall be less than $0.60L_a$ at all times when containment integrity is required.

The surveillance acceptance criteria for airlocks are as specified in Technical Specifications, and administrative limits do not apply. In addition, there is other leakage rate testing specified in the Technical Specifications that contain Surveillance Acceptance Criteria and Surveillance Frequencies, for example, vent and purge valves; and BWR main steam isolation and feedwater isolation valves. This guideline does not address the performance-based frequency determination of those surveillances.

If the surveillance frequency has not been extended for specific Type B and Type C components, As-found testing is not required unless:

- The result is to be used to determine adequate performance for purposes of extending the surveillance frequency, or
- The result is to be used for the As-found Type A test, or
- Work is to be performed that can affect the leak rate of a component whose leakage integrity is suspect.

Administrative limits are not required to be established for these components.

10.2.1 Type B Test Intervals

10.2.1.1 Initial Test Intervals (Except Containment Airlocks)

Type B tests shall be performed prior to initial reactor operation. Subsequent periodic Type B tests shall be performed at a frequency of at least once per 30 months, until acceptable performance is established per Section 10.2.1.2.

10.2.1.2 Extended Test Intervals (Except Containment Airlocks)

The test intervals for Type B penetrations may be increased based upon completion of two consecutive periodic As-found Type B tests where results of each test are within a licensee's allowable administrative limits. Elapsed time between the first and last tests in a series of consecutive satisfactory tests used to determine performance shall be 24 months or the nominal test interval (e.g., refueling cycle) for the component prior to implementing Option B to Appendix J. An extended test interval for Type B tests may be increased to a specific value in a range of frequencies from greater than once per 30 months up to a maximum of once per 120

months. The specific test interval for Type B penetrations should be determined by a licensee in accordance with Section 11.0.

10.2.1.3 Repairs or Adjustments (Except Containment Airlocks)

In addition to the periodic As-found Type B test, an As-found Type B test shall be performed prior to any maintenance, repair, modification, or adjustment activity if the activity could affect the penetration's leak tightness. An As-left Type B test shall be performed following maintenance, repair, modification or adjustment activity. In addition, if a primary containment penetration is opened following As-found testing, a Type B test shall be performed prior to the time primary containment integrity is required. If the As-found and As-left Type B test results are both less than a component's allowable Administrative Limit, a change in test frequency is not required. If As-found or As-left test results are greater than the allowable administrative limit, provisions of Section 10.2.1.4 apply.

Frequency for a Type B testing shall be in accordance with Section 10.2.1.1 if the penetration is replaced or engineering judgment determines that modification of the penetration has invalidated the performance history. Testing shall continue at this frequency until adequate performance is established in accordance with Section 10.2.1.2.

10.2.1.4 Corrective Action

If Type B test results are not acceptable, then the testing frequency should be set at the initial test interval per Section 10.2.1.1. In addition, a cause determination should be performed and corrective actions identified that focus on those activities that can eliminate the identified cause of failure[1] with appropriate steps to eliminate recurrence. Cause determination and corrective action should reinforce achieving acceptable performance. Once the cause determination and corrective actions have been completed, acceptable performance may be reestablished and the testing frequency returned to the extended interval in accordance with Section 10.2.1.2.

Failures of Type B penetrations discovered during performance of a Type A test should be considered as failures of a Type B test for purposes of cause determination and corrective action. This includes failures of penetrations that were not previously identified by a Type B testing program.

[1] A failure in this context is exceeding an administrative limit and not the total failure of the penetration. Administrative limits are established at a value low enough to identify and allow early correction of potential total penetration failures.

10.2.2 Containment Airlocks

10.2.2.1 Test Interval

Containment airlock(s) shall be tested at an internal pressure of not less than P_a prior to a preoperational Type A test. Subsequent periodic tests shall be performed at a frequency of at least once per 30 months. Containment airlock tests should be performed in accordance with ANSI/ANS 56.8-[1994 or 2002 revision]. In addition, equalizing valves, door seals, and penetrations with resilient seals (i.e., shaft seals, electrical penetrations, view port seals and other similar penetrations) which are testable, shall be tested at a frequency of once per 30 months.

Airlock door seals should be tested prior to a preoperational Type A test. When containment integrity is required, airlock door seals should be tested within 7 days after each containment access.

For periods of multiple containment entries where the airlock doors are routinely used for access more frequently than once every 7 days (e.g., shift or daily inspection tours of the containment), door seals may be tested once per 7 days during this time period.

Door seals are not required to be tested when containment integrity is not required, however they must be tested prior to reestablishing containment integrity. Door seals shall be tested at P_a, or at a pressure stated in the plant Technical Specifications.

10.2.2.2 Repairs or Adjustments of Airlocks

Following maintenance on an airlock pressure retaining boundary, one of the following tests shall be completed:

- Airlock shall be tested at a pressure of not less than P_a; or
- Leakage rate testing at P_a shall be performed on the affected area or component.

10.2.2.3 Corrective Action

If containment airlock Type B test results are not acceptable, then a cause determination should be performed and corrective actions identified that focus on those activities that can eliminate the identified cause of a failure[2] with appropriate steps to eliminate recurrence. Cause determination and corrective action should reinforce achieving acceptable performance.

10.2.3 Type C Test Interval

10.2.3.1 Initial Test Interval

Type C tests shall be performed prior to initial reactor operation. Subsequent periodic Type C tests shall be performed at a frequency of at least once per 30 months, until adequate performance has been established consistent with Section 10.2.3.2.

10.2.3.2 Extended Test Interval

Test intervals for Type C valves may be increased based upon completion of two consecutive periodic As-found Type C tests where the result of each test is within a licensee's allowable administrative limits. Elapsed time between the first and last tests in a series of consecutive passing tests used to determine performance shall be 24 months or the nominal test interval (e.g., refueling cycle) for the valve prior to implementing Option B to Appendix J. Intervals for Type C testing may be increased to a specific value in a range of frequencies from 30 months up to a maximum of 60 months. Test intervals for Type C valves should be determined by a licensee in accordance with Section 11.0.

[2] A failure in this context is exceeding performance criteria for the airlock, not a total failure.

10.2.3.3 Repairs or Adjustments

In addition to the periodic As-found Type C test, an As-found Type C test shall be performed prior to any maintenance, repair, modification, or adjustment activity if it could affect a valve's leak tightness. An As-left Type C test shall be performed following maintenance, repair, modification or adjustment activity to demonstrate the valve's leak tightness and functionality.

If As-found and As-left Type C test results are both less than a valve's allowable administrative limit, a change of the test frequency is not required. If As-found or As-left test results are greater than the allowable administrative limit, then provisions of Section 10.2.3.4 apply.

The frequency for Type C testing shall be in accordance with Section 10.2.3.1 if a valve is replaced or engineering judgment determines that modification of a valve has invalidated the valve's performance history. Testing shall continue at this frequency until an adequate performance history is established in accordance with Section 10.2.3.2.

10.2.3.4 Corrective Action

If Type C test results are not acceptable, then the testing frequency should be set at the initial test interval per Section 10.2.3.1. In addition, a cause determination should be performed and corrective actions identified that focus on those activities that can eliminate the identified cause of a failure[3] with appropriate steps to eliminate recurrence. Cause determination and corrective action should reinforce achieving acceptable performance. Once the cause determination and corrective actions have been completed, acceptable performance may be reestablished and the testing frequency returned to the extended interval in accordance with Section 10.2.3.2.

Failures of Type C valves that are discovered during performance of a Type A test should be considered as a failure of a Type C test for purposes of cause determination and corrective action. This includes failures of valves that were not previously identified by a Type C test.

[3] A failure in this context is exceeding an administrative limit and not the total failure of the valve. Administrative limits are established at a value low enough to identify and allow early correction of total valve failures.

11.0 BASES FOR PERFORMANCE AND RISK-BASED TESTING FREQUENCIES FOR TYPE A, TYPE B, AND TYPE C TESTS

11.1 Introduction

This section provides guidance on establishing leakage testing frequencies and provides information regarding the risk impact of extending leakage rate testing intervals. Extended test intervals in Sections 9.0 and 10.0 have been selected based on performance, and have been assessed for risk impact. The various factors and discussion in this section should be considered when establishing different plant-specific testing frequencies.

Section 9.0 Provides guidance on extending Type A ILRT surveillance intervals.

Section 10.0 presents a range of acceptable extended test intervals for Type B and Type C tests. Individual licensees may adopt specific testing intervals of up to 60 months or three refueling cycles as discussed in Section 10.0 without additional detailed analysis provided the performance factors discussed in Section 11.3.1 are considered. For Type B tests, additional programmatic controls are discussed in Section 11.3.2 and should be considered when the extended test intervals are greater than 60 months or three refueling cycles.

11.2 Discussion

Assessments of the risk impact of extending leakage rate testing have been performed at two different times to support similar objectives. The more recent risk impact assessment, completed in 2003 supported optimized ILRT interval extensions of up to twenty years. The previous assessments, completed in 1994-1995 supported Type A ILRT extensions of up to ten years, as well as extensions of Type B and Type C testing intervals.

The objective of the work concluded in 2003 and published as EPRI Product No. 1009325, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals" was to perform a generic risk impact assessment for optimized ILRT intervals of up to twenty years, utilizing current industry performance data and risk-informed guidance, primarily NRC Regulatory Guide 1.174. The following paragraphs discuss the approach taken and results of this assessment.

Approach

An initial step in the assessment was to obtain current containment leak rate testing and performance information. This was obtained through an NEI industry-wide survey conducted in 2001. A database was generated using this information supplemented with industry failure reports and previous survey information. The data indicated that there were no failures that could result in a risk-significant large early release. This information, in itself was deemed insufficient for determination of risk-significant large failure magnitude and frequency. Therefore, an expert panel was convened to elicit this information, based on the available data. The expert panel also considered defense-in-depth approaches such as alternative inspections that supplement the testing programs.

Having this elicited information on large failure magnitude and frequency, the risk impact was determined for two "representative" plants, a PWR and BWR, with accident classes developed similar to the original report, but with enhancements for assessing changes in large early release frequency (LERF). Core damage frequency (CDF) directly impacts LERF. The representative plants were hypothetical and the PWR plant was assigned a CDF equal to the NRC subsidiary objective (NRC safety goal policy statement) of 1E-4 per year and is assumed inclusive of external events and other hazards.

Results

The assessment demonstrates that, from a generic perspective, there is very little risk associated with extension of Type A ILRT intervals up to twenty years. Specifically, the change in population dose is extremely small, less that 0.02% of the total dose. The change in LERF is less than 10^{-7}, the Reg. Guide 1.174 acceptance guidelines for "very small changes". This confirms previous (NUREG-1493) conclusions regarding risk in extending ILRT intervals up to twenty years, using current regulatory guidance and risk-informed concepts.

Similar approaches were taken in 1994-1995, although the guidance of Regulatory Guide 1.174 was not available at that time. The following paragraphs discuss these approaches.

The effect of extending containment leakage rate testing intervals is a corresponding increase in the time that an excessive leak path would exist undiscovered and uncorrected. The degree to which intervals can be extended is a direct function of the potential effects on the health and safety of the public that occur due to an increased likelihood of undiscovered containment leakage.

In order to determine the acceptability of extended testing intervals, the methodology described in NUREG-1493 was applied, with some modifications, to historical representative industry leakage rate testing data gathered from approximately 1987 to 1993, under the auspices of NEI. The range of testing intervals recommended for Type B and Type C testing was evaluated to determine the level of increased risk in the event of an accident. The same methodology was also applied to the 10-year interval for Type A testing. In all cases, the increased risk corresponding to the extended test interval was found to be small and compares well to the guidance of the NRC's safety goals.

NUREG-1493 provided the technical basis to support rulemaking to revise leakage rate testing requirements contained in Option B to Appendix J. The basis consisted of qualitative and quantitative assessments of the risk impact (in terms of increased public dose) associated with a range of extended leakage rate testing intervals.

NUREG-1493 found the effect of Type B and Type C testing on overall accident risk is small and concluded that:

- Performance-based alternatives to local leakage rate testing requirements are feasible without significant risk impacts; and

- Although extended testing intervals led to minor increases in potential off-site dose consequences, the actual decrease in on-site (worker) doses exceeded (by at least an order of magnitude) the potential off-site dose increases.

NEI, in conjunction with EPRI, undertook a similar study in order to supplement NRC's rulemaking basis and provide added assurance the more detailed elements in this guideline have an adequate basis. Results of the EPRI study are documented in EPRI Research Project Report TR-104285, "Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals."

EPRI developed an abbreviated methodology that was used to assess plant risk impact associated with containment leakage rate testing alternatives currently being proposed by this guideline. The overall approach involved an examination of the risk spectra from accidents reported in PWR and BWR IPEs. Plant risk was quantified for a PWR and BWR representative plant. Quantification of the risk considered the consequences from containment leakage in more detail than reported in IPEs. The impact associated with alternative Type B and Type C test intervals, measured as a change in risk contribution to baseline risk, is presented in Table 1. The risk values compare well with the analysis in NUREG-1493.

The risk model was specifically quantified by using a "failure to seal" probability (as opposed to failure to close considered in IPEs). This required failure rates to be developed for this failure mode. Type B and Type C test data obtained by NEI allowed determination of failure rates where failure is defined as the measured leakage exceeding allowable administrative limits for a specific Type B or Type C component. The failure rate values were used in the containment isolation system fault tree, and used to calculate a failure-to-seal probability. Characterization of baseline risk (in terms of accident sequences that are influenced by containment isolation valve or containment penetration leakage rate) allowed the plant models to calculate the risk impact associated with changes in test intervals.

As indicated above, historical industry failure rate data was used to develop the component failure to seal probabilities used in the analysis. This approach is quite conservative because these guidelines require demonstration of performance prior to extending the component leakage rate testing interval. The performance demonstration consists of successful completion of two consecutive leakage rate tests to increase the interval from 30 to 60 months or three refueling cycles. It should be noted that NUREG-1493, Appendix A, suggests that "If the component does not fail within two operating cycles, further failures appear to be governed by the random failure rate of the component," and "Any test scheme considered should require a failed component pass at least two consecutive tests before allowing an extended test interval." In addition, the penetration failure analysis considered components which exceeded the administrative limits as failures. The containment leakage rate computation conservatively used maximum pathway leak rates derived from the upper bounds of the NEI data. Therefore, the analysis is very conservative, and the component performance trending provides the necessary confidence demonstration that component leakage is being managed at a low level.

For Type C test, a bounding analysis was performed that assumed all valves have test intervals that were extended to 48, 60, 72 and 120 months. For Type B tests, it was assumed that electrical penetrations were tested at a nominal 120 months frequency. In addition, it was assumed that some portion of the penetrations was tested periodically during the 120 months. Airlock tests were assumed to be conducted every 24 months. Blind flanges were assumed to be tested after each opening, or at 48-month intervals.

There are many points of similarity between the NUREG-1493 report and the EPRI study, both in methodology and assumptions, reflecting close agreement on elements important to safety for containment leakage rate testing. The similarity also extends to the results. The EPRI study confirms the low risk significance associated with Type A testing intervals of 10 years. Similarly, extending the Type B and Type C test intervals to 120 months was found acceptable provided the Type B or Type C components have successfully passed two consecutive tests, and provided that certain controls were imposed on the leakage rate testing program.

Changing Appendix J test intervals from those presently allowed to those in this guideline slightly increases the risk associated with Type B and Type C-specific accident sequences as discussed in Table 1. The data suggests that increasing the Type C test interval can slightly increase the associated risk, but this ignores the risk reduction benefits associated with increased test intervals. In addition, when considering the total integrated risk (representing all accident sequences analyzed in the IPE), the risk impact associated with increasing test intervals is negligible (less than 0.1 percent of total risk). This finding is further reinforced by the conservative assumptions used in the analysis. The EPRI study reaffirms the conclusion in NUREG-1493 that changes to leakage testing frequencies are "feasible without significant risk impact."

11.3 Plant-Specific Testing Program Factors

A licensee may adopt specific surveillance frequencies from Section 10.0 provided that plant-specific test performance history is acceptable as discussed in Section 10.0, and certain performance factors and controls are reviewed and applied as appropriate in the determination of test intervals. Each licensee should demonstrate by quantitative or qualitative review that plant-specific performance is adequate to support the extended test interval.

Except for Type A extended frequencies beyond eighteen years, an extension of up to 25 percent of the test interval (not to exceed 15 months) may be allowed on a limited basis for scheduling purposes only. For Type A extended frequencies beyond eighteen years, an extension of up to three months may be allowed on a limited basis for scheduling purposes only.

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Table 1

Risk Results for Type B, and Type C Test Intervals

Test Type	*Risk-Impact Current Test Intervals*	*Risk-Impact Extended Test Intervals*	*Comment*
		PWR Representative Plant Summary	
Type B	«0.001% incremental risk contribution 6.9E-05 person-rem/yr rebaselined risk	<0.001% incremental risk contribution, 1.3E-04 person-rem/yr rebaselined risk. Based on testing with some components tested periodically during time interval months. In addition, blind flanges and penetrations would be removed and retested during every refueling outage. Airlocks to be tested every 24 months.	A range of 0.2 to 4.4 percent is provided for other plants for both Type B and Type C penetrations in NUREG-1493.
Type C	0.022% of total risk 4.9E-03 person-rem/yr	0.04% incremental risk contribution, 8.8E-03 person-rem/yr rebaselined risk, based on 48 month test intervals. 1E-2, 1.2E-2, and 1.64E-2 person-rem/yr risk, based on 60, 72, and 120 month test intervals	A range of 0.2 to 4.4 percent of total risk is provided for other plants for both Type B and Type C penetrations in NUREG-1493.

		BWR Representative Plant Summary	
Type B	<0.001% of total risk 8.0E-06 person-rem/yr	0.001%, 1.85E-05 person-rem/yr Based on testing with some components tested periodically during time interval months. In addition, blind flanges and penetrations would be removed and retested during every refueling outage. Airlocks to be tested every 24 months.	A range of 0.2 to 4.4 percent is provided for other plants for both B and C penetration types in NUREG-1493.
Type C	0.002% of total risk 4.5E-06 person-rem/yr	0.006% of total risk, 1.1E-04 person-rem/yr, based on 48 months test intervals. 1.8E-4, 2.3E-4, and 5.01E-4 person-rem/yr risk, based on 60, 72, and 120 month test intervals.	A range of 0.2 to 4.4 percent is provided for other plants for both B and C penetration types in NUREG-1493.

11.3.1 Performance Factors

Prior to determining and implementing extended test intervals for Type B and Type C components, an assessment of the plant's containment penetration and valve performance should be performed and documented. The following are some factors that have been identified as important and should be considered in establishing testing intervals:

- *Past Component Performance* — Based on a survey sample of industry data from approximately 1987 to 1993, 97.5% of the industry's containment penetrations have not failed a Type B test, and 90% of the isolation valves have never failed a Type C test in over 500 reactor–years of commercial operation. Of the 10% of the Type C tests that have failed, only 22% of those have failed more than once. A licensee should ensure that leakage rate testing intervals are not extended until plant-specific component performance of two successful consecutive As-found tests is performed.

- *Service* — The environment and use of components are important in determining its likelihood of failure. For example, a plant may have experienced high leakage in valves in a high–flow steam environment due to effects of valve seat erosion. Certain valves that open and close frequently during normal plant operations may have experienced higher leakage. The licensee's existing testing program should identify these types of components to establish their testing intervals based on their performance history.

- *Design* — Valve type and penetration design may contribute to leakage. For example, motor operated valves in a plant may be found to leak less frequently than check valves, and may support a longer test interval. Vendor recommendations for valve or penetration subcomponent service life may be a factor in determining test intervals. Certain passive penetrations, such as electrical penetrations, may have had excellent performance history. Test intervals for these penetrations may be relatively longer.

- *Safety Impact* — The relative importance of penetrations can be judged in terms of the potential impact of failure in limiting releases from containment under accident conditions. Due to size or system inter–connections, some components or penetrations may be more important than others in ensuring the safety function of a containment penetration is achieved. This relative importance should be considered in determining the test interval.

- *Cause Determination* — For failures identified during an extended test interval, a cause determination should be conducted and appropriate corrective actions identified. Part of a corrective action process should be to identify and address common–mode failure mechanisms.

11.3.2 Programmatic Controls

If a licensee considers extended test intervals of greater than 60 months or three refueling cycles for a Type B tested component, the review to establish surveillance test intervals should include the additional considerations:

- *As-found Tests* — In order to provide additional assurance that the increased probability of component leakage is kept to a minimum, and is reasonably within the envelope of industry data, a licensee should consider requiring three successive periodic As-found tests to determine adequate performance.

- *Schedule* — To minimize any adverse effects of unanticipated random failures, and to increase the likelihood unexpected common-mode failure mechanisms will be identified in a timely manner, a licensee should implement a testing program that ensures components are tested at approximate evenly-distributed intervals across the extended testing interval. A licensee should schedule a portion of the tests during each regularly scheduled outage or on some regular periodic basis, such that some percentage of the components are tested periodically, and all components are tested at the new extended test interval of greater than 60 months or three refueling cycles.

- *Review* — A review of the entire process should be performed prior to establishing alternate test intervals under Option B to 10 CFR 50, including plant-specific performance history, data analysis, establishment of surveillance frequencies, and, if available and applicable, any risk-impact assessment. This review should include adjustments to the program as required, based on expert insight or engineering judgment. Results of the review should be documented.

12.0 RECORDKEEPING

12.1 Report Requirements

A post-outage report shall be prepared presenting results of the previous cycle's Type B and Type C tests, and Type A, Type B, and Type C tests, if performed during that outage. The technical contents of the report are generally described in ANSI/ANS 56.8-[1994 or 2002 revision], and will be available on-site for NRC review. The report shall also show that the applicable performance criteria are met, provide for comparison of Type A test results with previous results, and serve as a record that continuing performance is acceptable.

12.2 Records

Documentation developed for implementation of Option B to Appendix J should be done in accordance with licensee established procedures. Sufficient documentation shall be collected and retained so that the effectiveness of the implementation of Option B to Appendix J can be reviewed and determined. This documentation shall be available for internal and external review, but is not required to be submitted to the NRC.

EPRI

Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals

Technical Report

Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals

1009325

Final Report, December 2003

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REPORT SUMMARY

This report consists of a risk impact assessment for extending integrated leak rate test (ILRT) surveillance intervals from the present 10 years to up to 20 years. The assessment demonstrates on an industry-wide generic basis that there is very small risk associated with the extension, provided that the performance bases and defense-in-depth are maintained. There is an obvious benefit to the nuclear power industry in not performing costly, critical-path, time-consuming tests that provide a limited benefit from a risk perspective.

Background

In 1995, the Nuclear Regulatory Commission (NRC) amended its regulation to provide an Option B to 10CFR50, Appendix J. Option B is a performance-based approach to leakage testing requirements in Appendix J and allows licensees with good test performance history to extend surveillance intervals. At that time, provisions were made for extending ILRT intervals from three in 10 years to one in 10 years, although the NRC's assessment (NUREG-1493) stated that there was an imperceptible increase in risk associated with ILRT intervals up to 20 years. In about 2001, many licensees began to submit requests for one-time ILRT interval extensions, and it was deemed appropriate and resource-effective to perform the risk assessments on a generic basis to support changes to the industry (Nuclear Energy Institute, NEI) and regulatory (NRC) guidance for ILRT surveillance intervals.

Objectives

The objective of this project was to perform a generic risk impact assessment for optimized ILRT intervals of up to 20 years, utilizing current industry performance data and risk-informed guidance, primarily NRC Regulatory Guide 1.174. This risk impact assessment complements the previous EPRI report, TR-104285, *Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals.* The earlier report considered changes to local leak rate testing intervals as well as changes to ILRT testing intervals. The original risk impact assessment considers the change in risk based on population dose, whereas the revision considers dose as well as large early release frequency (LERF) and containment conditional failure probability (CCFP). This report deals with only changes to ILRT testing intervals and is intended to provide bases for supporting changes to industry (NEI) and regulatory (NRC) guidance on ILRT surveillance intervals.

Approach

The first step was to obtain current containment leak rate testing performance information. This was obtained through an NEI industry-wide survey conducted in 2001. A database was generated using this information supplemented with industry failure reports and previous survey information. The data indicate that there were no failures that could result in a risk-significant large early release. This information in itself was deemed insufficient for determination of

risk-significant large failure magnitude and frequency. Therefore, an expert panel was convened to elicit this information, based on the available data.

The expert panel also considered defense-in-depth approaches such as alternative inspections that supplement the testing programs.

Having this information, the risk impact was determined for two "representative" plants, a PWR and BWR, with accident classes developed similar to the original report but with enhancements for assessing changes in LERF. The representative plants were hypothetical but were assigned high values for core damage frequency (CDF) that directly impacts LERF.

Results

The assessment demonstrates that from a generic, maximum perspective, there is very little risk associated with extension of ILRT intervals up to twenty years. Specifically, the change in population dose is extremely small, less than 0.02% of the total dose. The change in LERF is less than 10^{-7}, which is the NRC Regulatory Guide 1.174 acceptance guidelines for "very small changes." This confirms previous conclusions regarding risk in extending ILRT intervals up to 20 years, using current regulatory guidance and risk-informed concepts.

EPRI Perspective

This report demonstrates that, generically, there is very small risk increase associated with the extension of ILRT intervals of up to 20 years. However, it is also necessary from a risk-informed perspective to maintain an awareness of and attention to defense-in-depth concepts. With respect to ILRT interval extension of up to 20 years, other supplemental means of verifying containment integrity such as containment inspections, monitoring, and maintenance of thorough local leak rate testing programs are considered necessary, as is maintenance of the ILRT performance basis.

Appropriate application of the report results should benefit the industry by reducing testing that has limited value from a risk perspective, especially with its attendant impact on resource and exposure. Expert elicitation was utilized to develop information not available from the data. The methodology for the expert elicitation process is contained in this report as well.

Keywords

Containment
Integrated leak rate testing (ILRT)
Risk-informed
Large early release frequency (LERF)
Expert elicitation
Risk impact assessment

CONTENTS

1 INTRODUCTION 1-1

2 PROBLEM STATEMENT 2-1

2.1 Background 2-1

2.2 Framework 2-2

2.3 Expert Elicitation Input 2-4

3 ILRT DATA APPLICABILITY 3-1

3.1 NUMARC Survey Data 3-1

3.2 NEI Survey Data (2001) 3-2

3.3 Combined Survey Data 3-2

3.4 ILRT Failure Rate Determination 3-2

3.5 No Alternate Means of Detection 3-4

3.6 Estimation of Containment Leakage 3-4

4 EXPERT ELICITATION PROCESS 4-1

4.1 Introduction to the Elicitation Process 4-1

4.2 Expert Elicitation Summary 4-1

4.3 Requirement 1: Identification of the Expert Judgment Process 4-2

4.3.1 Defining the Specific Issue 4-2

4.3.2 Determining the Degree of Importance and Level of Complexity 4-3

4.3.2.1 Determining the Degree of Importance 4-3

4.3.2.2 Determining the Level of Complexity 4-3

4.4 Requirement 2: Identification and Selection of Experts 4-5

4.5 Requirement 3: Determination of the Need for Outside Expert Judgment 4-5

4.6 Requirement 4: Utilize the TI or TFI Process 4-6

4.6.1 Identifying Available Information and Analysis and Information-Retrieval Methods 4-6

4.6.2 Accumulating Information Relevant to the Issue, Performing the Analysis, and Developing the Community Distribution 4-6
4.6.3 Performing the Peer Review 4-7
4.7 Requirement 5: Responsibility for the Expert Judgment 4-7

5 EXPERT ELICITATION INPUT 5-1
5.1 Stage 1: Expert Elicitation Preparation 5-1
5.2 Stage 2: Expert Elicitation Meeting 5-2
5.3.1 Expert Elicitation Meeting: Day 1 – Morning Session 5-3
5.3.2 Expert Elicitation Meeting: Day 1 – Afternoon Session 5-4
5.3.3 Expert Elicitation Meeting: Day 2 – Morning Session 5-4
5.3.4 Expert Elicitation Meeting: Day 2 – Afternoon Session 5-5
5.3.5 Expert Elicitation Meeting: Day 3 – Morning Session 5-5
5.4 Steering Committee Review 5-5
5.5 Expert Elicitation Input Form 5-6
5.5.1 Summary of Expert Elicitation Input Table Description 5-6
5.5.2 Summary of Expert Elicitation Input Table Rows 5-8

6 EXPERT ELICITATION RESULTS AND ANALYSIS 6-1
6.1 Expert Elicitation Input Changes 6-1
6.2 Expert Elicitation Input 6-2
6.3 Statistical Analysis of the Expert Elicitation Input 6-3
6.3.1 Statistical Analysis – Introduction 6-3
6.3.2 Statistical Analysis – Input Information 6-5
6.3.3 Statistical Analysis – Generalized Least Squares Method 6-7
6.3.4 Statistical Analysis – Uncertainty Bounds 6-8
6.3.5 Statistical Analysis – Combining Expert Opinion 6-9
6.3.6 Statistical Analysis – Final Results 6-10

7 TECHNICAL APPROACH 7-1
7.1 Step One: Baseline Risk Determination 7-4
7.2 Step Two: Determination of Containment Leakage Rates 7-4
7.3 Step Three: Develop the Baseline Population Dose 7-5
7.4 Step Four: Determine Baseline Dose Rate 7-5
7.5 Step Five: Determine Change in Pre-Existing Leak Probability 7-5
7.6 Step Six: Determine Revised Population Dose Rate 7-5

7.7 Step Seven: Determine Percentage Increase In Population Dose 7-5
7.8 Step Eight: Evaluate Change In LERF 7-5
7.9 Step Nine: Evaluate Conditional Containment Failure Probability (CCFP) 7-6
7.10 EPRI Accident Class Descriptions 7-6

8 APPLICATION OF TECHNICAL APPROACH 8-1
8.1 Hypothetical Plant Application – PWR Large Containment 8-1
8.1.1 Step One: Baseline Risk Determination 8-2
8.1.2 Step Two: Determination of Containment Leakage Rates 8-3
8.1.3 Steps Three and Four: Determine Dose Rate 8-3
8.1.4 Step Five: Determine Change in Pre-Existing Leak Probability 8-4
8.1.5 Step Six: Determine Revised Population Dose Rate 8-6
8.1.6 Step Seven: Determine Percentage Change In Population Dose 8-7
8.1.7 Step Eight: Evaluate Change In LERF 8-7
8.1.8 Step Nine: Evaluate Conditional Containment Failure Probability (CCFP) 8-8
8.1.9 Hypothetical PWR Example Results 8-9
8.2 Hypothetical Plant Application – BWR Small Containment 8-11
8.3 Sensitivity Studies 8-13
8.4 External Events and Other Hazards 8-13

9 RESULTS SUMMARY AND CONCLUSIONS 9-1

10 REFERENCES 10-1

A ILRT DATA A-1

B EXPERT ELICITATION INPUT DATA B-1

C EXPERT ELICITATION RESULTS C-1

LIST OF FIGURES

Figure C-1 Large Containment – All Failure Modes C-15
Figure C-2 Small Containment – All Failure Modes C-15
Figure C-3 Comparison of Small and Large Containment – Failure Probability C-16

LIST OF TABLES

Table 3-1 Statistical Methods of Failure Probability Estimation Given Zero Observed Occurrences 3-3
Table 4-1 Degrees of Issues and Levels of Study 4-8
Table 4-2 ILRT Expert Elicitation Panel 4-9
Table 5-1 Expert Elicitation Meeting Agenda 5-2
Table 5-2 Summary of Expert Elicitation 5-9
Table 6-1 Expert Elicitation Results – Leak Size Versus Probability 6-10
Table 7-1 Description of the EPRI Accident Classes 7-10
Table 8-1 Hypothetical PWR CDF Classes 8-1
Table 8-2 Hypothetical PWR Revised CDF Classes 8-3
Table 8-3 Hypothetical PWR Revised Population Dose 8-4
Table 8-4 Hypothetical PWR Accident Class Frequencies for Various ILRT Testing Intervals 8-5
Table 8-5 Hypothetical PWR Population Dose Rates for Various ILRT Testing Intervals 8-6
Table 8-6 Hypothetical PWR Accident Class Percent Dose for Various ILRT Testing Intervals 8-7
Table 8-7 Delta Large Early Release Frequency for Various ILRT Testing Intervals 8-8
Table 8-8 Conditional Containment Failure Probability for Various ILRT Testing Intervals 8-8
Table 8-9 Hypothetical PWR Summary for Various ILRT Testing Intervals 8-10
Table 8-10 Hypothetical BWR CDF by Accident Class 8-11
Table 8-11 Hypothetical BWR Summary for Various ILRT Testing Intervals 8-12
Table 8-12 Hypothetical PWR Sensitivity Case – LERF Represented by 600 La 8-15
Table 8-13 Hypothetical PWR Sensitivity Case – LERF Represented by 35 La 8-16
Table B-1 Expert Elicitation Input – Large Containment with Small Leakage Pathway B-2
Table B-2 Expert Elicitation Input – Large Containment with Medium Leakage Pathway B-3
Table B-3 Expert Elicitation Input – Large Containment with Large Leakage Pathway B-4
Table B-4 Expert Elicitation Input – Large Containment with Extremely Large Leakage Pathway B-5
Table B-5 Expert Elicitation Input – Small Containment with Small Leakage Pathway B-6
Table B-6 Expert Elicitation Input – Small Containment with Medium Leakage Pathway B-7
Table B-7 Expert Elicitation Input – Small Containment with Large Leakage Pathway B-8
Table B-8 Expert Elicitation Input – Small Containment with Extremely Large Leakage Pathway B-9

Table C-1 Large Containment – Construction Error or Deficiency C-3
Table C-2 Large Containment – Human Error (Testing or Maintenance) C-4
Table C-3 Large Containment – Human Error (Design Error) C-5
Table C-4 Large Containment – Corrosion C-6
Table C-5 Large Containment – Fatigue Failures C-7
Table C-6 Large Containment – All Failure Modes C-8
Table C-7 Small Containment – Construction Error or Deficiency C-9
Table C-8 Small Containment – Human Error (Testing or Maintenance) C-10
Table C-9 Small Containment – Human Error (Design Error) C-11
Table C-10 Small Containment – Corrosion C-12
Table C-11 Small Containment – Fatigue Failures C-13
Table C-12 Small Containment – All Failure Modes C-14

1
INTRODUCTION

This document describes the methodology that is used to assess the risk impact associated with changes to the containment integrated leakage rate testing (ILRT) frequencies. The methodology considers the previous version of this report [1] and NUREG-1493, *Performance-Based Containment Leak-Testing Programs* [2], and builds upon the finding of these reports. In addition, submittals to the Nuclear Regulatory Commission (NRC) that proposed extensions to the Type A ILRT testing interval are also considered in the development of this report.

