NUREG-1273

Technical Findings and Regulatory Analysis for Generic Safety Issue II.E.4.3, "Containment Integrity Check"

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

A. W. Serkiz

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ABSTRACT

This report contains the technical findings and regulatory analysis for Generic Safety Issue II.E.4.3, "Containment Integrity Check." An evaluation of the containment isolation history from 1965 to 1983 reveals that (except for a small number of events) containment integrity has been maintained and that the majority of reported events have been events related to exceeding Technical Specification limits (or 0.6 of the allowable leakage level). In addition, more recent risk analyses have shown that allowable leakage rates even if increased by a factor of 10 would not significantly increase risk. Potential methods of continuous monitoring are identified and evaluated. Therefore, these technical findings and risk evaluations support closure of Generic Safety Issue II.E.4.3.

CONTENTS

FIGURES

TABLES

APPENDICES

1 SAFETY ISSUE BACKGROUND

Generic Safety Issue II.E.4.3, "Containment Integrity Check," is a part of the broader Task II.E.4, "Containment Design," described in the TMI Action Plan (Ref. 1). The TMI Action Plan proposed a requirement for a feasibility study to evaluate the need for tests and possible test methods to ensure that there are no gross openings in the containment structure (i.e., that there is no undetected gross loss of containment isolation capability).

Appendix J to Title 10 of the Code of Federal Regulations Part 50 (10 CFR 50) specifies containment leakage test requirements, the types of tests required (i.e., Type A, Type B, and Type C), how such tests should be conducted, the frequency of testing, and reporting requirements. Type A tests (integrated leak rate tests, ILRTs) are performed in the preoperational phase, and then three Type A tests are required at approximately equal intervals over a 10-year service period. Type A tests evaluate total containment leakage. Type B and C tests are performed during reactor shutdown or refueling intervals, but not at intervals greater than 2 years. Type B tests are intended to detect local leaks across containment piping and electrical penetrations, gaskets, etc. Type C tests measure containment isolation valve leakage. Allowable leakages are calculated in accordance with 10 CFR 100 and are incorporated into Technical Specifications; excessive leakages are reported through licensee event reports (LERs).

The concern about undetected loss of containment isolation capability stems from a 1979 discovery that two 3-inch containment exhaust bypass valves at one nuclear plant had been left open for approximately 1.5 years, as well as from several other similar incidents.

To investigate this concern, staff members and contractors of the U.S. Nuclear Regulatory Commission (NRC) undertook a series of studies of containment isolation history (derived from LERs) and also evaluated alternate leak detection methods. The results are given below. Appendices A, B, C, and D provide more detailed discussions related to these studies.

2 CONTAINMENT ISOLATION OPERATIONAL HISTORY

The containment isolation history data base was derived primarily from LERs submitted between April 1965 and May 1983. In all, information on more than 3400 suspected containment isolation failures derived from these LERs and related materials were used to compile a data base. The LERs were submitted as required if allowable leakage levels prescribed in Technical Specifications were exceeded.

NUREG/CR-4220 (Ref. 2) provides an overview and assessment of the loss of containment isolation capability using this data base. NUREG/CR-4220 also includes an extensive listing of dBASE III command programs that allow, through use of a personal computer, retrieval of information on containment isolation failures and their underlying causes. However, the brief operational histories provided in NUREG/CR-4220 have a very conservative basis. They are based on reports of exceeding Technical Specification limits related to the Type B and Type C tests described in Appendix J of 10 CFR 50. Any leakage greater than 0.6 of the maximum allowable leakage (L_a) specified for periodic tests in the operating license is required to be reported. In addition, NUREG/CR-4220 does not identify which of the reported events fall into the "immediate detection" category, nor does it identify which of the reported events were leakages located in lines that would not provide direct air paths to the environment. Simply stated, the findings in NUREG/CR-4220 equate loss of containment isolation capability to reported exceeding Technical Specification limits only. On this conservative basis, the containment unavailability was calculated to be 0.3.

Because the findings in NUREG/CR-4220 were simplistic and used very conservative assumptions, the staff contracted to have a more refined analysis performed (Appendices A and B). The results of those analyses are cited in the discussion that follows.

Figure 1 provides an overview of 3447 reported events (per Appendix J reporting requirements) from April 1965 to May 1983. This data base shows that:

(1) About one-third of the events (1258) were leaks that were immediately detected and therefore were of little threat to containment integrity.

(2) Reportable events for tested components (valves) residing in direct air paths which could pose a threat of undetected leakage and a potential hazard were considerably less than the overall total (552 of a total of 3447 events, or 16%).

The distribution of reported failure modes and location (valves versus penetrations) for the immediately detected events is shown in Table 2. Failure to close on demand is the dominant failure mode (922 of 1258 events), followed by measured leakage (236 of 1258 events) and unplanned opening (84 of 1258 events). Potential leakers that resided in air paths comprised only 84 of 1258 events (or 7%). Therefore, removal of the 1258 events from the total data base of 3447 events because of the immediate detection criteria noted above is also supported from the risk perspective associated with "air path" versus "inside containment." Examination of penetration versus valve location (191 versus 1067 events) in Table 2 leads to a similar conclusion.

Thus, both "immediate" detection (see Table 1) and the limited number of events occurring in direct air paths (see Figure 1) reduce the magnitude of undetected loss of containment isolation capability. Therefore, using the entire data base (3447 events) to portray a containment unavailability, as was done in NUREG/CR-4220, is not correct.

Using the allowable leakages (L_a) prescribed by Appendix J of 10 CFR 50, the leakage categories were defined as follows:

"Small" leakage events were leaks that came from small-bore leakage paths or whose leak rates were actually reported to be in the range of 1 to 10 L_a.

- "Large" leakage events were those reported in medium to large size penetrations or reported to be in excess of 10 L_a, or were too large to measure, or came from open valves of any size.
- "Very large" leakage events were obvious breaches of containment involving open air locks or the failure of other containment openings, open purge/vent pathways, or similar direct air path system valves or penetrations. Many of these reported occurrences (especially open air locks) were of such extremely short duration that they were placed in the "immediate detection" category and are noted as such in Figure 1 and Table 1.

Unless they were specifically reported, these estimated levels of leakage were difficult to determine. Generally the LERs did not provide leak rate, leak area information, test pressures, or penetration sizes. Thus, in all cases, a significant amount of engineering judgment (based on familiarity with the system, the plant, and testing requirements) went into estimating leakage levels and assigning events to categories (Appendices A and B).

Table 1 shows the estimated distribution of leakage levels excluding the events that were immediately detected, for boiling-water reactors (BWRs) and pressurized-water reactors (PWRs). Because the LERs often did not provide a means to estimate the potential--or actual--leakage levels, a high percentage of reported occurrences fell in the "indeterminate" category (see Table 1). And because potential leakage could not be ruled out, for regulatory risk analysis purposes (i.e., estimating the upper bounds of potential leakers), the "indeterminant" category noted in Table 1 was distributed in the same proportions as the reported events with known levels of estimated leakage. This large proportion (1569 of 2189 events) in the indeterminant category reflects the limited level of data provided in the LERs.

The chronological distribution of reported failures (based on exceeding a 0.6 L_a Technical Specification limit) is shown in Figures 2 and 3. Although annual reported occurrences increased starting in 1979, a specific trend is not apparent. It is likely that the sharp increase in reportable events at that time is attributable to revised LER reporting requirements that went into effect at that time.

Levels of estimated leakage are as important. Figures 4 and 5 show the distribution of leakage levels for BWRs and PWRs from 1965 to 1983, and compare air pathway events with total number of events reported.

Using the reduced data base in Table 1, which excludes events that were immediately detected (2189 of 3447 total events reported), the following profile emerges.

(1) "Small" leaks made up 67% of the data base (1485 of 2189 events).
(2) "Large" leaks were 25% of the data base (546 of 2189 events).
(3) "Very large" leaks were 7% of the data base (158 of 2189 events).
(4) However, if only events that were direct air paths are included (552 events as shown in Figure 1) "large" and "very large" leaks within direct air pathways were less than 15% of the total number of events (these are the most important from a risk perspective).

The question of containment unavailability can be examined from the chronology of reported events which were in components and in a direct air path line, and the estimated leak size distribution. Figures 6 and 7 show the Appendix J reportable events by calendar year and the estimated size of such potential direct air path leaks. As noted above, the "indeterminant" category (see Table 1) has been included in these figures.

The annual frequency distribution of potential direct air path occurrences is shown in Figures 8 and 9. For reasons discussed above, only those reported events for components within direct air paths are considered. Figures 8 and 9 show a range of frequency of occurrences as follows for the estimated leakage levels:

Estimated leakage levels

Estimated leakage, L_a	Occurrences per reactor-year	
	BWRs	PWRs
1-10	0.06 to 1.30	0.09 to 2.95
10-100	0.03 to 0.49	0.03 to 0.90
100	0.02 to 0.333	0.03 to 1.15

Using the reduced data base (2189 events) to estimate loss of containment isolation, and a "failure-on-next-demand" model using the Poisson distribution:

$$P(1) = 1 - e^{\lambda\tau}$$

where P(1) is the estimated probability of failure-on-next-demand results in the following estimates of P(1), assuming that leakage is undetected for a period of one year, τ, and the frequency of occurrences, λ, noted above.

P(1) estimated probability of component failure (1965 to 1983)

L_a	BWRs			PWRs		
	High	Low	Average	High	Low	Average
1	0.73	0.06	0.32	0.95	0.08	0.56
10	0.39	0.03	0.19	0.59	0.03	0.29
100	0.28	0.02	0.10	0.68	0.03	0.27

This table is valid for any of the components included in the data base used to make these estimates.

The unavailability of containment isolation capability, however, should be derived from the double-barrier concept (two valves in series) because this is the design concept generally used to ensure containment isolation capability. However, this design concept is more applicable to the small and large leakage categories. Some of the very large leakage occurred in single barriers. Using a "two-valves-in-series" model will result in estimated loss of containment isolation, or unavailability, as follows:

$$\text{Unavailability} = [P(1)] * [P(1)] = [P(1)]^2$$

Estimated unavailability (1965 to 1983)

L_a	BWRs			PWRs		
	High	Low	Average	High	Low	Average
1	0.53	0.004	0.10	0.90	0.006	0.31
10	0.15	0.001	0.04	0.35	0.001	0.08
100	0.08	.001	0.01	0.46	0.001	0.07

It is clear that estimates based on very small leakages ($L_a \geq 1$) result in the highest averaged unavailabilities (0.1 for BWRs and 0.31 for PWRs) because of the larger number of occurrences in that category. However, the large potential leakages (10 to 100 L_a) constitute a larger public risk from undetected leakages. For these cases, the estimated undetected loss of containment isolation (on a yearly averaged basis) is less than 5% for BWRs and less than 10% for PWRs. For the very large leakages (>100 L_a), the unavailability lies between 1% and 7% for BWRs and PWRs, respectively, assuming all of these sized leaks are in paths with a double barrier, and 10% or 27%, assuming only a single barrier exists.

As would be expected, the performance of BWRs is better than the performance of PWRs in all leak size categories, because the containment design of the BWRs utilizes primary and secondary containment volumes. This results in significantly fewer direct-air pathways to the environment, because credit is given for the secondary containment. Even though some PWRs also have secondary containments, those secondary containments were not considered available for the purposes of these estimates. In addition, some BWRs are inerted, thereby making access to primary containment during normal operation very restricted. On the other hand, PWR containments are generally more accessible and the potential for leaving hatches open or damage/wear to containment access doors is much greater.

The distribution of reported events by reactor containment type is as follows:

Distribution of reported events

Containment type	Total events	Potential direct air path
PWR large, dry	567	291
PWR subatmospheric	131	37
PWR ice condenser	247	46
Mark I	1081	127
Mark II	34	1
Other* and unknown	132	50
Totals	2192	552

*Includes Indian Point 1, San Onofre Nuclear Generating Station 1, Yankee Rowe, Dresden 1, Big Rock Point, and LaCrosse plants, using the characterizations in NUREG/CR-4220. Figure 1 redistributes the "others" as BWR and PWR events.

Reportable events are generally distributed in direct proportion to the number of plants of each containment type, with a somewhat higher proportion of events per number of operating plants occurring in PWR ice condenser containments.

Other significant findings derived from a review of plant operational history from 1965 to 1985 are as follows:

(1) The great majority of reportable events were detected by Type B testing (382 of 2192 events) and by Type C testing (1785 of 2192 events). Only 25 events were detectable only by Type A testing (integrated leak rate testing, ILRT). Thus, the current reliance on periodic local leak rate tests (Types B and C) appears to be quite effective and should be maintained.

(2) The underlying causes of the reportable events and the percentage of events they caused were as follows (see also Appendix A):

Mechanical	1343 (61%)
None or unknown	450 (21%)
Personnel or procedures	165 (7%)
Design or construction	11 (<1%)
Electrical	37 (<2%)
Environmental or process	186 (8%)

This distribution does not support the hypothesis that containment integrity could be significantly improved by improving the procedural and administrative areas. Rather, the listing above and in Table 3 show that the majority of reportable events were related to mechanical malfunctions. Table 3 also indicates that of the 2189 events, 130 to 295 events might have been attributable to human error. The higher value assumes that personnel or procedural errors also were counted.

3 ALTERNATE LEAKAGE TESTING METHODS

Sandia National Laboratory (SNL) reviewed containment integrated leakage rate testing methods (Appendix C) and identified a number of alternate leakage detection methods (Appendix D) that might provide a continuous leakage-monitoring capability.

The picture that emerges from these studies is as follows:

(1) A wide range of alternative leakage monitoring techniques exists (see Table 4). Three methods (Type A test instrumentation, reference vessel, and differential trace gas concentration) are generally applicable to all plants. The estimate of equipment cost is a perceived relative ranking based only on the required equipment for the monitoring technique noted.

(2) The applicability of the various monitoring methods to the various containment types is shown in Table 5. These methods cannot be ranked numerically in unique order but have been divided into three categories based on the amount of overall promise a particular method had for applicability to the containment type noted. This ranking considers cost, reliability, and sensitivity as perceived to date. The ranking is not precise because many of the techniques noted have not been completely developed. Type A instrumentation is currently used for all containments, but is rated moderate because of the relatively slow response of that method.

(3) Implementation considerations versus alternative sampling are shown in Table 6. Costs associated with development, support, installation, and operation are for the most part uncertain (except for the Type A (ILRT) test sensors and techniques currently employed).

The conclusions drawn from Appendix C are as follows:

(1) Although some alternate methods of checking containment isolation integrity appear practical and sufficiently sensitive, these methods do not have the accuracy of Type A testing. However, these methods seem to offer enough accuracy and speed of detection to justify their use for detecting gross leakage.

(2) As discussed in Appendix C, the current integrity testing program (consisting of Type A, B, and C tests) is capable of detecting all reported events documented in the LER data base in NUREG/CR-4220, and it appears that the additional use of alternate test methods will not detect any additional breaches of containment integrity. Further, Type B and Type C tests together are capable of detecting about 99.4% of the documented breaches of containment integrity. Only the remaining 0.6% of such events must be detected by some test in addition to the Type B and Type C tests. For these remaining events, the alternate methods are estimated to be capable of detecting five out of six events. This indicates that using alternate methods of testing in addition to the Type B and Type C tests could increase the number of events detected by only 0.5%.

(3) The alternate test methods offer one advantage over current testing techniques. This advantage is speed of detection of total containment leakage, which can range from 1 day to several weeks. The current Type A test requirements are based on testing at intervals of approximately three years (i.e., three tests per ten-year interval). As a result, the leaks detected by the Type A, Type B, and Type C tests could have existed for an average of 6 to 12 months before detection. Even the slowest alternate method can provide an order of magnitude improvement over current detection techniques. The alternative methods, however, can not detect leaks in a double barrier. Thus the estimated unavailability of containment isolation for the small and large leak categories would not be improved significantly if an alternate method were adopted, since leaks of these sizes generally occur in paths with double barriers. For the very large leak category, the unavailability might be improved by as much as an order of magnitude (i.e., from 0.10 to 0.27 for BWRs and PWRs respectively, to 0.01 to 0.03).

(4) The alternate test methods should not be considered a complete replacement for Type A tests, because all of the alternate methods are intended for use at reduced pressure under standard operating conditions. Thus, these methods do not test plant equipment under higher containment pressure. The correlation between low-pressure leakage and leakage at accident pressure is not accurate and, because of the wide variety of containment leak paths, it is unlikely that a single correlation could provide the confidence needed for precise containment integrity measurements.

4 RISK OVERVIEW

Currently, the allowable containment leakage rate is determined on a plant-specific basis, and it must meet the radioactivity dose guidelines in 10 CFR 100, assuming a hypothetical major release of fission products from the core. In general, a plant's Technical Specifications establish a limit that is lower than the limit required by 10 CFR 100.

Typical allowable leakage rates are 0.1% a day for PWRs and 1% a day for BWRs. NUREG/CR-4330 (Ref. 3) gives the results of studies of the contribution of containment leakage to risk from a variety of accident conditions. Table 7 gives examples of releases for the respective release categories. For PWRs, containment leakage contributes significantly only to PWR-6, PWR-7, and PWR-9 release levels. Results derived from the probabilistic risk analyses (PRAs) for Surry Unit 1 and Oconee Unit 3 show that the effects of containment leakage are small contributors to the risk of exposure to radioactivity (1 to 2 person-rem per reactor-year) versus total dose levels of 71 to 207 person-rem per reactor-year from other causes for the severe accident postulated. For BWRs, containment leakage contributes significantly only to BWR-4 and BWR-5 release levels. The results derived from the PRAs for Peach Bottom Unit 2 and Grand Gulf Unit 1 show that this contribution is 1 to 1.2 person-rem per reactor-year, versus the total risk levels of 151 to 250 person-rem per reactor-year from other causes for the severe accident postulated.

NUREG/CR-4330 also gives the results of studies of the effect of increasing allowable leakage rates. The estimated risks derived in this study were as follows:

Estimated risks

PWR leak rate, % per day	Estimated population dose, person-rem/reactor-year		Estimated dose increase ΔR, person-rem/reactor-year	
	Surry 1	Oconee 3	Surry 1	Oconee 3
0.1	71	207	--	--
1.0	71	207	--	--
10.0	72	210	1	3
100.0	82	238	11	31

The nonlinear relationship of estimated dose increase (ΔR) versus leak rate should be clearly noted (i.e., an increase of a factor of 1000 in leakage results in only approximately a 15% increase in risk potential).

Estimated dose increase vs. leak rate

BWR leak rate, % per day	Estimated population dose, person-rem/reactor-year		Estimated dose increase ΔR, person-rem/reactor-year	
	Peach Bottom	Grand Gulf	Peach Bottom	Grand Gulf
0.5	151	250	--	--
5.0	153	254	2	4
50.0	174	288	17	38

The estimated dose increases (ΔRs) attributable to undetected leakage are very small, even for increased leakage levels up to 10% per day for PWRs and 5% per day for BWRs. Because these increases in dose attributable to higher undetected leakage levels are of the same order of magnitude as the containment leakage contributions calculated for the base cases (see Table 7), increased leakage levels (up to 10%) would not pose a significant threat to the public health and safety. On the basis of these low-level contributions to risk, consideration might be given to relaxing the regulatory requirements somewhat, perhaps by increasing allowable leakage levels specified in the Technical Specifications.

This risk and operational perspective (discussed previously) must be used with caution. As discussed above, the current Type B and Type C tests identify nearly all of potential leaks. Therefore, prudence dictates maintaining the current 12-month or refueling-cycle time period for conducting Type B and Type C tests.

With respect to Generic Safety Issue II.E.4.3 (which originated with the hypothesis that alternate leakage detection methods were needed), neither plant operational data nor the risk assessments support requiring backfit actions. On the contrary, the risk perspectives discussed above and the containment isolation history data base indicate there is no need to study this safety issue further. They also indicate that there is no risk justification for imposing alternate sampling methods to monitor containment leakage.

5 TECHNICAL FINDINGS SUMMARY

The following conclusions and recommendations are based on a review of reportable loss of containment isolation capability events from 1965 to 1983, on the availability of state-of-the-art alternate testing methods, and on an evaluation of the risk associated with allowing containment leakage levels to increase:

(1) The public risk associated with undetected containment leakage (based on current Appendix J requirements) is very small. The estimated contribution of such undetected leakage to the total risk associated with other sources of radiation in a severe accident is less than 0.5% to 3% (see Table 7) of the total estimated risk.

(2) Earlier assessments of loss of containment isolation capability significantly overestimated leakage because all reportable violations of Technical Specification limits were included in the calculation of how often containment isolation capability was lost. When the estimates were recalculated considering only violations located in direct air paths and events with large leakage (10-100 L_a), the resulting estimate of unavailability of containment isolation is less than 10%. The probability of a very large (>100 L_a) leak is less than 10% in BWRs and 30% in PWRs, but more than 1% and 7%, respectively.

(3) The Type A, Type B, and Type C tests required by Appendix J should be continued since they provide the assurance of continued high containment availability. Alternative methods are unlikely to improve the availability, but might improve the unavailability for very large leaks by less than an order of magnitude.

(4) Except for currently utilized Type A instrumentation, implementation of alternate testing methods in some cases would require the development of sensors, as well as the development of a complete operational system. State-of-the-art alternate testing systems do not exist.

(5) The alternate testing methods evaluated would not significantly improve the surveillance currently provided by Type B and Type C tests coupled with less frequent Type A tests.

(6) Procedural errors are a relatively small contributor to reported Technical Specification violations, and little would be gained from revising procedures.

(7) Use of alternate leak monitoring methods cannot be supported as a substantial increase in the protection of the public. On the other hand, utilities that already have instrumentation installed, or other monitoring procedures in place (such as nitrogen-usage monitoring for inerted systems) may find that continuous monitoring enhances containment availability during the operating cycle.

6 OPTIONS AND COST/BENEFITS

Potential options follow:

(1) Install a continuous monitoring system.

(2) Revise test procedures.

(3) Change the frequency of testing.

(4) Continue current 10 CFR 50, Appendix J Type A, Type B, and Type C tests.

(5) Relax current monitoring requirements.

The risk assessment discussed in Section 4 shows that dose contributions associated with leakage pathways (see also Table 7) are very small when compared to the dominant release pathways associated with severe accidents that would result in core damage. These evaluations also show that allowable leakages could be increased to 10% per day without significant dose increases (i.e., <5 person-rem/reactor-year). Thus risk assessments do not support imposing new requirements. Further, evaluation of the available data indicates that the probability of having a significant containment leak (i.e., >100 L_a) is less than 10%. Each of the options noted above is discussed in the material that follows.

6.1 Option 1: Install a Continuous Leakage Monitoring System

Installation of a continuous monitoring system would incur new plant expense. The evaluation of alternate leakage detection methods (see Section 3 and Appendix D) found that, except for currently used Type A instrumentation, a continuous monitoring system would be a developmental task. It would not be unreasonable to estimate installation and operational costs to be on the order of $0.5 to $1.0 million per plant. In addition, currently employed Type B and C tests are identifying the great majority of potential leakers. Implementing Option 1 would result in an additional cost impact and is not supportable given the apparent success of Type B and C testing.

6.2 Option 2: Revise Testing Procedures

Option 2 deals with reviewing and revising test procedures to reduce reportable Technical Specification violations, thereby enhancing containment availability. The number of failures resulting from these underlying causes is, however, low (see Table 3 and Appendices A and B). Revision and implementation of new procedures are likely to cost on the order of \$100,000 to \$300,000 per plant. Neither risk levels nor experience warrants imposition of such a requirement. However, a licensee could benefit from a review of such underlying causes if the causes were impacting the availability of containment for a specific unit. In a case of that sort, the licensee could initiate the change and submit it for approval.

6.3 Option 3: Change Frequency of Testing

Operating experience (see Section 2 and Appendices A and B) reveals that current Type B and C tests are very effective in identifying leaks, or potential leaks, in the time between Type A tests. Although risk assessments would support increasing the time between Type A tests, the current 12-month to 18-month test interval associated with Type B and C tests would be stretched further. If air lock testing is excluded, it is conceivable that the probability of undetected penetration and isolation valve leak detection would increase. This is not a desirable safety compromise and, therefore, this option should not be pursued without a detailed, plant-specific analysis.

6.4 Option 4: Continue With Type A, B, and C Tests

Continued Type A, Type B, and Type C (per Appendix J, 10 CFR 50) testing appears to have been effective in detecting leakages and has been effectively integrated into operating plant refueling cycles. Although Type A tests have been critized as being too expensive, an integrated leakage test provides the only means to check total containment isolation integrity. Although they are quite effective in identifying local leaks, Type B and C tests do not provide the level of assurance of containment integrity necessary to ensure that the required low levels of risks to public health and safety are met.

6.5 Option 5: Relax Current Monitoring Requirements

Although some relaxation of current monitoring requirements might appear to be justified, based on the low risk associated with containment leakage, this issue was not evaluated for determining whether such relaxation would be compatible with the goal of maintaining an acceptable level of containment isolation and integrity, as is currently achieved by Appendix J testing requirements.

7 RECOMMENDED RESOLUTION

Risk assessments and technical findings discussed above do not support backfit actions. Therefore, the recommended resolution of Generic Safety Issue II.E.4.3 is:

(1) Continue with the Type A, Type B, and Type C testing required by 10 CFR 50, Appendix J. Do not decrease the frequency of testing.

(2) Close Generic Safety Issue II.E.4.3.

8 REFERENCES

(1) U.S. Nuclear Regulatory Commission, NUREG-0660, "NRC Action Plan Developed as a Result of the TMI-2 Accident," May 1980.

(2) U.S. Nuclear Regulatory Commission, "Reliability Analysis of Containment Isolation Systems," NUREG/CR-4220, June 1985.

(3) U.S. Nuclear Regulatory Commission, "Review of Light Water Reactor Regulatory Requirements: Assessments of Selected Regulatory Requirements That May Have Marginal Importance to Risk," NUREG/CR-4330, Vols. 1 and 2, June 1986.

