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American National Standard for Containment System Leakage Testing Requirements

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Foreword

(This foreword is not part of American National Standard for Containment System Leakage Testing Requirements, ANSI/ANS-56.8-1994.)

This standard provides a basis for determining leakage rates through the primary reactor containment systems of light-water-cooled nuclear power plants.

The leakage rate tests performed on the primary reactor containment system simulate some of the conditions (e.g., penetrations vented, flooded, or in operation) that exist during a design basis accident. The test methodology and the associated requirements for both whole containment (integrated) and individual pathway (local) leakage rate testing are contained in this document.

The appendices contain Type A and verification test methods, formula derivations, data rejection criteria, containment atmosphere stabilization criteria, and test termination criteria.

The regulatory requirements for containment leakage rate testing are contained in Title 10, "Energy," Code of Federal Regulations (CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix J, "Leakage Rate Testing of Containments of Light-Water-Cooled Nuclear Power Plants." This standard is not in complete agreement with the current version of Appendix J.

The previous revision to this standard was issued in 1987. This revision was written to take advantage of subsequent advancements in computer and instrument technology. Also incorporated are items which the committee believed to be improvements in testing methodology and requirements. These include: an as-found and as-left section, minimum and maximum pathway leakage rates, test termination limits, containment air mass stabilization criteria, and improved data rejection guidelines.

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Comments on this standard are encouraged and should be sent to Society Headquarters.

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Containment System Leakage Testing Requirements

1. Introduction

1.1 Purpose. This standard provides a basis for determining leakage rates through the primary containment of light-water reactor nuclear power plants.

The examples given in various sections of this standard do not contain or modify any requirements. These examples are for illustration only and clarify the intent of the text. Furthermore, the examples are not meant to be all-inclusive. Examples of alternative methods or exceptions to general requirements do not constitute permission to categorically apply the exceptions. Each alternative or exception needs to be evaluated to determine its validity and effect.

1.2 Scope.[1] This standard specifies acceptable primary containment leakage rate test requirements to assure valid testing. The scope includes
(1) Leakage test requirements
(2) Test instrumentation
(3) Test procedures
(4) Test methods
(5) Acceptance criteria
(6) Data analysis
(7) Inspection and reporting of test results.

2. Definitions[2]

The following terms are for general use in this standard:

acceptance criteria. The standards against which test results are to be compared for establishing the functional acceptability of the primary containment as a leakage limiting boundary.

accuracy. Conformity of an indicated value to an accepted standard value or true value.

active failure. A malfunction, excluding passive failures, of a component which relies on mechanical movement or change of state to complete its intended function upon demand. Examples of active failures include the failure of a valve or a check valve to move to its correct position, or the failure of a pump, fan, or diesel generator to start. Spurious action of a power-operated component originating within its actuation or control system shall be regarded as an active failure unless specific design features or operating restrictions preclude such spurious action. An example is the unintended energization of a power-operated valve to open or close.

as-found leakage rate. The leakage rate prior to any repairs or adjustments to the barrier being tested.

as-found testing. Leakage rate testing after some period of normal service conditions, performed prior to any repairs or adjustments.

as-left leakage rate. The leakage rate following any repairs or adjustments to the barrier being tested.

as-left testing. Leakage rate testing performed following repair or adjustment.

confidence level. The probability that the true leakage rate does not exceed the upper confidence limit.

containment atmosphere volume weighted average temperature (T). The temperature derived from weighting each temperature sensor reading by the volume it represents.

containment integrated leakage rate test (CILRT). The leakage rate test performed on the primary containment by simulating some of the conditions (e.g., penetrations vented, drained, flooded, or in operation) that exist during a design basis accident. The CILRT consists of the following phases or activities:
(1) inspecting the primary containment
(2) pressurizing the primary containment system
(3) stabilizing the containment atmosphere

[1] At the time this standard was approved, it contained certain requirements (i.e., testing frequency requirements) that were not fully consistent with existing regulations in the United States. The user of the standard should ensure that its application in a regulated facility is appropriate.

[2] Specialized definitions used in the appendices are defined in the appendix where they are used.

(4) conducting a Type A test
(5) conducting a verification test
(6) depressurizing the primary containment.

containment isolation valve. A valve subject to Title 10, "Energy," Code of Federal Regulations (CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria," Criteria 55, 56, and 57, [1][3] and also comparable valves in those plants not required to conform to Appendix A to this part. A containment isolation valve is any valve which is relied upon to provide a barrier between the containment environment and the outside environment under post-accident loss-of-coolant conditions, in the plant licensing basis.

continuous leakage monitoring system. A permanently installed, on-line pneumatic measurement system which continuously monitors the leakage rate of containment system penetrations at a pressure not less than P_{ac} subject to Type B testing, and is either alarmed or recorded at least daily.

containment leakage rate test program. The comprehensive testing of the primary containment that includes Type A, B, C, and leakage rate verification tests.

data acquisition system (DAS). The system used to collect data during performance of a CILRT.

data set. A collection of the recorded values of each sensor used in the calculation of the containment dry air mass at a specified time.

design basis accident (DBA). The accident initiated by a single component failure or operator error, as described in the safety analyses of the plant, which results in the maximum primary containment internal peak pressure and in fission product release to the containment atmosphere.

fluid. A substance (liquid or gas) tending to flow or conform to the outline of its container.

L_a (weight %/24h). The maximum allowable Type A test leakage rate at P_{ac}.

[3] Numbers in brackets refer to corresponding numbers in Section 7, References.

L_{am} (weight %/24h). Estimate of the leakage rate, derived as a function of the least squares slope and intercept, for the Type A test at pressure P_{ac} obtained from testing the primary containment by simulating some of the conditions that would exist under DBA conditions (e.g., vented, drained, flooded, or pressurized).

L_c (weight %/24h). The composite primary containment leakage rate measured using the CILRT instruments after L_o is superimposed.

L_o (weight %/24h). The known leakage rate superimposed on the primary containment during the verification test.

leak. An opening which allows the passage of fluid through it.

leakage. The quantity of fluid escaping from a leak or leaks.

leakage rate. The rate at which the contained fluid escapes from the test volume at a specified test pressure.

local leakage rate test (LLRT). The leakage rate test performed on Type B and Type C components

maximum pathway leakage rate (MXPLR). The maximum leakage rate attributed to a penetration leakage path. The MXPLR is the larger, not the total, leakage of two valves in series.

measurement system. The collection of sensors, cables, instrumentation, DAS, and computer facilities inclusive.

minimum pathway leakage rate (MNPLR). The minimum leakage rate that can be attributed to a penetration leakage path (e.g., the smaller of either the inboard or outboard barrier's individual leakage rates). The pathway's MNPLR can be determined by one-half of the total measured leakage rate when tested by pressurizing between the inboard and outboard barriers.

NOTE: Testing the inboard barrier in the reverse direction shall result in a conservative leakage rate.

overall integrated leakage rate. The total leakage through all tested leakage paths including containment welds, valves, fittings, and components that penetrate the primary containment, expressed in units of weight percent of contained air mass at test pressure per 24h.

P_{ac} (psig or kPa). The calculated peak containment internal pressure related to the DBA.

P_d (psig or kPa). The containment design pressure.

pathway. A leakage path from the primary containment.

NOTE: An individual penetration can have more than one pathway.

primary containment. The principal enclosure that acts as a leakage barrier, after the reactor coolant pressure boundary, to control the release of radioactive material from the fuel in the reactor core under DBA conditions. It is comprised of:
(1) the primary containment structure, including access closures, penetration closures, and appurtenances;
(2) those valves, pipes, closed systems, and other pressure-retaining components used to effect isolation of the primary containment atmosphere from the outside environs; and
(3) those systems or portions of systems that, by their system functions, extend the primary containment structural boundary.

This does not include the "secondary containment," "containment enclosure building," or "reactor building" surrounding some containment systems, whose function is to control primary containment leakage.

primary test instrumentation. Instruments whose recorded values are used directly or indirectly in the calculation of any values compared against test acceptance criteria.

qualified seal system. A system that is capable of sealing the leakage with a liquid at a pressure no less than 1.1 P_{ac} for at least 30 days following the DBA.

repair or adjustment. Any action performed on the primary containment that affects its leakage characteristics.

repeatability. The closeness of agreement among a number of consecutive measurements of the output for the same value of the input under the same operating conditions, approaching from the same direction for full range traverses.

resolution. The degree to which equal values of a quantity can be discriminated by the device.

shall, should, may. The word "shall" is used to denote a requirement, the word "should" to denote a recommendation, and the word "may" to denote permission, neither a requirement nor a recommendation.

standard conditions. Standard atmospheric conditions referred to by this standard are pressure 14.6959 psia (101.325 kPa), temperature 68°F, 527.67 R (20°C, 293.15 K), and dry air density 0.07517 lb_m (1.2041 kg/m^3).

structural integrity test (SIT). A pneumatic test that demonstrates the capability of a primary containment to withstand a specified internal design pressure load.