However, this study provides additional analysis that supports relaxing the Type A containment leak rate testing to an optimized permanent testing interval of up to 20 years. The additional analysis includes:

- Regulatory Guide 1.174 concepts, including the acceptable change in core damage frequency (CDF) and large early release frequency guidelines and defense-in-depth philosophy
- Considering expert opinion in the development of the probability of a large pre-existing containment leak
- As part of the expert elicitation, consideration of the potential risk benefits associated with other containment inspections and potential indirect containment monitoring techniques that would provide indications of a containment leak
- Consideration of comments made on ILRT extension submittals

2
PROBLEM STATEMENT

The Nuclear Energy Institute (NEI) has initiated a project to revise the industry guidance and associated requirements for containment ILRT. Based on performance history, risk insights, and other containment testing and inspections, it is believed that the required ILRT Type A testing interval, presently one test in 10 years, can be optimized to one test in up to 20 years.

This project builds on the previous work performed in EPRI TR-104285, *Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals* [1], and NUREG-1493, Performance-Based Leakage Test Program [2]. In fact, NUREG-1493 states, "Reducing the frequency of Type A tests (ILRTs) from the current three per 10 years to one per 20 years was found to lead to imperceptible increase in risk." Since the publication of NUREG-1493, additional containment inspections are now performed at all nuclear power plants (ASME Code Section XI Subsections IWE and IWL), and historical integrated and local leak rate testing performance has been good. Using new methods and the additional recent data, this project will demonstrate that this conclusion remains valid.

2.1 Background

A revision to the NEI Guidance (NEI 94-01) permitting an optimized ILRT Type A testing interval of up to once per 20 years is planned. The revision will be based on a risk impact assessment that will partially supersede EPRI TR-104285, *Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals* [1]. The risk impact assessment will generically assess the risk impact of the up-to-once-per-twenty-year testing interval and consider industry experience and appropriate regulatory guidance (RG 1.174) [4].

This document focuses on a "problem statement" that illustrates the need for, and the role of, the expert elicitation process in developing the risk impact assessment of the revised containment leak rate testing intervals. Additional details on the expert elicitation process are contained in "ILRT Type A Test Interval Optimization Methodology - Expert Elicitation Process" in Section 4 of this report.

2.2 Framework

Risk is defined as the product of probability and consequence, where probability is the periodic occurrence of an undesired event and consequence is the magnitude of the undesired event.

RISK = PROBABILITY x CONSEQUENCE

In the case of the risk associated with the revised ILRT testing interval, the probability is defined as the probability of a containment leakage event that would not be detected by alternative means such as a local leak rate test or other inspection. Note that containment leakage or degradation detectable by alternative means does not impact the risk associated with revising the ILRT interval.

The consequence is defined as the increase in, or delta of, large early release frequency (LERF). The LERF figure of merit is one traditional figure of merit in risk-informed applications [4]. In the case of the risk impact assessment of the revised ILRT testing interval, the delta LERF is determined by multiplying the CDF by the change in the probability of a containment leakage event that would not be detected by means other than an ILRT.

Additional figures of merit including the increase in, or delta of, population dose and conditional containment failure probability (CCFP) are also developed. The delta population dose is calculated by multiplying the base population dose by the change in the probability of a containment leakage event for the affected CDF end states. The CCFP is defined as the probability that the containment is failed following a core damage event (for example, pre-existing containment leakage pathway).

RISK	=	Probability	x	Consequence
Δ LERF	=	Δ ILRT Failure [1] Probability	x	CDF
Δ Population Dose	=	Δ ILRT Failure [1] Probability	x	Population Dose
CCFP	=	1 – (Intact CDF	/	Total CDF)

In the previous "one time" ILRT extension submittals [3, 6], and as a matter of course in most risk-informed applications, a bounding approach was taken. This bounding approach utilized

[1] The term "ILRT failure" is used in this report. The reader is reminded that in this context, "ILRT failure" is not a failure of the ILRT test to measure the containment leakage, nor does it indicate a failure of a Type A test to meet the performance criteria of NEI 94-01. Rather, the term "ILRT failure" is used to describe those ILRT tests in which containment leakage was identified above the acceptance criteria that would not be detected by a local leak rate test, containment inspections, or other alternate means and is of sufficient size to potentially result in a large early release.

very conservative assumptions with respect to assessing the risk increase as a function of a revised ILRT testing interval. These assumptions include conservatisms associated with the determination of the ILRT failure probability as well as conservatisms associated with the determination of the consequences (delta population dose and delta LERF):

- **Data applicability.** Data used to estimate the initial probability of ILRT failure are conservatively classified. Containment leakage events that would not significantly affect population dose and/or LERF calculations are included in the estimation of the ILRT failure probability. For example, events such as steam generator manway leakage are included in the estimation of ILRT failure probability. Steam generator manway leakage would be discovered during reactor startup or during normal operation and should not impact the risk associated with an ILRT Type A testing extension.
- **No alternate means of detection.** The probability of alternate means of detection such as local leak rate tests, inspections, or other means are not always considered.
- **Estimation of containment leakage.** Low containment leakage rates (low La values) with higher probabilities of occurrence are used to represent a large early release.

Despite the very conservative assumptions above, the submittals to date have been able to demonstrate that the revised ILRT testing interval has little impact on risk. That is, the risk or the delta population dose and delta LERF are small.

In the case of delta LERF, Regulatory Guide 1.174 describes changes to the licensing basis with a delta LERF impact below $1x10^{-7}$ per year as "very small." Such changes are generally acceptable. Proposed delta LERF impacts between $1x10^{-6}$ and $1x10^{-7}$ per year are described as "small" changes and are acceptable. However, they result in increased NRC management and technical attention, including consideration of the plants' baseline LERF.

When applying the existing methods to all plants, particularly those with higher CDF values, it is possible that a fraction of the calculated delta LERF values will fall into the "small" change region and therefore result in increased NRC management and technical attention. The increased NRC management and technical attention, when based on a conservative conclusion, are not an optimum use of either the NRC's or utility resources. By considering and reducing the conservatisms in the current methods, most, if not all, calculated delta LERF values will be in the "very small" change region, thereby optimizing resources associated with the ILRT testing as well as NRC and utility management and technical resources.

The risk impact evaluation methodology technical approach is presented in detail in Section 7 of this report.

2.3 Expert Elicitation Input

In order to obtain more realistic values for delta LERF, the conservatisms in the current methodology and presented in Section 2.2 must be addressed. The expert elicitation process is a key element in addressing the conservatisms presented above.

A full description of the conservative assumptions as well as the expert elicitation process and results are presented in the report sections that follow.

3
ILRT DATA APPLICABILITY

Data from ILRT tests have been collected at various times to support various applications. In summary, two NEI utility surveys [8, 9] collected ILRT data for 182 ILRT Type A tests that have been performed in the nuclear industry. Based on these data, the number of containment leakage events found during the performance of these tests is very small. In fact, no failures that would result in a large early release have been found. As such, the testing data alone does not, without expert opinion, support the development of realistic values for the probability of a large containment leakage event.

Consider the containment leakage or degradation event data contained in Appendix A. This Appendix A is a compilation of data from two NEI utility surveys, NUREG-1493, and other events discovered in reviewing other industry data (Licensee Event Reports (LERs), reportable events, and so on).

3.1 NUMARC Survey Data

The first ILRT survey was performed in early 1994 [8] and represented the NEI (known as NUMARC at that time) input used in NUREG-1493. In this survey, the data from 144 ILRT Type A tests were collected. Reported in NUREG-1493 were 23 ILRT failures. However, upon further review, it has been determined that these failures were conservatively classified. Of the 23 ILRT failures:

- A total of 14 were due to addition of Type B and C testing leakage penalties (local leak rate testing identified) and would not increase the time a leak path would go undetected in an ILRT interval extension.
- Four were due to steam generator in-leakage. The steam generator leak paths are identifiable during startup and normal operation and would not increase the time a leak path would go undetected in an ILRT interval extension. Leakage from the steam generators into the containment would be monitored via identified and un-identified leakage and controlled via plant technical specifications.
- Two were due to ILRT line-up errors and did not constitute valid leak paths.
- One was due to a discrepancy in a verification test and did not constitute a valid leak path.
- Two were due to failures, which should have been indicated by the local leak rate testing programs. It is expected that these discrepancies would have been corrected at the next local leak rate test and therefore would not increase the time that a leak path would go undetected in an ILRT Type A interval extension.

3.2 NEI Survey Data (2001)

The second ILRT survey was performed in the fall of 2001 [9]. In the second survey, data were collected from 58 plants (91 units), reporting 38 ILRT (Type A) tests performed. The one ILRT-identified failure that should have been indicated by the local leak rate testing program would not increase the time a leak path would go undetected in an ILRT interval extension. This is because it was caused by contamination of the penetration with construction debris during a modification, which somehow passed the post-modification LLRT. However, the contamination the failure would have most likely been identified by subsequent LLRT's had the subsequent ILRT not been conducted.

3.3 Combined Survey Data

In order to provide a comprehensive review of all the ILRT experience collected to date, the combined surveys and other ILRT data were collected and are presented in Appendix A. The combined data were then sorted by those events that resulted in excessive leakage when compared with the established acceptance criteria. These include all causes that resulted in ILRT tests exceeding 1 La criteria, including those that are a result of local leak rate test penalties. A total of 71 leakage or degraded liner events are included in Appendix A. The details associated with these 71 events are provided in the appendix.

It should be noted that the combined surveys do not represent all ILRTs performed. In the initial NUMARC survey, utilities were chosen that represented a broad spectrum of reactor designs and associated ILRTs were considered a representative sample of industry ILRTs performed. The response to the most recent NEI survey was significant (91 nuclear units responded), and the data are considered a representative set of recent ILRT Type A test experience. Lastly, the data collected by the surveys are supplemented by data in NUREG-1493 and additional literature searches, including LERs and reportable events.

3.4 ILRT Failure Rate Determination

From a review of the data in Appendix A and knowledge of the number of tests performed, a failure rate can be determined. In order to determine a failure rate, the number of failed events are divided by the number of demands, or in this case the number of ILRTs performed.

In order to determine the numerator (number of failed events) in the failure rate determination, a definition of what constitutes a failure must be developed. In this case, the ILRT failure is defined as the existence of a pre-existing leak in the containment that is not detected by local leak rate testing or alternate means and is detectable only in performance of an ILRT. Moreover, this pre-existing leak is capable of resulting in a LERF of fission products following a core damage accident. The definition of LERF is generally given as the exchange of a single containment volume before the effective implementation of the offsite emergency response and public protective actions [7]. In turn, public protective actions are generally assumed to be taken approximately 2 to 4 hours following a core damage event. The exchange of a single containment volume within a 4-hour period corresponds to a leakage rate of 600% per

day or 600 to 6000 La (assuming that the ILRT acceptance criteria for the plant in question is between 1% and 0.1% per day).

Some previous submittals have conservatively assumed (based on Reference [1]) that four failures have occurred (based on the 1994 NUMARC survey). However, based on a more comprehensive review of the data, no containment leakage events where leakage greater than 21La have been discovered [2]. As discussed further in Section 3.6, events with leakages from 600 La to 6000 La are a more realistic representation of a large early release. Previous submittals (specifically, Reference [3]) conservatively assumed that events with a leakage greater than 35 La were capable of producing a large early release. While still conservative, 100 La is used in this analysis to represent the leakage value capable of producing a large early release.

Using either the very conservative definition of large early release from Reference [3] (35 La) or the conservative value from this analysis (100 La), there are no containment leakage events that could result in a large early release in the current dataset. The zero failures are based on the combined ILRT database (NUMARC and NEI surveys [8, 9] and other sources) in which the results of 182 ILRTs have been documented.

With zero failed events, a variety of statistical methods is available to estimate a failure rate. Each method assumes a number of failed events to obtain a failure rate.

The number or fraction of assumed failed events varies by the statistical method as illustrated in Table 3-1. The comments section of the table provides the basis for the use of the statistical method.

Table 3-1
Statistical Methods of Failure Probability Estimation Given Zero Observed Occurrences

Statistical Method	Assumed No. of Failures	No. of Demands	ILRT "Failure" Probability	Comments
Chebychev	1	182	5.5E-3	Upper bound estimate.
Jeffery's non-informative prior	0.5	182	2.7E-3	Based on no physical or engineering information available.
Typical range	0.3	182	1.6E-3	Typical range of values for a non-informative basis.
	0.1	182	5.0E-4	

[2] There are several tests where the resulting leakage was indicated as above the acceptance criteria but not quantified. The reasons for not quantifying leakage are not clear, but could include leakage exceeding instrument ranges or a desire to simply correct the path without quantifying the as-found data. Based on available information, the magnitude of these leak paths is not expected to exceed that of known, quantified leak paths.

As can be seen from the table, the resulting ILRT failure probabilities vary widely depending on the statistical method employed. The statistical method is in turn dependent on the uses of the final information (conservative estimate) or assumptions concerning the amount of physical or engineering information concerning failure rates or failure modes and causes. Therefore, the determination of the probability of a containment leakage event is candidate for expert elicitation.

3.5 No Alternate Means of Detection

Various alternative methods of detecting a leakage pathway ("ILRT failure") in containment exist. These methods include local leak rate tests (LLRT), reactor startup, normal operation, and other containment and piping inspections. Since the publication of NUREG-1493, additional containment inspections are now performed at all nuclear plants (ASME Code Section XI, Subsections IWE and IWL).

In addition, experience has shown that during normal reactor startup and during normal power operation it is fairly routine for most containment designs to either vent the overpressure that has built up or to provide nitrogen makeup (for inerted containment designs) to maintain positive pressure within specified limits. The increase in pressure can be caused by increase in the average air temperature during heatup and startup, changes in barometric pressure, and an increase in the containment air mass from compressed air equipment bleeds and leakage. Absence, or significant changes in the frequency, of pressure build-up and venting over a substantial period of time will provide a qualitative indication of the existence of a containment atmosphere to outside atmosphere leak path. These factors, as well as others, provide additional means of detection of containment leakage pathways. Expert opinion will assist in the determination of the probability of detection over an increased ILRT interval.

3.6 Estimation of Containment Leakage

Previous one-time ILRT extension submittals have used an estimated leakage rate as a result of an assumed large ILRT failure of 35 La [3, 6, 10]. This leakage was assumed to conservatively represent the leakage rate associated with a large early release as calculated in the Level 2 probabilistic risk assessment (PRA). However, the definition of LERF is generally given as the exchange of a single containment volume before the effective implementation of the offsite emergency response and public protective actions [7]. In turn, public protective actions are generally assumed to be taken approximately 2 to 4 hours following a core damage event. The exchange of a single containment volume within a 4-hour period corresponds to a leakage rate of 600% per day or 600 to 6000 times La, assuming that the ILRT acceptance criteria for the plant in question are between 1% and 0.1% per day. While still conservative, 100 La is used in this analysis to represent the leakage value capable of producing a large early release.

From an examination of the events with stated leak rates in Appendix A, the highest known leakage event has a leakage of 21 La (event number 10). This event was discovered during performance of an LLRT. The next highest leakage event has a leakage of 15 La (number 35)

and was discovered during the performance of the ILRT. However, this event was the result of excessive local leakage that would be discovered during the next LLRT.

Therefore, there are no events that have occurred in the database that would constitute a large early release pathway. In fact, the use of 100 La to represent a large early release is conservative given the definition provided in this evaluation.

However, the data collected do provide useful information on the type of failures that have occurred, the potential failure mechanisms, and the historical sizes of these failures. Various sorts were performed on the data to better understand the available information and the conclusion that can be drawn from them.

Of the 71 events in the ILRT database, 32 involved leakages ≤ 1 La; the remaining 39 events have unknown leakages or leakages greater than 1 La. Of these 39 events, 20 were identified by local leak rate testing (18) or involved steam generator manway leakage (2). Because steam generator manway leakage will result in a loss of steam generator water (secondary side) to the containment during reactor startup and normal operation and identified and unidentified leakage is monitored in technical specifications, these can be removed from consideration.

Of the remaining 19 events, 3 are the result of the previous practice of performing an ILRT prior to completing local leak rate tests. This results in the ILRT discovering leakages that would normally be found during a local leak rate test. These events are indicated in Appendix A with the phrase "ILRT prior to LLRT" in the description column.

Of the 16 remaining events, 7 are discovered by alternate means (not impacted by extension of ILRT intervals), specifically operator or other inspections. It is assumed for these 7 events that the frequency of detection and ILRT failure frequency would remain constant regardless of testing because no changes to the frequency of other tests or inspections are proposed. Therefore, these seven events are not considered in the calculation of the ILRT failure rate. In addition, one event is the result of instrumentation problems and does not appear to be an actual ILRT failure.

The nine remaining events are presented below. The sizes in terms of leakage rates of the nine events are as follows:

- Unknown leakage events: 4
- Small leakage events (<2 La): 3
- Medium leakage events (2–10 La): 1
- Large leakage events (>10 La): 1

Of these nine events, three events (Nos. 34, 35, and 61) represent LLRT failures to discover leakage, and one event (No. 41) represents failure of the drywell head seal due to relaxation of improper spherical washer material. In the case of the LLRT failures that should have been identified by local leak rate testing, the leakage would most likely be detected during the performance of the next LLRT and therefore does not affect the ILRT failure rate for the purposes of ILRT testing interval extension. In the case of the drywell head leakage, this event

would be identified and corrected in the next refueling outage and therefore does not impact the ILRT failure frequency with regards to ILRT testing interval extension.

The remaining five events were detected by the ILRT. In four of the five events, the estimated leakage is unknown. The fifth event (No. 45) falls into the small leakage category (1.4 La). Of these five events, two events could have been detected only by conducting an ILRT (Nos. 1 and 45). However, these events had either unknown leakage rates or leakage rates less then 2 La. One event (No. 1) involved two holes drilled in a liner (unknown leakage rate), and the other (No. 45) involved the ejection of a radiation monitor during an ILRT (1.4 La).

Event 30 is of unknown leakage and unknown cause. Two events (Nos. 25 and 33) should have been detected by an LLRT and were not. NEI 94-01 does not allow extension of the ILRT interval if the performance criteria cannot be met. That is, if a leak path involving a penetration cannot be determined by an LLRT then the ILRT interval cannot be extended (NEI 94-01, Section 9.1.1).

In summary, from a detailed review of the available data, there have been no events identified that could have resulted in a large early release as currently defined. Several ILRT events had unknown leakage rates. From the description of the events it can be inferred, although not proven, that the leakage was not large (for example, holes drilled in liner and penetration leakage). In any event, the limited ILRT data result in an inability to directly calculate an ILRT failure rate. However, the information that the data provide is valuable in an expert elicitation designed to estimate the probability of ILRT failure rates for a wide magnitude of leakage rates.

4
EXPERT ELICITATION PROCESS

This report section provides an overview of the expert elicitation process [11, 12] and its application to the solicitation of expert opinion for the ILRT Type A Testing Interval Optimization Project. The process is based on the "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" (NUREG/CR-6372) [12] and "Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program" (NUREG-1563) [11].

4.1 Introduction to the Elicitation Process

The goal of the expert elicitation process is to obtain frequency and magnitude estimates for containment leakage that would not be detected by other inspections, tests, or alternative means.

There are five functional requirements of the expert elicitation process. These five requirements are:

- Requirement 1: Identification of the expert judgment process
- Requirement 2: Identification and selection of experts
- Requirement 3: Determination of the need for outside expert judgment
- Requirement 4: Utilization of either the technical integrator (TI) or technical facilitator/integrator (TFI) process
- Requirement 5: Responsibility for the expert judgment

The five functional requirements of the expert judgment process identify the issue, identify the experts, outline the process used in the solicitation of their opinion, and specify the use of their judgment in the ILRT Type A testing interval optimization process. Each of the five functional requirements is discussed in detail in the following sub-sections.

4.2 Expert Elicitation Summary

The goal of the expert elicitation process is to determine the probability and magnitude of containment leakage events. The probability and magnitude of containment leakage events will be used in the determination of the risk impact associated with the ILRT Type A testing interval optimization.

The expert elicitation process inputs are derived from an ILRT events database, consisting of information collected via NEI surveys, LER's, and NRC reports (NUREG-1493). The expert elicitation process uses a facilitated expert meeting that considers data, containment design, maintenance, and testing. The process was consistent with the approach described in References [11] and [12].

Using the process outlined in those two references, the ILRT Type A testing interval optimization has been assigned a degree of importance of Degree II and a level of complexity of C. These assignments indicate that a TI process is sufficient for the expert panel process. In the case of a level of complexity of Level C, a facilitated expert panel meeting is required to solicit the opinions of the technical community. Through a nomination process, experts are selected. Each of the experts has significant expertise in areas related to containment structures and/or containment testing.

The technical integrator facilitates the expert panel meeting in which the problem statement is provided. The problem statement includes an ILRT events database and potential approaches (in addition to expert elicitation) and their results. The expert panel then provides its individual judgments. The technical integrator integrates the individual results to obtain the community distribution. The community distribution is provided to the expert panel to ensure agreement with the final community distribution. The results are then used in the risk impact assessment.

4.3 Requirement 1: Identification of the Expert Judgment Process

There are several forms that the expert elicitation process can take depending on the complexity of the issue, the resources available to address the issue, and other factors. This requirement provides the outline of the expert judgment process based on these factors. Three topics are discussed in the following report sub-sections that assist in the determination of the details of the expert elicitation process. These topics are:

- Defining the specific issue
- Determining the degree of importance and degree of complexity of the issue
- Deciding whether to use a TI or TFI

4.3.1 Defining the Specific Issue

The technical issue for which expert judgment is to be applied needs to be defined clearly and narrowly enough that it is possible to identify the relevant expertise and to use it correctly. Defining the technical issue requires:

- Clearly identify the issue such that one or more technical experts can be selected.
- Define how the issue fits into the PRA.
- Allow the experts to redefine the issue that allows the experts to provide input.

The issue associated with the optimization of ILRT Type A testing interval has been clearly defined in the ILRT problem statement. Therefore, this requirement is considered satisfied.

4.3.2 Determining the Degree of Importance and Level of Complexity

In the following sub-sections, the process used to determine the degree of importance and level of complexity of the ILRT testing optimization are discussed.

4.3.2.1 Determining the Degree of Importance

To assist the experts in the expert elicitation process as well as to define the form of the process, it is necessary to classify the technical issue into one of three degrees. These three degrees, defined as Degree I, Degree II, and Degree III, are intended for use in the determination of the expert elicitation process to be used. The determination of the degree of importance is based on technical criteria only. The degree characterizations are as follows:

- Degree I: Non-controversial issue and/or not significant to the overall results of the analysis.
- Degree II: Issue has significant uncertainty or diversity of opinion; controversial; moderately significant to the overall result of the analysis; and/or moderately complex.
- Degree III: Highly contentious issue; very significant to the overall result of the analysis; and/or highly complex.

In assigning the degree of importance of an issue, there is some judgment necessary because the degree categories represent a course partition of the range of potential degrees.

In the case of the optimization of the ILRT testing intervals, Degree II is selected. Degree I is not chosen because the results of the expert elicitation process are indeed significant to the results of the analysis. In fact, a case could be made that the results of the expert elicitation process are very significant to the results of the analysis necessitating an assignment of a Degree III. However, the sensitivity of the results of the analysis to the expert elicitation process is mitigated by the availability of significant amounts of data. These data, although not complete enough to perform the analysis, do provide information upon which the experts can base their judgments. In addition, experts will be chosen for the knowledge of the mechanisms that can result in containment leakage events and therefore provide additional assurance that their judgment is only moderately significant to the overall result. Lastly, the issue of testing extension and specifically ILRT Type A test optimization is not considered highly complex, nor is the issue considered highly contentious. Therefore, the assignment of degree of importance of Degree II is appropriate.

4.3.2.2 Determining the Level of Complexity

Once the degree of the issue has been selected, it is necessary to select the level of complexity. There are four levels of complexity defined as Level A, B, C, and D. A key input to the assignment of the level of complexity is the degree of importance. The degree of importance

captures how complex and how controversial the issue is, but alone is not sufficient for the choice of the level of complexity.

In summary, levels of complexity of A, B, or C are characterized by the TI approach. In the technical integrator approach, the technical integrator plays the role of "evaluator." Input to the technical integrator varies depending of the level of complexity assigned to the issue from basing judgments on his/her own experience and literature to obtaining input through the communication with other experts.

With an issue of a level of complexity of A, the technical integrator's role is to evaluate and weight models based on literature review and experience. With a level of complexity of A, the technical integrator would estimate the community distribution.

With an issue assigned a level of complexity of B, the technical integrator's role is to conduct a literature review and contact those individuals who have developed interpretations or who have particular relevant experience and develop the community distribution.

With an issue assigned a level of complexity of C, the technical integrator's role is to gain additional insight by bringing together experts and focusing their interactions. In the sessions with the technical experts, the experts are given an opportunity to explain their hypotheses, data, and bases. Proponents or advocates of particular technical positions are asked to describe and defend their positions to the other experts. As with levels A and B, the technical integrator develops the community distribution.

Issues assigned a level of complexity of D are characterized by the TFI approach. In level D, a group of expert "evaluators" is identified and their judgments elicited. The technical facilitator/integrator is responsible for identifying the roles of the proponents and evaluators and for ensuring that their interactions provide an opportunity for focused discussion challenge. In the Level D analysis, resources permit and the situation dictates multiple evaluators, and hence a technical facilitator integrator takes responsibility for the aggregated product. The TFI organizes and manages interactions among the proponents and evaluators, identifies and mitigates problems that potentially develop during the course of the study (for example, an expert who is unwilling or unable to play the evaluator role), and ensures that the evaluators' judgments are properly represented and documented.

Regardless of the level of the study, the goal in the various approaches is the same: to provide the community distribution, which is defined as a representation of the informed technical community's view of the important components and issues and, finally, the result. Also, regardless of the level of the study, a peer review is performed to review the process and substance of the study.

The level of complexity of the ILRT Type A testing optimization is chosen as Level C. The factors affecting this assignment include but are not limited to regulatory issues, public and technical community perception, and resource constraints.

A level of complexity of D is not chosen because empirical data are available that provide an indication of the range of the result of the final analysis. In addition, the phenomena related to containment leakage events are generally understood. In addition, the conceptual models that are involved in the optimization of the ILRT testing interval and potential containment leakage events are relatively limited. Given the required resources and the above discussion, a complexity level of D is not chosen.

Assignment of a level of complexity of A is rejected because it does not significantly involve the technical community in the development of the analysis. Given the regulatory nature of the analysis, it is important to involve the technical community in the development of the analysis.

While a level of complexity of B does involve the technical community, it does not provide a forum for the exchange of alternate conceptual models. Therefore, a level of complexity of B is also not chosen.

A level of complexity of C provides the optimum use of resources because it allows for the technical community to participate in the development of the analysis results and the proposal of alternate conceptual models while limiting the resources associated with the solicitation of the expert judgment.

4.4 Requirement 2: Identification and Selection of Experts

One or more evaluators (individuals capable of evaluating the relative credibility of multiple alternative hypotheses to explain the available information) need to be identified. In addition, other experts such as proponents (experts who advocate a particular hypothesis or technical position) as well as resource experts (technical experts with knowledge of a particular area of importance to an issue) will also be identified and nominated for participation.

Experts will be nominated to the panel by the ILRT optimization project manger. Experts should have extensive nuclear power experience and expertise in one or more of the following areas:

- Containment structure testing and/or maintenance
- Performing ILRTs or interpreting/characterizing ILRT test results
- Statistics/probability theory/probabilistic risk assessment
- Failure mechanics

4.5 Requirement 3: Determination of the Need for Outside Expert Judgment

In the case of the ILRT Type A testing optimization, the decision to seek outside (expert elicitation process) expert judgment has already been made as opposed to using members of the NEI ILRT Optimization Project Team. As previously mentioned, the regulatory nature of the

analysis requires that the technical community be involved in the development of the analysis. The selection of the participants will be in accordance with Section 4.4 of this report.

