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Evaluation of Containment Leak Rate Testing Criteria

J. R. Dougan

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EVALUATION OF CONTAINMENT LEAK RATE TESTING CRITERIA

J. R. Dougan

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EVALUATION OF CONTAINMENT LEAK RATE TESTING CRITERIA

J. R. Dougan

ABSTRACT

Containment leaktightness is verified periodically through pressure tests and the measurement of the subsequent leakage. The verification process is composed of three types of test: Type A tests of the entire containment system; Type B tests of all containment penetrations, except isolation valves; and Type C tests of isolation valves. These tests are conducted in accordance with Appendix J of the *Code of Federal Regulations* and an industry standard, ANSI/ANS-56.8-1981. Revision of Appendix J, to reflect technological advances and testing experience, has been under consideration for years and has culminated in the issuance of a draft version of a proposed revision. To assist in the revision process, a review of the existing and proposed guidelines in light of utility test data and experience was conducted.

A review of 49 Type A test reports and 46 Type B and C test reports was accomplished. Exemption requests found in 25 reports and 100 Licensee Event Reports (LERs) were also reviewed. Two major findings of the data analysis were that Type A test durations of less than 24 h are practical and that almost all Type A test failures and delays were caused by excessive leakage through Type B- and C-tested components. Excessive valve leakage represented 38% of the LERs and highlighted the need for improved maintenance, repair, and testing of these components. Excessive airlock leakage was generally the result of worn, damaged, misaligned, or dirty door seals.

The proposed revision to Appendix J appears to be very responsive to the results of test experience and technological changes. One major change is the requirement that "as found" leakages must be reported as well as "as left" leakages. This change should help eliminate the poor performance of local leak testing programs. The clarification and rewording of several areas should help reduce the number of exemptions requested. The introduction of a regulatory guide provides a vehicle for the Nuclear Regulatory Commission to specify any exceptions to the relevant industry standards and to resolve areas of conflict.

---

1. INTRODUCTION

All nuclear power plants in the United States use a containment structure of some type to completely envelop the nuclear steam supply

system. The two principal functions of a containment are to protect the reactor coolant system from potentially disastrous events, such as aircraft impact and earthquakes, and to prevent the release of radioactivity in the event of a loss-of-coolant accident. To accomplish the latter function, containments must exhibit minimal leakage under accident conditions. Verification of this leaktightness is accomplished by pressurizing the containment volume to the accident pressure and measuring the rate at which air escapes by observing changes in the contained air mass. Allowable leakage rate values range from ~0.1%/d of the contained air mass to 2.6%/d of the contained air mass. These rates are generally site dependent and are determined from such siting factors as allowable exposure doses and prevailing atmospheric conditions. To place these values in perspective, a 0.1%/d leakage rate out of a containment volume of 56,634 m^3 (2,000,000 ft^3) under a pressure of 380 kPa (55 psia) at 339 K (150°F) is equivalent to that represented by a hole with a diameter of ~0.152 cm (0.06 in.).[1]

The process of verifying leaktightness through pressure tests to measure leakage is known as leakage rate testing. Fundamentally, leakage rate testing is composed of three parts (not conducted simultaneously): a Type A test of the entire containment system, a Type B test of all containment penetrations (except isolation valves), and a Type C test of isolation valves. Type B and C tests are intended to detect local leaks through potential leak paths, whereas Type A tests measure the overall integrated leakage rate and detect unexpected leak paths. These tests are conducted in accordance with the requirements stated in Appendix J of the *Code of Federal Regulations*.[2] Appendix J, which was enacted in 1973 and slightly revised in 1980, contains the requirement that all Type A tests be conducted in accordance with American National Standards Institute (ANSI) N45.4 — 1972,[3] which was developed under American Nuclear Society (ANS) sponsorship. This industry standard has been upgraded to reflect knowledge gained from testing experience and changes in testing technology and has been reissued as ANSI/ANS-56.8-1981.[4] Thus, Appendix J requirements now in effect refer to an outdated standard.

Revision of Appendix J has been under consideration for years, but with the issuance of ANSI/ANS-56.8-1981, new impetus was provided. Recognizing the new standard, however, was not the only reason for revising Appendix J. Many aspects of Appendix J concern the technical details of test performance. The current philosophy of the majority of industry and regulatory bodies is that the technical details of performing a test are more correctly in the realm of industry and industry/generated standards, with Appendix J providing the acceptance criteria. To incorporate this philosophy would require revising Appendix J, as would incorporating more flexibility in the appendix, updating it to match changing technologies, and clarifying questions of interpretation.[5]

To assist the Nuclear Regulatory Commission (NRC) in the process of revising Appendix J, the Oak Ridge National Laboratory (ORNL) conducted an NRC-sponsored evaluation of the practicality of containment leak testing programs and the compatibility of regulatory requirements and industry standards. This evaluation consisted of a review of the existing regulatory requirements in light of the testing experience obtained over the years, a review of the proposed Appendix J revision,[6] and a review of ANSI/ANS-56.8-1981 for compatibility with the proposed Appendix J.

A rather large number of leakage rate testing reports have been published, although many of them did not contain sufficient information to be included in this evaluation. Over 250 reports are known to exist,[7] but only 65 documents were readily available to be used in this study. Of these 65 documents, 49 represented Type A test reports (with and without Type B and C reports included), 4 represented Type B and C test reports only, 5 represented tests of secondary containments, and 7 were supplemental reports containing corrections and amplifications to the Type A, B, or C test reports.

This report documents the evaluation of the testing programs and the regulatory and industry standards. Relevant standards are reviewed, and the major technical criteria are evaluated in light of the test data. Exemption requests and Licensee Event Reports (LERs) are also discussed. Lastly, the proposed revision to Appendix J is evaluated based on the results of the preceding work.

Two aspects of Type A tests should be defined before proceeding further: the test method and the data analysis method.

Two kinds of Type A test methods have been used: the absolute method and the reference vessel method. Both methods determine air and moisture weight losses from the containment under the assumption that the perfect gas law holds. The absolute method calculates air mass based on direct measurements of vessel absolute pressure and the average absolute air temperature determined from pressure, temperature, and humidity measuring devices placed throughout the containment. Each of the sensors is volume weighted, and the containment-free air volume is assumed to remain constant. The reference vessel method determines the air mass from the pressure differential between the containment atmosphere and the reference vessel atmosphere. The pressure differential is determined from a manometer, one leg of which is open to the pressurized and leaking containment, while the other leg is connected to a leaktight pressurized system of tubing placed throughout the containment. The reference vessel temperature and the containment temperature are assumed to be equal. Additional information in much greater detail can be found in Refs. 8—10.

Changes in the contained air mass define the leakage rate. Three methods have been used to calculate the leakage rate from the air mass values. These methods are named the point-to-point, total time, and mass plot. Air mass calculations are made at routine intervals, usually on the order of 10—30 min. The point-to-point method calculates leakage rates from the data immediately taken and the data of the preceding set. In this manner a leakage rate is calculated for all data sets except the first. A linear least-squares fit to these rates determines the overall leakage rate. The total time method calculates leakage rates from the most recently obtained data and the data taken at the start of the test. Therefore, each calculation is over a successively longer period of time. As before, a number of leakage rates are computed by this method, and a linear least-squares fit to them defines the overall leakage rate. The mass plot method determines the leakage rate by a linear least-squares fit to the air mass data. Only one rate is calculated in this method. Additional information about these methods can be found in Refs. 4 and 11.

2. EXISTING GUIDELINES FOR TESTING

The major guidelines for testing are Appendix J of the *Code of Federal Regulations* and the industry standard, ANSI/ANS-56.8-1981. A third, less widely implemented but still important document is a Bechtel topical report (BN-TOP-1), which provides guidance for conducting an acceptable Type A test in less time than is usually required.[12] Each of these guidelines will be discussed, and the more prominent technical criteria in each will be outlined. The following discussions are not intended as exhaustive presentations of each standard but rather as a means of highlighting certain areas of each standard.

2.1 Appendix J

Appendix J requires a 24-h leakage test of the containment following a 4-h stabilization period of the containment atmosphere after pressurization. The test pressure may be at the peak pressure (P_a) or at a reduced pressure (P_t) of not less than one-half the peak pressure. If a reduced pressure test option is chosen, then a preoperational peak pressure test must also be performed to provide a relationship between the two leakage rates for future reduced pressure tests. The maximum allowable leakage rate from a reduced pressure test is defined by

$$L_t < L_a \, (L_{tm}/L_{am}) \, , \tag{2.1}$$

where

L_t = the maximum allowable leakage rate at P_t,
L_a = the maximum allowable leakage rate at P_a,
L_{tm} = the measured leakage rate at P_t,
L_{am} = the measured leakage rate at P_a.

If L_{tm}/L_{am} is >0.7, then L_t is defined by

$$L_t = L_a \, (P_t/P_a) \, . \tag{2.2}$$

The acceptance criteria require that L_{tm} be $<0.75\ L_t$ for the reduced pressure test, and that L_{am} be $<0.75\ L_a$ for the peak pressure test.

All Type B and C tests are to be conducted at a pressure not less than P_a. The combined leakage rate of all penetrations and valves (Type B and C tests) is required to be $<0.60\ L_a$ (with exceptions for some valves) to be acceptable.

The frequency for Type A tests is as follows: After the preoperational leakage test, three tests are to be performed at approximately equal intervals during the next 10 years, with the third test coinciding with the 10-year plant shutdown. Type B tests (except for airlocks)

are to be conducted at shutdown periods, but at intervals of less than 2 years unless continuous monitoring is used, in which case the maximum interval is 3 years. Airlocks are to be tested every 6 months unless they are opened. Airlocks opened when containment integrity is not required are to be tested prior to the time when containment integrity will be required. Airlocks opened during periods when containment integrity is required must be tested within 3 d of the opening. Airlocks opened more often than once every 3 d must be tested once every 3 d during the time of the frequent openings. Testing of the airlock seals fulfills the 3-d test requirement but may not be substituted for the 6-month test. Type C tests are to be performed at shutdown periods but at intervals of less than 2 years.

A supplemental or verification test is required by Appendix J to verify the accuracy of the Type A test. The supplemental test involves inducing a known leakage out of the containment and measuring the new leakage rate. The results are acceptable if the difference in the leakage rate of the supplemental test and L_{am} (or L_{tm}) is within 0.25 L_a (or 0.25 L_t).

Appendix J references ANSI N45.4-1972 as the acceptable procedure for conducting leakage rate tests. This ANSI standard allows the use of either the absolute or reference vessel method and either the point-to-point or total time analysis method (the mass plot method was not widely known, if at all, at this time). The test duration in the ANSI standard is 24 h unless it can be demonstrated to all responsible parties that an accurate leakage rate may be obtained in less time. However, this standard is no longer in effect, having been replaced by ANSI/ANS-56.8-1981.

2.2 BN-TOP-1

The Bechtel topical report (BN-TOP-1) was intended to show that Type A tests could be successfully completed in less than 24 h and provide some recommended criteria for determining when the test may be stopped. Specifically, four criteria to be met were stated as necessary for the successful completion of the test. The first of these required a minimum test of 6 h and at least 20 data points. The second required the trend report (indicating the trend of the mean of the measured leak rates, the trend of the least-squares fit to these leak rates, and the trend in the change of the least-squares fits) based on total time calculations to indicate stabilization of the least-squares fit value at a value less than L_a. The third criterion required the mean of the measured leak rates, again based on total time calculations, to be less than L_a. The fourth criterion required the satisfactory completion of a supplemental leak test. Although not specified as a criterion, the report also recommended the use of the absolute method of testing over the reference vessel method.

2.3 ANSI/ANS-56.8-1981

The ANSI standard states that a Type A test shall last at least 8 h after stabilization and shall have at least 20 data sets obtained at approximately equal time intervals. The stabilization period is at least

4 h, after which the temperature is considered stable if the latest rate of change of the weighted average air temperature, averaged over the last hour, does not deviate by more than 0.3°C/h (0.5°F/h) from the average rate of change of the weighted average air temperature averaged over the last 4 h. A sample calculation is presented in Appendix F of Ref. 4 for clarity. Pressure stabilization is assumed to have occurred with temperature stabilization.

The Type A test pressure is specified as P_a. No provisions are included for a test at a reduced pressure. The acceptance criteria for a Type A test require the one-sided 95% upper confidence limit (UCL) on the leakage rate to be less than 0.75 L_a.

Type B and C tests are to be conducted at P_a, unless otherwise noted in the technical specifications, and must last at least 15 min. To be acceptable, the combined leakage rate (including the UCL) for all Type B and C leak paths must be $<0.75\ L_a$. As in Appendix J, some exceptions for valves are noted.

Type A tests are to be conducted at the first refueling outage but not more than 3 years after the preoperational test, and thereafter at approximately equal intervals of less than 5 years. Type B tests (except for airlocks) and Type C tests shall be conducted during shutdown or normal operation periods with the interval between tests of an individual component being less than 2 years. Airlock testing is the same as specified in Appendix J, except that if an airlock is not opened during a 6-month period, it need not be tested until it is opened.

The ANSI standard also requires a verification test be performed after each Type A test. Two methods of performing the verification test are described, one being the introduction of a known calibrated leak rate and the other involving the injection or removal of a metered mass of air. For the superimposed leak verification test, the difference in the leakage rate of the verification test and L_{am} must be within 0.25 L_a (which is the same requirement as in Appendix J). For the mass step-change verification test, the metered mass of air and the measured change in containment air mass shall agree within 25% of the metered value.

The absolute method of leakage determination is specified in ANSI/ANS-56.8-1981, as is the mass plot method of data analysis. These methods, along with the other methods (reference vessel, total time, point-to-point), are described in Appendix A of the standard. These descriptions are included for information only, since the appendixes are not part of the ANSI standard.

Since the publication of ANSI/ANS-56.8-1981, several typographical errors have been found, and certain aspects of the methodology have been challenged. The typographical errors are confined to the appendixes to the standard, and the methodology challenges refer to the equation for computing the air mass and the definition of sensor weighting factors. Appendix A of this report contains a discussion of these challenges as well as a discussion of some apparent oversights in the standard. To summarize the more important findings of Appendix A, the air mass equation contained in the ANSI standard is fully adequate, the method of determining sensor placement and the volume fraction it represents (the weighting factor) should be addressed in more detail, the typographical errors should be corrected as soon as possible, and the additional oversights are not critical but should be addressed.