Type A test. A test to measure the containment system overall integrated leakage rate under conditions representing DBA containment pressure and systems alignments.

Type B test. A test intended to detect or measure leakage across pressure-retaining or leakage-limiting boundaries other than valves, such as
(1) containment penetrations whose design incorporates resilient seals, gaskets, sealant compounds, expansion bellows, or flexible seal assemblies
(2) seals, including door operating mechanism penetrations, which are part of the primary containment
(3) doors and hatches with resilient seals or gaskets except for seal-welded doors.

Type C test. A pneumatic test to measure containment isolation valve leakage rates.

upper confidence limit (UCL).[4] A calculated value constructed from test data which places a statistical upper bound on the true leakage rate (%/24h).

NOTE: UCL is calculated at 95 percent confidence level in this standard.

verification test. A test to confirm the capability of the Type A test method and equipment to measure L_e.

[4] See formula in Appendix B.

3. Leakage Testing Requirements

3.1 General. A testing program including a schedule for conducting Type A, B, and C tests shall be developed for the leakage rate testing of the primary containment boundaries. Any modification, component replacement, repair, or adjustment which could affect primary containment integrity shall require the Type A, B, or C test, as applicable, to demonstrate that the affected component meets the applicable leakage requirements.

3.2 Type A Test Requirements

3.2.1 Containment Inspection and Repair. A general visual inspection of the accessible interior and exterior surfaces of the primary containment and components shall be performed prior to the CILRT pressurization. The purpose of this inspection is to identify evidence of structural deterioration that might affect either the primary containment structural integrity or leak tightness.

Any irregularities such as cracking, peeling, delamination, corrosion, and structural deterioration shall be recorded and evaluated or repaired as required, prior to conduct of the CILRT.

3.2.2 Preoperational Tests. The preoperational CILRT shall follow the preoperational SIT. Type B and Type C leakage rate tests should be completed prior to the preoperational CILRT. Any Type B or Type C leakage rate not accounted for in the Type A test shall be added to the Type A test leakage rate UCL to determine an upper bound on the overall integrated leakage rate. The addition shall be based on the MNPLR.

3.2.3 Periodic Tests. Type B and C leakage rates not accounted for in the CILRT shall be added to the Type A test leakage rate UCL to determine an upper bound on the overall integrated leakage rate. The additions shall be based on the MNPLR.

3.2.4 Containment Isolation Valve Closure. Closure of primary containment isolation valves for Type A testing shall be accomplished by normal means and without adjustment (e.g., no hand tightening of remotely operated valves after closure). Alternative methods of valve closure may be used provided they are documented, and are equivalent to normal means. If a leakage path requires isolation (blocking) to successfully complete a CILRT, the Type B or Type C leakage rate determined after completion of the CILRT shall be added to the Type A test leakage rate UCL based on MNPLR.

3.2.5 Pathway Venting and Draining. Pathways that are open to the primary containment atmosphere under post-DBA conditions shall be vented to the primary containment atmosphere during the CILRT. Pathways are considered open to the primary containment atmosphere if the system fluid is drained or driven off by the DBA. This includes portions of pathways inside or outside containment that penetrate the primary containment and may rupture inside primary containment under a DBA. Vented pathways shall be drained of fluid inside the primary containment, between the primary containment isolation valves, and outside the primary containment to expose the pathway to post-accident differential pressure. The MNPLR for pathways which are not vented and drained shall be added to the Type A leakage rate UCL.

Exceptions to these requirements include the following:

(1) Pathways in systems that are normally filled with liquid and operable under post-accident conditions, such as the containment heat removal system, need not be vented or drained. However, if under the most limiting single active failure these systems become potential post-accident pathways, their MNPLR shall be added to the Type A test leakage rate UCL.

(2) Portions of the pathways outside primary containment that are designed to Seismic Category I and at least Safety Class 2 (or equivalent), need not be vented. Additionally, if it can be shown that the portion of these systems outside primary containment will remain fluid filled post-accident, they need not be drained. However, the system outside primary containment shall be in a post-accident alignment.

(3) Pathways in systems which are required for proper conduct of the CILRT, or to maintain the plant in a safe condition during the CILRT, may be operable in their normal mode and need not be vented or drained.[5] However, if these pathways are potential post-DBA leakage pathways, their MNPLR shall be added to the Type A test leakage rate UCL.

3.2.6 Pressurized Components. Gas pressurized lines inside primary containment shall be depressurized. Gas pressurized primary containment leakage pathways outside primary containment shall be isolated during the CILRT and vented between the outboard primary containment isolation barrier and the pressurized test boundary isolation valve.

[5] For more information, see NUREG-1449, *Shutdown and Low Power Operation at Commercial Nuclear Power Plants in the United States* (draft), issued by the Nuclear Regulatory Commission (available from address in Section 7, "References.")

Pressurized components within primary containment such as tanks shall be removed, or depressurized and vented during the Type A test. All possible sources of gas leakage into the containment from any system shall be isolated and vented or disconnected during the Type A test. An acceptable alternative, if a pressurized isolated component cannot be depressurized and vented, is to measure the pressure prior to and after the Type A test. A leakage rate shall be calculated and added to the UCL.

If certain pressurized sealing or testing systems cannot be isolated, such as inflatable airlock door seals, leakage into the primary containment shall be accounted for and the Type A test results corrected accordingly.

3.2.7 Liquid Level Monitoring. In cases where water levels inside the test volume are gaining water from or losing it to the outside, changes in the resulting total primary containment free volume will affect the calculation of total primary containment dry air mass. Compensation for changes in free air volume shall be made for net increases in water levels and may be made for net decreases in water levels.

If the instantaneous primary containment free volume[6] is known, it may be factored into the results as the test proceeds. Alternately, the final Type A test leakage rate UCL may be modified by adding the effective leakage rate calculated from the volume change indicated by the initial and final water level readings.

3.2.8 As-Found Requirements. The as-found overall integrated leakage rate shall be determined when performing a periodic CILRT. The as-found requirements do not apply to a preoperational CILRT. The CILRT may be conducted with any portion of the Type B and C tests complete. The as-found overall integrated leakage rate shall be calculated by adding to the UCL the quantities given below as (1) and (2):

(1) the positive differences between the as-found MNPLR and the as-left MNPLR for each pathway tested and adjusted prior to the CILRT;

(2) the as-found MNPLR of all leakage paths isolated during the performance of the CILRT.

3.2.9 As-Left Requirements. The as-left Type A test leakage rate shall be the sum of the UCL and the as-left MNPLR of all leakage paths isolated during the performance of the CILRT.

[6] Refer to Appendix F.

3.2.10 Isolation, Repair, or Adjustment to Pathways. Pathways are isolated if they are closed, unvented, not drained, or closed by a method not equivalent to normal means. Isolation, repair, or adjustment to a leakage pathway that may affect the leakage rate through that pathway is permitted prior to or during the Type A test provided that:

(1) All potential leakage paths of the isolated, repaired, or adjusted pathways are locally testable, and

(2) The leakage rate is measured before and after the repair, or adjustment, or any other action taken that will affect the leakage rates by the performance of a Type B or Type C test, as applicable.

All changes in leakage rates resulting from isolation, repair, or adjustment of leakage paths subject to Type B or Type C testing are determined using the MNPLR method and are also added to the Type A test leakage rate UCL to obtain the as-found and as-left leakage rates.

The effects of the isolation, repair, or adjustment to the pathway after the start of the CILRT (i.e., the beginning of the containment inspection) on the Type A test results shall be quantified or accounted for and the appropriate analytical or tested corrections made (e.g., tightening valve stem packing, additional tightening of manual valves, or any actions taken that affect the leak rate). If quantification of the as-found leakage rate is not possible, the as-found leakage rate for the Type A test shall be recorded as greater than L_a and reported as an as-found failure.

3.2.11 Type A Test Pressure. The Type A test pressure shall not be less than $0.96P_{ac}$ nor exceed P_d. For those plants with a P_{ac} of 25 psig (172.33 kPa) or less, P_{ac} minus 1 psi (6.89 kPa) shall be the minimum test pressure for the duration of the Type A test. The test pressure shall be established relative to the external pressure of the primary containment measured at the start of the Type A test.

3.2.12 CILRT Frequency. A preoperational Type A test shall be conducted prior to initial reactor operation. If initial reactor operation is delayed greater than 36 months after completion of the preoperational Type A test, a second Type A test shall be performed prior to reactor operation. The first periodic Type A test shall be performed within 36 months after the successful completion of the latest preoperational Type A test. Subsequent Type A tests shall not exceed an interval of 48 months. Each interval begins upon completion of the Type A test and ends at the start of the next test. This surveillance interval may be extended up to 12 months provided that the total elapsed time for three consecutive intervals does not exceed 156 months.