4.6 Requirement 4: Utilize the TI or TFI Process

This requirement is used to determine whether the TI process or the TFI process will be used and to specify the requirements of the process chosen. Because a Level C analysis has been chosen and there is no other basis to decide differently, the TI process is to be used. As described earlier, the TFI process is applied to only Level D analysis. The TI process includes the following significant elements:

- Identifying available information and analysis and information-retrieval methods
- Accumulating information relevant to the issue
- Performing the analysis and the data diagnostics
- Developing the community distribution

4.6.1 Identifying Available Information and Analysis and Information-Retrieval Methods

The TI is responsible for assembling all relevant technical databases and other information important to the analysis problem at hand, including any data that have been gathered specifically for the analysis. The TI also identifies technical researchers and proponents that he/she intends to contact during the course of the study to gain insight into their positions and interpretations (in a Level C analysis, this means identifying those individuals that he/she intends to assemble for discussion and interactions). In addition, the TI defines the procedures and methods that will be followed in conducting the analysis.

4.6.2 Accumulating Information Relevant to the Issue, Performing the Analysis, and Developing the Community Distribution

The TI is responsible for understanding the entire spectrum of technical information that is brought to bear on the issue, including written literature, recent works by other experts, and other technical resources. (In advanced technical work, it is always the responsibility of the investigator to learn about the most recent advances in the field, often by direct contact with other experts through personal correspondence, personal meetings, telephone conversations, and so on.) In a level C study, members of the technical community are brought together, and the TI orchestrates interactions and possibly workshops to focus the discussions on the technical issues of most significance to the analysis to be sure that he/she is aware of the diversity in interpretations for these key issues. The TI uses all this information to develop a community distribution of the range of uncertainty for the particular issue being addressed.

4.6.3 Performing the Peer Review

The TI needs to use the peer review team as a sounding board to learn whether the full range of technical views has been identified and assimilated into the project. The ILRT Optimization Project Team will serve as the peer reviewers for the expert panel. In addition, the expert panel will be free to consult other resources as they see necessary.

4.7 Requirement 5: Responsibility for the Expert Judgment

A basic principle is that it is an absolute requirement that there must be a clear definition of the ownership of expert judgments, opinions, and/or interpretations, both as expressed by the individual experts and as integrated together.

In the case of the ILRT Type A testing optimization (Table 4-1), the owner of the process and the results is the technical integrator. The individual experts will own their individual judgments and interpretations.

Table 4-1
Degrees of Issues and Levels of Study

Issue Degree	Decision Factor	Study Level
Degree I Non controversial; and/or insignificant to the result	Regulatory concern	Level A TI evaluates/weighs models based on literature review and experience; estimates community distribution
Degree II Significant uncertainty and diversity; controversial; and complex	Resources available	Level B TI interacts with proponents and resource experts to identify issues and interpretations; estimates the community distribution
Degree III Highly contentious; significant to result and highly complex	Public perception	Level C TI brings together proponents and resource experts for debate and interaction; TI focuses debate and evaluates alternative interpretations; estimates community distribution
		Level D TFI organizes panel of experts to interpret and evaluate; focused discussions; avoids inappropriate behavior on the part of the evaluators; draws picture of evaluators' estimate of the community's composite distribution; has ultimate responsibility for project

Table 4-2
ILRT Expert Elicitation Panel

Name	Experience Summary			
	Degree	Years Experience	Area of Expertise	Company, Title, and Selected Experience
H. Duncan Brewer Panel Member	B.S., Nuclear Engineering; M.E., Mechanical Engineering Registered Professional Engineer	23	Probabilistic risk assessment and safety analysis	Duke Power Company Section manager, severe accident analysis Section manager and lead engineer for nuclear plant probabilistic risk assessment group Lead design engineer responsible for severe accident consequence analysis Integrated nuclear plant safety analysis Chairman, ASME subcommittee on PRA technology
Kenneth Canavan (Facilitator)	BChE, Bachelors of Chemical Engineering Minor in Nuclear Engineering	17	Safety and risk analysis	Data Systems and Solutions Manager, strategic decision support Davis-Besse PRA development Oyster Creek PRA development Three Mile Island PRA development External event PRA development for Oyster Creek and TMI nuclear power stations Lead engineer risk analysis for GPU Decommissioning PRA for Oyster Creek Various risk-informed applications Contributor to peer review process development
John M. Gisclon Panel Member	BS, Mechanical Engineering Registered Professional Engineer	35	Nuclear Power Plant Engineering, Safety Analysis, Testing, & Management	Electric Power Research Institute (EPRI) Nuclear Power Consultant EPRI project manager for risk impact assessment of revised containment leak rate testing intervals (1994) EPRI manager, maintenance technology Developed procedures, conducted and supervised local and integrated leak rate testing at a small BWR and a large PWR.

Table 4-2 (cont.)
ILRT Expert Elicitation Panel

Name	Experience Summary			
	Degree	Years Experience	Area of Expertise	Company, Title, and Selected Experience
Alex McNeill Panel Member	BS, Nuclear Engineering	22	Materials/Inservice Inspection, IWE/IWL	Dominion Energy Principle Level III Inspector IWE/IWL ISI program administrator Risk-informed inservice inspection program administrator Lead inservice inspection program engineer Member ASME section XI working group on implementation of risk-based examination
James C. Pulsipher Panel Member	BS, Physics MS, Nuclear Engineering	25	Containment Leakage Rate Testing, Containment Systems	U. S. Nuclear Regulatory Commission, Plant Systems Branch, Containment Systems Analyst NRC expert on Appendix J testing Member of ANS 56.8 working group for 19 years Principal NRC participant for revision of 10CFR50, Appendix J, Option B Co-author of Regulatory Guide 1.163 Co-author of recent NRC safety evaluations for one-time extension of ILRT intervals to 15 years.
Jim E. Staffiera Panel Member	BS, Mechanical Engineering; MBA, Master of Business Administration	32	Containment Fabrication, Erection, and Testing; Containment Inservice Inspection	First Energy Nuclear Operating Company Lead engineer, civil/structural element, design engineering section, nuclear engineering Department, containment inservice inspection program development (ASME subsections IWE/IWL) Chairman, ASME subcommittee (SC) XI working group on containment Member ASME subcommittee (SC) XI Member ASME SC/XI subgroup on water-cooled systems Member ASME SC/XI special working group on editing and review

Table 4-2 (cont.)
ILRT Expert Elicitation Panel

Name	Experience Summary			
	Degree	Years Experience	Area of Expertise	Company, Title, and Selected Experience
Henry M. Stephens, Jr. Panel Member	BS, Physics and Mathematics	32	Inservice Inspection, NDE	EPRI NDE Center Program manager, NDE training and containment inspection Manager, inservice inspection training NDE training coordinator, NDE instructor Quality assurance engineering Chairman, ASME section XI task group on risk-informed containment inspection Secretary, ASME section XI working group on containment Member, ASME section XI subgroup on water cooled systems

5
EXPERT ELICITATION INPUT

This report section provides a description of the expert elicitation input process. Combined with the ILRT problem statement and the ILRT expert elicitation process, this report section provides a full description of the expert elicitation inputs, process, and its application to the risk impact assessment of the ILRT test optimization. The ILRT problem statement and the ILRT expert elicitation process are discussed in previous report sections.

The expert elicitation is accomplished in several stages. In the first stage, the experts provide the problem statement. The problem statement contains a statement of issues associated with the extension of the ILRT testing interval as well as information from the Containment Leakage/Degraded Liner Events database.

In the second stage, the experts are brought together to present the issues as well as the planned the approach to the solicitation of their input.

In the third and final stage, the experts are presented with the final results of their collective input ("ILRT failure" probability) as well as the results of the use of their input in the final assessment of the risk impact assessment of the ILRT Type A test interval optimization.

5.1 Stage 1: Expert Elicitation Preparation

In preparation for the expert elicitation meeting, the problem statement as well as the Containment Leakage/Degraded Liner Events database were provided to the experts. As part of the transmittal, experts were requested to provide input to revise the problem statement and focus their collective efforts on the problem. Specifically, experts were asked:

- Does the problem statement adequately address the factors and issues associated with the determination of ILRT failure rate?
- Do you have any suggestions for improvement of the problem statement?
- Was the expert elicitation process adequately described?

In preparation for stage 2, all input received from the experts is incorporated into the problem statements and expert elicitation process.

5.2 Stage 2: Expert Elicitation Meeting

The following sub-section describes the attributes and the detailed agenda of the expert elicitation meeting. The expert elicitation meeting has the following attributes:

- A two-and-one-half-day meeting was planned.
- Conducted in a location remote to the experts to allow undistracted ILRT optimization panel meeting.
- The expert elicitation integrator facilitates the meeting.

The planned two-and-one-half-day meeting was organized around the agenda shown in Table 5-1.

Table 5-1
Expert Elicitation Meeting Agenda

Day 1 – Morning Session		
	Introductions	8:00 – 8:30 am
	Presentation of Problem Statement	8:30 – 9:30 am
	Presentation of the Expert Elicitation Process	9:30 – 10:00 am
	Break	10:00 – 10:30 am
	Expert Panel Training	10:30 – 12:30 pm
	Lunch	12:30 – 1:30 pm
Day 1 – Afternoon Session		
	PRA Concepts	1:30 – 2:30 pm
	Application of PSA Concepts to ILRT Optimization	2:30 – 3:00 pm
	Break	3:00 – 3:30 pm
	Presentation of Containment Degradations	3:30 – 4:30 pm
	ILRT Database and other relevant data	4:30 – 5:00 pm

Table 5-1 (cont.)
Expert Elicitation Meeting Agenda

Day 2 – Morning Session		
	Review of Expert Training and ILRT Database	8:00 – 8:30 am
	Presentation of the Expert Elicitation example	8:30 – 9:30 am
	Break	9:30 – 10:00 am
	Expert Discussion of ILRT Issues	10:00 – 12:00 pm
	Lunch	12:00 – 1:30 pm
Day 2 – Afternoon Session		
	Expert Discussion of ILRT Issues (continued)	1:30 – 2:30 pm
	Break	2:30 – 3:00 pm
	Individual Expert ILRT Input Development	3:00 – 5:00 pm
Day 3 – Morning Session		
	Discussion of ILRT Failure Probability Results	8:30 – 9:00 am
	Discussion of ILRT Risk Impact Results	9:00 – 9:30 am
	Meeting Conclusion	9:30 – 10:00 am

5.3.1 Expert Elicitation Meeting: Day 1 – Morning Session

In the Day 1 morning session, the topics presented include: introduction, a presentation of problem statement, presentation of the expert elicitation process, and expert panel training. Except for the training, the material included in these presentations is familiar to the experts because they will have been provided all preparation materials as part of the expert elicitation preparation.

The expert panel elicitation meeting begins with a 30-minute introduction. During this period, the experts are introduced to each other, and the goals and objectives of the expert elicitation are provided.

In the first presentation, the problem statement is reviewed. This material has already been provided as part of the expert elicitation preparation material. It is presented and reviewed with the experts.

In the second presentation, an overview of the expert panel elicitation process is provided. As in the case with the problem statement, experts are familiar with the material because it was

provided as part of the preparation package. This presentation serves as a primer for the last presentation of the morning session, which is the expert elicitation training session.

During the two-hour expert elicitation training session, experts are provided training on the details of the expert elicitation process. The details include information on potential bias mechanisms and an in-class exercise of "almanac" type of questions designed to illustrate bias mechanisms.

5.3.2 Expert Elicitation Meeting: Day 1 – Afternoon Session

In the afternoon session, the topics presented include probabilistic safety assessment (PSA) concepts, application of PSA concepts to ILRT optimization, presentation of containment degradation events and mechanisms, and the ILRT database and other relevant data.

The first presentation of the afternoon session is a presentation on PSA concepts. This presentation is an overview of basic concepts of probabilistic safety assessment.

The second presentation of the afternoon session is on the application of the PSA concepts to the assessment of the risk impact associated with the optimization of ILRT intervals. Specifically, both methods employed to determine the risk impact and the role of expert elicitation are discussed.

The third presentation of the afternoon session covers containment degradation events and mechanisms. This presentation is a primer for the final presentation of the day.

The final presentation of Day 1 covers the ILRT events database and other relevant data. The process of the collection of the events, the availability of additional information, and the preliminary sorting of the data are also discussed.

5.3.3 Expert Elicitation Meeting: Day 2 – Morning Session

In the Day 2 morning session, the topics presented include: review of expert training and ILRT database, presentation of the expert elicitation example, and expert discussion of ILRT issues.

The morning session of Day 2 begins with a review of the expert elicitation training and the ILRT database.

The second presentation is the expert elicitation example. In this example, the use of the expert elicitation gathered information is demonstrated. This demonstration includes the assessment of the ILRT failure probability and the resulting effect of that failure probability on the assessment of the risk impact associated with the optimization of the ILRT Type A testing intervals.

The third presentation of the morning session is the discussion of ILRT issues. This discussion includes, but is not limited to, discussion of the potential containment failures modes and causes. The failure modes include those that have been experienced in the data as well as those potential

failure modes that have not yet been experienced. Also included in the presentation will be actual database of found degradations, some commonly found during in-service inspections (such as corrosion of liner plates or steel shell near moisture barriers), and some that are found after a number of years of hibernation (concealed corrosion).

5.3.4 Expert Elicitation Meeting: Day 2 – Afternoon Session

The afternoon session begins with the continuation of the discussion on the ILRT issues.

The second presentation of the afternoon session is the solicitation of the experts' individual opinions. The expert solicitation is performed using the form contained in Appendix B to this report. This is the first part of the expert opinion elicitation. Following the collection of the expert opinion, the individual expert opinions are shared and discussed. The presentation ends with the submission of the final individual expert opinions. The individual expert opinions are combined to produce the common community distribution. The community distribution is developed by the technical integrator. The community distribution is presented to the experts on the morning of Day 3.

5.3.5 Expert Elicitation Meeting: Day 3 – Morning Session

On the morning of the third day, the community distribution is presented to the experts. The community distribution is discussed in detail including the significant contributors to the distribution and the resulting risk impact associated with the ILRT testing interval optimization.

During the discussion of the community distribution and risk impact assessment results, feedback from the experts is solicited. Any changes to the community distribution and the resulting impacts on the ILRT testing interval optimization are presented to the experts.

Experts are finally asked for "buy in" to their personal inputs, the resulting community distribution, and the resulting risk impact assessment from the optimization of ILRT testing intervals.

5.4 Steering Committee Review

Following completion of the expert elicitation, the NEI ILRT task force will be given the draft report, including the results of the expert elicitation and the results of the risk impact assessment of the ILRT testing optimization for review. This review is intended to provide a broad overview of the processes employed and industry-wide results of the risk impact assessment of ILRT interval extension optimization.

5.5 Expert Elicitation Input Form

The attached expert elicitation input table presents the form and type of input requested from the experts. The input from the experts is requested in tabular format. The table is described in detail in the following report sub-sections.

In summary, the experts are asked to complete the table based on 1000 hypothetical tests. The experts are requested to augment the table with additional failure modes that may not appear on the table. Special attention to the effects of aging on potential containment failure modes is emphasized.

Fractions as well as whole numbers can be used in the table entries. For example, a fraction of 0.1 indicates that this failure mode would be expected once per 10,000 tests. A faction of 0.01 indicates that this failure mode would be experienced once per 100,000 tests.

From the ILRT database, an initial attempt is made to complete the table. Because only small ILRT degradations have occurred, the entries on the table are limited. Experts are asked to augment the current small containment leakage columns. The initial attempt to complete the table is performed because it is preferable to elicit relative rather than absolute values from the experts, because people are generally more comfortable making comparisons than estimating frequencies for phenomena with which they have little or no experience.

Therefore, for small leakage pathways, frequencies relative to failure mode frequencies for which data are available are elicited. For example, if few data are available for design deficiencies, ask the experts to estimate the ratio of the design deficiency frequency to the corrosion frequency.

The same process is applied to the elicitation of frequencies for medium-leakage pathways. That is, for medium-leakage pathways, frequencies relative to the corresponding frequencies for small leaks, for the same failure mode, are elicited. For large leaks, frequencies relative to medium-leak frequencies, for the same failure mode, are elicited.

5.5.1 Summary of Expert Elicitation Input Table Description

Table 5-2 shows the summary of the expert elicitation input. Column 1 of the table, "No.," is the numerical entry number.

Column 2 of the table, "Containment Degradation or Failure Mode," presents a potential failure mode of the ILRT. The majority of entries in this column are taken from the ILRT database representing previous linear degradations or leakage pathways. Other potential ILRT failure modes or containment degradation modes are also listed whether they have been experienced in the data or not. Blank lines are provided for experts to add additional containment degradation mechanisms not listed in the table. These additional failure modes or containment degradation events are discussed among the experts during the various expert elicitation discussion sessions.

Column 3, "Estimate of Low, Best and High Values," presents the characterization of the estimate provided by the experts. That is, for each containment failure classification (small, medium, large, and extremely large), the experts are requested to provide a "best" estimate as well as a low and high value relative to the "best" estimate.

Column 4, "Small Leakage Pathway," is comprised of three sub-columns (4a, 4b, and 4c). These sub-columns are described in detail below.

Column 4a, "Small Leakage Pathway – Total Degraded ILRTs," presents the total number or fraction of events for each containment degradation or containment leakage pathway that the experts feel could result in a small leakage pathway. The number or fraction of degraded events should represent the number of events out of 1000 containment degradations discovered either through the ILRT, containment inspections, or other means. A small leakage pathway is defined as a leakage pathway that would result in an La of 1 or greater and less than 2 La. In addition, experts are asked to augment column 2 with any additional failure modes or containment degradations that do not currently appear in the table.

On the spreadsheet containing the historical ILRT data, the number of events from the ILRT database is a ratio that represents the number of failures in 1000 tests for each containment degradation or failure mode. It is conservatively assumed that the ILRT database was representative of approximately 400 successful tests. Therefore, the number of events was multiplied by 2.5 so that the result represented the number of events out of 1000 hypothetical tests.

Column 4b, "Small Leakage Pathways – Detected by Alternate Means," presents the number or fraction of ILRT events for each containment degradation or containment leakage pathway that is small and that the experts feel could be detected or discovered by alternate means. Detection by alternate means includes other inspections, normal operation, or other tests such as a local leak rate test. This column can include a fraction that is thought would be detected. The experts are asked to complete or change this column. As with the other columns in this table, it is to be based on 1000 ILRTs performed and entries can be in fractional form.

On the spreadsheet containing the historical ILRT data, the number of small-leakage events that were detected by alternate means is a ratio that represents the number of detections per 1000 ILRTs performed.

Column 4c, "Small Leakage Pathway – Detectable by ILRT Only (failures)," represents those leakage path events identified in the course of conducting ILRTs or that could only be detected by an ILRT Type A test. This value is calculated by subtracting the detected events from the total number of events (subtract column 4b from 4a). The resulting value is used in the estimation of the risk impact associated with the optimization of ILRT testing intervals, because these leakage path events represent those detectable only during the conduct of an ILRT.

Column 5, "Medium Leakage Pathway," is comprised of three sub-columns (5a, 5b, and 5c). These three sub-columns descriptions are similar to the above for the small leakage pathway,

except that a medium pathway is defined as a leakage pathway that would result in an La from 2 to <10 La.

Column 6, "Large Leakage Pathway," is comprised of three sub-columns (6a, 6b, and 6c). The three sub-columns descriptions are similar to the above for the small leakage pathway, except that a large pathway is defined as a leakage pathway that would result in an La of greater than 10 La.

Column 7, "Extremely Large Pathway," is comprised of three sub-columns (7a, 7b, and 7c). The three sub-columns descriptions are similar to the above for the small leakage pathway except that an extremely large pathway is defined as a leakage pathway that would result in an La greater than 100 La. Experts should note that certain failure modes may not be applicable given the size of this postulated leakage path. Experts should note these cases in the comments section of the form.

Column 8, "Notes," provides a space for the experts to provide a basis for the assigned values. Due to space limitations on the table, experts are asked to number their notes and comments and provide them on a separate lined form.

5.5.2 Summary of Expert Elicitation Input Table Rows

The rows in the expert elicitation input table are sequentially numbered. Each numbered entry represents a containment failure mode that can result in a containment leakage event. Some failure modes have been experienced in the ILRT database, and these appear on the table. Other containment failure modes have not been experienced and are hypothetical. Experts are encouraged, based on their experience, to augment or change the table with the deletion or addition of failure modes. Special consideration is given to those failure modes that are age-related and may appear in the current ILRT testing data.

A summary row is provided in the table. In this summary row, the contributions to small, medium, large, and extremely large containment degradations or failure modes are summed. In addition, those failure modes detected by alternate means are also summed for the leakage classes of small, medium, large, and extremely large. Lastly, the same is performed for the total "Detectable by ILRT Only" columns for each size category.

The above report sections present the planned elicitation of expert opinion. The experts were free to change the process and/or inputs as they saw fit to account for all the potential contributors to the ILRT failure probability. The details of the experts' changes to the process and input are provided in the "Expert Elicitation Results and Analysis," Section 6.

Table 5-2
Summary of Expert Elicitation

No.	Failure Mode or degradation Description	Estimate of Low, Best, and High Value	Small Leakage Pathway (< 2La)			Medium Leakage Pathway (2 - 10 La)			Large Leakage Pathway (> 10 La)			Extremely Large Pathway (> 100 La)			Notes
			Total Degraded ILRTs	Detected by Alternate Means	Detectable by ILRT Only (failures)	Total Degraded ILRTs	Detected by Alternate Means	Detectable by ILRT Only (failures)	Total Degraded ILRTs	Detected by Alternate Means	Detectable by ILRT Only (failures)	Total Degraded ILRTs	Detected by Alternate Means	Detectable by ILRT Only (failures)	
1	Original containment design deficiency	Low													
		"Best"													
		High													
2	Construction error or deficiency (e.g., construction debris in concrete)	Low													
		"Best"													
		High													
3	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low													
		"Best"													
		High													
4	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low													
		"Best"													
		High													
5	Erosion	Low													
		"Best"													
		High													
6	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low													
		"Best"													
		High													
7	Fatigue failures (e g., bellows fatigue failure)	Low													
		"Best"													
		High													
8	Others / Unknown	Low													
		"Best"													
		High													
9	TBD	Low													
		"Best"													
		High													
	TOTALS	Low													
		"Best"													
		High													

6
EXPERT ELICITATION RESULTS AND ANALYSIS

This report section provides the results of the expert elicitation as well as the analysis of those results. Included in the results are the changes made by the experts to the input form and processes.

6.1 Expert Elicitation Input Changes

As part of the expert elicitation process, the experts are free to change the expert elicitation process and inputs based on their collective experience and judgment. As a result of expert deliberation, several changes were made to the expert elicitation form. These changes included the following:

- Development of separate input forms for the collection of containment failure modes based on containment size. Separate forms were developed to address large containment types as well as small containments. For the purposes of discussion, small containments were those less than a million cubic feet in free volume. Those containments larger than approximately one million cubic feet in free volume were considered large containments. In general, the small containments were those associated with certain BWRs and ice condenser containment designs. It was agreed by the experts to collect expert opinion on both containment designs and to decide based on statistical analysis whether significant differences existed to warrant the development of separate ILRT "failure" probabilities.
- The collection of expert opinion was based on the existing testing scheme that is present in the data. This is conservatively considered to be an ILRT test every three years. While it was recognized that the data were indeed collected over a period where the ILRT testing interval ranged from an average of once every three years (three ILRTs per 10-year interval) to once per 10 years, the experts felt that the majority of testing data were obtained from the three-in-10-year ILRT testing interval.
- Adjustment of the column for large leakage pathway from representing leakage of >10 La to a leakage of 10–100 La.

- Significant changes to failure modes were made by the experts. Specifically, a smaller number of failure modes were addressed in the input form based on the expert opinion that the current set of containment failure modes overlapped and potentially double-counted the potential containment failure modes. The failure modes (1) original containment design deficiency and (5) erosion were eliminated. Events initially assigned to these categories were re-categorized into the final "Tabulation and Categorization of Historical Data," Appendix A.

The revised expert elicitation input forms are displayed in Appendix B.

6.2 Expert Elicitation Input

The input received from the experts is presented in detail in Appendix B. The experts deliberated on all the facets of containment bypass pathways. The significant areas for deliberation included:

- The potential containment failure modes to be considered
- The effect of the failure modes on containment leakage
- The potential to detect excessive leak paths (failures) with tests, maintenance, and inspections, other than integrated leak rate testing
- The effects of aging on the containments and the resulting failure modes
- The fact that not all potential containment failure modes may appear in the current data (failure mode hibernation)
- Different containment types having the potential for different failure modes with potentially different failure rates

Following significant deliberation, the experts provided their individual input on the adjusted expert elicitation forms. The input from the experts is solicited in the following form.

As stated previously, input is elicited for four ranges of leakage pathways. These four ranges are presented in columns in the expert elicitation form. The four leakage pathways size ranges are as follows:

- From 1 La to <2 La
- From 2 La to <10 La
- From 10 La to 100 La [3]
- Greater than 100 La

Within each leakage pathway range, input is elicited on the potential for any containment bypass pathway of the specific size, the potential to detect the leakage pathway by alternate means including other testing, maintenance, inspections, and finally the total containment bypass

[3] The initial expert elicitation form contained the ranges of ">10 La" and ">100 La." During the expert elicitation, these entries were clarified to "10–100 La" and ">100 La."

pathway that can only be detected by the performance of the ILRT. This input is presented in columns in the expert elicitation form under each leakage pathway range.

For each of these leakage pathway ranges, the input is solicited by containment failure mode. The containment failure modes are presented in rows of the input elicitation form. A total of five containment failure modes were identified by the experts. These five failure modes are:

1. **Construction errors or deficiency.** An example is construction debris in concrete.

2. **Human error associated with testing or maintenance.** For example, testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, and/or improper components such as o-rings or washers in mechanical joints.

3. **Human error, design error, or other deficiency associated with modifications.** For example, purge valves installed in wrong direction, spare pipes not capped, and debris left in isolation valve.

4. **Corrosion.** For example, corrosion near water interface in bilges, corrosion of expansion bellows, and corrosion of pipe caps.

5. **Fatigue failures.** An example is bellows fatigue failure.

For each containment failure mode, the experts provided a low, "best," and high estimate for the number of failures based on 1000 hypothetical tests. In addition, a row was added to the table that provides the totals for the potential for a containment bypass pathway within the specified range. These totals included a total of the potential for the failure, a detection of the failure by alternate means, and the potential that the bypass pathway can only be detected by the performance of an ILRT.

The experts completed this input for both small and large containments. The detailed expert input is contained in Appendix B.

6.3 Statistical Analysis of the Expert Elicitation Input

Given the large amount of input collected from the experts, it is necessary to perform analysis of their collective input to develop the community distribution. Specifically, the risk impact assessment of the ILRT interval optimization requires the determination of the ILRT "failure" rate as a function of containment leakage pathway.

6.3.1 Statistical Analysis – Introduction

The purpose of this analysis is to determine a relationship between the containment leak size determined by an ILRT and its probability of occurrence. Let A be a random variable denoting

the containment leak size measured in La. The desired relationship is the complementary cumulative distribution function (CCDF), $Q(a)$, of A, which is defined as:

$$Q(a) \equiv \Pr\{A \geq a\} \qquad \text{Eq. 6-1}$$

In this analysis, it is assumed that A has a Weibull distribution, which has been chosen because of its ability to assume a wide variety of shapes (both increasing and decreasing hazard rates) and mathematical convenience. In reliability engineering, the Weibull distribution is often used to model the breaking strengths of materials. The CCDF of the Weibull distribution is:

$$Q(a) \equiv \exp(-\lambda a^{\beta}) \qquad a, \lambda, \beta > 0 \qquad \text{Eq. 6-2}$$

The parameter λ is termed the scale parameter; the parameter β is termed the shape parameter. Thus, the objective of the statistical analysis is to estimate the parameters λ and β using the information obtained through the expert elicitation process.

Least squares estimation has been used to determine the values of the parameters λ and β. Equation (2) may be linearized using a double logarithmic transformation:

$$\ln\left[\ln\left(\frac{1}{Q(a)}\right)\right] = \ln\lambda + \beta \ln a \qquad \text{Eq. 6-3}$$

Assume that estimates of $Q_j = Q(a_j)$ exist for various containment leak sizes a_j. Define:

$$\begin{aligned} y_j &= \ln\left[\ln\left(\frac{1}{Q_j}\right)\right] \\ x_j &= \ln a_j \\ b_1 &= \ln\lambda \\ b_2 &= \beta \end{aligned} \qquad \text{Eq. 6-4}$$

Then, the parameters λ and β may be determined through solution of the linear regression model:

$$y = b_1 + b_2 x + \varepsilon \qquad \text{Eq. 6-5}$$

The quantity ε denotes a random quantity to account for the measurement error in each y_j value. In ordinary least squares estimation, it is assumed that:

- The measurement errors are independent across the y_j values (the measurement error for a given y_j value is independent of the measurement errors for all other y_j values).
- The measurement errors are described by a common normal uncertainty distribution having variance σ^2.

As discussed in the following paragraphs, neither of these assumptions holds. Therefore, a generalized least squares method must be used.