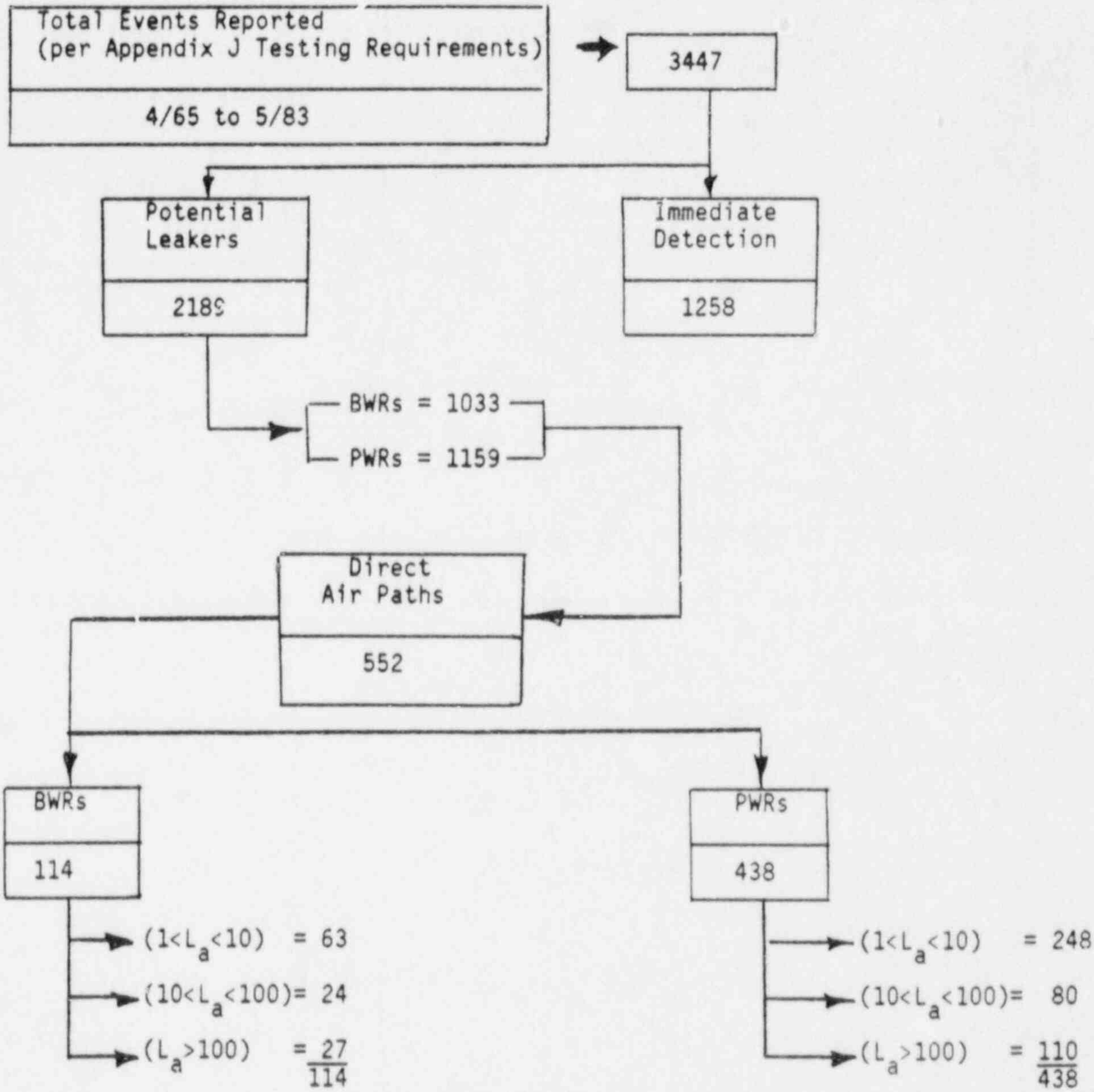

Figure 1 Overview of containment isolation history

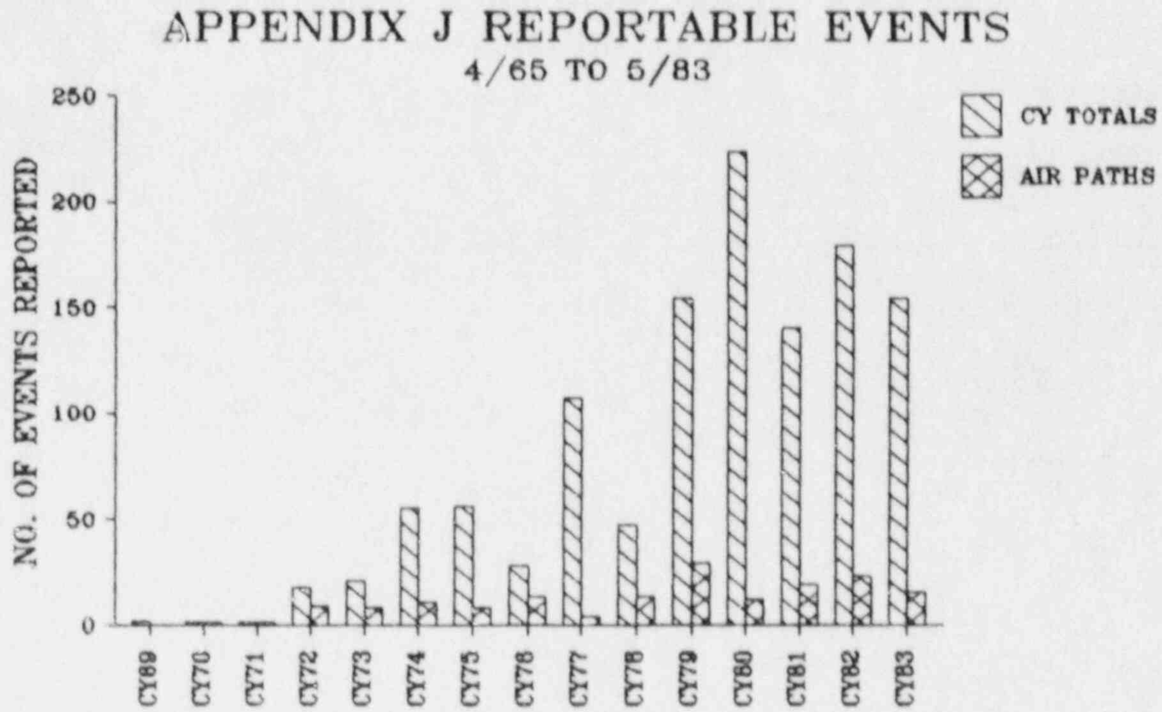

Figure 2 BWR containment isolation history

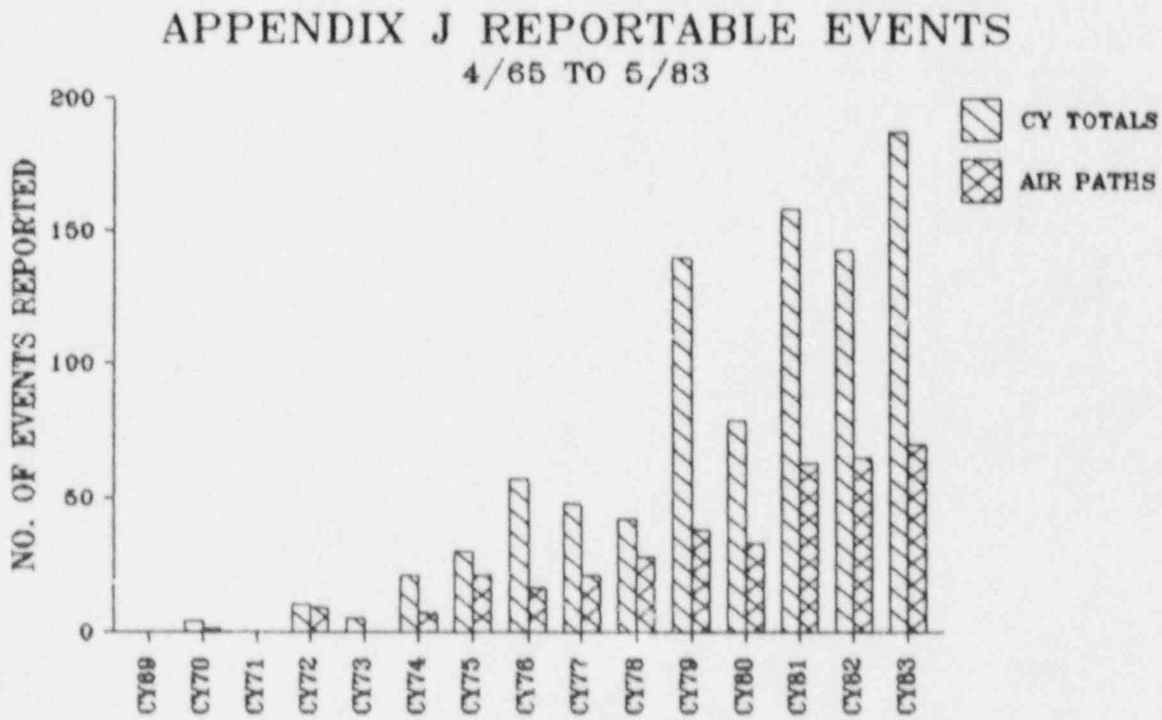

Figure 3 PWR containment isolation history

APPENDIX J REPORTABLE EVENTS
4/65 TO 5/83

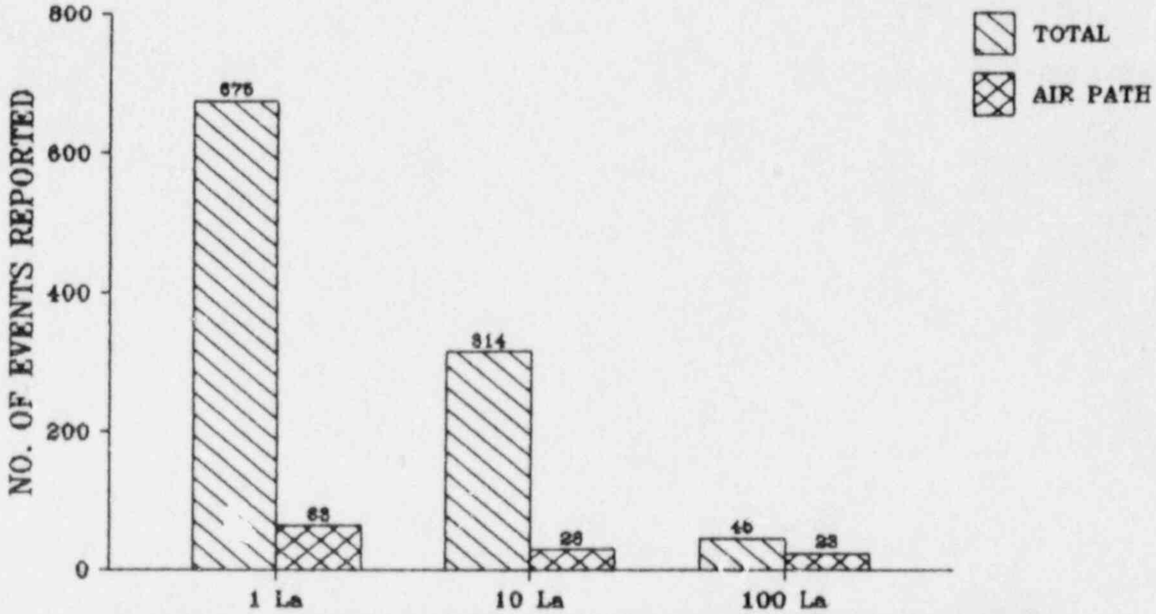

Figure 4 Estimated leakage size distribution in BWRs

APPENDIX J REPORTABLE EVENTS
4/65 TO 5/83

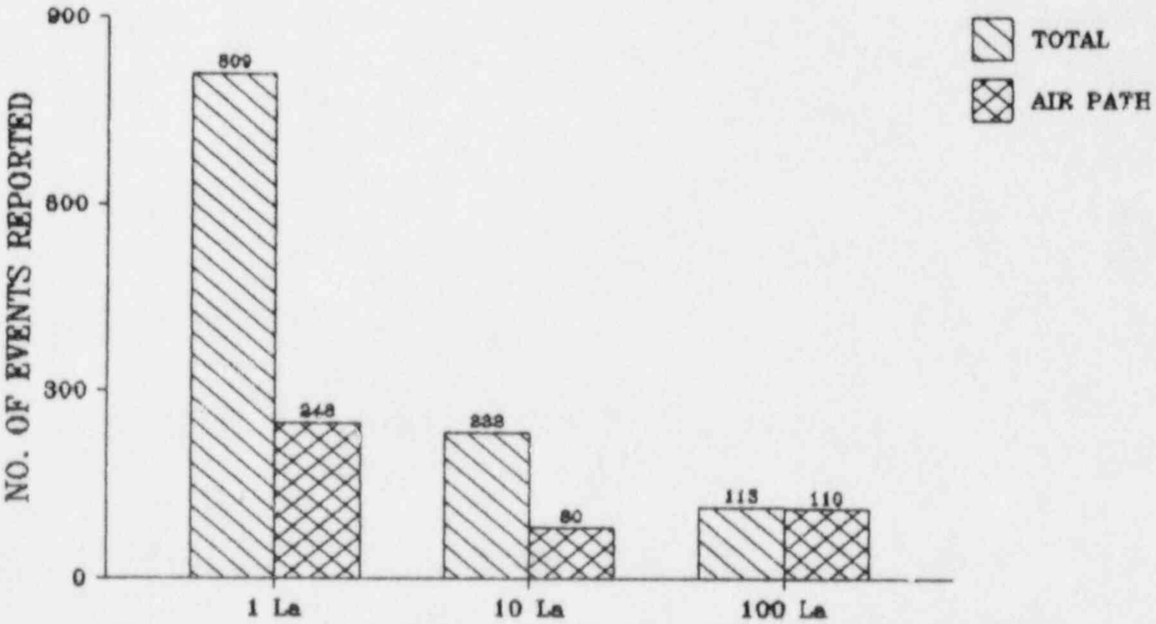

Figure 5 Estimated leakage size distribution in PWRs

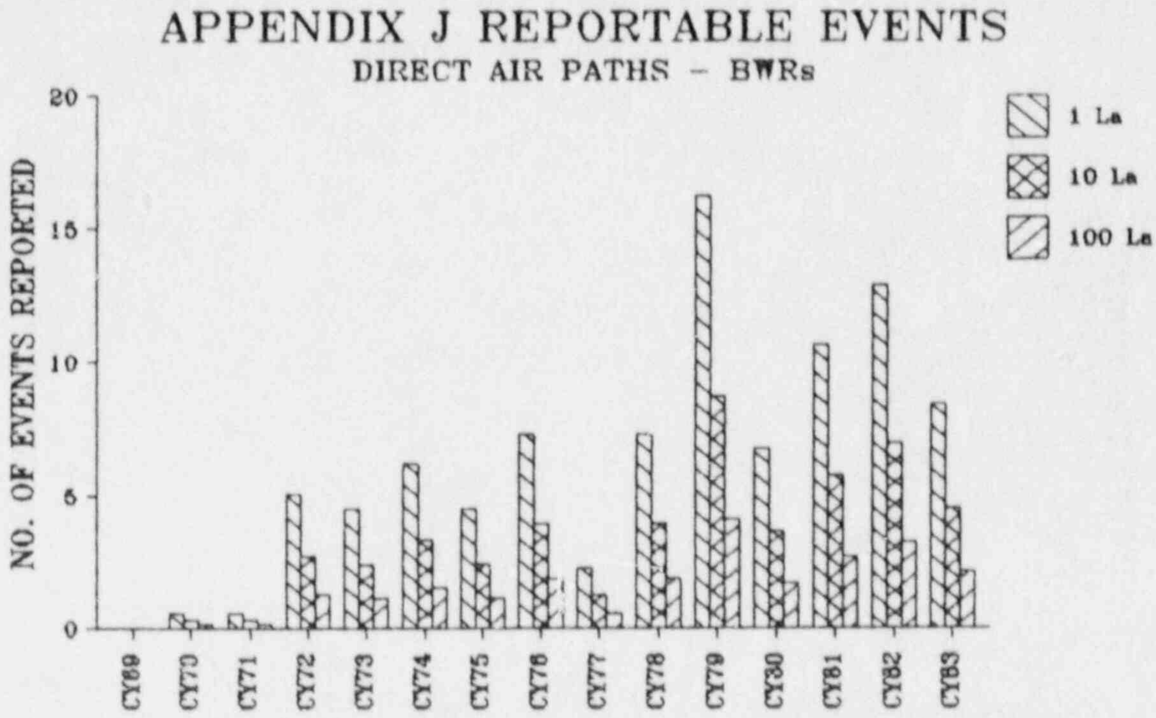

Figure 6 Reportable air path events in BWRs per year

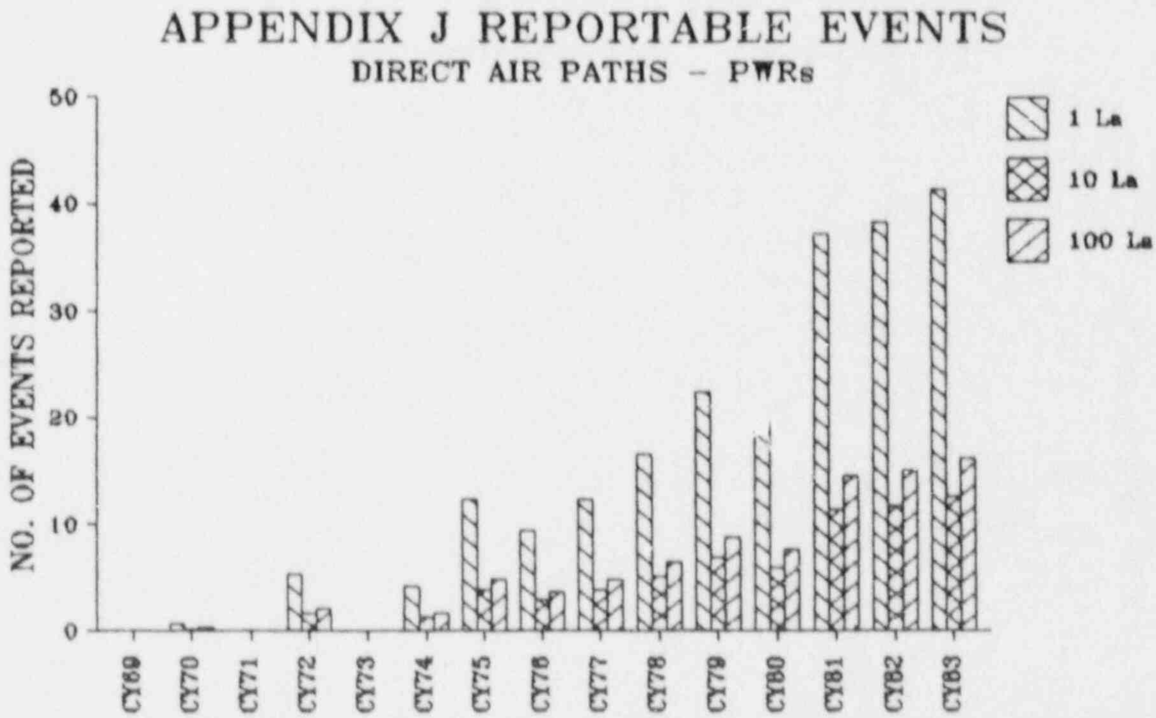

Figure 7 Reportable air path events in PWRs per year

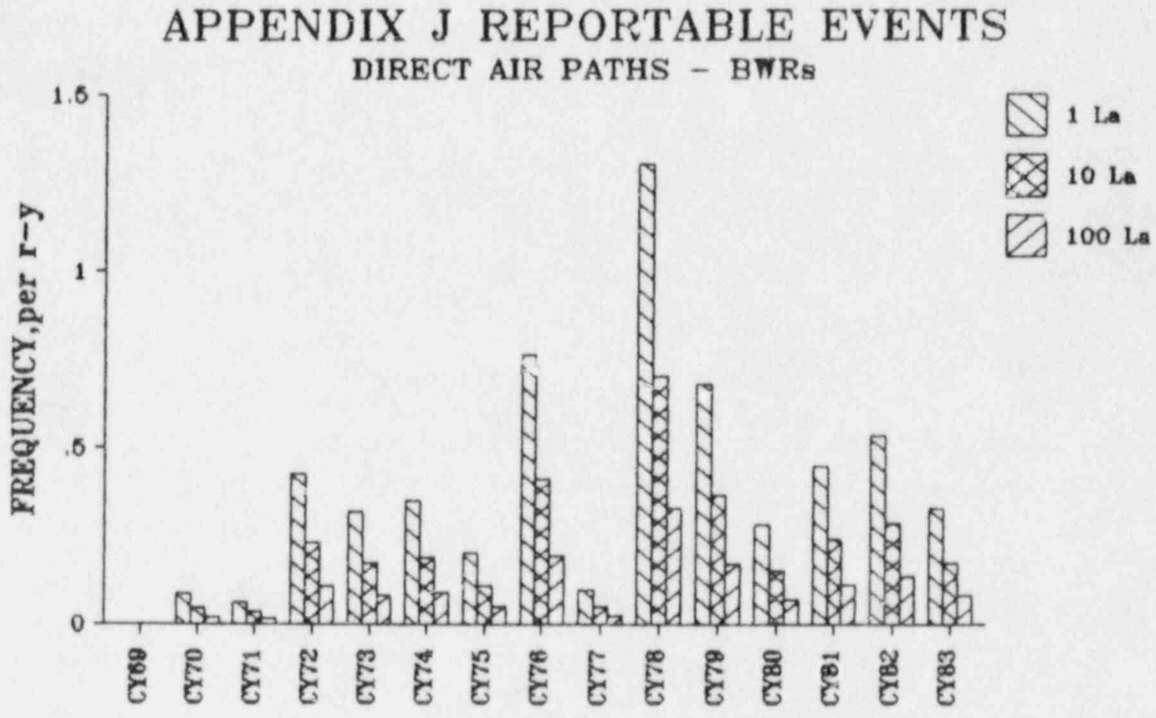

Figure 8 Frequency of reportable BWR events per year

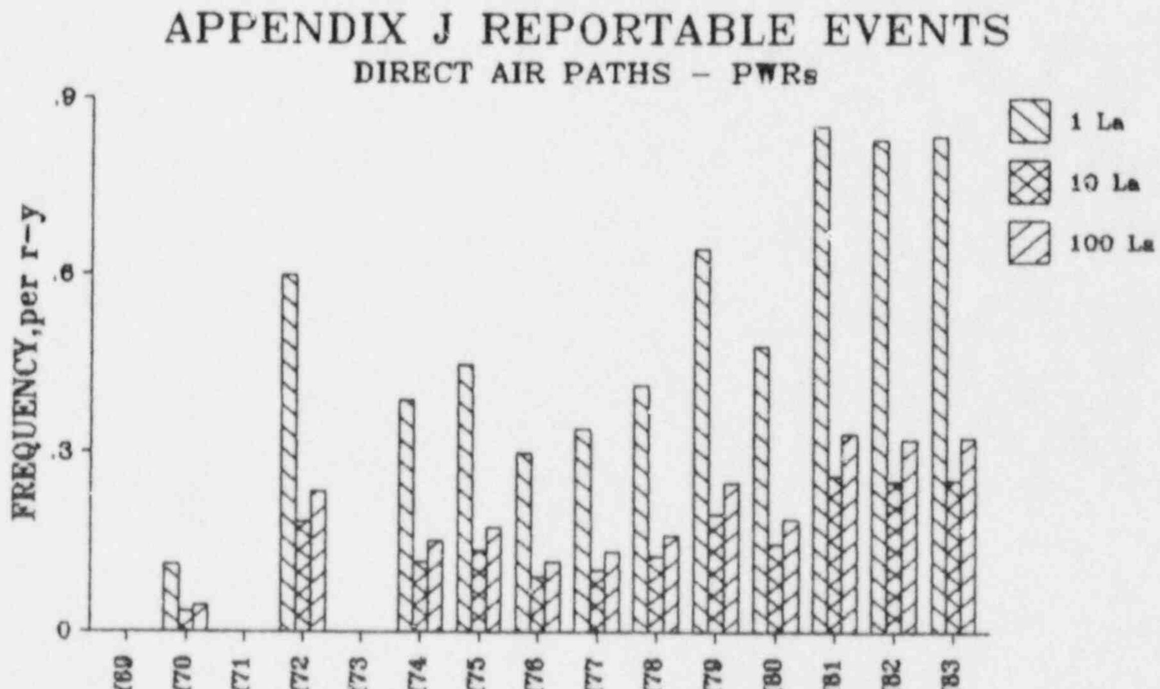

Figure 9 Frequency of reportable PWR events per year

Table 1 Containment isolation history, April 1965 to May 1983*

Estimated leakage	Reduced data base	Redistribution*** of all occurrences	Redistribution by reactor type	
			PWRs	BWRs
Small ($\geq$1 L_a)	417	1485	809	676
Large ($\geq$10 L_a)	162	546	232	314
Very large ($\geq$100 L_a)	41	158	113	45
Indeterminant	1569	--	--	--
Totals	2189	2189	1154	1035

*Data base was derived from approximately 3400 LERs and related correspondence; data base and related evaluations are reported in NUREG/CR-4220.

**These occurrences (or events) were immediately detected, investigated, and fixed; typical examples are a valve failing to close on demand during surveillance testing and a second air lock door being opened simultaneously with the first door. Table 2 identifies failure modes and distributions for the reported events which were "immediately" detected.

***The reported LER information did not provide a means to estimate leakage levels for the majority of detections; these are listed as indeterminate. Because these events could not be ruled out as nonleakers, they (the 1569 indeterminate events) were redistributed among the categories defined above in the same proportions as the events with determinate leakage.

Note: Total events reported = 3447;
Events immediately detected ** = 1258;
Reduced data base = 2189 occurrences.

Table 2 Distribution of immediately detected leakage events

(a) Leakage in BWRs and PWRs

Failure mode	BWRs		PWRs	
	Total events	Air paths	Total events	Air paths
None identified	6	--	10	--
Leak	125	1	98	12
Failure to close	394	75	404	49
Unplanned opening	14	2	62	6
Totals	539	78	574	67

(b) Leakage in valves and penetrations

Failure mode	Valves	Penetrations*
None identified	17	0
Leak	179	71
Failure to close	843	56
Unplanned opening	28	64
Totals	1067	191

*Personnel access, fuel handling, equipment access, electrical, instrument lines, process piping, and other unspecified causes.

Table 3 Overview of leakage events relatable to procedural causes

Category	Primary cause	Remarks	Failure
00	Unknown, un-assigned	Procedural deficiencies: maintenance, operations	18
7.10	Normal wear, foreign contam-ination	Housekeeping: process deficiencies	74
12	Mechanical parts, adjustments	Maintenance and adjustment	22
13	Seal/gasket	Door seals, improper installation, housekeeping, ill use	19
14	Packing	Installation, checking, application	22
16	Electrical input	Inadequate electrical maintenance	*
18	Welds	Weld activities affecting/causing failure of other components	*
19	Lubrication	Inadequate, inappropriate, untimely	10
23	Torque switches	Poor adjustment, surveillance	17
25	Seat/disc	Installation, alignment	2
26	Limit switches	Poor adjustment, surveillance	14
28	Air solenoid	Dirty air, poor air system operation and maintenance	14
	Other (1, 2, 3, 6)	From those above and miscellaneous	20
Totals			165
1, 2, 3, 6		Operations (valve lineups, openings), mainentance (housekeeping, not following procedures, leaving things open, undone, uncapped, improperly assembled), other (open path in refueling outage, uncapped connections, poor methods)	130
Totals			295

*The primary cause categories are those given in NUREG/CR-4220.

Table 4 Summary of characteristics of alternate test methods

Alternate method	Method characteristics					
	Plant applicability	1% detection time (days)	Humidity insensitivity	Temperature insensitivity	Inleakage insensitivity	Equipment costs
External detection	BWRs	N	Yes	Yes	Yes	L
Tracer gas dilution	Subatm.	2	Yes	Yes	No	L
Continuous injection	PWRs	22	No	No	No	H
Direct weighing	Large dry subatm.	12	No	Yes	No	M
Acoustic velocity	Large dry subatm.	8	No	Yes	No	H
Reference vessel	All	12	No	Yes	No	H
Type A test instrumentation	All	5	Yes	Yes	No	H
Trace gas mass concentration	Subatm.	20	Yes	Yes	No	M
Differential trace gas concentration	All	20	Yes	Yes	Yes	M
Periodic air mass injection	PWRs	12	No	No	No	H
Nitrogen usage monitor	BWRs	22	No	No	No	L

Note: N - not applicable, L - low, Subatm - subatmospheric, H - high, M - moderate.

Table 5 Distribution of alternate test methods by containment type

Alternate method	Containment type: Large dry	Subatmospheric	Ice condenser	Mark I	Mark II	Mark III
External detection	N	N	N	L	L	N
Tracer gas dilution	M	H	N	N	N	N
Continuous injection	M	N	L	N	N	M
Direct weighing	H	M	N	N	N	L
Acoustic velocity	L	L	N	N	N	L
Reference vessel	M	M	M	M	M	M
Type A test instrumentation	M	M	M	M	M	M
Trace gas mass concentration	M	M	M	M	M	M
Differential trace gas concentration	M	M	M	M	M	M
Periodic air mass injection	M	M	L	N	N	M
Nitrogen usage monitor	N	N	N	H	H	N

Note: N - not applicable, L - low, M - moderate, H - high.

Table 6 Near-term implementation aspects of alternate test methods

Alternate method	Implementation aspects				
	Sensor availability	Support complexity	Complexity of installation	Maintenance/ operation	Licensing implementation
External detection	Yes	L	L	L	L
Tracer gas dilution	U	M	L	M	L
Continuous injection	Yes	L	L	L	M
Direct weighing	Yes	M	M	M	L
Acoustic velocity	U	H	H	H	L
Reference vessel	Yes	M	V	M	L
Type A test instrumentation	Yes	H	V	H	L
Trace gas mass concentration	U	M	M	M	L
Differential trace gas concentration	U	M	H	M	M
Periodic air mass injection	Yes	M	H	M	M
Nitrogen usage monitor	Yes	L	L	L	L

Note: L - low, U - unknown, M - moderate, H - high, V - varies.

Table 7 Estimated dose contributions of containment leakage, by reactor type

Category	Estimated dose (risk), person-rem per reactor-year	
	Surry 1	Oconee 3
PWR-1	4.86	0.59
PWR-2	38.40	48.0
PWR-3	21.60	156.6
PWR-4	1.35	0.26
PWR-5	0.70	0.46
PWR-6	[0.90]	[1.1]
PWR-7	[0.90]	[0.08]
PWR-8	3.00	--
PWR-9	[0.05]	--
Totals	71	207
	Peach Bottom	Grand Gulf
BWR-1	5.40	0.59
BWR-2	42.60	241.4
BWR-3	102.0	7.14
BWR-4	[1.22]	[0.98]
BWR-5	[0.002]	[-]
Totals	151	250

*These baseline calculations assumed a leakage rate of 1% per day for PWRs and 0.5% per day for BWRs and were excerpted from NUREG/CR-4330.

[ ] Highlights pathways where containment leakage is contributor.

APPENDIX A

FINAL INTERIM LETTER REPORT FOR SUBTASK 3.1, ANALYZE CONTAINMENT ISOLATION FAILURES

FINAL INTERIM LETTER REPORT

For

Subtask 3.1

Analyze Containment Isolation Failures

ALTERNATIVE CONTAINMENT INTEGRITY TEST METHODS PROGRAM

FIN A1802

By: Douglas A. Brosseau

Of: International Energy Associates Ltd. (IEAL)

For: Sandia National Laboratories

November 21, 1986

Table of Contents

List of Tables

List of Figures

FINAL INTERIM LETTER REPORT

1.0 Introduction

Since the accident at Three Mile Island and as a result of recommendations concerning operational errors and containment integrity, numerous tasks have been conducted to further define needs and changes to operating nuclear plants to prevent occurrence of any similar events and to mitigate the effects of such events should they occur. One concern that has been raised is the possibility of undetected breaches of containment integrity (UBCI). The NRC staff has concluded that the safety significance of UBCI warrants a high priority ranking and has been designated as a Generic Safety Issue (II.E.4.3).

The Task Action Plan developed to resolve Issue II.E.4.3 identified the following three tasks:

1. Collect operating data and information on UBCI.
2. Establish the expected frequency of UBCI.
3. Evaluate the feasibility of alternative containment test methods for periodically verifying containment integrity.

Under contract to NRC, Pacific Northwest Laboratory (PNL) prepared a report--"Reliability Analysis of Containment Isolation Systems" (NUREG/CR-4220)--which involved a data base developed from License Event Reports (LERs) and Integrated Leak Rate Test (ILRT) reports describing containment "unavailability" due to various causes. In this report, containment unavailability was defined as the probability that the containment will not perform its function successfully at any given time during plant life. Nuclear containments must limit leakage below plant specific technical specification requirements so as to reduce the radiological consequences and risk to the public from various postulated design basis accident conditions. Estimates of unavailability were derived from estimated leak size and duration for selected ranges of leakage events reported in the data base. The data base contains a wide range of events reported in LERs and include actual measured leakage failures, unquantified leakage events, failures representing potential inability to isolate containment, and events in which containment isolation and integrity were actually breached. A significant condition that was noted numerous times in the report was the general lack of information regarding leak size, leak rates, failure duration, and whether or not containment was isolated.

To address Item 3 above, SNL has been requested by NRC to evaluate possible methods of increasing containment reliability. This effort has three major objectives. Specifically, the first objective is to determine if alternate containment test methods could be useful for detecting gross containment leakages during power operation. The second objective is to determine if modifications to containment structures or operating procedures might be helpful in preventing UBCI. The third objective--and subject of this report--is to determine the underlying causes of UBCI using the PNL data base developed in NUREG/CR-4220 and to compile a preliminary list of procedural and administrative changes which could reduce containment isolation system failures.

This third objective was completed as a two-month effort. In the analysis, there was no attempt to specifically define what constitutes a failure in terms of leak magnitude, duration, or effect on containment integrity. Each LER record was simply treated as a failure event or events. These LER events were each individually analyzed with respect to underlying causes and potential for detection by current and alternate containment test methods. The subject of unavailability or risk assessment of the events reported in this data base was not addressed in this effort.

2.0 Purpose and Approach

The purpose of the subtask effort discussed in this interim letter report was to conduct a review of sources of containment breaches to identify failure trends. This information was to be used as input to other subtasks in evaluating improvements in containment isolation and assessing the effectiveness of procedural changes on detecting or preventing UBCI.

The general approach to this effort was as follows:

1. Obtain and become familiar with the PNL data base, by specifying numerous preliminary searches.
2. Establish leakage event parameters and categories for each parameter as bases for further search and analysis efforts.

-2-

3. Generate a matrix that relates the parameters to each other by number of LER event occurrences.

4. Search the matrix to determine trends.

5. Summarize and report results to be used in succeeding subtasks.

This effort was limited to a two month duration and is summarized in the following sections.

3.0 Significant Findings, Conclusions and Recommendations

This section provides a brief summary of the significant findings, conclusions, and recommendations of this subtask effort. Section 6.0 provides detailed discussion, tables, and figures which serve as the basis of conclusions summarized herein. Three major areas will be discussed, as follows:

1. Feasibility of alternate containment test methods
2. Trends in time, normalized to operating reactors per year
3. Personnel and procedural deficiencies

3.1 Feasibility of Alternate Containment Test Methods

Approximately 280 events reported in 15 LERs in the PNL data base were actually detected by Type A testing (ILRTs). The balance of over 2200 data base events were detected by Type B and C local leak rate tests.

As discussed in more depth in Section 6.2 in assessment of leak detection capability, the vast majority of all the data base events were judged as being detectable by Type A and B tests in the case of penetrations and Type A and C tests for valves. Only 25 events in the data base were judged detectable by Type A testing only (see also Section 5.2.2 for more discussion of detection capability). There is possibly a small subset of the data base that was detectable by Type B or C test methods only; however, this assessment could not be made or quantified.

Approximately 25% of the data base events were detectable by alternate leak test methods (as further defined in Section 5.2.3 and Appendix A). Of these, all were also detectable by Type A, B, or C tests. Of the 25 events in the data base detectable by Type A testing only, [illegible] 4 were not detectable by the alternate m[illegible]

-3-

These data indicate that (1) Type B and C local leak rate tests are heavily relied upon and necessary in leakage detection and assurance of containment integrity; (2) Type A testing actually detects a small percentage yet significant number of all containment leakage events; and (3) alternate methods cannot detect a large number of potential leakage events, but could detect many of those that Type B and C tests do not detect.

Implementation of alternate methods of leak detection in conjunction with Type B and C testing could reduce the need for Type A testing and more quickly detect those breaches which occur when the plant is on-line and which are not normally detected until the next set of current testing methods, typically at the next refueling outage.

However, many events were actually detected by ILRTs which would have gone undetected in the absence of Type A testing. Many of those could not have been detected by the alternate methods. Therefore, justification for elimination or reduction of Type A testing cannot be made based upon the preliminary analysis provided in this report. Implementation of a low-cost alternate detection method to complement Type A testing could be of value in the verification of containment integrity.

See Section 6.2 for further in-depth discussion of these results.

3.2 Trends in Time, Normalized to Operating Reactors Per Year

Generally, events of all types in all plants and all causes are occurring more frequently each year. Figures 1-5 provide a brief summary of some of these trends normalized by dividing the number of events in a given year by the number of reactors (and fractions) on line that year. Note that no allowance (or subtraction) was made for normal or extended outages as many events are detected during these outages and containment integrity must generally still be met. Generally, PWRs have performed better than BWRs, with the exception of the ice condenser containments, where large, wide swings have occurred. All containment types are trending upwards, with a significant jump in the 1978-1979 timeframe, generally. Possible changes in LER reporting requirements about this period in time could have caused the results depicted. Leakage events follow these increasing trends. The fail to close and unplanned opening events follow a much flatter trend. Finally, procedural causes appear to be trending at a fairly flat even rate. See Section 6.3 for more discussion of these figures and results.

3.3 Personnel and Procedural Deficiencies

Only about 6% of the data base can be readily identified as caused by personnel error or procedural problems. Further investigation into other cause categories identified an additional 165 possible events that might have been due to personnel/procedural deficiencies--or 13% of the data base. Though the benefits to be gained by pursuing changes or improvements to personnel/procedural/operating practices are probably small, the associated costs and time required to implement various alternatives are probably also relatively small. A more thorough cost/benefit analysis could be conducted to support selective implementation of improvements in current plant procedures or personnel training. See Section 6.4 for further discussion of the results.

4.0 PNL Data Base

The primary purpose for the development of the PNL computer data base as reported in NUREG/CR-4220 was to compile available containment and containment isolation system (CIS) operating and performance data. The overall objective was to use this data to perform reliability analyses of containment isolation systems. The goal was to quantify the probability of pre-existing containment boundary leak areas (UBCIs). The data base consists of over 1800 License Event Reports (LERs) and information derived from Integrated Leak Rate Test (ILRT) reports. The data base software, written using DBase III, allows simple searches of the various LER fields to analyze different combinations of events. PNL developed overall containment unavailability as a function of leak size and duration. The conclusion was that there is room for improvement in CIS performance.

4.1 Observations

The purpose of the Sandia effort was to refocus on the data base and conduct further, in-depth searches of selected parameters to detect trends and analyze key underlying causes. As a result, the PNL report and analytical methods, as well as the data base search routines, were of limited use for the purposes of this study. A number of key observations were made, as follows:

a. The data base was generated for a different purpose--to estimate unavailability due to all UBCI. Information important to this subtask effort was either difficult to obtain or had to be separately compiled.

b. The "canned" search routines were quite limited, for the purposes of this subtask.

c. The data base is incomplete, contains numerous errors, and requires considerable judgment and a certain measure of "reading between the lines" to interpret the original basis of many entries.

d. Many events were not applicable to specific containment leakage test methods. These events, referred to later in this report as "immediate detection" events, were of lesser significance in analyzing alternate detection methods.

e. The data base is quite incomplete regarding leakage rate, size (area), and event duration as well as other particulars on the actual leakage path.

f. Often, specific equipment (such as valve names, locations) is not identified and the extent of a potential leak path is not noted (i.e., is the second valve in a series path also open or leaking).

4.2 Search Routines

A number of preliminary searches of the complete, unedited, data base were conducted to become familiar with the search routines and content of the data base.

As noted above, the PNL search routines are limited, both in speed and comprehensiveness, as well as in ultimate utility of results. Each data base record consists of 14 fairly complete fields of information, with an option of displaying 29 fields. Searching on 29 fields was faster, as these are coded, and yields more information. However, there are many unknown or blank entries, which can skew the results on searches of the entire data base. Searches are relatively simple to initiate. There are options available regarding logical search relations to specify that a field is equal to, greater than, less than, etc...a certain value. Only three of these relations for any given search is possible. Beyond that, "progressive searches" are required to look at further breakdowns of the previous search. Once a search is complete--and DBase III on any PC will be slow--numerous options to review the resulting LERs and/or print all or portions are provided. There are also options to display or print any number or combination of LERs, edit records, purge previous searches, and look at special field columnar formats.

In summary, the search routines are adequate for limited use and relatively small numbers of searches. Any extensive use of the data base to conduct large numbers of searches, in many parameters, is either impractical or impossible, respectively.

5.0 SANDIA Search Routine

To overcome many of the limitations and problems that were noted above when conducting data base searches, a much more comprehensive, faster and useful strategy was developed. The general approach was to transfer the data base and a separate coded matrix, here designated IMATRIX, to an HP 9816 computer and utilize the HP Basic 3.0 program language as a much superior "number crunching" tool to the DBase III software program originally developed by PNL. Below is a summary of those tasks and resultant search routines and findings.

5.1 IMATRIX Parameters and Categories

Table 1 is a listing of the matrix parameters selected to be used as a basis for searches of leakage trends. Positions 4-8 were automatically assigned from the PNL data. Positions 1-3 were selected as a means to categorize the data base events relative to leak size, potential detection by applicable Type A, B, or C tests, and potential detection by alternative testing methods. Table 2 provides separate listings of the categories to be assigned to each parameter position in the matrix, and are explained in the next section.

5.2 Summary of IMATRIX Development Effort

Computer routines were developed to automatically assign categories to Positions 4-8 and to facilitate manual assignment of the first 3 positions, in accordance with the numbering scheme developed and summarized in Tables 1 and 2. The greatest effort and time (almost 3 man weeks) was required to manually assign categories to those first 3 matrix positions for all of the data base records. The assignments often required significant engineering judgment based upon actual plant experience and familiarity with plant systems and equipment arrangements. This task proved more difficult due to the variability and incomplete nature of the data base. There is a wide spectrum of events involving all types of plants, systems, operating philosophies, reporting habits, and many years of operation. Consistency of assignment was a major concern.

The following is a summary of the basis and assumptions made for the definition and assignment of the various categories, by IMATRIX position. Appendix B includes more complete listings of what the various categories included from the original PNL report listings. These complete breakdowns were not used in the trend searches of the data base in order to simplify the analysis and reduce the enormous number of possible searches to a more manageable scale.

5.2.1 Leak Rate

Leak rate was the most difficult category to assign. Generally, actual leak rate and leak area information, as well as test pressures and penetration sizes, were not provided in the data base. The None or N/A category was assigned in those cases where there was no leakage or leakage determination did not apply. Most of these fell into the "immediate detection" category further discussed in Section 5.2.2.