If the test interval ends while primary containment integrity is either not required or is required solely for shutdown activities (such as handling of irradiated fuel or performing core alternations), that specific test interval may be extended indefinitely. A successful Type A test shall be completed prior to the time when primary containment integrity is required for reactor operation. If this extension results in the total elapsed time for three consecutive tests that exceeds the 156 months criterion, subsequent intervals shall not exceed 48 months until this criterion is met.

3.2.13 Error Accountability. The effects of random errors for the Type A and verification leakage rate tests are inherently accounted for in the least squares fit analysis under the assumption that the leakage is essentially constant. The effects of instrument errors are accounted for by meeting section 4.3 and the UCL requirements.

3.2.14 Statistical Data Rejection. A statistical data rejection technique[7] may be used to identify data sets which do not conform to the pattern of all data sets.

The data rejection technique applies to a time sequence of air mass calculations. If a calculated air mass is identified as an outlier, the cause should be investigated by reviewing the recorded value of every sensor associated with that spurious data set. Raw data, such as temperature, pressure, and humidity, shall not be rejected solely on statistical grounds. A compelling physical reason shall be provided in support of rejecting any raw data.

The statistical data rejection technique may be used in the Type A or the verification test. The decision to use a statistical rejection technique shall be made prior to the beginning of the test. If it is decided to use the statistical rejection technique, all of the calculated air masses in the respective test shall be compared against the rejection criterion. The criterion shall not be applied selectively to segments of the data. The statistical data rejection technique shall only be applied once to a sequence of data.

[7] See Appendix D for Data Rejection Criteria.

3.2.15 Equipment Protection. Prior to closing the primary containment for pressurization, equipment not able to withstand the test pressure should be removed from the primary containment.

3.3 Local Leakage Rate Testing Requirements

3.3.1 General. This section provides acceptable means of performing Type B and Type C preoperational and periodic testing. Primary containment boundaries not requiring Type B or Type C testing include:

(1) Boundaries that do not constitute potential primary containment atmospheric pathways during and following a DBA

(2) Boundaries sealed with a qualified seal system

(3) Test connection vents and drains between primary containment isolation valves which

(a) are one inch (2.54 cm) or less in size, and

(b) are administratively secured closed, and

(c) consist of a double barrier (e.g., two valves in series, one valve with a nipple and cap, one valve and a blind flange).

3.3.2 Test Pressure. Type B and Type C tests shall be conducted at a differential pressure of not less than P_{ac}, except on airlock door seals, which may have a lower pressure specified in the plant's licensing basis. When a higher differential pressure results in increased sealing, such as a check valve, the differential pressure shall not exceed 1.1 P_{ac}.

3.3.3 Containment Isolation Valve Closure. Closure of primary containment isolation valves for Type C testing shall be accomplished by normal or equivalent means and without adjustment (e.g. no hand tightening of remotely operated valves after closure). Exercising valves for the purpose of improving leakage performance shall not be permitted.

3.3.4 Test Frequency

3.3.4.1 Type B and Type C Tests (Excluding Airlocks). Type B and Type C tests shall be performed prior to initial reactor operation. Subsequent Type B and Type C tests shall be performed at intervals no greater than 30 months. The test interval for each barrier begins after its Type B or C test is completed and ends when it is next tested. If the test interval ends while primary containment integrity is not required, or is required solely for cold shutdown or refueling activities, that specific test interval may be extended, provided that all deferred testing is successfully completed prior to the time primary containment integrity is required for reactor operations. Additionally, independent of the previous provisions, any single test interval may be extended up to 7.5 months ~~of the specified interval~~, but the combined interval for any 3 consecutive tests shall not exceed 97.5 months.

If opened following a Type A test or Type B test, primary containment penetrations subject to Type B testing shall be Type B tested prior to the time primary containment integrity is required.

Whenever repairs or adjustments are performed that affect the leakage rate of a component subject to Type B or Type C testing, the component shall be tested prior to its being relied upon for establishing or maintaining primary containment integrity.

3.3.4.2 Airlocks. Airlocks shall be tested by pressurizing the space between the inner and outer doors to at least P_{ac}. They shall be tested prior to the preoperational Type A test and subsequently in accordance with the following schedule:

(1) Not more than 6 months following any opening of the inner door;

(2) At the end of each refueling outage.

If an airlock door is opened while primary containment integrity is required, the seals on that door shall be tested not more than 72 hours after such opening. If the seals are not testable, then the airlock shall be tested by pressurizing between the inner and outer doors to at least P_{ac} as specified in the plant's licensing basis. If the airlock has not been tested by pressurizing the space between the inner and outer doors to at least P_{ac} within the last 6 months, the door seals or the entire airlock shall be tested at a reduced pressure within 6 months after the last test at P_{ac}, and within 6-month intervals thereafter until the next test is done at P_{ac}. If such a test becomes due during a period when primary containment integrity is not required, it may be deferred until the end of that period.

An airlock test shall be performed whenever repairs or adjustments have been performed that affect the leakage rate characteristics of the airlock. Opening of the airlock for the purpose of removing airlock testing equipment following an airlock test does not require further testing of the airlock. Local testing of airlock components (e.g., shaft seals or equalization valves) at not less than P_{ac} fulfills this requirement, provided that the maintenance only affected the components being locally tested.

3.3.5 Test Medium. Type B and Type C tests shall be conducted with air or nitrogen. Tests of boundaries and primary containment isolation valves in lines sealed with a qualified seal system shall be conducted with water.

3.4 Qualified Seal System Testing Requirements. Primary containment barriers sealed with a qualified seal system are not required to be local leakage rate tested. If a seal system is used as a primary containment barrier, it shall be periodically tested to prove its functionality. This functional test shall demonstrate that the seal system is capable of sealing the primary containment barrier(s) with the sealing liquid at a differential pressure of not less than 1.1 P_{ac} for at least 30 days following a DBA. Qualified seal system testing is as specified in the plant's licensing basis.

4. Instrumentation

4.1 Calibration

4.1.1 Calibration Requirements. Primary test instrumentation shall be calibrated. The calibrations shall span the temperatures, humidities, pressures, or flows expected during use. Humidity sensor calibration for either dew point sensors or relative humidity sensors is not required in excess of 90% relative humidity.

4.1.2 Calibration Parameters. Primary test instrumentation accuracy shall be traceable to the standards of National Institute of Standards and Technology (NIST). Accuracy shall be determined from calibration data. Resolution and repeatability of the measurement system shall be obtained from vendor specifications or by direct measurement.

4.1.3 Calibration Frequency. Primary test instruments shall be individually calibrated not more than six months prior to use, or in accordance with the facility's measuring and test equipment control program.

Post-test calibration for CILRT instruments is not required if a successful verification test has been performed.

4.2 Pretest Checks (Type A Test)

4.2.1 Pretest Requirement. The accuracy of pressure, temperature, dew point temperature or relative humidity, and flow rate channels shall be checked after the final connections have been made. The pretest check verifies that the complete instrumentation loop is functioning correctly. Pretest checks are not required for mechanical flow rate devices.

4.2.2 Pretest Check Methods. Several methods for completion of the pretest check include, but are not limited to, the following:

(1) Confirmation that the DAS or computer output for each sensor agrees with an independent measurement made through use of a calibrated instrument traceable to NIST standards.

(2) The independent checks can consist of comparisons between like sensors, provided that a check against common mode failure has been performed. An example of an acceptable check of the DAS or computer system would be to input a resistance, voltage, or current source into the instrument wiring in place of a sensor, and then verify the expected reading at the DAS or computer. Following this check, the DAS or computer output for like sensors can be checked against one another.

(3) When sensors with a local digital output are in use, confirmation that the local digital reading agrees with the DAS or computer system output.

4.2.3 Pretest Check Criteria. If an independent measurement is used to verify instrument performance, then the instrument display and independent measurement check shall not differ by more than the following:

(1) Absolute pressure ±0.04% full scale
(2) Drybulb temperature ±2.0°F (±1.1°C)
(3) Dew point temperature (if used) ±5.0°F (±3.0°C)
(4) Relative humidity (if used) ±5% RH
(5) Induced flow rate ±5% full scale

4.3 Instrumentation Specifications. This section specifies the requirements for each type of measurement required.

4.3.1 CILRT Measurement System. The measurement system criteria given includes the combined error from the sensor to the display inclusive for each parameter.