6.3.2 Statistical Analysis – Input Information

In general, each expert has estimated the probability that the containment leak size falls into one of four ranges:

$$\begin{aligned} P_1 &= \Pr\{1 < A \leq 2\} \\ P_2 &= \Pr\{2 < A \leq 10\} \\ P_3 &= \Pr\{10 < A \leq 100\} \\ P_4 &= \Pr\{A > 100\} \end{aligned} \qquad \text{Eq. 6-6}$$

Recognizing the uncertainties involved, the actual information provided by each expert consists of order triplets (P_{iL}, P_{iB}, P_{iH}), denoting the low, best, and high estimate of the various P values. Thus, the P values are random variables, whose distributions must be determined by using the ordered triplets provided by each expert. It is assumed that the P values are independent random variables having the following parameters:

$$\mu_{Pi} = \text{mean}$$
$$\sigma^2_{Pi} = \text{variance}$$

The variance of each P value is estimated using Chebyshev's Inequality, which applies to all probability distributions:

$$\Pr\{P_{iL} < P_i < P_{iH}\} = \Pr\{\mu_{Pi} - k\sigma_{Pi} < P_i < \mu_{Pi} + k\sigma_{Pi}\} \geq 1 - \frac{1}{k_i^2} \qquad \text{Eq. 6-7}$$

Thus:

$$\begin{aligned} P_{iL} &= \mu_{Pi} - k\sigma_{Pi} \\ P_{iB} &= \mu_{Pi} \\ P_{iH} &= \mu_{Pi} + k\sigma_{Pi} \end{aligned} \qquad \text{Eq. 6-8}$$

Which suggests:

$$\mu_{Pi} = P_{iB}$$
$$\sigma_{Pi}^2 = \max\left[\frac{(P_{iB} - P_{iL})^2}{k^2}, \frac{(P_{iH} - P_{iB})^2}{k^2}\right] \qquad \textbf{Eq. 6-9}$$

The parameter k is related to the probability that P_i lies within the open interval (P_{iL}, P_{iH}). For example:

$$0.9 = \Pr\{P_{iL} < P_i < P_{iH}\} \geq 1 - \frac{1}{k^2} \quad \Rightarrow \quad k = \sqrt{\frac{1}{1-0.9}} = \sqrt{10} \qquad \textbf{Eq. 6-10}$$

The P values relate to $Q(a)$ through the following equations:

$$\begin{aligned}
P_1 &= \Pr\{1 < A \leq 2\} = \Pr\{A > 1\} - \Pr\{A > 2\} = Q(1) - Q(2) \\
P_2 &= \Pr\{2 < A \leq 10\} = \Pr\{A > 2\} - \Pr(A > 10\} = Q(2) - Q(10) \\
P_3 &= \Pr\{10 < A \leq 100\} = \Pr\{A > 10\} - \Pr(A > 100\} = Q(10) - Q(100) \\
P_4 &= \Pr\{A > 100\} = Q(100)
\end{aligned} \qquad \textbf{Eq. 6-11}$$

Rearranging the above equations shows that:

$$\begin{aligned}
Q_1 &= Q(1) = \Pr\{A > 1\} = P_1 + P_2 + P_3 + P_4 \\
Q_2 &= Q(2) = \Pr\{A > 2\} = P_2 + P_3 + P_4 \\
Q_3 &= Q(10) = \Pr\{A > 10\} = P_3 + P_4 \\
Q_4 &= Q(100) = \Pr\{A > 100\} = P_4
\end{aligned} \qquad \textbf{Eq. 6-12}$$

Note that the Q values are dependent random variables because they are functions of the P values. In general, the Q values have different variances. Noting that the Q values are sums of independent random variables, then:

$$\begin{aligned}
\sigma_{Q1}^2 &= \sigma_{P1}^2 + \sigma_{P2}^2 + \sigma_{P3}^2 + \sigma_{P4}^2 \\
\sigma_{Q2}^2 &= \sigma_{P2}^2 + \sigma_{P3}^2 + \sigma_{P4}^2 \\
\sigma_{Q3}^2 &= \sigma_{P3}^2 + \sigma_{P4}^2 \\
\sigma_{Q4}^2 &= \sigma_{P4}^2 \\
\therefore \quad & \sigma_{Q1}^2 \neq \sigma_{Q2}^2 \neq \sigma_{Q3}^2 \neq \sigma_{Q4}^2
\end{aligned} \qquad \textbf{Eq. 6-13}$$

The covariance between any two Q values is given by:

$$Cov(Q_i, Q_j) = \sum_{k=\max(i,j)}^{4} \sigma_k^2 > 0 \qquad \text{Eq. 6-14}$$

6.3.3 Statistical Analysis – Generalized Least Squares Method

The generalized least squares method determines parameter estimates by minimizing the following quantity:

$$D^2 = \mathbf{e}'\Sigma^{-1}\mathbf{e} \qquad \text{Eq. 6-15}$$

Where D^2 is a weighted sum of the squared residuals. The "D" means deviation, and the "2" implies squared. The **e** is an n x 1 matrix (column vector) of the residuals ($e_j = y_j - b_1 - b_2 x_j$), and Σ is an n x n covariance matrix that describes the measurement errors in the y_j values. For the superscripts, the prime denotes matrix transpose and the exponent -1 denotes matrix inversion. Define:

$$\mathbf{y} = \begin{bmatrix} y_1 \\ \\ y_n \end{bmatrix} \qquad \mathbf{x} = \begin{bmatrix} 1 & x_1 \\ \\ 1 & x_n \end{bmatrix} \qquad \mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \qquad \text{Eq. 6-16}$$

Then, the generalized least squares solution is given by:

$$\mathbf{b} = \left(\mathbf{x}'\Sigma^{-1}\mathbf{x}\right)^{-1} \mathbf{x}'\Sigma^{-1}\mathbf{y} \qquad \text{Eq. 6-17}$$

The covariance matrix of the parameter estimates is given by:

$$Var(\mathbf{b}) = \left(\mathbf{x}'\Sigma^{-1}\mathbf{x}\right)^{-1} = \begin{bmatrix} \sigma_{b1}^2 & \sigma_{b1b2}^2 \\ \\ \sigma_{b1b2}^2 & \sigma_{b2}^2 \end{bmatrix} \qquad \text{Eq. 6-18}$$

The Σ matrix is determined by considering the impact of the uncertainties of the P values on the y values. These impacts can be approximated using statistical error propagation (the "delta method"):

$$\sigma_{Yi}^2 \approx \sum_{k=1}^{4} \left(\frac{\partial Y_i}{\partial P_k}\right)^2 \sigma_{Pk}^2 \qquad \text{variance terms}$$

$$\sigma_{YiYj}^2 \approx \sum_{k=1}^{4} \left(\frac{\partial Y_i}{\partial P_k}\right)\left(\frac{\partial Y_j}{\partial P_k}\right) \sigma_{Pk}^2 \qquad \text{covariance terms} \qquad \text{Eq. 6-19}$$

Where the partial derivatives are evaluated at the means of the P values. It is convenient to define:

$$\phi_k = \mu_{Qk} \ln \mu_{Qk} \qquad \text{Eq. 6-20}$$

Then:

$$\Sigma = \begin{bmatrix} \frac{\sigma_{Q1}^2}{\phi_1^2} & \frac{\sigma_{Q2}^2}{\phi_1\phi_2} & \frac{\sigma_{Q3}^2}{\phi_1\phi_3} & \frac{\sigma_{Q4}^2}{\phi_1\phi_4} \\ \frac{\sigma_{Q2}^2}{\phi_1\phi_2} & \frac{\sigma_{Q2}^2}{\phi_2^2} & \frac{\sigma_{Q3}^2}{\phi_2\phi_3} & \frac{\sigma_{Q4}^2}{\phi_2\phi_4} \\ \frac{\sigma_{Q3}^2}{\phi_1\phi_3} & \frac{\sigma_{Q3}^2}{\phi_2\phi_3} & \frac{\sigma_{Q3}^2}{\phi_3^2} & \frac{\sigma_{Q4}^2}{\phi_3\phi_4} \\ \frac{\sigma_{Q4}^2}{\phi_1\phi_4} & \frac{\sigma_{Q4}^2}{\phi_2\phi_4} & \frac{\sigma_{Q4}^2}{\phi_3\phi_4} & \frac{\sigma_{Q4}^2}{\phi_4^2} \end{bmatrix} \qquad \text{Eq. 6-21}$$

6.3.4 Statistical Analysis – Uncertainty Bounds

The generalized least squares parameter estimates and their associated covariance matrix are used to estimate *Q(a)* and its uncertainty bounds. The point estimate of *Q(a)* is given by:

$$\hat{Q}(a) = \exp\left[-\exp(\hat{b}_1 + \hat{b}_2 \ln a)\right] \qquad \text{Eq. 6-22}$$

Let X be a random variable defined as the logit transformation of *Q(a)*:

$$X = \text{logit}(Q) = \ln\left(\frac{Q}{1-Q}\right) \qquad \text{Eq. 6-23}$$

It is assumed that X has a normal distribution, with mean μ_V and standard deviation σ_V. Using statistical error propagation, the parameters of V are given by:

$$\mu_V = \ln\left(\frac{\hat{Q}(a)}{1-\hat{Q}(a)}\right) \qquad \text{Eq. 6-24}$$

$$\sigma_V = \frac{\exp(\hat{b}_1 + \hat{b}_2 \ln a)}{1-\hat{Q}(a)}\sqrt{\hat{\sigma}_{b1}^2 + (\ln a)^2 \hat{\sigma}_{b2}^2 + 2(\ln a)\hat{\sigma}_{b1b2}^2} \qquad \text{Eq. 6-25}$$

Applying Equations (23) through (25), it can be demonstrated that:

$$\hat{Q}_{0.05}(a) = \frac{\hat{Q}(a)}{\hat{Q}(a) + \left(1 - \hat{Q}(a)\right)w}$$

$$\hat{Q}_{0.95}(a) = \frac{\hat{Q}(a)}{\hat{Q}(a) + \left(1 - \hat{Q}(a)\right)\frac{1}{w}}$$

Eq. 6-26

Where:

$$w = \exp(z_{0.95}\sigma_V)$$

Eq. 6-27

and $z_{0.95}$ is the 95th percentile of the standard normal distribution (≈1.645).

6.3.5 Statistical Analysis – Combining Expert Opinion

For a given leak size a, *Q(a)* has an associated uncertainty distribution. Define:

$$F(q) = \Pr\{Q(a) \le q\}$$

Eq. 6-28

That is, *F(q)* is the cumulative probability distribution function of *Q(a)*. Expert opinions have been aggregated by forming a mixture distribution of the *Q(a)* probability distributions developed for each expert:

$$F(q) = \frac{1}{n}\sum_{i=1}^{n} F_i(q)$$

Eq. 6-29

Where *F(q)* denotes the aggregated cumulative distribution of *Q(a)*, $F_I(q)$ denotes the cumulative distribution function of *Q(a)* developed from the information provided by the *i*th expert, and *n* denotes the number of experts. Explicitly:

$$F(q) = \frac{1}{n}\sum_{i=1}^{n} \Phi\left[\frac{\text{logit}(q) - (b_{1i} + b_{2i}\ln a)}{\sigma_{yi}}\right]$$

Eq. 6-30

Where Φ() denotes the standard normal cumulative distribution function. In order to determine percentiles of the aggregated distribution, Equation (30) must be solved numerically for *q* given that *F(q)* equals a specified value (for example, 0.05 or 0.95).

6.3.6 Statistical Analysis – Final Results

The detailed final results of the statistical analysis of the expert elicitation are provided in Appendix C. In summary, a spreadsheet and visual basic computer routines were developed to assist in the analysis of the input data (see Table 6-1).

Table 6-1
Expert Elicitation Results – Leak Size Versus Probability

Leakage Size (La)	Mean Probability of Occurrence
1	2.65E-02
2	1.59E-02
5	7.42E-03
10	3.88E-03
20	1.88E-03
35	9.86E-04
50	6.33E-04
100	2.47E-04
200	8.57E-05
500	1.75E-05
600	1.24E-05
1000	4.50E-06
2000	1.01E-06
5000	1.11E-07
10000	1.73E-08

The input data used was the trim mean. That is, the lowest and highest experts were not included in the development of the community distribution. This treatment was performed for several reasons. One expert used zero several times in the assignment of the probability of ILRT failure. Zeros are difficult to treat in the statistical evaluation of the expert input. Therefore, this expert was not included in the development of the community distribution. Because the lowest expert was not included in the development of the community distribution, it was prudent to not include the highest expert in the development of the community distribution as well. This treatment results in the use of a set of four experts as opposed to six to develop the community distribution. Therefore, the community distribution represents the center of the input data collected.

In addition, no community distribution was developed for the small containment case. This is a result of the fact that analysis of the small containment input data actually produces slightly lower values for the probability of a leakage pathway in the small containments. The differences are very small and do not represent a significant difference in the probability. Therefore, the small containment case was not evaluated. It should be noted that one expert did not complete small containment input sheets because he or she believed that there was no reason to treat the small containments differently than the large containment type.

Both of the above treatments of the input data were discussed with experts during the elicitation meeting as being potential treatments of the final results. Experts agreed with this treatment. The final results of the determination of the probability of a leakage pathway can be described in tabular format as follows:

Appendix C contains the detailed results of the expert elicitation. It is interesting to note that the values contained in Table 6-1 agree relatively closely with those produced using other methods such as those in the joint applications report for containment integrated leak rate test interval extension [15].

7
TECHNICAL APPROACH

The guidance provided in this report section builds on the EPRI Risk Impact Assessment Methodology [1] and the NRC Performance-Based Containment Leakage Test Program [2] and is consistent with applicable risk-informed decision-making principles of NRC Regulatory Guide 1.174 [4]. This assessment methodology also considers approaches utilized in various utility submittals, including Indian Point 3 (and the associated NRC SER) and Crystal River [3, 5, 6].

The guidance in this report section improves on the above methods in several areas.

The first area involves the methodology for determining the impact resulting from extending surveillance intervals. References [1] and [2] both consider the percentage increase in the probability of leakage as an appropriate multiplier to be used in risk impact dose calculations. It is now believed that the multiplier used should be a factor representing the change in probability of leakage. As stated in References [1] and [2], relaxing the test interval from three in 10years to one in 10 years increases the average time that a leak detectable only by an ILRT would go undetected from 18 (three years/2) to 60 (10 years/2) months. This is a factor of 60/18 = 3.333.

The baseline dose determined in the EPRI report was $7x10^{-3}$ person-rem per year, and the dose associated with the ten-year interval was calculated using the percentage increase (10%), or 1.1 times the baseline, $7.7x10^{-3}$ person-rem per year. Using 3.33 would yield a 10-year dose of $3.33 \times 7x10^{-3} = 2.3x10^{-2}$ person-rem per year [4]. The 10-year dose increase is still a very small risk contribution, only 0.11% of the total dose of 22 person-rem per year. This represents an increase in risk of 0.078% from the baseline contribution of 0.032%. The small increase in total dose results because ILRTs address a very small portion of the severe accident risk. NUREG-1493 reported a similar 0.07% risk increase for Surry under the same assumptions and interval extension.

The second improvement area is in the methodology used to determine the frequencies of leakages detectable only by ILRTs, Classes 3a and 3b. The method utilized in the aforementioned utility submittals involved using a 95% confidence of the distribution of the noted ILRT failures (4 of 144 reported in NUREG-1493). Data collected recently by NEI

[4] The EPRI report was based on the logic that because ILRTs detect only 3% of leaks, the factor of a 3.333 increase results in a change in the overall probability of leakage from 3% to 3 * 3.333 = 10%, or a 10% increase in the baseline dose. The baseline dose determined in the EPRI report was $7x10^{-3}$ person-rem/yr, and the dose associated with the 10-year interval was calculated as a 10% increase or 1.1 times the baseline, $7.7x10^{-3}$ person-rem/yr. It is now believed that the dose associated with the 10-year interval should have been calculated based on the change in the probability of leakage, 3.333, rather than the factor of 1.10. The argument above shows this difference to not affect the overall conclusions regarding ILRT interval changes.

from 91 nuclear power plants indicates that 38 plants have conducted ILRTs since January 1995, with only one failure (due to construction debris from a penetration modification). This would indicate that the statistical information should be based on five out of 182 failures. Rather than using the 95% confidence of the distribution, it had been considered more appropriate (and more conservative) to utilize the mean (5/182 = 0.027) for the class 3a distribution, and Jeffreys non-informative prior distribution [7] for the class 3b distribution.

In this methodology, expert elicitation is used to develop a relationship between the size of the potential containment leakage pathway, expressed as La, and the probability of occurrence. The expert elicitation considers the data, experience, potential undetected failure modes, hibernating failure modes, and other issues. This method of the development of the probability of containment leakage is a considerable improvement over the use of non-informative priors.

The third improvement includes provisions for utilizing representative plant dose calculations that are related to NUREG-1150 doses[5]. This approach will be employed in this report for the industry-wide generic assessments conducted to assess the risk impact of optimized extension of ILRT intervals. However, if an individual plant desired to conduct a plant-specific assessment and the plant information was available in the plant PRA, it could be utilized.

The EPRI methodology [1] employed a simplified risk model. PRA containment event trees (CETs) provide a risk framework for evaluating the effect of containment isolation failures affected by leakage testing requirements. The complexity of the CET models, however, is not necessary to evaluate the impact of containment isolation system failures. Therefore, a simplified risk model was developed to distinguish between those accident sequences that are affected by the status of the containment isolation system versus those that are a direct function of severe accident phenomena. The simplified risk model allowed for a smaller number of CET scenarios to be evaluated to determine the baseline risk as well as subsequent analysis to quantify risk effects of extending test intervals. The methodology regrouped core damage accident sequences reported in PRAs that were reviewed in the study into eight classifications to permit the aforementioned differentiation. See Table 7-1 for a description of the eight end-state classifications. The risk metric was defined as the product of frequency and consequence (person-rem/reactor-year).

The Indian Point Methodology [3] quantifies leakage from accident sequences in end states (3a and 3b). Accident sequence end states 3a and 3b have the potential to result in a change in risk associated with changes in ILRT intervals because a pre-existing leak is assumed to be present for these end states. By manipulating the probability of a pre-existing leak of sufficient leak size, an evaluation of the change in LERF can be performed. The NRC [5] considered this an improvement on the EPRI study. Similar information is contained in the Crystal River submittal [6].

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[5] EPRI report TR-104285 developed consequence measures in terms of population dose for each accident class. The analysis required defining offsite consequences. While the representative plants were not NUREG-1150 plants, this analysis used the MACCS consequence (population dose) calculations conducted for NUREG-1150, Surry, and Peach Bottom. See page 4-5 of the EPRI report for more detail.

This interim assessment guidance incorporates these and other features of the above methodologies. The first seven steps of the interim methodology calculate the change in dose. The change in dose is the principal basis upon which the Type A ILRT interval extension was previously granted and is a reasonable basis for evaluating additional extensions. The eighth step in the interim methodology calculates the change in LERF and compares it to the guidelines in Regulatory Guide 1.174. Because there is no change in CDF, the change in LERF suffices as the quantitative basis for a risk-informed decision per current NRC practice, namely Regulatory Guide 1.174. The ninth and final step of the interim methodology calculates the change in containment failure probability. The NRC has previously accepted similar calculations [2], referred to as conditional containment failure probability (CCFP), as the basis for showing that the proposed change is consistent with the defense-in-depth philosophy. As such, this last step suffices as the remaining basis for a risk-informed decision per Regulatory Guide 1.174:

1. Quantify the base line (nominal three year ILRT interval) risk in terms of frequency per reactor year for the EPRI accident classes of interest. Note that Classes 4, 5, and 6 are not affected by changes in ILRT test frequency, and their contribution to population dose is quite small. Therefore, these classes are not considered in this assessment methodology.

2. Determine the containment leakage rates for applicable cases, 3a and 3b.

3. Develop the baseline population dose (person-rem, from the plant PRA or IPE, or calculated based on leakage) for the applicable accident classes.

4. Determine the population dose rate (person-rem/year) by multiplying the dose calculated in step 3 by the associated frequency calculated in step 1.

5. Determine the change in probability of leakage detectable only by ILRT, and associated frequency for the new surveillance intervals of interest. Note that with increases in the ILRT surveillance interval, the size of the postulated leak path and the associated leakage rate are assumed not to change. However, the probability of leakage detectable only by ILRT does increase.

6. Determine the population dose rate for the new surveillance intervals of interest.

7. Evaluate the risk impact (in terms of population dose rate and percentile change in population dose rate) for the interval extension cases.

8. Evaluate the risk impact in terms of LERF.

9. Evaluate the change in CCFP.

The methodology is employed to assess the risk impact of extending optimized ILRT intervals of up to twenty years. Representative plant assessments are provided at the end of this document.

7.1 Step One: Baseline Risk Determination

In this step, the baseline risk is determined in terms of core damage frequency per reactor year for the EPRI accident classes[6] excluding accident classes 4, 5, and 6. EPRI accident classes 4, 5, and 6 are excluded because ILRT Type B&C tests, and multiple failures of redundant isolation valves to stroke closed, are not impacted by changes in ILRT frequency, and their contribution to population dose is small. The determination of the baseline risk is accomplished as follows:

- Referring to the plant PRA or IPE, obtain core damage frequency (CDF) values for the EPRI accident classes 1, 2, 7, and 8 or the plant specific accident class equivalent.
- Determine the frequencies for Class 3a and Class 3b as follows:
  - frequency = Intact CDF (class 1) * Class 3a leakage probability
  - frequency = intact CDF (class 1) * Class 3b leakage probability

    To calculate the probability that a liner (or other leak path not monitored by local leak rate testing and/or alternate means) leak will be large (accident Class 3b), use was made of expert elicitation to establish the relationship between the size of potential containment leakage expressed as La and the probability of occurrence.

    A similar approach was used to calculate the probability that a liner leak will be small (accident Class 3a), using the relationship developed by the expert elicitation.
- Adjust the accident Class 1 frequency as (individual plant examination [IPE] Class 1) minus (Class 3a and Class 3b). This is necessary to maintain the sum of the frequencies of the accident classes equal to the CDF.

7.2 Step Two: Determination of Containment Leakage Rates

Determine the base-line accident dose for the accident classes, except for 4, 5, and 6:

- From the plant IPE or PRA, determine the relationship between offsite dose (person-rem) and containment leakage rate (the dose in person-rem) for Class 1, 1.0 La.
- From the plant IPE, determine the offsite dose (person-rem) for the accident classes where analysis is available, typically Classes 1, 2, 7, and 8.
- For those accident classes where analysis is not available in the IPE or PRA, determine the dose by first determining the class containment leak rate and multiplying by the 1.0 La dose.
- For accident Classes 3a and 3b leak rate, conservative values of 10 La and 100 La, respectively are used.

[6] See Section 7.10 for a complete description of the EPRI accident classes.

7.3 Step Three: Develop the Baseline Population Dose

In this step, the baseline population dose (person-rem, from the plant PRA, or calculated based on leakage) is developed for the applicable accident classes.

7.4 Step Four: Determine Baseline Dose Rate

Determine the baseline accident class dose rates (person-rem/year) by multiplying the dose by the frequency for each of the accident classes. Sum the accident class dose rates to obtain the total dose rate.

7.5 Step Five: Determine Change in Pre-Existing Leak Probability

Determine the change in probability of leakage detectable only by ILRT (Classes 3a and 3b) for the new surveillance intervals of interest.

NUREG 1493 [5] states that relaxing the ILRT frequency from three in 10 years to one in 10 years will increase the average time that a leak that is detectable only by ILRT goes undetected from 18 to 60 months (1/2 the surveillance interval), a factor of 60/18 = 3.33 increase.

Therefore, relaxing the ILRT testing interval from three in 10 years to one in 20 years will increase the average time that a leak that is detectable only by ILRT goes undetected from 18 to 120 months (1/2 the surveillance interval), a factor of 120/18 = 6.67 increase.

7.6 Step Six: Determine Revised Population Dose Rate

Determine the population dose rate for the new surveillance intervals of interest by multiplying the dose by the frequency for each of the accident classes. Sum the accident class dose rates to obtain the total dose rate.

7.7 Step Seven: Determine Percentage Increase In Population Dose

Determine the percentile increase in dose rate for each extended interval as follows: Percent increase = [(total dose rate of interval minus total baseline dose rate) divided by (total baseline dose rate)] x 100

7.8 Step Eight: Evaluate Change In LERF

Evaluate the risk impact in terms of change in LERF. The risk associated with extending the ILRT interval involves a potential that a core damage event that normally would result in only a small radioactive release from containment could result in a large release due to an undetected

leak path existing during the extended interval. As discussed in References [1] and [2], only Class 3 sequences have the potential to result in early releases if a pre-existing leak were present. Late releases are excluded regardless of size of the leak because late releases are not, by definition, LERF events. The frequency of class 3b sequences are used as a measure of LERF, and the change in LERF is determined by the change in class 3b frequency.

ΔLERF = (frequency class 3b interval x) - (frequency class 3b baseline).

Refer to Regulatory Guide 1.174 [4] for criteria defining acceptable changes in LERF.

7.9 Step Nine: Evaluate Conditional Containment Failure Probability (CCFP)

Evaluate the change in CCFP. The conditional containment failure probability is defined as the probability of containment failure given the occurrence of a core damage accident, which can be expressed as:

CCFP = 1 - (frequency that results in no containment failure)/CDF

CCFP = 1 - (frequency class 1 + frequency class 3a)/CDF

7.10 EPRI Accident Class Descriptions

Extension of the Type A interval does not influence those accident progressions that involve containment isolation failures associated with Type B or Type C testing or containment failure induced by severe accident phenomena. The CET containment isolation models are reviewed for applicable isolation failures and their impacts on the overall plant risk. Specifically, a simplified model to predict the likelihood of having a small or large pre-existing breach in the containment that is undetected due to the extension of the Type A ILRT test interval is developed. For this work, the EPRI accident classes are used to define the spectrum of plant releases. The intact containment event was modified to include the probability of a pre-existing containment breach at the time of core damage. Two additional basic events are addressed. These are Event Class 3a (small leak) and Class 3b (large leak). (This addresses the "Class 3" sequence discussed in EPRI TR-104285.) Both event Class 3a and 3b are considered in estimating the public exposure impact of the ILRT extension. However, since leaks associated with event Class 3a are small (that is, marginally above normal containment leakage), only event Class 3b frequency change is considered in bounding the LERF impact for the proposed change. The eight EPRI accident classes are discussed in the following paragraphs.

Class 1 sequences: This sequence class consists of all core damage accident progression bins for which the containment remains intact with negligible leakage. Class 1 sequences arise from those core damage sequences where containment isolation is successful and long-term containment heat removal capability is available. The frequency of an intact containment is established based on the individual plant's PRA. For Class 1 sequences, it is assumed that the intact containment end state is subject to a containment leakage rate less than the containment allowable leakage

(La). To obtain the class 1 event frequency, intact containment events are parsed into three classes: Class 3a, Class 3b and Class 1. Class 1 represents containments with expected leakages less than La. Class 3a represents intact containments with leakages somewhat larger than La, and class 3b represents intact containment end states with large leaks. The frequency for class 1 events is related to the intact containment core damage frequency (CDF_{Intact}) and the class 3 categories, as follows.

$$F_{Class\ 1} = CDF_{Intact} - F_{Class\ 3a} - F_{Class\ 3b}$$

Where:

CDF_{Intact} = the core damage frequency for intact containment sequences from the plant-specific PRA.

The calculation of Class 3 frequencies is discussed below. Radiological releases for Class 1 sequences are established assuming a containment leakage rate equal to the design basis allowable leakage (La).

Class 2 sequences: This group consists of all core damage accident progression bins for which a pre-existing leakage due to failure to isolate the containment occurs. These sequences are dominated by failure-to-close of large (>2 inches [5.1 cm] in diameter) containment isolation valves. The frequency per year for these sequences is determined from the plant-specific PRA as follows:

$$F_{Class\ 2} = PROB_{large\ CI} * CDF_{Total}$$

Where:

$PROB_{large\ CI}$ = random containment large isolation failure probability (large valves), and

CDF_{Total} = Total plant specific core damage frequency, which is obtained from plant-specific PRA.

Class 3 sequences: Class 3 end states are developed specifically for this application. The Class 3 end states include all core damage accident progression bins with a pre-existing leakage in the containment structure in excess of normal leakage. The containment leakage for these sequences can be grouped into two categories: small leakage or large. The respective frequencies per year are determined as follows:

$$F_{Class\ 3a} = PROB_{Class\ 3a} * CDF_{Intact}$$

$$F_{Class\ 3b} = PROB_{Class\ 3b} * CDF_{Intact}$$

Where:

- $PROB_{Class\ 3a}$ = the probability of small pre-existing containment leakage in excess of design allowable but less than 10 La. $PROB_{Class\ 3a}$ is a function of ILRT test interval.
- $PROB_{Class\ 3b}$ = the probability of large (>100La) pre-existing containment leakage. $PROB_{Class\ 3b}$ is a function of ILRT test interval.
- CDF_{Intact} = the core damage frequency for intact containment sequences from the plant-specific PRA (EPRI class 1).

No ILRT has identified a pre-existing leakage in excess of 21 La. However, a 100 La upper limit has been conservatively selected for defining the frequency of Class 3a. Class 3a releases are estimated to be 10 La. Class 3b releases are approximated to be 100 La.

Class 4 sequences: This group consists of all core damage accident progression bins for which a failure-to-seal containment isolation failure of Type B test components occurs. Because these failures are detected by Type B tests and their frequency is very low compared with the other classes, this group is not evaluated any further. The frequency for Class 4 sequences is subsumed into Class 7, where it contributes insignificantly.

Class 5 sequences: This group consists of all core damage accident progression bins for which a failure-to-seal containment isolation failure of Type C test components occurs. Because these failures are detected by Type C tests and their frequency is very low compared with the other classes, this group is not evaluated any further. The frequency for class 5 sequences is subsumed into Class 7, where it contributes insignificantly.

Class 6 sequences: This group is similar to class 2. These are sequences that involve core damage accident progression bins for which a failure-to-seal containment leakage, due to failure to isolate the containment, occurs. These sequences are dominated by misalignment of containment isolation valves following a test/maintenance evolution, typically resulting in a failure to close smaller containment isolation valves. All other failure modes are bounded by the Class 2 assumptions.

Class 7 sequences: This group consists of all core damage accident progression bins in which containment failure induced by severe accident phenomena occurs (for example, H_2 combustion and direct containment heating):

$$F_{Class\ 7} = CDF_{CFL} + CDF_{CFE}$$

Where:

CDF_{CFE} = the core damage frequency resulting from accident sequences that lead to early containment failure, and

CDF_{CFL} = the core damage frequency resulting from accident sequences that lead to late containment failure.

$F_{Class\ 7}$ can be determined by subtracting the intact, bypass (see class 8 discussion) and loss of isolation CDFs from the total CDF. These end states include containment failure.

Class 8 Sequences: This group consists of all core damage accident progression bins in which containment bypass occurs. Each plant's PRA is used to determine the containment bypass contribution. Contributors to bypass events include ISLOCA events and SGTRs with an unisolated steam generator.

$$F_{Class\ 8} = CDF_{ISLOCA} + CDF_{Unisolated\ SGTR}$$

The magnitude of bypass releases is plant specific and is typically considerably larger (two or more orders of magnitude) than releases expected for leakage events. The containment structure will not impact the release magnitude for this event class.

Table 7-1
Description of the EPRI Accident Classes

Class No.	Description	Frequency	Leakage	Population Dose (Person-rem)	Population Dose Rate (Person- rem/rx-yr)
1	Containment intact	Calculated value $F_{Class\ 1} = CDF_{Intact} * F_{Class\ 3a} * F_{Class\ 3a}$	La	Value from plant PRA or EPRI/NUREG 1150	Dose 1 * frequency 1
2	Large containment isolation failures	Value from plant PRA $F_{Class\ 2} = PROB_{large\ CI} * CDF_{Total}$	Value from plant PRA	Value from plant PRA or EPRI/NUREG 1150	Dose 2 * Frequency 2
3a	Small pre-existing leak in containment	Calculated value $F_{Class\ 3a} = PROB_{Class\ 3a} * CDF_{Intact}$	10 La	(Class 1 dose for La) * 10La	Dose 3a * frequency 3a
3b	Large pre-existing leak in containment	Calculated value $F_{Class\ 3b} = PROB_{Class\ 3b} * CDF_{Intact}$	100 La	(Class 1 dose for La) * 100La	Dose 3b * frequency 3b
4	Small isolation failure – failure to seal – (Type B test)	NA	NA	NA	NA
5	Small isolation failure – failure to seal - (Type C test)	NA	NA	NA	NA
6	Containment isolation failures (dependent failures personnel errors)	NA	NA	NA	NA

Table 7-1 (cont.)
Description of the EPRI Accident Classes

Class No.	Description	Frequency	Leakage	Population Dose (Person-rem)	Population Dose Rate (Person- rem/rx-yr)
7	Severe accident phenomena induced failures (early and late containment failures)	Value from plant PRA $F_{Class\ 7} = CDF_{CFL} + CDF_{CFE}$	Value from plant PRA	Value from plant PRA or EPRI/NUREG-1150	Dose 7 * frequency 7
8	Containment bypass (SGTR, MSIV leakage and ISLOCA)	Value from plant PRA $F_{Class\ 8} = CDF_{ISLOCA} + CDF_{Unisol\ SGTR}$	Value from plant PRA	Value from plant PRA or EPRI/NUREG-1150	Dose 8 * frequency 8

CDF_{Intact} = the core damage frequency for intact containment sequences from the plant specific PRAs

$PROB_{large\ C1}$ = random containment large isolation failure probability (i.e. large valves)

CDF_{Total} = total plant specific core damage frequency

$PROB_{Class\ 3a}$ = the probability of small (10 La) pre-existing containment leakage

$PROB_{Class\ 3b}$ = the probability of large (>100La) pre-existing containment leakage

CDF_{CFE} = the core damage frequency resulting from accident sequences that lead to early containment failure

CDF_{CFL} = the core damage frequency resulting from accident sequences that lead to late containment failure

8
APPLICATION OF TECHNICAL APPROACH

In this report section, the technical approach outlined in Section 7 is applied to two hypothetical plants. Both of the hypothetical plants presented are based on actual plant data. The first hypothetical plant is a PWR with a large containment. The second hypothetical plant is a BWR with a small containment. There are several differences between the two applications of the methodology other than reactor and containment type. These differences include the total core damage frequency and the accident classes that comprise the core damage frequency. In addition, the PWR hypothetical example is chosen to represent a bounding application of the methodology with a core damage frequency equal to the NRC Safety Goal (that is, 1E-04 per year) whereas the BWR hypothetical plant is more representative of the BWR population of reactors.