3. TYPE A TESTS

A total of 49 Type A test reports were reviewed. The test method, pressure, duration, analysis method, and special problems were recorded. These data provided the necessary background for the evaluation of the practicality of the standards. The results of this evaluation regarding the major aspects of the standards follow.

3.1 Method

Industry has used two methods to conduct Type A tests: the reference vessel and the absolute method. Of the 49 Type A test reports reviewed, 4 were conducted using only the reference vessel method, 43 used only the absolute method, and 2 used both. One of the reference vessel test methods was used as late as 1980; however, it was used in conjunction with an absolute test method for comparison.

Major difficulties with the reference vessel method have led to its rejection by practically all of the utilities, as is evidenced by the data analysis. The difficulty in maintaining a leaktight reference vessel system is the principal problem;[13] therefore, the absolute method of conducting a test is recommended. All three existing guidelines recognize and endorse the absolute method, but only Appendix J still allows the use of the reference vessel method.

3.2 Pressure

The pressure for a Type A test is intended to be P_a, the peak pressure associated with the design basis accident. However, testing at a reduced pressure, P_t, is less hazardous, presents less risk of component damage, requires less pressurization time, and is cheaper. The disadvantages are that reduced pressure testing does not measure the desired leak rate directly, and the extrapolation factors used for correlating the full and reduced pressure leak rates may be erroneous. These errors are associated with changes in the leak path and flow characteristics at the different pressures. Therefore, the successful use of a reduced pressure test, which appears to be advantageous, depends entirely on the confidence in the accuracy of the extrapolation factors.

In the available data base, full pressure tests are represented 43 times, and reduced pressure tests are represented 23 times. Of the 23 reduced pressure tests, 17 were part of the preoperational tests conducted with the full pressure tests to develop the correlation between the two tests. Therefore, reduced pressure tests were used only six times to determine the leak rate.

Table 3.1 contains the reported preoperational test data for the 17 plants that chose to conduct reduced pressure tests. Columns 2–4 contain the full pressure, reduced pressure, and the ratio of the two, respectively. Column 5 contains the maximum allowable leakage rate at the full

Table 3.1. Preoperational test data for reduced pressure tests

Plant	P_a [kPa (psig)]	P_t [kPa (psig)]	P_t/P_a	L_a (%/d)	L_{am} (%/d)	L_{tm} (%/d)	L_{tm}/L_{am}	L_t[a] (%/d)
1	330.9 (48.0)	172.4 (25.0)	0.521	1.600	0.16340	0.20000	1.22399	1.15470
2	330.9 (48.0)	172.4 (25.0)	0.521	1.600	0.23200	0.01750	0.07543	0.12069
3	337.8 (49.0)	172.4 (25.0)	0.510	2.000	0.56600	0.71000	1.25442	1.42857
4	270.3 (39.2)	172.4 (25.0)	0.638	0.100	0.02160	0.02540	1.17593	0.07986
5	317.2 (46.0)	158.6 (23.0)	0.500	0.500	0.01410	0.00870	0.61702	0.30851
6	282.7 (41.0)	144.8 (21.0)	0.512	0.100	0.02700	0.00500	0.18519	0.01852
7	399.9 (58.0)	206.2 (29.9)	0.516	0.635	0.17600	0.16900	0.96023	0.45593
8	317.2 (46.0)	158.6 (23.0)	0.500	0.500	0.04840	0.00680	0.14050	0.07025
9	317.2 (46.0)	158.6 (23.0)	0.500	0.250	−0.00020	0.01520	−76.00000	0.17678
10	406.8 (59.0)	206.8 (30.0)	0.508	0.200	0.08150	0.02920	0.35828	0.07166
11	344.7 (50.0)	172.4 (25.0)	0.500	0.200	0.04660	0.01340	0.28755	0.05751
12	337.8 (49.0)	172.4 (25.0)	0.510	0.500	0.14990	0.04870	0.32488	0.16244
13	337.8 (49.0)	172.4 (25.0)	0.510	0.500	0.18701	0.15339	0.82022	0.35714
14	273.0 (39.6)	136.5 (19.8)	0.500	0.500	0.02500	0.01600	0.64000	0.32000
15	372.3 (54.0)	186.2 (27.0)	0.500	0.500	0.27600	0.00670	0.02428	0.01214
16	372.3 (54.0)	186.2 (27.0)	0.500	0.100	0.01900	0.00100	0.05263	0.00526
17	379.2 (55.0)	193.1 (28.0)	0.509	0.072	0.00484	0.02230	4.62656	0.05137

[a]For $L_{tm}/L_{am} < 0.7$, $L_t = L_a\ (L_{tm}/L_{am})$; for $L_{tm}/L_{am} > 0.7$, $L_t = L_a\ (P_t/P_a)^{1/2}$.

pressure, and columns 6–8 contain the measured leak rates at full pressure, those at reduced pressure, and the ratio of the two, respectively. Column 9 contains the maximum allowable leakage rate at the reduced pressure as calculated in accordance with the Appendix J equations shown at the bottom of the table.

Five of the plants, numbers 1, 3, 4, 9, and 17, measured higher leakages at the reduced pressure than at full pressure. Plants 9 and 17 measured significantly higher leakages at the reduced pressure, with plant 9 recording a negative leakage at the full pressure. The verification tests for plants 3, 4, and 9 confirmed the measured leakage rates, whereas the verification tests for plant 1 were considered inconclusive. Verification test information was not readily available for plant 17. Both plants 1 and 4 rejected the reduced pressure test method and subsequently conducted full pressure tests. Plants 3, 9, and 17 all continued to conduct reduced pressure tests to determine the containment leak rate.

The remaining plants all measured higher leakages at full pressure than at reduced pressure. Of these 12 plants, only plants 5 and 14 continued to conduct reduced pressure tests. Plant 2 failed verification of the reduced pressure test leakage measurement check; however, no reasons are apparent as to why the other nine plants decided against the reduced pressure test. The verification tests were successful in all cases. Plant 10 may be continuing to use reduced pressure tests, but no information other than preoperational test data was available.

Data inconsistencies and the limited amount of data available in the test reports reviewed do not enable a conclusion to be derived relative to the retention of reduced pressure testing.

3.3 Instrumentation

The instrumentation of a Type A test is composed of pressure, temperature, and humidity (vapor pressure) measuring devices. A quartz manometer is generally recommended for the pressure sensors, and platinum resistance temperature detectors (RTDs) are recommended for the temperature sensors. Both the chilled-mirror dewpoint hygrometer and the lithium chloride dewcell have been used successfully to measure humidity.[13] Evaluation of the test reports showed that dewcells were used about 60% of the time, with the dewpoint hygrometers used the remainder of the time.

A sufficient number of pressure, temperature, and vapor pressure sensors are required to adequately sample the containment atmosphere. Figures 3.1, 3.2, and 3.3 indicate the number of temperature sensors, vapor pressure sensors, and pressure sensors, respectively, as indicated in the test reports. The bars in Fig. 3.1 indicate a range of sensors and show that over 50% of the tests were conducted using 20 to 25 RTDs. Figure 3.2 indicates that most tests were conducted with six vapor pressure sensors, and Fig. 3.3 shows that most tests were conducted with either one or two pressure sensors only. Judging from the recorded data values, the spatial variation of temperature over an entire test was <5 K (9°F), and there appeared to be sufficient sensors to measure temperature and vapor pressure. However, it is difficult to state that one or even

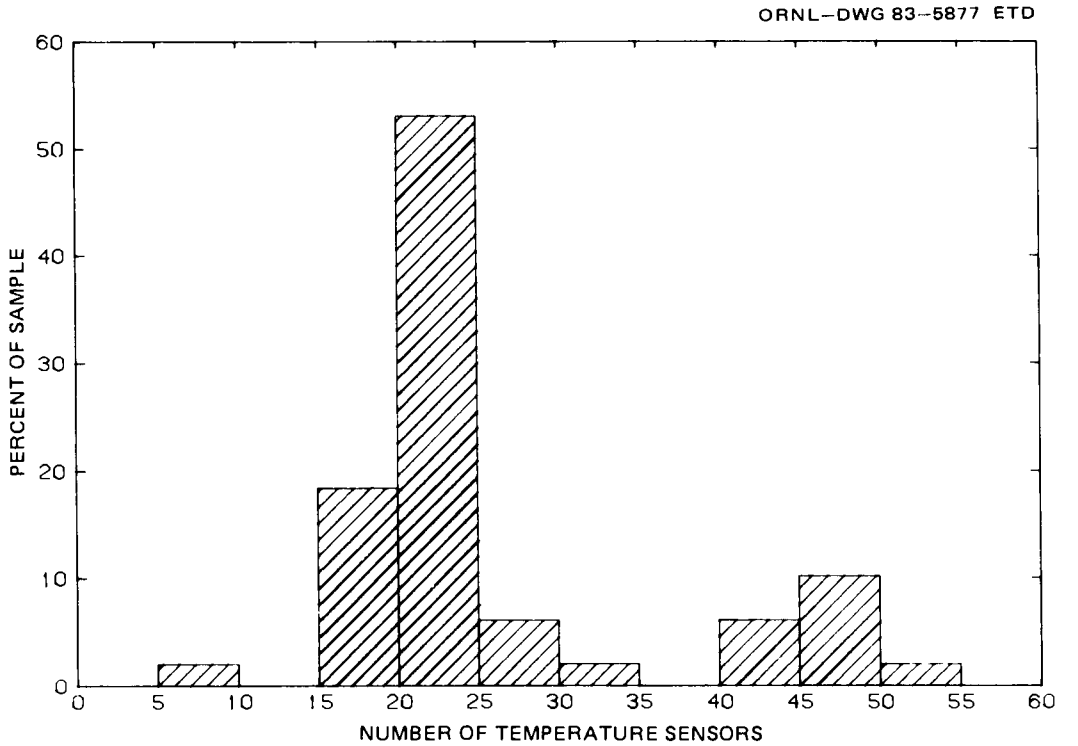

Fig. 3.1. Number of temperature sensors per test.

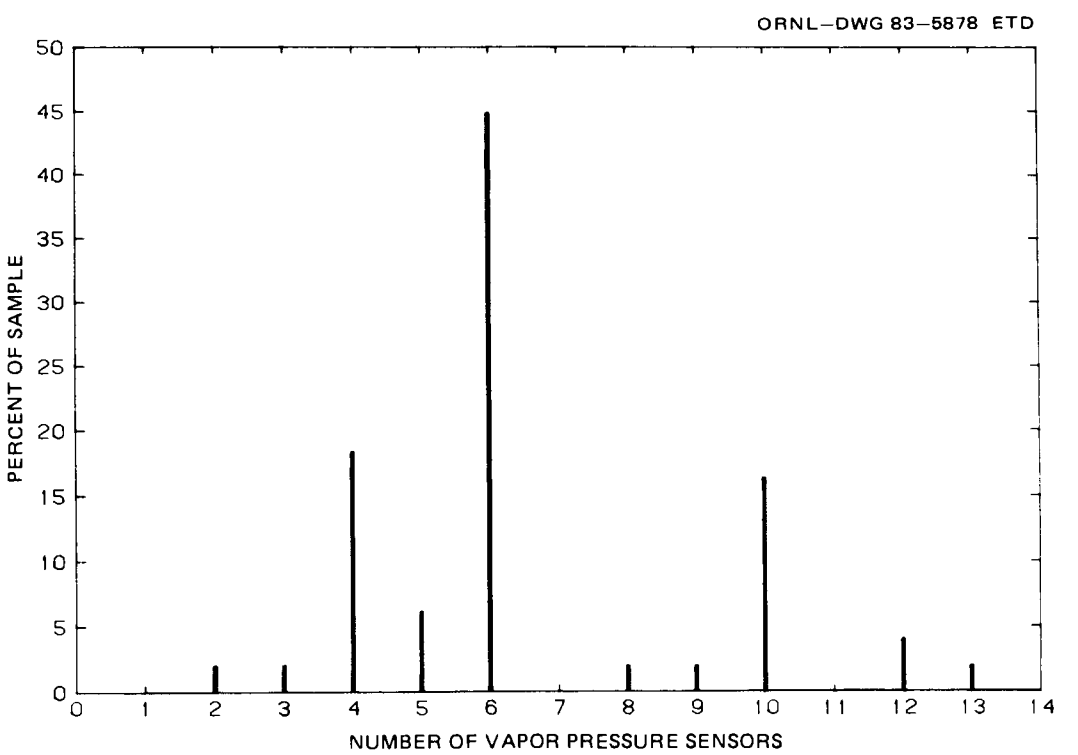

Fig. 3.2. Number of vapor pressure sensors per test.