4.3.1.1 Drybulb Temperature. The measurement system specifications shall meet the following criteria:

(1) Accuracy	±1.0°F (±0.55°C)
(2) Resolution	±0.03°F (±0.017°C)
(3) Repeatability	±0.2°F (±0.11°C)

4.3.1.2 Dew Point Temperature or Relative Humidity. The measurement system specifications shall meet the following criteria:

(1) Accuracy	±2.0°F (±1.1°C) dew point ±3.5% RH
(2) Resolution	±0.1°F (±0.055°C) dew point ±0.5% RH
(3) Repeatability	±0.2°F (±0.11°C) dew point ±1% RH

4.3.1.3 Absolute Pressure. The measurement system specifications shall meet the following criteria:

(1) Accuracy	±0.02 psi (.1379 kPa)
(2) Resolution	±0.001 psi (.0069 kPa)
(3) Repeatability	±0.005 psi (.0345 kPa)

4.3.1.4 Flow. The measurement system specifications shall meet the following criteria:

(1) Accuracy	±2% full scale
(2) Resolution	±2% full scale
(3) Range	not greater than $2L_a$

4.3.1.5 Ambient Pressure. The accuracy of the pressure measuring device used for measuring atmospheric pressure shall be equal to or better than ±0.1 psi (0.6895 kPa).

4.3.1.6 Water Level Measurement. Each level channel used to correct CILRT results during performance of the test shall have sufficient accuracy and resolution to calculate corrections to the containment dry air mass.

4.3.1.7 Minimum Number of Sensors. The minimum numbers of operable sensors shall be as follows:

(1) One containment pressure sensor shall be in operation during the Type A test and the verification test.

(2) One flow measurement device shall be operational during the verification test.

(3) Ten dry bulb temperature sensors shall be operational during the Type A test and the verification test.

(4) Three dew point or relative humidity sensors shall be in operation during the Type A and verification test. Dry-bulb temperature sensors may be used in place of dewpoint or relative humidity sensors if saturated conditions are shown to exist in that subvolume.

4.3.2 LLRT Measurement System

4.3.2.1 Pressure Decay. The measurement system specifications shall meet the following criteria:

(1) Temperature -

Accuracy	±1.0°F (±0.55°C)
Resolution	±0.5°F (±0.28°C)
Repeatability	±0.5°F (±0.28°C)

(2) Pressure -

Accuracy	±1% of P_{ac}
Resolution	±0.1% full scale
Repeatability	±0.1% full scale

4.3.2.2 Flow Make-up Method. The measurement system specifications shall meet the following criteria:

(1) Temperature - (as required)

Accuracy	±2.0°F (±1.1°C)
Resolution	±1.0°F (±0.55°C)
Repeatability	±1.0°F (±0.55°C)

(2) Pressure -

Accuracy	±2% of P_{ac}
Resolution	±1% full scale
Repeatability	±1% full scale

(3) Flow -

Accuracy	±2% full scale

4.3.3 Data Collection Clock. The measurement system specifications shall meet the following criteria:

(1) Accuracy	±1 min/24 h
(2) Resolution	1 second

4.4 Sensor Rejection Criteria. Consistent sensor rejection criteria shall be applied when evaluating a sensor for failure and subsequent removal of its data from the data set. A sensor's data may be rejected and not used in the calculation of dry air mass provided that:

(1) A good physical reason exists that warrants rejection such as loss of instrument power.

(2) The reason for rejection of the data is recorded in the CILRT log.

(3) The rejected sensor's volume fraction is redistributed to the remaining sensors which are exposed to the volume containing the rejected sensor. The containment dry air mass and corresponding leakage rates for each data set acquired since the start of the Type A test shall be recalculated using the redistributed volume fractions. If a sensor is rejected during the verification test, the Type A test leakage rate, the verification test leakage rate, and the verification leakage rate limits shall be recalculated.

(4) Data from the rejected sensor is continually recorded, if possible, for the duration of the CILRT.

A sensor shall not be rejected solely because its removal improves the leakage rate result.

5. CILRT Procedure.

5.1 Recording of Data. The following data shall be collected, recorded, and retained during the conduct of the CILRT.

5.1.1 Primary Data. As a minimum, 30 data sets shall be taken and each data set shall consist of the following:

(1) absolute primary containment pressure sensor readings

(2) individual primary containment air dry bulb temperature sensor readings

(3) individual containment air dew point temperature or relative humidity sensor readings

(4) time and date at which the data set was recorded.

5.1.2 Secondary Data. The following data shall be collected and recorded at the times specified:

(1) absolute ambient atmospheric pressure outside of the primary containment under test, recorded once, at the start of the test

(2) liquid levels in primary containment that can affect the primary containment's free air volume, at intervals needed to support the leakage rate calculations

(3) superimposed flow, recorded hourly during the verification test.

5.1.3 Supporting Data. A dated log of events and pertinent observations taken during the CILRT shall be kept to support interpretation of the data sets. Supporting data to be recorded shall include:

(1) calibration data;

(2) primary containment subvolume calculations and associated volumes;

(3) identity of each sensor assigned to each subvolume.

5.2 Containment Drybulb Temperature Survey. A drybulb temperature survey shall be performed in advance of the preoperational and initial periodic CILRT to establish any areas of regional variations. The temperature pattern revealed by the survey shall be used to confirm proper sensor placement. The sensors shall be located away from heat sources, heat sinks, and sources of thermal radiation, or shall be adequately thermally shielded such that their temperature readings are not adversely affected.

The primary containment subvolume partitioning and the location of the drybulb temperature sensors shall be validated and recorded prior to each CILRT by one of the following methods:

(1) The survey shall contain a requirement to measure and record a specified number of drybulb temperatures in each readily accessible subvolume prior to the CILRT. The difference between the arithmetic mean of all temperature measurements within a given subvolume and the CILRT temperature sensor should be less than a specified amount.

(2) If a documented temperature survey exists from a previous CILRT on the same unit or a similar one, a new survey is not required providing the sensors are placed in the same locations as those in the previously documented survey. If conditions in the primary containment have changed in any way that could potentially alter

the temperature distribution since the previous survey, a new survey, as specified in 5.2(1), shall be performed.

The calculated volume fractions combined with the placement of each sensor shall ensure that each sensor represents its assigned volume. The sum of the volume fractions is unity. If during either test a sensor fails or is rejected, the sensor's volume fraction shall be redistributed to other sensors on the basis of the survey results.

5.3 Pressurization. The primary containment should be pressurized with air that is clean, relatively dry, and free of contaminants.

5.4 Preoperational Test Pressure. The SIT shall be performed at a pressure above P_{ac} and precedes the Type A test. The pressure shall be reduced to less than 85% P_{ac} for at least 24 hours prior to repressurization to P_{ac} for the Type A test.

5.5 Computation of Type A Leakage Rate. The analytical technique presented in this section shall be used to compute the primary containment leakage rate. The leakage rate shall be reported in weight percent per day of the calculated primary containment air mass from the beginning of the test.

5.5.1 Symbols and Subscripts. The following symbols and subscripts are used in subsequent subsections:

A = Slope of least squares line, lbm/h (kg/h)
B = Intercept of least squares line, lbm (kg)
i = Subscript denoting the i^{th} data set
n = Number of (t_i, W_i) pairs of measurements
P = Total absolute pressure in the containment, psia (kPa)
P_v = Containment atmosphere volume weighted vapor pressure, psia (kPa)
R = Gas constant for dry air, 53.35 ft-lbf/lbm R (8.3144 joules/gm K)
S_A = Estimate of standard deviation of slope of least squares line, lbm/hr (kg/h)
T = Containment atmosphere volume weighted absolute drybulb temperature, R (K)
t = Time interval of measurement after initial measurement, h
$t_{.95}$ = 95th percentile of Student's t distribution[8]
V = Internal free volume of the containment, ft^3 (m^3)
W_i = Measured dry air mass of containment air, lbm (kg)
$\hat{W}_i$ = Least squares line relating measured masses to corresponding times of measurement, lbm (kg)

5.5.2 The Absolute Method. The absolute method of leakage determination shall be utilized for all Type A tests. This method of leakage rate determination shall be based on the measurement of the temperature and pressure of the primary containment atmosphere with correction for changes in water vapor pressure.

The primary containment's free air volume shall be assumed to change only due to changes in water levels inside the containment during the test. Free air volume calculations shall be made if necessary to ensure conservative results.

5.5.3 Mass Point Analysis.[9] The analysis technique shall be used to determine the dry air mass in the primary containment utilizing the Ideal Gas Law, at each time point during the test. The rate of change of air mass shall be calculated using regression analysis (least squares fit) to the air mass points. The rate of change of air mass shall be converted to the leakage rate in units of percent per day (%/24h) by dividing the slope of the regression line by the intercept of the regression line and multiplying the ratio obtained by negative 2400. An upper confidence limit for the leakage rate shall be based upon normal regression theory.

5.5.4 Calculation of the Total Containment Dry Air Mass. For each time point (t_i), the corresponding total dry air mass of contained air (W_i) from a data set shall be determined directly from the Ideal Gas Law shown below in English units:

$$W_i = \frac{144\ V}{R}\left[\frac{(P_i - P_{vi})}{T_i}\right]$$

T_i is calculated from:

$$T_i = \frac{1}{\sum_{j=1}^{M} \frac{Vf_j}{T_j}}$$

where

M = Number of temperature sensors
Vf_j = Volume fraction represented by the j^{th} sensor
T_j = Absolute temperature of the j^{th} sensor at the i^{th} interval

and P_{vi} is calculated from:

[8] See Table B1 for values of $t_{.95}$ corresponding to selected values of "degrees of freedom" = D_F (one-sided test tables).