8.1 Hypothetical Plant Application – PWR Large Containment

The hypothetical plant is a PWR with a large dry containment. The attributes of the risk profile are contained in the following table.

Table 8-1
Hypothetical PWR CDF Classes

Accident Class	Base Frequency	Dose (Person-rem)
1	4.67E-05	9.79E+05
2	4.97E-08	4.90E+08
3a		
3b		
7	4.70E-05	1.37E+09
8	6.47E-06	5.47E+08
Totals	1.00E-04	2.52E+09

Accident classes 4, 5, and 6 are not affected by the optimization of the ILRT testing interval and therefore are not included in the evaluation.

8.1.1 Step One: Baseline Risk Determination

In this step the baseline risk is obtained using the core damage frequency and large early release frequency.

The hypothetical PWR plant has been chosen to have a core damage frequency equal to 1.0×10^{-4} per year. This core damage frequency was chosen for the hypothetical PWR since it represents one of the highest core damage frequencies for a PWR with a large dry containment. The applicable leakage probability is taken from the expert elicitation results presented in Section 6. Specifically, an La of 10 is chosen to represent a small leakage pathway (accident class 3a) and an La of 100 is chosen to represent large early release frequency (accident class 3b). The basis for this selection is given in Section 8.1.2.

Therefore, the probability of a small leakage pathway (accident class 3a) is 3.90×10^{-3} and a large pre-existing leak in containment is 2.47×10^{-4} and is equivalent to EPRI accident class 3b. The resulting frequency of accident class 3a is equal to:

Frequency of Class 3a = Class 1 CDF * class 3a leakage probability

Frequency of Class 3a = 4.67×10^{-5} per year * 3.90×10^{-3}

Frequency of Class 3a = 1.81×10^{-7} per year

The resulting frequency of accident class 3b, or large early release is equal to:

Frequency of Class 3b = Class 1 CDF * class 3b leakage probability

Frequency of Class 3b = 4.67×10^{-5} per year * 2.47×10^{-4}

Frequency of Class 3b = 1.15×10^{-8} per year

Subtracting these totals from the intact accident class (accident class 1) provides a conservation of total CDF. The complete accident class frequencies are provided in Table 8-2.

Table 8-2
Hypothetical PWR Revised CDF Classes

Accident Class	Base Frequency	Revised Frequency (3/10 Year Testing Interval)
1	4.67E-05	4.65E-05
2	4.97E-08	4.97E-08
3a		1.81E-07
3b		1.15E-08
7	4.70E-05	4.70E-05
8	6.47E-06	6.47E-06
Totals	1.00E-04	1.00E-04

8.1.2 Step Two: Determination of Containment Leakage Rates

In the determination of the leakage rates that correspond to the 3a and 3b categories (that is, small and large containment leaks, respectively), previous submittals have chosen values of La of 10 to represent small containment leakage and 35 to represent large containment leakage. However, the definition of LERF is generally given as the exchange of a single containment volume before the effective implementation of the offsite emergency response and public protective actions [7]. In turn, public protective actions, are generally assumed to be taken approximately 2 to 4 hours following a core damage event. The exchange of a single containment volume within a 4 hour period corresponds to a leakage rate of 600% per day or 600–6000 times La assuming that the ILRT acceptance criteria for the plant in question is between 1% and 0.1% per day.

Assuming that the large early release frequency can best be represented conservatively for this evaluation, a value of 100 La is chosen to represent large early release frequency. This value is based on judgment and the desire to remain conservative versus the current accepted definition of large early releases. The value of 100 La represents, in the most conservative case, the exchange of a single volume of containment over a 24 hour period. No estimation is made of small containment bypass frequency.

8.1.3 Steps Three and Four: Determine Dose Rate

In this step the baseline and population dose rates are calculated. The base dose for accident classes 1, 2, 7, and 8 remain the same. The dose is calculated for classes 3a and 3b by multiplying the dose associated with class 1 by the increase in the leakage (10 for class 3a and 100 for class 3b).

Class 3a dose = Class 1 dose * increase in La

Class 3a dose = 9.79E+05 person-REM * 10

Class 3a dose = 9.79E+06 person-REM

For Class 3b where the increase in leakage rate is 100:

Class 3b dose = 9.79E+05 person-REM * 100

Class 3b dose = 9.79E+07 person-REM

The dose rate is then calculated by multiplying the dose by the frequency of occurrence of the accident class. A summary is provided in Table 8-3.

Table 8-3
Hypothetical PWR Revised Population Dose

Accident Class	Adjusted Base Frequency	Dose (Person-rem) (3/10 Year Interval)	Dose Rate (Person-rem/yr) (3/10 Year Interval)
1	4.65E-05	9.79E+05	4.55E+01
2	4.97E-08	4.90E+08	2.44E+01
3a	1.81E-07	9.79E+06	1.77E+00
3b	1.15E-08	9.79E+07	1.13E+00
7	4.70E-05	1.37E+09	6.44E+04
8	6.47E-06	5.47E+08	3.54E+03
Totals	1.00E-04	2.52E+09	6.80E+04

8.1.4 Step Five: Determine Change in Pre-Existing Leak Probability

The change in the pre-existing leak probability is based on the assumption that the pre-existing leak is a function of the time between surveillance test (that is, ILRT) testing interval. The change in the pre-existing leak probability therefore increases from 36 months divided by 2 (18 months) assuming a three year testing interval to 120 months divided by 2 (60) assuming a revised testing interval of once per 10 years. This results in a factor 3.33 increase in the probability of a pre-existing leak.

Therefore, the change in probability of leakage detectable only by ILRT (classes 3a and 3b) for the new surveillance intervals of interest is given as:

Change in Class 3b Frequency	=	Class 3b Baseline Frequency	*	(Revised Interval/2)	/	(Baseline Interval/2)
		Substituting				
Change in Class 3b Frequency	=	1.15E-08 per year	*	120/2	/	36/2
		Yields				
Change in Class 3b Frequency	=	3.84E-08 Per Year				

A summary of the various testing intervals and resulting changes in accident class frequency are given in Table 8-4.

Table 8-4
Hypothetical PWR Accident Class Frequencies for Various ILRT Testing Intervals

Accident Class	Testing Interval (Factor Increase for Classes 3a and 3b)			
	3 per 10 years (1)	1 per 10 years (3.33)	1 per 15 years (5)	1 per 20 years (6.67)
1	4.65E-05	4.61E-05	4.57E-05	4.54E-05
2	4.97E-08	4.97E-08	4.97E-08	4.97E-08
3a	1.81E-07	6.03E-07	9.05E-07	1.21E-06
3b	1.15E-08	3.84E-08	5.76E-08	7.68E-08
7	4.70E-05	4.70E-05	4.70E-05	4.70E-05
8	6.47E-06	6.47E-06	6.47E-06	6.47E-06
Totals	1.00E-04	1.00E-04	1.00E-04	1.00E-04

8.1.5 Step Six: Determine Revised Population Dose Rate

The revised population rate dose is calculated by multiplying the base population dose by the change in the frequency of a leakage pathway for the interval of consideration. For example, if the ILRT interval is increased from 1 per three years to once per 10 years the calculation is as follows:

Δ Population Dose (Class 3a)	=	Base Population Dose Rate (Class 3a)	*	Revised Interval/2 (Months)	/ Base Interval/2 (Months)
Δ Population Dose (Class 3a)	=	1.77E+00	*	120/2	/ 36/2
Δ Population Dose (Class 3a)	=	5.91E+00			

This is performed for each of accident classes. The results for each accident class for various testing intervals are provided in Table 8-5.

Table 8-5
Hypothetical PWR Population Dose Rates for Various ILRT Testing Intervals

Accident Class	Population Dose Rate (Person-rem/yr) for Testing Intervals of			
	3 Per 10 Years	1 Per 10 Years	1 Per 15 Years	1 Per 20 Years
1	4.55E+01	4.51E+01	4.48E+01	4.45E+01
2	2.44E+01	2.44E+01	2.44E+01	2.44E+01
3a	1.77E+00	5.91E+00	8.86E+00	1.18E+01
3b	1.13E+00	3.76E+00	5.64E+00	7.52E+00
7	6.44E+04	6.44E+04	6.44E+04	6.44E+04
8	3.54E+03	3.54E+03	3.54E+03	3.54E+03
Totals	6.80E+04	6.80E+04	6.80E+04	6.80E+04

8.1.6 Step Seven: Determine Percentage Change In Population Dose

In this step the percentage of the dose rate attributable to classes 3a and 3b of the total dose rate is determined (see Table 8-6). This is accomplished by dividing the dose rate for accident classes 3a and 3b by the total dose rate.

Table 8-6
Hypothetical PWR Accident Class Percent Dose for Various ILRT Testing Intervals

Accident Class	Accident Class Percentage Dose for Testing Intervals of			
	3 Per 10 Years	1 Per 10 Years	1 Per 15 Years	1 Per 20 Years
1	0.067%	0.066%	0.066%	0.065%
2	0.036%	0.036%	0.036%	0.036%
3a	0.003%	0.009%	0.013%	0.017%
3b	0.002%	0.006%	0.008%	0.011%
7	94.689%	94.689%	94.689%	94.689%
8	5.204%	5.204%	5.204%	5.204%
Totals	100%	100%	100%	100%

8.1.7 Step Eight: Evaluate Change In LERF

The change in the large early release frequency is defined as the large early release frequency associated with a revised ILRT testing interval minus the large early release frequency associated with the base ILRT testing interval. The large early release frequency is defined as the accident class 3b. For example,

Δ LERF = (frequency class 3b interval 10 years) - (frequency class 3b baseline)

or

Δ LERF = 3.84E-08 per year - 1.15E-08 per year

Therefore

Δ LERF = 2.69E-08 per year

Table 8-7 provides a summary of the change in large early release frequency as a result of ILRT testing interval.

Table 8-7
Delta Large Early Release Frequency for Various ILRT Testing Intervals

Accident Class	Delta LERF for Testing Intervals of		
	1 Per 10 Years	1 Per 15 Years	1 Per 20 Years
3b	2.69E-08	4.61E-08	6.53E-08

8.1.8 Step Nine: Evaluate Conditional Containment Failure Probability (CCFP)

In this step the change in the conditional containment failure probability is calculated for the various ILRT testing intervals. The conditional containment failure probability is calculated as follows:

CCFP = 1 – (Intact Containment Frequency/Total Core Damage Frequency)

Or

CCFP = [1 – ((Class 1 Frequency + Class 3a Frequency)/CDF)] * 100%

For example, the CCFP for an ILRT testing change from three times per 10 years to once per 10 years is as follows:

CCFP = [1 – ((4.65E-05 + 1.81E-07)/1.00E-04] * 100%

CCFP = 53.4%

The same procedure is performed for each of the ILRT testing intervals. The results are provided in Table 8-8.

Table 8-8
Conditional Containment Failure Probability for Various ILRT Testing Intervals

Conditional Containment Failure Probability			
3 Per 10 Years	1 Per 10 Years	1 Per 15 Years	1 Per 20 Years
53.41%	53.44%	53.46%	53.48%

8.1.9 Hypothetical PWR Example Results

The detailed results associated with the hypothetical PWR are presented in Table 8-9. The hypothetical PWR example has core damage frequency value that is high in the range of typical CDF values. In addition, the La and corresponding probability of occurrence are based on an assumed value of 100 La corresponding to a large early release. This value of La results in higher probabilities of occurrence than would more typical values of 600 to 6000 La.

Despite these conservative assumptions, the risk impact assessment results in an increase of 6.53E-08 per year in large early release frequency for the ILRT interval of once per 20 years. The resultant change in the large early release frequency falls into the "very small change" region of Figure 4 of Regulatory Guide 1.174. Core damage frequency does not change as a result of the proposed change in ILRT testing intervals.

In addition, the other figures of merit associated with the evaluation of the change in the ILRT testing frequency are also very small. There is almost no change (0.01%) in the percentage population dose rate and the conditional containment failure probability increases from 53.41% to 53.48% or approximately 0.07% for the once-in-20-year testing interval.

Table 8-9
Hypothetical PWR Summary for Various ILRT Testing Intervals

Accident Class	ILRT Interval													
	3 Per 10 Years					1 Per 10 Years			1 Per 15 Years			1 Per 20 Years		
	Base Frequency	Adjusted Base Frequency	Dose (Person-rem)	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate
1	4.67E-05	4.65E-05	9.79E+05	4.55E+01	0.067%	4.61E-05	4.51E+01	0.066%	4.57E-05	4.48E+01	0.066%	4.54E-05	4.45E+01	0.065%
2	4.97E-08	4.97E-08	4.90E+08	2.44E+01	0.036%	4.97E-08	2.44E+01	0.036%	4.97E-08	2.44E+01	0.036%	4.97E-08	2.44E+01	0.036%
3a	N/A	1.81E-07	9.79E+06	1.77E+00	0.003%	6.03E-07	5.91E+00	0.009%	9.05E-07	8.86E+00	0.013%	1.21E-06	1.18E+01	0.017%
3b	N/A	1.15E-08	9.79E+07	1.13E+00	0.002%	3.84E-08	3.76E+00	0.006%	5.76E-08	5.64E+00	0.008%	7.68E-08	7.52E+00	0.011%
7	4.70E-05	4.70E-05	1.37E+09	6.44E+04	94.689%	4.70E-05	6.44E+04	94.680%	4.70E-05	6.44E+04	94.673%	4.70E-05	6.44E+04	94.667%
8	6.47E-06	6.47E-06	5.47E+08	3.54E+03	5.204%	6.47E-06	3.54E+03	5.204%	6.47E-06	3.54E+03	5.204%	6.47E-06	3.54E+03	5.203%
Totals	1.00E-04	1.00E-04	2.52E+09	6.80E+04	100%	1.00E-04	6.80E+04	100%	1.00E-04	6.80E+04	100%	1.00E-04	6.80E+04	100%
Δ LERF	N/A					2.69E-08			4.61E-08			6.53E-08		
CCFP	53.41%					53.44%			53.46%			53.48%		

8.2 Hypothetical Plant Application – BWR Small Containment

This report section provides a detailed assessment of the application of the technical methods associated with the optimization of the ILRT testing interval to a hypothetical plant that is a BWR with a small containment. Table 8-10 shows the hypothetical plant with the following risk profile in terms of accident classes.

Table 8-10
Hypothetical BWR CDF by Accident Class

Accident Class	Base Frequency	Dose (Person-REM)
1	3.64E-06	8.97E+01
2	2.73E-09	4.07E+06
3a		
3b		
7	1.82E-06	2.16E+06
8	Negligible	Negligible
Totals	5.46E-06	6.24E+06

Accident classes 4, 5, and 6 are not affected by the optimization of the ILRT testing interval and therefore are not included in the remainder of the evaluation.

The same process outline in Section 8.1 is performed for the hypothetical BWR plant. The results of this process are provided in Table 8-11.

Table 8-11
Hypothetical BWR Summary for Various ILRT Testing Intervals

Accident Class	ILRT Interval													
	3 Per 10 Years					1 Per 10 years			1 Per 15 Years			1 Per 20 Years		
	Base Frequency	Adjusted Base Frequency	Dose (Person-rem)	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate
1	3.64E-06	3.62E-06	8.97E+01	3.25E-04	0.00%	3.59E-06	3.22E-04	0.01%	3.56E-06	3.20E-04	0.01%	3.54E-06	3.18E-04	0.01%
2	2.73E-09	2.73E-09	4.07E+06	1.11E-02	0.05%	2.73E-09	1.11E-02	0.28%	2.73E-09	1.11E-02	0.28%	2.73E-09	1.11E-02	0.28%
3a	N/A	1.41E-08	8.97E+02	1.27E-05	0.00%	4.70E-08	4.22E-05	0.00%	7.05E-08	6.33E-05	0.00%	9.40E-08	8.44E-05	0.00%
3b	N/A	8.98E-10	8.97E+03	8.06E-06	0.00%	2.99E-09	2.69E-05	0.00%	4.49E-09	4.03E-05	0.00%	5.99E-09	5.37E-05	0.00%
7	1.82E-06	1.82E-06	2.16E+06	3.93E+00	17.21%	1.82E-06	3.93E+00	99.71%	1.82E-06	3.93E+00	99.71%	1.82E-06	3.93E+00	99.71%
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00%	0.00E+00	0.00E+00	0.00%
Totals	5.46E-06	5.46E-06	6.24E+06	3.94E+00	17%	5.46E-06	3.94E+00	100%	5.46E-06	3.94E+00	100%	5.46E-06	3.94E+00	100%
Δ LERF	N/A					2.09E-09			3.59E-09			5.09E-09		
CCFP	33.38%					33.42%			33.45%			33.48%		

8.3 Sensitivity Studies

In this section, the sensitivity of the ILRT testing interval risk impact assessment to the key assumption of the analysis is performed. The key assumption of this analysis is the value of La that is chosen to represent large early release frequency. In the hypothetical examples, the La that is assumed to represent LERF is 100 La. The actual value depends on the assumptions regarding the timing of effective implementation of public protective actions and the plant specific La value in terms of weight percent. Assuming effective implementation of public protective actions within four hours and an La between 0.1% and 1%, the La corresponding to LERF is between 600 and 6000 La.

The first sensitivity case is performed for the hypothetical PWR. The hypothetical PWR case is chosen since the most significant risk impacts were associated with this case. In the sensitivity, an La of 600 was chosen to represent LERF. This La represents the lower end of the range of the more realistic definition of LERF and results in the assumption that the plant's weight fraction is 0.1% per day. For small releases the La remains 10 La.

The results of this sensitivity case are provided in Table 8-12. To summarize, the risk impact associated with the extension of ILRT interval to once in twenty years for this sensitivity case is negligible, with delta LERF equal to 3.28E-09 per year. The percentage change in the population dose of the 3a and 3b accident classes is also negligible at 0.00% for both classes. The change in the conditional containment failure probability is from 53.40% to 53.416%, which also represents a negligible change.

The second sensitivity case is also related to the value of La chosen to represent large early release. In this sensitivity case an La of 35 is chosen to represent LERF. The value of 35 has been used in several ILRT submittals. These ILRT submittals were generally one-time extensions to the ILRT interval. It should be noted that 35 La representing LERF is considered extremely conservative. In this sensitivity case 10 La is chosen to represent small containment bypass pathways.

The results of this sensitivity case are provided in Table 8-13. To summarize the risk impact associated with the extension of ILRT interval to once in twenty years for this sensitivity case is small with a delta LERF equal to 2.61E-07 per year. The percentage change in the population dose for both accident classes 3a and 3b is negligible (0.00%). The change in the conditional containment failure probability is small, increasing from 53.45% to 53.71% for a net increase of 0.26%.

8.4 External Events and Other Hazards

External events and other hazards are not explicitly treated in this analysis. The high core damage frequency chosen for the PWR hypothetical plant is equal to the NRC safety goal for core damage frequency of 1E-4 per year and is assumed to be inclusive of external events and other hazards. Note that significantly more margin exists in the BWR plant with CDF

at 5.45E-6 and respective delta LERF at twenty years of 5.09E-9, and therefore the BWR was not evaluated at the CDF safety goal.

Core damage frequencies in excess of the 1E-4 per year safety goal could result in a delta LERF in excess of the 1E-7 per year, given an increase of ILRT testing interval to once per 20 years. However, it is unlikely that even an extremely high core damage frequency would result in a delta LERF above the "very small" region of Figure 4 of Regulatory Guide 1.174 (that is, 1E-7 per year) given the use of the most realistic assumptions regarding the magnitude of La for a LERF (that is, 600 La). In addition, using the current conservative values for the magnitude of La representing LERF, extremely high core damage frequency values are unlikely to result in values for delta LERF that are higher than the "small" region on Figure 4 of Regulatory Guide 1.174 (that is, delta LERF greater than 1E-6 per year).

Table 8-12
Hypothetical PWR Sensitivity Case – LERF Represented by 600 La

Accident Class	ILRT Interval													
	3 Per 10 Years					1 Per 10 years			1 Per 15 Years			1 Per 20 Years		
	Base Frequency	Adjusted Base Frequency	Dose (Person-rem)	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate
1	4.67E-05	4.65E-05	8.97E+01	4.17E-03	0.00%	4.61E-05	4.14E-03	0.00%	4.58E-05	4.11E-03	0.00%	4.55E-05	4.08E-03	0.00%
2	4.97E-08	4.97E-08	4.90E+08	2.44E+01	0.04%	4.97E-08	2.44E+01	0.04%	4.97E-08	2.44E+01	0.038%	4.97E-08	2.44E+01	0.04%
3a	N/A	1.81E-07	8.97E+02	1.62E-04	0.00%	6.03E-07	5.41E-04	0.00%	9.05E-07	8.12E-04	0.00%	1.21E-06	1.08E-03	0.00%
3b	N/A	5.79E-10	5.38E+04	3.12E-05	0.00%	1.93E-09	1.04E-04	0.00%	2.90E-09	1.56E-04	0.00%	3.86E-09	2.08E-04	0.00%
7	4.70E-05	4.70E-05	1.37E+09	6.44E+04	99.838%	4.70E-05	6.44E+04	99.838%	4.70E-05	6.44E+04	99.838%	4.70E-05	6.44E+04	99.838%
8	6.47E-06	6.47E-06	1.24E+07	8.02E+01	0.12%	6.47E-06	8.02E+01	0.12%	6.47E-06	8.02E+01	0.12%	6.47E-06	8.02E+01	0.12%
Totals	1.00E-04	1.00E-04	1.87E+09	6.45E+04	100%	1.00E-04	6.45E+04	100%	1.00E-04	6.45E+04	100%	1.00E-04	6.45E+04	100%
Δ LERF	N/A					1.35E-09			2.32E-09			3.28E-09		
CCFP	53.40%					53.40%			53.41%			53.41%		

Table 8-13
Hypothetical PWR Sensitivity Case – LERF Represented by 35 La

Accident Class	ILRT Interval													
	3 Per 10 Years					1 Per 10 years			1 Per 15 Years			1 Per 20 Years		
	Base Frequency	Adjusted Base Frequency	Dose (Person-rem)	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate	Frequency	Dose Rate (Person-rem/yr)	Percent of Total Dose Rate
1	4.67E-05	4.65E-05	8.97E+01	4.17E-03	0.00%	4.59E-05	4.12E-03	0.00%	4.56E-05	4.09E-03	0.00%	4.52E-05	4.06E-03	0.00%
2	4.97E-08	4.97E-08	4.07E+06	2.02E-01	0.11%	4.97E-08	2.02E-01	0.11%	4.97E-08	2.02E-01	0.11%	4.97E-08	2.02E-01	0.11%
3a	N/A	1.81E-07	8.97E+02	1.62E-04	0.00%	6.03E-07	5.41E-04	0.00%	9.05E-07	8.12E-04	0.00%	1.21E-06	1.08E-03	0.00%
3b	N/A	4.61E-08	3.14E+03	1.45E-04	0.00%	1.54E-07	4.82E-04	0.00%	2.30E-07	7.23E-04	0.00%	3.07E-07	9.65E-04	0.00%
7	4.70E-05	4.70E-05	2.16E+06	1.02E+02	55.79%	4.70E-05	1.02E+02	55.79%	4.70E-05	1.02E+02	55.79%	4.70E-05	1.02E+02	55.79%
8	6.47E-06	6.47E-06	1.24E+07	8.02E+01	44.09%	6.47E-06	8.02E+01	44.09%	6.47E-06	8.02E+01	44.09%	6.47E-06	8.02E+01	44.09%
Totals	1.00E-04	1.00E-04	1.86E+07	1.82E+02	100%	1.00E-04	1.82E+02	100%	1.00E-04	1.82E+02	100%	1.00E-04	1.82E+02	100%
Δ LERF	N/A					1.07E-07			1.84E-07			2.61E-07		
CCFP	53.45%					53.56%			53.63%			53.71%		

9
RESULTS SUMMARY AND CONCLUSIONS

This analysis confirms the earlier findings of NUREG-1493 that reducing the frequency of Type A tests (ILRTs) from the current three-per-10-years to one-per-20-years was found to lead to imperceptible increase in risk.

Using relatively conservative assumptions concerning the leakage and timing associated with a large early release, the reduction in frequency of the type A ILRT test results in a change in large early release frequency of 6.53E-08 per year in worst case evaluated. The core damage frequency remains unchanged. Comparing the change to the risk acceptance criteria of Regulatory Guide 1.174, the change is in the "very small region."

Other figures-of-merit have similar very small changes, including the population dose rate (0.01%) and the conditional containment failure probability (from 53.41% to 53.48%, or 0.07%).

Defense-in-depth as well as safety margins are maintained through the continued inspection of containment as required by ASME Section XI, Subsections IWE and IWL, and other required inspections, such as those performed to satisfy the Maintenance Rule. In addition, NEI 94-01 [16] requires acceptable historical performance of Type A Integrated Leak Rate Tests before integrated leak rate testing intervals can be extended. Lastly, some activities, performed during normal operation, considerably increase the likelihood that a containment bypass pathways would be discovered. Experience has shown that during normal reactor startup and during normal power operation it is fairly routine, for most containment designs, to either vent the overpressure that has built up or to provide nitrogen makeup (for inerted containment designs) to maintain positive pressure within specified limits. The increase in pressure can be caused by increase in the average air temperature during heatup and startup, changes in barometric pressure, and an increase in the containment air mass from compressed air equipment bleeds and leakage. Absence, or significant changes in the frequency, of pressure build-up and venting over a substantial period of time will provide a qualitative indication of the existence of a containment-atmosphere-to-outside-atmosphere leak path. This aspect of operation provides additional means of detection of containment leakage pathways.

10
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A
ILRT DATA

This appendix provides the database of ILRT events. These events are taken from two NEI utility surveys [8][9], NUREG-1493, and other events from industry data such as LER and reportable event reports.