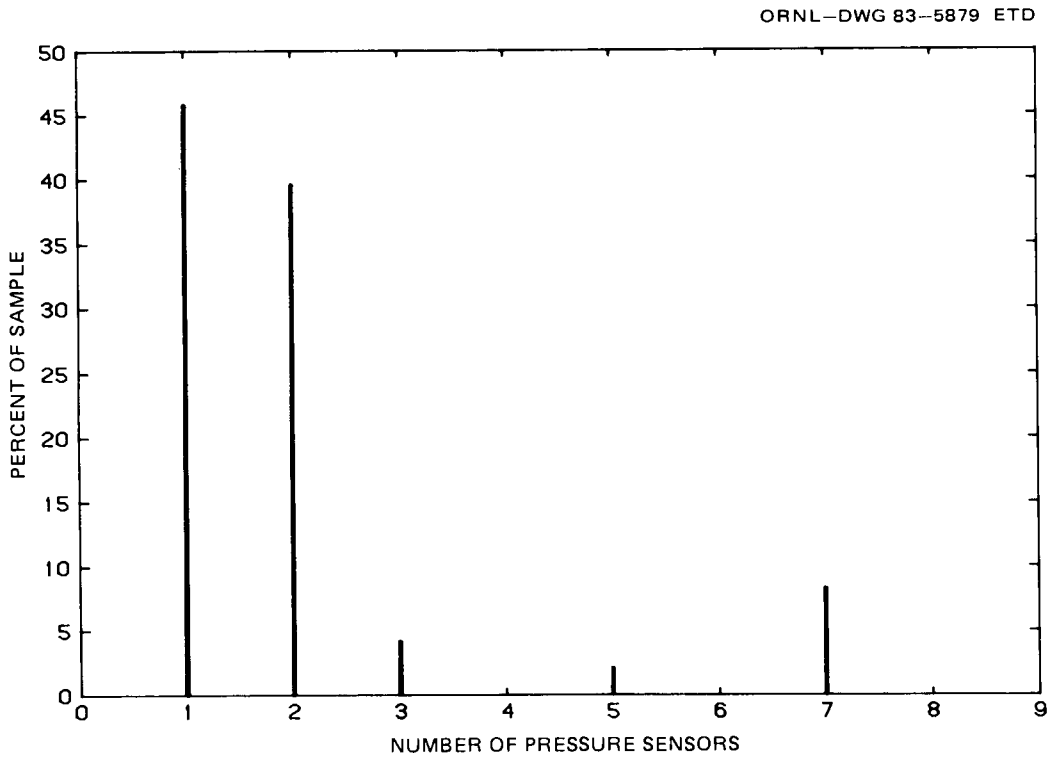

Fig. 3.3. Number of pressure sensors per test.

two pressure sensors is sufficient. Data were not available to allow a firm conclusion to be drawn regarding multiple pressure sensors.

No requirements for the number of instruments are contained in Appendix J. A minimum number of sensors is specified in ANSI/ANS-56.8-1981. Sufficient temperature sensors are required such that no one sensor samples greater than 10% of the total value. At least three humidity sensors are required, and at least one pressure sensor is required. Assuming the containment is adequately sampled, the number of sensors becomes an economic decision.

3.4 Duration

Type A tests are normally conducted during refueling outages because they require the unit to be shut down. Theoretically, a test would not necessarily be a controlling event in returning the unit to power, but, in practice, these tests often take quite a lot of time to complete. Thus the tests often are controlling events in returning a unit to power and therefore should take no longer than necessary to establish the leakage rate of the containment.

In the early days of containment testing, leak rate tests were conducted from a minimum of 24 h to a maximum of several days. The reasoning behind the minimum of 24 h is not completely clear, although the general consensus is that the 24-h minimum time period eliminated any diurnal effects on the early steel containments. In any event, the minimum

time period of 24 h was adopted and continues to form the fundamental approach of the NRC.[5] However, there does not appear to be technical justification for the minimum test period of 24 h. In fact, several industry sources have shown that successful tests can be conducted in much less time.[7,12,14] The NRC has recognized this fact and has approved tests of less than 24 h. However, some utilities still feel constrained to use the 24-h test because of their Technical Specification's requirements. Analysis of the test reports revealed that the vast majority of tests lasted 24 h, as shown in Fig. 3.4. Those tests shown lasting more than 24 h experienced problems with leakage so early in the test that they were corrected without stopping the test.

Although criteria for determining the duration of a test have been published,[7,12,15] no specific criteria have been agreed upon as final. However, as the result of a panel discussion at a recent conference, a consensus was reached regarding 13 items that should be considered in determining a Type A test duration. These items are to be forwarded to the committee responsible for ANSI/ANS-56.8-1981 for technical review and evaluation.[16] The 13 items are preliminary and therefore subject to change. Of these, only six are directly related to test duration, the balance being recommendations concerning instrumentation, test method, data analysis method, weighting factors, volume divisions, diurnal effects, and temperature stabilization. While all of the items are important to the conduct of a successful test, only those items directly relating to test duration will be discussed here.

First, the test must be conducted for a minimum number of hours. This criterion is difficult to justify on a technical basis. The test

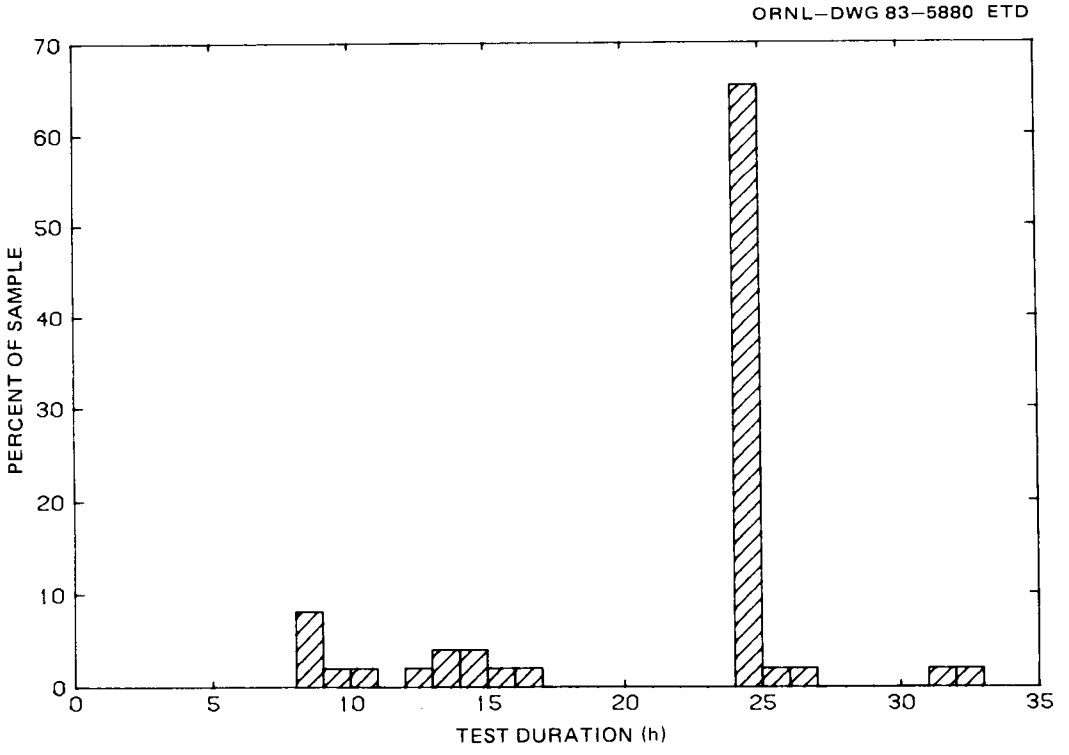

Fig. 3.4. Reported durations of Type A tests.

period must be long enough to obtain a sufficient number of data points to define a trend and to verify the consistency of the data. But these two points can be met using other criteria such as a required minimum number of data points and convergence criteria. Specifying a minimum time interval between data sets and a minimum number of points automatically specifies the minimum number of hours, but the minimum time interval between data sets was dropped in favor of the minimum number of hours. In any event, it is highly likely that a minimum number of hours will be specified. The choice of the number will be subjective and will probably fall in the range of 5 to 8 h. This time period is in addition to the time required for stabilization.

Second, a minimum number of data points must be obtained. The number most favored is 20, based on utility experience with test data that indicate a trend toward stability of the leak rate occurring around 20 data points in many cases.

The third item regards verification that the leak rate data are converging. The best method for accomplishing this verification is not clear yet, but the need for one is clear. Data that are not converging indicate either instrumentation problems or instability of the containment atmosphere. Both conditions are cause for concern, and no Type A test should be completed under these conditions.

Fourth, the one-sided 95% UCL on the leak rate must be either zero or a positive value. For the UCL to be a negative value, significant negative leakage (leakage into the pressurized containment) is necessary and obviously in error. Minor apparent negative leakage can be expected to occur for an extremely leaktight containment (actual leakage close to zero) because of instrument error. This kind of leakage, however, would not usually cause the UCL to become negative. Therefore, a negative one-sided 95% UCL on the leak rate indicates errors in either the instrumentation or the data analysis, and the test should be considered unacceptable.

The fifth item, which is similar to the third, is that the least-squares fit (LSF) to the leak rate data as a function of time shall have stabilized with a negligible slope. The quantification of what is negligible has not yet been decided. Lack of stabilization of the LSF indicates an insufficient amount of data, a change in the containment atmosphere, or a change in the instrumentation.

The sixth item is that the "as left" leakage rate of the containment must be $<0.75\ L_a$. Although this is an acceptance criteria, it must be met before the test may be successfully concluded. The rationale behind this limit is that by requiring the "as left" leakage rate to be $<0.75\ L_a$, a $0.25\ L_a$ allowance is being made for potential containment degradation between the current test period and the next one.

These six items represent reasonable criteria for defining Type A test duration. Many details remain to be worked out, but solutions will be found based on industry and regulatory experience. The 24-h minimum test period specified in Appendix J should be replaced by technical criteria based on the data, such as the six items just discussed. The duration criteria in ANSI/ANS-56.8-1981 should be expanded to provide assurances of data convergence and stabilization. With the likelihood of the further development of the 13 items mentioned before based on industry

and regulatory cooperation, the need for a separate set of criteria (such as BN-TOP-1) disappears.

3.5 Frequency

The available data indicated that the utilities conduct Type A tests every 3 to 4 years, with few exceptions. The deviations from this pattern are not considered critical. The analyses of the test reports, exemption requests, and LERs revealed that, although most tests were successfully completed, many required repairs or corrections to Type B and C leak paths. Practically all Type A test leakage problems were caused by Type B- and C-tested leak paths.[7] The evidence indicates that the Type A test frequency is certainly adequate for discovering leaks other than those attributed to Type B and C components, because practically none have been found. The one instance uncovered in this evaluation concerned several holes inadvertently drilled in the containment liner. Otherwise, no failures have been found that involved the degradation of the containment shell. Thus, the Type A test interval could possibly be lengthened, but only if increased testing of Type B and C components is initiated (to be discussed in the next chapter). The testing frequency in Appendix J is comparable to the one in ANSI/ANS-56.8-1981; both are more than adequate provided the Type B and C frequency is increased.

3.6 Analysis Method

There are three generally used data analysis methods: total time, point-to-point, and mass plot. Review of the test reports revealed that total time was used ~80% of the time, point-to-point ~35% of the time, and mass plot ~48% of the time. The percentages do not sum to 100% because many utilities use more than one method. The method that appears to have the most stability and logically direct means of analyzing the data is the mass plot method,[11] in which the leakage rate is equal to the slope of the linear LSF line to the air mass data. The slope is a direct measure of leakage, that is, change in air mass with respect to time. A typical comparison of the three methods is shown in Fig. 3.5. Linear LSF lines were calculated by each method after each data point and were plotted vs time. The stability of the mass plot method is readily seen, and, although the differences in the final leak rates are small in this instance, they can be quite large.

Appendix J, through its reference to ANSI N45.4-1972, allows the use of either the total time or the point-to-point method, whereas ANSI/ANS-56.8-1981 specifies the mass plot method. The mass plot method has recently become the preferred method of most utilities and should be acknowledged. The other two methods could still be used for verification of data trends.

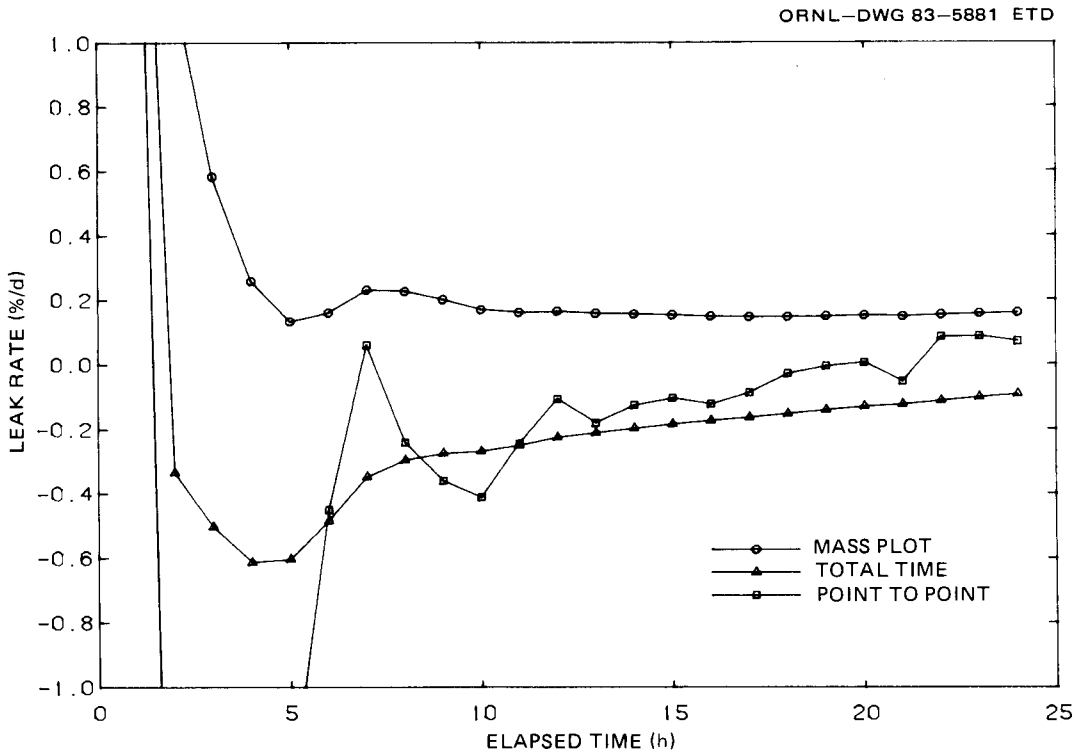

Fig. 3.5. Typical comparison of the mass plot, total time, and point-to-point methods of calculating leak rates.

3.7 Verification Test

A verification test is intended to verify the ability of the Type A test measurement system and test method to determine the leak rate. This test is conducted immediately following the Type A test so that there is little risk of change in the containment environment. The test may take the form of an imposed calibrated leak rate or the metered removal or injection of an air mass. The imposed leak should be on the order of L_a, and the metered mass change should approximate the daily allowable leakage. If the instrumentation is capable of measuring these allowable leakages, then confidence in its ability to measure values less than the allowable is increased. If the instrumentation system is not able to measure the allowable leakage, then clearly it cannot measure values less than the allowable.