The Indeterminate category was assigned where it was impossible to venture a guess or judgment as to the nature or extent of leakage (or non-leakage). This proved to be a dominant categorization as is discussed elsewhere in the results sections of this report.

The Small category was for actual leaks of a small nature in small bore leakage paths or other penetrations where leak rates were actually reported. When possible to determine, these leak rates were considered small if they fell in the range of 1-10 La, the maximum allowable containment leakage rate as provided by the technical specification limits. For this and the following categories, a significant amount of judgment was called for based on system and plant familiarity and other system or component information that was provided in the data base comments.

Large leaks were assigned for events reported in medium to large size penetrations, leak rates well in excess of tech spec limits, leaks too large to measure, and for open valves of any size. Again, significant judgment was required. Many events and breaches of containment that were assigned of Indeterminate leakage might have fallen into this category had penetration size or bore been provided.

The Very Large leaks were reserved for those obvious gross breaches of containment involving open airlocks or other containment openings and large failures or open purge/vent or similar direct airpath system valves or penetrations. Many of these, especially open airlocks, were of extremely short duration and were placed into the "immediate detection" category and eliminated for the purposes of this subtask effort in analyzing events of significance to the assessment of alternate containment leak detection methods.

5.2.2 Applicable Test

This parameter was established to assign a judgment to each LER event as to which current testing method--Types A, B, and C--or methods could have detected the indicated event. It is important to stress that this assignment did not necessarily match which method, if any, actually detected the event, only which methods were capable of detecting the leak or breach.

The None category was established as a possibility though there were no historical events reported in the LERs that were not detectable by any current testing method.

The next three categories, Type A only, Type B only, and Type C only--were to be assigned for those cases where it was judged that a particular testing method, and only that particular method, could have potentially detected the event (again contrast this with which methods actually detected the event, information which was seldom and inconsistently provided in the data base).

Categories 4 and 5--Type A and B, Type A and C--were assigned when it was judged that both test methods individually could have detected the event. In other words, for many valves, both a Type A test and a

Type C test could detect valve leakage or failure. By the same token, many of the penetration failures could be detected by both Type A and Type B tests. In those cases assigned Categories 4 or 5, which were the majority, it was difficult to determine the <u>actual</u> leakage path and which valve, or valves, in the series path were involved. It is possible that some of the reported LER events were detectable by Type B or C tests only (say, the outboard valve during a Type A test). However, that judgment could not be made based upon the contents of the data base records. This resulted in assigning none of the events to Categories 2 (Type B Only) or 3 (Type C Only).

Finally, the Immediate Detection category was established where it was judged that no test method was required or applicable. For those events that were immediately detected, investigated and fixed and thus of short duration (as in a valve failing to close on demand or during surveillance testing, or the second airlock door opened simultaneously to the first), leak testing methods were not used and did not apply from the standpoint of evaluating alternative methods of detecting breaches of containment. During plant operation, there are many normally open isolation valves that are periodically stroked or tested for response to isolation signals. When tested, they sometimes fail to close, or to respond, to the initial signal. Sometimes they are simply restroked and closed. Though no actual leaks occurred, they were reported as a potential breach of containment integrity. In other cases, a technician is sent to investigate the reason for the event, discovers the root cause (a bad switch, corroded contact, too-tight packing, mechanical binding, ill-adjusted limit or torque switches, etc.), fixes it and, following retesting, the system is returned to normal operating status. Though a reportable event, there was no actual leakage or need to include this event in actual assessments of leak rate or detection test methods. In a few cases there were "failure to open" events and similar equipment malfunctions and events involving unattached pump vaults or secondary containment which did not apply or even belong in the data base.

When these events are eliminated from consideration--and they constitute over 45% of the data base--a "reduced" data base remains which is more meaningful in analyzing underlying causes of failure events of significance to containment leak rate testing. This reduced data base was used in later discussions and analyses of underlying causes and trends.

5.2.3 Alternate Method

This parameter was established to assign a judgment to each LER event as to which alternate testing methods could detect the indicated event. Actual power level or plant operational status was ignored. All events were considered as potential breaches during plant operation. The alternate methods, which are used when the plant is on line, were judged according to their ability to potentially detect the leak at a lower test pressure over a relatively long though unquantified detection interval.

There are a number of proposed alternate test methods that are either applicable to all plants or useful in only certain containment types. A summary of these is provided in the Interim Letter Report titled "Subtask 1.2 Compilation of Alternative Containment Leak Rate Test Methods." Appendix A is a summary listing of these methods along with their applicability to a given set of containments. To simplify the analysis of trends and the underlying causes of reported events, only four groupings of these methods were used.

The None category was assigned for those cases when none of the alternate methods could detect the event. Many events, particularly those involved with water-filled systems and penetrations normally under significant pressure with no normal path available for direct leak detection, fell into this category.

The Air Mass Inventory category was a general grouping of the majority of the alternate leak detection methods which are applicable to all or most plant containment types. These methods are based upon a continuous inventory of containment air mass. Detection requires that the leak path be directly from containment atmosphere to the exterior environment.

Category 2, External Tracer, applies primarily to BWRs and includes those plants and configurations whereby a tracer gas, upon leakage from the primary containment atmosphere, will be collected and monitored via a centralized exhaust.

Finally, the All Types category was assigned for those BWRs where both Air Mass Inventory and External Tracer methods could detect a leak from containment atmosphere to the outside.

5.2.4 Containment Type

This parameter was divided into the dominant containment categories currently in operation in the United States. The first five categories are self explanatory for those familiar with nuclear containments. BWR Mark IIIs were not included as a separate category as there was only one LER event reported from Mark IIIs in the entire data base of over 3400 events. The Other category of containments included older "pre-Mark" containments as listed in Appendix B.

5.2.5 Equipment Type

As stated above, to reduce the parameter categories to a manageable number, the various equipment types for both valves and penetrations were assigned to general category groupings as the category headings indicate. Appendix B lists the original categories assigned in the PNL data base under the respective categories used in this analysis. As no further basis or explanation was provided in the PNL report as to the selection of these categories, it was assumed that category assignments were correct unless an obvious error was noted when reviewing the LER record comments section.

The No Subtype category was established for those many events where the major equipment type was given (valve or penetration) but no subtype was assigned or could not be determined from the LER report.

5.2.6 Failure Mode

This parameter was established and categorized in a manner identical to the PNL report, with the addition of the None category for those events that had no specific failure mode assigned. Leakage was assigned for the majority of events. Failure to Close events were a significant number. Unplanned Opening events were of the lowest, though not insignificant, frequency.

5.2.7 Cause

As in Section 5.2.5, the categories for Cause represent groupings of a larger set of categories originally assigned in the PNL data base. These categories were reduced to sets of related causes to simplify the trend searches. Again, Appendix B provides a summary of the original categories listed under category headings used in this analysis.

There were a large number of LER events where no primary cause was assigned or where cause was listed as unknown; these were assigned to Categories 0 or 6. Appendix B provides definition of the remaining categories.

5.2.8 Date

This parameter was subdivided into an arbitrary, consistent set of date range categories for the trend analysis simplification previously mentioned. As the data base covers events reported through early 1984 only, the last category 8, 1984-1986, consists of a deceivingly small number of events. Therefore in many of the trend searches, event totals for Categories 7 and 8 were combined.

5.3 Initial Event Search Results

Tables 3-10 are a summary of initial results of 1D and 2D searches of IMATRIX on the data base. These results are further discussed in later paragraphs in Section 6.1. The first column represents initial searches of the entire data base. The second column results when the "immediate detection" events--column three--are removed from the complete data base. The second column of initial search results was used as the basis for developing search routines and strategies to further analyze event trends, underlying causes, and assessments of the potential for alternate test methods.

It is important to note that these preliminary searches, though providing much useful information, are not adequate to determine trends. Many more searches and search combinations were required to look at multidimensional combinations of the various parameters and categories. A summary of this larger effort is provided in Section 5.5.

During the category assignment effort, many obvious errors and typos were noted in the data base and corrected later. Appendix C is a summary of all corrections, changes and deletions made to the data base. Therefore, there were minor differences in search results between the early initial results and searches conducted later. These small differences are of not concern in determining leakage trends.

It is important to note that these results and all trends reported are based simply upon a total number of occurrences. There was no comprehensive attempt to "normalize" these results by reactor years of operation. Section 6.3 provides results of a simple analysis made by reactor years for significant findings.

5.4 "Immediate Detection" Events

As indicated earlier, a large portion of the data base (45%) was categorized as "Immediate Detection "--events of little significance from the standpoint of leak detection. Examples of such events include short duration events, many Fail to Close, that have nothing to do with leak rates or testing methods. Most are for normally open valves that are tested, do not respond (or fail to respond on first initiation), are checked and fixed and returned to normal status. Many events are "potential" breaches (in the event of an isolation signal) where no leak applies. There are events involving short duration, accidental openings of access doors, "failure to open" events, and similar equipment malfunctions; and some involving unattached pump vaults or secondary containment that do not apply or belong in the data base.

The second and third columns of Tables 3-10 are search summaries of the remaining ("reduced") data base and immediate detection events, respectively. To summarize the latter, almost 50% of the events occurred in PWRs, 44% in BWRs. About 86% were valve related events, 10% personnel hatch events of short duration, and 73% Fail to Close. Almost 40% were mechanical causes, 25% electrical and only 6% personnel. The reduced data base event count for electrical causes was almost eliminated, as most of those were immediate detection events (such as a dirty or failed relay, control switch, breaker, or improper wiring). More of these events (by percentage) occurred in earlier years with a lower rate of increase in occurrences in recent years, as compared to the rest of the data base.

5.5 "Binary Search" Routine

It soon became evident that a large number of searches were necessary to strategically analyze the reduced data base for trends and causes of leakage. From this need evolved a very powerful, comprehensive search routine allowing a large number of possible event search combinations to be completed simultaneously.

Strategically applying this "binary search" routine to families of related searches yielded large numbers, and multidimensional tables, of results. These tables were then compiled and reviewed by hand to locate trends and note interesting results, anomalies, and new search ideas. Appendix D contains two examples of these tables. These, and others, were used in combination to derive the significant findings noted elsewhere in this report. Eventually, an even more comprehensive routine involving 23 positions and associated categories was developed which provided even greater flexibility to search a much larger possible set of event combinations and was used to supplement the observed trends and results obtained.

6.0 Results

6.1 General Observations

This section is a summary of general trends noted and observations while conducting searches of the reduced data base. Tables 3-10 summarize some of these results. Regarding leak rates and leak detection, over 70% of the data base was of indeterminate leakage. Of over 620 remaining events, 67% were small leakage, 26% were large leakage, and 7% very large leakage events. In the data base, test pressures were seldom given, as was the case for leak area or valve/equipment size. Because of this lack of data, it was often impossible to hazard even a guess of the existence or general size of a leak. Many of the LERs simply stated in the "Comments" section that there was a leak (or leaks) or that a penetration was leaking above tech. spec. limits, with no quantitative information provided. Even the number of events per LER was sometimes unknown; for these, PNL made assumptions of the number of failures (often times, for ILRTs, 40 failures were assumed).

For the reduced data base, over 50% of LER events occurred in BWRs, 25% in PWR large, dry containments. Over 80% of all events involved valves, and was the predominant equipment involved in BWRs (96%). When "immediate detection" events are eliminated, almost 60% of valve-electrical failures are eliminated and become a smaller percentage of those events important to leak detection (34% to 23%, respectively). Access hatch/air lock events are a significant number (15%) of all events and constitute over 30% of events in PWRs.

For all events, the primary mode of failure as discussed in Section 5.2.6 is leakage (over 60% on the full data base). Since the majority of the "immediate detection" events are Fail to Close, the resulting percentages in the reduced data base shift significantly--over 86% of the events are due to leakage. When personnel/procedurally caused events occur, the mode of failure is usually fail to close or unplanned opening.

Over 20% of all events were categorized with no or unknown causes. Mechanical causes account for over 60% of the data base; only 6% of causes were categorized as procedural deficiencies or personnel error. When the "immediate detection" events were eliminated from the full data base, there was a large percentage shift towards a larger share of mechanical causes and fewer electrical causes.

6.2 Leak Detection Assessment

Actual detection of the events in the reduced data base by current leak rate test methods was difficult to surmise due to inconsistent reporting and the general lack of such information in the comments section of each LER. With this limitation in mind, a review of the data base yielded approximately 280 events reported in 15 LERs which were historically detected by Type A ILRT tests. As stated in Section 6.1, six of these LERs each reported 40 assumed failures, or 240 total "assumed" events. The actual number could be much lower. It was assumed that the remainder of almost 2200 events were then actually detected by Type B or Type C local leak rate tests.

As explained in Section 5.2.2, in the assignment of the Applicable Test parameter, each LER event was judged as to which testing method could have detected the indicated event, in contrast to actual historical detection summarized above. Referring to Table 4, the vast majority of all events--regardless of leak rate--were detectable by Types A and B tests (penetrations, Category 4) or Types A and C tests (valves, Category 5). The remainder of the data base--25 events--were judged as being detectable by Type A (ILRT) testing alone (Category 1).

There were no events in the data base in which it was judged that <u>only</u> the local leak rate test methods, Type B or C, could detect the leak. As previously stated in Section 5.2.2, it is quite possible that some of the reported LER events were detectable by local leak rate methods only. For instance, outboard valve leakage might not be detectable during conduct of the ILRT and would only be found by a Type C test. However, the information to make that judgment did not generally exist and quantification of such events could not be made based upon the contents of the data base records.

In summary, all historical events were detectable by existing test methods, with detection of only a few (25) dependent on a single method. Actual historical detection, though the numbers are undoubtedly inaccurate due to the state of the data base, indicates a heavy reliance on the periodic local leak rate tests, with a relatively small percentage detected during ILRTs.

From Table 5, alternate testing methods were deemed capable of detecting about 25% of events on the reduced data base. Other multidimensional searches showed that all of these were also judged as being detectable by current Type A, B, or C tests, as appropriate. Those 75% not detectable by alternate methods were primarily in the pressurized, closed, fluid-filled systems that do not allow a direct air path from containment for on-line leak detection. Of the 25 events that were Type A only detectable, only 4 could not be detected by the alternate methods of almost 2200 historical events.

The above data shows that alternate methods, in conjunction with periodic local leak rate testing, could detect the vast majority (all but 4, historically) of containment leak events. Local leak rate testing as currently practiced would periodically detect the majority of events. For those events not detected by the local tests and those that later develop during operation, many could be detected on-line by alternate means. The obvious benefit is quicker detection of events that occur during operation (rather than during the next outage ILRT) with shorter duration of actual leakage or potential breaches resulting in a positive impact on safety and containment integrity. Utilization of this testing approach could provide justification for reduction on elimination of periodic Type A testing.

However, the historical data indicates that many (the 280 events reported in 15 LERs) actual penetration leaks were detected by Type A tests. Since most ILRTs are conducted after the local leak rate tests (which document as-found leakage) and prior to start-up (to document as-left leakage), it is apparent that Type A tests are needed to detect those leaks either not detectable by B and C tests (such as holes in containment) or which later develop during the outage. Also, many of these leaks will be present in the closed, pressurized systems that the alternate methods are not sensitive to. Therefore, if those leakage events are missed due to elimination of Type A testing, many would go undetected (assuming 75% of the 280 events, results in 210 events) until the next set of testing during the following outage. This duration--typically 12 to 18 months--is clearly of safety significance from the standpoint of potential degradation of containment integrity.

How many actual events would go undetected by alternate methods in the absence of Type A testing and the resulting safety risk could not be (and was not) quantified simply on the basis of the information provided in the data base. It is therefore not possible without further research, to justify elimination or reduction of Type A testing.

Implementation of alternate methods will need to be assessed based on an in-depth benefit/cost analysis, which was outside the scope of this subtask effort. Those events which occur during operation and result in a direct air path from containment to the exterior environment--open airlocks, hatches, holes in containment, large purge/vent valve leaks or open events--will not be detected in a timely manner by current methods and can (and do) result in large leakage, significant duration events detrimental to containment integrity. Though no further assessment was provided in this report, implementation of a relatively low-cost continuous on-line alternate leak detection method to complement Type A testing could be of value in timely verification of nuclear containment integrity.

6.3 Dates and Durations

Specifics on event duration were given in less than 10% of the data base. For the remainder, it is essentially impossible--and inappropriate--to assume durations. From the information given in the data base alone, it is difficult to determine or assume the last occurrence of leakage or leak rate test. Any assumptions regarding event duration were of little value for the purposes of this task.

Generally, searches by date yield increasing numbers of events, chronologically, per year. A number of trends were noted from the simple trends, as in Table 10:

1. Older plants (other category) have had fewer leakage events in recent years.

2. Mode C--unplanned opening--events have tapered off.

3. Environmental/process caused events are becoming fewer with more reactor-years of operation.

4. Mechanical causes in BWR Mk I's and older plants have dropped off somewhat.

5. There has been a significant increase in events designated caused by personnel/procedures in recent years.

Again, these trends are based upon the total set of occurrences and were not normalized by reactor years of operation.

In a later requested effort, data was gathered on the number of reactors in operation each year for the period of the data base. Allowances were made for decommissioned plants; however, outage time (normal or extended) was not accounted for as many leak events are detected regardless of plant operational status and containment integrity is usually required, especially during fuel movements.

Figures 1-5 depict the results for a number of selected parameters. For all events, Figure 1, there was a slow general increase from the range of 0.5-2 events per operating reactor-year which jumped significantly in the 1978-1979 timeframe to around 4.5 events thereafter. This general trend may have been due to changes in LER reporting requirements. The PNL report stated that ". . . From 1965 through mid-1977, the abstracts contained only general information about incidents. . ." and later that ". . . From mid-1977 through 1981, the quality of the abstracts improved . . ." with ". . . some relapse in the reporting quality . . . with the most recent LER abstracts (1982-1983) . . .".

PWRs as a class have seen a steadily increasing trend of events (in the ranges of 0.5-1.5, then 2-4 after 1978) though numbers are lower overall than for BWRs

(Figure 2). For the individual PWR containments, Figure 3, large dry containments trend right along the same line, though with a lower share--and flatter trend--in the 1979-1983 timeframe. Ice condensers have gone through wide, high swings, particularly high in the 1975-76 and 1981 periods. These are mostly leakage events. This trend may be due to the small number of plants in this category where a few events can significantly alter results. Also, three new plants came on-line in the 1981-82 timeframe which may have partially caused the high number of events during that period. Subatmospheric containments started out very low in the initial mid-70s (< 1 event), but there was a large jump after 1977-1978 to a higher plateau. Many of the events noted for these containments in the full data base were categorized "immediate detection" and resulted in a large reduction of events and lower, less drastic, trend over the years.

BWRs were low initially (0.5-3 events) but hit a new plateau after 1978 of 6-8 events which is flat and even trending down now (Figure 2). Again, this emphasizes the possible reporting requirement changes. Mark Is, comprising the bulk of historical data, followed the same trend (Figure 3). Little can be said for recent operation of Mark II and Mark III containments as there is little operating history and few events reported. Finally for the older pre-Mark containments, performance prior to 1977 was exceptional. There was a large increase in events in the 1977 to 1980 timeframe (particularly 1979) which came back down to a steady trend at close to 2-3 events from 1981 on.

Actual leakage mode events followed a very similar trend as the total set of events. This is shown in Figure 4. Generally the Fail to Close and Unplanned Opening modes have remained level with time.

Procedural caused events, when trended on a basis normalized to reactors in operation per year, have remained fairly level along with the Fail to Close and Unplanned Opening modes. As shown in Figure 5, there was a significant increase in 1981 followed by a downward trend recently.

6.4 Personnel/Procedural Causes

Leakage events by Cause (primary) category are as follows:

1.	Mechanical	1378 (63%)
2.	None Assigned/Unknown	450 (21%)
3.	Personnel/Procedures	130 (6%)
4.	Design/Construction	11 (.5%)
5.	Electrical	37 (1.5%)
6.	Environmental/Process	186 (8%)

Other causes were investigated to make a preliminary determination of additional events that could be attributable to personnel or procedural root causes, perhaps as a secondary cause. Examples of the PNL data base cause categories reviewed include:

1. Mechanical control/parts
2. Packing failure/problems
3. Lack of lubrication
4. Torque switch failure/problem
5. Limit switch failure/problem
6. Air solenoid failure/problem
7. Foreign contamination
8. Seal/gasket failure
9. Electrical input failure
10. Seat/disc failure
11. Unknown/unassigned
12. Others, on a random basis

The preliminary result of this brief study was an additional possible 165 failures that MIGHT be caused by procedural deficiencies--or a total of 13% of the data base. Table 11 is a brief summary of these events with remarks regarding the general nature of the cause.

Possible procedural problems that may be changed to help alleviate or prevent these types of occurrences include:

1. Insufficient frequency of instrument maintenance and calibration.

2. Infrequent or improper installation/checking of valve packings, or improper packing application.

3. Inadequate PM schedules for lubrication.

4. Surveillance/inspection of critical penetration components at infrequent intervals.

5. Inadequate housekeeping and maintenance practices.

6. Insufficient or inadequate operator training; incorrect valve/equipment checklists.

Many of these problems could potentially be reduced by implementation of relatively low cost measures such as increased training, emphasis on use of accurate checklists and procedures, and improved maintenance and housekeeping practices. More frequent maintenance and calibration will, of course, involve increasing costs in terms of procedure development/review, man hours, radiation exposure, and capacity penalties for reduced power during testing.

TABLE 1
IMATRIX PARAMETERS

Position Names:

1. Leak Rate
2. Applicable Test
3. Alternate Method
4. Containment Type
5. Equipment Type
6. Failure Mode
7. Cause
8. Date

TABLE 2
IMATRIX PARAMETER CATEGORIES

Leak Rate
1. None or N/A
2. Small (1-10 La)
3. Large (open valve)
4. Very Large (penetration)
5. Indeterminate

Applicable Test
0. None
1. Type A Only
2. Type B Only
3. Type C Only
4. Type A and B
5. Type A and C
6. Immediate Detection

Alternate Method
0. None
1. Air Mass Inventory
2. External Tracer
3. All Types

Containment Type
1. PWR Large Dry
2. PWR Subatmospheric
3. PWR Ice Condenser
4. BWR Mk I
5. BWR Mk II
6. Other

TABLE 2 (Cont.)
IMATRIX PARAMETER CATEGORIES

Equipment Type
0. Valve - No Subtype
1. Valve - Electrical
2. Valve - Mechanical
3. Valve - Other
4. Penetration - No Subtype
5. Personnel Hatch
6. Equipment Hatch
7. Electrical Penetration
8. Inst or Process Line Penetration
9. Penetration - Other

Failure Mode
0. None Assigned
1. Leakage
2. Fail to Close
3. Unplanned Opening

Cause
0. None Assigned
1. Personnel/Procedure
2. Design/Construction
3. Mechanical
4. Electrical
5. Environmental/Process
6. Unknown

Date
0. None
1. <1966
2. 1966-1968
3. 1969-1971
4. 1972-1974
5. 1975-1977
6. 1978-1980
7. 1981-1983
8. 1984-1986

TABLE 3
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Leak Rate

Category	Entire Data Base	Reduced Data Base	Immediate Detection
1. None or N/A	1255	3	1252
2. Small	417	417	0
3. Large	162	162	0
4. Very Large	43	41	2
5. Indeterminate	1570	1569	1
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 4
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Applicable Test

Category	Entire Data Base	Reduced Data Base	Immediate Detection
0. None	0	0	0
1. Type A only	25	25	0
2. Type B only	0	0	0
3. Type C only	0	0	0
4. Type A and B	382	382	0
5. Type A and C	1785	1785	0
6. Immediate Detection	1255	0	1255
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 5
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Alternate Method

Category	Entire Data Base	Reduced Data Base	Immediate Detection
0. None	2890	1638	1252
1. Air Mass Inventory	404	402	2
2. External Tracer	3	3	0
3. All Types	150	149	1
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 6
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Containment Type

Category	Entire Data Base	Reduced Data Base	Immediate Detection
1. PWR Large Dry	944	567	377
2. PWR Subatmospheric	218	131	87
3. PWR Ice Condenser	395	247	148
4. BWR Mk I	1617	1081	536
5. BWR Mk II	45	34	11
6. Other	227	131	96
Total Events	3447	2192	1255
Total LERs	1354	997	857

TABLE 7
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Equipment Type

Category	Entire Data Base	Reduced Data Base	Immediate Detection
0. Valve-No Subtype	1201	932	269
1. Valve-Electrical	1182	498	684
2. Valve-Mechanical	304	161	143
3. Valve-Other	228	202	26
4. Penetration-No Subtype	17	11	6
5. Personnel Hatch	394	295	99
6. Equipment Hatch	31	26	5
7. Electrical Penetration	44	33	11
8. Inst. or Process Line Penetration	25	23	2
9. Penetration-Other	21	11	10
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 8
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Failure Mode

Category	Entire Data Base	Reduced Data Base	Immediate Detection
0. None Assigned	23	7	16
1. Leakage	2113	1880	233
2. Fail to Close	1168	246	922
3. Unplanned Opening	143	59	84
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 9
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Cause

Category	Entire Data Base	Reduced Data Base	Immediate Detection
0. None Assigned	322	208	114
1. Personnel/Procedure	204	130	74
2. Design/Construction	78	11	67
3. Mechanical	1829	1378	451
4. Electrical	337	37	300
5. Environmental/Process	294	186	108
6. Unknown	383	242	141
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 10
INITIAL 1D AND 2D MATRIX SEARCH RESULTS

Parameter: Date

Category	Entire Data Base	Reduced Data Base	Immediate Detection
0. None	4	2	2
1. < 1966	0	0	0
2. 1966-1968	0	0	0
3. 1969-1971	106	8	98
4. 1972-1974	254	131	123
5. 1975-1977	572	327	245
6. 1978-1980	1001	685	316
7. 1981-1983	1390	961	429
8. 1984-1986	120	78	42
Total Events	3447	2192	1255
Total LERs	1854	997	857

TABLE 11
PROCEDURAL CAUSE SUMMARY

PRIMARY CAUSE	REMARKS	FAILURES
00. Unknown, Unassigned	Procedural deficiencies; maint., operations	18
7,10 Normal Wear	Housekeeping; process deficiencies	7*
Foreign Contamination		*
12. Mech. parts, adj.	Maintenance & adjustment	22
13. Seal/gasket	Door seals, improper install., housekeeping, ill use	19
4. Packing	Installation, checking, application	22
16. Electrical Input	Inadequate elec. maint. performance	*
18. Welds	Weld activities affecting, causing fail. of other comp.	*
19. Lubrication	Inadequate, inappropriate, untimely PM	10
23. Torque Switches	Poor adjustment, surveillance	17
25. Seat/Disc	Installation, alignment	2
26. Limit Switches	Poor adjustment, surveillance	14
28. Air Solenoid	Dirty air; poor air syst. oper. & maint.	14
*, Other (Causesec=1,2,3,6)	From those above & misc.	20
		165
1,2,3,6	Operators (valve lineups, open valves); Maintenance (housekeeping; not following procedures; leaving things open, uncapped, undone; improper assembly); Other (open path during outage refueling movements; uncapped test connections, poor test methods).	130
		295

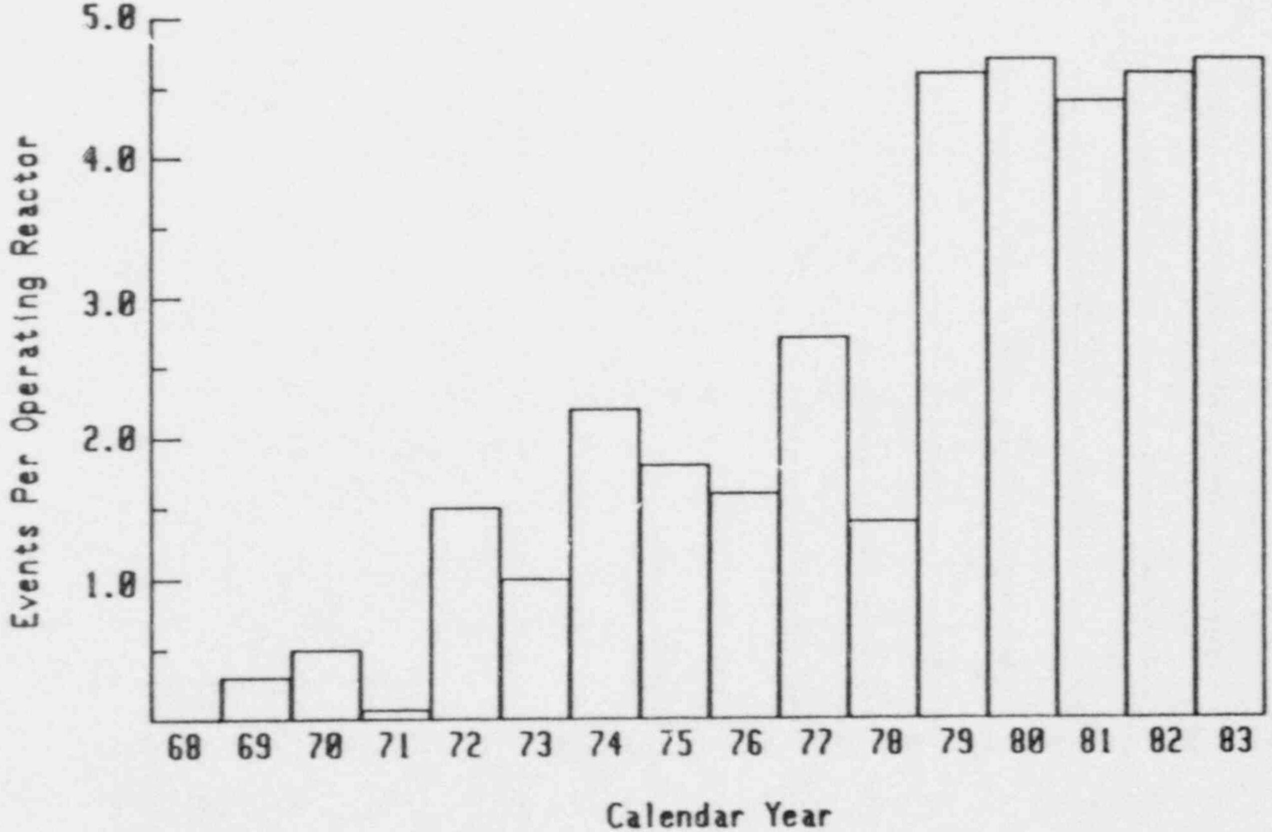

Figure 1 - Events per Operating Reactor
All Data Base Events

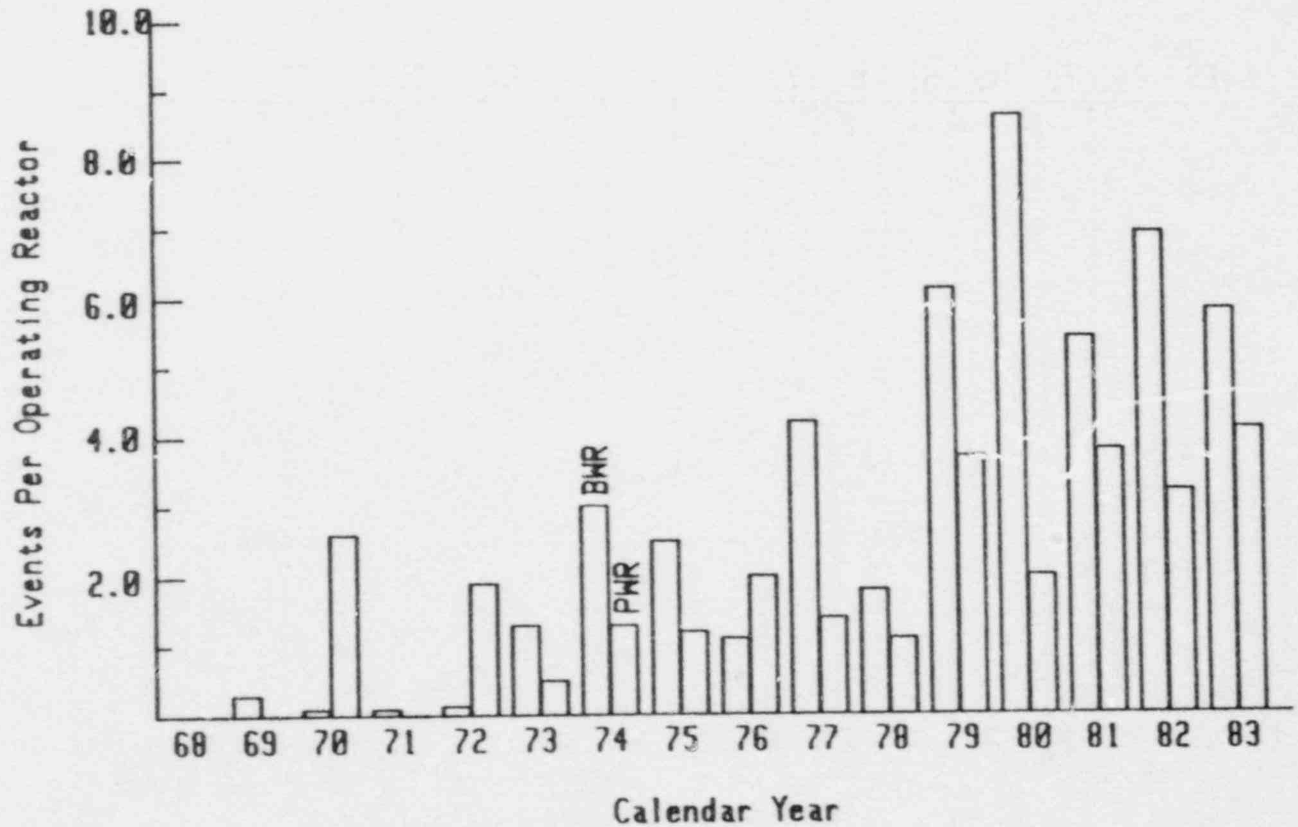

Figure 2 - Events per Operating Reactor
BWR and PWR Events

CONTAINMENT TYPE	CALENDAR YEAR															
	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
BWR Mark I	0	0	0.3	0.2	2.5	1.9	3.9	2.9	1.2	4.7	1.6	6.2	9.5	5.9	7.8	5.8
BWR Mark II	NO USEFUL DATA															
BWR Mark III	NO USEFUL DATA															
PWR Large Dry & Dual	0	0	0.7	0	1.3	0.5	1.3	1.1	1.4	1.4	1.0	2.9	2.1	1.8	2.3	2.5
PWR Ice Condenser								0	23.0	5.0	3.3	10.5	2.0	28.7	2.8	12.4
PWR Subatmospheric					0	0.6	1.0	0.5	0	0.7	1.4	5.3	1.7	3.6	9.0	5.8
Other (Pre-Mark, older)	0	0.4	0.5	0	0.5	0.3	1.0	1.8	1.0	2.4	2.9	7.3	3.8	2.3	2.5	2.8