No.	Date	Unit or Reference Contmt Type	Reference LER, Report, etc.	Leakage, Fraction of La	La, SCCM or %/day	How Detected	Cause	Description	Detection Method	Will ILRT Interval Affect Non Detection Time?	Cause Category (Failure Mode)	Size of Leakage	Detected by	Containment Size Applicability	Notes
1	Mar-77	NUMARC note unknown	NUMARC letter 2/18/94 to NRC	Unknown	Unknown	ILRT	Holes inadvertently drilled in liner		A	Yes	4	U	ILRT	All	
2	Apr-77	NUMARC 24 PWR		Unknown, >1La	175000	ILRT	SG manway gasket leak	Excessive leakage identified by ILRT	A, O	No	10	U	ILRT	None	1
3	Mar-78	NUMARC 4 PWR		0.88 La+ (B&C)	346800	ILRT	SG manway gasket leak	Excessive leakage identified by ILRT	A, O	No	10	S	ILRT	None	1
4	Jun-80	NUMARC 25 unknown		0.072 La+ (B+C)	538000	LLRT Penalty		Excessive C local leakage identified by LLRT	B, A	No	10	S	Other	None	
5	Feb-81	NUMARC 21 unknown		N/A		Verification test		ILRT Exceedance due to instrument verification test discrepancy	A, I	No	9	N/A	ILRT	None	2
6	Jun-82	NUMARC 4, unknown		0.43 La+ (B&C)	346000	ILRT	Lineup Error	ILRT Exceedance due to lineup error. Not real leakage.	A, I	No	9	N/A	ILRT	None	2
7	Aug-83	NUMARC 19 unknown		1.3La	83200	LLRT		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
8	Apr-84	NUMARC 25 unknown		0.031 La+ (B&C)	538000	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
9	Aug-84	NUMARC 28 unknown		0.071 La(A) 14.91 La w/(B&C)	95330	LLRT penalty		Excessive C local leakage identified by LLRT	B, A	No	10	L	Other	None	
10	Jun-85	NUMARC 26 unknown		0.19 La(A) 20.82 La w/(B&C)	862307	LLRT penalty		Excessive B&C local leakage identified by LLRT	B, A	No	10	L	Other	None	
11	Nov-85	NUMARC 3 unknown		0.36 La (A) 1.89 La w/(B&C)	211600	LLRT penalty		Excessive C local leakage identified by LLRT	B, A	No	10	S	Other	None	
12	Apr-86	NUMARC 28 unknown		<0.05 La(A) <9.55 La w/(B&C)	95330	LLRT penalty		Excessive C local leakage identified by LLRT	B, A	No	10	M	Other	None	
13	May-86	NUMARC 23 unknown		0.27 La(A) 0.99 La w/(B&C)	135920	LLRT penalty		Excessive B&C local leakage identified by LLRT	B, A	No	10	S	Other	None	
14	Jun-86	Susquehanna 2 BWR Mark 2	NUREG-1493	2.6 La	1.00%	ILRT		ILRT prior to LLRT	A, B	No	8	M	ILRT	None	5a

No.	Date	Unit or Reference Contmt Type	Reference LER, Report, etc.	Leakage, Fraction of La	La, SCCM or %/day	How Detected	Cause	Description	Detection Method	Will ILRT Interval Affect Non Detection Time?	Cause Category (Failure Mode)	Size of Leakage	Detected by	Containment Size Applicability	Notes
15	Nov-86	Quad cities-2 BWR Mark 1	NUREG-1493	0.88 La	1.00%	ILRT	Faulty drywell head gasket	Excessive local leakage identified by ILRT	A, B	No	3	S	ILRT	All	7a
16	Nov-86	TMI-1 PWR Large dry	NUREG-1493	1.0 La	0.10%	ILRT		ILRT prior to LLRT	A, B	No	8	S	ILRT	None	5a
17	Nov-86	NUMARC 24 PWR		1.0 La, 1.0 La w/(B&C)	175000	ILRT	SG manway gasket leak	Excessive leakage identified by ILRT	A, O	No	10	S	ILRT	None	1
18	Aug-87	NUMARC 27 PWR		0.027 La (A) 2.46 La w/(B&C)	236203	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	M	Other	None	
19	Sep-87	Quad cities-1 BWR Mark 1	NUREG-1493	Unknown		ILRT		ILRT without prior LLRT	A, B	No	8	U	ILRT	None	5a
20	Sep-87	NUMARC 28 unknown		0.43 La + (B&C)	287407	LLRT penalty		Excessive B&C local leakage identified by LLRT	B, A	No	10	S	Other	None	
21	Sep-88	NUMARC 30 unknown		Unknown	218503	LLRT penalty		Excessive C local leakage identified by LLRT	B, A	No	10	U	Other	None	
22	Oct-89	Harris-1 PWR large dry	NUREG-1493	Unknown		ILRT		ILRT without prior LLRT, as found not quantified	A, B	No	8	U	ILRT	None	5a
23	Nov-89	Hatch-2 BWR Mark 1	NUREG-1493	0.86 La	1.20%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
24	Nov-89	Fermi-2 BWR Mark 1	NUREG-1493	1.9 La	0.50%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
25	Dec-89	Beaver Valley-1 PWR Subatm	NUREG-1493	Unknown	0.10%	ILRT	Two penetration leaks discovered during ILRT	Excessive local leakage identified by ILRT and not identified by LLRT	A	Yes, however ILRT interval would not be extended under NEI 9401	3	U	ILRT	All	8
26	Feb-90	Dresden 3 BWR Mark 1	NUREG-1493	0.78 La	1.60%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
27	Feb-90	Brunswick-2 BWR Mark 1	NUREG-1493	0.94 La	0.50%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
28	May-90	Sequoyah-1 PWR ice condenser	NUREG-1493	2.8 La	0.25%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	M	Other	None	

No.	Date	Unit or Reference Contmt Type	Reference LER, Report, etc.	Leakage, Fraction of La	La, SCCM or %/day	How Detected	Cause	Description	Detection Method	Will ILRT Interval Affect Non Detection Time?	Cause Category (Failure Mode)	Size of Leakage	Detected by	Containment Size Applicability	Notes
29	May-90	Sequoyah-2 PWR ice condenser	NUREG-1493	<1.0 La	0.25La	ILRT	Penetration leakage, faulty LLRT	Excessive local leakage identified by ILRT and not identified by LLRT	A, B	No	8	S	ILRT	None, leakage <La	5b
30	Jun-90	LaSalle-2 BWR Mark 2	NUREG-1493	Unknown, >La	0.63%	Unknown			A	Maybe	8	U	ILRT	None	
31	Jun-90	Trojan PWR large dry	NUREG-1493	Unknown	1.30%	ILRT	Instrumentation problems		A, I	No	9	N/A	ILRT	None	2
32	Sep-90	NUMARC 31, unknown		Unknown	218503	LLRT penalty		Excessive C local leakage identified by LLRT	B, A	No	10	U	Other	None	
33	Oct-90	Callaway PWR large dry	NUREG-1493	Unknown, >La	0.20%	ILRT	Penetration leakage	Excessive local leakage identified by ILRT.	A	Yes, however ILRT interval would not be extended under NEI 9401	3	U	ILRT	All	8
34	Oct-90	NUMARC 20 unknown		1.7 La w/(B&C)	188945	ILRT		Excessive B&C local leakage identified by ILRT and not identified by LLRT	A, B	Maybe	4	S	ILRT	All	5a
35	Dec-90	Dresden 2 BWR Mark 1	NUREG-1493	15.3 La	1.60%	ILRT	Vacuum breaker leakage discovered during ILRT	Excessive local leakage identified by ILRT	A, B	Maybe	3	L	ILRT	All	5a
36	Feb-91	Braidwood 1 PWR large dry	NUREG-1493	0.56 La	0.10%	ILRT	Type B failure found during ILRT w/outer doors open, airlock hatch shaft seal	Excessive local leakage identified by ILRT and not identified by LLRT	A, B	Maybe	3	S	ILRT	None, leakage <La	5a
37	Feb-91	Brunswick 1 BWR Mark 1	NUREG-1493	0.99 La	0.50%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
38	Apr-91	NUMARC 2 unknown		0.47 La (A) 0.84 La w/(B&C)	163000	ILRT		Excessive B&C local leakage identified by ILRT and not identified by LLRT	A, B	Maybe	8	S	ILRT	None, leakage <La	5a
39	Jun-91	Millstone-1	NUREG-1493	Unknown, >0.75 La	1.20%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	U	Other	None	
40	Jun-91	BWR?		0.29 La+ (B&C)	236203	LLRT penalty		Excessive C local leakage identified by LLRT	B, A	No	10	S	Other	None	

No.	Date	Unit or Reference Contmt Type	Reference LER, Report, etc.	Leakage, Fraction of La	La, SCCM or %/day	How Detected	Cause	Description	Detection Method	Will ILRT Interval Affect Non Detection Time?	Cause Category (Failure Mode)	Size of Leakage	Detected by	Containment Size Applicability	Notes
41	Jul-91	Pilgrim BWR Mark 1	NUREG-1493, LER 91-023-00	1.2 La	1.00%	ILRT	Drywell head bolts loose, improper spherical washer material	Failure of spherical washers led to loosening of 11 of 76 bolts, drywell head contribution .74%/day	A, O, B	Probably not	4	S	ILRT	Small	7b
42	Sep-91	Braidwood 2 PWR large dry	NUREG-1493	0.55 La	0.10%	ILRT	Several local leaks found during ILRT w/outer doors open	Excessive local leakage identified by ILRT and not identified by LLRT	A, B	Maybe	8	S	ILRT	None, leakage <La	5a
43	Dec-91	Brunswick 2 BWR Mark 1	NUREG-1493	0.79 La	0.50%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
44	Dec-91	PVNGS-2 PWR large dry	NUREG-1493	0.83 La	0.10%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
45	Dec-91	Cooper BWR Mark 1	NUREG-1493, LER 91-020-00	1.4 La	149623	ILRT	Structural failure of radiation monitor	Radiation monitor breached its shield chamber during ILRT pressurization at 51 psig. Leakage from monitor path =0.61 La.	A	Yes, not a pre-existing leak;	4	S	ILRT	All	
46	Mar-92	Dresden-3 BWR Mark 1	NUREG-1493	Unknown, >La	1.60%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	U	Other	None	
47	Mar-92	LaSalle-2 BWR Mark 2	NUREG-1493	0.56 La	0.63%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
48	Apr-92	Sequoyah-2 PWR ice condenser	NUREG-1493	1.68 La	0.25%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	9
49	Apr-92	Vogtle-2 PWR large dry	NUREG-1493, NUMARC 1	0.62 La (A) >.75 La w/(B&C), Unknown	360000 0.2%	LLRT penalty		Excessive B&C local leakage identified by LLRT	B, A	No	10	U	Other	None	9
50	May-92	ANO-1 PWR large dry	NUREG-1493	Unknown, >La	0.20%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	U	Other	None	9
51	Aug-92	River Bend BWR Mark 3	NUREG-1493	Unknown, >La	0.26%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	U	Other	None	
52	Sep-92	NUMARC 21 PWR		1.3 La+ (B&C)	442525	ILRT	SG manway gasket leak	Excessive leakage identified by ILRT	A, O	No	10	S	ILRT	None	1

No.	Date	Unit or Reference Contmt Type	Reference LER, Report, etc.	Leakage, Fraction of La	La, SCCM or %/day	How Detected	Cause	Description	Detection Method	Will ILRT Interval Affect Non Detection Time?	Cause Category (Failure Mode)	Size of Leakage	Detected by	Containment Size Applicability	Notes
53	Oct-92	Fermi-2 BWR Mark 1	NUREG-1493	< 2 La	0.50%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
54	Nov-92	Hatch-2 BWR Mark 1	NUREG-1493	1.11 La	1.20%	LLRT penalty		Excessive local leakage identified by LLRT	B, A	No	10	S	Other	None	
55	Nov-93	NUMARC 3 Unknown		0.21 La(A) 1.34 La w/(B&C)	211600	ILRT	Lineup error	Excessive local leakage identified by ILRT due to lineup error	A, I	No	9	N/A	ILRT	None	2
56	Feb-94	Ginna PWR large dry	LER 94-003-00	Unknown		I&C observation	Instrument plug not installed	Instrument plug not installed following I&C work. Procedures enhanced to insure installation in future	O	No	3	N/A	Other	None	3
57	Feb-94	Surry 1 PWR Subatm	LER 94-003-00	>La		Piping inspection	Failure of coal tar epoxy coating followed by corrosion	Hole in piping for recirculation spray water heat exchanger	V, A	No	6	U	Other	All	4
58	Mar-94	Braidwood 1 PWR large dry	LER 94-003	0.9 La	216908 0.1%	ILRT	Construction deficiency not previously identified	Concrete vent pipes associated with emergency hatch not capped. Leakage from vent pipes = 0.09 La.	A	Yes	4	S	ILRT	None, leakage <La	
59	Apr-94	Sequoyah-1 PWR Ice condenser	LER 94-005-00	0.75-1.0 La	0.25%	Inability to maintain PRT P	Circumferential crack in RV bellows	This bellows failure was detected during normal operation	O, A	No	7	S	Other	All	
60	Dec-94	Pilgrim BWR Mark 1	LER 94-007-00	>La	1.00%	I&C inspection	Instrument plug not installed	Plug for torus-atmosphere dp transmitter not installed; corrective action includes verification surveillance	O, A	No	3	U	Other	None	10
61	Apr-95	Vermont Yankee BWR Mark 1	NEI Survey	2 La	0.80%	ILRT	Excessive local leakage	Valves contaminated with construction debris after passing LLRT	A, B	Maybe	4	M	ILRT	All	5a
62	Sep-95	Indian Point 3 PWR Large Dry	LER 95-019-00	Insignificant leakage	0.10%	Inspection/radiograph	Excessive local leakage	Through wall cracks on pipe caps on spare penetration due to contaminated stagnant water	V, O	No	6	N/A	Other	None	6

No.	Date	Unit or Reference Contmt Type	Reference LER, Report, etc.	Leakage, Fraction of La	La, SCCM or %/day	How Detected	Cause	Description	Detection Method	Will ILRT Interval Affect Non Detection Time?	Cause Category (Failure Mode)	Size of Leakage	Detected by	Containment Size Applicability	Notes
63	Feb-96	Surry 2 PWR Subatm	LER 96001	Unknown		Observation at power		Leaking weld on return pipe from refueling cavity to RWST	O, A	No	6	N/A	Other	All	
64	Oct-96	Oyster Creek BWR Mark 1	LER 96-011-0	2 La		Low pressure monitoring	Vacuum breaker valve cover leaking	Misalignment of valve cover during assembly, shifting during heatup	L, A	No	3	M	Other	All	5a
65	Sep-99	North Anna 2 PWR Subatm	NEI Survey, LER 1999-002-00	0.07 La		Liner coating inspection	1/4" defect hole	Wooden timber in concrete in back of liner. Leakage through defect = 0.07 La.	V, A	No	2	S	Other	All	
66	Nov-99	PVNGS 1 PWR large dry	LER 2000-004	Insignificant leakage	0.10%	ILRT	Inadequate procedure for LLRT of Purge valves, valve seat adjustment	Purge valve penetration leakage identified during ILRT.	B	No	3	N/A	ILRT	None	2
67	Nov-99	Cook 2 PWR ice condenser	NEI survey	Unknown < La		Liner, coatings inspection	3/16" hole in liner	Leak rate within limits. Cook 1 had identified pitting in 1998 but no through wall penetration.	V, A	No	6	N/A	Other	All	
68	99	Brunswick 2 BWR Mark 1	NEI survey	Unknown < La	0.50%	IWE inspection	Three thru wall defects in liner	Pitting corrosion and debris in concrete	V, A	No	2	S	Other	All	
69	Aug-01	PVNGS-3 PWR large dry	Non-emergency event report 8/17/01	Unknown	0.10%	Operations monitoring containment sump	Quick opening closure device not properly closed, or loosening of device in service.	Fuel transfer tube quick operating closure device leak path.	O, A	No	3	U	Other	None	5a
70	Oct-01	Vermont Yankee BWR Mark 1	Non-emergency event report 10/30/2001	Unknown, > La	0.80%	Operator observation and isolation		Tube broke on discharge of H2O2 monitor sample pump.	O, A	No	4	U	Other	All	11
71	?	Vermont Yankee BWR Mark 1	NUREG-1493	1.0 La	0.80%	ILRT	Drywell manway penetration leakage		A, B	Maybe	3	S	ILRT	Small	5a

1 Steam generator manway leakage is detectable during startup and normal operation.
Monitored via Technical Specification identified and un-identified leakage limits.
2 The event does not appear to be the result of ILRT failure or true containment leakage.
3 Leakage pathway from containment to atmosphere would exist only when the equipment hatch inner door was open
4 Radiation monitors and isolation valves are also provided. Fluid leakage would be detected by subsequent piping inspections.

5a	Leakage pathway would be identified in next local leak rate test (LLRT)
5b	This leakage path should have been identified by LLRT. Would be discovered during subsequent LLRTs, after correction of faulty LLRT.
6	Containment integrity was not an issue as the penetration was pressurized and monitored.
7a	Leaking drywell head gasket would have been replaced at next refueling.
7b	Had this not been identified in an ILRT, loose bolts and washer failures should have been identified nad replaced in the next refueling.
8	If leakage cannot be identified by local testing, Type A test does not meet NEI 94-01 performance criteria for ILRT interval extension.
9	ILRT La Exceedance due to B&C Leakage Penalty Identified by LLRT.
10	This pathway would probably have been identified in the next instrument calibration cycle.
11	Engineering evaluation determined that under accident conditions leakage would have exceeded allowable leakage limits.

B
EXPERT ELICITATION INPUT DATA

This appendix presents a summary of the expert elicitation input. A total of eight tables are presented.

The first four tables are associated with the "large" containment type. A large containment was defined for the expert elicitation panel as a containment of greater than 1 million cubic feet of free volume. The four large containment type tables that are presented are the small leakage pathway (1–2 La), medium leakage pathway (2–10 La), large leakage pathway (10–100 La) and the extremely large leakage pathway (> 100 La).

The second four tables are associated with "small" containments. A small containment was defined for the expert elicitation panel as a containment with less than 1 million cubic feet of volume. The four tables associated with the small containment type are the small leakage pathway (1–2 La), medium leakage pathway (2–10 La), large leakage pathway (10–100 La) and the extremely large leakage pathway (> 100 La).

Each of the eight tables contain rows associated with the five containment failure modes identified by the expert elicitation panel as well as a total row. There are three major columns in each table. These major columns are the "Total Degraded ILRTs," "Detected by Alternate Means," and "Detectable by ILRT Only (failures)." Each of the major columns has six minor columns. Each minor column represents a different expert's input. The input is provided in the form of expected occurrences given 1000 hypothetical ILRT tests.

Table B-1
Expert Elicitation Input – Large Containment with Small Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Small Leakage Pathway (1 - 2 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	1	5	0	1	0.1	5	0.9	4	0	1	0.1	4	0.1	0	0	0.1	0.1	0.01
		"Best"	10	10	0	10	7.5	8	9	7.5	0	7.5	5	6	1	2.5	0	2.5	2.5	2
		High	30	15	0	25	19	16	25	12	0	25	16	19	5	5	0	15	12	12
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	3	10	0	1	1	1	1.5	5	0	0.5	1	1	1.5	2	0	0.5	1	0.05
		"Best"	10	15	0	7.5	15	8	5	10	0	3.75	5	4	5	5	0	3.75	10	4
		High	30	22	0	25	31	25	15	15	0	20	16	16	15	7	0	20	23	16
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	5	5	0	2	1	1	2.5	4	0	1	0.1	1	2.5	2	0	2	1	0.05
		"Best"	12.5	10	0	12.5	12.5	10	6.25	7	0	2.5	2.5	4	6.25	3	0	10	10	6
		High	20	15	0	30	27	30	10	10	0	15	12	20	10	5	0	25	23	25
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	2	5	0	5	1	1	1.8	5	0	2	1	1	0.2	2	0	1	0.1	0.05
		"Best"	10	15	0	15	10	10	9	10	0	10	7.5	8	1	5	0	5	2.5	2
		High	50	25	0	40	23	30	45	15	0	30	19	30	5	10	0	20	10	20
5	Fatigue failures (e.g., bellows fatigue failure)	Low	0.5	1	0	1	0.1	0.01	0.4	0.5	0	1	0.1	0.01	0.1	0.2	0	0.1	0.01	0.01
		"Best"	2.5	3	0	2.5	2	0.1	2	2.5	0	2.5	1.9	0.05	0.5	0.5	0	0.5	0.1	0.05
		High	25	5	0	12	12	10	20	3	0	12	12	10	5	1	0	10	1	10
	TOTALS	Low	11.5	26	0	10	3.2	8.01	7.1	18.5	0	5.5	2.3	7.01	4.4	6.2	0	3.7	2.21	0.17
		"Best"	45	53	0	47.5	47	36.1	31.3	37	0	26.3	21.9	22.1	13.8	16	0	21.8	25.1	14.1
		High	155	82	0	132	112	111	115	55	0	102	75	95	40	28	0	90	69	83

Table B-2
Expert Elicitation Input – Large Containment with Medium Leakage Pathway

o.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Medium Leakage Pathway (2 - 10 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	B	c	d	e	f	a	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	0.2	2	0	0.1	0.1	2	0.18	0	0	0.1	0.1	1	0.02	0	0	0.1	0.1	0.1
		"Best"	2	5	0	5	2.5	3	1.8	2.5	0	2.5	1.5	2	0.2	2.5	0	2.5	1	1
		High	20	10	0	20	12	16	18	5	0	12	10	12	2	5	0	12	9	10
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	0.2	0	0	0.1	1	1	0.1	0	0	0.1	0.1	0.05	0.1	0	0	0.1	0.1	0.2
		"Best"	1	0	0	1.25	3	4	0.5	0	0	1.25	1.5	2	0.5	0	0	1	1.5	2
		High	5	2	0	15	14	20	2.5	2	0	15	10	20	2.5	0	0	10	10	20
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	0.2	0	0	0.1	1	0.1	0.1	0	0	0.1	0.1	0.1	0.1	0	0	0.1	0.1	0.1
		"Best"	1	0	0	1.25	3	2	0.5	0	0	1	1.5	1	0.5	0	0	1.25	1.5	1
		High	5	3	0	10	14	15	2.5	2	0	5	10	10	2.5	1	0	10	10	10
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	0.1	0	0	0.1	0.1	0.5	0.09	0	0	0.1	0.1	0.5	0.01	0	0	0.1	0.1	0.25
		"Best"	1	1	0	5	2.5	5	0.9	1	0	2.5	1.5	4	0.1	0	0	2.5	1	1
		High	10	3	0	20	10	20	9	2	0	12	5	20	1	1	0	12	5	20
5	Fatigue failures (e.g., bellows fatigue failure)	Low	0.01	0	0	0.01	0.01	0.005	9E-3	0	0	0.01	0.01	0.001	1E-3	0	0	0.01	0.001	0.001
		"Best"	0.1	0	0	0.1	0.1	0.01	9E-2	0	0	0.05	0.09	0.005	1E-2	0	0	0.05	0.01	0.005
		High	1	0	0	2	1	8	0.9	0	0	1	1	8	1E-1	0	0	1	0.1	8
	TOTALS	Low	0.71	2	0	0.41	2.21	3.61	0.48	0	0	0.41	0.41	1.65	0.23	0	0	0.41	0.4	0.65
		"Best"	5.1	6	0	12.6	11.1	14	3.79	3.5	0	7.3	6.09	9.01	1.31	2.5	0	7.3	5.01	5.01
		High	41	18	0	67	51	79	32.9	11	0	45	36	70	8.1	7	0	45	34.1	68

Table B-3
Expert Elicitation Input – Large Containment with Large Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Large Leakage Pathway (> 10 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	0.01	0	0	0.1	0.1	0.05	0.009	0	0	0.1	0.1	0.25	1E-3	0	0	0.1	0.1	0.1
		"Best"	0.1	0	0	2.5	1.5	2	0.09	0	0	1.25	1	1	1E-2	0	0	1.25	0.5	1
		High	1	5	0	12	10	15	0.1	2.5	0	8	7	15	0.1	2.5	0	8	6	20
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	0.01	0	0	0.1	0.1	0.05	0.005	0	0	0.1	0.1	0.25	0.005	0	0	0.1	0.1	0.1
		"Best"	0.1	0	0	1.25	1.5	1	0.05	0	0	1	1	0.5	0.05	0	0	1.25	0.5	0.5
		High	1	0	0	15	10	16	0.5	0	0	10	10	12	0.5	0	0	15	10	12
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	0.01	0	0	0.1	0.1	0.01	0.01	0	0	0.01	0.1	0.01	0.01	0	0	0.01	0.1	0.1
		"Best"	0.05	0	0	1	1.5	1	0.05	0	0	0.5	1	0.05	0.05	0	0	0.5	0.5	0.5
		High	0.5	0	0	10	10	15	0.5	0	0	5	10	12	0.5	0	0	5	10	12
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	0.01	0	0	0.1	0.1	0.5	9E-3	0	0	0.1	0.1	0.25	1E-3	0	0	0.1	0.1	0.1
		"Best"	0.1	0	0	2.5	1	2	9E-2	0	0	1.25	0.75	1	1E-2	0	0	1.25	0.25	1
		High	1	0	0	12	5	15	0.9	0	0	8	5	15	1E-2	0	0	8	3	20
5	Fatigue failures (e.g., bellows fatigue failure)	Low	1E-3	0	0	0.01	0.001	1E-4	9E-4	0	0	0.01	0.001	1E-4	1E-4	0	0	0.01	1E-4	1E-4
		"Best"	1E-2	0	0	0.1	0.01	1E-3	9E-3	0	0	0.05	0.01	1E-3	1E-3	0	0	0.05	0.001	5E-4
		High	0.1	0	0	2	0.1	8	9E-2	0	0	1	0.1	8	1E-2	0	0	1	0.01	8
	TOTALS	Low	0.04	0	0	0.41	0.4	0.61	0.03	0	0	0.32	0.4	0.76	0.01	0	0	0.32	0.4	0.4
		"Best"	0.36	0	0	7.35	5.51	6	0.29	0	0	4.05	3.76	2.55	0.12	0	0	4.3	1.75	3
		High	3.6	5	0	51	35.1	69	2.09	2.5	0	32	32.1	62	1.12	2.5	0	37	29	72

Table B-4
Expert Elicitation Input – Large Containment with Extremely Large Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Extremely Large Pathway (> 100 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	a	B	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	1E-4	0	0	0.01	0.1	0.1	9E-5	0	0	0.01	0.1	0.05	1E-5	0	0	0.01	0.1	0.05
		"Best"	1E-3	0	0	0.1	0.5	0.5	9E-4	0	0	0.05	0.25	0.25	1E-4	0	0	0.05	0.25	0.25
		High	1E-2	0	0	5	5	12	9E-3	0	0	2	4	15	1E-3	0	0	2	3.00	15
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	1E-4	0	0	0.001	0.1	0.05	9E-5	0	0	0.001	0.1	0.05	1E-5	0	0	0.001	0.10	0.001
		"Best"	1E-3	0	0	0.01	0.5	0.25	9E-4	0	0	0.01	0.25	0.2	1E-4	0	0	0.01	0.25	0.1
		High	1E-2	0	0	1	10	12	9E-3	0	0	1	10	12	1E-3	0	0	1	10.00	15
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	1E-4	0	0	0.001	0.1	0.05	9E-5	0	0	0.001	0.1	0.05	1E-5	0	0	0.001	0.10	0.05
		"Best"	1E-3	0	0	0.01	0.5	0.25	9E-4	0	0	0.01	0.25	0.2	1E-4	0	0	0.01	0.25	0.1
		High	1E-2	0	0	1	10	15	9E-3	0	0	1	10	15	1E-3	0	0	1	10.00	15
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	1E-4	0	0	0.01	0.01	0.1	9E-5	0	0	0.01	0.01	0.05	1E-5	0	0	0.01	0.001	0.05
		"Best"	1E-3	0	0	0.1	0.1	0.5	9E-4	0	0	0.05	0.075	0.25	1E-4	0	0	0.05	0.03	0.25
		High	1E-2	0	0	5	1	12	9E-3	0	0	2	1	15	1E-3	0	0	2	0.10	15
5	Fatigue failures (e.g., bellows fatigue failure)	Low	1E-4	0	0	0.001	0.001	1E-4	9E-5	0	0	0.001	0.001	1E-5	1E-5	0	0	0.001	1E-4	1E-4
		"Best"	1E-3	0	0	0.01	0.01	1E-4	9E-4	0	0	0.01	0.01	5E-5	1E-4	0	0	0.01	0.001	5E-4
		High	1E-2	0	0	5	0.1	8	1E-3	0	0	0.5	0.1	8	1E-4	0	0	0.5	0.01	8
	TOTALS	Low	5E-4	0	0	0.02	0.31	0.3	5E-4	0	0	0.02	0.31	0.2	5E-5	0	0	0.02	0.3	0.15
		"Best"	0.01	0	0	0.23	1.61	1.5	5E-3	0	0	0.13	0.83	0.9	5E-4	0	0	0.13	0.78	0.7
		High	0.05	0	0	17	26.1	59	0.04	0	0	6.5	25.1	65	4E-3	0	0	6.5	23.1	68

Table B-5
Expert Elicitation Input – Small Containment with Small Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Small Leakage Pathway (1 - 2 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	A	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	1	5	25	1	0.1	5	0.9	3	2	1	0.1	4	0.1	0	0.5	0.1	0.1	0.1
		"Best"	10	10	15	10	2.5	8	9	5	13	7.5	1.5	6	1	5	2	2.5	1	2
		High	30	15	65	25	12	16	25	7	50	25	10	19	5	10	15	15	9	12
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	3	5	2	1	1	1	0.75	3	1.5	0.5	0.1	1	0.75	1	0.5	0.5	1	0.5
		"Best"	10	10	7	7.5	7.5	4	5	7.5	7	3.75	2.5	2	5	2.5	3	3.75	5	2
		High	30	15	25	25	35	20	15	10	15	20	25	20	15	5	10	20	35	25
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	5	5	0.8	2	1	1	2.5	4	0.2	1	0.1	1	2.5	2	0.6	2	1	0.5
		"Best"	12.5	10	15	12.5	12.5	10	6.25	7	7	2.5	2.5	4	6.25	3	8	10	10	6
		High	20	15	30	30	45	30	10	10	12	15	25	20	10	5	18	25	40	25
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	1	10	2	5	1	1	0.9	10	1.5	2	1	1	0.1	2	0.5	1	0.1	0.5
		"Best"	5	20	25	15	5	5	4.5	15	20	10	4	4	0.5	5	8	5	1	1
		High	25	30	60	40	16	20	22.5	20	50	30	14	20	2.5	10	10	20	9	20
5	Fatigue failures (e.g., bellows fatigue failure)	Low	0.5	1	0.4	1	0.1	0.01	0.4	0.5	0.2	1	0.1	0.01	0.1	0.2	0.2	0.1	0.01	0.01
		"Best"	2.5	3	2	2.5	2	0.1	2	2.5	1.2	2.5	1.9	0.05	0.5	0.5	8	0.5	0.1	0.05
		High	25	5	8	12	12	10	20	3	5	12	12	10	5	1	3	10	1	10
	TOTALS	Low	10.5	26	30.2	10	3.2	8.01	5.45	20.5	5.4	5.5	1.4	7.01	3.55	5.2	2.3	3.7	2.21	1.61
		"Best"	40	53	64	47.5	29.5	27.1	26.8	37	48.2	26.3	12.4	16.1	13.3	16	29	21.8	17.1	11.1
		High	130	80	188	132	120	96	92.5	50	132	102	86	89	37.5	31	56	90	94	92

Table B-6
Expert Elicitation Input – Small Containment with Medium Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Medium Leakage Pathway (2 - 10 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	0.2	2	2	0.1	0.1	2	0.18	0	1.5	0.1	0.1	1	0.02	0	0.5	0.1	0.1	0.1
		"Best"	2	5	5	5	1	3	1.8	2.5	4	2.5	0.5	2	0.2	2.5	1	2.5	0.5	1
		High	20	10	20	20	9	16	18	5	16	12	6	12	2	5	4	12	6	10
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	0.5	1	1.5	0.1	1	0.5	0.25	1	1.3	0.1	0.1	0.5	0.25	0	0.2	0.1	0.1	0.05
		"Best"	2.5	2.5	7	1.25	5	1	1.25	2.5	4	1.25	2.5	1	1.25	0	3	1	2.5	0.1
		High	10	7.5	20	15	35	25	10	5	16	15	25	25	5	2.5	4	10	25	15
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	0.5	0	0.5	0.1	1	0.1	0.25	0	0.2	0.1	0.1	0.1	0.25	0.1	0.3	0.1	0.1	0.1
		"Best"	2.5	2.5	12	1.25	5	2	1.25	2	5	1	2.5	1	1.25	0.5	7	1.25	2.5	1
		High	10	5	20	10	35	15	5	4	8	5	25	10	5	1	12	10	25	10
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	0.1	0	1.8	0.1	0.1	0.5	0.09	0	1.4	0.1	0.1	0.5	0.01	0	0.4	0.1	0.01	0.25
		"Best"	1	2	20	5	1	2	0.9	2	17	2.5	0.75	1	0.1	0	3	2.5	0.25	1
		High	10	3	45	20	5	15	9	2	30	12	5	15	1	1	15	12	3	20
5	Fatigue failures (e.g., bellows fatigue failure)	Low	0.01	0	0.3	0.01	0.01	0.005	9E-3	0	0.2	0.01	0.01	0.001	1E-3	0	0.1	0.01	0	0.001
		"Best"	0.1	0	1.8	0.1	0.1	0.01	9E-2	0	1.1	0.05	0.09	0.005	1E-2	0	7	0.05	0.01	0.005
		High	1	0	7	2	1	8	9E-1	0	5	1	1	8	1E-1	0	2	1	0.1	8
	TOTALS	Low	1.31	3	6.1	0.41	2.21	3.11	0.78	1	4.6	0.41	0.41	2.1	0.53	0.1	1.5	0.41	0.31	0.5
		"Best"	8.1	12	45.8	12.6	12.1	8.01	5.29	9	31.1	7.3	6.34	5.01	2.81	3	21	7.3	5.76	3.11
		High	51	25.5	112	67	85	79	42.9	16	75	45	62	70	13.1	9.5	37	45	59.1	63