Appendix J, by referencing ANSI N45.4-1972, requires a supplemental (or verification) test using the imposed leak method. No magnitude of the leak is specified, and the test is satisfactory if the difference between the verification test leak and L_{am} (or L_{tm}) is $<0.25\ L_a$ (or $0.25\ L_t$). Because no magnitude is specified, some utilities imposed large leak rates that masked L_{am} (or L_{tm}) and made the test inconclusive. The magnitude of the leak is specified in ANSI/ANS-56.8-1981 as between 75% and 125% of L_a or the daily allowable leak rate, depending on the method chosen. If the imposed leak is chosen, then the Appendix J acceptance

criteria just discussed apply. If the mass injection or removal is chosen, then the metered mass of air injected or removed and the change in the containment air mass must agree within 25% of the metered amount.

The successful completion of a verification test provides added confidence that the instrumentation system is capable of measuring the allowable containment leak rate. Analysis of the test reports indicates that few difficulties are encountered in verification tests. And there is no apparent justification for making the acceptance criteria more restrictive since, in all probability, the same result (successful completion of the test) would be achieved but over a longer period of time. Some thought has been given to including a 95% UCL on the verification test leakage, but, with the relatively large range of acceptability (±25%), this does not seem necessary.

3.8 Acceptance Criteria

Once the containment leak rate has been determined, it must be evaluated against an acceptance criteria. The obvious choice is the maximum allowable leakage rate (L_a) as specified in the technical specifications and operating licenses. However, the use of this value does not provide any margin of safety against potential degradation of the containment during the time until the next Type A test. To provide the margin of safety, a value of 0.75 L_a has been provided to and used by the industry.

The 25% margin of safety is more than adequate for leak paths other than those tested by Type B and C tests. These paths include the containment liner and certain valves and penetrations exempted from Type B and C testing. Few Type A test problems have been associated with these paths.[17] Therefore, any degradation occurring between Type A tests is probably in the Type B- and C-tested leak paths. It is difficult, however, to assess the degree of degradation in Type B and C leak paths. This fact will be considered in the next chapter. For the immediate purpose, it is sufficient to say that because of considerable uncertainty in the amount of "as found" leakage in Type B and C components,* an accurate evaluation of the margin of safety cannot be made.

Appendix J requires the measured leak rate, L_{am} (or L_{tm}), to be $<0.75\ L_a$ (or $0.75\ L_t$). But ANSI/ANS-56.8-1981 requires the one-sided 95% UCL on L_{am} to be $<0.75\ L_a$. Ignoring the reduced pressure test requirements (L_{tm} and L_t), the only difference is in the use of the one-sided 95% UCL. Because an accurate evaluation of the 25% margin of safety cannot be made at this time, there is no justification for changing the acceptance criteria. However, the use of the one-sided 95% UCL is recommended.

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*Information is not reported but is generally available.

4. TYPE B AND C TESTS

A total of 46 Type B and C test reports were reviewed in this study. Of these 46 reports, only 4 were not a part of a Type A test report. Those reports that were included with the Type A test reports generally lacked details concerning the conduct of the Type B and C tests and usually presented only the results of the tests plus a brief discussion of any significant problems. Therefore, with the exception of the test results, most of the information used in the evaluation of the Type B and C tests was obtained from exemption requests and LERs, which will be discussed in detail in the next chapter.

4.1 Medium and Pressure

Both hydraulic (using water) and pneumatic tests (using air or nitrogen) have been used in Type B and C tests. Hydraulic testing has only been used for Type C tests of valves, whereas pneumatic tests have been used for both Type B and C tests. Air or nitrogen is the preferred medium because they most closely approximate the containment environment following an accident. Hydraulic testing has been used to verify that valves covered with water (from a seal system) will remain so for the expected duration of an accident. In some special cases, hydraulic testing has been conducted in lieu of pneumatic testing because the systems could not be completely drained, thereby making pneumatic testing impractical. In these instances the water leakage was required to be conservatively converted to an equivalent air leakage.

The test pressure used for the majority of the pneumatic tests of Type B and C components was P_a. In some cases, such as airlock testing and reverse pressurization of isolation valves, the use of test pressure P_a prohibited the conduct of meaningful tests (details will be presented in the next chapter). Therefore, tests of these components at a pressure lower than P_a were allowed in these cases. But the leakage rates were required to be extrapolated to an equivalent leakage rate at P_a.

The hydraulic tests conducted in lieu of pneumatic tests were performed at P_a. The hydraulic tests intended to verify that valves covered with water will remain so, were conducted at 1.1 P_a, because these systems are pressurized to a magnitude slightly higher than P_a to ensure that any leakage during an accident will be into containment.

Type B and C pneumatic tests at a pressure of P_a provide a direct measure of the expected leakage under accident conditions, as do hydraulic tests at 1.1 P_a of valves covered with water from a seal system. In some special cases, such as airlock testing, reduced pressure tests may be necessary part of the time. However, the difficulties encountered in extrapolating the leakage rates from a lower pressure to a higher pressure require that reduced pressure tests be used sparingly. Although it is recognized that in some cases no viable options may exist, the use of hydraulic testing in lieu of pneumatic testing is not recommended. The changes in leakage characteristics and the lack of acceptable correlation between water and air leakage rates should serve to deter the use of hydraulic tests in lieu of pneumatic tests.

Appendix J currently requires all Type B and C tests to be pneumatic tests conducted at P_a, with the exception of valves pressurized from a seal system. These valves are to be hydraulically tested at 1.1 P_a. The same requirements are specified in ANSI/ANS-56.8-1981.

4.2 Valve Temperature and Waiting Period

Two items of importance that have a direct bearing on the conduct and results of Type C testing of valves are the temperature at which the valve is tested and the length of time after seating that the valve is tested. Arguments have been made that many valves exhibit better leakage rates (i.e., lower) at higher temperatures than at lower temperatures. Some utilities test their isolation valves shortly after an outage begins because the valves are at operating temperature and would be at this temperature in the event of an accident. Yet other utilities test isolation valves at room temperature and have expressed no desire to change. Also, some utilities have discovered that certain valves seal better after being pressed against the seat for a couple of hours and have indicated a desire to delay testing until a few hours after seating.

Requiring a valve test temperature would be useful only if the valve could be shown to be at that temperature throughout an accident. If a valve has a lower leakage rate at its operating temperature than at room temperature, then a test at its operating temperature is clearly beneficial. However, if the valve temperature is expected to drop some hours after the start of an accident but at a time that leak integrity is still needed, then the leakage rate would be higher than the measured rate and might be unacceptable. Thus, the test temperature for valves should be the temperature expected during an accident that yields the highest leak rate.

Specifying a waiting period before valve testing to obtain a better seal should probably be discouraged. Leak integrity is necessary from the very beginning of an accident, and, although the leakage through a component might decrease throughout the course of the accident, the initial leakage rate must be shown to be low enough to be acceptable. Provided the seal does get better with time and the leakage decreases, an initially large leakage that diminishes fairly quickly might not be critical. Only an evaluation of the leakage characteristics of valves with time would provide the necessary data.

No information regarding the valve test temperature or the waiting period was available in the test reports, the LERs, or the exemption requests. Therefore, a search of the Nuclear Science Abstracts and the Department of Energy's Energy Database was conducted. No useful information was obtained by the search, which indicates that little, if any, published research exists on these subjects.

Therefore, provided sufficient interest is expressed in resolving these issues, additional research is recommended for determining the effects of valve test temperature and waiting period. This research should be aimed at determining what valves are involved and if the temperature effects are consistent between different types and manufacturers. Likewise, the waiting period could be evaluated for different types.

Neither Appendix J nor ANSI/ANS-56.8-1981 mentions either a valve test temperature or a waiting period.

4.3 Frequency

The review of the test reports indicates that most utilities conduct Type B and C tests on all components within a 2-year interval. In some instances, the local leak testing programs did not cover all components within a 2-year interval because of scheduling errors; however, these cases were infrequent and are not considered critical.

The single largest source of concern for the utilities regarding frequency was in airlock testing. These tests prompted numerous exemption requests that will be discussed in detail in the next chapter. But, as a result of the requests, the NRC revised the airlock testing frequency to the present schedule in Appendix J.

Based on the reports reviewed, many Type A tests experienced problems and delays caused by excessive leakage through Type B and C testable components. In most instances these components had been tested and repaired when necessary according to the Type B and C test schedules; however, they had obviously deteriorated by the time of the Type A test. Also, Weinstein has noted that valve leakage, which comprises the majority of component failures, is a repetitive problem that indicates difficulty in maintaining leakage integrity.[17] Rather than penalize the Type A test frequency, it seems more logical to require increased testing of the faulty component. Because many Type B and C reports contain only the "as left" leakage rates, it is difficult to determine the leakage status prior to the tests. Thus the good record of leaktightness may be misleading. And, based on the Type A test problems and LERs, a testing frequency of Type B and C components tied directly to their performance at each test is warranted. For instance, two successive failures of a component on the normal schedule would result in the testing of that component at half the normal interval for the next two tests. Additional failures would result in additional reductions in the time interval between the tests. Continued successes would result in the increase of the test interval up to the 2-year maximum. Because of the economics involved, this process should encourage utilities to maintain improved leakage integrity of Type B and C components.

Reductions in the time interval between tests may result in the necessity of testing components during plant operation. Many utilities currently conduct such tests, especially on airlocks. For many other components, such as electrical and piping penetrations that constitute a static barrier, this testing may be quite practical, provided the radiological hazard to test personnel is acceptable. In other cases, the radiological hazard to personnel may be unacceptable or the component may be required to function during plant operation, as in the case of some valves. Testing of these components during plant operation would not be feasible. Because of the individuality of containments, it is not possible to determine in general which components can or cannot be locally leak tested during plant operation. But with the potential of reduced time intervals between tests, it seems likely that many faulty components will have to be tested during operation.

In addition to periodic testing of components, many utilities employ continuous monitoring or continuous pressurization. By pressurizing the component to P_a continuously, any observance of pressure decay indicates a degradation of the leaktightness of that component. Continuous leak testing is advantageous because a leak is discovered as soon as it occurs. Continuous testing at pressures less than P_a is to be discouraged because of the difficulty in extrapolating leak rates and in changing leak paths. Exceptions would be made for some continuous testing at pressures less than P_a when the testing is designed to demonstrate leaktightness over a short interval of time such as in the case of airlock door seals. In such exceptions, testing at P_a of the entire component is necessary as soon as practical. Continuous leak testing at P_a should be encouraged by the elimination of periodic testing of these components. Leakage measurements would be taken at the same frequency for the determination of Type B and C test acceptability. The use of continuous monitoring is largely an economic consideration for individual utilities.

Appendix J specifies the Type B test frequency as less than 2-year intervals, except for continuous monitoring systems which must be tested at intervals under 3 years. Other exceptions are airlocks, which should be tested once every 6 months unless opened, and then within 3 d after the opening and once every 3 d during periods of frequent openings. The criteria in ANSI/ANS-56.8-1981 for Type B and C test frequency are essentially the same as those in Appendix J. Continuous testing is mentioned in both guidelines, but only Appendix J requires a periodic test of the component in addition to continuous monitoring, although the frequency is reduced.

4.4 Acceptance Criteria

The acceptance criteria in Appendix J for Type B and C tests state that the combined leakage of all penetrations and valves subject to Type B and C tests shall be less than 0.6 L_a. Fluid leakages from valves that are covered by water (and will remain so in an accident) are excluded but are evaluated against allowable fluid rates in the technical specifications. The criteria for acceptance in ANSI/ANS-56.8-1981 state that the combined leakages, including the UCL, for all paths subject to Type B and C tests shall be less than 0.75 L_a. Again, fluid leakages are excluded.

All Type B and C test results that were reviewed were evaluated through the Appendix J requirements. In most cases the results were acceptable, but the leakages used in the evaluation were generally "as left" values obtained after repair of the component. Thus the apparent good record of Type B and C testing may be misleading.

The determination of the acceptability of the results by considering the leak paths as a conglomerate may need to be revised. The determination of the acceptability of the leak rates should be made at the time of the test, which would require specifying allowable leak rates for all components. The review of the test reports revealed that, in the past, several utilities specified allowable leak rates for individual components. Although it may not be practical for all utilities to specify individual limits, some means of evaluating the acceptability of the components on a one-by-one basis is necessary to help eliminate the occurrence

of Type A test failures or delays due to excessive leaks through already tested (and presumably satisfactory) components. In order to implement this kind of evaluation, utilities would be required to report the "as-found" leakage measurements, which would most likely reveal that many individual components are leaking excessively and that repairs made to eliminate such leakage are temporary at best. The conglomerate of the individual allowable leakage rates would still have to be less than some percentage of L_a. Because of the relatively poor performance of Type A tests (due to excessive leakage through Type B and C components) following the successful completion of local leak testing programs, no reason is evident to justify relaxing the currently enforced limit of 0.6 L_a on the conglomerate. This limit should remain the subject of review once the effects of potential changes in the testing frequency and individual leakage limits of components can be evaluated.

5. EXEMPTION REQUESTS AND LICENSEE EVENT REPORTS

The basis for the information used in the evaluation of the exemption requests was a series of reports by the Franklin Research Center (FRC). Twenty-five reports were reviewed and two typical references are provided.[18,19] These reports were prepared for the NRC to provide technical assistance in support of operating reactor licensing actions.

The Licensee Event Reports, or LERs, were obtained through a search of the Nuclear Safety Information Center computer files located in Oak Ridge, Tennessee. The search produced abstracts of 100 LERs directly related to leak rate testing.

The analysis of the exemption requests and LERs was not intended to highlight any request or event. Instead, the focus of the analysis was to categorize the requests and events as much as possible to aid in identifying repeated requests or events. These repeated items could be evaluated to determine if changes in the guidelines are necessary.

5.1 Type A Test Exemption Requests

The majority of requests for exemptions in Type A tests formed four categories: conducting local leak tests just prior to a Type A test and back correcting the Type A test results, venting and draining of fluid-filled systems, test duration, and test frequency.