Figure 3 - Events per Operating Reactor
All Containment Types

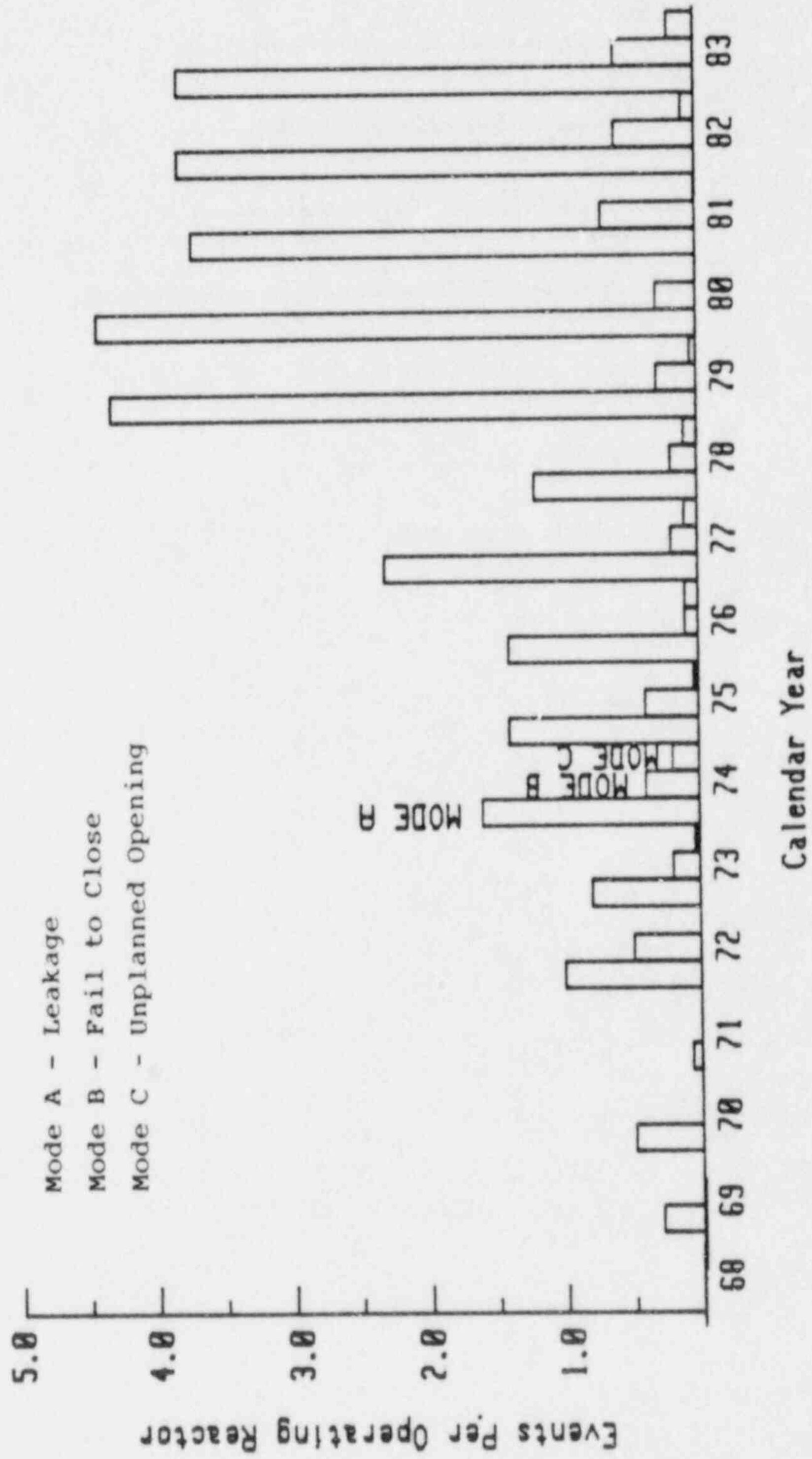

Figure 4 - Events per Operating Reactor Events by Failure Modes

-37-

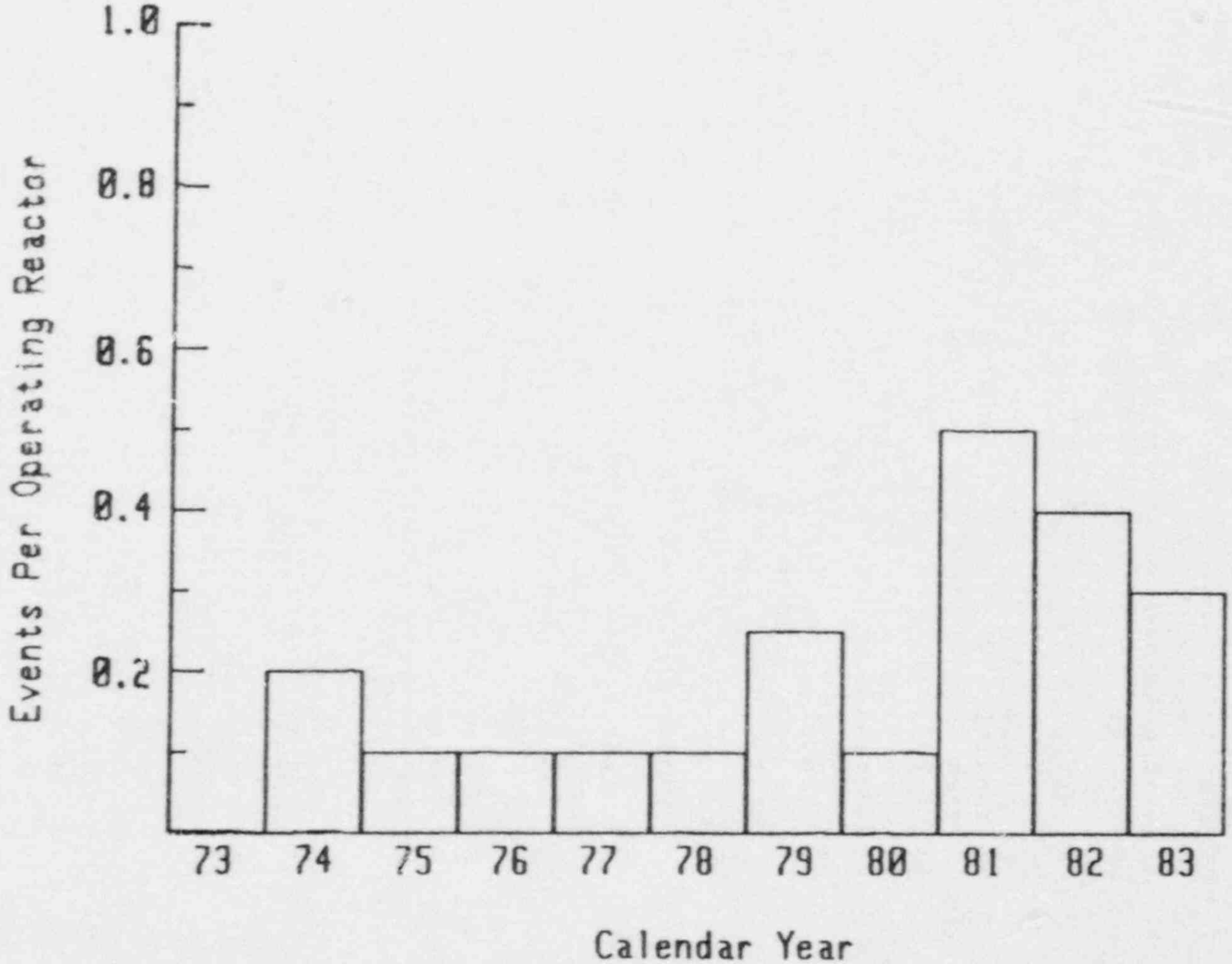

Figure 5 - Events per Operating Reactor
Personnel/Procedural Caused Events

APPENDIX A

ALTERNATE TEST METHOD DESCRIPTIONS

The various alternative test methods currently considered to be the most feasible are discussed here. A brief discussion of each method is presented. The discussion includes a description of each technique and comments concerning applicability to various containment types.

While the individual alternative methods are discussed below, a few general observations concerning the applicability and potential use of the methods is appropriate. Most methods exhibit a sensitivity to in leakage of instrument air which serves to mask existing leakage rates by adding air to containment. Secondly, several types of breaches of containment integrity cannot be detected with the alternative methods. These breaches include leaking valves which are open during plant operation and closed, fluid tilled systems under pressure. Specifically, if low pressure air (about 1 psig) from within containment will not leak through the breach, then an alternative method will not detect it.

METHOD 1: External Detection

In this method, the concentration f a tracer existing within containment is monitored outside the containment and an unusually high concentration is an indication of an unacceptable leakage rate.

For this method, Mark I and II BWRs are of primary interest because of the existence of a single vent, the effluent stack, through which the entire atmosphere surrounding the containment is vented.

The primary tracer being considered for this method is ozone since it is created in containment by the interaction of oxygen with ionizing radiation. Further, ozone is detectable in concentrations as small as 1 part per billion (ppb). Use of ozone would not require introduction of a tracer within containment.

Instrumentation of sufficient accuracy to monitor expected ozone concentrations is commercially available. A true leakage rate is not determined here but rather an indication of • unsatisfactory leakage. The method applicability is limited to BWRs and may be unsuitable in some areas due to the required high sensitivity of ozone detection.

METHOD 2: Tracer Gas Dilution

This technique involves the maintenance and monitoring of a chemical tracer element introduced within the containment. The change in concentration of the tracer over time is a direct measure of the integrated leakage into containment since inleakage proportionally dilutes the tracer concentration and outleakage carries tracer with it resulting in no net dilution. This fact limits the method to containments which may operate at negative gage pressure.

Typical allowable negative pressures are about -6 psig for subatmospheric and -1 psig for large, dry containments. BWR and ice condenser containments do not typically operate at negative gage pressures.

The tracer of greatest interest is Neon gas which is being considered because of chemical inertness and molecular weight close enough to that of air (20 vs. 29) so that stratification should not cause extreme difficulties.

The system envisioned would consist of a concentration monitor and equipment to periodically introduce trace amounts of Neon into the containment. At the beginning of a test cycle, such as following a shutdown, a low concentration of Neon (100-1000 ppm) is established in containment. The actual value of the concentration is then measured by a concentration monitor to establish a benchmark concentration. The Neon concentration is monitored continuously or at intervals with the per cent reduction in concentration being equal to the integrated per cent of inleakage.

This method is inherently insensitive to humidity, temperature and pressure changes in containment since the mass concentration of Neon is unaffected by these factors. The method is sensitive to instrument air usage since the air serves as an inleakage which dilutes the tracer.

Equipment to introduce and control trace gas concentrations is readily available. However, a sufficiently accurate concentration monitor for neon has not yet been located.

METHOD 3: Continuous Injection Into Containment

With this method, air is injected into the containment to maintain a low positive pressure sufficient to promote flow through existing leak paths, but within tech spec limits. The integration of the air input over extended time gives the average leakage rate. This method is sensitive to changes in humidity and air temperature.

Addition of small amounts of temperature and dew point instrumentation could significantly increase system accuracy with a corresponding penalty in terms of cost and system complexity.

In the case where air is injected into the containment separately from the instrument air system, some compensation for instrument air usage may be required. Methods of compensating for instrument air usage include averaging the leakage rate measured under both positive and negative pressures; measuring instrument air usage and adding or subtracting the value to the quantity injected; and sourcing the instrument air from within containment.

Equipment and instrumentation for this method consists of a compressor as an air source, if not currently installed, and an integrating mass flow meter. Both items are readily available in the appropriate size and accuracy which would be required.

This method is applicable to all non-inerted containments. In the case of inerted containments, the nitrogen monitor technique performs the same function.

METHOD 4: Direct Atmosphere Weighing

This technique provides a direct and rapid method of weighing the air mass of a containment. The equipment consists of a differential pressure transducer placed in the bottom of containment with one side of the transducer open to the environment and the other attached to a dry, air filled tube. The other end of the tube is connected to a second differential pressure transducer at the top of the containment. The difference in static pressure produced by the air in the containment between the two pressure transducers is the difference in the transducer readings plus the known constant static pressure of the air in the tube. This value, multiplied by a suitable containment cross-sectional area, yields the weight of air in the containment. The system does not compensate for changes in humidity within the containment.

This method is considered applicable primarily to containments with open geometries, specifically, large dry and subatmospheric PWRs.

METHOD 5: Acoustic Velocity Measurement

The time of transit of an acoustic wave across the containment serves to integrate the square root of the absolute temperature in the wave path. This principle could be applied to measure a bulk average temperature of the containment air, the most difficult facet of mass determination by ideal gas behavior.

Application of the concept is envisioned by using two sonic transmitting units to establish a standing acoustic wave in containment. The number of wavelengths and measured frequency in a known distance of the standing wave can be used to determine the average velocity of the wave which directly determines the bulk temperature. This temperature, coupled with the current pressure would be used to provide periodic or continuous measurements of the containment atmosphere mass through use of the ideal gas relationship.

The applicability of this method is limited to containments with open geometries where wave transit across much of the containment volume is feasible, primarily large dry containments and possibly subatmospherics.

METHOD 6: Reference Vessel Technique

This technique involves monitoring the enclosed air mass of containment through use of a reference vessel similar to those which have been used in Type A testing. The reference vessel acts as a gas thermometer with the pressure in the vessel being a measure of the bulk temperature of the containment. The reference vessel envisioned would consist of a run of seamless tubing, permanently installed. Volumetric weighting of this vessel is not as critical as in Type A testing since the accuracy of the mass determination need not be as great.

The simplest form of this system would consist of pressure measurements of the reference vessel and the containment atmosphere and, assuming thermal equilibrium between the two, the ratio of the pressures would be a relative measure of the contained air mass. Comparison of this ratio with an initial value will yield the fraction of mass change. Instrument air usage and humidity are not compensated for.

All necessary instrumentation and technology to use this method is commercially available. This method is applicable to all containment types.

METHOD 7: Continuous Use of Type A Test Instrumentation

This method involves continuous monitoring of permanently installed Type A instrumentation to determine contained air mass. Like Type A testing, humidity and temperature variations are compensated for. This method is currently employed in some plants with success.

This method is applicable to all containment types but could be one of the most expensive techniques to install due to the large amount of instrumentation and monitoring equipment involved. The cost of technique implementation may vary widely, however, due to the plant specific variations in procedures regarding permanent installation of Type A test instrumentation.

All necessary instrumentation and equipment is available commercially since the equipment is identical to that used in current Type A tests. Some difficulties with long term reliability of dewcells may exist based on the frequent dewcell failure experienced during Type A testing.

METHOD 8: Tracer Gas Mass-Concentration Correlation

A tracer gas is initially introduced into containment and the resulting mass concentration and total amount of gas introduced is accurately measured. The correlation between the introduced tracer amount and the mass concentration is a direct measure of the total air mass within the containment. Subsequent introductions of measured amounts of tracer and the resulting change in mass concentration will give measures of the air mass at any given time. The total change in air mass over a period of time can then be used to determine the average leakage rate.

This method is insensitive to humidity, temperature and pressure changes within containment and no correction for or measurement of these values is needed.

The required instrumentation and commercial availability is identical to the trace gas dilution method discussed in method 2, with the exception of the need for a integrating linear mass flow meter to accurately measure the tracer usage. Such meters are commercially available for all conceivable tracer gases.

METHOD 9: Differential Trace Gas Concentration Measurement

This method is extremely similar in operation to the trace gas mass-concentration correlation method just described but provides a decreased sensitivity to instrument air and humidity at the cost of reduced accuracy. With this technique, a trace gas is introduced into containment to achieve an approximate predetermined concentration (about 1000 ppm). The amount of tracer required to achieve this concentration is accurately measured. After a suitable time to allow mixing, the concentration of the tracer is measured. At intervals when total leakage is to be determined, a small, measured amount of tracer is introduced into containment. The resulting tracer concentration before and after addition of the new amount may be used to determine the total mass of tracer remaining in containment. The ratio of this total mass remaining as compared to the total mass introduced is a direct measure of total integrated leakage.

This method appears completely insensitive to various air inleakages (such as instrument air usage), pressure, temperature and humidity. The primary drawbacks foreseen are the finite life of the system caused by the ever increasing level of tracer and the limitations imposed by the accuracy of tracer concentration measurement. Accuracy of this method is considerably less than the previous method due to the use of a deviation from an expected differential concentration to determine the total enclosed mass.

The availability of the necessary equipment is identical to the tracer gas mass-concentration correlation described in Method 8.

METHOD 10: Differential Air Mass Injection

This method determines the total amount of air within containment by measuring the change in containment pressure resulting from the introduction into containment of a measured mass of air. Air may be either injected or withdrawn from containment. An integrating mass flow meter may be used to determine the total amount of air injected.

This system is sensitive to overall humidity levels but is sensitive to only those temperature changes which occur during the air injection time. By using both injection and withdrawal of air, the method may be used over long periods of time without overpressurizing the containment.

The method is applicable to all plant types.

Equipment and instrumentation to implement this method is commercially available. The need for a compressor capable of injecting large amounts of air over relatively short times could make equipment costs among the highest of any method.

METHOD 11: Nitrogen Usage Monitor

This method is analogous to the continuous air injection technique described for PWRs but is designed for use with nitrogen inerted containments. With this method, nitrogen pressure is maintained in the containment at a low positive

-A6-

pressure sufficient to promote flow through existing leak paths, but within tech spec limits. Monitoring of the nitrogen usage with an integrating flow meter over extended time gives the average leakage rate. In this form, this method, does not compensate for changes in humidity and air temperature.

Addition of small amounts of temperature and dew point instrumentation could significantly increase sensitivity with a corresponding penalty in terms of cost and system complexity.

Since inerted containments use internally sourced nitrogen or tank boil-off for instrument air, accounting for its use should not be difficult.

This method is applicable to all nitrogen inerted containments.

Equipment needed to implement this method consists of an integrating linear mass flow meter, which is commercially available. Some operating plants may already have this equipment installed to monitor nitrogen usage for economic reasons.

APPENDIX B
IMATRIX CATEGORY DEFINITION

Position	Category	PNL Field Name	PNL Categories
Containment Type	1. PWR Large Dry	CISCLASS	Class 1. PWR Large Dry Containment Class 3. PWR Dual (Double) Containment
	2. PWR Subatmospheric		Class 2. PWR Subatmospheric Containment
	3. PWR Ice Condenser		Class 4. PWR Ice Condenser Containment
	4. BWR Mk I		Class 5. BWR Mark I Containment
	5. BWR Mk II		Class 6. BWR Mark II Containment
	6. Other		Class 8. Other CIS Note: Specific plants included in this category were Big Rock Point, Dresden 1, LaCrosse, Indian Point 1, San Onofre 1, and Yankee Rowe.
Equipment Type	0. Valve-No Subtype	TYPESUB1	None
	1. Valve-Electrical		A - Electric Motor Operated (AC) B - Electric Motor Operated (DC) E - Solenoid Operated (AC) F - Solenoid Operated (DC) K - Electric motor operated (unspecified) L - Solenoid Operated (unspecified) N - Remotely Operated
	2. Valve-Mechanical		C - Hydraulic Operated D - Pneumatic Diaphragm/cylinder operated G - Float Operated H - Explosive Squib Operated J - Mechanically Operated M - Manually Operated

Position	Category	PNL Field Name	PNL Categories
	3. Valve-Other		P - Damper Q - Vacuum Breaker R - Relief or Safety S - Check X - Other
	4. Penetration-No Subtype		None
	5. Personnel Hatch 6. Equipment Hatch		A - Personal Access C - Equipment Access G - Access (unspecified)
	7. Electrical Penetration 8. Inst/Process Line Pene.		D - Electrical E - Instrument Line F - Process Piping
	9. Penetration-Other		X - Other
Failure Mode	0. None Assigned 1. Leakage 2. Fail to Close 3. Unplanned Opening	MODE	None A - Leakage (fail to seal) B - Fail to Close C - Unplanned Opening (fail to remain closed)
Cause	0. None Assigned	CAUSEPRI	None
	1. Personnel/Procedure		01 - Personnel (Operation) 02 - Personnel (Maintenance) 03 - Personnel (Testing) 06 - Procedural Discrepancy

Position	Category	PNL Field Name	PNL Categories
	2. Design/Construction		04 - Design Error 05 - Fabrication/Construction/QC 32 - Personnel (Construction)
Cause	3. Mechanical	CAUSEPRI	12 - Mechanical Control/Parts; failed or out of adjustment 13 - Seal/Gasket Fail/Problem 14 - Packing Fail/Prob. 15 - Bellows/Boot Fail/Prob. 17 - Bearing/Bushing Fail/Prob. 18 - Weld Failure 19 - Lack of Lubrication 22 - Leaking/Ruptured Diaphragm 24 - Failure of Component Supply System (air supply interrupt) 25 - Seat/Disc Fail/Prob. 27 - Pilot Valve Fail/Prob. 28 - Air Solenoid Fail/Prob. 29 - Solenoid (unspecified) Fail/Prob. 30 - Operator (unspecified) Fail/Prob. 31 - Penetration Sealant Fail/Prob. 33 - Rupture 34 - Equalizing Valve (on airlock) Fail/Prob. 35 - Hydraulic Operator Fail/Prob.
	4. Electrical		16 - Electrical Input Fail/Prob. (electrical power interrupt) 20 - Electric motor operator Fail/Prob. 21 - Electric Solenoid Fail/Prob. 23 - Torque Switch Fail/Prob. 26 - Limit Switch Fail/Prob.
	5. Environmental/Process		07 - Normal Wear 08 - Excessive Wear 09 - Corrosion 10 - Foreign Material Contamination 11 - Excessive Vibration
	6. Unknown		00 - Unknown

APPENDIX C
Data Base Corrections, Changes, Deletions

The following is a brief summary of all corrections, changes and deletions made to the PNL data base as they were discovered during the parameter assignment phase and subsequent search efforts. The record number is the sequential number of each of the original 1858 records stored in the data base.

Record No.	Change Description
22	Mode changed from none assigned to B, Fail to Close
40	Typemain changed from X(?) to V (valve replaced)
141	Doesn't appear to belong in the data base; assigned "Immediate Detection"
229	NSSS vendor changed to C
230	NSSS vendor changed to C
258	NSSS vendor changed to B
259	NSSS vendor changed to B
268	NSSS vendor changed to B Failure mode changed from b to B
290	NSSS vendor changed to B
291	NSSS vendor changed to B
325	NSSS vendor changed to B
327	NSSS vendor changed to B
328	NSSS vendor changed to B
383	CISCLASS changed to 4, not 1
416	Typemain changed to P, consistent with #417
449	Doesn't appear to belong in the data base; assigned "Immediate Detection"
451	CISCLASS changed to 5, not 8
482-486	NSSS vendor changed to G
504	Failure mode changed from a to A
519	Doesn't appear to belong in the data base; assigned "Immediate Detection"
543	Failure Mode of D (?, failed to open) deleted, consistent with #545. Also, a discrepancy in failure # (2 or 3 in code and comments sections) noted
545	No failure mode assigned--fail to open--left as-is
568	Failure mode changed to C
600	Typemain changed to V, for data base consistency
629	Typemain changed to V
654	Failure mode blank, changed to B
699	Reactor type changed from p to P
741	Typemain changed to V
769	Typemain changed to P
808	NSSS vendor changed to W
827	Reactor type changed to B NSSS vendor changed to G

-C1-

845	Failure mode changed from a to A
852	NSSS vendor changed to C
859	NSSS vendor changed to C
860	NSSS vendor changed to C Reactor type changed from p to P
938	NSSS vendor changed to C Failure mode changed to B
939	NSSS vendor changed to C
940	CISCLASS changed to 2
961	Deleted from data base; 29 spare pipe penetrations found uncapped at one end and fixed--no applicable leakage or breach though undetected for years
980	Mode B deleted; another fail to open event
984	Deleted from data base; entire record garbled
1040	Reactor type changed to B NSSS vendor changed to G
1044	Reactor type changed to B NSSS vendor changed to G
1052	Failure mode changed to B
1087	NSSS vendor changed to B
1089	CISCLASS changed to 1
1144	NSSS vendor changed to C
1156	Typemain changed to V
1157	Typemain changed to V
1204	Failure mode changed to A
1293	Wrong system designator noted, though right label indeterminate
1301	Failure mode changed from a to A
1315	Failure mode changed to B
1322	CISCLASS changed to 1; reactor type changed to P; NSSS vendor changed to W
1367	Doesn't appear to belong in the data base; assigned "Immediate Detection"
1369	Doesn't appear to belong in the data base; assigned "Immediate Detection"
1400	Doesn't appear to belong in the data base; assigned "Immediate Detection"
1424	Failure mode deleted (not A); another fail to open event
1433	Failure mode changed to C
1437	Failure mode changed to B
1462	NSSS vendor changed to B
1472	Failure mode deleted (not C); another fail to open event
1479	Failure mode changed to B
1542	Failure mode changed to B
1561	Failure mode deleted (not C); fail to open event
1565	CISCLASS changed to 4 Failure mode changed to B

-C2-

1607	NSSS vendor changed to W
1608	Failure mode changed to C
1624	Deleted; reason similar to #961
1625	Deleted; reason similar to #961
1644	Failure mode changed to B
1674-76	NSSS vendor changed to B
1696	Failure mode changed to C
1800	Failure mode changed to B
1808	Reactor type changed to P
1809	Reactor type changed to P
1851	CISCLASS changed to 1

-C3-

APPENDIX D

EXAMPLES OF MULTIDIMENSIONAL SUMMARY/ANALYSIS TABLES

-D2-

9/4/86

All Groups		Group Totals All		PWR Large Dry			PWR Subatmospheric			PWR Ice Condenser			BWR Mark I			BWR Mark II			Other ([illegible])			All	Dates	Causes
		[illegible]	Areas	2 Valves	2 [illegible]	Total	U	P	T	U	P	T	U	P	T	U	P	T	U	P	T	Totals		
		1/1	1/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	1/1	3/1	0/0	0/0	0/0	0/0	1/1	1/1	4/3	0-3	(1) Mechanical
		[illegible]	6/6	3/3	1/1	3/4	1/1	0/0	1/1	0/0	0/0	0/0	[illegible]	[illegible]	[illegible]	0/0	0/0	0/0	1/1	1/1	1/2	[illegible]	3-4	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0/0	1/1	1/1	[illegible]	0/0	[illegible]	[illegible]	1/6	[illegible]	0/0	0/0	0/0	[illegible]	6/6	[illegible]	[illegible]	4-5	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6/6	[illegible]	[illegible]	0/0	[illegible]	0/0	0/0	0/0	[illegible]	[illegible]	[illegible]	[illegible]	5-6	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0/0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7-8	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0/0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Totals	
		[illegible]	2/2	0/0	1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	1/1	0/0	0/0	1/0	4/3	1/1	[illegible]	7/6	0-3	(2) [illegible]
		[illegible]	13/11	[illegible]	0/5	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	[illegible]	[illegible]	[illegible]	0/0	0/0	0/0	3/3	1/1	[illegible]	[illegible]	4	
		6/5	3/3	1/1	0/2	3/3	0/0	0/0	0/0	0/0	0/0	0/0	0/2	1/1	3/3	0/0	0/0	0/0	3/2	0/0	3/2	[illegible]	5	
		[illegible]	0/2	11/6	0/1	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	[illegible]	0/0	[illegible]	0/0	0/0	0/0	3/2	1/1	[illegible]	[illegible]	6	
		[illegible]	[illegible]	[illegible]	3/3	[illegible]	[illegible]	1/1	[illegible]	[illegible]	3/3	[illegible]	[illegible]	0/0	[illegible]	3/3	0/0	3/3	1/1	0/0	1/1	[illegible]	7-8	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/1	[illegible]	[illegible]	3/3	[illegible]	[illegible]	6/6	[illegible]	3/3	0/0	3/3	[illegible]	3/3	[illegible]	[illegible]	Totals	
		0/0	1/0	0/0	0/0	1/0	0/0	0/0	1/0	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0-3	(3) Manual/Procedural
		0/0	[illegible]	0/0	0/0	0/0	0/0	[illegible]	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/2	[illegible]	1/2	4	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/1	0/0	1/1	0/0	0/0	0/0	[illegible]	0/0	[illegible]	0/0	0/0	0/0	0/0	[illegible]	0/0	[illegible]	5	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0/0	1/1	1/1	[illegible]	0/0	[illegible]	[illegible]	[illegible]	[illegible]	0/0	0/0	0/0	0/0	0/0	[illegible]	[illegible]	6	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/1	[illegible]	[illegible]	0/0	[illegible]	0/0	0/0	0/0	[illegible]	7-8	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6/6	[illegible]	[illegible]	1/0	[illegible]	0/0	[illegible]	[illegible]	[illegible]	Totals	
		0/0	1/0	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0/0	1/0	0/1	0/0	1/0	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0-3	(4) Design/Construction
		1/1	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	1/1	0/0	0/0	0/1	0/0	1/1	1/1	1/1	4	
		1/1	1/1	1/1	1/1	[illegible]	1/1	0/0	[illegible]	0/0	0/0	0/0	0/0	1/0	0/0	0/0	0/0	0/0	0/0	1/1	1/1	1/1	5	
		1/1	1/1	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	1/1	6	
		[illegible]	[illegible]	0/0	3/3	[illegible]	0/0	0/0	0/0	1/1	0/0	1/1	1/1	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	[illegible]	7-8	
		[illegible]	[illegible]	1/1	[illegible]	[illegible]	0/0	0/0	0/0	1/1	0/0	1/1	[illegible]	0/0	[illegible]	0/0	0/0	0/1	0/0	0/0	1/1	[illegible]	Totals	
		0/0	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0-3	(5) Electrical
		1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1	0/0	1/1	0/0	0/0	0/0	0/0	0/0	0/0	1/1	4	
		3/3	0/0	1/1	0/0	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	3/3	0/0	3/3	0/0	0/0	0/0	0/0	0/0	0/0	3/3	5	
		[illegible]	1/1	1/1	1/1	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	3/2	0/0	3/2	0/0	0/0	0/0	0/0	0/0	0/0	[illegible]	6	
		[illegible]	1/1	3/3	0/0	3/3	0/0	1/1	1/1	0/0	0/0	0/0	5/3	0/0	5/3	1/1	0/0	1/1	0/0	0/0	0/0	10/8	7-8	
		[illegible]	[illegible]	[illegible]	1/1	1/6	0/0	1/1	1/1	[illegible]	0/0	0/0	[illegible]	0/0	[illegible]	1/1	0/0	[illegible]	0/0	0/0	0/0	[illegible]	Totals	
0-3	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0-3	(6) Environmental
4	[illegible]	[illegible]	0/0	[illegible]	0/0	[illegible]	0/0	0/0	0/1	0/0	0/0	0/0	[illegible]	0/0	[illegible]	0/0	0/0	0/0	0/0	0/0	0/0	[illegible]	4	
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0/0	[illegible]	0/0	0/0	0/0	[illegible]	0/0	[illegible]	0/0	0/0	0/0	[illegible]	0/0	[illegible]	[illegible]	5	
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0/0	[illegible]	0/0	[illegible]	1/1	[illegible]	1/1	[illegible]	0/0	0/0	[illegible]	[illegible]	[illegible]	1/1	[illegible]	6	
7-8	[illegible]	[illegible]	3/3	[illegible]	1/0	[illegible]	[illegible]	1/1	[illegible]	3/3	1/1	[illegible]	[illegible]	0/0	[illegible]	0/0	0/0	1/0	0/0	1/1	1/1	[illegible]	7-8	
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1/1	[illegible]	3/3	[illegible]	[illegible]	[illegible]	1/1	[illegible]	[illegible]	[illegible]	1/0	[illegible]	1/1	[illegible]	[illegible]	Totals	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL	

-D3-

-D2-

APPENDIX B

LETTER FROM BARRY L. SPLETZER, SANDIA NATIONAL LABORATORIES, TO ALECK SERKIZ, U.S. NUCLEAR REGULATORY COMMISSION, DATED DECEMBER 22, 1986

Sandia National Laboratories
Albuquerque, New Mexico 87185

December 22, 1986

Mr. Aleck Serkiz
Reactor Safety Issues Branch
Division of Safety Review and Oversight
U. S. Nuclear Regulatory Commission
7920 Norfolk - Phillips Bldg.
Bethesda, MD 20555

Dear Mr. Serkiz:

In an October 24, 1986, letter to you, we summarized the scope and approach we would take for additional information and searches which you requested following completion of Subtask 3.1 of FIN A1802. This letter is a summary of that effort and provides the results obtained in tabular form.

Searches were made on the PNL "reduced data base" (as explained in the letter report for Subtask 3.1) for the following parameters:

1. Plant system in which leakage events occurred
2. Determination of the existence of a direct air path outside containment for each event (as explained below).
3. Existing tests capable of detecting the event
4. Approximate size of any leak paths

Searches of all possible combinations of the above four parameters were generated, as appropriate. No new information was identified or categorical judgments made on the data base beyond that reported in Subtask 3.1. The following is a summary of the categories selected for each parameter to complete the required searches:

Plant Systems	Alternate Test Methods	Existing Test Methods	Leak Size
No categories (see discussion below)	All Events (All)	All Events	All Events
	No Methods (0)	A and B	Small
	All Alt. Methods (123)	A and C	Large
			Very Large
			Indeterminate

All plant systems were individually listed in the event searches to obtain the desired number of events by system. Due to the sequential listing of systems in the search output, it was possible to break down the results into PWR and BWR system groups, including an "unknown" category which includes both PWR and BWR systems.

We assumed that those events categorized as being detectable by any of the alternate test methods was generally indicative of the existence of a direct air path from containment. To display the search results, this parameter was categorized into 1) all events, 2) no methods applicable (probably not a direct air path), and 3) events detectable by alternate test methods. The first category is the sum of the second and third.

The existing test methods parameter was categorized as outlined and explained in the final letter report for Subtask 3.1. Categories chosen for this search effort included 1) all events, 2) events detectable by Type A and B tests, and 3) those detectable by Type A and C test methods. The Type A only events--a total of 25--can be deduced by difference from these categories.

Finally, leak size was tabulated for the familiar small, large, very large, and indeterminate categories. The sum of these, or all events, was also tabulated as a separate category.

Table 1 provides a comprehensive multidimensional summary of the results of all searches according to the parameters and categories summarized above. Note that the final total is the sum of "unknown," PWR systems, and BWR systems. Table 2 is a summary of a subset of selected systems that were judged to most likely involve direct air path leak events. Table 3 provides a further condensation of results
including those events in the "direct air" column only. Finally, Table 4 is simply another summary which includes all events irrespective of the system. Note that all blanks not filled in are zeros, with no events applicable.