Table B-7
Expert Elicitation Input – Small Containment with Large Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Large Leakage Pathway (> 10 La to 100La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	0.01	0	1	0.1	0.1	0.5	0.01	0	0.8	0.1	0.1	0.25	1.E-3	0	0.2	0.1	0.1	0.1
		"Best"	0.1	0	3	2.5	0.5	2	0.09	0	2	1.25	0.25	1	1.E-2	0	1	1.25	0.25	1
		High	1	5	10	12	6	15	0.1	2.5	8	8	4	15	0.1	2.5	2	8	4	20
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	0.5	0	0.8	0.1	0.1	0.1	0.25	0	0.5	0.1	0.1	0.1	0.25	0	0.3	0.1	0.1	0.05
		"Best"	2.5	0	2	1.25	2.5	0.5	1.25	0	1.8	1	1	0.5	1.25	0	0.2	1.25	1.5	0.1
		High	10	1	10	15	25	12	5	1	6	10	10	12	5	0	4	15	15	12
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	0.1	0	0.3	0.1	0.1	0.1	0.05	0	0.1	0.01	0.1	0.1	0.05	0	0.2	0.01	0.1	0.1
		"Best"	1	0	4	1	2.5	1	0.5	0	1.5	0.5	1	0.5	0.5	0	2.5	0.5	1.5	0.5
		High	10	0	15	10	25	15	5	0	7	5	10	15	5	0	8	5	15	15
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	0.01	0	1.1	0.1	0.1	0.1	9E-3	0	0.8	0.1	0.01	0.1	1E-3	0	0.3	0.1	0.01	0.05
		"Best"	0.1	0	6	2.5	0.5	0.5	9E-2	0	4	1.25	0.350	0.25	1E-2	0	2	1.25	0.15	0.25
		High	1	0	20	12	4	15	9E-1	0	15	8	4	15	1E-1	0	5	8	2	1.5
5	Fatigue failures (e.g., bellows fatigue failure)	Low	1E-3	0	0.2	0.01	1E-3	1E-4	9E-4	0	0.1	0.01	0.001	1E-4	1E-4	0	0.1	0.01	1E-4	1E-4
		"Best"	1E-2	0	1.2	0.1	0.01	0.001	9E-3	0	0.8	0.05	0.01	0.001	1E-3	0	0.4	0.05	1E-3	5E-4
		High	1E-1	0	6	2	0.1	8	9E-2	0	4	1	0.1	8	1E-2	0	2	1	0.01	8
	TOTALS	Low	0.62	0	3.4	0.41	0.4	0.8	0.32	0	2.3	0.32	0.31	0.55	0.3	0	1.1	0.32	0.31	0.3
		"Best"	3.71	0	16.2	7.35	6.01	4	1.94	0	10.1	4.05	2.61	2.25	1.77	0	6.1	4.3	3.4	1.85
		High	22.1	6	61	51	60.1	65	11.1	3.5	40	32	28.1	65	10.2	2.5	21	37	36	56.5

Table B-8
Expert Elicitation Input – Small Containment with Extremely Large Leakage Pathway

No.	Failure Mode or Degradation Description	Estimate of Low, Best, and High Value	Extremely Large Leakage Pathway (> 100 La)																	
			Total Degraded ILRTs						Detected by Alternate Means						Detectable by ILRT Only (Failures)					
			a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
1	Construction error or deficiency (e.g., construction debris in concrete)	Low	1.E-4	0	0.5	0.01	0.1	0.1	9.E-5	0	0.3	0.01	0.01	0.05	1.E-5	0	0.2	0.01	0.01	0.05
		"Best"	1.E-3	0	1	0.1	0.25	0.5	9.E-4	0	0.7	0.05	0.1	0.25	1.E-4	0	0.3	0.05	0.15	0.25
		High	1.E-2	0	5	5	4	12	9.E-3	0	3	2	3	15	1.E-3	0	2	2	2	15
2	Human error associated with testing or maintenance (e.g., testing equipment left on penetration, not replacing caps on containment pressure instruments, improper alignment of valve components, use of improper components such as o-rings, washers in mechanical joints)	Low	1E-3	0	0.6	0	0.1	0.05	9E-4	0	0.2	0.001	0.1	0.05	1E-4	0	0.4	0.001	0.1	0.01
		"Best"	1E-2	0	1	0.01	1	0.1	9E-3	0	0.4	0.01	0.5	0.1	1E-3	0	0.6	0.01	0.5	0.05
		High	1E-1	0	8	1	10	12	9E-2	0	3	1	10	12	1E-2	0	8	1	10	12
3	Human error, design error or other deficiency associated with modifications (e.g., purge valves installed in wrong direction, spare pipes not capped, debris left in isolation valve, etc.)	Low	1E-3	0	0.2	0	0.1	0.05	9E-4	0	0.1	0.001	0.1	0.05	1E-4	0	0.1	0.001	0.1	0.05
		"Best"	1E-2	0	2	0.01	1	0.25	9E-3	0	1	0.01	0.5	0.2	1E-3	0	1	0.01	0.5	0.1
		High	1E-1	0	8	1	10	20	9E-2	0	3	1	10	20	1E-2	0	5	1	10	20
4	Corrosion (e.g., corrosion near water interface in bilges, corrosion of expansion bellows, corrosion of pipe caps, etc.)	Low	1E-4	0	0.4	0.01	0.01	0.05	9E-5	0	0.3	0.01	0.001	0.05	1E-5	0	0.1	0.01	0.001	0.05
		"Best"	1E-3	0	4	0.1	0.05	0.2	9E-4	0	8	0.05	0.025	0.1	1E-4	0	1	0.05	0.025	0.1
		High	1E-2	0	15	5	1	15	9E-3	0	12	2	1	15	1E-3	0	3	2	10	15
5	Fatigue failures (e.g., bellows fatigue failure)	Low	1E-4	0	0.2	1E-3	0.001	1E-3	9E-5	0	0.1	0.001	0.001	9E-5	1E-5	0	0.1	0.001	1E-4	1E-4
		"Best"	1E-3	0	0.5	0.01	0.01	1E-3	9E-4	0	0.2	0.01	0.01	9E-4	1E-4	0	0.3	0.01	0.001	1E-4
		High	1E-2	0	3	5	0.1	8	9E-3	0	1	0.5	0.1	8	1E-3	0	2	0.5	0.01	8
	TOTALS	Low	0	0	1.9	0.02	0.31	0.25	0	0	1	0.02	0.21	0.2	0	0	0.9	0.02	0.21	0.16
		"Best"	0.02	0	8.5	0.23	2.31	1.05	0.02	0	10.3	0.13	1.13	0.65	0	0	3.2	0.13	1.18	0.5
		High	0.23	0	39	17	25.1	67	0.21	0	22	6.5	24.1	70	0.02	0	20	6.5	32	70

C
EXPERT ELICITATION RESULTS

This Appendix presents the detailed results of the statistical analysis of the expert elicitation.

The input data used was the trim mean. That is, the lowest and highest experts were not included in the development of the community distribution. This treatment was performed for several reasons. One expert used zero several times in the assignment of the probability of ILRT failure. Zeros are difficult to treat in the statistical evaluation of the expert input. Therefore, this expert was not included in the development of the community distribution. Since the lowest expert was not included in the development of the community distribution, it was prudent to not include the highest expert in the development of the community distribution as well. This treatment results in the use of a four expert set as opposed to the six to develop the community distribution and therefore the community distribution represents the center of the input data collected.

In addition, no community distribution was developed for the small containment case. This is a result of the fact that analysis of the small containment input data actually produces similar values for the probability of a leakage pathway in the small containments. The differences are very small and do not represent a significant difference in the probability, therefore the small containment case was not evaluated. It should be noted that one expert did not complete small containment input sheets since he believed that there was no reason to treat the small containments different from the large containment type.

Both of the above treatments of the input data were discussed with experts during the elicitation meeting as being potential treatments of the final results. Experts agreed with this treatment.

The following tables and figures present the results of the expert elicitation process. The following tables are presented:

- Table C-1: Large Containment – Construction Error or Deficiency
- Table C-2: Large Containment – Human Error (Testing or Maintenance)
- Table C-3: Large Containment – Human Error (Design Error)
- Table C-4: Large Containment – Corrosion
- Table C-5: Large Containment – Fatigue Failures
- Table C-6: Large Containment – Aggregate
- Table C-7: Small Containment – Construction Error or Deficiency
- Table C-8: Small Containment – Human Error (Testing or Maintenance)

- Table C-9: Small Containment – Human Error (Design Error)
- Table C-10: Small Containment – Corrosion
- Table C-11: Small Containment – Fatigue Failures
- Table C-12: Small Containment – Aggregate

Several figures are produced from the tables above. These figures are:

- Figure C-1: Large Containment – Failure Probability vs. La
- Figure C-2: Small Containment – Failure Probability vs. La
- Figure C-3: Comparison of Small & Large Containment – Failure Probability

Table C-1
Large Containment – Construction Error or Deficiency

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	4.25E-03	3.04E-04	3.36E-02	1.06E-03	1.68E-04	6.62E-03	6.19E-03	1.56E-03	2.42E-02	4.62E-03	8.90E-04	2.36E-02	5.13E-03	2.28E-04	1.04E-01
2	2.89E-03	1.07E-04	4.11E-02	4.01E-04	6.78E-05	2.37E-03	3.99E-03	9.25E-04	1.70E-02	3.16E-03	5.66E-04	1.75E-02	4.01E-03	4.58E-05	2.62E-01
5	1.72E-03	2.01E-05	8.25E-02	8.99E-05	1.53E-05	5.28E-04	2.10E-03	2.74E-04	1.60E-02	1.84E-03	2.17E-04	1.55E-02	2.85E-03	3.38E-06	7.08E-01
10	1.15E-03	4.52E-06	1.61E-01	2.40E-05	3.48E-06	1.66E-04	1.24E-03	7.67E-05	1.95E-02	1.19E-03	8.04E-05	1.72E-02	2.17E-03	3.57E-07	9.30E-01
20	7.68E-04	6.97E-07	3.18E-01	5.33E-06	5.12E-07	5.56E-05	6.93E-04	1.65E-05	2.82E-02	7.39E-04	2.44E-05	2.19E-02	1.63E-03	3.03E-08	9.89E-01
35	5.49E-04	1.18E-07	4.99E-01	1.36E-06	7.46E-08	2.46E-05	4.19E-04	3.99E-06	4.22E-02	4.92E-04	8.10E-06	2.91E-02	1.29E-03	3.53E-09	9.98E-01
50	4.43E-04	3.30E-08	6.31E-01	5.23E-07	1.80E-08	1.52E-05	2.98E-04	1.47E-06	5.70E-02	3.76E-04	3.77E-06	3.61E-02	1.10E-03	8.30E-10	9.99E-01
100	2.91E-04	1.91E-09	8.46E-01	6.75E-08	7.20E-10	6.32E-06	1.48E-04	1.74E-07	1.12E-01	2.16E-04	7.38E-07	5.95E-02	8.00E-04	4.18E-11	1.00E+00
200	1.91E-04	6.49E-11	9.54E-01	6.52E-09	1.48E-11	2.87E-06	6.90E-05	1.53E-08	2.38E-01	1.19E-04	1.19E-07	1.07E-01	5.75E-04	1.65E-12	1.00E+00
500	1.09E-04	3.37E-13	9.92E-01	1.77E-10	2.66E-14	1.18E-06	2.28E-05	3.76E-10	5.80E-01	5.12E-05	7.75E-09	2.53E-01	3.62E-04	1.56E-14	1.00E+00
600	9.75E-05	1.12E-13	9.95E-01	7.99E-11	6.31E-15	1.01E-06	1.80E-05	1.67E-10	6.59E-01	4.29E-05	4.29E-09	3.00E-01	3.29E-04	5.82E-15	1.00E+00
1000	7.13E-05	2.99E-15	9.99E-01	7.37E-12	7.82E-17	6.95E-07	9.04E-06	1.50E-11	8.45E-01	2.56E-05	7.55E-10	4.65E-01	2.51E-04	3.32E-16	1.00E+00
2000	4.65E-05	1.30E-17	1.00E+00	1.96E-13	7.95E-20	4.82E-07	3.31E-06	4.00E-13	9.65E-01	1.22E-05	5.75E-11	7.21E-01	1.70E-04	5.28E-18	1.00E+00
5000	2.62E-05	3.00E-21	1.00E+00	7.26E-16	1.26E-24	4.16E-07	7.69E-07	1.66E-15	9.97E-01	4.22E-06	1.27E-12	9.33E-01	9.97E-05	1.37E-20	1.00E+00
10000	1.67E-05	1.46E-24	1.00E+00	5.22E-18	5.21E-29	5.23E-07	2.28E-07	1.46E-17	1.00E+00	1.77E-06	5.02E-14	9.84E-01	6.50E-05	1.03E-22	1.00E+00

Table C-2
Large Containment – Human Error (Testing or Maintenance)

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	7.90E-03	1.23E-03	3.47E-02	4.27E-03	1.68E-03	1.08E-02	6.10E-03	8.31E-04	4.33E-02	1.45E-02	6.53E-03	3.21E-02	6.69E-03	8.19E-04	5.25E-02
2	4.48E-03	2.23E-04	7.08E-02	1.58E-03	6.10E-04	4.09E-03	4.40E-03	3.67E-04	5.06E-02	9.04E-03	1.04E-03	7.38E-02	2.88E-03	3.05E-05	2.15E-01
5	2.07E-03	4.83E-06	3.18E-01	3.20E-04	1.02E-04	9.97E-04	2.77E-03	6.82E-05	1.02E-01	4.43E-03	3.81E-05	3.42E-01	7.60E-04	5.56E-08	9.12E-01
10	1.15E-03	8.34E-08	7.63E-01	7.37E-05	1.66E-05	3.28E-04	1.90E-03	1.37E-05	2.09E-01	2.41E-03	1.74E-06	7.71E-01	2.27E-04	9.26E-11	9.98E-01
20	6.42E-04	5.74E-10	9.79E-01	1.30E-05	1.62E-06	1.05E-04	1.28E-03	2.17E-06	4.29E-01	1.22E-03	4.46E-08	9.71E-01	5.55E-05	2.76E-14	1.00E+00
35	3.99E-04	4.08E-12	9.98E-01	2.56E-06	1.62E-07	4.04E-05	9.07E-04	4.13E-07	6.66E-01	6.71E-04	1.44E-09	9.97E-01	1.50E-05	8.68E-18	1.00E+00
50	2.93E-04	1.36E-13	1.00E+00	8.02E-07	2.97E-08	2.16E-05	7.23E-04	1.32E-07	7.98E-01	4.44E-04	1.25E-10	9.99E-01	5.94E-06	2.23E-20	1.00E+00
100	1.61E-04	3.23E-17	1.00E+00	6.21E-08	6.26E-10	6.17E-06	4.56E-04	1.20E-08	9.45E-01	1.86E-04	5.89E-13	1.00E+00	7.85E-07	2.43E-26	1.00E+00
200	8.75E-05	2.10E-21	1.00E+00	3.02E-09	5.47E-12	1.67E-06	2.79E-04	8.43E-10	9.89E-01	7.10E-05	1.10E-15	1.00E+00	7.39E-08	9.32E-34	1.00E+00
500	3.89E-05	6.28E-29	1.00E+00	2.34E-11	1.98E-15	2.77E-07	1.39E-04	1.63E-11	9.99E-01	1.67E-05	5.24E-20	1.00E+00	1.75E-09	2.41E-46	1.00E+00
600	3.30E-05	1.37E-30	1.00E+00	7.78E-12	3.13E-16	1.93E-07	1.20E-04	7.00E-12	1.00E+00	1.22E-05	5.61E-21	1.00E+00	7.54E-10	2.70E-49	1.00E+00
1000	2.09E-05	1.01E-35	1.00E+00	2.70E-13	1.04E-18	7.01E-08	7.87E-05	5.81E-13	1.00E+00	4.86E-06	6.55E-24	1.00E+00	5.90E-11	1.75E-58	1.00E+00
2000	1.11E-05	5.50E-44	1.00E+00	1.38E-15	1.06E-22	1.81E-08	4.30E-05	1.48E-14	1.00E+00	1.23E-06	1.90E-28	1.00E+00	1.12E-12	2.04E-73	1.00E+00
5000	4.61E-06	1.09E-57	1.00E+00	2.89E-19	2.45E-29	3.41E-09	1.83E-05	6.65E-17	1.00E+00	1.57E-07	1.40E-35	1.00E+00	2.12E-15	1.78E-98	1.00E+00
10000	2.28E-06	2.92E-72	1.00E+00	1.21E-22	1.25E-35	1.16E-09	9.10E-06	7.02E-19	1.00E+00	2.69E-08	5.69E-42	1.00E+00	7.23E-18	2.09E-122	1.00E+00

Table C-3
Large Containment – Human Error (Design Error)

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	1.07E-02	3.18E-03	3.06E-02	7.43E-03	5.46E-03	1.01E-02	1.29E-02	6.03E-03	2.74E-02	1.45E-02	6.53E-03	3.21E-02	8.01E-03	1.33E-03	4.68E-02
2	5.65E-03	5.26E-04	6.79E-02	2.72E-03	1.81E-03	4.09E-03	5.83E-03	1.62E-03	2.08E-02	9.04E-03	1.04E-03	7.38E-02	5.03E-03	8.63E-05	2.29E-01
5	2.28E-03	1.78E-05	3.38E-01	5.22E-04	2.33E-04	1.17E-03	1.62E-03	8.99E-05	2.85E-02	4.43E-03	3.81E-05	3.42E-01	2.54E-03	5.26E-07	9.25E-01
10	1.11E-03	6.50E-07	7.87E-01	1.11E-04	3.02E-05	4.07E-04	5.00E-04	4.52E-06	5.25E-02	2.41E-03	1.74E-06	7.71E-01	1.43E-03	4.68E-09	9.98E-01
20	5.32E-04	1.37E-08	9.76E-01	1.71E-05	2.33E-06	1.26E-04	1.24E-04	9.96E-08	1.35E-01	1.22E-03	4.46E-08	9.71E-01	7.61E-04	1.86E-11	1.00E+00
35	2.86E-04	2.84E-10	9.97E-01	2.88E-06	1.88E-07	4.42E-05	3.37E-05	2.22E-09	3.39E-01	6.71E-04	1.44E-09	9.97E-01	4.38E-04	1.12E-13	1.00E+00
50	1.90E-04	2.02E-11	1.00E+00	7.97E-07	2.95E-08	2.16E-05	1.33E-05	1.32E-10	5.72E-01	4.44E-04	1.25E-10	9.99E-01	3.01E-04	3.06E-15	1.00E+00
100	8.15E-05	4.24E-14	1.00E+00	4.48E-08	4.23E-10	4.75E-06	1.70E-06	1.95E-13	9.37E-01	1.86E-04	5.89E-13	1.00E+00	1.38E-04	1.24E-18	1.00E+00
200	3.24E-05	2.63E-17	1.00E+00	1.40E-09	2.19E-12	8.93E-07	1.50E-07	5.62E-17	9.98E-01	7.10E-05	1.10E-15	1.00E+00	5.86E-05	1.52E-22	1.00E+00
500	8.34E-06	1.89E-22	1.00E+00	4.68E-12	2.88E-16	7.59E-08	3.00E-09	4.98E-23	1.00E+00	1.67E-05	5.24E-20	1.00E+00	1.66E-05	1.24E-28	1.00E+00
600	6.24E-06	1.40E-23	1.00E+00	1.26E-12	3.54E-17	4.49E-08	1.24E-09	1.87E-24	1.00E+00	1.22E-05	5.61E-21	1.00E+00	1.27E-05	5.52E-30	1.00E+00
1000	2.66E-06	3.02E-27	1.00E+00	2.23E-14	5.09E-20	9.74E-09	8.28E-11	6.53E-29	1.00E+00	4.86E-06	6.55E-24	1.00E+00	5.76E-06	4.90E-34	1.00E+00
2000	7.58E-07	6.30E-33	1.00E+00	3.54E-17	1.17E-24	1.08E-09	1.18E-12	3.34E-36	1.00E+00	1.23E-06	1.90E-28	1.00E+00	1.80E-06	3.20E-40	1.00E+00
5000	1.21E-07	3.21E-42	1.00E+00	8.93E-22	1.64E-32	4.87E-11	1.28E-15	1.50E-48	1.00E+00	1.57E-07	1.40E-35	1.00E+00	3.27E-07	9.05E-50	1.00E+00
10000	2.61E-08	6.55E-51	1.00E+00	4.32E-26	4.34E-40	4.31E-12	2.40E-18	1.86E-60	1.00E+00	2.69E-08	5.69E-42	1.00E+00	7.76E-08	3.52E-58	1.00E+00

Table C-4
Large Containment – Corrosion

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	4.30E-03	1.76E-04	4.03E-02	5.54E-04	1.22E-04	2.50E-03	8.32E-03	2.70E-03	2.54E-02	3.57E-03	1.06E-03	1.19E-02	4.76E-03	7.92E-05	2.24E-01
2	2.65E-03	7.48E-05	4.54E-02	1.99E-04	5.89E-05	6.70E-04	4.97E-03	1.38E-03	1.77E-02	2.03E-03	6.48E-04	6.32E-03	3.42E-03	2.08E-05	3.60E-01
5	1.34E-03	2.06E-05	8.81E-02	4.12E-05	2.03E-05	8.33E-05	2.31E-03	3.18E-04	1.66E-02	8.80E-04	3.08E-04	2.51E-03	2.14E-03	1.33E-06	7.74E-01
10	7.76E-04	6.00E-06	1.78E-01	1.03E-05	6.52E-06	1.64E-05	1.20E-03	7.13E-05	1.99E-02	4.35E-04	1.58E-04	1.20E-03	1.46E-03	9.53E-08	9.57E-01
20	4.40E-04	7.08E-07	3.46E-01	2.15E-06	8.08E-07	5.72E-06	5.83E-04	1.18E-05	2.82E-02	2.00E-04	7.08E-05	5.67E-04	9.73E-04	4.50E-09	9.95E-01
35	2.75E-04	8.39E-08	5.81E-01	5.18E-07	9.24E-08	2.90E-06	3.08E-04	2.17E-06	4.18E-02	1.01E-04	3.24E-05	3.16E-04	6.89E-04	2.86E-10	9.99E-01
50	2.03E-04	1.87E-08	7.20E-01	1.93E-07	1.94E-08	1.92E-06	1.99E-04	6.57E-07	5.67E-02	6.37E-05	1.83E-05	2.22E-04	5.48E-04	4.29E-11	1.00E+00
100	1.12E-04	6.65E-10	9.19E-01	2.33E-08	6.08E-10	8.92E-07	7.95E-05	4.87E-08	1.15E-01	2.42E-05	5.10E-06	1.15E-04	3.44E-04	7.86E-13	1.00E+00
200	6.18E-05	1.54E-11	9.84E-01	2.10E-09	1.02E-11	4.35E-07	2.88E-05	2.39E-09	2.58E-01	8.34E-06	1.13E-06	6.17E-05	2.10E-04	9.29E-15	1.00E+00
500	2.81E-05	4.68E-14	9.98E-01	5.25E-11	1.46E-14	1.89E-07	6.36E-06	2.15E-11	6.53E-01	1.73E-06	1.06E-07	2.82E-05	1.04E-04	1.27E-17	1.00E+00
600	2.40E-05	1.08E-14	9.99E-01	2.33E-11	3.32E-15	1.63E-07	4.59E-06	7.55E-12	7.36E-01	1.23E-06	6.29E-08	2.42E-05	9.01E-05	3.09E-18	1.00E+00
1000	1.53E-05	2.21E-16	1.00E+00	2.06E-12	3.72E-17	1.14E-07	1.76E-06	3.24E-13	9.05E-01	4.58E-07	1.32E-08	1.59E-05	5.91E-05	4.79E-20	1.00E+00
2000	8.21E-06	4.92E-19	1.00E+00	5.19E-14	3.35E-20	8.04E-08	4.22E-07	2.62E-15	9.86E-01	1.06E-07	1.23E-09	9.12E-06	3.23E-05	1.03E-22	1.00E+00
5000	3.45E-06	5.05E-23	1.00E+00	1.82E-16	4.74E-25	7.01E-08	5.06E-08	1.49E-18	9.99E-01	1.22E-08	3.33E-11	4.49E-06	1.37E-05	1.22E-26	1.00E+00
10000	1.72E-06	1.09E-26	1.00E+00	1.28E-18	1.87E-29	8.79E-08	8.32E-09	1.99E-21	1.00E+00	1.97E-09	1.43E-12	2.71E-06	6.87E-06	6.01E-30	1.00E+00

Table C-5
Large Containment – Fatigue Failures

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	8.97E-05	7.88E-36	1.00E+00	4.77E-05	1.97E-06	1.15E-03	2.36E-04	7.82E-07	6.67E-02	1.58E-05	1.03E-06	2.43E-04	5.91E-05	3.15E-65	1.00E+00
2	5.37E-05	2.26E-207	1.00E+00	2.25E-05	1.23E-06	4.14E-04	1.70E-04	5.62E-07	4.87E-02	1.09E-05	9.20E-07	1.30E-04	1.18E-05	0.00E+00	0.00E+00
5	3.06E-05	0.00E+00	0.00E+00	7.66E-06	6.58E-07	8.92E-05	1.07E-04	1.09E-07	9.55E-02	6.59E-06	6.00E-07	7.23E-05	9.29E-07	0.00E+00	0.00E+00
10	2.05E-05	0.00E+00	0.00E+00	3.15E-06	4.13E-07	2.41E-05	7.44E-05	1.43E-08	2.79E-01	4.42E-06	3.29E-07	5.94E-05	9.34E-08	0.00E+00	0.00E+00
20	1.38E-05	0.00E+00	0.00E+00	1.21E-06	2.60E-07	5.67E-06	5.10E-05	1.16E-09	6.92E-01	2.93E-06	1.42E-07	6.02E-05	6.43E-09	0.00E+00	0.00E+00
35	9.94E-06	0.00E+00	0.00E+00	5.34E-07	1.78E-07	1.60E-06	3.71E-05	1.14E-10	9.24E-01	2.08E-06	6.27E-08	6.90E-05	5.39E-10	0.00E+00	0.00E+00
50	8.04E-06	0.00E+00	0.00E+00	3.08E-07	1.38E-07	6.88E-07	3.02E-05	2.32E-11	9.75E-01	1.66E-06	3.51E-08	7.88E-05	9.37E-11	0.00E+00	0.00E+00
100	5.28E-06	0.00E+00	0.00E+00	9.95E-08	6.23E-08	1.59E-07	2.00E-05	8.26E-13	9.98E-01	1.07E-06	1.02E-08	1.11E-04	2.06E-12	0.00E+00	0.00E+00
200	3.42E-06	0.00E+00	0.00E+00	2.95E-08	1.06E-08	8.26E-08	1.30E-05	2.18E-14	1.00E+00	6.73E-07	2.63E-09	1.72E-04	2.41E-14	0.00E+00	0.00E+00
500	1.88E-06	0.00E+00	0.00E+00	5.15E-09	5.26E-10	5.03E-08	7.15E-06	1.13E-16	1.00E+00	3.58E-07	3.71E-10	3.46E-04	2.13E-17	0.00E+00	0.00E+00
600	1.66E-06	0.00E+00	0.00E+00	3.56E-09	2.74E-10	4.63E-08	6.33E-06	3.71E-17	1.00E+00	3.15E-07	2.46E-10	4.03E-04	4.41E-18	0.00E+00	0.00E+00
1000	1.17E-06	0.00E+00	0.00E+00	1.22E-09	3.97E-11	3.76E-08	4.46E-06	1.48E-18	1.00E+00	2.18E-07	7.47E-11	6.37E-04	3.74E-20	0.00E+00	0.00E+00
2000	7.16E-07	0.00E+00	0.00E+00	2.60E-10	2.27E-12	2.99E-08	2.73E-06	1.42E-20	1.00E+00	1.31E-07	1.36E-11	1.25E-03	2.29E-23	0.00E+00	0.00E+00
5000	3.63E-07	0.00E+00	0.00E+00	2.82E-11	3.24E-14	2.45E-08	1.39E-06	1.84E-23	1.00E+00	6.46E-08	1.23E-12	3.40E-03	1.93E-28	0.00E+00	0.00E+00
10000	2.12E-07	0.00E+00	0.00E+00	4.52E-12	8.83E-16	2.31E-08	8.10E-07	8.12E-26	1.00E+00	3.72E-08	1.76E-13	7.79E-03	5.04E-33	0.00E+00	0.00E+00

Table C-6
Large Containment – All Failure Modes

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	2.65E-02	4.50E-03	1.33E-01	1.27E-02	4.99E-03	3.20E-02	3.06E-02	7.94E-03	1.11E-01	3.68E-02	1.41E-02	9.27E-02	2.57E-02	1.43E-03	3.27E-01
2	1.59E-02	1.23E-03	1.99E-01	5.24E-03	2.00E-03	1.36E-02	1.87E-02	3.71E-03	8.90E-02	2.30E-02	4.00E-03	1.22E-01	1.65E-02	1.29E-04	6.86E-01
5	7.42E-03	7.54E-05	5.35E-01	1.22E-03	4.21E-04	3.55E-03	8.77E-03	6.51E-04	1.07E-01	1.12E-02	3.18E-04	2.86E-01	8.51E-03	1.23E-06	9.84E-01
10	3.88E-03	4.71E-06	8.57E-01	3.13E-04	8.69E-05	1.13E-03	4.49E-03	1.02E-04	1.66E-01	5.90E-03	2.61E-05	5.74E-01	4.79E-03	1.32E-08	9.99E-01
20	1.88E-03	1.38E-07	9.82E-01	6.08E-05	1.12E-05	3.30E-04	2.10E-03	9.95E-06	3.07E-01	2.85E-03	1.21E-06	8.71E-01	2.52E-03	5.44E-11	1.00E+00
35	9.86E-04	5.56E-09	9.98E-01	1.27E-05	1.41E-06	1.15E-04	1.05E-03	1.03E-06	5.16E-01	1.47E-03	6.20E-08	9.72E-01	1.42E-03	2.90E-13	1.00E+00
50	6.33E-04	5.34E-10	9.99E-01	4.13E-06	2.98E-07	5.73E-05	6.46E-04	1.99E-07	6.78E-01	9.26E-04	7.19E-09	9.92E-01	9.55E-04	6.79E-15	1.00E+00
100	2.47E-04	2.65E-12	1.00E+00	3.33E-07	8.09E-09	1.37E-05	2.29E-04	4.88E-09	9.15E-01	3.44E-04	5.64E-11	1.00E+00	4.14E-04	1.63E-18	1.00E+00
200	8.57E-05	4.17E-15	1.00E+00	1.61E-08	8.76E-11	2.96E-06	7.01E-05	5.59E-11	9.89E-01	1.11E-04	1.61E-13	1.00E+00	1.62E-04	8.21E-23	1.00E+00
500	1.75E-05	1.68E-19	1.00E+00	1.12E-10	3.76E-14	3.33E-07	1.13E-05	3.71E-14	1.00E+00	1.93E-05	1.08E-17	1.00E+00	3.93E-05	1.02E-29	1.00E+00
600	1.24E-05	1.61E-20	1.00E+00	3.57E-11	6.03E-15	2.11E-07	7.57E-06	6.94E-15	1.00E+00	1.31E-05	1.19E-18	1.00E+00	2.89E-05	2.80E-31	1.00E+00
1000	4.50E-06	1.28E-23	1.00E+00	1.06E-12	1.98E-17	5.74E-08	2.27E-06	4.08E-17	1.00E+00	4.14E-06	1.36E-21	1.00E+00	1.16E-05	4.97E-36	1.00E+00
2000	1.01E-06	1.74E-28	1.00E+00	3.94E-15	1.67E-21	9.27E-09	3.62E-07	1.20E-20	1.00E+00	7.13E-07	2.96E-26	1.00E+00	2.95E-06	1.90E-43	1.00E+00
5000	1.11E-07	2.69E-36	1.00E+00	4.04E-19	2.01E-28	8.11E-10	2.14E-08	2.26E-26	1.00E+00	4.73E-08	7.77E-34	1.00E+00	3.75E-07	3.02E-55	1.00E+00
10000	1.73E-08	1.92E-43	1.00E+00	7.40E-23	3.99E-35	1.37E-10	1.77E-09	1.17E-31	1.00E+00	4.31E-09	7.43E-41	1.00E+00	6.32E-08	6.09E-66	1.00E+00