Appendix J requires that the Type A test be conducted in as close to the "as is" condition as practical; if excessive leakage is observed, the Type A test is terminated, local leak tests are conducted and repairs are made, and a Type A test is run again. Many utilities requested an exemption from this sequence of events so that they could conduct local leak tests just prior to Type A tests, thereby discovering and repairing excessive leaks before conducting the Type A test. In this way the utilities will probably only have to conduct one Type A test because the possibility of failing the test has been virtually eliminated. However, this test is not an indication of the "as found" condition but rather the "as left" condition. Therefore, the utilities have been required to use the measured leakage rates from the local leak tests to back correct the Type A test results and obtain the "as found" condition. The NRC has ruled that back correcting of the Type A test results is allowable provided all measured local leakages are conservatively assumed to be outleakages. This ruling prompted additional exemption requests regarding the measured local leakage obtained by pressurizing between isolation valves.

The practice of pressurizing between two isolation valves during a local leak test results in the determination of a combined leakage of valves. Under accident conditions, the pressure is applied to the valves in series so that the leakage would be determined by the smaller of the two leak paths rather than the combined leakage. Therefore, the assumption has not been that the leakage in this case be totally outleakage, but the conservative assumption that the valves leak equally. Thus, only

one-half of the leakage measured by pressurizing between isolation valves would be considered outleakage.

Appendix J does not specify that Type B and C tests be completed prior to conducting a Type A test; ANSI/ANS-56.8-1981 does. By completing the local leak tests prior to the Type A test, the "as found" condition of the containment is lost unless the Type A test results are back corrected using the "as found" leakages from the local leak tests. Back correcting of the Type A test results is acceptable provided the "as found" local leakages are used and are all considered outleakages, with the exception of some isolation valve leakages. Only one-half of the combined leakage measured by pressurizing between two isolation valves need be considered outleakage.

The requirements for venting and draining fluid-filled systems are the same in both Appendix J and ANSI/ANS-56.8-1981. The requirements state that those portions of fluid systems that are part of the reactor coolant pressure boundary that may be open to the containment atmosphere under accident conditions shall be vented to the containment atmosphere during the test. Portions of closed systems inside the containment that penetrate the containment boundary and may rupture during the accident shall be vented to the containment atmosphere during the test. The vented systems should be sufficiently drained to allow exposure of the isolation valves to the containment air test pressure (including any differential pressure caused by the accident). Systems required for safety during the test shall remain operable and not be vented or drained. Also, systems that are normally filled and operating under post-accident conditions need not be vented or drained. However, the isolation valves of these systems must be periodically tested by local leak tests.

The majority of the exemptions requested concerning venting and draining of fluid-filled systems were the result of misinterpretation of Appendix J. In many cases, no exemption was required because the exemption request was within the requirements of Appendix J. In some cases, temporary exemptions were requested until connections for draining and venting could be installed on certain systems. In one case, a request was made that the reactor vessel not be vented but rather filled with water to prevent inleakage. Because of numerous leak paths isolated by the water, NRC found the request unacceptable.

Because a Type A test is intended to evaluate the leak integrity of the containment in a condition simulating accident conditions, every effort should be made to vent and drain all fluid systems that may be exposed to the containment atmosphere during an accident. Of course, systems that are required for safety during the test should not be vented and drained but should remain operable. Systems that will remain fluid filled after an accident need not be vented and drained.

One issue that was raised during this evaluation concerned the possibility and subsequent effect of an earthquake in conjunction with the accident. Under accident conditions alone, a system designed to remain fluid filled need not be vented and drained. Some of these systems, at least, are not designed for seismic events, in which case the fluid might escape and expose the system to the total containment air pressure rather than the lower differential pressure present when the fluid is present. For this sequence, these systems should be vented and drained.

The remaining two categories of Type A test exemptions concern test frequency and duration. Requirements for frequency and duration have already been discussed in Chap. 3 for both Appendix J and ANSI/ANS-56.8-1981. The exemption regarding the frequency requested that the interval between tests be extended to 5 years because of the good performance of previous tests. Test data were reviewed in Chap. 3 with regard to frequency, and the results indicated that the Type A test frequency could possibly be decreased; however, it was also noted that the data may be misleading because of poor reporting of Type B and C test results. Therefore, there is no justification for changing the Type A test frequency at present. All exemption requests concerning the duration of Type A tests were asking permission to conduct such tests of <24 h. As discussed in Chap. 3, successful tests lasting <24 h have been shown to be achievable. Although specific criteria have not yet been finalized, the Type A test duration will most probably be determined by the behavior of the recorded data rather than an arbitrary period of time.

5.2 Type B and C Test Exemption Requests

Most Type B and C test exemption requests could be classified into four categories: airlocks, isolation valves, special types of penetrations, and the test schedule. Exemptions concerning airlocks dealt with the frequency and pressure of the tests. Isolation valve exemptions dealt with the test medium, pressure, and direction of pressure. The special types of penetrations for which exemptions were requested were passive barriers (e.g., instrument lines), unused penetrations, and those not easily tested. The test schedule exemptions were basically generated from differences in the technical specifications and Appendix J.

Airlock testing has prompted numerous exemption requests from the utilities concerning frequency. Because airlocks represent large leak paths that are more prone to human error than other isolation components, the testing frequency is correspondingly higher. Normally, the frequency is once every 6 months during periods when containment integrity is required. However, during periods when the airlocks are being used quite often, the possibility of damage or misalignment of the seals is increased and, therefore, so is the testing frequency. The original NRC philosophy concerning this increase in testing because of an increase in use was that the airlocks must be tested after each opening. Many exemptions from this frequency were requested because the time involved in conducting a test, even a test at less than P_a, made testing after each opening impractical during periods of frequent openings. The NRC relaxed the requirement to the present frequency of once every 3 d (72 h) during periods of frequent openings. This same frequency is included in ANSI/ANS-56.8-1981.

Many exemptions concerning the testing of airlocks at P_a were also requested. Testing the airlocks once every 6 months at P_a is necessary to identify leakage past the door operating components and the seals under accident conditions. However, during periods of frequent openings when the airlocks will be tested once every 72 h, testing at P_a may be impractical. Many plants designed prior to the issuance of Appendix J

are not equipped to test airlocks at P_a without the use of strongbacks or a modification of the inner door operating mechanisms. The inner doors were designed to seat under pressure from the containment side of the door. During a local leak test of the airlock, pressure is applied within the airlock, thus exerting pressure on the inner door in a manner opposite that for which it was designed. The opposite direction pressure will cause the door to unseat and prevent the conduct of a meaningful test unless strongbacks are employed or adjustments made to the door to prevent unseating. These modifications require extensive amounts of time as does the subsequent test at P_a. Therefore, during periods of frequent openings, testing at P_a becomes impractical in many cases.

Also, improper seating of airlock door seals is the most frequent cause of excessive airlock leakage. Leak testing of the seals can be accomplished by pressurizing between seals (for double-gasketed doors) or by pressurizing the airlock to a pressure substantially less than P_a. Thus, recognizing that the seals are the most probable leak path, during periods of frequent openings the airlock could be satisfactorily leak tested at a pressure less than P_a (low enough to not require door modifications) or by testing the seals directly, as in the case of double-gasketed doors. Appendix J was revised to incorporate this philosophy at the time airlock testing frequency was being revised. The requirements of ANSI/ANS-56.8-1981 also allow seal tests or testing of airlocks at a pressure less than P_a during periods of frequent openings.

The test medium specified in Appendix J and ANSI/ANS-56.8-1981 for isolation valve tests is air or nitrogen unless the valves are pressurized with a fluid from a seal system, in which case the medium is the fluid (water or nitrogen). Several utilities requested that they be allowed to conduct hydraulic tests in lieu of pneumatic tests on certain isolation valves that were part of a fluid-filled system and not easily exposed to an air or nitrogen test. In many cases the fluid-filled system could be shown to remain fluid filled during and after an accident; consequently, the Appendix J requirements were satisfied and hydraulic testing was allowed (no exemption was required). In other cases, the valves could potentially be exposed to air and therefore should be tested with air. The use of hydraulic tests in lieu of pneumatic tests should be prohibited where possible because of the lack of an acceptable water-to-air leakage correlation.

The exemptions concerning the test pressure and the direction of the test pressure for isolation valves were closely related. The design of most operating boiling-water reactor plants necessitates leak testing the main steam isolation valves by pressurizing between the inboard and outboard valves. In so doing, the inboard valve is being pressurized in the reverse direction of the accident pressure. Because these valves are designed to seat better under pressure, the test pressure tends to unseat the inboard valve causing increased leakage. Appendix J and ANSI/ANS-56.8-1981 allow reverse direction testing if the leakages so determined can be shown to be conservative or equivalent. If the conservatism or equivalency of the reverse pressure testing cannot be shown, then the test must be conducted so that both valves are exposed to the pressure in the direction in which they perform their safety function.

Because testing between isolation valves is acceptable in many cases, exemptions from the required test pressure of P_a were sought.

Testing at P_a unseats the inboard valve giving rise to excessive leakage. Testing at a reduced pressure would not unseat the valve because the reduced pressure would not exert enough force on the valve. Pressurizing between isolation valves at a reduced pressure is inherently conservative. Testing of the valves at P_a in the direction of the accident pressure creates a greater seating force on the valves than is achieved by applying a reduced pressure between the valves. Therefore, reduced pressure testing is acceptable provided testing between the valves is also acceptable. Appendix J requires valve tests to be performed at P_a, whereas ANSI/ANS-56.8-1981 allows for reduced pressure testing if the pressure is included in the technical specifications.

Many requests were made for the exemption of several types of penetrations from local leak rate testing. These types of penetrations were passive barriers such as unused and capped penetrations, instrument lines, and others not easily tested. Appendix J requires Type B tests for penetrations whose design incorporates resilient seals, gaskets, or sealant compounds, piping penetrations fitted with expansion bellows, and electrical penetrations fitted with flexible metal end assemblies. The results of both Type A and Type B tests indicate that passive barriers are not generally prone to degradation between Type A tests. Therefore, exemptions from local leak testing are in order for certain penetrations provided they are exposed to Type A tests periodically. These penetrations could generally be described as those not designed to be locally tested and that represent minor leak paths. Because each containment is unique, there does not appear to be any justification for exempting all passive barriers. These exemptions should be handled on a case-by-case basis as in the past.

Several exemptions were requested from the schedule of Type B and C tests because of differences between the technical specifications and Appendix J and to allow time for modifications to be made that would permit testing of certain components. Such requests usually came after a request for the component to be exempt was denied. In these cases, strict adherence to the test frequency is impractical and exemptions should be granted. Such requests should continue to be evaluated on a case-by-case basis.

5.3 Licensee Event Reports

Of the 100 LERs reviewed, 87 were able to be placed in groups of 5 or more representative of the same type of event. The remaining 13 events dealt with such items as exceeding the specified time limit for closure of isolation valves and exceeding the time limit on filing the results of a Type A test. The LERs listed, although not a complete listing, are a representative group.

Six of the LERs dealt with the violation of the scheduled test frequency for either Type A, B, or C tests. The violations were generally attributed to personnel oversight and were promptly corrected. In one case the tests were postponed to allow the completion of seismic-related modifications. In all instances, measures were instituted to help prevent a recurrence.

Ten of the LERs concerned failed Type A tests, and nine concerned failed local leak tests. Of the failed Type A tests, nine were directly attributable to leaks through penetrations or valves that were subject to local leak testing. The remaining failure of a Type A test was due to excessive leakage through two holes that had been inadvertently drilled through the containment shell. The failed local leak tests were due primarily to excessive leakage through valves. In all cases, repairs or modifications were made and the components retested. In at least one instance, the frequency of testing was increased for particularly leaky components.

The next three categories concern excessive valve leakage, excessive airlock leakage, and excessive penetration leakage. Excessive leakage was reported in these LERs, but it was not explicitly stated whether the local leak test program had failed. Therefore, these LERs could not be included in the previously discussed category.

Excessive valve leakage was the subject of 38 of the LERs. This subject accounted for practically three times as many LERs as any other subject. Valve leakages were repeatedly discovered during both Type A and Type C tests, which indicates the need for more frequent testing of these components and improved repair procedures. Valve leakages were caused by an incorrect valve lineup (valve left open) in one instance, but most often by packing leaks, worn seats, deteriorated elastic seals, and loose flange bolts. In most cases, repairs were made (tightening packing nuts and flange bolts, lapping worn seats, and replacing elastic seals) and the valves were successfully retested. Component replacement was required only occasionally. Because Type C tests are intended to uncover and correct potential leakage problems before they become critical, the continued occurrence of excessive leakage through isolation valves during Type A tests indicates a general failure on the part of the Type C test programs to correct the problem. A test frequency that is increased or decreased based on the leakage performance of the valve should help encourage utilities to ensure more leaktight valves.

Excessive airlock leakage was reported in 12 of the 100 LERs reviewed. Leakage was attributed to such causes as a loose chain on the handwheel operating mechanism, improper adjustment of the operating mechanism creating a low seating force, and inadequate tightening of strongbacks. Leakage through the handwheel shaft seal was noted three times, and leakage past the door seals was mentioned six times; worn or damaged door seals were the cause of leakage in four of these six LERs. In all cases the seals were replaced. The remaining two door seal leakages were caused by misaligned door seals and dirty seals. Repairs were effected by realigning and cleaning the seals, respectively. All leakages were found during Type B tests.

Seven LERs described excessive penetration leakages. Excessive leakage was found past an escape hatch outer door and was traced to a worn seat in the pressure equalizing valve. An electrical penetration was found to be unpressurized because of an insulator bushing failure; other electrical penetrations were found to be leaking through the epoxy end seals. Also, a test connection had broken off from a residual heat removal system because of fatigue from vibration. During a Type A test, leakage was found in the reactor building differential pressure switches resulting from ruptured diaphragms. The diaphragms had been incorrectly

designed for a pressure less than P_a. A drywell head flange was found to be excessively leaking during a Type A test due to insufficient torque on the head flange. A through-the-wall crack was also discovered in a purge line during local leak tests. The specific cause was listed as unknown. Repair or replacement of the components was provided as required, and the retests were successful.