General observations are as follows:

1) The system "unknown" and BWR or PWR "other" categories included a significant portion of all events -- over 60% for the totals in the data base.

2) There is no dominant PWR system of interest which includes a large number of historical leak events. Reactor coolant, service water, steam generator, and containment purge (unspecified) were the only significant items that standout.

3) In contrast, main steam (MSIV's) is a dominant category for BWR system events. A high percentage of these (80%) are indeterminate in leak size. Containment HVAC and main feedwater system-related events are distant seconds.

4) The direct air systems in PWR's involve about 20% of all events. In BWR's the percentage is about the same.

5) Most of the direct air system events were detectable by existing Type A and C tests (90%) in contrast to Type A and B tests. Over 65% were of indeterminate leakage.

6) From Table 3, when "direct air events" are considered only, then, for PWR's, the fraction of all events is over 35%; for BWR's, the fraction is only 14%.

7) From Table 3, when also considering the selected "direct air systems" in combination with the "direct air events," the totals drop significantly for those events detected by Type A and B tests. Whereas, the Type A and C events are still a significant fraction of the totals in the first half of the Table.

8) Over 80% of the Type A and B events were of indeterminate leakage and over 75% were in the unknown system category. For Type A and C, 70% are indeterminate; over 33% are in the unknown category.

9) No new observations were noted with respect to leak size and the large "indeterminate" category.

This concludes the summary of the additional work outlined in the October 24 letter. In accordance with that letter and other letters which provided our cost/schedule for closeout of FIN A1802, we have now completed all work associated with the project.

Sincerely,

Barry L. Spletzer
Adverse Environment Safety
Assessment Division 6447

Copy to:
NRC W. Minners
NRC G. Marzetis
6440 D. A. Dahlgren
6440 D. [illegible]
6447 D. L. Berry

Existing Test Methods	A & B					A & C				
Leak Rate	Small	Large	Very Large	Indet.	Total	Small	Large	Very Large	Indet.	Total
Unknown Systems	16	4	22	245	287	1	3	0	10	14
PWR Systems	13	1	6	62	82	15	8	6	43	72
BWR Systems	2	0	0	7	9	13	8	4	44	69
Total	31	5	28	314	378	29	19	10	97	155
* PWR Direct Air Systems	0/0	0/0	0/0	16/16	16/16	8/3	16/8	4/4	44/28	72/43
BWR Direct Air Systems	0/0	0/0	0/0	1/1	1/1	28/9	10/8	4/4	74/33	116/54
Total	0/0	0/0	0/0	17/17	17/17	36/12	26/16	8/8	118/61	188/97

*The first number is all alternate methods; the second is the events detected by methods 1, 2, or 3 as in the first half of this table.

TABLE 3 DIRECT AIR EVENTS ONLY
(Alt. Method - 1 2 3)

Existing Test Methods	All			A & B			A & C		
Alt. Test Methods	All	0	123	All	0	123	All	0	123
Leak Rate =									
All	2192	1638	554	382	4	378	1785	1630	155
Small	417	355	62	31	0	31	383	354	29
Large	162	138	24	5	0	5	157	138	19
Very Large	41	3	38	29	1	28	12	2	10
Indeterminate	1569	1139	430	317	3	314	1230	1133	97

TABLE 4 EVENT SUMMARY WITHOUT SYSTEM BREAKDOWN

Existing Test Methods	All Tests (A,B,C)														
Leak Rate	Small			Large			Very Large			Indet.			Total		
Alternate Test Methods (123 – direct air path)	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
Unknown (BWR and PWR)	199	182	17	87	80	7	23	1	22	860	593	267	1169	856	313
Reactor Coolant	5	2	3	1	1					13	8	5	19	11	8
Main Steam	3	3		0	0					5	5	0	8	8	0
High Pressure Inj/Recirc	1	1		1	1					0	0	0	2	2	0
Low Pressure Inj/Recirc										0	0	0	0	0	0
Instrument Air	2		2	2	2					5	3	2	9	5	4
Service Air	3	3		1	1					5	0	5	9	4	5
Air (Unspecified)	1		1	1	1					2	0	2	4	1	3
Service Water	1	1		1	1					28	28	0	30	30	0
Residual Heat Remover	1	1								1	0	1	2	1	1
Containment HVAC				4	2	2				6	0	6	10	2	8
Containment Pressure	1		1	1	1					5	3	2	7	4	3
Integrated Leak Rate Test				4	4					1	0	1	5	4	1
Fire Protection				0	0					0	0	0	0	0	0
Containment Atmosphere	1	1		5	4	1				10	3	7	16	8	8
Component Cooling Water	7	7		1	1					8	7	1	16	15	1
Radwaste										2	2	0	2	2	0
Containment Waste Gas										3	2	1	3	2	1
Main Feedwater										5	3	2	5	3	2
Aux Feedwater										0	0	0	0	0	0
Pressurizer							1	0	1	6	2	4	7	2	5
Safety Injection										2	2	0	2	2	0
Demineralized Water										3	2	1	3	2	1
Containment Sump	3	3								7	4	3	10	7	3
Steam Generator				3	3		1	0	1	24	21	3	28	24	4
Cont. Large Volume Purge										1	0	1	1	0	1
Cont. Small Volum. Purge										0	0	0	0	0	0
Cont. Hydrogen Purge	3	3		1		1				5	4	1	9	7	2
Cont. Purge (unspec)	4	1	3	3	1	2	4	0	4	31	4	27	42	6	36
Nitrogen Supply	2	2								5	3	2	7	5	2
Cont. Spray	1	1								4	1	3	5	2	3
Chemical Volume Control										2	1	1	2	1	1
Refueling Canal				2		2				1	1	0	3	1	2
Cont. Instrumentation (elec.)										1	0	1	1	0	1
Other	71	51	20	1		1	6	0	6	101	74	27	179	125	54
PWR Sub Total	110	80	30	32	23	9	12	0	12	292	183	109	446	286	160

Existing Test Methods	A and B														
Leak Rate	Small			Large			Very Large			Indet.			Total		
Alternate Test Methods (123 – direct air path)	All	0	123	All	0	123	All	0	123	All	0	123	All	0	1[illegible]
Unknown (BWR and PWR)	16		16	4		4	23	1	22	248	3	245	291	4	2[illegible]
Reactor Coolant	2		2							4		4	6	0	
Main Steam	0												0	0	
High Pressure Inj/Recirc	0												0	0	
Low Pressure Inj/Recirc	0												0	0	
Instrument Air	0												0	0	
Service Air	0									5		5	5	0	
Air (Unspecified)	1		1							0		0	1	0	
Service Water	0									0		0	0	0	
Residual Heat Remover	0									1		1	1	0	
Containment HVAC										2		2	2	0	
Containment Pressure										1		1	1	0	
Integrated Leak Rate Test										1		1	1	0	
Fire Protection										0		0	0	0	
Containment Atmosphere										6		6	6	0	
Component Cooling Water													0	0	
Radwaste													0	0	
Containment Waste Gas													0	0	
Main Feedwater													0	0	
Aux Feedwater													0	0	
Pressurizer							1		1	2		2	3	0	
Safety Injection										0		0	0	0	
Demineralized Water										0		0	0	0	
Containment Sump										0		0	0	0	
Steam Generator							1		1	3		3	4	0	
Cont. Large Volume Purge										0		0	0	0	
Cont. Small Volum. Purge										0		0	0	0	
Cont. Hydrogen Purge										0		0	0	0	
Cont. Purge (unspec)										7		7	7	0	
Nitrogen Supply										2		2	2	0	
Cont. Spray										3		3	3	0	
Chemical Volume Control										0		0	0	0	
Refueling Canal										0		0	0	0	
Cont. Instrumentation (elec.)										1		1	1	0	
Other	10		10	1		1	4		4	24		24	39	0	
PWR Sub Total	13	0	13	1	0	1	6	0	6	62	0	62	82	0	

Table 1 - Multidimensional Search Summary

Indet.		Total			A and B															A and C														
					Small			Large			Very Large			Indet.			Total			Small			Large			Very Large			Indet.			Total		
0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
593	267	1169	856	313	16		16	4		4	23	1	22	248	3	245	291	4	287	183	182	1	83	80	3				599	589	10	865	851	14
8	5	19	11	8	2		2							4		4	6	0	6	3	2	1	1	1					9	8	1	13	11	2
5	0	8	8	0	0												0	0	0	3	3	0	0	0					5	5	0	8	8	0
0	0	2	2	0	0												0	0	0	1	1	0	1	1					0	0	0	2	2	0
0	0	0	0	0	0												0	0	0	0	0	0	0						0	0	0	0	0	0
3	2	9	5	4	0												0	0	0	2	0	2	2	2					5	3	2	9	5	4
0	5	9	4	5	0									5		5	5	0	5	3	3	0	1	1					0	0	0	4	4	0
0	2	4	1	3	1		1							0		0	1	0	1	0	0	0	1	1					[illegible]	0	2	3	1	2
28	0	30	30	0	0									0		0	0	0	0	1	1	0	1	1					28	28	0	30	30	0
0	1	2	1	1	0									1		1	1	0	1	1	1	0	0	0					0	0	0	1	1	0
0	6	10	2	8										2		2	2	0	2	0	0		4	2	2				4	0	4	8	2	6
3	2	7	4	3										1		1	1	0	1	0	0		1	1					3	2	1	4	3	1
0	1	5	4	1										1		1	1	0	1	0	0		4	4					0	0	0	4	4	0
0	0	0	0	0										0		0	0	0	0	0	0		0	0					0	0	0	0	0	0
3	7	16	8	8										6		6	6	0	[illegible]	1	1		5	4	1				4	3	1	10	8	2
7	1	16	15	1													0	0	0	7	7		1	1	0				7	7	0	15	15	0
2	0	2	2	0													0	0	0										2	2	0	2	2	0
2	1	3	2	1													0	0	0										3	2	1	3	2	1
3	2	5	3	2													0	0	0										4	2	2	4	2	2
0	0	0	0	0													0	0	0										0	0	0	0	0	0
2	4	7	2	5							1		1	2		2	3	0	3										4	2	2	4	2	2
2	0	2	2	0										0		0	0	0	0										2	2	0	2	2	0
2	1	3	2	1										0		0	0	0	0										2	2	C	2	2	0
4	3	10	7	3										0		0	0	0	0	3	3								7	4	3	10	7	3
21	3	28	24	4							1		1	3		3	4	0	4				3	3	0				21	21	0	24	24	0
0	1	1	0	1										0		0	0	0	0	0	0		0	0					1	0	1	1	0	1
0	0	0	0	0										0		0	0	0	0	0	0		0	0					0	0	0	0	0	0
4	1	9	7	2										0		0	0	0	0	3	3		1	0	1				5	4	1	9	7	2
4	27	42	6	36										7		7	7	0	7	4	1	3	3	1	2	4	0	4	23	4	19	34	6	28
3	2	7	5	2										2		2	2	0	2	2	2		0	0					3	3	0	5	5	0
1	3	5	2	3										3		3	3	0	3	1	1		0	0					1	1	0	2	2	0
1	1	2	1	1										0		0	0	0	0	0	0		0	0					2	1	1	2	1	1
1	0	3	1	2										0		0	0	0	0	0	0		2	0	2				1	1	0	3	1	2
0	1	1	0	1										1		1	1	0	1	0	0		0	0					0	0	0	0	0	0
74	27	179	125	54	10		10	1		1	4		4	24		24	39	0	39	59	50	9	0	0		2	0	2	[illegible]	74	2	127	124	13
183	109	446	286	160	13	0	13	1	0	1	6	0	6	62	0	62	82	0	82	94	79	15	31	23	8	6	0	6	224	181	43	[illegible]	283	72

Table 1 - Multidimensional Search Summary

Existing Test Methods	All Tests (A,B,C)														
Leak Rate	Small			Large			Very Large			Indet.			Total		
Alternate Test Methods (123 - direct air path)	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
Reactor Coolant	4	4	0	0						18	17	1	22	21	1
Main Steam -	23	21	2	17	17		2	2	0	180	170	10	222	210	12
High Pressure Inj/Recirc	5	5	0	1	1					14	13	1	20	19	1
Low Pressure Inj/Recirc	1	1	0	0						1	1	0	2	2	0
Instrument Air	0	0	0	0						0	0	0	0	0	0
Service Air	1	1	0	0						3	2	1	4	3	1
Air (unspec)	0	0	0	0						0	0	0	0	0	0
Service Water	5	5	0	2	2					0	0	0	7	7	0
Residual Heat Removal	2	2	0	2	2					12	11	1	16	15	1
Containment HVAC	1	0	1	4	1	3				26	9	17	31	10	21
Drywell Pressure	1	1	0							0	0	0	1	1	0
Integrated Leak Rate Test	0	0	0							1	0	1	1	0	1
Fire Prot.	0	0	0							0	0	0	0	0	0
Drywell Atmosphere	5	4	1	2	0	2				9	7	2	16	11	5
Component Cooling Water	0	0	0							0	0	0	0	0	0
Radwaste	0	0	0							3	3	0	3	3	0
Drywell Waste Gas	0	0	0							1	1	0	1	1	0
Main Feedwater	10	10	0	5	5					27	27	0	42	42	0
Aux Feedwater	0	0	0		0					0	0	0	0	0	0
Reactor Core Isolation Cooling	5	5	0	1	1					11	10	1	17	16	1
Standby Liquid Control	0	0	0	1	1					2	2	0	3	3	0
Reactor Cleanup	4	2	2	3	3					17	16	1	24	21	3
Drywell Purge	5	5	0	0	0		3	0	3	9	2	7	17	7	10
Drywell Vent	6	3	3	3	1	2				4	1	3	13	5	8
Drywell Equip. Sump	1	1	0	1	1					3	3	0	5	5	0
Drywell Floor Sump	1	1	0							1	1	0	2	2	0
Drywell Pump (unspec)	1	1	0							20	19	1	21	20	1
Control Rod Drive	11	11	0							1	1	0	12	12	0
Core Spra	0	0	0							10	10	0	10	10	0
Vessel Head Spray	1	1	0							0	0	0	1	1	0
Containment Cooling	0	0	0							1	1	0	1	1	0
Traversing Incore Probe	3	1	2							2	1	1	5	2	3
Wetwell Vent	8	6	2							11	10	1	19	16	3
Vacuum Relief	2	0	2				1	0	1	9	7	2	12	7	5
Drywell Instrumentation (elec.)	0	0	0							0	0	0	0	0	0
Wetwell Instrumentation (elec.)	1	1	0							6	6	0	7	7	0
Nitrogen Supply	1	1	0							8	8	0	9	9	0
Wetwell Purge	0	0	0	1	0	1				7	4	3	8	4	4
Other	0	0	0							0	0	0	0	0	0
BWR Subtotal	108	93	15	43	35	8	6	2	4	417	363	54	574	493	81
Total	417	355	62	162	138	24	41	3	38	1569	1139	430	2189	1635	554

Existing Test Methods	A and B													
Leak Rate	Small			Large			Very Large			Indet.			Total	
Alternate Test Methods (123 - direct air path)	All	0	123	All	0	123	All	0	123	All	0	123	All	0
Reactor Coolant										0		0	0	0
Main Steam -	2		2							6		6	8	0
High Pressure Inj/Recirc										0		0	0	0
Low Pressure Inj/Recirc										0		0	0	0
Instrument Air										0		0	0	0
Drywell Atmosphere										1		1	1	0
BWR Subtotal	16	0	2	0	0	0	0	0	0	9	0	7	9	0
Total	31	0	31	5	0	5	29	1	28	317	3	314	382	4

)

						A and B															A and C														
Indet.			Total			Small			Large			Very Large			Indet.			Total			Small			Large			Very Large			Indet.			Total		
All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
18	17	1	22	21	1										0		0	0	0	0	4	4		0	0					18	17	1	22	21	1
180	170	10	222	210	12	2		2							6		6	8	0	8	21	21		17	17		2	2	0	174	170	4	214	210	4
14	13	1	20	19	1										0		0	0	0	0	5	5		1	1					14	13	1	20	19	1
1	1	0	2	2	0										0		0	0	0	0	1	1		0	0					1	1	0	2	2	0
0	0	0	0	0	0										0		0	0	0	0	0	0		0	0					0	0	0	0	0	0
3	2	1	4	3	1																1	1		0	0					2	2	0	3	3	0
0	0	0	0	0	0																0	0		0	0					0	0	0	0	0	0
0	0	0	7	7	0																5	5		2	2					0	0	0	7	7	0
12	11	1	16	15	1																2	2		2	2					11	[illegible]	0	15	15	0
26	9	17	31	10	21																1	0	1	4	1	3				26	9	17	31	10	21
0	0	0	1	1	0																1	1		0	0					0	0	0	1	1	0
1	0	1	1	0	1																0	0		0	0					1	0	1	1	0	1
0	0	0	0	0	0																0	0		0	0					0	0	0	0	0	0
9	7	2	16	11	5										1		1	1	0	1	5	4	1	2	0	2				8	7	1	15	11	4
0	0	0	0	0	0																0	0		0	0					0	0	0	0	0	0
3	3	0	3	3	0																0	0		0	0					3	3	0	3	3	0
1	1	0	1	1	0																0	0		0	0					1	1	0	1	1	0
27	27	0	42	42	0																10	10		5	5					27	27	0	42	42	0
0	0	0	0	0	0																0	0		0	0					0	0	0	0	0	0
11	10	1	17	16	1																5	5		1	1					11	10	1	17	16	1
2	2	0	3	3	0																0	0		1	1					2	2	0	3	3	0
17	16	1	24	21	3																4	2	2	3	3					17	16	1	24	21	3
9	2	7	17	7	10																5	5		0	0		3	0	3	9	2	7	17	7	10
4	1	3	13	5	8																6	3	3	3	1	2				4	1	3	13	5	8
3	3	0	5	5	0																1	1		1	1					3	3	0	5	5	0
1	1	0	2	2	0																1	1								1	1	0	2	2	0
20	19	1	21	20	1																1	1								20	19	1	21	20	1
1	1	0	12	12	0																11	11								1	1	0	12	12	0
10	10	0	10	10	0																0	0								10	10	0	10	10	0
0	0	0	1	1	0																1	1								0	0	0	1	1	0
1	1	0	1	1	0																0	0								1	1	0	1	1	0
2	1	1	5	2	3																3	1	2							2	1	1	5	2	3
11	10	1	19	16	3																8	6	2							11	10	1	19	16	3
9	7	2	12	7	5																2	0	2				1	0	1	8	7	1	11	7	4
0	0	0	0	0	0																0	0								0	0	0	0	0	0
6	6	0	7	7	0																1	1								6	6	0	7	7	0
8	8	0	9	9	0																1	1								8	8	0	9	9	0
7	4	3	8	4	4																0	0	0	1	0	1				7	4	3	8	4	4
0	0	0	0	0	0																0	0	0							0	0	0	0	0	0
417	363	54	574	493	81	16	0	2	0	0	0	0	0	0	9	0	7	9	0	9	106	93	13	43	35	8	6	2	4	407	363	[illegible]	[illegible]	493	69
569	1139	430	2189	1635	554	31	0	31	5	0	5	29	1	28	317	3	314	382	4	378	383	354	29	157	138	19	12	2	10	1230	1133	[illegible]	1782	1627	155

Existing Test Methods	All Tests (A,B,C)														
Leak Rate	Small			Large			Very Large			Indet.			Total		
Alternate Test Methods (123 - direct air path)	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
Containment HVAC	0	0	0	4	2	2	0	0	0	6	0	6	10	2	8
Containment Pressure	1	0	1	1	1	0	0	0	0	5	3	2	7	4	3
Containment Atmosphere	1	1	0	5	4	1	0	0	0	10	3	7	16	8	8
Containment Waste Gas	0	0	0	0	0	0	0	0	0	3	2	1	3	2	1
Cont. Large Vol. Purge	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
Cont. Small Vol. Purge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cont. Hydrogen Purge	3	3	0	1	0	1	0	0	0	5	4	1	9	7	2
Cont. Purge (unspec)	4	1	3	3	1	2	4	0	4	31	4	27	42	6	36
Refueling Canal	0	0	0	2	0	2	0	0	0	1	1	0	3	1	2
PWR Subtotal	9	5	4	16	8	8	4	0	4	62	17	45	91	30	61
Containment HVAC	1	0	1	4	1	3	0	0	0	26	9	17	31	10	21
Drywell Pressure	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
Drywell Atmosphere	5	4	1	2	0	2	0	0	0	9	7	2	16	11	5
Drywell Waste Gas	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0
Drywell Purge	5	5	0	0	0	0	3	0	3	9	2	7	17	7	10
Drywell Vent	6	3	3	3	1	2	0	0	0	4	1	3	13	5	8
Wetwell Vent	8	6	2	0	0	0	0	0	0	11	10	1	19	16	3
Vacuum Relief	2	0	2	0	0	0	1	0	1	9	7	2	12	7	5
Wetwell Purge	0	0	0	1	0	1	0	0	0	7	4	3	8	4	4
BWR Subtotal	28	19	9	10	2	8	4	0	4	76	41	35	118	62	56
Total	37	24	13	26	10	16	8	0	8	138	58	80	209	92	117

Existing Test Methods	A and B														
Leak Rate	Small			Large			Very Large			Indet.			Total		
Alternate Test Methods (123 - direct air path)	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
Containment HVAC	0	0	0	0	0	0	0	0	0	2	0	2	2	0	2
Containment Pressure	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
Containment Atmosphere	0	0	0	0	0	0	0	0	0	6	0	6	6	0	6
Containment Waste Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cont. Large Vol. Purge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cont. Small Vol. Purge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cont. Hydrogen Purge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cont. Purge (unspec)	0	0	0	0	0	0	0	0	0	7	0	7	7	0	7
Refueling Canal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PWR Subtotal	0	0	0	0	0	0	0	0	0	16	0	16	16	0	16
Containment HVAC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drywell Pressure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drywell Atmosphere	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
Drywell Waste Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drywell Purge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drywell Vent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetwell Vent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vacuum Relief	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetwell Purge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BWR Subtotal	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
Total	0	0	0	0	0	0	0	0	0	17	0	17	17	0	17

Table 2 - Direct Air System Tabulation

t.	Total			A and B: Small			Large			Very Large			Indet.			Total		
123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
6	10	2	8	0	0	0	0	0	0	0	0	0	2	0	2	2	0	2
2	7	4	3	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
7	16	8	8	0	0	0	0	0	0	0	0	0	6	0	6	6	0	6
1	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	9	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	42	6	36	0	0	0	0	0	0	0	0	0	7	0	7	7	0	7
0	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	91	30	61	0	0	0	0	0	0	0	0	0	16	0	16	16	0	16
17	31	10	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	16	11	5	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	17	7	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	13	5	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	19	16	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	12	7	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	8	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	118	62	56	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
80	209	92	117	0	0	0	0	0	0	0	0	0	17	0	17	17	0	17

t.	A and C: Small			Large			Very Large			Indet.			Total.		
123	All	0	123	All	0	123	All	0	123	All	0	123	All	0	123
6	0	0	0	4	2	2	0	0	0	4	0	4	8	2	6
2	0	0	0	1	1	0	0	0	0	3	2	1	4	3	1
7	1	1	0	5	4	1	0	0	0	4	3	1	10	8	2
1	0	0	0	0	0	0	0	0	0	3	2	1	3	2	1
1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	3	0	1	0	1	0	0	0	5	4	1	9	7	2
27	4	1	3	3	1	2	4	0	4	23	4	19	34	6	28
0	0	0	0	2	0	2	0	0	0	1	1	0	3	1	2
45	8	5	3	16	8	8	4	0	4	44	16	28	72	29	43
17	1	0	1	4	1	3	0	0	0	26	9	17	31	10	21
0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
2	5	4	1	2	0	2	0	0	0	8	7	1	15	11	14
0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0
7	5	5	0	0	0	0	3	0	3	9	2	7	17	7	10
3	6	3	3	3	1	2	0	0	0	4	1	3	13	5	8
1	8	6	2	0	0	0	0	0	0	11	10	1	19	16	3
2	2	0	2	0	0	0	1	0	1	8	7	1	11	7	4
3	0	0	0	1	0	1	0	0	0	7	4	3	8	4	4
35	28	19	9	10	2	8	4	0	4	74	41	33	116	62	54
80	36	[illegible]	12	26	10	16	8	0	8	118	57	61	188	91	97

*Table 2 - Direct Air System Tabulation

APPENDIX C

A SUMMARY OF CONTAINMENT INTEGRATED LEAKAGE RATE TESTING TECHNIQUES INCLUDING LIMITATIONS AND ADVANTAGES OF CONTINUOUS INTEGRITY MONITORING

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Abstract

A summary of the status of containment integrity testing as applied to nuclear power plants is presented in support of an ongoing feasibility study of alternative methods of containment integrity testing. A survey of existing literature relative to containment leak testing is presented. Limitations and advantages of forseeable alternative test method principles are also discussed in detail. The results of a survey of operating power plants in regard to integrated leakage rate test procedures and plant operating conditions of interest for alternative test methods is discussed. The report concludes that alternative test methods could address an important safety concern in the area of containment integrity and that such methods appear feasible at present. Specific alternative test methods are not presented and are intended as the primary subject of a future report.

Table of Contents

Executive Summary

Nuclear power plant containments are designed to prevent leakage of radioactive materials into the environment in the event of an accident. To insure that this capability exists, containments are pressurized to accident pressure and the leakage rate measured at about three year intervals. The containment must meet stringent leakage criteria during the test. The possibility exists for an undetected breach of containment integrity between these tests which could allow unacceptable leakage from containment in the event of an accident.

The overall purpose of this project is to conceive and analyze alternative test methods by which a breach of containment integrity could be detected between leak tests. This report deals with the first phase of that effort which is the background information and data collected for use in evaluation of alternative test methods. A summary, through a literature review of containment leakage rate testing is presented. Constraints and advantages of alternative methods are discussed. The results of an operating plant survey of information pertinent to alternative test methods is presented.

Industry effort in leakage rate testing is not normally concerned with alternative methods of testing and is concentrated on refinement of the existing test techniques. The possibility of development of alternative test methods is considered good since low pressure testing can detect leaks which may be only a few times larger than those detected at high pressure. Further, extended time periods, which have a proportional effect on the leak test sensitivity, may frequently be available for low pressure testing but are not available at high pressures.

A survey of operating plants revealed only moderate differences in operating plants of a single containment type such that, a single test method could be applicable to an entire containment type with only small plant specific changes. On the other hand variations between containment types are considered large enough that it is unlikely that a single test method will be developed that is applicable to all types.

A range of alternative test methods is being considered with several different underlying operating principles. The range is considered wide enough that at least one applicable technique should result from the method analysis effort which is yet to be completed.

1. Introduction

Nuclear power plant containments must meet stringent criteria in terms of leakage rate in order to assure that unacceptable amounts of radioactive particulates and gases within the containment will not be released to the atmosphere in the event of an accident. To provide assurance that operating power plants meet the established leakage criteria, the Nuclear Regulatory Commission (NRC) has issued Title 10 of the Code of Federal Regulations, Chapter I, Part 50, Appendix J [1] which requires that operating power plants perform Integrated Leakage Rate Tests (ILRT) approximately every three years. The test consists of elevating the containment pressure to a specified value and measuring the amount of leakage from the pressurized containment, these tests are termed Type A ILRTs. Other local leak tests are also conducted on containment penetrations and isolation valves. These local tests are termed Type B and Type C tests respectively.

The Type A ILRT is a test which can only be conducted during a plant shutdown and, because of this and the time required to complete the test, can only be done at relatively infrequent intervals. The integrity of the containment as a whole is not normally tested during the time between Type A tests but loacal leak tests on valves and penetrations are performed. Therefore, an undetected breach of containment integrity (UBCI) could exist for an extended period of time before discovery. Pacific Northwest Laboratories has investigated the probability of containment unavailability caused by UBCIs [2], and concluded that the probability that the specified level of containment integrity will be unavailable (i.e. the Type A allowable leakage rate criteria will be met) at any given time is approximately 0.3. The basis for the conclusion is operating plant experience with estimates of the time of existence of documented breaches of containment integrity prior to discovery.

Concern about the possibility of long term UBCIs has resulted in the initiation of this project by NRC in which Sandia National Laboratories has been asked to study the feasibility of alternative containment integrity test methods and to develop methods which could be used to detect breaches of containment integrity in a timely manner. This document reports the first phase of this effort which involves a summary of ILRT as currently practiced; discussion of the overall advantages and limitations af alternative test methods; presentation of the results of a survey of operating power plants with respect to ILRT and plant operating conditions; and specific topics of concern in the evaluation of alternative containment integrity test methods. The primary purpose of the report is to provide a basis for the evaluation of alternative methods of containment integrity testing by using the Appendix J tests as a standard and to provide a discussion of the current state of knowledge concerning the advantages and limitations of alternative test methods which could be of interest. Specific alternative test methods will not be discussed here but a complete analysis of all such known methods will be presented the final project report.

2. Literature Review

A review of published literature pertaining to leakage rate testing has been conducted. The results of this review are intended to serve as a basis for this project and provide a single summary of the status of leakage rate testing. For the purpose of summarizing the information available on this subject, five separate areas will be discussed. The areas are: regulations; test histories and reports; calculational techniques; instrumentation; and general guideline and summary documents. The five areas are discussed in order in the following sections

2.1 Regulation

The governing regulatory document for integrated leakage rate testing is Title 10 of the Code of Federal Regulations, Chapter I, Part 50, Appendix J [1], hereafter referred to as Appendix J. Appendix J stipulates the leakage test requirements which the primary reactor containment of water-cooled power reactors must meet. A preoperational test and periodic verification tests are required to insure that an acceptable level of leak-tightness is maintained. Specifics of the test and required instrumentation are stipulated in the American Nuclear Society Standards N45.4-1972(ANS-7.60) [Y] and ANSI/ANS-56.8-1981 [4]. The technique specified for determining leakage rate consists of measuring the contained dry air mass versus time for the duration of the test. Dry air mass is determined by accurately measuring the containment pressure in a single location, measuring the air temperature in about 20 locations, and measuring the dew point in several locations. Using the ideal gas relation, the temperature and pressure readings are used to determine the total mass of the enclosed atmosphere. Dew point readings are used to determine the amount of contained water vapor which is subtracted from the total contained mass. This method of mass determination is referred to as the absolute method. The mass versus time behavior is then used to infer the leakage rate from containment.

Since very small leakage rates are being measured (as low as 0.1% per day maximum allowable leakage), accurate instrumentation is required. Accuracies of 0.5 F for temperature, 2 F for dewpoint and 0.02% of reading for pressure are specified [4]. Instrument sensitivity of 0.1 F for temperature, 0.5 F for dewpoint and 0.001% of full scale for pressure is also indicated [4].

A revision to Appendix J has been considered for some time and currently a draft form of the revision exists [5]. While the changes being proposed to the current Appendix J are significant in terms of compliance to the requirements, the changes do not effect the basic method and required accuracy of the test so that, for the purpose of this report, the proposed changes are not of great interest.

Initially, Type A tests were of 24 hour duration. In the interest of cost reduction for the utilities, considerable effort has been expended to justify tests of shorter duration and analyze proceedures for such tests to insure sufficient accuracy of leakage rate measurement exists. Two documents in this area are Testing Criteria for Integrated Leakage Rate Testing of Primary Containment Structures for Nuclear Power Plants [6] from Bechtel and Criteria for Determining the Duration of Integrated Leakage Rate Tests of Reactor Containments [7] by EPRI. The Bechtel report lays out guidelines and techniques for conducting Type A tests and provides for reduced duration testing of as short as 6 hours. Statistical techniques are used to assign appropriate confidence limits to the measured leakage rate. The EPRI report contains an analysis and case study of 53 ILRTs and provides technical basis for deciding when a test has produced accurate results such that the test may be terminated.

2.2 Test Histories and Reports

This section of the literature review encompasses any literature directly relating to the conduction of ILRTs. This section does not include the NRC required report issued by the utility following each Type A test, except in cases where the report is considered directly applicable to the goals of this project.

Of some interest in the area of continuous monitoring, is the experience reported by Zakaib [8] for the Ontario Hydro CANDU plants. For these plants, a slight subatmospheric pressure is maintained (-0.5 psig) during operation with periodic on line leakage tests at -2 psig. Containment allowable leakages are much larger than other types of plants because the containment is attached to a vacuum building which is maintained at about 1 psia. In the event of an accident, gases from the containment are drawn into the vacuum building thus providing relatively short-lived and low-level acident pressures. The CANDU test experience has shown a reasonably linear behavior of mass leakage rate versus pressure for test pressures of -6 psig to 6 psig. Continuous monitoring is done at CANDU plants by measuring the exhaust air, instrument air and service air flow along with temperature, pressure, and water vapor pressure. The information gathered is used with the ideal gas relation to monitor the total amount of contained air mass. This technique has been shown to produce reliable measurements of leakage rates for the CANDU plants. The predictable dependence of leakage rate on test pressure is not widely accepted as fact. Especially over large pressure ranges, meachanisms exist by which leakage paths can be distorted by the applied pressure. This phenomenon can result in either an increasing or decreasing leakage rate with increasing pressure. Research is currently being conducted to provide a better understanding of the pressure dependence of leakage rate.

There is a question as to the existance of leakage paths in containment which could be detected by a continuous method. The majority of such documented leaks have been through valves and penetrations where Type B and C tests could eventually discover the leak. A few cases have been reported where a leak could have only been discovered using a Type A test or some alternative technique capable of assessing overal containment integrity. A case of some note is that of the Douglas Point Generating Station reported by Cooke [9], where leakage rates on the order of 100 scfm. A major source of the leakage was through caulked joints and cracks in the concrete containment wall. Two instances have been documented [2] at San Onofre 1 and Surry 1 where holes were drilled which could not be detected by Type B or Type C tests. It appears that these leaks could have been detected by a continuous monitoring system.

Frank [10] reports a Stone & Webster study and research project to provide definative guidelines for short (less than 24 hours) duration Type A testing. The conclusions of the project are the result of a review of 27 ILRT test reports and the conduction of two reduced duration tests. The report recommends the procedures, staffing and techniques to be followed to conduct reduced duration tests.

2.3 Calculations

Since Type A testing requires an accuracy of measurement which is near the limits of available instrumentation, considerable literature has been devoted to the discussion of calculational techniques used to properly determine the leakage rate from the instrument signals. The information gathered from the instruments consists of temperature measurements at about 20 discrete points, dew point measurements at about 4 points and a single pressure measurement. Weighting schemes to apply the discrete measurements to the entire containment atmosphere, determination of the leakage from discrete time-mass points, statistical treatment of the determined leakage rate, and the suitability of the ideal gas relation for mass determination have been the subject of discussion in this area.