[9] See Appendix B for detailed calculations and equations.

$$P_{vi} = T_i \sum_{j=1}^{k} \frac{P_{vj}\, Vf_j}{T_j}$$

where

P_{vj} = Partial absolute vapor pressure represented by the j^{th} sensor at the i^{th} interval.
k = Number of sensors used to determine vapor pressure.

An approximation of sufficient accuracy for testing purposes for calculating the containment atmosphere volume weighted vapor pressure at the i^{th} interval (P_{vi}) shall be obtained from Tdp_i using the Steam Tables or equivalent formulations[10] where:

$$Tdp_i = \sum_{j=1}^{k} (\, Vf_j \,)(\, Tdp_j \,)$$

where

Tdp_i = Summation at the i^{th} interval
Tdp_j = Dewpoint temperature of the j^{th} sensor at the i^{th} interval.

5.5.5 Data Analysis and Confidence Limit. A linear least squares fit of the data points shall be made according to the following equation:

$$\hat{W}_i = At_i + B$$

The estimate of the leakage rate in units of percent per day is a function of both the slope and the intercept of the regression line and shall be computed according to the following equation:

$$L_{am} = -2400\ A/B$$

An upper confidence limit (UCL) shall be set so that there is only a 5% chance that the actual primary containment leakage rate exceeds the reported UCL value. This is expressed as the upper 95% confidence limit on the leakage rate. In general, the following approximation may be used:

$$UCL = L_{am} + 2400t_{.95}\,(S_A/B)$$

5.6 Containment Atmosphere Stabilization. Upon completion of primary containment pressurization to the test pressure, the primary containment air mass shall be allowed to stabilize prior to the start of the Type A test. Primary containment atmosphere stabilization shall demonstrate that containment dry air mass is stable. The minimum duration for this stabilization period shall be four hours. The primary containment atmosphere is assumed to be stabilized for Type A test purposes when the following criteria are simultaneously met[11]:

(1) The absolute value of the difference between L_{2h} and L_{1h} shall be less than or equal to $0.25L_a$,

(2) L_{1h} shall be greater than or equal to zero and shall be less than L_a,

where

L_{1h} = estimate of the leakage rate, derived from the least squares slope and intercept using the mass data over the last hour (percent/24 h).
L_{2h} = estimate of the leakage rate, derived from the least squares slope and intercept using the mass data over the last two hours (percent/24 h).

If one or more leakage pathways require isolation, repair or adjustment in order to meet (2), criterion (2) need not be reverified provided that this criterion was met prior to the time of the isolation, repair, or adjustment. The change in L_{1h} should be demonstrated to be a direct result of this isolation, repair, or adjustment.

5.7 Termination Limits.[12] Two termination limits shall be met before a Type A test is considered successful. The limit on curvature describing the trend of primary containemnt dry air mass over time assures that the function relating containment dry air mass to time is either linear or the curvature of that function is within acceptable bounds.

A data scatter limit of primary containment dry air mass shall provide a statistical test to evaluate whether the scatter of the air mass points about a regression line are within acceptable bounds.

5.8 Type A Test Acceptance Criteria

5.8.1 As-Left Criteria. Prior to declaring the as-left Type A test to be successfully completed, the test data shall be shown to simultaneously meet the following criteria:

(1) The Type A test leakage rate UCL, plus the required LLRT additions as described in sections 3.2.2, 3.2.3, 3.2.4, 3.2.5, 3.2.6, 3.2.7, and 3.2.10, shall not exceed $0.75L_a$. This combined value shall be reported as the as-left Type A test leakage rate.

[10] See Appendix F for equivalent formulation.

[11] See Appendix E for a sample problem.

[12] An acceptable method is listed in Appendix G.

(2) The limits on curvature and the data scatter as described in section 5.7 shall be satisfied for the last hour or the last four consecutive data sets (whichever is longer).

(3) The Type A duration shall be at least 24 hours for a preoperational test or at least 8 hours for a periodic test and shall consist of a minimum of 30 data sets taken at approximately equal time intervals.

5.8.2 As-Found Criteria. The as-left Type A test leakage rate UCL as determined in section 5.8.1 (1) plus the total leakage savings, as described in section 3.2.8, shall be less than L_a. This value shall be reported as the as-found Type A leakage rate.

5.9 Verification Test. The results of the Type A test shall be validated by the performance of the verification test. Data acquisition should not be interrupted without justification from the end of the successful Type A test to the start of the verification test.

5.9.1 Superimposed Leakage Rate (L_o). The superimposed leakage rate shall be between $0.75L_a$ and $1.25L_a$.

5.9.2 Stabilization Period. A stabilization period may be used, but should not exceed one hour unless extenuating circumstances exist and are documented in the CILRT log.

5.9.3 Verification Test Acceptance Criteria. The verification test shall last at least 4 hours, with a minimum of 15 data sets taken at approximately equal time intervals. The composite leakage rate, L_c, shall be within the following limits for the last hour or the last four consecutive data sets (whichever is longer):

$$(L_o + L_{am} - 0.25L_a) \leq L_c \leq (L_o + L_{am} + 0.25L_a)$$

5.10 Depressurization. Primary containment depressurization shall be conducted in a controlled and safe manner. A means of rapid isolation of the blowdown path should be available throughout the depressurization. Concerns for the safe return of the primary containment to normal atmospheric pressure include, but are not limited to:

(1) The potential for structural damage to tanks and volumes that cannot depressurize at the same rate as the primary containment and that are not designed to withstand the resulting differential pressures (e.g., airlocks or pressurizer relief tanks).

(2) Personnel or equipment hazards that can be present from pressurization of piping or isolated volumes during the CILRT. These volumes can remain pressurized for long periods following primary containment depressurization.

(3) The expansion of air trapped in liquid lines that can generate problems of level control or spillage during depressurization.

(4) The ability of discharge piping, valves, and other components to withstand the stresses of high velocity air discharge.

(5) Personnel safety with regard to noise and entrained debris.

(6) The potential for release of radioactive material.

5.11 Reporting of Results

5.11.1 Content. Adequate data for an independent review of the primary containment leakage rate test results shall be provided in a written report. This section lists information required for reporting CILRT results. The information listed in 5.11.1.1 through 5.11.1.3 shall be recorded.

5.11.1.1 General Data.

(1) Owner: Plant name, Unit
(2) Docket Number
(3) Location
(4) Primary containment description
(5) Test completion date

5.11.1.2 Technical Data.

(1) Primary containment net free air volume, ft^3 (m^3)
(2) Design pressure, psig (kPa)
(3) Calculated peak accident pressure, P_{ac}, psig (kPa)

5.11.1.3 Test Data.

(1) Data analysis technique
(2) Test pressure(s) psig (kPa)
(3) Maximum allowable leakage rate L_a (%/24 h)
(4) Calculated leakage rate at upper confidence limit, UCL (%/24 h)
(5) Calculated leakage rate, L_{am} (%/24 h)
(6) Superimposed leakage rate, L_o (%/24 h)
(7) Verification test composite leakage rate, L_c (%/24 h)

5.11.2 Analysis and Interpretation. The report shall include an analysis of leakage rate data and the interpretation of the following test results:

(1) CILRT;

(2) All LLRT results performed since the last CILRT;

(3) Type A leakage rate corrections for pathways not tested, and comparison of the overall Type A leakage rate, including corrections, to the acceptance criteria;

(4) A listing of all test exceptions taken, including changes in primary containment boundaries, and data set rejection to conclude successful testing;

(5) Description of sensor malfunctions, repairs, and methods used to redistribute volume fractions to operating instrumentation.

This interpretation shall clearly state if the test has passed or failed the acceptance criteria.

5.11.3 Summary of LLRTs. A summary of all local leakage rate tests conducted since the last CILRT shall be included in the report.

5.12 Containment Leakage Rate Backup Data. The following information shall be retained and shall be made available for review at the facility, as required.

(1) Access Procedure. When not included in the test, procedures that were established to limit ingress to primary containment during testing should be available.

(2) Operating Instrument Status. A listing of normal operating instrumentation used for the leakage rate test shall be provided.

(3) Systems Status (at time of test). A system line-up, showing required valve positions and status of piping systems, shall be provided (e.g., "Valve open-line filled" or "System in normal service," monitoring of liquid levels required).

(4) CILRT Log. A sequential log of events during the CILRT.

(5) Instrumentation Validation. Documentation of instrumentation calibrations and standards.

(6) Test Procedure. The working copy of the test procedure that includes signature sign-offs of procedural steps. If the procedure does not contain test control requirements, these should be provided separately.