The remaining category concerned the failure of tests on secondary containments and includes five LERs. One test failed to demonstrate the required vacuum due to a deteriorated seal on a railroad airlock. Another failed because of excessive leakage past a deteriorated seal in the rector building roof manway. Another LER described the failure of a test to demonstrate that the leakage was within the allowable limits of the technical specifications, but concluded that the specifications had been changed to a higher limit. Leakage through the reactor building roof hatch, the main steam tunnel to the turbine generator building, and a heat exchanger access plug caused the failure of another secondary containment test. Finally, during a preoperational test, leakages were discovered around reactor building roof flashing, personnel doors, electrical penetrations, and the railroad airlock doors. Repairs and replacement were made as needed, and satisfactory retests were performed.

6. PROPOSED APPENDIX J REVISION

The need for a revision to Appendix J has been growing for many years, as has been evidenced by the large number of exemption requests, changes in testing procedures, and questions on interpretation. The original Appendix J, issued in 1973, contained several specific requirements for test parameters, such as the stabilization period and the test duration. The inclusion of such requirements severely inhibited the ability of the Appendix to be adaptable to changes in leak rate technology. In general, the Appendix should specify the items to be tested, the frequency of the tests, the acceptability criteria for the tests, procedures for handling failed tests, and the process for reporting the results. The industry-generated standard ANSI/ANS-56.8-1981 is available to define the various technicalities of the test methods, and this document could be referenced in the Appendix. Any changes or additional requirements to the ANSI standard would be dealt with through the use of a regulatory guide. In this manner, Appendix J would be insulated against the technological changes inherent in any field of testing. Thus, any revisions necessitated by technological change would be handled through a revision to the regulatory guide and not Appendix J, a much less stringent process.

The NRC has developed a proposed revision to Appendix J in draft form not yet generally released. This draft has been reviewed in light of the utility and NRC experience through testing. The proposed requirements that represent a significant change from the current Appendix J requirements or are new requirements will be highlighted, as will those areas that conflict with ANSI/ANS-56.8-1981. The resolution of these conflicts will probably be handled through a regulatory guide, a draft of which has been prepared by the NRC.[20] A review of the major points of the regulatory guide will also be presented.

6.1 Revised Requirements

The proposed revision to Appendix J contains several revised requirements. One of the most apparent changes is not in the requirements but rather in the presentation of the requirements. Editorial changes have been made extensively to provide a more readable and understandable "plain English" text. Also, the level of detail has been reduced to encompass only general leak testing criteria. The details of testing are to be left to the industry-standard ANSI/ANS-56.8-1981, with any conflicts to be resolved through the use of a regulatory guide.

One major change in the requirements concerns the test pressure. Appendix J currently allows the use of a reduced pressure test, whereas the proposed revision allows only the full pressure test. The advantages of conducting a reduced pressure test vs a full pressure test are that it is less hazardous because of the lower pressure, it has less risk of component damage, it requires less pressurization time, and it generally should be cheaper. The disadvantages of a reduced pressure test are that the desired leak rate is not directly measured, and the extrapolation

factors used to determine the full pressure leak rate may be erroneous because of changes in the leak paths and the flow characteristics.

A review of the utility test data indicated that the difficulty in defining and validating extrapolation equations and the potential for changing leak paths and leak characteristics with time prompted most utilities to abandon reduced pressure testing. Recognizing that the difficulties involved will generally prohibit reduced pressure testing, but acknowledging that the economic benefits make it attractive, it appears beneficial to maintain reduced pressure testing as an alternative means of determining the leak rate.

Another major change concerns the duration of the Type A test. The proposed revision to Appendix J contains no requirements for a test duration, therefore removing the stigma of the 24-h test specified in the current Appendix J. The duration of the test should be dependent on the behavior of the recorded data and not on an arbitrary time period. The new test duration criteria will be best specified in an industry-generated standard or a regulatory guide. The new definition of test duration probably will incorporate requirements for a minimum number of data points and a minimum time duration. The measured leakage rate probably will be required to meet some quantitative limits on stability for a specified length of time before the test may be concluded. Additional criteria may be factored in to provide a test duration that will likely ensure the successful completion of the verification test.

The proposed Appendix J also more clearly states the NRC position that the Type A test determines the "as is" leakage status. Acceptance criteria for Type A tests have been changed to incorporate limits on the "as found" leakage as well as the "as left." Thus 95% UCL on the "as found" leakage of a containment must be $<L_a$, whereas the 95% UCL on the "as left" leakage must be $<0.75\ L_a$. Both the use of the 95% UCL and the limit on the "as found" leakage are new requirements. The use of the 95% UCL will provide added confidence in the results, and the limit on the "as found" leakage should provide a better indication of the leakage status of a containment while helping to prohibit the "tightening up" of a containment just prior to Type A tests.

The current Appendix J has only the one Type A test acceptance criterion of $0.75\ L_a$. The currently proposed revision incorporates a procedure by which the containment may be evaluated between Type A tests by using the Type B and C test results. The maximum allowable leakage may be prorated between $0.75\ L_a$ and L_a in proportion to the elapsed time since the last "as left" Type A test and the anticipated time remaining to the next scheduled "as found" test. This procedure assumes a linear degradation in the containment leakage rate which may not necessarily be the case. One proposed alternative is to add the increase in Type B and C leakage (noted from the local leak tests) to the last "as left" Type A leakage rate and compare the result to L_a. In either case the idea is to provide a more nearly continuous status report of the containment leakage without conducting Type A tests more frequently. Because the leakage changes or degradation may not be linear, the alternative method appears more justifiable. However, Type B and C leakage increases added to the last "as left" Type A leakage must be determined from the "as found" leakage rates.

The combined leakage rate of all Type B and C tests must be <0.60 L_a as before, but the proposed revision stipulates that this limit be met at all times. Therefore, both the "as found" and "as left" leakage rates of Type B and C testable components will be examined. Also, the results of any Type B or C test must be evaluated in conjunction with the last Type A test results discussed in the preceding paragraph, to verify that the maximum allowable leakage is not exceeded. Allowance is also made for the possibility of specifying individual leakage limits for individual components in the technical specifications. For those components utilizing continuous monitoring at P_a, leakage measurements from the monitoring system are acceptable in lieu of Type B tests.

The Type A test frequency remains essentially the same but is no longer tied to the 10-year inspection period. This change will eliminate possible scheduling problems of the first periodic Type A test caused by a delay in the licensing of the plant following the preoperational Type A test. The retest frequency following failure of Type A tests is essentially the same in the proposed revision as it is in the current Appendix J, with one major exception. If a Type A test fails solely due to a specifically identified (and subsequently corrected) Type B- or C-tested leak path, then the increase in testing frequency will apply only to the Type B or C test schedule, not the Type A schedule. This requirement penalizes the Type B or C tests (not the Type A tests) because the Type B- or C-tested leak path caused the failure. The requirement is necessary and probably will be welcomed by utilities because of the economics involved.

A modification to airlock testing has also been incorporated. Because partial pressure tests and tests of seals have been considered acceptable to the NRC, the requirement of testing an airlock at P_a after a period of time when containment integrity was not required has been relaxed to the use of seal tests on tests at less than P_a. This change should eliminate the possibility of an airlock test taking longer to complete than the plant was shut down, which is a distinct possibility for brief shutdown periods of a few days or less.

Finally, a provision has been made for hydraulic testing of isolation valves. Although the recommended test medium is air or nitrogen for valves that are not part of a seal system, the NRC has recognized that in some cases pneumatic testing of a valve simply may not be practical. For those cases, the valves must have allowable liquid leakages specified in the technical specifications that can be compared to the results of the hydraulic tests. This change should eliminate a large number of exemption requests.

6.2 Conflicts with ANSI/ANS-56.8-1981

Although ANSI/ANS-56.8-1981 is expected to be referenced either directly in the proposed revision to Appendix J or, more likely, in a regulatory guide, areas of conflict between the revised Appendix J and ANSI/ANS-56.8-1981 will still exist. These conflicts, along with other exceptions taken by the NRC to the industry standard, will be dealt with in a regulatory guide. A draft of this regulatory guide containing some

25 recommended changes to ANSI/ANS-56.8-1981 has been prepared. The areas of direct conflict will be discussed first, followed by a discussion of the areas of ANSI/ANS-56.8-1981 to which the NRC has taken exception.

Five areas of direct conflict between the proposed revision of Appendix J and ANSI/ANS-56.8-1981 have been noted. These areas are the Type A test frequency, the test pressure for Type B and C tests, airlock testing frequency, the acceptance criterion for Type B and C tests, and the pressure for hydraulic tests.

The conflict regarding the Type A test frequency is based on the maximum interval allowed between Type A tests. The proposed revision to Appendix J specifies this interval as 4 years, whereas ANSI/ANS-56.8-1981 allows 5 years. The evidence presented in preceding chapters indicates that most Type A test problems are caused by Type B- and C-tested leak paths. Thus, Type A tests are continuing to uncover excessive leak paths on a routine basis. Until changes in Type B and C test programs force improvement in leakage characteristics of certain components (most notably, isolation valves), the more conservative interval of 4 years should be used. This frequency should be reevaluated in a few years to assess the impact of the revised requirements of the proposed Appendix J regarding local leak testing.

The test pressure for Type B and C tests is required to be P_a for pneumatic tests, except under special conditions. Both revisions of Appendix J (proposed revision and current) and ANSI/ANS-56.8-1981 contain this requirement; however, the ANSI standard allows a vacuum test to substitute for a test to P_a. Because the extrapolation of test results from a pressure less than P_a is not well defined or generally accepted, the differential test pressure must be P_a. Therefore, the vacuum test pressure substitution should contain the stipulation that the differential pressure must be at least P_a and subject to NRC approval.

Both the proposed revision to Appendix J and the version currently in force require that all Type B tests be performed within 2-year intervals. This time requirement in ANSI/ANS-56.8-1981 is the same but is somewhat unclear in the airlock testing section. If an airlock is not used during a 6-month period, then ANSI/ANS-56.8-1981 allows testing of the airlock after the next use rather than the 6-month interval. Because the time period until the next use could exceed the 2-year test period for all Type B tests, a discrepancy exists. A qualifying statement should be included in the airlock testing section to limit this test period to a maximum of 2 years, thus satisfying the intent of Appendix J and ANSI/ANS-56.8-1981.

Another conflict between ANSI/ANS-56.8-1981 and the proposed revision to Appendix J concerns the acceptability criterion for the results of Type B and C tests. To be acceptable, ANSI/ANS-56.8-1981 requires the combined leakage rate (including the upper confidence limit) of Type B and C tests to be <75% of the maximum allowable leakage rate. The proposed revision to Appendix J states that the combined leakage rate of all Type B and C tests must be <60% of the maximum allowable leakage rate at all times. The differences in these criteria are twofold. ANSI/ANS-56.8-1981 includes an upper confidence limit on the combined leakages determined by adding the standard deviation of the leakage rate to the

leakage rate, whereas the proposed revision to Appendix J does not. The second difference regards the 75% vs 60% criterion.

The inclusion of the measurement error through the use of the standard deviation is very worthwhile. Presentation of the leakage rate data in this manner provides a better indication of the accuracy of the Type B and C leak tests. Because ANSI/ANS-56.8-1981 uses 75% with a confidence limit and the proposed revision to Appendix J uses 60% without a confidence limit, the only way the two could provide the same result would be for the standard deviation of the combined leakages to equal 15% of the maximum allowable leak rate. With the sophisticated instrumentation available today, such a large standard deviation is very unlikely, which means the criteria in the proposed revision to Appendix J are more conservative than the ANSI criteria.

The remaining question concerns the degree of conservatism to use in evaluating the results (i.e., specifying the percentage of the maximum allowable leak rate). Recognizing that practically all Type A test leakage problems were the results of Type B and C component leak paths, it is felt that the currently enforced 60% rule should be retained as a check on Type B and C tests. In fact, except for the knowledge of potential changes elsewhere in local leak testing programs, the 60% criterion should probably be more strict. The 60% rule should stand until the effects of potential changes in local leak testing programs can be evaluated.

The final area of conflict concerns the test pressure for hydraulic tests. Both versions of Appendix J require a pressure of 1.1 P_a, whereas ANSI/ANS-56.8-1981 specifies a pressure of only P_a. For water-filled systems that will remain so following an accident, the test pressure should be 1.1 P_a because these systems are normally pressurized to a level slightly higher than P_a to ensure that all leakage is into the containment. Therefore, the component will experience a pressure greater than P_a during an accident and should be tested at a pressure greater than P_a. For a hydraulic test conducted in lieu of a pneumatic test on a system that will not be water filled, a test pressure of 1.1 P_a provides an added degree of conservatism.

Apart from the 5 direct conflicts just discussed, the draft regulatory guide contains 20 positions or exceptions to ANSI/ANS-56.8-1981. Some positions are to revise the wording of some sections for increased clarity. One position emphasizes that Appendix J requirements take precedence over ANSI/ANS-56.8-1981. Another states that auxiliary steam lines penetrating the containment system for use during outages should be isolated and vented to eliminate a potential energy source that might prove difficult to account for in the calculations. Also, in the event that severe structural deterioration is noticed, after repairs a structural integrity test may be necessary prior to a Type A test. Additionally, any instrument error corrections to the Type A test results should be at the UCL, because the Type A test results and any Type B and C corrections are at the UCL. The NRC also reiterates its position of applying a single active failure criterion in the review of containment-related systems. The format for test reports specified in ANSI/ANS-56.8-1981 is recommended for use in reporting the results required by Appendix J. Also included are recommendations for the visual inspection of airlock door seals and the clarification of instrumentation calibration. As

presently written, the instruments are required to be individually calibrated within 6 months prior to a Type A test. Because of the possibilities of instrument damage, the NRC requests that instruments be calibration checked within 1 month prior to a Type A test. The preceding positions were mainly NRC clarifications and a reemphasis of NRC philosophy regarding certain points. Exceptions of greater significance taken by the NRC are discussed in the following paragraphs.