The technique usually used to weight the discrete temperature data is that of linearly weighting the temperatures by the amount of volume each one represents and using the result as a bulk temperature value which appears in the deniminator of the applicable ideal gas relation:

$$M = PV/RT$$

The theoretically correct method for weighting the volumes associated with the temperature data would be to sum the reciprocals of the temperature-volume products and mujltiply the final sum by the total volume. The result of this calculation would be the reciprocal of the bulk temperature. Glover [11] estimates the error in total mass measurement produced by not using the theoretically correct weighing as no more than .08% of the contained air mass for typical ILRT conditions. The error determined is relatively small since Type A test conditions require a quiet atmosphere with releatively small temperature gradients. In the case of continuous monitoring techniques, containment conditions in terms of temperature gradients and convective currents will be much more severe because of large heat sources introduced by plant operation. This factor should be considered in assessing alternative test methods which require the determination of containment average temperature.

The ideal gas relation is accepted for use in all ILRTs. However, van Domselaar [12] advocates the use of the van der Waals gas relation which acounts for some of the non-ideal behavior of the air. The example presented concludes that large errors in leakage rate measurement can result from the use of the ideal gas relation. The analysis, which shows that errors as large as 17% can occur, appears to use an error definition for which the error becomes infinite as the leakage approaches zero. Using an error definition which relies on a change in measured air mass, the error introduced by the use of the ideal gas relation is much smaller, on the order of 1% measured leakage.

Type A test leakage rate measurments are made by determining the dry air mass at approximately equal time intervals and using the mass versus time response to determine the rate of change of the mass. Two methods currently in use are the total time method and the mass plot method. The total time method uses the first mass determination made and the most recent mass determination as two points which determine a straight line the slope of which a leakage rate data point. In the mass plot method, the available mass points are used to determine the linear least squares fit to the data. The slope of the fit is the mass leakage rate. Lurie [13], indicates the statistical problems with the methods as being the assignment of too much weight to the first value in the total time method and the fact that the confidence interval for the mass plot method approaches zero as more readings are added. He proposes a hybrid method which calculates a leakage rate by a least squares fit for all previous data whenever a new data point is available. The set of leakage rate estimates are then used to determine the mean leakage rate and its standard deviation.

Zakaib [8] discusses the existence of systematic errors in leakage rate measurment for the Ontario Hydro CANDU plants. The errors are primarily produced by diurnal and seasonal variations. A technique is presented where the sampling frequency of the test is adjusted so that periodic effects do not introduce excessive error in the determined leakage rate. While long term effects, such as seasonal temperature variations) are not normally of concern during Type A tests, it is possible that a continuous monitoring technique could be more sensitive to such effects due to the much longer time of testing.

2.4 Instrumentation

The literature published concerning instrumentation used during ILRTs is primarily that produced by instrument manufacturers to provide information concerning the use of their own equipment. Some of the literature which is of more general interest is discussed here. Leakage test instrumentation typically involves ›asurement of temperature, pressure and dew point at levels of accuracy which are near the limit of available instrumentation. ANSI 56.8-1981 [4] specifies a temperature accuracy of 0.5 F, a dewpoint accuracy of 2 F, and a pressure accuracy of 0.02% of reading.

Dew point determination requires the most complex equipment of the three measurment types. Cortina [14] presents an extensive discussion of humidity analysis including definitions and physical laws governing humidity as well as an explanation of the operating principles of all common types of humidity instrumentation. Two types of hygrometers discussed, the lithium chloride cell and the chilled mirror, are in common use for ILRTs. Carp [15] states that the chilled mirror is recommended for reduced duration testing since it is inherently more accurate. From surveys of operating plant ILRT experience it appears that the lithium chloride cell is used much more frequently than the chilled mirror in Type A tests. Primarily, according to the utilities, due to greater inherent ruggedness of the lithium chloride cell.

Temperature measurements are typically carried out using platinum resistance temperature detectors (RTDs) which provide a well defined resistance versus temperature behavior. Trietley [16] discusses the possibility of employing metal oxide thermistors rather than RTDs for ILRTs. He points out that the characteristics of a thermistor in the temperature range of interest make it equally suited and perhaps superior for ILRT temperature measurements. From operating experience surveys, it appears that RTDs are employed universally in Type A testing.

Pressure measurements in ILRTs have not been the subject of extensive literature. The only reference discovered that discusses the subject is that of Gunn [17] who points out the problems associated with the temperature dependent response of pressure transducers. He points out that the quartz manometers generally used for ILRT pressure measurement exhibit a very low thermal dependence when compared to othe pressure transducers but the error induced is still significant. To reduce the thermal error, isothermal transducer enclosures or temperature-pressure correction schems are suggested.

2.5 General

This area of the literature survey is intended to present a discussion of documents which present a summary of practices, findings, and Type A tests. Also included in this area is literature which does not properly apply to any of the above categories but is of interest in terms of ILRT in general.

Pacific Northwest Laboratory [2] has performed a reliability analysis of containment systems by reviwing licensee event reports and ILRT reports. The study resulted in an estimation of the level of containmwent unavailability made from ILRT failures. The overall level of containment unavailability resulting is 0.29. The report indicates that most leaks are caused by isolation valves (70%) with the remainder attributed to penetrations. A few leaks are also identified from other breaches of containment.

Renton [18] reviewed operating experience to investigate the validity of reduced duration testing as outlined in EPRI NP-3400 [7] through an analysis of ILRT experiences. The conclusion of the study was that reduced duration testing can produce accurate and predictable results.

Dougan [19], in the Evaluation of Containment Leak Rate Testing Criteria, provides a summary of regulations and guidelines and a brief discussion of the terms, techniques and procedures involved in leakage rate testing. The report summarizes a review of ILRT reports and LERs and reaches the conclusion that the proposed Appendix J is responsive to the results of test experience and technological changes.

3. Type A Test Procedures and Complications

3.1 Test Conduction Procedures

The theory underlying Type A testing is the determination of leakage rate though periodic determination of the enclosed containment air mass and the use of the mass versus time data to determine a mass leakage rate. The ideal gas relation is used to determine the air mass from the available readings and, since condensing water vapor or evaporating liquid water can give an erroneous indication of leakage, the amount of water vapor contained in the atmosphere is measured and that value is subtracted from the total mass determined. Containments are tested at a predetemined test pressure which relates to a postulated accident pressure. Tests are conducted only during plant shutdown with isolation valves positioned so they may be tested. The test must be conducted three times in ten years and usually is on the critical path during shutdown. The actual leakage test usually does not last more than 24 hours but other operations associated with the test (i.e. pressurization, stabilization, verification, depressurization) usually cause the test to occupy several days of containment time. During conduction of the test, access to the containment is not allowed so the amount of work that may be done in parallel with a Type A test is limited.

Type A testing techniques can be divided into two categories. The first is called the reference vessel method which uses a sealed vessel (usually a tube that runs throughout the containment) which is assumed to have the same average temperature as the containment. The density of the gas in the tube is constant regardless of pressure and the change in differential pressure between the tube and the containment is a direct measure of the change in contained atmospheric mass. The reference vessel method is no longer used due to difficulties in maintaining a leak tight reference vessel.

The second method is termed the absolute method and is the only test method currently employed. This method involves the gathering of sufficient pressure and temperature data within the containment to allow the direct determination of the enclosed air mass through use of the ideal gas relationship. Typically 18-24 temperature readings are taken using resistance temperature detectors (RTDs). The average temperature of the atmosphere is determined by volume weighting of the various temperatures read. Containment pressure is measured with a quartz manometer. The pressure and temperature values are used with the ideal gas relation to yield the total air mass in containment at various points in time.

Calculation of the leakage rate from the measured mass versus time values is typically done by either of two methods. The first method discussed is the total time method. This technique uses a set of leakage rates determined by the slope of the lines connecting the initial contained mass reading to each subsequent reading. The second method is termed the mass plot method in which the mass values determined are plotted versus time with the slope of a linear least squares fit to the data being the mass leakage rate.

Following completion of the leakage rate measurement, a verification test is conducted to confirm the reliability of the instrument readings. During this test a known flow rate or step mass change is introduced into containment and the leakage rate or mass change measured by the instrumentation is determined and compared to the known value. Appendix A to ANSI 56.8-1981 provides also provides a summary of Type A test procedures.

3.2 Contstraints and Limitations of Type A Testing

Most of the constraints which apply to Type A testing stem from the pressure to conduct the test in minimum possible time. The testing technique is reliable and accurate, but the limited amount of time available to conduct the test requires optimum conditions for testing. Since the Type A test relys upon the measurement of contained air mass and infers the leakage from the change in mass over time, extended periods of time for testing would allow much less sensitivity in the instrumentation and weighting schemes to yield an acceptable leakage rate accuracy. For a 24 hour test, an error in readings of 0.5 F or 0.05 psi from beginning to end of the test can yeild a 0.1% per day error in the determined leakage rate. For reduced duration testing, the effect of an instrument innacuracy will be proportionately larger. Such an error is well beyond acceptable limits since plants have allowable leakage rates as low as 0.1% per day.

While the above stated instrument errors are larger than the minimum error readily obtainable, errors in estimating average containment temperature may also be caused by errors in weighting the temperatures read. Estimation of the amount of error introduced by the weighting schemes is difficult since it requires that a temperature profile within the containment be assumed when test data to support the assumption is not available. Glover [11], as discussed before, estimates the resulting error from linear and quadratic temperature profiles and concludes the error to be small enough to be insignificant. An upper bound to the error could be estimated by using the extreme temperature subtaracted from the average temperature as the temperature error. This bound then assumes, in effect, that the bulk of the containment is at the extreme read temperature while other temperatures only occur at points where temperature sensors are placed. While being extremely conservative, the technique does provide an upper error bound. By this method, an error of no more than 1% can be expected. Conversely, in an operating conrtainment, an error bound of 10 to 20% can be determined.

4. Constraints on Leakage Rate Monitoring Imposed by Plant Operation

Type A testing as currently implemented requires that the plant be shutdown to perform the test. A continuous monitoring technique is expected to operate primarily while a plant is operating when control over many plant parameters is not allowed for the testing. The containment atmosphere tends to be much more turbulent during operation since fan coolers are frequently operating and large heat sources (e.g. steam generators, steam pipes) produce significant convective currents. The large amounts of heat being released into containment produce large thermal gradients and contribute to greater diurnal effects. Other effects observed in operating containments which could effect leakage rate monitoring systems are the usage of instrument air; continuous sample lines; containment access; vent and purge operations; and gas releases into containment from coolant systems.

The primary effect of thermal gradients relates to proper weighting of the containment temperature with volume. An instrumentation scheme which uses 18 RTDs to obtain sufficient accuracy for a Type A test may well provide significantly lower accuracy and sensitivity when used as a continuous monitoring technique. In general, sufficient data is not available to assess the extent of this effect, since most power plants record very few containment temperatures during operation. The application of a continuous monitoring technique which requires accurate and properly weighted measurement of bulk containment atmosphere temperature could require a detailed analysis of operating temperature gradients during operation on a plant specific basis to estimate the maximum error resulting from the gradients.

For most alternative methods, air velocities, whether induced by thermal or mechanical means, do not present a severe problem. The complications caused by the air velocities are expected to be related to continuous monitoring difficulties in terms of changes in the stagnation pressure head in areas of high velocities. The change in the pressure is relatively small (about 0.003 psi at 20 feet per second) but could create difficulties in techniques requiring extremely accurate determinations of pressure. Such techniques could require either relatively stagnant areas to operate in or a system by which the pressure transducers are shielded from high local velocities.

Since leakage rate monitors primarily operate on the principle of determining the mass of the containment atmosphere and detecting a change in the determined mass over time, the introduction or release of any air mass during a monitoring period is of concern. Several sources of mass change exist in an operating containment. Those sources currently recognized as important will be discussed below.

Access to containment during operation can range from several times per day to never. Since containments typically operate at a pressure other than atmospheric, there will be a air mass transport associated with each containment access. There is normally npo need for access to BWR containments during operation. With the exception of subatmospheric containments, which only require very infrequent access, containment operating pressure is limited to no more than 3 psig. Typical volumes for the personnel air lock are on the order of 1000 cubic feet. Assuming a containment volume of 2,000,000 cubic feet, the per cent weight mass loss per air lock operation is:

dm = 3psid/15 psia*1000 cubic feet/2000000 cubic feet*100

dm= 0.01 %

This estimate assumes that the air lock is pressurized with containment atmosphre rather than an external source and still produces a total mass change such that one access per shift (the maximum found during the plant surveys) can produce a leakage rate that is less than .3 La. In any event, the amount of air lost through air lock operation can be easily estimated or perhaps measured and factored into any mass determination methods which might be employed.

Another source of mass change is that of instrument air. In the plant survey, this input of air into the containment was large enough to require periodic venting to reduce containment pressure in several plants. A mass addition rate of such size is of considerable concern for leakage rate determination. The approaches to dealing with the problem are: (1) Monitoring the use of the air to determine the total mass added to the containment; (2) Reduce intrument air usage through repair, better maintenance and replacement of leaking equipment (in some plants this effort has eliminated the need for containment venting); (3) using the containment atmosphere as the source for instrument air; and (4) Tagging the instrument air with an appropriate tracer when using tracer detection leakage rate monitoing techniques.

Continuous sample lines can represent a source of mass change that is similar to the instrument air usage. Typically sample lines use only a few scfm (1 scfm is about 0.07% per day leakage rate) and often the sample is returned to the contianment. However the apparent leakage rate which results from unreturned samples is on the order of the leakage rate which is to be measured. Since tracer tagging of the sample and reduction of sample use are not feasible alternatives, return of the sample to containment or measuring of the quanity of air removed are considered the most likely prospect to account for the mass change.

Vent and purge operations represent the largest single obstacle to the use of continuous monitoing techniques. While some plant do not routinely vent or purge containment, frequency of venting and purging was found to be be as often as twice daily. Generally venting frequency for PWRs appeared strongly linked to instrument air usage for the plant, with high venting frequency corresponding to large instrument air usage. The impact of vent and purge frequency on continuous monitoring systems is great beacause it represents a large and rapid change in the containment air mass that cannot be accurately measured. This means that any continuous monitoring system only has a single purge or vent cycle period to measure the existing leakage. As discussed in Chapter 5, the availability of extended time periods for continuous monitoring is the primary factor which may make the implementation and use of continuous monitoring systems feasible. In the case of plants that cannot reduce the purge and vent frequencies to the extent that continuous monitoring techniques can function properly, alternative testing techniques will not be able to be used or the sensitivity of such techniques will be limited to the detection of large leaks only.

5. Inherent Advantages and Simplifications of Continuous Monitoring Techniques

The existing Appendix J regulations for ILRT require that a Type A test be conducted approximately every three years and at least three times in ten years. The tests are usually conducted for a period of 24 hours although reduced duration testing of as short as 8 hours may be used. The reduced duration testing is desireable for the utilities since it reduces the total time of plant shutdown as much as possible. In the case of alternative methods which use continuous monitioring techniques, the time required to assess the leakage rate does not have an impact on plant operation. This factor allows for the use of techniques which require times significantly longer than the 8 or 24 hours.

Even though a continuous monitoring technique may require several days or even weeks to detect a leak of a given size, the time from onset to detection of a leak is likely to be orders of magnitude less than that for a Type A test where the time between tests is about 1000 days. The maximum time that an UBCI can exist before detection by a continuous method is very dependent on the method used. Even a method that requires 10 days to detect a leak would yeild a potential improvement in leak detection time of two orders of magnitude, providing that plant conditions allow the required monitoring time.

The much larger amount of time which is available for leak detection and measurement reduces the required accuracy of the instrumentation system designed to determine the leakage rate. For example, a system designed to detect a given leakage rate over a ten day period needs only one-tenth the accuracy of a Type A test method which must measure the same leakage in 24 hours or less. It is true, however, that the reduced pressure available during plant operations will reduce the mass fraction leakage rate. The amount of this reduction is not as great as might be anticipated. This area is discussed in detail in Chapter 6.

One difficult area in terms of instrumentation and accuracy with regard to Type A testing is compensation for water vapor in the air. Defining relative humnidity of air as the ratio of the weight of contained vapor to the maximum amount of vapor the air could hold, if air with a relative humidity H and an initial absolute pressure P is pressurized, the dew point will be reached and condensation will occur when the pressure reaches P/H. At or near the condensation point there can be changes in the contained water vapor mass which must be accounted for by use of several accurate dewcells.

A typical humidity range in a large, dry containment at atmospheric pressure and 100F is 30% to 40% so that a pressure of about 3 atmospheres will produce condensation. This pressure is well below the required 60 psia typical test pressure for such containments. The problem of humidity is treated in Type A tests by carefully measuring and weighting zones of assumed constant humidity and sometimes by using dry air for pressurization.

In the case of a continuous monitoring system, the pressure is not significantly changed and the range of contained water vapor is very narrow for most containments. For many types of techniques, where humidity effects the leakage rate determination, the narrow humidity range, coupled with the long time for detection, allows the omission of humidity measurements entirely or at least a significant reduction in the required accuracy. For example, in a large, dry containment with a bulk temperature of 80 F and a 10% per cent total humidity range, the maximum error possible by not reading the humidity level is 0.3% of the contained mass. An error of this size, while unacceptable for Type A tests could be acceptable for a continuous monitoring technique which is expected to detect a 0.1% per day leak over the course of several days.

A similar effect applies to temperature measurement in containment. Unlike humidity, temperature variations tend to be more severe during operation than shutdown. From plant surveys, it appears that the average operating palnt temperature is relatively constant even though large spatial gradients occur. As with humidity, with increasing time to detection of a leak, the need for accurate temperature measurement reduces. A bulk containment temperature change of 10F will result in a leakage rate measurement error of 0.2% over a ten day monitoring cycle. Measurement of the temperature at a few well chosen points should reduce the total temperature error to less than 10 F.

6. Correlation of UBCI leak rates at reduced pressures

In general, techniques for evaluating containment integrity rely on sensing a change in an appropriate air mass or concentration which results from leakage between the containment structure and the outside atmosphere. During operation the pressure available to drive this leakage is limited by the plant technical specifications. Typically, the maximum allowable pressure is less than 3 psig. The notable exception to this value is that of subatmospheric containments where a differential pressure of 6 psig is normal. To properly assess the sensitivity of any leak rate test method, some correlation between the leakage at the low available operating pressure and the leakage that could be expected at Type A test pressures is needed.

The main objective of the alternative test methods is to indicate the presence of an undetected breach of containment integrity. With this in mind, and for ease of analysis, the correlation of leak rate to pressure will be developed for a long, relatively small, circular tube. Such a leak would exist if, for example, a sampling line was left open or any small line was not properly isolated. The equation governing compressible isothermal flow is derived by integrating the equation which defines the friction factor over differential lengths of the flow path. The result is:

$$P1^2-P2^2=2w^2RT/A^2(\ln(v1/v2)+fL/D) \quad (1)$$

This result is published in Reference [20], where:

- P1 = Inlet pressure, absolute (pounds/square foot)
- P2 = Exit pressure, absolute (pounds/square foot)
- w = Mass flow rate (slugs/second)
- R = Ideal gas constant (1717 foot-pounds/slug-deg R)
- T = Absolute temperature (degrees Rankine)
- A = Flow area (square feet)
- v1 = Specific volume of inlet fluid (cubic feet per slug)
- v2 = Specific volume of outlet fluid (cubic feet per slug)
- L = Length of flow path (feet)
- D = Diameter of flow path (feet)
- f = Friction factor (unitless)

The friction factor is related to various flow parameters by the Colebrook equation:

$$1/f^{.5} = 1.74-2\log(e/r+18.7/f^{.5}/Re) \quad (2)$$

From Pao [21] where:

- e/r = Relative roughness of the pipe, ratio of surface roughness to flow path radius (unitless)
- Re = Reynold's number (unitless)

The Reynold's number is defined as:

$$Re = pVD/u \quad (3)$$

Where:

p = Fluid density (slugs/cubic foot)
V =Fluid velocity (feet/second)
u = Absolute viscosity (pound-seconds/square foot)

The mass flow of the fluid is:

$$w = pVA \tag{4}$$

so:

$$Re = wD/Au \tag{5}$$

Therfore Reynold's number is constant over the flow length and it follows directly from the Colebrook equation (2) that the friction factor is also constant. The equation (1) can be re-written to express the friction factor as:

f=D/2/L(A^2(P1^2-P2^2)/2/R/T/w^2-ln(v1/v2)) (6)

And taking into account the circular cross-section of the tube and the ideal gas relation:

$$Pv=RT \tag{7}$$

The following results:

f=D/2/L(D^4Pi^2(P1^2-P2^2)/32/R/T/w^2-Ln(P2/P1)) (8)

For the analysis a tempreature of 80 F (540 R) will be used, so:

f = (3.32x10^-7 D^4(P1^2-P2^2)/w^2 - Ln(P2/P1))D/(2L) (9)

The viscosity of air at 80 F is 3.8E-7 pound-seconds/square foot, so the Reynold's number expression becomes:

Re = 3.34x10^6 w/D (10)

Equations 2, 9 and 10 comprise a complete set of equations which define the relationship between end pressures, tube diameter length, roughness and mass flow rate. The equations may be solved numerically to determine the mass flow rate for any desired set of conditions. The equations have been solved for the case of a 50 foot tube of various diameters under pressures ranging from 1 to 50 psig at the inlet and standard atmospheric pressure at the outlet.

To assure that the range of parameters used in the model leakage rate calculations is compatible with the equation, several representative tests were conducted in which the flow of air through a fifty foot length of smooth tubing was measured for different pressure drops. Table 1 presents a comparison of the predicted results from the above equation versus the measured test results. The deviation of the ratios from 1 is a measure of the amount of discrepancy between the predicted and actual flow rates. With the exception of the smallest tubing diameter, the correlation is very good. In the case of the smallest tube, the flow characteristics are in the laminar or transition zone which is not covered by the derived compressible flow equations which assume fully turbulent flow and the equivalent leakage rate is much lower than that generally of interest in containment testing.

The plot of predicted mass flow rate versus tubing size for various pressures is shown in Figure 1. The information in Figure 1 can be converted to terms of per cent mass per day leakage by assuming a typical containment volume (2,000,000 cubic feet was chosen as reasonable) and applying the appropriate correction for the atmospheric density within the containment during the test. This correction serves to improve the apparent accuracy of low pressure testing techniques since the total mass leakage required to give a certain per cent change in total mass is directly proportional to the absolute pressure of the containment.

Figure 2 is a plot of the ratio of per cent mass leakage rate at reduced pressure to the per cent mass leakage rate at 50 psig versus the per cent mass per day leakage at 50 psig. Notice that for a low pressure test at 1 psig, the indicated leak rate (in per cent mass per day) will be .14 to .24 times the 50 psig rate, and at 5 psig it will be .35 to .55 times the 50 psig leakage rate. Therefore, while the pressure driving the leak has been reduced by a factor of 50, the mass fraction leakage of the containment atmosphere has only been reduced by a factor of 5. To experimentally measure the accuracy of this result, the flow rate through 50 foot lengths of various diameter copper tubes was measured over a range of differential pressures. The results of the measurements are presented in Table 1. The numbers listed are the ratio of actual flow rate measured to flow rate predicted from the analysis. The ratios are very nearly unity, indicating good agreement between measured and predicted values, for all cases except the smallest tubing. In the case of the smallest tubing, the Reynold's number resulting from the flow indicates laminar or transitional behavior which is not included in the derived model. Further, the leakage rate, in typical per cent per day, resulting from this tube is only 0.01% per day which is on the lower limit of leakage rates of interest. Finally, these results are only designed to give a qualitative assessment of reduced pressure leakage rate measurement since the leak path geometry assumptions were chosen for convienence due to the lack of existing leakage path geometry data.

This result indicates that low pressure, continuous monitoring techniques with a sensitivity similar to that of the current Type A test methods could detect leaks that are only a few times greater than the technical specification allowed leakage and, considering the longer detection time period available for continuous methods, could conceivably measure leakage rates which are less than the technical specification requirements.

7. Plant Survey Items Relating to Test Principles

While this report is not intended to discuss specific alternative test methods, the underlying physical principles and methods by which these principles may be applied is considered of interest here with respect to the operating plant survey. Many of the questions for the survey were generated to help assess the applicability of the various methods to operating plant conditions. In the following sections, the methods to be evaluated in the final report are grouped by category of operating principle. Several of the proposed methods may employ the same principle for leakage rate determination.

7.1 Ideal Gas Mass Determination

The use of the ideal gas relationship to determine the contained air mas through measurement of air temperature, humidity, and pressure is the principle upon which current Type A testing is based. While ther is no question as to the ability of the method to accurately determine leakage rates under shutdown conditions, it is possible that the larger thermal gradients and air velocities in an operating containment could affect the accuracy of the technique. For this reason, several survey questions relating to temperatures and air velocities were discussed.

7.2 Tracer Gas Detection

This type of method uses the measurement of a natural or introduced gaseous tracer to detect containment leakage. Two such methods are under consideration. The first is that of the detection of a tracer gas outside of the containment which has a known concentration within containment. A tracer of interest for this method is ozone since it is generated within containment and detection techniques are extremely sensitive. To help assess this method, questions concerning the natural ozone concentration in containment were asked. Unfortunately, no surveyed plant had ever monitored ozone during operation. Also of interest in evaluation of this technique is the ventilation of the area immediately surroounding the containment. In the case of Mark I, Mark II and possibly dual wall PWRs, the leakage through all possible leak paths is drawn through a single duct, making tracer detection relatively straightforward.

The second type of tracer detection technique is that of a concentration monitor within containment to record dilution of the tracer caused by inleakage. This method is only applicable to containments at negative gage pressure and, therfore, a portion of the survey dealt with allowable vacuum levels for various plants.

7.3 Bulk Temperature Measurements

Bulk temperature measuring techniques are related to the ideal gas determination but use global methods of determining a properly weighted temperature of the atmosphere. Techniques under consideration here include acoustic velocity measurements and refractive index measurements. Both these techniques require arelatively open containment geometry which was discussed qualitatively in the survey.

7.4 Mass Change Input/Exhaust Monitoring

Methods which depend on the introduction or removal of a quantity of air in a continuous or discrete manner are included here. Of primary interest in the survey was the existence of equipment on site capable of producing the desired mass change. Also of interest was the capability to measure small pressure changes produced by the mass change and the allowable limits for containment pressure during operation.

7.5 Reference Vessel Methods

Several techniques are being considered which use a device similar to the reference vessel for Type A tests. Support of thses techniques required information concerning pressures, temperatures, and temperature gradients existing in operating containments.

7.6 Direct Air Weighing

This principle includes a single method in which the differential atmopspheric pressure from top to bottom of containment is used to directly determine the enclosed air mass. The method is extremely sensitive to local stagnation pressures and somewhat dependent on containment internal geometry and variations in temperature profile shape. While these areas were discussed in the plant survey, only very limited information was gathered because they are not of normal interest in plant operation.

8. Plant Specific Test Constraints and Data

Containment integrity test methods can be inherently sensitive to conditions existing within the containment during the monitoring period. The Type A test procedure requires a reasonably isothermal containment where venting, purging and access to the containment are not allowed during testing. To aid in the evaluation of the various alternative test techniques to be considered, contact was made with many operating power plants to collect information concerning conditions inside the containment during operation, instrumentation and requirements of Type A tests, and plant conditions or operational procedures which could have impact on the effectiveness of continuous monitoring techniques.

This section presents a summary of the data gathered with some insights and comments concerning the effect this information has on the various classes of alternative containment integrity test methods. For the purpose of this summary, reactor plant containment types have been divided into 7 major categories. The seven categories including the number of sites with operating plants and the number of sites contacted is included as Table 2.

The table indicates that two containment types (Pre-Mark and Mark III) are not represented in the data. The Pre-Mark containments are not represented since they are not a single containment type and only two such containments are expected to remain in operation. The Mark III containment was not included since no site exists with the full power operating and ILRT experience needed to provide useful information. The lack of data on these two containment types does not mean that the constraints and limitations imposed by containment conditions at other plants cannot be logically extended to thse containments.

The presentation and summary of the data is broken into categories based on the five remaining containment types (i.e. Large Dry, Subatmospheric, Ice Condenser, Mark I, and Mark II). The next section presents information about the survey which is applicable to all containment types. Following this section, each containment category is presented separately. A summary of the survey findings is presented in Table 3.

8.1 General Survey Information

Specifics concerning Type A testing were discussed in the survey such as, containment volume, allowable leakage, instrument placement, and Type A test experiences. The volume is of interest in assessing the applicability and sensitivity of the various alternative maethods to be considered. Allowable leakage provides a relative measure of the sensitivity limit desired for a continuous monitoring system. Instrument placement is important in determining the variations in humidity and temperature within the containment. Type A test experiences were discussed to help determine the general nature of leaks found and any information which could be useful in the analysis of alternative test methods. Information was also gathered concerning the partitioning of the containment volume. For some of the alternative test methods, an open volume of air is needed to obtain the desired measurements. This parameter is largely qualitative in nature and tends to be containment type specific rather than plant specific. Finally, concerning Type A testing, the vast majority of plants have penetrations available to transmit the individual transducer signals through the containment boundary. The only exception is the case of plants that use in containment multiplexers during testing. For those plants, the additional penetrations do not exist. Except for plants where continuous monitoring by Type A test methods is employed, the test transducers are removed while the associated wiring is left in tact following a test.

Any mechanisms by which air mass is introduced into containment were discussed in the survey. These mechanisms include access to containment, instrument air usage, oxygen steam line inleakage, purging, and venting. The introduction or removal of air mass in containment presents a difficult problem with regard to continuous monitoring techniques. The extent of the problem is discussed in Chapter 4. The survey addressed these issues to determine the severity and extent of the mechanisms.

The temperatures measured within a containment are of interest in two different areas. The first area is that of bulk containment temperature. This is of interest for certain alternative test methods which do not measure the air temperature but must assume a value to estimate leakage. For a wide possible error in bulk temperature, more time is required to detect a leak of a given size. The second temperature measure of interest is that of temperature gradients. Gradients are defined here as the range of tmperatures existing in containment at a single point in time. Temperature gradients are of interest because they can serve to provide a bound to the error in measuring a bulk temperature when the bulk temperature is being estimated from a limited amount of temperature data. One additional aspect of containment temperature, for which no direct data is available, is the variation in relative temperature distribution over time. However, this variation can be bounded by the bulk temperature flucuations and the known gradients.

Humidity ranges in operating containments can be used to determine the necessity and accuracy of humidity measurements in continuous monitoring techniques. The maximum amount of water vapor that can be contained in 80F air is 2.2 w/o. Which indicates the absolute limits of a mass determination scheme which does not include humidity measurements. The weight per cent of water vapor which the air can hold doubles for about each 20F rise in air temperature indicating that possible errors in mass determination in high temperature containments can be very large.

The available pressure within containment is of great interest in assessing alternatinve test methods. Operating containment pressure is used to drive the atmosphere through existing leakage paths to detect the existance of the leaks. Wherever possible, both the technical specification pressure limit and the typical operating limits were recorded.

8.2 Large Dry Containment

The largest single category of containment type, in terms of number of operating plants is the large, dry containment for a pressurized water reactor. There are about 28 sites with operating reactors having with this containment type. Nine of the 28 sites were surveyed.

Typical free volume of containment of 2,000,000 cubic feet with a range of 1,000,000 to 3,000,000 cubic feet. Relatively open containment geometry exists. Even though large amounts of equipment are located in containment, extensive open areas, especially in the dome, exist. Allowable leakage (La) ranges from 0.1% to 0.5% per day, with 0.2% being typical. Type A test pressures range from 30 to 60 psig with about 50 psig being reported most often.

Twelve to 24 temperature zones are used during Type A testing, but typically about 24 resistance temperature detectors (RTD) are used to provide the information. Three to 12 humidity zones are assigned, typically using lithium chloride dewcells and occassionally using chilled mirror devices. For all sites surveyed, two pressure transducers, one for reading and one for back-up, were used. In one plant surveyed, instrument signals for the Type A test are passed through a single line requiring multiplexing of the data within containment.

Personnel access to containment may be required on a daily basis. For the sites surveyed, containment access frequency ranged from daily to quarterly with most containments requiring access twice per month. While it would appear that frequent containment access would cause difficulties with most continuous monitoring techniques due to the loss of containment atmosphere through the air lock, this is not the case. A typical personnel air lock has an air volume of about 1000 cubic feet. The amount of air lost through the air lock is the amount which is required to pressurize the lock to the containment pressure. Containment pressure may be as high as 3-4 psig in some containments but is typically maintained at about 1 psig. For example, for a 2 psig containment, it would require 140 cubic feet to pressurize a 1000 cubic foot air lock. This amount of air corresponds to 0.007% of the total air mass of a 2,000,000 cubic foot. Therefore, access frequency on the order of weekly does not, by itself, introduce significant errors in a continuous monitoring system.

Venting and purging on line is not unusual. The frequency for venting and purging varies widely between plants. Plants which currently employ continuous monitoring techniques, and a few others, do not vent or purge on line and are able to control containment pressure completely with fan coolers. Some plants vent and purge continuously to maintain pressure below the technical specification limit. The largest single contributor to the vent and purge frequency is usage of instrument air. Any air introduced into containment on a continuous basis will eventually require exhausting that air from the containment to maintain pressure. Small amounts of air usage can be compensated for by reducing bulk containment temperature. A one degree Fahrenheit reduction in corresponds to the addition of about 0.2% total mass (4000 scf) without increasing pressure. Therfore a 5 degree drop in temperature would compensate for an air addition of 1 scfm for a two week period.

Instrument air is typically drawn from outside the containment which could mask leaks, but in a few cases is drawn from the containment atmosphere. The amount of instrument air usage is not usually measured or known. The only qualitative evidence of instrument air usage is the range of venting frequency for plants which correlates roughly to the relative quantity of air usage. A plant which vents daily will have an air usage rate on the order of 45 scfm. This number is based on a 2,000,000 cubic foot containment venting a 0.5 psig pressure once daily.

Effects caused by continuous air sample lines are frequently cancelled by the fact that the sample is usually returned to containment. In cases where the sample is not returned, it represents an apparent leakage of about 5 scfm (0.4% per day) and must be accounted for to provide accrate leakage rate measurements.

In the large, dry containments, bulk temperature variations were reported with 10 degrees Fahrenheit being the most common and 30 degrees being the maximum. Daily temperature variations of 5 to 10F were typical with the extreme limit being 20F. Maximum local containment temperature was usually reported as 120 F with the minimum local temperature typically being 80 F but values as low as 55 F exist at fan cooler outlets and in certain basement locations. A range of temperatures of about 60F within containment was reported.

Humidity is quite low (30-40% R.H.) and nearly constant. Some plants have installed humidity monitors to detect coolant leakage. Typically, humidity levels above 40% indicate coolant leakage.