(7) LLRTs. The procedure and all data that verifies completion of penetration or valve testing (B & C type tests), including as-found leakage rates, corrective action taken, and final leakage rate.

(8) CILRT Data. The accumulated computer and manual data along with a summary description of computer program, when applicable.

6. Test Procedures for Type B and Type C Tests

6.1 General Methods. This section describes acceptable methods to determine the leakage rates of primary containment boundaries and isolation valves. Examples of some acceptable methods (but not limited to only those listed) for measuring leakage rates are:

(1) Pressure decay

(2) Make-up flow rate.

6.2 Direction of Testing. Tests shall be performed so that the test pressure is applied in the same direction as that which would occur during the DBA, unless it can be shown that the results from applying the pressure in a different direction will provide equivalent or more conservative test results. The following examples might provide equivalent or more conservative test results:

(1) Butterfly valves with concentric stems and non-tapered seats, tested in the reverse direction.

(2) Globe valves located inside the primary containment, tested in the reverse direction, provided that the pressure during the DBA assists in seating the disk and the pressure during reverse direction testing aids in unseating the disk. Globe valves located outside the primary containment, with the same orientation, may be tested in the reverse direction, provided that leakage from the valve packing and the bonnet is quantified.

(3) Double disc gate valves, tested by pressurization between the disks.

6.3 System Line-Up. Systems that contain water during normal operation, but are not designed to be water filled following a DBA, shall be drained to expose the barrier under test to the test medium. Any water remaining in a horizontal portion of a line between the outboard barrier and the vent may remain during the testing.

If a vertical distance exists between the outboard barrier and the vent, the resulting water head can result in a pressure differential less than P_{ac} across the barrier. This condition is acceptable if the water head can be shown to remain in the line under post-accident conditions, e.g., the line shall be water filled, Seismic Category I or II, and Safety Class 2. In cases where the pathway outboard of the barrier cannot be shown to be intact under post-accident conditions, those pathways shall be drained for testing, or the test pressure shall be increased to achieve a differential pressure of not less than P_{ac}.

6.4 Test Methods.

6.4.1 Pressure Decay. The test volume initially shall be pressurized with air or nitrogen to a test pressure greater than P_{ac}. The final test pressure shall be greater than P_{ac}. The pressure and temperature shall be recorded at the start and end of the test. The leakage rate shall be calculated from the following formula:

$$L_L = \left(\frac{P_1}{T_1} - \frac{P_2}{T_2}\right)\left(\frac{VT_s}{tP_s}\right)$$

where:

L_L	=	leakage rate, SCFH
P_1, P_2	=	test pressure at the start and end of the test, respectively, absolute units, psia
T_1, T_2	=	ambient absolute temperature at start and end of test, respectively, absolute units, R
V	=	total test free air volume, ft^3
t	=	test duration, h
T_s	=	standard atmospheric temperature, R
P_s	=	standard atmospheric pressure, psia

6.4.2 Makeup Flowrate. The test volume shall be pressurized and maintained to at least P_{ac}, using a pressure regulator to maintain test pressure. Makeup fluid flow to the test volume required to maintain test pressure shall be used as the leakage rate of the barrier under test.

6.4.3 Test Duration. Pressure decay tests should have a test duration of not less than 15 minutes after stable conditions have been attained. A flow makeup test should be used if a pressure decay test cannot be performed for at least 15 minutes. No minimum test duration shall be required for a make-up flow test; however, test data shall be obtained during stable conditions.

6.4.4 Acceptance Criteria. The combined leakage rate for all penetrations subject to Type B or Type C tests shall be less than or equal to $0.60L_a$ when determined on a MNPLR basis from the as-found LLRT results.

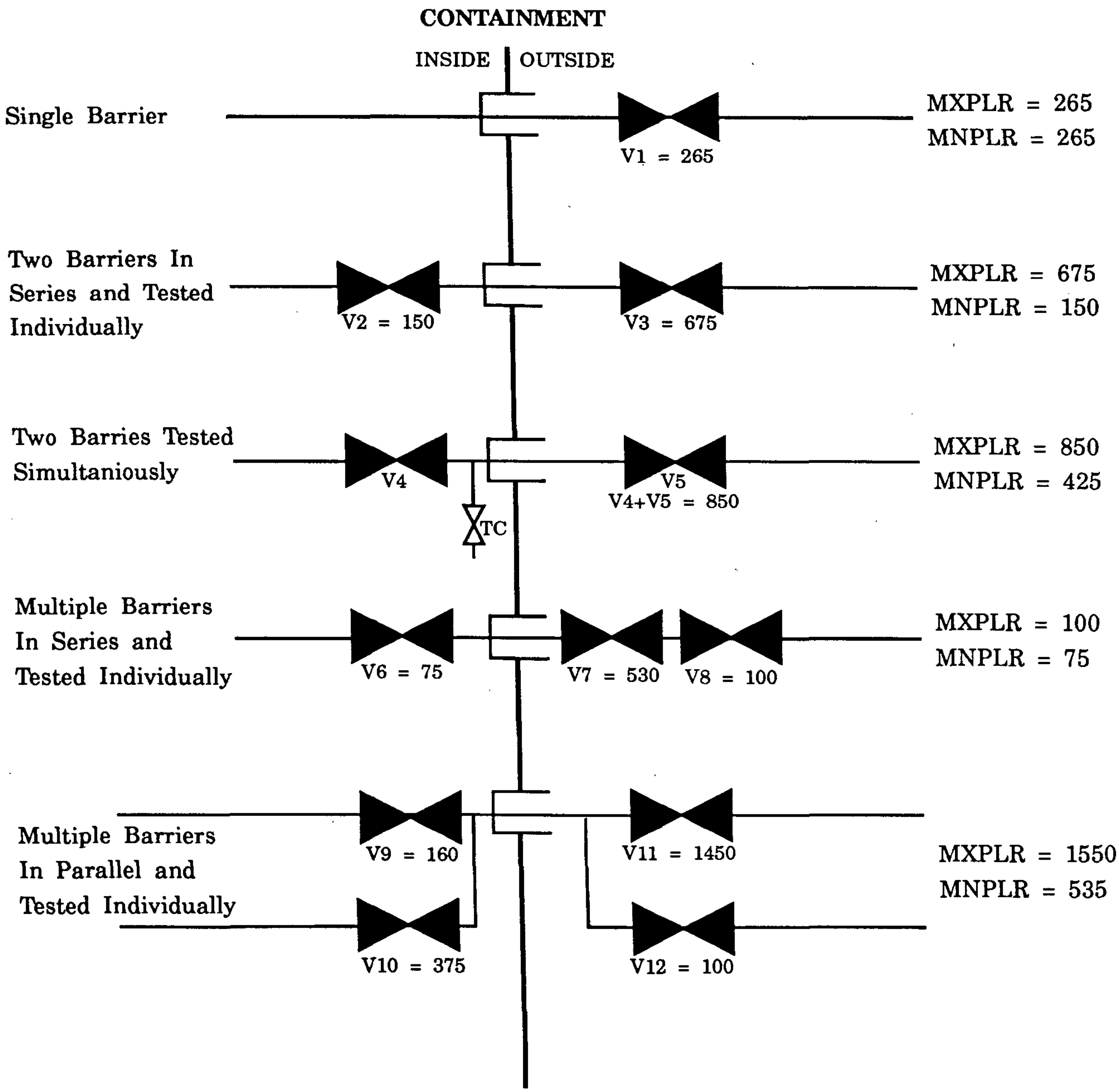
The combined leakage rate for all penetrations subject to Type B or Type C tests shall be less than or equal to $0.60L_a$ as determined on a MXPLR basis from the as-left LLRT results. Figure 6-1 illustrates some typical examples of MNPLR and MXPLR.

7. References

[1] Title 10, "Energy," Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria," Criteria 55, 56, and 57. Available from the Superintendent of Documents, Government Printing Office, Washington, DC 20402.

Figure 6-1

Typical Minimum and Maximum Pathway Determination



Appendix A

(This appendix is not a part of American National Standard for Containment System Leakage Testing Requirements, ANSI/ANS-56.8-1994, but is included for information purposes only.)

Type A Test Methods

A1. Introduction

The standard requires that the absolute test method be used to compute the containment dry air masses, and the mass point method be used to compute the reactor containment Type A leakage rate. Other computational techniques have been utilized for containment leakage rate computations, and this appendix describes them briefly. The approved techniques of data gathering and analysis are presented in the main body of the standard. The description of other techniques in this appendix does not endorse their application in future tests.

A2. Absolute Method

The Absolute Method is a direct application of the Ideal Gas Law for the calculation of dry air masses. It is assumed that changes in the containment structure due to the effects of temperature and pressure are not sufficient to change its free air volume significantly during the test.

A3. Data Analysis

Three basic techniques for data analysis are mass point, total time, and point to point. The standard endorses the mass point analysis technique. The other methods are listed here for historical perspectives only.