The containment sump level should be considered as affecting the containment volume. The error resulting from neglecting the changes in the sump level is not related to the fact that the water responsible for sump level changes came from the containment air. The effect of water vapor changes in the air mass is eliminated by air mass equations; however, no provision is made for volume changes caused by water vapor conversion to water (or vice versa).

The mass step change verification test should specify a minimum number of data sets (similar to the technique of requiring 20 data sets for a Type A test). As it is presently written, only two data sets are required, one before the mass change and one after. In all probability one measurement will not provide an accurate estimate of the mass change. Therefore, a minimum number of data sets is required. The determination of this number should be subject to the same type of evaluation as the Type A test duration criteria.

Both the "as found" and the "as left" leakage rates of Type B- and C-tested components should be recorded to allow a more accurate evaluation of the containment leak integrity between Type A tests. Such a requirement would help to eliminate the practice of finding and correcting local leak paths just prior to a Type A test without recording the "as found" leakage.

The NRC also takes exception to the minimum duration of 8 h for the Type A test. The draft regulatory guide calls for a 24-h minimum with at least 20 data sets, unless a shorter duration test is explicitly approved. This requirement is expected to change in light of recent developments regarding test duration and will probably be eliminated by the time the regulatory guide takes effect. Of course, should the work now being done on Type A test duration criteria prove unacceptable to the NRC, the 24-h test period might still be required.

As mentioned previously, the draft regulatory guide recommends the format specified in ANSI/ANS-56.8-1981 for reporting test results. Because of the varied report formats encountered during the evaluation of the test reports, the specification of one uniform format would be useful in aiding any future evaluations. The format contained in ANSI/ANS-56.8-1981 is good; however, three recommendations are in order. First, both the "as found" and "as left" leakage measurements for all Type B and C tests since the last Type A test should be included in the report submitted to the NRC. Second, the data sets used to determine the Type A leak rate should be tabulated with individual sensor readings indicated. Inclusion of individual sensor readings would show the stability of the containment environment and the degree of stratification of temperature. And third, a chronology of significant events that occurred during the test should be reported. This information is currently required by ANSI/ANS-56.8-1981 to be held as backup data, but its inclusion in the

report to the NRC would allow a more complete assessment of a plant's leak testing program at the time of the test.

Furthermore, to ensure that such information is reported, the format and contents (plus revisions as discussed) could be specified in Appendix J. At the very least, a format could be specified in Appendix J to eliminate the wide variation in reporting results encountered in this evaluation.

7. CONCLUSION

An evaluation of leak rate testing practices has been conducted. Forty-nine Type A test reports and 46 Type B and C test reports were reviewed. Twenty-five reports describing exemption requests and 100 LERs were also reviewed. The significant areas of the tests were discussed, with utility practices and data presented along with the existing guidelines contained in Appendix J and ANSI/ANS-56.8-1981.

The absolute test method is the most widely used method and is preferred because of difficulties with the reference vessel method. Reduced pressure Type A tests were generally unsuccessful because of problems in validating extrapolation equations; therefore, a test pressure of P_a is recommended. However, reduced pressure testing is a valid alternative, provided acceptable correlations are defined. The number of sensors is related to individual containments, but some minimums could be specified according to volume. The 24-h test duration will probably be replaced by criteria based on the characteristics of the data. The Type A test frequency is more than adequate for determining leaks resulting from causes other than Type B and C components; however, many Type A tests experience delays and failure because of excessive leakage through Type B and C components. The mass plot analysis technique is preferred because of its apparent greater stability and ability to directly measure the leak rate. The verification test is a useful tool and should be maintained. And an accurate evaluation of the Type A acceptance criteria could not be made because of the difficulty in assessing the true degree of containment degradation between Type A tests.

Pneumatic testing at P_a is recommended for all Type B and C tests, with the exception of water-filled systems that remain filled in an accident. These systems should be tested at 1.1 P_a. Hydraulic testing in lieu of pneumatic testing is not recommended, but it is recognized that in some cases exceptions will have to be made. The Type B and C test frequency should be coupled to the performance of each component by obtaining both "as found" and "as left" leakages. The "as found" leakages could be evaluated against individual component acceptance criteria (either a specified leakage rate or a percentage of L_a). Insufficient data were available to permit accurate evaluation of the Type B and C test acceptance criteria.

Back correcting Type A test results is acceptable provided that all Type B and C leakage is assumed to be outleakage, with the exception of leakage determined by pressurizing between isolation valves. In this case, the outleakage may conservatively be taken as one-half the measured leakage. Pressurizing between isolation valves at less than P_a is acceptable because it is inherently conservative. Excessive valve leakage represented 38% of the LERs studied and highlighted the need for improved maintenance, repair, and testing of these components. Excessive airlock leakage was generally the result of worn, damaged, misaligned, or dirty door seals, which supports the consensus that seal tests are adequate to provide a short-term indication of airlock leak integrity. Minor leakage was also noted through other penetrations and, in general, indicated the poor performance of local leak testing programs to effectively maintain leaktight components.

The proposed revision to Appendix J appears to be very responsive to the results of the test experiences. Elimination of the 24-h test duration as a requirement and penalizing the frequency of Type B and C tests instead of the Type A test frequency, that is, when Type A tests fail because of Type B- and C-tested components, are two of the more significant revisions. Also, the requirement that "as found" leakages must be reported as well as "as left" leakages is a major change. These revisions follow directly from utility and NRC test experience and are supported by the data evaluated in this report. Also, clarification of allowable test pressures (for airlock and isolation valves), provisions for hydraulic testing in lieu of pneumatic testing, and the general rewording of several areas improve the regulation and should help reduce the number of exemption requests.

To maintain flexibility, reference to ANSI/ANS-56.8-1981 probably will not be made directly in Appendix J. More likely, reference will be made in a regulatory guide that can be more easily revised than Appendix J in case it becomes necessary to reference a new industry standard should one be developed to replace ANSI/ANS-56.8-1981. Also, exceptions taken by the NRC to the guidelines in ANSI/ANS-56.8-1981 can be dealt with in a regulatory guide, as can areas of direct conflict between the ANSI standard and Appendix J. Five areas of direct conflict were noted in the evaluation. First is the Type A test frequency, which should remain as specified in Appendix J because the data are somewhat unclear as to whether or not a change is warranted. Second is the test pressure for Type B and C tests, which should be P_a (except for special cases); any vacuum tests should reflect a differential pressure of P_a. The third area is airlock testing frequency. All Type B and C tests should be conducted at intervals of 2 years or less. The wording in ANSI/ANS-56.8-1981 could allow an unused (or little used) airlock to remain untested for many years. The acceptance criteria for Type B and C tests comprise the fourth area of conflict. Because of the overall repeated poor performance of many Type B- and C-tested components, no relaxation in the Appendix J acceptance criteria is warranted. In fact, except for the knowledge that the testing frequency is being changed to more frequent testing of faulty (excessively leaky) components, the acceptance criteria should probably be more strict. The final area concerns the pressure for hydraulic tests, which should be 1.1 P_a. The higher pressure is required for water-filled systems that remain water filled after an accident, because these systems are generally pressurized to a pressure slightly higher than P_a and should be tested at a higher pressure. For hydraulic tests conducted in lieu of pneumatic tests (not recommended), the higher pressure provides an added degree of conservatism.

One area that is not covered by Appendix J but probably should be is the format for reporting the results of the tests. The format contained in ANSI/ANS-56.8-1981 is recommended, with three additional comments. First, both the "as found" and "as left" leakage measurements should be reported. Second, the data sets obtained during Type A tests should be reported with individual sensor readings. And third, a chronology of significant events should also be reported.

The proposed revision to Appendix J represents a valuable and necessary update to the current Appendix J. Rewording of certain parts of the

document and additional clarifications should help eliminate many misinterpretations and, consequently, reduce the number of exemption requests. Furthermore, the elimination of certain technical aspects will allow the regulation to remain current without the need for costly and time-consuming revisions. The introduction of a regulatory guide will allow the NRC a vehicle for specifying any exceptions to the relevant industry standards.

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Appendix A

RECOMMENDED REVISIONS TO ANSI/ANS-56.8-1981

During the evaluation of CILRT experience and the relevant guidelines, several areas of potential improvement in ANSI/ANS-56.8-1981 were noted. Also, an independent review of the ANSI standard by EXTRAN, Inc., was made available.[1] The two principal findings of the EXTRAN review were that the air mass equation in the ANSI standard is incorrect and extremely unconservative in some cases, and that the standard lacked important definitions, thereby allowing manipulation of the test data by utilities to achieve an acceptable test. Another equation was proposed by EXTRAN for calculating the air mass; this equation was compared to the ANSI/ANS equation for two sets of utility Type A test data. Additional evaluation of the EXTRAN equation was made using a computer program to generate simulated temperature data. The results of the evaluation of the EXTRAN equation will be discussed first, followed by a discussion of the missing definitions and the other noted areas of potential improvement.

The mass of air M in a volume V may be defined as

$$M = \int_V \rho dv \ , \tag{A.1}$$

where dv is a volume element and ρ is the density within that volume element. The perfect gas law may be written as

$$\rho = \frac{P}{RT} \ , \tag{A.2}$$

where ρ is the density, P is the pressure. R is the gas constant, and T is the temperature. Substituting Eq. (A.2) into Eq. (A.1) yields

$$M = \int_V \frac{P}{RT} dv \ . \tag{A.3}$$

Because the pressure is assumed to be uniform in the containment (for a given point in time) and R is a constant, Eq. (A.3) may be rewritten as

$$M = \frac{P}{R} \int_V \frac{1}{T} dv \ . \tag{A.4}$$

For the trivial case in which T is uniform over the volume, Eq. (A.4) becomes

$$M = \frac{PV}{RT} , \tag{A.5}$$

which is the basis of the air mass equation in the ANSI/ANS standard. However, the temperature within the containment is known to be variable over the containment volume, although the exact relationship between the temperature and volume at every point is not known. Instead, only a few points are known through the use of temperature sensors. Therefore, the integral in Eq. (A.4) must be approximated rather than exactly determined.

By definition

$$\int_V \frac{1}{T}\, dv = \lim_{N\to\infty} \sum_{i=1}^{N} \frac{1}{T_i} \Delta v_i \sim \sum_{i=1}^{n} \frac{1}{T_i} \Delta v_i , \tag{A.6}$$

where N is the theoretical number of volume subdivisions (approaching infinity in theory), and n is the actual number of volume subdivisions (a finite number in practice). Substituting the end result of Eq. (A.6) for the integral in Eq. (A.4) yields

$$M = \frac{P}{R} \sum_{i=1}^{n} \frac{1}{T_i} \Delta v_i , \tag{A.7}$$

and, furthermore, by defining the weighting factor w_i for a temperature sensor as the fraction $\Delta v_i/V$, Eq. (A.7) may be rewritten as

$$M = \frac{PV}{R} \sum_{i=1}^{n} \frac{w_i}{T_i} . \tag{A.8}$$

This equation represents the EXTRAN formulation of the air mass equation.

The ANSI/ANS formulation of the air mass equation assumes the special case of uniform temperature as indicated in Eq. (A.5). Because the temperature is known not to be uniform, this formulation is technically incorrect. The temperature term used in Eq. (A.5) is the mean of the sensor readings, generally obtained by the following equation:

$$T = \sum_{i=1}^{n} w_i\, T_i . \tag{A.9}$$

Rewriting Eq. (A.5) to reflect this calculation yields

$$M = \frac{PV}{R \sum_{i=1}^{n} w_i \, T_i} \, . \tag{A.10}$$

By comparing Eq. (A.10) with Eq. (A.8), the difference between the ANSI/ANS formulation and the EXTRAN formulation may be seen to be in the value of the temperature term. Because both equations are approximations of Eq. (A.4), an evaluation was conducted to determine if the difference was significant.

The air mass was calculated at each time period that data were obtained for two sets of utility Type A test data. Both sets included the sensor temperature readings and the weighting factors as well as the pressure readings (corrected for water vapor pressure effects) and the containment volume. The results for utility data set 1 are presented in Table A.1 and indicate that no observable difference exists between the two equations for this example. The mass plot leak rate for the EXTRAN air mass data is 0.098%/d and is also 0.098%/d for the ANSI/ANS data, again indicating no observable difference between the two equations for these data. The results for utility data set 2 are presented in Table A.2 and show a slight difference in the results of the two equations; however, the difference is so small (<0.25%) that it can be neglected. The mass plot leak rate for the EXTRAN air mass data in this instance is 0.358%/d; for the ANSI/ANS data the leak rate is 0.360%/d; this yields a difference on the order of 0.75%, which is negligible.

Equations (A.8) and (A.10) will yield identical results if the temperature is uniform. As the temperature becomes less uniform, the difference between the two equations becomes more pronounced. The maximum spatial variation in temperature for the two utility data sets just discussed was ~4.97 K (8.95°R) at any given time. The maximum change in temperature over the test (obtained by subtracting the lowest recorded temperature of any sensor from the highest of any sensor) was 5.04 K (9.07°R). The containment temperatures were on the order of 300 K (540°R); therefore, the spatial variation represents a variation of less than 2%. It is because of this temperature uniformity that little difference between the air mass equations was observed in the previous examples. This type of uniformity is believed to be typical of industry experience.