Technical specification limits on operating containment pressure ranges from 1.5 to 4.0 psig with typical in practice opreating limits of 0.5 to 1 psig. Most plants are allowed to establish a vacuum of 0.2 to 1 psid but in no case was this normally done. Pressure is normally controlled by venting or by using fan coolers.

8.3 Subatmospheric Containments

Two of the four operating sites with subatmospheric containments were surveyed. In general, conditions at subatmospheric plants are the most favorable of all containment types to continuous monitoring techniques.

Containment free volume is about 1,800,000 cubic feet with an allowable leakage of 0.1% per day. Relatively open containment geometry exists, although the slightly smaller volume than the large dry makes the containment proportionally more crowded. Type A test pressure of 60 psig is used.

Eighteen to 21 temperature sensors are used during Type A testing. Two to five humidity zones are assigned, using lithium chloride or chilled mirror dewcells. For both sites surveyed, two pressure transducers, one for reading and one for back-up, were used. Penetrations exist for instrument signals to be taken out of containment without multiplexing.

Personnel access to containment is very infrequent, on the order of monthly or less and may not be needed at all during operation. The amount of apparent leakage caused by containment access may be estimated in the same manner as was done for the large, dry containment. Even though the differential pressure is larger, the very infrequent access results in an in leakage of 0.0001% per day from quarterly containment access or a mass change of 0.009% per access.

Purging is not normally conducted on line. The containment is continuously vented to maintain the required amount of vacuum. Venting is accomplished by exhaust fans which run as needed to maintain pressure. The exhaust fans are small enough in capacity that large leaks may be detected by the inability of the fans to maintain vacuum. Also the possibility exists for accurate monitoring of the exhaust fan rate. Currently the fan duty cycle is used as an estimate of exhaust rate. The largest single contributor to the exhaust rate is usage of instrument air. However, one of the two sites surveyed draws the instrument air from within containment which eliminates a large fraction of the otherwise required venting.

Temperature within containment ranges seasonally from average values of about 75F to 110F. Daily variations of 5 to 10F were reported. The maximum temperature gradient (coldest to hottest area at one time) was reported to be about 30F. Overall, the subatmospheric containment temperatures were the most uniform and stable of the containment types.

Humidity ranges of 35 to 75% were reported although information concerning on line humidity instrumentation is not available. Even though the humidity range is higher than that of the large, dry containment, the maximum possible error caused by humidity in mass determination is only twice as great due to the lower and more stable temperatures.

Technical specification limits on operating containment pressure do not list a single pressure ranmge but are dependent on plant conditions, a typical operating value is about 9 psia (6 psi vacuum). The resulting pressure differential between containment and the outside atmosphere is the largest of any containment type. However, the negative value of the differential pressure could complicate the extrapolation of continuous monitoring leakage results to accident pressure leakages. Also all leakage measured in subatmospheric containments will be inleakage which could dictate the use of techniques specifically adapted for use here.

8.4 Ice Condenser

Five ice condenser containment sites exist, two of which were contacted for the survey. Overall, the ice condenser containment represents the most difficult containment for the implementation of continuous monitoring techniques due to the highly compartmentatized volume, large temperature gradients and low allowable operating pressure.

Free volume of containment is 1,900,000 cubic feet. The existence of ice condensing equipment requires that the containment be relatively crowded and very compartmentalized. Since containment geometry is such that the only passage between certain areas of containment is through the ice banks, free flow of air through the containment does not exist. Allowable leakage (La) of 0.25% per day was reported Type A test pressures is the lowest of all containment types being 12 psig.

Due to the existence of the ice, the containment has large thermal gradients such that about 50 RTDs are needed for Type A testing. This number is by far the largest of any containment type. Two pressure transducers, one for reading and one for back-up, are used.

Personnel access to containment is required every 12 hours. containment pressure. However, the extremely low allowable operating pressure causes this access frequency to yeild an effective leakage rate of 0.002% per day.

Venting and purging on line is frequent. Venting frequency of 8 hours was reported. It is felt, however, that, as with large dry containments, the venting frequency is a strong function of the instrument air usage. Continuous monitoring of instrument air usage could provide valuable information concerning reduction of venting frequency. Purging is done on a weekly basis and is not of great interest due to the much more frequent venting operations.

Instrument air is drawn from outside the containment which could mask leaks and, as mentioned before, probably determines the venting frequency. The amount of instrument air usage is not usually measured or known.

Effects caused by continuous air sample lines are frequently cancelled by the fact that the sample is usually returned to containment. In cases where the sample is not returned, it represents an apparent leakage of about 5 scfm (0.4% per day) and must be accounted for to provide accrate leakage rate measurements.

The containment temperature for an ice condenser is, expectedly, unlike all other containment types. The concept of a bulk or average temperature, discussed for all other containment types, is not valid here. The existence of large quantities of ice and large heat sources within containment indicate that a single containment air temperature would be meaningless. The temperatures in containment are well controlled by the ice and the associated refrigeration equipment such that seasonal or daily temperature variations are not noted. Containment air temperatures range from 20F near the ice to 110F in the lower compartment.

Humidity is maintained at low levels to prevent formation of frost on the ice. The consumption of ice by sublimation and removel of resulting humidity was not reported. However, the amount of water vapor that can exist in saturated 20F air is about 0.2 w/o.

Technical specification limits on operating containment pressure to 0.3 psig with typical in practice opreating limits of 0.1 to 0.2 psig. These low operating pressure limits will very likely place severe limitations onthe sensitivity of continuous monitoring techniques since a measured leakage is driven by the available pressure.

8.5 Mark I

Mark I BWR containments comprise the second largest containment group in terms of operating sites. There are currently 14 sites with operating Mark I BWRs. Of the fourteen, five were contacted for this survey.

Free volume of containment is 300,000 cubic feet including both the torus and the drywell. The containment geometry is extremely crowded due to the very small containment volume. Allowable leakage (La) ranges from 0.5% to 1.5% per day. Even though the per cent leakage is larger than that of a large, dry containment, the total mass leakage allowed is about the same due to the smaller volume. Type A test pressures range from 40 to 50 psig.

Twenty to thirty temperature sensors are used during Type A testing. Two to 10 humidity sensors are used and may be lithium chloride or chilled mirror type. Both temperature and humidity sensors are assigned individually to the torus and drywell so that each volume is treated separately during the test. Either one or two pressure transducers are used. When two are used, one is placed in the drywell and one in the torus. In one case it was found that instrument signals were multiplexed within containment and sent through a single penetration. In all other plants, dedicated penetrations are used for the instrumentation lines.

Due to the nitrogen inerting of the containment, personnel access to containment is not allowed during plant operation. Venting and purging occurs about every two weeks. Venting alone is done primarily to release instrument air from containment. The instrument "air" is nitrogen which may be drawn from the containment atmosphere or taken from the nitrogen tanks which supply nitrogen to contianment. Nitrogen tanke are located on site which contain liquid nitrogen. Frequently the instrument air is the nitrogen boil-off which results from maintaining the nitrogen in a liquid form. Most plants have some form of nitrogen usage monitoring system which may be as simple as periodic checks on the remaining nitrogen in a tank. Due to the significantly smaller containment volume than a large, dry containment, instrument air usage at the same rate will produce a proportionately higher rate of per cent mass change and pressure rise. A 1 scfm usage will increase the contained mass at a rate of 0.5% per day and the pressure at a rate of .07 psi per day. As such, BWR containments require a more accurate accounting of instrument air usage to employ continuous monitoring methods.

Containment purging is done to reduce the oxygen content of the containment atmosphere to less than the required 4%.

postulated by some plants. Three possible sources were identified, the first being that of air being drawn in the suction line for instrument air between the containment and the compresser. The second source suggested is through main steam isolation valves which leak steam into containment where the steam contains oxygen produced by the breakdown of water whcih is caused by ionizing radiation. The final theory again involves steam leakage into containment but the oxygen source is thought to be air drawn into the steam in the steam condenser which is maintained at a large neagative pressure.

BWR containments tend to have higher temperatures than PWRs. In Mark I containments, bulk temperature variations of 20 to 30F were reported. Maximum containment temperatures of 130F to 160F with a typical value of 150F were found. The maximum temperature typically occurs in the upper drywell region with corresponding temperatures of 80F in the wetwell. Daily temperature variations are almost none existent due to the fact that the external containment walls are not exposed to the weather. Large temperature gradients, typically 80F, were reported.

A single humidity value for the entire containment is not meaningful due to the very different conditions in the drywell and wetwell. Wetwell humidity is at saturation (100%) while drywell humidity is estimated to be 30-40% although it is seldom measured.

A single operating pressure for containment does not exist due to the differential pressure required between the drywell and torus. Typically, the torus is maintained at atmospheric pressure while the drywell is at 2 psig. This fact could have important implications on continuous monitoring tecniques since no pressure exists in the wetwell to drive leakage through existing paths.

A final note on containment geometry is the fact that the entire containment is placed within a building from which exhaust is drawn and sent through a single source, the effluent stack. This passing of all containment leakage through a single point could be the basis of a leak detection method based on detection of an escaping tracer gas.

8.6 Mark II

For the purpose of the survey the Mark I and Mark II containments are very similar. As will be indicated in the following discussion, much of the information presented above for Mark I is also applicable to the Mark II. There are currently 4 operating Mark II sites, two of which were surveyed.

Free volume of containment is 350,000 to 400,000 cubic feet. Again, the containment geometry is extremely crowded, but not quite as much as the Mark I. Allowable leakage (La) ranges from 0.5% to 1.0% per day. These rates and th total resulting mass leakage are similar to the Mark I. Type A test pressures of 40 and 45 psig were reported.

Twenty-four to thirty temperature sensors are used during Type A testing. About ten humidity sensors are used and may be lithium chloride or chilled mirror type. Drywell and wetwell instrumentation is similar to the Mark I containment. Instrument signals were multiplexed within containment and sent through a single penetration in one case.

Purging, venting, and instrument air usage is very similar to that of the Mark I containments.

Temperature data for Mark II containments during operation is the same as the Mark I with the exception of higher overall temperature values. Maximum temperatures may be as high as 225F and minimum temperatures of 100F are reported.

Humidity values are the same as for Mark I except that a per cent relative humidity does not exist when air temperatures are above the local boiling point. However, even though humidity is not directly measured, dew point levels are expected to be about the same as those in Mark I drywells.

Operating containment pressures are typically 1 psig with a maximum allowable pressure of 1.6 psig. As in the Mark I wetwell pressures are usually atmospheric with the same implications for continuous monitoring as were expressed in the discussion of Mark I containments.

Like Mark I containments, the Mark II is completely enclosed with a single effluent stack exhaust so that the implications for gas tracer detection on Mark I containments are applicable here.

9. Conclusions

The object of this report is the discussion of the current status of integrated leakage rate testing and the presentation of any information which could be useful in the evaluation of alternative containment leakage rate testing methods. In terms of current leakage rate testing, industry wide practice is invariant between plants of a given type and, at most, current developments relate to subtle changes in instrumentation and data processing.

With regard to alternative containment testing methods, it has been shown that the reduction in leakage through open lines by the pressure reduction from Type A testing to operating pressure limits is not as severe as could be anticipated such that the sensitivity of low pressure test methods may be great enough to detect leakage rates in the range of allowable values. The brief analysis, however, makes no attempt to address the problem of leak path changes caused by changes in pressure.

The principles of operation of alternative methods to be considered indicates that a wide range of techniques are possibly applicable to the problem of leakage measurement. At this time, the specific methods are not dicussed but only mentioned as a preliminary step to the plant information survey.

Information gathered in the operating plant survey shows only a limited amount of variation between plants with a given containment type concerning parameters of importance to the application of continuous leakage rate measurement techniques. The item of greatest variation and concern is the purge and vent frequency. Alternative test methods rely on long testing cycles to be able to achieve the desired measurement sensitivity. Plant purging and venting is the major factor in determining the test cycle time available. Other plant specific variations such as source of instrument air, humidity monitoring, disposition of samples, and operating pressure may require plant specific action to achieve acceptable test sensitivity.

Variations in paramaters between containment types is very large, as expected. Items such as atmosphere inerting, typical operating pressures, containment compartmentalization, required access, on power variations, and containment volume are examples of these parameters. The variations make it extremely unlikely that a single alternative test method would be suitable for all containment types. It is most likely that a separate test method will be best for each large drys, ice condensers, subatmospherics, and BWRs.

From the survey, it appears that applicability of atlernative test methods to containment types, in order, beginning with most applicable, is: subatmospheric, Mark II, Mark I, large dry, and ice condenser. At the current time, the combination of plant operating parameters with underlying principles of alternative test methods does not exclude the possibility of developing a test method for each containment type.

APPENDIX D

INTERIM LETTER REPORT FOR SUBTASK 1.2,
COMPILATION OF ALTERNATIVE CONTAINMENT LEAK RATE TEST METHODS

ALTERNATIVE CONTAINMENT INTEGRITY TEST METHODS PROGRAM
FIN A1802

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List of Figures

List of Tables

1. INTRODUCTION

Nuclear power plant containments must meet stringent criteria in terms of leakage rate to assure that unacceptable amounts of radioactive particulates and gases within the containment will not be released to the atmosphere in the event of an accident. To provide assurance that operating power plants meet the established leakage criteria, the Nuclear Regulatory Commission (NRC) has issued Title 10 of the Code of Federal Regulations, Chapter I, Part 50, Appendix J [1] which requires that operating power plants perform Integrated Leakage Rate Tests (ILRT) approximately every three years. The test consists of elevating the containment pressure to a specified value and measuring the amount of leakage from the pressurized containment. These tests are also termed Type A tests. Local leak tests are also conducted on individual containment penetrations and isolation valves. These local tests are termed Type B and Type C tests respectively.

The Type A test can only be conducted during a plant shutdown and, because of this and the time required for completion, it can only be done at relatively infrequent intervals. The integrity of the containment as a whole is not normally tested during the time between Type A tests but local leak tests on valves and penetrations may be performed. Therefore, an undetected breach of containment integrity (UBCI) could exist for an extended period of time before discovery. Pacific Northwest Laboratories (PNL) has investigated the probability of containment unavailability caused by UBCIs [2], and concluded that the probability that the specified level of containment integrity will be unavailable (i.e. the Type A allowable leakage rate criteria would not be met) at any given time is approximately 0.3. The basis for this conclusion is the analysis of a data base consisting primarily of licensee event reports (LERs) which was compiled by PNL [2].

Concern about the possibility of long term UBCIs has resulted in the initiation of this project by NRC under FIN A1802 in which Sandia National Laboratories has been asked to study the feasibility of alternative containment integrity test methods and to develop methods which could be used to detect breaches of containment integrity in a more timely manner. This report discusses Subtask 1.2 of the project and Subtask 2.2 to the extent that it is complete. Subtask 1.2 consists of compiling alternative containment integrity test methods and performing a preliminary ranking of the methods based on a knowledge of data acquisition techniques and leakage rate testing. Subtask 2.2 involves the detailed evaluation of the methods and final conclusions concerning applicability and effectiveness. Since Subtask 2.2 is not complete, much of the detailed analysis and description of the methods is not available. Further, Subtask 2.1, which was designed to provide cost of implementation data for the methods, has been cancelled such that no actual cost information is presented. The purpose of this document is to present as complete a description as currently possible for each of the alternative test methods being considered. The lack of detail in the analyses and descriptions of the various methods is due to the fact that the study of the methods is not complete and only interim results are available. This report also presents a very brief discussion of concepts for alternative methods which were investigated to the extent that the method was deemed not practical for application in containment monitoring. These abandoned techniques are presented to provide a complete overview of the status of containment integrity monitoring through alternative test methods.

2. BACKGROUND

Current requirements for reactor plants require a test of the integrity of the containment pressure boundary be conducted at least 3 times during 10 years. The test consists of pressurizing the containment and monitoring the leakage from the containment by precisely measuring the pressure, temperature, and dew point and relating these measurements to the mass of air contained through use of the ideal gas relation. Containment volumes are on the order of 1,000,000 cubic feet and typical leakage rate acceptance criteria may allow as low as 0.1% contained air mass leakage in 24 hours. Typical test pressures range from 10 to 65 psig.

The scope of the current study is to devise and analyze methods by which an undetected breach of containment integrity (UBCI) might be detected in an operating plant during the time in between ILRTs. Such a system need not be capable of detecting the extremely low leakage rate required during ILRTs but such resolution may be considered an extreme limit. The typical allowable leakage for an ILRT is roughly the same as the amount of leakage which would pass through a .06 inch diameter orifice under similar test conditions. A system to detect an UBCI would be considered acceptable if it were able to detect a much larger hole, such as a valve unintentionally left open, within several days of the event. At present, methods covering a wide range of sensitivity are being considered.

Some difficulties are encountered during ILRTs which stem primarily from the extreme precision of measurement required to reliably detect an air mass change of less than 0.1%. The problem is compounded by the presence of diurnal temperature fluctuations and water condensing from the containment atmosphere due to the increased pressure of the test. The alternative methods being devised have the advantages of operating under much lower relative humidity and over significantly longer times but have disadvantages which include much greater thermal gradients due to plant operation and the lack of elevated pressure which serves to increase the leakage to be detected.

3. TECHNIQUE DESCRIPTIONS

The various alternative test methods currently considered to be the most feasible are discussed here. The techniques discussed range from fully developed and proven methods to concepts for methods which have no experimental confirmation. The discussions of the techniques presented are often limited by the lack of information concerning the technique, this is especially true of the unproven methods. The discussion includes a description of each technique, estimation of the sensitivity, and comments concerning applicability to various containment types. All available information regarding the near-term feasibility and implementation of the techniques is also presented.

In evaluating the sensitivity of the methods, information regarding containment volume, pressure, humidity, allowable leakage and a rough correlation between low and high pressure leakage rates is used in the form of average values taken from Reference [3]. Technique sensitivities are discussed in terms of the amount of time required to detect a leak of a given per cent enclosed mass leakage per day (typically 1% per day is used) at ILRT test pressure, a rough correlation is applied to account for the reduced leakage which would result at the tech spec allowable pressures. Since most alternative methods are sensitive to a minimum amount of enclosed mass change, the product of the per cent per day leakage and the total time to detection is typically a constant value characteristic of the method.

While the individual alternative methods are discussed in detail below, a few general observations concerning the applicability and potential use of the methods are appropriate. Most methods exhibit a sensitivity to inleakage of instrument air. In general, this inleakage serves to mask existing leakage rates by adding air to containment. Further, as discussed in the Reference [3] report, instrument air usage is the greatest single contributing factor to frequent venting of containment during operation. Frequent containment venting has the effect of decreasing the available monitoring span of most alternative methods and thus increasing the minimum leakage rate which may be detected. Plants with low instrument air usage or with the instrument air source inside containment will tend to have much greater success with the continuous monitoring techniques than others. Secondly, several types of breaches of containment integrity cannot be detected with the alternative methods. These breaches include leaking valves which are open during plant operation and closed, fluid filled systems under pressure. Specifically, if low pressure air (about 1 psig) from within containment will not leak through the breach, then an alternative method will not detect it. Reference [4] discusses the portion of UBCIs which could be detectable by alternative methods.

Some of the methods discussed exhibit a sensitivity to humidity and temperature changes within containment; meaning that such atmospheric changes result in monitoring system indications identical to those of containment leakage. This undesirable sensitivity requires that the smallest integrated leakage which may be reliably sensed must be greater than the largest expected leakage indication that could be produced by temperature and humidity changes. This limitation causes the methods to respond rather slowly to postulated leakage rates. One method of providing more rapid leakage indication is to use temperature and dew point instrumentation to reduce the large error limits otherwise introduced by assuming maximum fluctuations. From observations of Type A test experience, it appears that one or two dewcells and six to ten temperature sensors (RTDs) could typically provide the necessary information to reduce the errors by an order of magnitude and correspondingly reduce the detection time for a given leakage rate. In the method discussions where addition of such instrumentation is mentioned, the above amount of instrumentation and expected results are the same regardless of the specific method.

Several types of instrumentation are used by the various alternate methods. Principally the methods require the use of pressure, thermometry, dew cell, gas flow, and gas concentration instrumentation. Most of the required instrumentation is readily available from a wide variety of manufacturers. In cases where the transducer requirements are not readily available from many different sources, the known suppliers of such instrumentation will be discussed along with the technique descriptions.

3.1 External Detection

External detection schemes comprise a single method in the respect that all applicable schemes have the same applicability, sensitivity, and theory of operation. In this method, the concentration of a tracer is monitored outside the containment and an unusually high concentration is an indication of an unacceptable leakage rate.

A rough estimate of acceptable tracer concentration level outside containment can be made. An assumed leakage rate of 1000 actual cubic feet per day at test pressure (corresponds to most average containment values), converts to 250 standard cubic feet per day (.16 scfm) at 1 psig.

For this method, Mark I and II BWRs are of primary interest because of the existence of a single vent, the effluent stack, through which the entire atmosphere surrounding the containment is vented. While PWRs may not be ruled out entirely, the number of tracer detectors required to provide reasonable assurance of leak detection appears prohibitively large.

For a BWR effluent stack, flow rates of about 100,000 scfm are typical. This results in a dilution factor of 600,000 to 1 in concentration from inside containment to the effluent stack for the .16 scfm leakage. A more advantageous monitoring point may exist which would result in a lower dilution factor, depending on plant specific ventilation schemes.

The primary tracer being considered for this method is ozone since it is created in containment by the interaction of oxygen with ionizing radiation. Further, ozone is detectable in concentrations as small as .001 part per million (ppm). Use of ozone would not require introduction of a tracer within containment. Any other tracer which might be of interest to introduce in controlled amounts within containment must not be highly chemically active and must be detectable in very low concentrations to be of use. The only tracers currently envisioned which fit this category are radioactive isotopes of inert gases. No work has yet been carried out on determination and detection of a specific radioactive tracer.

Environmental standards impose a limit of about .1 ppm ozone in the atmosphere. This level of ozone in the effluent stack corresponds to a 100% per day leakage at test pressure with an ozone concentration in containment of 600 ppm (0.06%). While no information is currently available as to the naturally occurring ozone level within containment, the above level seems quite high. This may limit the use of this method to areas where environmental ozone concentrations are stable and low. An order of magnitude improvement might be achieved by comparing atmospheric and effluent stack ozone and correlating the existence of a leak to the difference between the two values. A detailed analysis of sensitivity of the system cannot be completed due to the lack of available data on containment ozone concentrations. However, the presentation of the feasibility of the system is done from the standpoint of acceptable sensitivity limits with respect to ozone concentrations. Therefore, it is important to remember the fact that the overall feasibility of the system is contingent upon sufficient ozone levels within containment. The reference [3] report which discusses a survey made of many operating plants states that none of the plants surveyed had measured ozone concentration during operation. While data concerning ozone concentration is not currently available, the ready availability of ozone monitors makes the collection of such data a relatively straightforward task. It is unlikely, however, that ozone concentrations large enough to allow detection of leakage rates lower than 10 La (about 10% per day) exist.

This method is relatively inexpensive as compared to other alternative methods in terms of instrumentation cost and plant modifications since it requires only two ozone monitors and associated recording equipment along with the necessary modifications to allow the sampling to be done. Instrumentation of sufficient accuracy to monitor expected ozone concentrations is commercially available. A true leakage rate is not determined here but rather an indication of unsatisfactory leakage. The method applicability is limited to BWRs and may be unsuitable in some areas due to the required high sensitivity of ozone detection compared to local atmospheric levels.

The measurement of ozone concentration is a well established practice such that near term implementation of a system such as this is reasonable. Due to the lack of data on existing containment ozone levels and the variation in atmospheric levels, this method must be approached on a plant specific basis. A logical approach to establishing a reliable system would be to install the two required ozone monitors plus one additional atmospheric monitor. The data obtained from these three sources could be used to establish a base line to allow sensing of deviation from the norm. The use of controlled breaches of containment integrity might also be considered to provide valuable calibration and sensitivity information for the system.

3.2 Tracer Gas Dilution

This technique involves the maintenance and monitoring of a chemical tracer element introduced within the containment. The change in concentration of the tracer over time is a direct measure of the integrated leakage into containment since inleakage proportionally dilutes the tracer concentration and outleakage carries tracer with it resulting in no net dilution. This fact limits the method to containments which may operate at negative gage pressure.

Typical allowable negative pressures are about -6 psig for subatmospheric and -1 psig for large, dry containments. BWR and ice condenser containments do not typically operate at negative gage pressures.

The tracer of greatest interest is neon gas which is being considered because of chemical inertness and molecular weight

-6-

close enough to that of air (20 vs. 29) so that stratification should not cause extreme difficulties. The selection of another gas with similar molecular weight and low chemical reactivity should not be ruled out. Neon does have the drawback of difficulty of concentration monitoring and other suitable gases may well exist.

The system envisioned would consist of a concentration monitor and equipment to periodically introduce amounts of tracer into the containment. At the beginning of a test cycle, such as following a shutdown, a low concentration of neon (100-1000 ppm) is established in containment. The actual value of the concentration is then measured by a concentration monitor to establish a benchmark concentration. The tracer concentration is monitored continuously or at intervals with the per cent reduction in concentration being equal to the integrated per cent of inleakage.

This method is inherently insensitive to humidity, temperature and pressure changes in containment since the mass concentration of tracer is unaffected by these factors. The method is sensitive to instrument air usage since the air serves as an inleakage which dilutes the tracer. Adding appropriate amounts of the tracer to the instrument air would greatly reduce the sensitivity to this effect. Also, using a source for the instrument air which is inside containment would eliminate this sensitivity.

The equipment requirements for this method are minimal and sensitivities on the order of 1% total integrated leakage may be expected or detection of a 1% per day leak at accident pressure in 4 days at -1 psig or in less than 2 days at -6 psig.

Equipment to introduce and control trace gas concentrations is readily available. However, a sufficiently accurate concentration monitor for neon has not yet been located. Use of a gas which is not completely inert would allow for much greater accuracy in concentration measurement, and a much greater likelihood of commercial availability of the required equipment. A complete investigation of possible trace gases has not been conducted.

Several items remain open for investigation for this method as follows:

a. As previously mentioned, the existence of a tracer monitor is somewhat uncertain for neon and other acceptable gases for which the concentration is more easily measured may exist.

b. The extent of stratification of the tracer has not been analyzed.

pressure variation from temperature and humidity effects (which is dependent on the amount of temperature and dewcell instrumentation employed), a leak would have been found. As the system monitors for longer time periods, the maximum temperature and humidity effects remain constant but the effect of a continuing leakage grows.

In the case where air is injected into the containment separately from the instrument air system, some compensation for instrument air usage may be required. Methods of compensating for instrument air usage include averaging the leakage rate measured under both positive and negative pressures; measuring instrument air usage and adding or subtracting the value to the quantity injected; and sourcing the instrument air from within containment.

The application of this method t subatmospheric containments is identical with the exception of the treatment of instrument air. Since subatmospheric containment leakages are into containment, instrument air usage acts as a breach of containment integrity instead of masking leaks. Therefore, instrument air usage as discussed above must be employed.

Equipment and instrumentation for this method consists of a an air source, if not currently installed, and an integrating mass flow meter. The required air source must provide air at a rate equal to the maximum leakage rate to be measured (about 200 scfm for 100 La) and at an available pressure slightly greater than the tech spec limit for plant operation. These requirements could be met with a small squirrel cage fan or vane type compressor depending on the maximum pressure needed. Both items are readily available in the appropriate size and accuracy which would be required.

This method is applicable to all containments which are not nitrogen inerted. However, the nitrogen monitor technique explained later provides a similar method of leak detection which is applicable to nitrogen inerted containments.

Although this method is quite slow in terms of leak detection, its simplicity makes it a good candidate for large leaks. If instrument air is the injection source or if the exhaust pumps of a subatmospheric containment are used, implementation of this method is quite simple. Further, this method is used to some extent in subatmospheric containments where exhaust pumps of a known capacity are monitored to determine the operating duty cycle. Excessive pump operation indicates a breach of containment integrity.

The equipment required for implementation of this method is commercially available and some of the required apparatus is already in place at some plants. In its simplest form, the close enough to that of air (20 vs. 29) so that stratification should not cause extreme difficulties. The selection of another gas with similar molecular weight and low chemical reactivity should not be ruled out. Neon does have the drawback of difficulty of concentration monitoring and other suitable gases may well exist.

The system envisioned would consist of a concentration monitor and equipment to periodically introduce amounts of tracer into the containment. At the beginning of a test cycle, such as following a shutdown, a low concentration of neon (100-1000 ppm) is established in containment. The actual value of the concentration is then measured by a concentration monitor to establish a benchmark concentration. The tracer concentration is monitored continuously or at intervals with the per cent reduction in concentration being equal to the integrated per cent of inleakage.

This method is inherently insensitive to humidity, temperature and pressure changes in containment since the mass concentration of tracer is unaffected by these factors. The method is sensitive to instrument air usage since the air serves as an inleakage which dilutes the tracer. Adding appropriate amounts of the tracer to the instrument air would greatly reduce the sensitivity to this effect. Also, using a source for the instrument air which is inside containment would eliminate this sensitivity.

The equipment requirements for this method are minimal and sensitivities on the order of 1% total integrated leakage may be expected or detection of a 1% per day leak at accident pressure in 4 days at -1 psig or in less than 2 days at -6 psig.

Equipment to introduce and control trace gas concentrations is readily available. However, a sufficiently accurate concentration monitor for neon has not yet been located. Use of a gas which is not completely inert would allow for much greater accuracy in concentration measurement, and a much greater likelihood of commercial availability of the required equipment. A complete investigation of possible trace gases has not been conducted.

Several items remain open for investigation for this method as follows:

a. As previously mentioned, the existence of a tracer monitor is somewhat uncertain for neon and other acceptable gases for which the concentration is more easily measured may exist.

b. The extent of stratification of the tracer has not been analyzed.

c. The time required for the released tracer to sufficiently mix with the containment atmosphere has not been determined.

This method will not be practical for on line usage until a suitable tracer gas which serves to solve the above three concerns is located.

Although this method is capable of providing rapid leak detection in subatmospheric containments with small amounts of instrumentation, the above mentioned open items preclude near-term implementation of this method without some development effort. However, the potential advantages of this method dictate that it be seriously considered for application.

3.3 Continuous Injection Into Containment

With this method, air is injected into the containment to maintain a low positive pressure sufficient to promote flow through existing leak paths, but within tech spec limits. The integration of the air input over extended time gives the average leakage rate. This may also involve the removal of air if a constant pressure environment or negative gage pressure is to be maintained. This method, in this form, does not compensate for changes in humidity and air temperature.

Since humidity changes can alter the apparent air mass by as much as 3% in a leaktight vessel and typical containment temperature changes can result in a pressure change of about 7% (40°F) the lower limit of integrated mass loss detection is about 10%. This lower limit would correspond to a 40 day period to detect a 1% leak at 1 psig and 22 days at subatmospheric conditions of -6 psig. This method is employed, to some extent at, subatmospheric plants where the duty cycle of the exhaust fans is monitored.

Addition of small amounts of temperature and dew point instrumentation could significantly reduce this lower limit with a corresponding penalty in terms of cost and system complexity. An order of magnitude decrease in detection time could be realized by employing a single dewcell and a few temperature sensors.

The simplest application of this method would consist of a flowmeter installed in the instrument air line to monitor instrument air usage and compare the actual containment pressure to that predicted by the ideal gas relation assuming constant or measured temperature and humidity. The ratio of the predicted and actual pressures is a direct measure of mass loss without accounting for humidity and temperature variations. When the ratio exceeds the maximum possible pressure variation from temperature and humidity effects (which is dependent on the amount of temperature and dewcell instrumentation employed), a leak would have been found. As the system monitors for longer time periods, the maximum temperature and humidity effects remain constant but the effect of a continuing leakage grows.

In the case where air is injected into the containment separately from the instrument air system, some compensation for instrument air usage may be required. Methods of compensating for instrument air usage include averaging the leakage rate measured under both positive and negative pressures; measuring instrument air usage and adding or subtracting the value to the quantity injected; and sourcing the instrument air from within containment.

The application of this method t subatmospheric containments is identical with the exception of the treatment of instrument air. Since subatmospheric containment leakages are into containment, instrument air usage acts as a breach of containment integrity instead of masking leaks. Therefore, instrument air usage as discussed above must be employed.

Equipment and instrumentation for this method consists of a an air source, if not currently installed, and an integrating mass flow meter. The required air source must provide air at a rate equal to the maximum leakage rate to be measured (about 200 scfm for 100 La) and at an available pressure slightly greater than the tech spec limit for plant operation. These requirements could be met with a small squirrel cage fan or vane type compressor depending on the maximum pressure needed. Both items are readily available in the appropriate size and accuracy which would be required.

This method is applicable to all containments which are not nitrogen inerted. However, the nitrogen monitor technique explained later provides a similar method of leak detection which is applicable to nitrogen inerted containments.

Although this method is quite slow in terms of leak detection, its simplicity makes it a good candidate for large leaks. If instrument air is the injection source or if the exhaust pumps of a subatmospheric containment are used, implementation of this method is quite simple. Further, this method is used to some extent in subatmospheric containments where exhaust pumps of a known capacity are monitored to determine the operating duty cycle. Excessive pump operation indicates a breach of containment integrity.

The equipment required for implementation of this method is commercially available and some of the required apparatus is already in place at some plants. In its simplest form, the installation of a mass flow meter in the instrument air source line would be the only equipment modification necessary. Long term measurement of instrument air usage provides a measure of containment leakage. The discussion presented above allows for a wide uncertainty in containment air temperature. The monitoring of already existing temperature transducers within containment would significantly reduce this uncertainty. This coupled with the relatively narrow humidity limits typically found in large dry containments [3] would make this method very practical for certain plants. With these factors in mind, a 7-day detection time for a 1% leak might be realized in a large, dry containment with sufficiently infrequent purge and vent cycles. Even more rapid detection times could be realized for subatmospheric containments.

This method should be seriously considered since it appears that it could provide a relatively simple, effective, and low cost approach to the monitoring of large breaches of containment integrity.

3.4 Direct Atmosphere Weighing

This technique provides a direct and rapid method of weighing the air mass of a containment. The equipment consists of a differential pressure transducer placed in the bottom of containment with one side of the transducer open to the environment and the other attached to a dry, air filled tube. The other end of the tube is connected to a second differential pressure transducer at the top of the containment. The difference in static pressure produced by the air in the containment between the two pressure transducers is the difference in the transducer readings plus the known constant static pressure of the air in the tube. This value, multiplied by a suitable containment cross-sectional area, yields the weight of air in the containment. Figure 1 is a conceptual sketch of this method.

The differential pressure produced by the enclosed column is a function of the mass of enclosed air and is unaffected by the column temperature and pressure. Temperature control of the connecting tube would allow the reading of the transducer to be centered around zero differential pressure which allows for high sensitivity of the transducer. The system does not compensate for changes in humidity within the containment which would lead to a lower sensitivity limit of about 3% total mass leakage.