Table C-7
Small Containment – Construction Error or Deficiency

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	3.55E-03	1.91E-04	3.74E-02	1.06E-03	1.68E-04	6.62E-03	6.19E-03	1.56E-03	2.42E-02	1.83E-03	1.00E-04	3.24E-02	5.13E-03	2.28E-04	1.04E-01
2	2.43E-03	8.23E-05	4.60E-02	4.01E-04	6.78E-05	2.37E-03	3.99E-03	9.25E-04	1.70E-02	1.31E-03	7.87E-05	2.14E-02	4.01E-03	4.58E-05	2.62E-01
5	1.47E-03	1.88E-05	9.31E-02	8.99E-05	1.53E-05	5.28E-04	2.10E-03	2.74E-04	1.60E-02	8.19E-04	4.05E-05	1.63E-02	2.85E-03	3.38E-06	7.08E-01
10	9.98E-04	4.24E-06	1.61E-01	2.40E-05	3.48E-06	1.66E-04	1.24E-03	7.67E-05	1.95E-02	5.62E-04	1.81E-05	1.72E-02	2.17E-03	3.57E-07	9.30E-01
20	6.77E-04	6.74E-07	3.18E-01	5.33E-06	5.12E-07	5.56E-05	6.93E-04	1.65E-05	2.82E-02	3.78E-04	6.26E-06	2.23E-02	1.63E-03	3.03E-08	9.89E-01
35	4.94E-04	1.12E-07	5.32E-01	1.36E-06	7.46E-08	2.46E-05	4.19E-04	3.99E-06	4.22E-02	2.70E-04	2.26E-06	3.13E-02	1.29E-03	3.53E-09	9.98E-01
50	4.03E-04	3.11E-08	6.63E-01	5.23E-07	1.80E-08	1.52E-05	2.98E-04	1.47E-06	5.70E-02	2.17E-04	1.10E-06	4.10E-02	1.10E-03	8.30E-10	9.99E-01
100	2.72E-04	1.82E-09	8.46E-01	6.75E-08	7.20E-10	6.32E-06	1.48E-04	1.74E-07	1.12E-01	1.38E-04	2.33E-07	7.59E-02	8.00E-04	4.18E-11	1.00E+00
200	1.83E-04	6.29E-11	9.54E-01	6.52E-09	1.48E-11	2.87E-06	6.90E-05	1.53E-08	2.38E-01	8.64E-05	4.12E-08	1.54E-01	5.75E-04	1.65E-12	1.00E+00
500	1.07E-04	3.30E-13	9.94E-01	1.77E-10	2.66E-14	1.18E-06	2.28E-05	3.76E-10	5.80E-01	4.46E-05	3.13E-09	3.89E-01	3.62E-04	1.56E-14	1.00E+00
600	9.65E-05	1.02E-13	9.96E-01	7.99E-11	6.31E-15	1.01E-06	1.80E-05	1.67E-10	6.59E-01	3.89E-05	1.80E-09	4.57E-01	3.29E-04	5.82E-15	1.00E+00
1000	7.15E-05	2.85E-15	9.99E-01	7.37E-12	7.82E-17	6.95E-07	9.04E-06	1.50E-11	8.45E-01	2.62E-05	3.57E-10	6.58E-01	2.51E-04	3.32E-16	1.00E+00
2000	4.72E-05	1.33E-17	1.00E+00	1.96E-13	7.95E-20	4.82E-07	3.31E-06	4.00E-13	9.65E-01	1.50E-05	3.35E-11	8.70E-01	1.70E-04	5.28E-18	1.00E+00
5000	2.68E-05	2.86E-21	1.00E+00	7.26E-16	1.26E-24	4.16E-07	7.69E-07	1.66E-15	9.97E-01	6.84E-06	1.06E-12	9.78E-01	9.97E-05	1.37E-20	1.00E+00
10000	1.72E-05	1.55E-24	1.00E+00	5.22E-18	5.21E-29	5.23E-07	2.28E-07	1.46E-17	1.00E+00	3.64E-06	6.05E-14	9.95E-01	6.50E-05	1.03E-22	1.00E+00

Table C-8
Small Containment – Human Error (Testing or Maintenance)

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	5.90E-03	1.16E-04	1.03E-01	5.63E-03	2.59E-03	1.22E-02	6.10E-03	8.31E-04	4.33E-02	9.12E-03	9.75E-04	7.99E-02	2.76E-03	6.26E-06	5.51E-01
2	3.87E-03	2.72E-06	5.93E-01	2.96E-03	1.35E-03	6.51E-03	4.40E-03	3.67E-04	5.06E-02	6.22E-03	5.91E-04	6.21E-02	1.91E-03	5.48E-09	9.98E-01
5	2.15E-03	1.03E-09	9.99E-01	1.12E-03	4.38E-04	2.87E-03	2.77E-03	6.82E-05	1.02E-01	3.57E-03	1.71E-04	6.98E-02	1.13E-03	2.40E-15	1.00E+00
10	1.34E-03	8.57E-13	1.00E+00	4.84E-04	1.47E-04	1.59E-03	1.90E-03	1.37E-05	2.09E-01	2.25E-03	4.37E-05	1.04E-01	7.33E-04	4.99E-21	1.00E+00
20	8.24E-04	6.27E-16	1.00E+00	1.88E-04	3.92E-05	9.02E-04	1.28E-03	2.17E-06	4.29E-01	1.37E-03	8.11E-06	1.88E-01	4.65E-04	2.02E-27	1.00E+00
35	5.48E-04	5.67E-19	1.00E+00	8.05E-05	1.13E-05	5.76E-04	9.07E-04	4.13E-07	6.66E-01	8.88E-04	1.67E-06	3.22E-01	3.16E-04	3.96E-33	1.00E+00
50	4.19E-04	4.60E-21	1.00E+00	4.49E-05	4.64E-06	4.35E-04	7.23E-04	1.32E-07	7.98E-01	6.64E-04	5.47E-07	4.47E-01	2.44E-04	4.91E-37	1.00E+00
100	2.45E-04	1.75E-25	1.00E+00	1.30E-05	6.69E-07	2.53E-04	4.56E-04	1.20E-08	9.45E-01	3.65E-04	4.95E-08	7.30E-01	1.44E-04	2.89E-45	1.00E+00
200	1.39E-04	2.07E-30	1.00E+00	3.23E-06	7.03E-08	1.49E-04	2.79E-04	8.43E-10	9.89E-01	1.91E-04	3.20E-09	9.20E-01	8.27E-05	2.14E-54	1.00E+00
500	6.29E-05	7.16E-37	1.00E+00	3.92E-07	2.05E-09	7.52E-05	1.39E-04	1.63E-11	9.99E-01	7.50E-05	4.88E-11	9.91E-01	3.75E-05	5.47E-68	1.00E+00
600	5.34E-05	2.00E-38	1.00E+00	2.48E-07	9.30E-10	6.59E-05	1.20E-04	7.00E-12	1.00E+00	6.15E-05	1.95E-11	9.95E-01	3.18E-05	6.49E-71	1.00E+00
1000	3.33E-05	5.19E-43	1.00E+00	6.32E-08	8.65E-11	4.61E-05	7.87E-05	5.81E-13	1.00E+00	3.45E-05	1.29E-12	9.99E-01	1.97E-05	1.57E-79	1.00E+00
2000	1.70E-05	8.01E-50	1.00E+00	8.11E-09	2.25E-12	2.93E-05	4.30E-05	1.48E-14	1.00E+00	1.49E-05	2.16E-14	1.00E+00	9.97E-06	2.90E-92	1.00E+00
5000	6.62E-06	5.75E-60	1.00E+00	3.62E-10	7.57E-15	1.73E-05	1.83E-05	6.65E-17	1.00E+00	4.42E-06	4.51E-17	1.00E+00	3.79E-06	4.21E-111	1.00E+00
10000	3.11E-06	1.35E-68	1.00E+00	2.46E-11	4.76E-17	1.27E-05	9.10E-06	7.02E-19	1.00E+00	1.62E-06	2.20E-19	1.00E+00	1.72E-06	5.14E-127	1.00E+00

Table C-9
Small Containment – Human Error (Design Error)

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	1.16E-02	2.81E-03	4.33E-02	9.16E-03	6.69E-03	1.25E-02	1.29E-02	6.03E-03	2.74E-02	1.57E-02	3.80E-03	6.25E-02	8.44E-03	1.18E-03	5.80E-02
2	6.49E-03	4.93E-04	8.25E-02	4.00E-03	2.51E-03	6.35E-03	5.83E-03	1.62E-03	2.08E-02	1.01E-02	1.88E-03	5.26E-02	6.01E-03	4.55E-05	4.46E-01
5	2.91E-03	2.02E-05	3.89E-01	1.06E-03	4.31E-04	2.62E-03	1.62E-03	8.99E-05	2.85E-02	5.27E-03	3.93E-04	6.66E-02	3.70E-03	1.70E-07	9.88E-01
10	1.58E-03	8.79E-07	8.05E-01	3.17E-04	7.77E-05	1.29E-03	5.00E-04	4.52E-06	5.25E-02	3.02E-03	7.94E-05	1.04E-01	2.49E-03	1.22E-09	1.00E+00
20	8.65E-04	2.29E-08	9.80E-01	7.63E-05	9.57E-06	6.07E-04	1.24E-04	9.96E-08	1.35E-01	1.64E-03	1.15E-05	1.90E-01	1.62E-03	4.59E-12	1.00E+00
35	5.33E-04	7.29E-10	9.97E-01	2.01E-05	1.27E-06	3.19E-04	3.37E-05	2.22E-09	3.39E-01	9.51E-04	1.85E-06	3.28E-01	1.13E-03	3.05E-14	1.00E+00
50	3.90E-04	5.71E-11	9.99E-01	7.83E-06	2.94E-07	2.09E-04	1.33E-05	1.32E-10	5.72E-01	6.57E-04	5.11E-07	4.59E-01	8.82E-04	9.70E-16	1.00E+00
100	2.10E-04	2.07E-13	1.00E+00	9.80E-07	1.09E-08	8.85E-05	1.70E-06	1.95E-13	9.37E-01	3.03E-04	3.05E-08	7.50E-01	5.35E-04	6.48E-19	1.00E+00
200	1.11E-04	2.89E-16	1.00E+00	8.50E-08	1.99E-10	3.63E-05	1.50E-07	5.62E-17	9.98E-01	1.28E-04	1.16E-09	9.34E-01	3.14E-04	1.82E-22	1.00E+00
500	4.54E-05	4.31E-21	1.00E+00	1.71E-09	2.69E-13	1.08E-05	3.00E-09	4.98E-23	1.00E+00	3.59E-05	6.87E-12	9.95E-01	1.46E-04	8.30E-28	1.00E+00
600	3.78E-05	3.14E-22	1.00E+00	7.06E-10	5.84E-14	8.53E-06	1.24E-09	1.87E-24	1.00E+00	2.73E-05	2.20E-12	9.97E-01	1.24E-04	5.78E-29	1.00E+00
1000	2.25E-05	1.91E-25	1.00E+00	4.82E-11	5.29E-16	4.38E-06	8.28E-11	6.53E-29	1.00E+00	1.22E-05	7.09E-14	1.00E+00	7.78E-05	2.19E-32	1.00E+00
2000	1.09E-05	8.09E-31	1.00E+00	7.23E-13	2.84E-19	1.84E-06	1.18E-12	3.34E-36	1.00E+00	3.67E-06	3.68E-16	1.00E+00	3.97E-05	1.76E-37	1.00E+00
5000	3.95E-06	4.35E-39	1.00E+00	8.81E-16	1.16E-24	6.69E-07	1.28E-15	1.50E-48	1.00E+00	6.20E-07	1.04E-19	1.00E+00	1.52E-05	4.32E-45	1.00E+00
10000	1.76E-06	6.05E-47	1.00E+00	1.92E-18	1.00E-29	3.70E-07	2.40E-18	1.86E-60	1.00E+00	1.37E-07	7.42E-23	1.00E+00	6.90E-06	1.40E-51	1.00E+00

Table C-10
Small Containment – Corrosion

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	2.99E-03	6.08E-05	3.63E-02	5.73E-04	9.22E-05	3.56E-03	8.32E-03	2.70E-03	2.54E-02	1.11E-03	5.50E-05	2.21E-02	1.96E-03	1.46E-05	2.10E-01
2	1.72E-03	4.62E-05	1.52E-02	2.25E-04	3.91E-05	1.29E-03	4.97E-03	1.38E-03	1.77E-02	6.78E-04	2.19E-05	2.06E-02	1.01E-03	5.91E-05	1.70E-02
5	7.68E-04	6.70E-06	1.96E-02	5.45E-05	9.44E-06	3.14E-04	2.31E-03	3.18E-04	1.66E-02	3.33E-04	1.24E-06	8.25E-02	3.76E-04	6.67E-06	2.07E-02
10	3.91E-04	3.18E-07	8.95E-02	1.59E-05	2.29E-06	1.11E-04	1.20E-03	7.13E-05	1.99E-02	1.86E-04	6.23E-08	3.57E-01	1.62E-04	5.23E-08	3.34E-01
20	1.88E-04	6.55E-09	4.91E-01	3.99E-06	3.71E-07	4.29E-05	5.83E-04	1.18E-05	2.82E-02	9.94E-05	1.84E-09	8.43E-01	6.39E-05	1.13E-10	9.73E-01
35	9.87E-05	1.50E-10	9.08E-01	1.15E-06	6.13E-08	2.16E-05	3.08E-04	2.17E-06	4.18E-02	5.80E-05	7.37E-11	9.79E-01	2.80E-05	3.24E-13	1.00E+00
50	6.39E-05	1.33E-11	9.82E-01	4.89E-07	1.66E-08	1.44E-05	1.99E-04	6.57E-07	5.67E-02	4.05E-05	7.93E-12	9.95E-01	1.60E-05	4.97E-15	1.00E+00
100	2.60E-05	4.74E-14	9.99E-01	7.91E-08	8.88E-10	7.05E-06	7.95E-05	4.87E-08	1.15E-01	1.94E-05	6.87E-14	1.00E+00	4.93E-06	4.96E-19	1.00E+00
200	9.74E-06	5.44E-17	1.00E+00	1.02E-08	2.76E-11	3.77E-06	2.88E-05	2.39E-09	2.58E-01	8.80E-06	3.31E-16	1.00E+00	1.34E-06	9.83E-24	1.00E+00
500	2.35E-06	2.69E-21	1.00E+00	4.56E-10	1.09E-13	1.90E-06	6.36E-06	2.15E-11	6.53E-01	2.83E-06	1.07E-19	1.00E+00	1.93E-07	3.37E-31	1.00E+00
600	1.74E-06	2.32E-22	1.00E+00	2.31E-10	3.15E-14	1.70E-06	4.59E-06	7.55E-12	7.36E-01	2.23E-06	1.87E-20	1.00E+00	1.27E-07	7.10E-33	1.00E+00
1000	7.27E-07	3.42E-25	1.00E+00	3.08E-11	7.32E-16	1.30E-06	1.76E-06	3.24E-13	9.05E-01	1.12E-06	1.07E-22	1.00E+00	3.70E-08	6.07E-38	1.00E+00
2000	2.10E-07	1.36E-29	1.00E+00	1.48E-12	2.16E-18	1.02E-06	4.22E-07	2.62E-15	9.86E-01	4.11E-07	4.90E-26	1.00E+00	5.97E-09	8.80E-46	1.00E+00
5000	3.73E-08	4.35E-37	1.00E+00	1.49E-14	2.27E-22	9.82E-07	5.06E-08	1.49E-18	9.99E-01	9.82E-08	4.96E-31	1.00E+00	3.95E-10	4.30E-58	1.00E+00
10000	9.67E-09	4.91E-43	1.00E+00	2.76E-16	6.09E-26	1.25E-06	8.32E-09	1.99E-21	1.00E+00	3.03E-08	2.70E-35	1.00E+00	3.93E-11	4.11E-69	1.00E+00

Table C-11
Small Containment – Fatigue Failures

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	8.91E-05	8.15E-37	1.00E+00	5.13E-05	2.00E-06	1.31E-03	2.36E-04	7.82E-07	6.67E-02	1.58E-05	1.03E-06	2.43E-04	5.29E-05	3.32E-67	1.00E+00
2	5.18E-05	8.08E-262	1.00E+00	2.30E-05	1.25E-06	4.24E-04	1.70E-04	5.62E-07	4.87E-02	1.09E-05	9.20E-07	1.30E-04	3.52E-06	0.00E+00	0.00E+00
5	3.02E-05	0.00E+00	0.00E+00	7.22E-06	5.72E-07	9.12E-05	1.07E-04	1.09E-07	9.55E-02	6.59E-06	6.00E-07	7.23E-05	3.02E-08	0.00E+00	0.00E+00
10	2.04E-05	0.00E+00	0.00E+00	2.76E-06	2.42E-07	3.16E-05	7.44E-05	1.43E-08	2.79E-01	4.42E-06	3.29E-07	5.94E-05	2.57E-10	0.00E+00	0.00E+00
20	1.37E-05	0.00E+00	0.00E+00	9.78E-07	6.87E-08	1.39E-05	5.10E-05	1.16E-09	6.92E-01	2.93E-06	1.42E-07	6.02E-05	5.90E-13	0.00E+00	0.00E+00
35	9.90E-06	0.00E+00	0.00E+00	3.98E-07	1.76E-08	9.01E-06	3.71E-05	1.14E-10	9.24E-01	2.08E-06	6.27E-08	6.90E-05	1.31E-15	0.00E+00	0.00E+00
50	8.02E-06	0.00E+00	0.00E+00	2.18E-07	6.29E-09	7.53E-06	3.02E-05	2.32E-11	9.75E-01	1.66E-06	3.51E-08	7.88E-05	1.36E-17	0.00E+00	0.00E+00
100	5.27E-06	0.00E+00	0.00E+00	6.27E-08	6.14E-10	6.41E-06	2.00E-05	8.26E-13	9.98E-01	1.07E-06	1.02E-08	1.11E-04	3.11E-22	0.00E+00	0.00E+00
200	3.41E-06	0.00E+00	0.00E+00	1.63E-08	3.99E-11	6.68E-06	1.30E-05	2.18E-14	1.00E+00	6.73E-07	2.63E-09	1.72E-04	3.75E-28	0.00E+00	0.00E+00
500	1.88E-06	0.00E+00	0.00E+00	2.33E-09	5.82E-13	9.32E-06	7.15E-06	1.13E-16	1.00E+00	3.58E-07	3.71E-10	3.46E-04	1.51E-38	0.00E+00	0.00E+00
600	1.66E-06	0.00E+00	0.00E+00	1.54E-09	2.30E-13	1.03E-05	6.33E-06	3.71E-17	1.00E+00	3.15E-07	2.46E-10	4.03E-04	4.79E-41	0.00E+00	0.00E+00
1000	1.17E-06	0.00E+00	0.00E+00	4.64E-10	1.46E-14	1.47E-05	4.46E-06	1.48E-18	1.00E+00	2.18E-07	7.47E-11	6.37E-04	5.87E-49	0.00E+00	0.00E+00
2000	7.16E-07	0.00E+00	0.00E+00	8.12E-11	2.34E-16	2.82E-05	2.73E-06	1.42E-20	1.00E+00	1.31E-07	1.36E-11	1.25E-03	3.12E-62	0.00E+00	0.00E+00
5000	3.63E-07	0.00E+00	0.00E+00	6.51E-12	4.65E-19	9.12E-05	1.39E-06	1.84E-23	1.00E+00	6.46E-08	1.23E-12	3.40E-03	1.51E-85	0.00E+00	0.00E+00
10000	2.12E-07	0.00E+00	0.00E+00	8.06E-13	2.23E-21	2.91E-04	8.10E-07	8.12E-26	1.00E+00	3.72E-08	1.76E-13	7.79E-03	6.84E-109	0.00E+00	0.00E+00

Table C-12
Small Containment – All Failure Modes

La	Aggregate			Expert A			Expert D			Expert E			Expert F		
	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper	Mean	Lower	Upper
1	2.26E-02	2.02E-03	1.86E-01	1.54E-02	6.77E-03	3.46E-02	3.06E-02	7.94E-03	1.11E-01	2.65E-02	3.68E-03	1.67E-01	1.79E-02	3.47E-04	4.90E-01
2	1.38E-02	3.82E-04	2.91E-01	7.43E-03	3.14E-03	1.75E-02	1.87E-02	3.71E-03	8.90E-02	1.76E-02	1.74E-03	1.55E-01	1.14E-02	1.69E-05	8.87E-01
5	6.58E-03	1.13E-05	7.60E-01	2.33E-03	8.11E-04	6.65E-03	8.77E-03	6.51E-04	1.07E-01	9.49E-03	2.93E-04	2.38E-01	5.74E-03	3.24E-08	9.99E-01
10	3.52E-03	3.84E-07	9.66E-01	8.08E-04	2.05E-04	3.18E-03	4.49E-03	1.02E-04	1.66E-01	5.60E-03	4.42E-05	4.18E-01	3.20E-03	7.03E-11	1.00E+00
20	1.78E-03	6.13E-09	9.98E-01	2.33E-04	3.57E-05	1.52E-03	2.10E-03	9.95E-06	3.07E-01	3.11E-03	4.25E-06	6.96E-01	1.67E-03	4.23E-14	1.00E+00
35	9.75E-04	1.16E-10	1.00E+00	7.31E-05	6.38E-06	8.36E-04	1.05E-03	1.03E-06	5.16E-01	1.85E-03	4.53E-07	8.83E-01	9.32E-04	3.72E-17	1.00E+00
50	6.49E-04	6.72E-12	1.00E+00	3.21E-05	1.81E-06	5.70E-04	6.46E-04	1.99E-07	6.78E-01	1.29E-03	9.14E-08	9.48E-01	6.27E-04	2.43E-19	1.00E+00
100	2.79E-04	2.12E-14	1.00E+00	5.28E-06	1.03E-07	2.72E-04	2.29E-04	4.88E-09	9.15E-01	6.09E-04	2.66E-09	9.93E-01	2.72E-04	3.60E-24	1.00E+00
200	1.10E-04	1.28E-17	1.00E+00	6.34E-07	3.08E-09	1.30E-04	7.01E-05	5.59E-11	9.89E-01	2.63E-04	4.12E-11	9.99E-01	1.07E-04	7.18E-30	1.00E+00
500	2.82E-05	8.08E-23	1.00E+00	2.15E-08	9.05E-12	5.13E-05	1.13E-05	3.71E-14	1.00E+00	7.51E-05	5.50E-14	1.00E+00	2.65E-05	5.73E-39	1.00E+00
600	2.11E-05	5.33E-24	1.00E+00	1.00E-08	2.34E-12	4.30E-05	7.57E-06	6.94E-15	1.00E+00	5.72E-05	1.24E-14	1.00E+00	1.96E-05	5.12E-41	1.00E+00
1000	8.98E-06	4.40E-27	1.00E+00	9.89E-10	3.62E-14	2.70E-05	2.27E-06	4.08E-17	1.00E+00	2.56E-05	1.38E-16	1.00E+00	8.01E-06	3.13E-47	1.00E+00
2000	2.56E-06	1.27E-32	1.00E+00	2.65E-11	4.50E-17	1.57E-05	3.62E-07	1.20E-20	1.00E+00	7.75E-06	1.31E-19	1.00E+00	2.11E-06	6.97E-57	1.00E+00
5000	4.00E-07	1.02E-40	1.00E+00	8.29E-14	7.14E-22	9.62E-06	2.14E-08	2.26E-26	1.00E+00	1.29E-06	2.29E-24	1.00E+00	2.88E-07	3.94E-72	1.00E+00
10000	8.30E-08	1.08E-48	1.00E+00	4.32E-16	2.15E-26	8.68E-06	1.77E-09	1.17E-31	1.00E+00	2.78E-07	1.25E-28	1.00E+00	5.21E-08	7.37E-86	1.00E+00

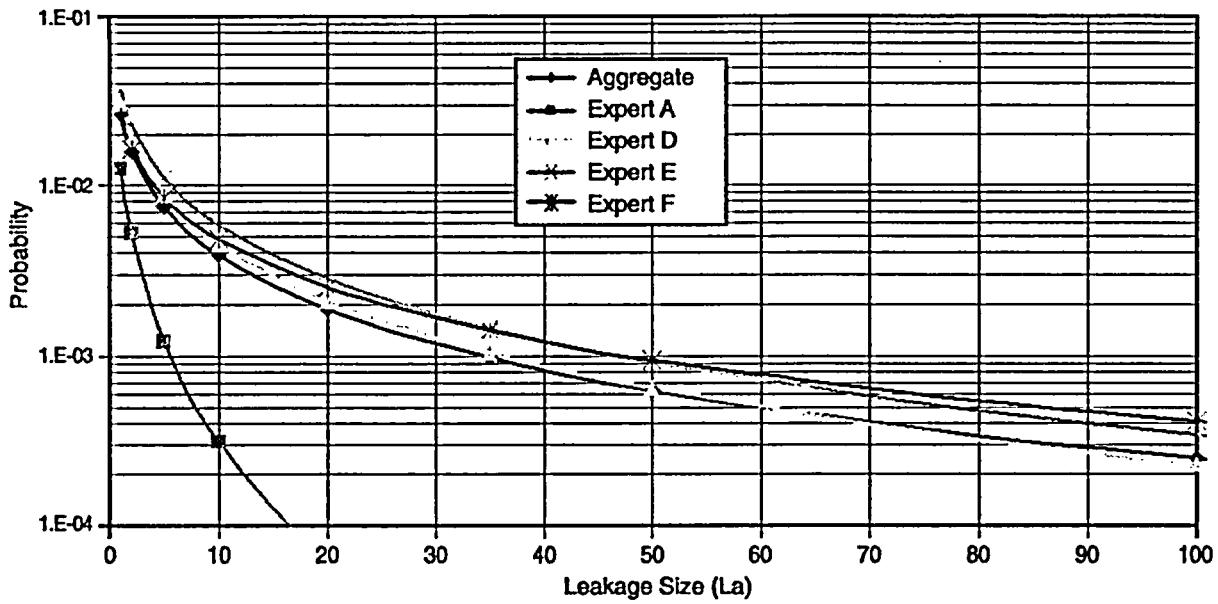

Figure C-1
Large Containment – All Failure Modes

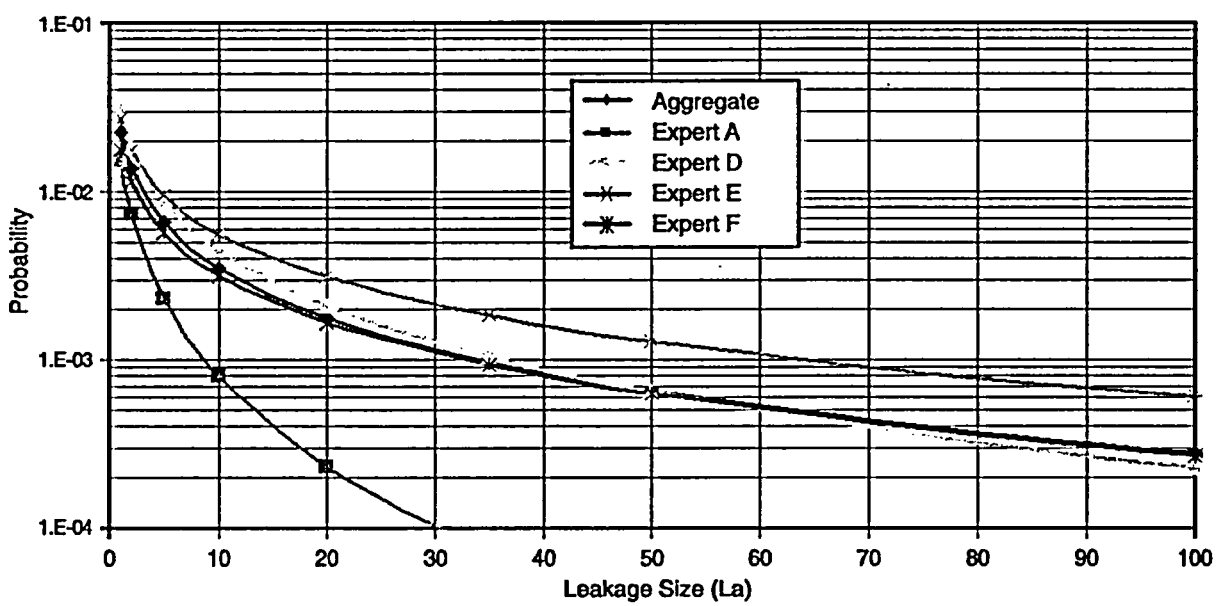

Figure C-2
Small Containment – All Failure Modes

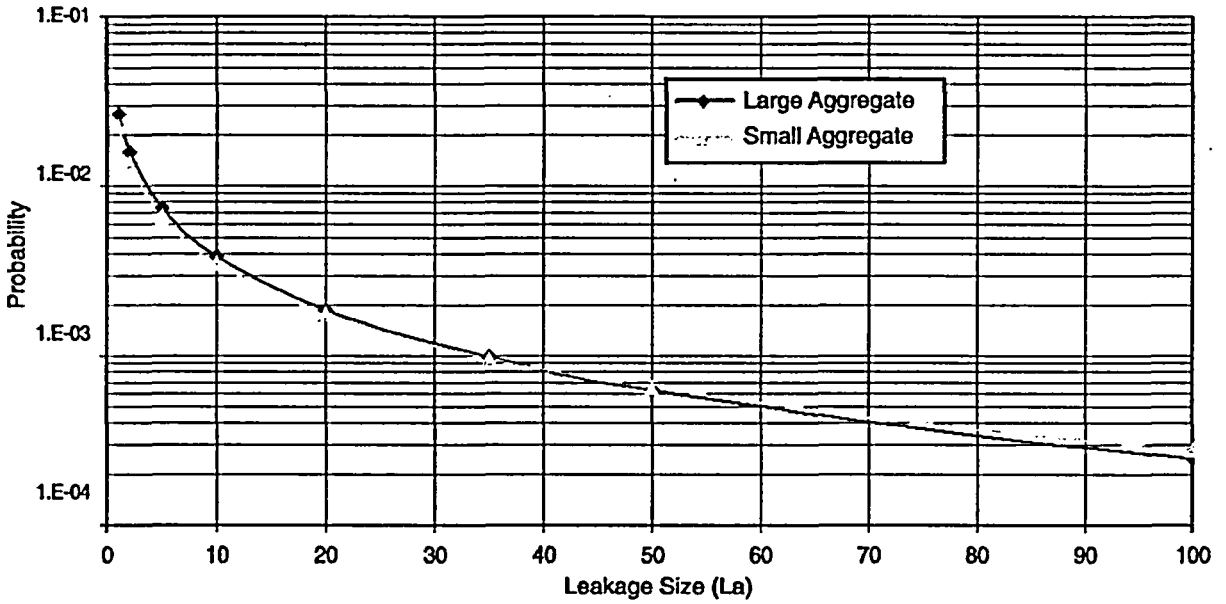

Figure C-3
Comparison of Small and Large Containment – Failure Probability

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