To determine the degree of nonuniformity in temperature necessary to create a substantial difference in the two equations, a computer program was developed that generates random temperature values to simulate temperature sensor data taken during a leak rate test. Input data consists of the approximate containment temperature, the number of temperature sensors, the sensor weighting factors, and the maximum allowable spatial temperature variations (excluding hot or cold spots). The program can also simulate a single hot or cold spot, which requires the inputting of the approximate temperature difference and the number of affected sensors. Sensor temperatures are assigned by the program by adding or subtracting a random percentage (<100) of the allowable spatial variations

Table A.1. Air mass calculations for utility data set 1

Data set	EXTRAN [Mg (tons)]	ANSI/ANS [Mg (tons)]	Difference (%)
1	296.882 (327.257)	296.882 (327.257)	0.000
2	296.881 (327.255)	296.881 (327.255)	0.000
3	296.881 (327.255)	296.881 (327.255)	0.000
4	296.881 (327.255)	296.881 (327.255)	0.000
5	296.878 (327.252)	296.878 (327.252)	0.000
6	296.880 (327.254)	296.880 (327.254)	0.000
7	296.869 (327.242)	296.869 (327.242)	0.000
8	296.874 (327.247)	296.874 (327.247)	0.000
9	296.854 (327.225)	296.853 (327.225)	0.000
10	296.861 (327.233)	296.860 (327.232)	0.000
11	296.843 (327.213)	296.843 (327.213)	0.000
12	296.847 (327.218)	296.847 (327.218)	0.000
13	296.847 (327.217)	296.846 (327.217)	0.000
14	296.845 (327.216)	296.845 (327.215)	0.000
15	296.832 (327.201)	296.831 (327.200)	0.000
16	296.824 (327.193)	296.824 (327.193)	0.000
17	296.825 (327.193)	296.825 (327.193)	0.000
18	296.819 (327.187)	296.818 (327.186)	0.000
19	296.801 (327.167)	296.801 (327.167)	0.000
20	296.814 (327.182)	296.814 (327.182)	0.000
21	296.823 (327.192)	296.823 (327.191)	0.000
22	296.820 (327.188)	296.820 (327.188)	0.000
23	296.821 (327.189)	296.821 (327.189)	0.000
24	296.814 (327.181)	296.814 (327.181)	0.000
25	296.789 (327.154)	296.789 (327.153)	0.000
26	296.793 (327.158)	296.793 (327.158)	0.000
27	296.793 (327.159)	296.793 (327.158)	0.000
28	296.782 (327.146)	296.782 (327.146)	0.000
29	296.782 (327.146)	296.782 (327.146)	0.000
30	296.813 (327.181)	296.813 (327.180)	0.000
31	296.788 (327.153)	296.788 (327.152)	0.000
32	296.804 (327.170)	296.804 (327.170)	0.000
33	296.796 (327.161)	296.796 (327.161)	0.000
34	296.793 (327.158)	296.792 (327.158)	0.000
35	296.785 (327.149)	296.784 (327.149)	0.000
36	296.783 (327.148)	296.783 (327.147)	0.000
37	296.786 (327.150)	296.785 (327.150)	0.000

Table A.2. Air mass calculations for utility data set 2

Data set	EXTRAN [Mg (tons)]	ANSI/ANS [Mg (tons)]	Difference (%)
1	39.853 (43.930)	39.772 (43.841)	0.203
2	39.857 (43.935)	39.776 (43.846)	0.203
3	39.842 (43.919)	39.762 (43.830)	0.203
4	39.847 (43.924)	39.766 (43.835)	0.203
5	39.836 (43.912)	39.755 (43.823)	0.203
6	39.843 (43.920)	39.762 (43.831)	0.203
7	39.834 (43.909)	39.753 (43.820)	0.203
8	39.829 (43.904)	39.748 (43.815)	0.203
9	39.834 (43.909)	39.753 (43.820)	0.203
10	39.831 (43.906)	39.750 (43.817)	0.203
11	39.824 (43.899)	39.743 (43.810)	0.203
12	39.830 (43.905)	39.749 (43.816)	0.203
13	39.818 (43.892)	39.737 (43.803)	0.203
14	39.815 (43.889)	39.735 (43.800)	0.203
15	39.822 (43.896)	39.741 (43.807)	0.203
16	39.820 (43.894)	39.739 (43.805)	0.203
17	39.815 (43.888)	39.734 (43.799)	0.203
18	39.815 (43.888)	39.734 (43.799)	0.203
19	39.803 (43.876)	39.723 (43.787)	0.203
20	39.802 (43.874)	39.721 (43.785)	0.203
21	39.804 (43.877)	39.723 (43.788)	0.203
22	39.807 (43.879)	39.726 (43.790)	0.203
23	39.804 (43.877)	39.724 (43.788)	0.203
24	39.807 (43.879)	39.726 (43.790)	0.203
25	39.794 (43.865)	39.713 (43.776)	0.203
26	39.791 (43.862)	39.710 (43.773)	0.203
27	39.788 (43.858)	39.707 (43.769)	0.203
28	39.791 (43.862)	39.710 (43.772)	0.203
29	39.791 (43.862)	39.710 (43.773)	0.203
30	39.788 (43.859)	39.707 (43.769)	0.203
31	39.775 (43.845)	39.694 (43.755)	0.203
32	39.780 (43.850)	39.699 (43.761)	0.203
33	39.779 (43.849)	39.699 (43.760)	0.203
34	39.774 (43.843)	39.693 (43.754)	0.203
35	39.821 (43.895)	39.740 (43.806)	0.204
36	39.819 (43.893)	39.738 (43.803)	0.204
37	39.778 (43.848)	39.697 (43.758)	0.204
38	39.763 (43.831)	39.682 (43.741)	0.204
39	39.758 (43.825)	39.676 (43.736)	0.204
40	39.755 (43.823)	39.674 (43.733)	0.204
41	39.755 (43.822)	39.674 (43.733)	0.204
42	39.794 (43.866)	39.713 (43.776)	0.204

to or from the approximate containment temperature. Sensor temperatures representing a hot or cold spot are obtained by modifying the approximate containment temperature by the specified difference of the hot or cold spot and then proceeding with the spatial variations. Following typical practice, the input temperatures are in degrees Fahrenheit, which are internally converted so that the output is in degrees Kelvin. The output consists of the generated sensor readings (for inspection), the temperature terms as formulated by EXTRAN and ANSI/ANS, and the actual maximum spatial variation that was generated.

A large number of simulations were conducted, and it became apparent that only under extreme circumstances was any significant difference in the EXTRAN and ANSI/ANS formulations noted. For a given set of input data, repeated simulations of sensor readings were performed. Only the results representing the widest variation in the two temperature terms are presented in the belief that they form an approximate upper bound. Table A.3 presents the simulated sensor readings and results for an input average temperature of 300 K (80°F), with a maximum allowable spatial

Table A.3. Simulated sensor readings and results[a] for an input temperature of ~300 K (80°F) with a maximum allowable spatial variation[b] of ~111 K (200°F) and no hot or cold spots

Sensor	Weighting factor	Temperature [K (°F)]
1	0.065	329.673 (133.742)
2	0.040	289.407 (61.263)
3	0.040	309.274 (95.222)
4	0.022	336.979 (146.892)
5	0.022	329.309 (133.086)
6	0.058	279.714 (43.816)
7	0.041	344.626 (160.656)
8	0.041	300.969 (82.074)
9	0.041	323.278 (122.230)
10	0.070	260.222 (8.729)
11	0.070	247.085 (−14.917)
12	0.070	302.786 (85.346)
13	0.070	349.679 (169.753)
14	0.070	256.561 (2.139)
15	0.070	331.069 (136.255)
16	0.070	355.134 (179.570)
17	0.070	296.061 (73.240)
18	0.070	252.881 (−4.484)

[a]EXTRAN temperature term = 297.18482; ANSI/ANS temperature term = 301.54499; percent difference = 1.46716.

[b]Actual spatial variation, 108.04859 K.

variation of 111 K (200°F). After the temperatures were generated, the actual spatial variation was about 108 K (194°F), and the difference in the two temperature terms is seen to be quite small (<1.5%). The results of another simulation are presented in Table A.4. The specified average temperature was 294 K (70°F), the maximum allowable spatial variation (excluding a hot or cold spot) was ~56 K (100°F), and a cold area was specified for the last four sensors. The cold area represented approximately an 83 K (150°F) difference from the average containment temperature. The actual spatial variation, which includes the cold spot, was ~131 K (236°F), and the difference in the two temperature terms was <5%. Another simulation was performed using the information from utility data

Table A.4. Simulated sensor readings and results[a] for an input temperature of ~294 K (70°F) with a maximum allowable spatial variation[b] of ~56 K (100°F) and a cold spot of 83 K (150°F) for four sensors

Sensor	Weighting factor	Temperature [K (°F)]
1	0.027	313.147 (103.995)
2	0.027	282.187 (48.267)
3	0.027	318.107 (112.922)
4	0.027	302.439 (84.721)
5	0.027	305.016 (89.359)
6	0.027	299.371 (79.197)
7	0.027	302.197 (84.284)
8	0.075	309.277 (97.028)
9	0.075	298.769 (78.114)
10	0.030	310.306 (98.880)
11	0.030	294.067 (69.650)
12	0.030	267.823 (22.412)
13	0.025	280.170 (44.637)
14	0.025	293.184 (68.062)
15	0.025	316.528 (110.080)
16	0.025	281.229 (46.542)
17	0.118	186.627 (−123.741)
18	0.118	229.712 (−46.189)
19	0.118	191.157 (−115.588)
20	0.118	213.111 (−76.070)

[a]EXTRAN temperature term = 244.63686; ANSI/ANS temperature term = 255.18517; percent difference = 4.31182.

[b]Actual spatial variation, 131.47970 K.

set 2 of Table A.2. The results are shown in Table A.5 and agree quite well with the difference observed previously. Therefore, for practical applications, little difference has been observed between the EXTRAN and ANSI/ANS equations. Extreme circumstances [spatial variations of 56—111 K (100—200°F) and extreme hot or cold spots] are required before any significant difference is noted. These circumstances are clearly outside the realm of normal conditions found during leak rate tests.

An important definition missing from the ANSI/ANS document is that concerning the sensor weighting factors. Although these factors are generally understood to be volume fractions determined by an assessment of the amount of volume a particular sensor is assumed to represent, no clear technique is known to exist for determining them. And it is not required for the utilities to verify that these factors are accurately determined. Along the same lines, there is no guidance provided for determining sensor placement. A technique for determining weighting factors and sensor placement should be developed and presented in ANSI/ANS-56.8-1981,

Table A.5. Simulated sensor readings and results[a] for an input temperature of ~300 K (80°F) with a maximum allowable spatial variation[b] of ~5 K (9°F) and no hot or cold spots

Sensor	Weighting factor	Temperature [K (°F)]
1	0.027	301.069 (82.255)
2	0.027	301.452 (82.943)
3	0.027	302.180 (84.253)
4	0.027	298.679 (77.952)
5	0.027	297.857 (76.473)
6	0.027	298.820 (78.207)
7	0.027	298.288 (77.248)
8	0.075	299.530 (79.484)
9	0.075	300.684 (81.561)
10	0.030	297.617 (76.041)
11	0.030	302.145 (84.192)
12	0.030	302.055 (84.030)
13	0.025	299.251 (78.982)
14	0.025	299.877 (80.108)
15	0.025	302.049 (84.018)
16	0.025	297.955 (76.650)
17	0.118	297.484 (75.801)
18	0.118	297.340 (75.542)
19	0.118	301.695 (83.381)
20	0.118	297.659 (76.115)

[a]EXTRAN temperature term = 299.00779; ANSI/ANS temperature term = 299.61716; percent difference = 0.20380.

[b]Actual spatial variation, 4.83954 K.

along with a requirement that the placement and weighting factors be verified.

The stabilization period called for in ANSI/ANS-56.8-1981 is intended to allow the containment environmental conditions (temperature, pressure, etc.) to come to some sort of equilibrium. Conditions are allowed to stabilize for at least 4 h after a test pressure has been reached, and stabilization of the containment atmosphere is based solely on the stability of the average air temperature readings. A definition of containment stabilization needs to be based on more than the containment average air temperature. Individual sensor readings of pressure, vapor pressure, and temperature should be consulted to determine containment stability.

Also, the equation in ANSI/ANS-56.8-1981 for calculating the air mass represents English units only. Use of the equation with variables having SI units will result in an error because of the English unit conversion factors. Because the equation symbols are defined with both English and SI units, it seems reasonable that the air mass equation should be presented in a form applicable to each system of units.

Furthermore, the definition of the gas constant R is not consistent with respect to the specified units. The value of R in English units is given as 53.35 ft lb_f lb_m^{-1} °R^{-1}, which is a specific value that includes the molecular weight of air. The supposedly corresponding value in SI units is given as 8.3144 J g-mol^{-1} °K^{-1}, which is a universal value that does not include the molecular weight of air. Both values are correct, but they represent different definitions of the R value. Both values should be presented as either specific (including the molecular weight of air) or universal (without the molecular weight of air).

Finally, several revisions are necessary to some of the Appendixes in order to correct typographical errors and to increase clarity. Because these corrections concern the Appendixes (which technically are not a part of the standard) and because they are generally known, they will not be presented here.

In summary, the EXTRAN formulation of the air mass equation is technically correct while the ANSI/ANS equation is not, because it is based on the invalid assumption that the containment air temperature is uniform. However, reported test results indicate that the temperature is very nearly uniform, so that the assumption may not be seriously in error. Also, a study of the amount of nonuniformity necessary to create a substantial difference in the EXTRAN and ANSI/ANS formulations indicates that unrealistic extremes are required to even begin to show a difference. Therefore, it does not appear that revision of the ANSI/ANS air mass equation is necessary.

Temperature sensor weighting factors should be properly defined, and the definition of stabilization should be improved to include pressure and vapor pressure stability. For clarity and consistency, the air mass equation should be presented in a form applicable to both SI and English units, and the definition of the gas constant should be consistent with respect to units.

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16. ABSTRACT (200 words or less)

Revision of Appendix J, to reflect technological advances and testing experience, has been under consideration for years and has culminated in the issuance of a draft version of a proposed revision to Appendix J. To assist in the revision process, a review of 49 Type A test reports and 46 Type B and C test reports was accomplished. Exemption requests found in 25 reports and 100 Licensee Event Reports were also reviewed. Two major findings of the data analysis were that Type A test duration of less than 24 hours are practical and that almost all Type A test failures and delays were caused by excessive leakage through Type B and C tested components. Excessive valve leakage represented 38% of the LERs and highlighted the need for improved maintenance, repair and testing of these components. Excessive airlock leakage was generally the result of worn, damaged, misaligned, or dirty door seals. The proposed revision to Appendix J appears to be very responsive to the results of test experience and technological changes. The introduction of a regulatory guide provides a vehicle for the NRC to specify any exceptions to the relevant industry standards and to resolve areas of conflict.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Appendix J
Containment
Exemption Requests
Leak Rate
Leakage
Licensee Event Reports
Type A test
Type B test
Type C test

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