The primary difficulty with this technique appears to be the use of an effective cross sectional area of the enclosed air. The varying cross section of an actual containment will introduce errors when the relative vertical temperature profile varies through the height of the containment. The use of several such systems, to reduce the variation in cross section in one area, is a possible solution to this variation.

To be effective, very low range, high resolution transducers are Such transducers are commercially available with full scale ranges of 0.02 psig and resolution of 0.1% of full scale. To date, only two suppliers of these transducers have been located. These suppliers are Setra Systems Inc. of Acton, Massachusetts and MKS Instruments Inc. of Burlington, Massachusetts. With such transducers, the temperature of the air in the tube should be controlled to maintain a pressure close to the containment pressure to prevent damage. Considering the relatively narrow pressure and temperature ranges of operating containments as a portion of absolute temperature (les than 20%), such a control system could be readily implemented.

For a 100 foot high containment, the total pressure difference will be about 7 psf or .05 psi which would allow resolution of the mass down to less than 0.1% of the total mass without consideration for the cross sectional area weighting. The contribution to total pressure produced by air velocities may be of concern with this method. It is assumed that screening or transducer placement could be used to reduce the local air velocity to less than 5 feet per second. Such a velocity corresponds to a total pressure elevation of .03 psf or .0001 psi which is equivalent to a mass change in containment of 0.5%. This would increase the lower limit of sensitivity to 4%.

This method is considered applicable primarily to containments with open geometries, specifically, large dry and subatmospheric PWRs. The lack of applicability to BWR containments limits the range of humidity variation to less than 1% of the total mass, since humidity variations in large dry containments are much less than that of BWR containments. Based on the large fraction of open volume in a large, dry containment and lack of variation in the spatial-thermal profile shape, it is likely that, with cross-sectional area effects included, a sensitivity limit of 3% overall may still be obtainable. Therefore, a 1% per day leak could be detected in 12 days.

The primary limitations of this method appear to stem from the determination of a cross-sectional area weighting term. The required analysis on this area has not been done and would be necessary on a plant specific basis before such a system could be seriously considered. While the necessary instrumentation and equipment to implement this method is available, the practicality and accuracy of the method have not yet been experimentally demonstrated. Any implementation of this method must be undertaken with that fact in mind. The disadvantages of required development might be outweighed by the insensitivity of the method to temperature and pressure in containments where highly nonisothermal conditions are known to exist. While development of this method does not appear difficult, the fact that it is an unproven method indicates that attempts at implementation should be approached with caution.

3.5 Acoustic Velocity Measurement

The time of transit of an acoustic wave across the containment serves to integrate the square root of the absolute temperature in the wave path. This principle could be applied to measure a bulk average temperature of the containment air, the most difficult facet of mass determination by ideal gas behavior. A procedure capable of yielding a theoretically correct temperature value would be one where the time of transit was directly proportional to the temperature of the fluid being traversed. The maximum error caused by the square root dependence has been bounded by computation for assumed worst case temperature variations and may be sufficiently small (typically <1%).

Application of the concept is envisioned by using two sonic transmitting units to establish a standing acoustic wave in containment. Figure 2 illustrates this arrangement. Since the number of wavelengths able to exist in the distance provided must be a fairly low integer, the bulk temperature may be measured by comparing the small set of allowable wavelengths of the standing wave to the measured frequency. The number of wavelengths and measured frequency can be used to determine the transit time of the wave. The result would be a single reasonable value for bulk temperature. Actual temperature measurements may not be required if a single benchmark point is taken at the beginning of the sampling cycle and combined with a measured absolute pressure. Subsequent measurements of transit time, coupled with the current pressure would be used to provide periodic or continuous measurements of the containment atmosphere through use of the ideal gas relationship.

The applicability of this method is limited to containments with open geometries where wave transit across much of the containment volume is feasible, primarily large dry containments and possibly subatmospherics.

Although work is far from complete on this method, an error in properly weighted temperature of less than 1% may be reasonably expected. Coupled with the 1% maximum humidity variation (since the technique is not applicable to BWRs), a 2% lower limit is obtained which would indicate detection of a 1% per day leak in 8 days at 1 psig. Sonic transmitters and receivers with the required 180 degree phase shift mechanism are readily available as are frequency meters needed to determine the standing wave frequency. Development would be required to produce a system capable of maintaining the standing wave frequency. Such development does appear to be within the scope of existing electronic measurement techniques.

In its present form this method is a concept with no demonstration of its feasibility or implementation. Further, no existing system is known which applies this principle of integrated temperature measurement in this way. This method would require significant amounts of development effort to produce an operating system and is not recommended for near term implementation. The equipment needed to implement this method is expected to consist of piezoelectric sensors and speakers and associated analog integrated circuitry.

3.6 Reference Vessel Technique

Historically, two methods of conducting Type A tests have been employed. The most common technique has been described in chapter 2. The second method, called the reference vessel method, employs a series of leaktight chambers with connecting tubing situated around the containment to provide a properly weighted air volume in thermal equilibrium with the containment atmosphere. Measurements of the pressure of the reference volume compared to the containment pressure are used to give a measure of leakage rate. This technique involves monitoring the enclosed air mass of containment through use of a reference vessel similar to those which have been used in Type A testing. The reference vessel is used here as a gas thermometer with the pressure in the vessel being a measure of the bulk temperature of the containment. The reference vessel envisioned would consist of a run of seamless tubing, permanently installed. Volumetric weighting of this vessel is not as critical as in Type A testing since the accuracy of the mass determination need not be as great.

The simplest form of this system would consist of pressure measurements of the reference vessel and the containment atmosphere and, assuming thermal equilibrium between the two, the ratio of the pressures would be a relative measure of the contained air mass. Comparison of this ratio with an initial value will yield the fraction of mass change. In this form, instrument air usage and humidity are not compensated for.

Another possible application of this technique is illustrated in Figure 3. In this form, a pressure controlled, integrating mass flow meter is used to maintain the containment and reference vessel at the same pressures. The resulting integrated mass flow into and out of the reference vessel is directly proportional to the integrated leakage for the containment. Use of this arrangement or using a sealed reference vessel with reference vessel and containment absolute pressures would produce the same results as the integrating mass flow meter configuration.

Instrument air compensation may be achieved by the methods previously discussed. Humidity compensation is not provided here and should be considered only to reduce the lower sensitivity limit to below 3%. Using this 3% lower limit of sensitivity, this technique could detect a 1% per day leakage rate in 12 days at 1 psig. Use of one or two dewcells could conceivably decrease the detection time by an order of magnitude.

All necessary instrumentation and technology to use this method is commercially available. Both integrating mass flow meters and precision pressure transducers are readily available from many sources. The flow meters needed for this application would likely be in the several cubic centimeter per minute range while pressure transducer resolution of .01 psi should be sufficient. Such accuracy for the required instrumentation is no greater than that required for current Type A testing. This method is applicable to all containment types.

There has been considerable experience with reference vessels in containment during Type A testing. The use of reference vessels in such testing has been largely abandoned due to difficulty encountered with set up and maintenance of a leak tight vessel. The continuous method presented here eliminates some of the difficulties by using a permanently installed vessel and by not requiring the extreme accuracy of mass determination of a Type A test due to the extended time periods available. The implementation of this method should be approached with some caution due to the high expense of installing the vessel and the questionable reliability of previous vessels. However, plants with previous successful experience in reference vessel testing and especially those with existing reference vessels may find this method acceptable and feasible for near-term implementation

3.7 Continuous Use of Type A Test Instrumentation

This method involves continuous monitoring of permanently installed Type A instrumentation to determine contained air mass. Like Type A testing, humidity and temperature variations are compensated for. This method is currently employed in some plants with success. The method is accurate and has an extremely low sensitivity limit (about 0.1%) which would indicate that a 1% per day leakage could be detected in about 10 hours. One concern with this method is the confidence assigned to the determination of bulk temperature. Type A instrumentation is placed to provide a properly weighted temperature in a relatively quiet containment environment. In an operating containment, temperature gradients, patterns and fluctuations are considerably different from those during shutdown. Preliminary estimates of these variations indicate that the sensitivity limit could be raised to 1%, giving a 4 day detection time for a 1% per day leakage rate.

As indicated in reference [3], the extent to which instrumentation used in Type A testing is available during plant operation varies widely between plants. At one extreme are the examples where Type A instrumentation is continuously monitored constituting an operating and documented continuous monitoring technique. At the other extreme are plants which remove Type A instrumentation after testing or multiplex data within containment due to a lack of available penetrations. Therefore, the cost of technique implementation may vary widely, due to these variations. For plants where the instrumentation or penetrations are unavailable, this technique could be one of the most expensive to implement. This method is applicable to all containment types.

All necessary instrumentation and equipment is available commercially since the equipment is identical to that used in current Type A tests. Some difficulties with long term reliability of dewcells may exist based on the dewcell failure experienced during Type A testing [3]. However, most such dewcell failures typically occur at the beginning of a Type A test such that long term reliability of the dewcell may not be a problem.

Use of this method has been proven by continuous operation in some plants for many years. For this reason, there are no open items concerning the feasibility of this technique. Near-term implementation of the method may be questionable, however, due to the possible high cost of installing the required instrumentation. Type A instrumentation in most plants is either not available or not configured in a manner which allows recording of the needed data [3] during plant operation. In plants where the instrumentation is available, this method could provide a low cost and rapidly implemented technique which provides very rapid leak detection. For the majority of the plants where the instrumentation is not available, the method should still be seriously considered because of its capability to provide a proven method for a one time cost of instrument installation.

3.8 Tracer Gas Mass-Concentration Correlation

A tracer gas is initially introduced into containment and the resulting mass concentration and total amount of gas introduced is accurately measured. The correlation between the introduced tracer amount and the mass concentration is a direct measure of the total air mass within the containment. Subsequent introductions of measured amounts of tracer and the resulting change in mass concentration will give measures of the air mass at any given time. The total change in air mass over a period of time can then be used to determine the average leakage rate.

This method is insensitive to humidity, temperature and pressure changes within containment and no correction for or measurement of these values is needed. Instrument air usage does serve to increase the air mass and must be accounted for, by sourcing instrument air within containment, by measuring total air usage and subtracting it from the contained air mass value, or by adding correct amounts of tracer to the instrument air.

One difficulty with this technique is the continually increasing tracer concentration which reduces the accuracy of each successive mass measurement. One way of eliminating this problem would be to use relatively short lived radioactive isotopes which would significantly decay over the sampling period. It has not yet been investigate whether sufficiently accurate half-life data is available to allow the level of precision needed for air mass determination.

This method is applicable to all plant types. Assuming a concentration monitor accuracy of 1%, a 1% per day leak could be detected in 4 days, provided the sampling frequency is that rapid. Since this method is periodic rather than continuous, the sampling frequency represents a lower bound on detection time. Allowing for reduced accuracy as subsequent samples are taken, a 1% per day leak at pressure could be detected in 20 days time if no more than 4 mass determinations are conducted during that period.

The required instrumentation and commercial availability is identical to the trace gas dilution method discussed in 3.2, with the exception of the need for a integrating linear mass flow meter to accurately measure the tracer usage. Such meters are commercially available for all conceivable tracer gases. In terms of consideration for near term implementation, this method has the same restrictions as the trace gas dilution method of section 3.2.

3.9 Differential Trace Gas Concentration Measurement

This method is extremely similar in operation to the trace gas mass-concentration correlation method just described but provides a decreased sensitivity to instrument air and humidity at the cost of reduced accuracy. With this technique, a trace gas is introduced into containment to achieve an approximate predetermined concentration (about 1000 ppm). The amount of tracer required to achieve this concentration is accurately measured. After a suitable time to allow mixing, the concentration of the tracer is measured. At intervals when total leakage is to be determined, a small, measured amount of tracer is introduced into containment. The resulting tracer concentration before and after addition of the new amount may be used to determine the total mass of tracer remaining in containment. The ratio of this total mass remaining as compared to the total mass introduced is a direct measure of total integrated leakage.

This method appears completely insensitive to various air inleakages (such as instrument air usage), pressure, temperature and humidity. The primary drawbacks foreseen are the finite life of the system caused by the ever increasing level of tracer and the limitations imposed by the accuracy of tracer concentration measurement. Accuracy of this method is considerably less than the previous method, perhaps by an order of magnitude, due to the use of a deviation from an expected differential concentration to determine the total enclosed mass. Problems with mixing time of the tracer are the same as with the previous method.

The sensitivity of the method is roughly estimated to detect a 1% per day leak in 20 to 40 days. While the technique has applicability to all plant types, the primary application is for plants where other methods of accounting for instrument air usage are not feasible.

The availability of the necessary equipment is identical to the tracer gas mass-concentration correlation described in section 3.8. The near-term implementation concerns are the same as the trace gas dilution method of section 3.2.

3.10 Differential Air Mass Injection

This method determines the total amount of air within containment by measuring the change in containment pressure resulting from the introduction into containment of a measured mass of air. Air may be either injected or withdrawn from containment. An integrating mass flow meter may be used to determine the total amount of air injected.

This system is sensitive to overall humidity levels but is sensitive to only those temperature changes which occur during the air injection time. The humidity sensitivity requires that a lower limit of detection be about 3% total leakage which converts to detection of a 1% per day leak at design pressure in 12 days at 1 psig. It is reasonable to expect that detection time could be decreased by an order of magnitude through use of a dewcell since the bulk of the mass determination error is caused by long term humidity changes.

Also, the narrow band of normal humidity ranges in large dry containments could reduce the detection time to about 1 day without any added instrumentation. By using both injection and withdrawal of air, the method may be used over long periods of time without overpressurizing the containment. Instrument air usage will effect this technique such that the usage must be monitored and accounted for or instrument air must be sourced within containment.

The method is applicable to all plant types.

Equipment and instrumentation to implement this method is commercially available. The need for a compressor capable of injecting large amounts of air over relatively short times could make equipment costs among the highest of any method. The need for rapid injection arises from the inherent sensitivity to temperature changes which occur during the injection time.

While this method has not been demonstrated, the simplicity of the principle of operation indicates that it should be feasible for near-term implementation. In the case of nitrogen inerted containments, the pressurized nitrogen source and the relatively small containment volume may allow the technique to be implemented primarily with existing plant equipment. A flow measurement device in the supply line and a precision pressure transducer would still be required.

3.11 Nitrogen Usage Monitor

This method is analogous to the continuous air injection technique described for PWRs but is designed for use with nitrogen inerted containments. With this method, nitrogen pressure is maintained in the containment at a low positive pressure sufficient to promote flow through existing leak paths, but within tech spec limits. Monitoring of the nitrogen usage with an integrating flowmeter over extended time gives the average leakage rate. In this form, this method, does not compensate for changes in humidity and air temperature.

Addition of small amounts of temperature and dew point instrumentation could significantly reduce this lower limit with a corresponding penalty in terms of cost and system complexity. An order of magnitude decrease in detection time could be realized by employing a single dewcell and a few temperature sensors.

Since inerted containments use internally sourced nitrogen or tank boil-off for instrument air, accounting for its use should not be difficult.

Humidity changes can alter the apparent air mass by as much as 3% in a leaktight vessel and typical containment temperature changes can result in a pressure change of about 7% (40°F). This gives a lower limit of integrated mass loss detection of about 10%. This lower limit would correspond to a 40 day period to detect a 1% leak at 1 psig.

This method is applicable to all nitrogen inerted containments.

Equipment needed to implement this method consists of an integrating linear mass flow meter, which is commercially available. Some operating plants may already have this equipment installed to monitor nitrogen usage for economic reasons. This method is very attractive for near-term implementation since all required apparatus is available at some plants and modest changes to equipment at many plants would complete the system. However, the sensitivity of the method is poor in terms of speed of detection and, while it would be useful to detect large breaches of containment integrity, additional instrumentation would be needed to sense leak rate in the 1% per day range at most plants. Such instrumentation could consist of a single dewcell and several RTDs which are currently available at some plants. The incorporation of the additional information into the technique would somewhat complicate the data gathering and leakage determination process but should still provide an attractive method of leak detection in terms of feasibility and implementation.

4. OTHER ALTERNATIVE TEST CONCEPTS

4.1 Refractive Techniques for Temperature Measurement

This method is similar to the acoustic velocity technique of temperature measurement except that light is used instead of sound to measure temperature. Theoretically, the increase in transit time of a light beam across the containment as compared to transit time through a vacuum gives a properly weighted measure of the bulk absolute temperature of the air. However, the change in transit time is so small relative to the total time that no practical technique has been devised for making the required measurements with sufficient accuracy. Interferometric techniques appear to be the most promising for an eventual solution but methods have yet been devised for maintenance of a reference beam in a vacuum across the containment and interpretation of the resulting wavelength shift

4.2 Dielectric Constant Measurement

The variation of the dielectric constant of air with density could possibly be applied to directly measuring containment air mass through use of a capacitance measurement using the air as the dielectric. This method has not been carried beyond this stage. The variations of dielectric constant with temperature and pressure have not been investigated.

4.3 Ultrasonic Leak Detection

This is a commercially applied technique for locating leakage paths by sensing the ultrasonic emissions caused by pressurized air passing through a small leak path causing acceleration of the flow to sonic velocities. In the case of the low pressures used in continuous monitoring techniques, sonic velocities are not obtained. Further, even for high pressure testing, it seems extremely doubtful that sufficiently quiet conditions, even in the high frequencies of interest could be obtained to make the technique feasible.

4.4 External sensor, chemically reactive tracer

This method requires maintenance of a reasonable tracer concentration in containment and use of detectors at likely leak sites. The detection method could involve painting a local surface such that reaction with the leaking tracer produces a stain or use of some type of conductivity cell where the tracer combines with a prepared surface to change the conductivity. An appropriate tracer could be vapor in containment conditions but liquid outside the containment.

The method is not being seriously pursued due to the difficulty of assuring that all possible leak paths are equipped with sensors. Even if such a large number of sensor sites could be established, monitoring the sites appears to be an unrealistic task.

4.5 Acoustic time of transit of a solid

This method uses the same principle as the acoustic transit time trough the containment atmosphere but uses a solid wire as the sound carrier rather than air. The solid transmission may have the capability of providing temperature weighting which is more close to the correct value than for air transmission. However, as discussed above, the error size for air transmission is acceptable and the change in transit time in the solid is much smaller than that for air resulting in difficulties in resolution to obtain the desired instrument output. Finally the practicality of stringing the required wires across the containment is very doubtful.

A more feasible application of the equipment would be to measure the change in length of a wire to determine the deviation from a given temperature. As with acoustic velocity, small geometric changes could overwhelm system response and the practicality of the wires is again questionable.

4.6 Trace Gas Diffusion

This method involves monitoring the reduction in a gaseous tracer concentration within containment. The mechanism of tracer reduction is diffusion through leakage paths more rapidly than the rest of the containment atmosphere. While the technique is unique in its ability to detect leakages when no differential pressure exists, the cross-sectional area available for diffusion compared to the containment volume is so large that the time to produce detectable amounts of concentration change for leakage rates of interest is on the order of years.

5. CONCLUSIONS

Several methods have been presented which cover applicability to all plant types and a wide range of complexities, cost, and sensitivity limits. A summary of the attributes of the various techniques is presented in Table 1. The estimate of equipment cost is a perceived relative ranking based only on cost of the required equipment for the monitoring system. Costs involved with licensing and operation are not part of this subtask but will be addressed at a later date in Subtask 2.1.

With the available information, an evaluation of the alternative methods by containment type has been performed. The methods cannot be numerically ranked in unique order but have been divided into three categories based on the amount of overall promise that a particular method has for application to various containments. This ranking considers cost, reliability, and sensitivity as they are perceived to date. The ranking is not precise due to the lack of complete development of the techniques and is preliminary and subjective but is in keeping with the level of information available on the techniques. The ranking, by containment type is shown in Table 2.

A third tabular presentation of the methods has also been performed. Table 3 summarizes the near term applicability and feasibility of the various techniques using the information presented in Chapter 3. Since the methods are generally not fully analyzed or operational, many of the items are a subjective evaluation drawn from somewhat limited information.

It is clear that alternative methods of checking containment integrity do exist which appear practical and sufficiently sensitive to be of use. While, in general, alternative methods do not achieve the accuracy of Type A testing, sufficient accuracy and speed of detection appear possible to justify the use of alternative methods as an interim technique allowing longer time periods between the conduction of Type A testing.

As indicated by Reference [4], the current testing program consisting of Type A, B, and C tests is capable of detecting all UBCIs documented in the PNL LER data base and it appears that the addition of alternative test methods to these tests will not result in the detection of additional UBCIs. Further, Type B and C tests alone are capable of detecting about 99.4% of documented breaches of containment integrity. Only the remaining 0.6% of breaches require some test in addition to Type B and C testing. For these remaining breaches, alternative methods are estimated to be capable of detecting 4 out of 5. This indicates that the use of alternative methods, in addition to Type B and C tests, would improve UBDI detection by only 0.5%

The methods do enjoy one advantage over current testing techniques, however. This advantage is speed of detection which can range from 1 day to several weeks in time. The currently employed test program requires testing on intervals of 1 year or more with the result being that the average leak discovered by Type A, B, or C testing has existed for 6 months. Even the slowest alternative method discussed can provide an order of magnitude improvement of this value.

Alternative test methods should not be considered as a complete replacement for Type A tests since all alternative methods are intended to operate at reduced pressure and standard operating conditions and, as such, do not test plant equipment under accident conditions. The correlation between low pressure leakage and leakage at accident pressure is not accurate and, due to the wide variety in the nature of containment leak paths, it is unlikely that a single correlation could ever provide the necessary confidence needed for actual containment integrity measurements.

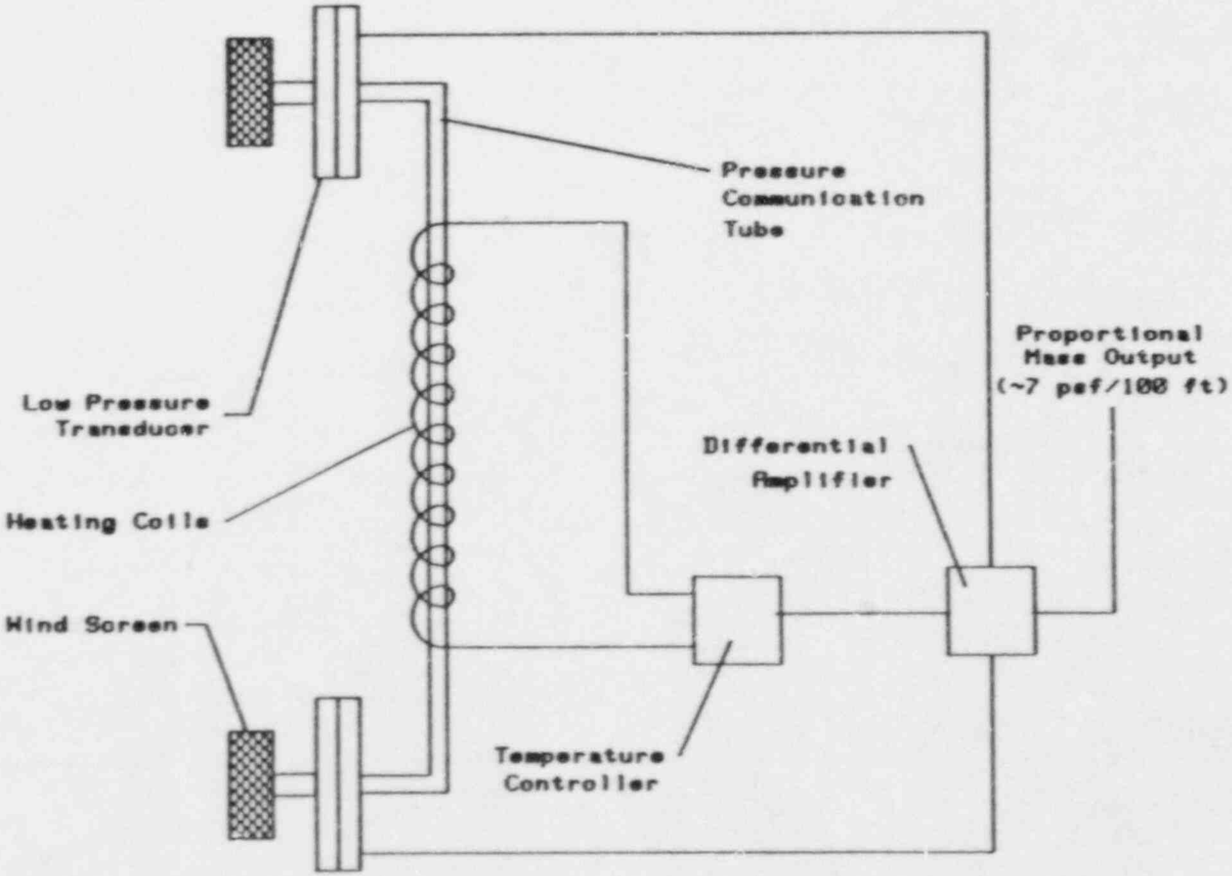

Figure 1: Schematic Representation of Direct Atmosphere Weighing Technique

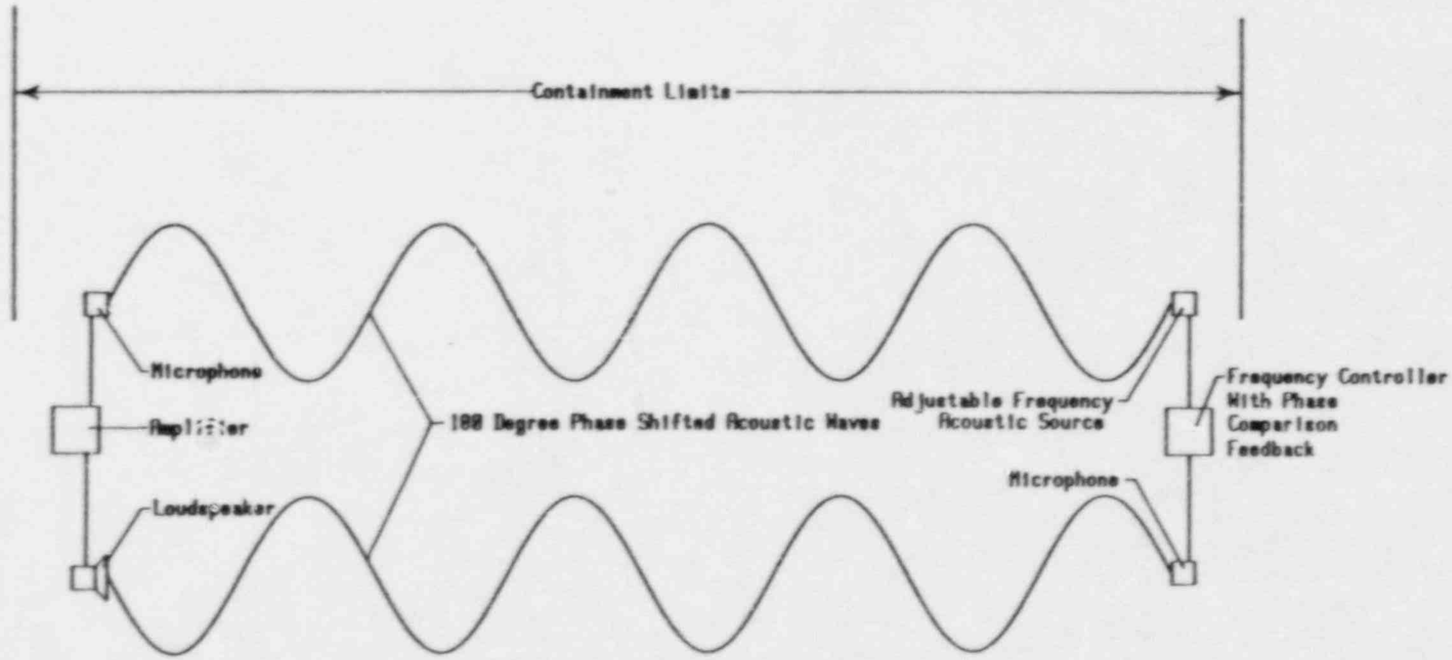

Figure 2: Schematic Representation of Acoustic Velocity Measurement Technique

-24-

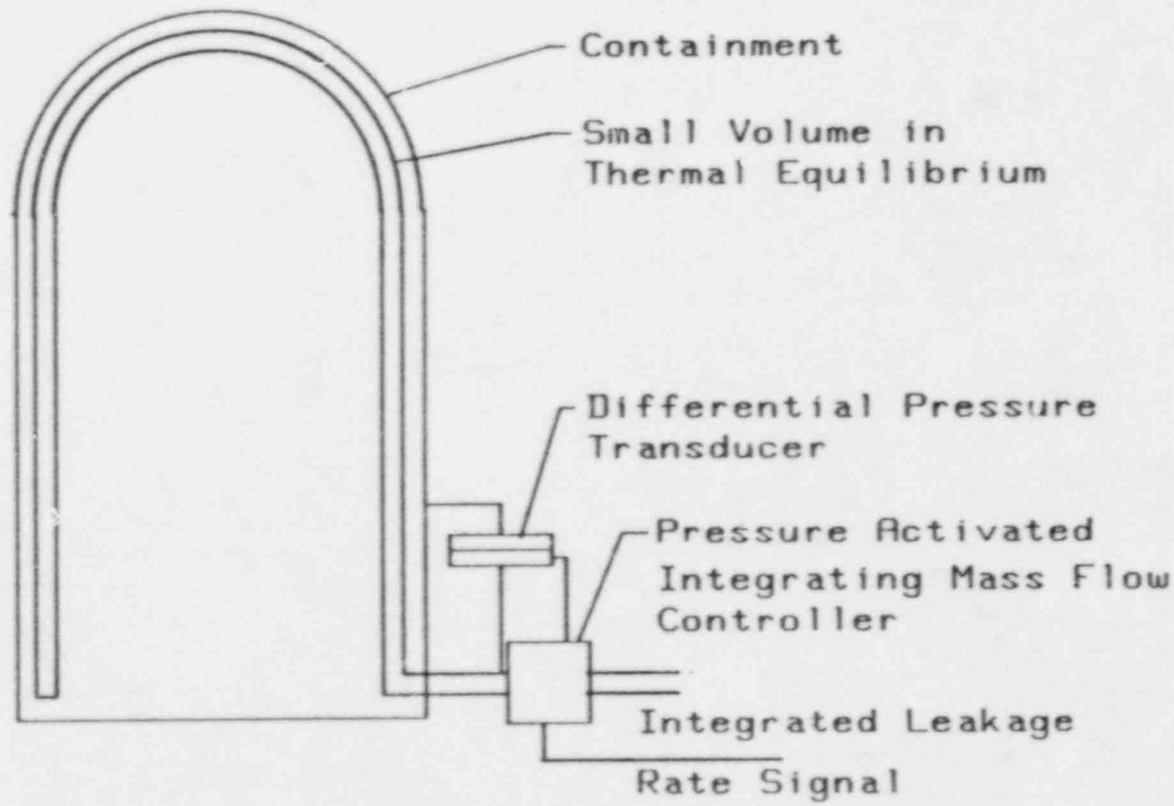

Figure 3: Schematic Representation of Reference Vessel Technique

Alternative Method	Plant Applicability	1% Detection Time (Days)	Humidity Insensitivity	Temperature Insensitivity	Inleakage Insensitivity	Equipment Costs
	Method Characteristics					
External Detection	BWRs	N/A	Yes	Yes	Yes	Low
Tracer Gas Dilution	Subatm	2	Yes	Yes	No	Low
Continuous Injection	PWRs	22	No	No	No	High
Direct Weighing	Large Dry Subatm	12	No	Yes	No	Moder.
Acoustic Velocity	Large Dry Subatm	8	No	Yes	No	High
Reference Vessel	All	12	No	Yes	No	High
Type A Test Instrumentation	All	4	Yes	Yes	No	High
Trace Gass Mass Concentration	Subatm	20	Yes	Yes	No	Moder.
Differential Trace Gas Concentration	All	20	Yes	Yes	Yes	Moder.
Periodic Air Mass Injection	PWRs	12	No	No	No	High
Nitrogen Usage Monitor	BWRs	22	No	No	No	Low

Table 1: Summary of Alternative method Characteristics

Alternative Method	Containment Type					
	Large Dry	Subatmospheric	Ice Condenser	Mark I	Mark II	Mark III
External Detection	N	N	N	L	L	N
Tracer Gas Dilution	M	H	N	N	N	N
Continuous Injection	M	N	L	N	N	M
Direct Weighing	H	M	N	N	N	L
Acoustic Velocity	L	L	N	N	N	L
Reference Vessel	M	M	M	M	M	M
Type A Test Instrumentation	M	M	M	M	M	M
Trace Gass Mass Concentration	M	M	M	M	M	M
Differential Trace Gas Concentration	M	M	M	M	M	M
Periodic Air Mass Injection	M	M	L	N	N	M
Nitrogen Usage Monitor	N	N	N	H	H	N

Legend: L-Low, M-Moderate, H-High, N-Not Applicable

Table 2: Applicability of Alternate Methods by Containment Type

-27-

Alternative Method	Implementation Concerns				
	Sensor Availability	Support Complexity	Complexity of Installation	Maintenance/ Operation	Licensing Implementation
External Detection	Yes	Low	Low	Low	Low
Tracer Gas Dilution	Unk.	Mod.	Low	Mod.	Low
Continuous Injection	Yes	Low	Low	Low	Mod.
Direct Weighing	Yes	Mod.	Mod.	Mod.	Low
Acoustic Velocity	Unk.	High	High	High	Low
Reference Vessel	Yes	Mod.	Var.	Mod.	Low
Type A Test Instrumentation	Yes	High	Var.	High	Low
Trace Gass Mass Concentration	Unk.	Mod.	Mod.	Mod.	Low
Differential Trace Gas Concentration	Unk.	Mod.	Mod.	Mod.	Low
Periodic Air Mass Injection	Yes	Mod.	High	Mod.	Mod.
Nitrogen Usage Monitor	Yes	Low	Low	Low	Low

Table 3: Near Term Implementation Aspects of Alternative Methods

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This report contains the technical findings and regulatory analysis for Generic Safety Issue II.E.4.3, "Containment Integrity Check". An evaluation of the containment isolation history from 1965 to 1983 reveals that (except for a small number of events) containment integrity has been maintained and that the majority of reported events have been events related to exceeding Technical Specification limits (or 0.6 times the allowable leakage level). In addition, more recent risk analyses have shown that allowable leakage rates even if increased by a factor of 10 would not significantly increase risk. Potential method of continuous monitoring are identified and evaluated. Therefore, these technical findings and risk evaluations support closure of Generic Issue II.E.4.3.

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