A3.1 Mass Point Analysis. Data from an absolute system are reduced to a contained mass of dry air by application of the Ideal Gas Law. The test data consist of a sequence of independent values of time stamped contained air mass. The assumption is made that the leakage rate is constant with time. These data sets are then analyzed by the method of linear least squares. The slope of this line represents the rate of change of air mass with respect to time, which is the leakage rate.

A3.2 Total Time Analysis. This techniques calculates leakage rate based on the most recent data and the data taken at the start of the test. Each successive leakage calculation is therefore based on a longer period of time. The overall leakage rate in percent per day is determined by applying linear regression analysis at each time point. The y-intercept of this line, rather than the slope, is the containment leakage rate.

A3.3 Point to Point Analysis. This technique calculates leakage based on the most recent data and the data immediately preceding. Leakage rate (weight percent per day) is calculated for each consecutive time interval. The overall leakage rate is determined by applying linear regression analysis to the leakage rates at each time point. The y-intercept of this line, rather than the slope, is the containment leakage rate.

Appendix B

(This appendix is not a part of American National Standard for Containment System Leakage Testing Requirements, ANSI/ANS-56.8-1994, but is included for information purposes only.)

Bases and Formulae for Containment Type A Tests

This appendix presents theoretical bases, justification, and derivations of formulae used in the computation of reactor containment Type A leakage rate and its associated upper confidence limit. The Mass Point Analysis Technique (also known as the Mass Plot Analysis Technique) is the method approved for use in accordance with this standard; it is based upon linear regression (least squares) methodology.

B1. Symbols and Notations

S_B	- Estimate of standard deviation in intercept of least squares line, lbm
S_{AB}	- Estimate of covariance between slope and intercept of least squares line, lbm^2/h
t_i	- Time from the beginning of the test to the i^{th} data set, h
$\bar{t}$	- Average time of n time values, h
$t_{.95}$	- 95th percentile of Student's t distribution. See Table B1 for values of $t_{.95}$ corresponding to selected values of degrees of freedom (D_F)
$\hat{W}$	- Average of n mass values, lbm
$\Sigma = \sum_{i=1}^{n}$	- Summation operator for all time points included in the test.

B2. Bases and Formulae for Leakage Rate Calculations

The theoretical basis for using least squares methods to compute a leakage rate lies in the so-called Gauss-Markoff theorem[13]. As applied to the measurement of leakage rates, the theorem states that if the relationship between W and t is linear, and if the W values are independent and equally variable, then the "best" estimators of the slope and intercept of the line are given by least squares analysis. (Here, "best" implies two properties: (1) the estimators are unbiased, and (2) the estimators have the smallest variances of any other unbiased estimators that might be derived from arbitrary linear combinations of the W values.)

The least squares line (also called the regression line) is given by

$$\hat{W}_i = At_i + B \tag{B.1}$$

where B and A are the intercept and the slope of the least squares line.

In the calculation of A and B, we first calculate the average time, $\bar{t}$, and the average air mass, $\overline{W}$ defined by

$$\bar{t} = \frac{\Sigma t_i}{n}$$

$$\overline{W} = \frac{\Sigma W_i}{n} \tag{B.2}$$

[13] Reference: *An Introduction to Linear Statistical Models*, A. Greybill, McGraw-Hill Book Company Inc., New York, 1961, Section 6.2.2.

where the summation sign (sigma) indicates that the summation is to be made over all time points.

$$A = \frac{\Sigma(t_i - \bar{t})(W_i - \overline{W})}{\Sigma(t_i - \bar{t})^2} \quad . \tag{B.3}$$

$$A = \frac{n(\Sigma t_i W_i) - (\Sigma t_i)(\Sigma W_i)}{n(\Sigma t_i^2) - (\Sigma t_i)^2} \quad . \tag{B.4}$$

The intercept, B, of the least squares line may be calculated by either Eq. B.5 or Eq. B.6.

$$B = \overline{W} - A\bar{t} \quad . \tag{B.5}$$

$$B = \frac{(\Sigma W_i)(\Sigma t_i^2) - (\Sigma t_i)(\Sigma t_i W_i)}{n(\Sigma t_i^2) - (\Sigma t_i)^2} \quad . \tag{B.6}$$

Each t_i is the elapsed time between a clock time at which the initial reading is taken and the clock time at which the i^{th} reading is taken. Thus, $t_1 = 0$, t_2 is the length of time elapsed before the first reading, and so on. In most tests, the time intervals between readings are constant, although the formulas for A and B do not require constancy.

The leakage rate is expressed as the ratio of the rate of change of mass to the calculated mass in the containment at time $t_1 = 0$. Since values of t_i have units of hours and percentage daily leakage rates are desired, the Mass Point leakage rate is expressed as what is expected to be a positive number by computing

$$L_{am} = (-2400)(A/B). \tag{B.7}$$

Note that B (the estimated air mass at the beginning of the test, obtained from the least squares line) rather than W_1 (the measured air mass at the beginning of the test) is used as the denominator of L_{am}. The uncertainty in the estimated value L_{am} is assessed in terms of the standard deviations of A and B and their covariance, followed by the computation of a 95% upper confidence limit about the true leakage rate. Detailed formulae are given below.

The estimate of the common standard deviation (following from the "equally variable" assumption) of the masses with respect to the line is given by

$$S = \left[\frac{\Sigma (W_i - \hat{W}_i)^2}{n-2} \right]^{1/2} \tag{B.8}$$

where

W_i is the measured mass at time t_i and

$\hat{W}_i$ is the estimated air mass at time t_i (i.e., $\hat{W}_i = At_i + B$).

Equation B.8 can be equivalently expressed as

$$S = \left\{ \left(\frac{1}{n-2} \right) \left[\Sigma W_i^2 - \frac{(\Sigma W_i)^2}{n} - \frac{[(\Sigma t_i W_i) - (\Sigma t_i)(\Sigma W_i)/n]^2}{\Sigma t_i^2 - (\Sigma t_i)^2/n} \right] \right\}^{1/2} . \tag{B.9}$$

Now, let

$$K = \frac{S}{[n(\Sigma t_i^2) - (\Sigma t_i)^2]^{1/2}} , \tag{B.10}$$

then, the standard deviation of the slope is

$$S_A = K[n]^{1/2} \tag{B.11}$$

Equation B.11 can be equivalently expressed as

$$S_A = \left\{ \left(\frac{1}{n-2} \right) \left[\frac{n(\Sigma W_i^2) - (\Sigma W_i)^2}{n(\Sigma t_i^2) - (\Sigma t_i)^2} - A^2 \right] \right\}^{1/2} . \tag{B.12}$$

The standard deviation of the intercept is

$$S_B = K\,[\Sigma t_i^2\,]^{1/2} \quad . \tag{B.13}$$

and the covariance of the slope and intercept is

$$S_{AB} = K^2\left[-\Sigma t_i\right] \quad . \tag{B.14}$$

In most leakage rate tests, the ratio S_B/B is very small compared with the ratio S_A/A. Thus, an approximate upper limit of the 95 percent confidence level on the true leakage is provided by

$$\text{UCL (approx)} = L_{am} + 2400\ t_{.95}\ (S_A/B) \tag{B.15}$$

where $t_{.95}$ is selected from Table B1 with $D_F = (n - 2)$.

The adequacy of this approximate confidence level is measured in terms of its closeness to the exact Fieller-type limit[14] derived from assumption that the W_i values are normally distributed about the straight line. Experience with Type A tests has shown this approximation to be entirely adequate. However, to obtain the exact limit, let

$$a = B^2 - t_{.95}{}^2\ S_B^2$$

$$b = AB - t_{.95}{}^2\ S_{AB}$$

$$c = A^2 - t_{.95}{}^2\ S_A{}^2$$

Then an exact upper one-sided limit of a 95 percent confidence level for the leakage rate is given by

$$UCL_{exact} = -2400\left[\frac{b - (b^2 - ac)^{1/2}}{a}\right] \quad . \tag{B.16}$$

[14] *The Advanced Theory of Statistics* (3rd Edition), by Maurice G. Kendall and Alan Stuart, Hafner Publishing Company, New York, 1961, pp. 130-132.

Table B1
95th Percentile of the Student's t Distribution for Selected Degrees of Freedom

D_F	$t_{.95}$	D_F	$t_{.95}$	D_F	$t_{.95}$
1	6.314	13	1.771	25	1.708
2	2.920	14	1.761	26	1.706
3	2.353	15	1.753	27	1.703
4	2.132	16	1.746	28	1.701
5	2.015	17	1.740	29	1.699
6	1.943	18	1.734	30	1.697
7	1.895	19	1.729	40	1.684
8	1.860	20	1.725	60	1.671
9	1.833	21	1.721	120	1.658
10	1.812	22	1.717	∞	1.645
11	1.796	23	1.714		
12	1.782	24	1.711		

For $D_F>3$, the following approximation[15] is correct to 4 significant figures:

$$t_{.95} = \frac{1.6449D_F + 3.5283 + 0.85602/D_F}{D_F + 1.2209 - 1.5162/D_F} \tag{B.17}$$

[15] "An Approximation to Student's t" by D. A. Gardiner and B. F. Bombay, *Technometrics,* Vol. 7, No. 1, pp. 71-72, 1965.

Appendix C

(This appendix is not a part of American National Standard for Containment System Leakage Testing Requirements, ANSI/ANS-56.8-1994, but is included for information purposes only.)

Verification Test Method

A known leak is intentionally superimposed on the existing leaks in a containment system. The leak is induced from the containment to outside the containment system.

A practical and simple arrangement for superimposing a measurable leak on the containment system employs the orifice leak of a micro-adjustable instrument flow valve installed at a convenient penetration of the containment system. The flow through the valve is measured with a calibrated flowmeter. The induced leakage rate shall be between 75 and 125 percent of the maximum allowable leakage rate allowed for that containment, (L_a). The flowmeter readings shall be recorded at least hourly. The measured leakage rate represents the composite of the containment leakage rate and induced leakage rate.

> **NOTE:** A relationship between mass and volumetric flow rate is given below. Standard air temperature and pressure are defined below.

The flow rate (L_o) to be induced, in units of standard cubic feet per minute, as a function of the %/day value is given below.

$$L_o\ (\text{scfm}) = L_o\ (\%/\text{day}) \left(\frac{V_c\ P_c\ (T_s + 459.67)}{144000\ P_s\ (T_{av} + 459.67)} \right)$$

or

$$L_o\ (\text{scfm}) = W_{\text{Type A}} \times \frac{13.3\ \text{scfm/lbm}}{144000} \times L_o\ (\%/\text{day})$$

where

V_c = Free volume of containment (ft^3) at the time of the base data set.
T_{av} = Weighted average containment temperature (°F) at the start of the verification test.
P_c = Total average containment pressure at the start of the verification test (psia).
P_s = 14.6959 psia.
T_s = 68 °F.
$W_{\text{Type A}}$ = Weight of containment air at the conclusion of the Type A test based on least squares fit line.

Appendix D

(This appendix is not a part of American National Standard for Containment System Leakage Testing Requirements, ANSI/ANS-56.8-1994, but is included for information purposes only.)

Data Rejection Criterion

An outlying observation, or an outlier, is a data point which is widely different from the remaining observations in a group of numbers. The outlying observation may be the result of an error in calculating a numerical value, and as such could be corrected if properly identified. An outlier could also result from an instrument error or an error in the reading of the instrument. If this is known to be the case, the false reading should be removed from the data set. Since one seldom, if ever, has such knowledge, it may be desirable to test whether the questionable data entry is likely to belong with the remaining observations.

Most traditional tests for outlying observation are not appropriate for testing for an outlier in a regression situation, such as in CILRT, since the standard error of the residual varies with time. An acceptable test criterion for a single outlier in a simple linear regression, however, is given by Tietjen *et al*[16] as follows:

Let t_i denote the i^{th} time (hours) for the i^{th} reading, W_i the corresponding air mass, and $\hat{W}_i = At_i + B$ the corresponding predicted mass (see Appendix B). The i^{th} residual $w_i = W_i - \hat{W}_i$ has a standard error s_i, where

$$s_i = S\sqrt{1 - \frac{1}{n} - \frac{(t_i - \bar{t})^2}{\Sigma\,(t_i - \bar{t})^2}} \qquad \text{(D.1)}$$

$$S^2 = \frac{1}{n-2}\Sigma(W_i - \hat{W}_i)^2 = \frac{1}{n-2}\Sigma w_i^2 \qquad \text{(D.2)}$$

and

$$\bar{t} = \frac{1}{n}\Sigma t_i$$

For each time point, i, calculate the standard residual $r_i = w_i/s_i$. Find $|r_i|$, the largest value of r_i. Let the time point m denote the subscript for which $|r_i|$ is the largest. Since W_m has the largest associated standardized residual, W_m is considered a potential outlier. Let $D=|r_i|$. Compare D to Table D2. If D exceeds the appropriate critical value, W_m is declared an outlier.

For a leakage rate test in which the data are collected at equal time intervals, Equation D.1 reduces to

$$s_i = S\sqrt{1 - \frac{1}{n} - \frac{(i - \bar{i})^2}{\Sigma\,(i - \bar{i})^2}} \qquad \text{(D.3)}$$

where

$$\bar{i} = \frac{1}{n}\Sigma i = \frac{(1 + 2 + 3 + ... + n)}{n} = \frac{n + 1}{2}$$

[16] "Testing for Single Outlier in Simple Regression," G. L. Tietjen, R. H. Moore, and R. J. Beckman, *Technometrics*, Vol. 15, No. 4. (Nov. 1973), pp. 717-721.

and, in still simpler form, Eq. D.3 is written as

$$s_i = S\sqrt{1 - \frac{1}{n} - \frac{12(i - \bar{i})^2}{n\,(n+1)\,(n-1)}} \qquad \text{(D.4)}$$

The technique is now demonstrated by an example. For every point in time, Table D1 shows the containment air mass, its deviation from the regression line, the standard error of the residual, and the standardized residual. In this example, with actual test data generated at 15 minute intervals, we have n = number of data points = 36. The estimated standard deviation of the containment air mass from the linear least squares is given by equation (D.3) with

$$\bar{i} = \frac{36 + 1}{2} = 18.5 \text{ and}$$

$$\Sigma w_i^2 = \Sigma(W_i - \hat{W}_i)^2 = 28848.83$$

so that

$$s_i = \sqrt{\frac{28848.83}{36-2}} \times \sqrt{1 - \frac{1}{36} - \frac{12(i - 18.5)^2}{(36)(37)(35)}}$$

The maximum absolute standardized residual is found from the last column of Table D1 for i = 28, where $D = |r_i| = 2.08$.

The computed statistic D is next compared to the critical deviation ratio for the corresponding number of points, n, and the predetermined level of significance, α. The critical ratios are given by Table D2 for $\alpha = 0.05$ and $\alpha = 0.01$, and for n between 6 and 100, inclusively. This appendix does not give explicit direction to handle a sequence with more than 100 data points. The notes after Table D2, however, may be useful in formulating a reasonable guideline to handle a large sequence or for multiple outliers in a sequence.

If α is selected at 0.05, the critical deviation ratio for n = 36 is read from Table D2 as 3.03. In our example, D = 2.08 and the corresponding observation (#28 in Table D1) is not rejected as an outlying observation. If D were calculated to be larger that 3.03, the corresponding data point would have been rejected on statistical principles.

Although in most applications of statistical tests the level of significance is selected at $\alpha = 0.05$, the choice of α for rejection of an outlier shall be made with consideration of the consequences of a wrong decision. The exclusion of a "good" point (a point which does belong to the data set) tends to reduce the standard error of the leakage rate estimator and, consequently, the upper confidence limit for the true leakage rate (UCL) is understated. The inclusion of a "bad" observation (a point which does not belong to the set), on the other hand, generally leads to an overstatement of UCL. Although a conservative view indicated preference for a small α to lessen the probability of rejection of a "good" point, the ultimate choice of α rests with the user.

Whereas the employment of a criterion for testing an outlier is permissible, it cannot be applied selectively. That is, one shall not apply the criterion to an outlier if its inclusion in the calculations would reduce the calculated leakage rate unless one is also prepared to reject an outlier whose inclusion would increase the calculated leakage rate or its UCL. For this reason, it is appropriate for the user to declare in advance of the test whether the criterion is used, and the rejection level if the test is to be used.

Table D1

Sample Containment Air Mass and Calculations for Detection of a Single Outlier

Data Point i	Air Mass W_i	Linear Least Square Fit $\hat{W}_i$	Residual from Least Square Fit $w_i = W_i - \hat{W}_i$	Standard Error of Residual s_i	Standardized Residual $r_i = w_i/s_i$
1	735478.1	735443.37	34.73	27.53	1.26
2	735473.5	735442.46	31.04	27.67	1.12
3	735475.8	735441.54	34.26	27.79	1.23
4	735451.1	735440.63	10.47	27.91	0.38
5	735439.8	735439.71	0.09	28.02	0.00
6	735449.6	735438.80	10.80	28.12	0.38
7	735444.2	735437.88	6.32	28.21	0.22
8	735426.6	735436.97	-10.37	28.30	-0.37
9	735415.1	735436.05	-20.95	28.38	-0.74
10	735396.7	735435.14	-38.44	28.45	-1.35
11	735391.3	735434.22	-42.92	28.51	-1.51
12	735426.3	735433.31	-7.01	28.56	-0.25
13	735440.7	735432.39	8.31	28.61	0.29
14	735424.8	735431.48	-6.68	28.64	-0.23
15	735432.3	735430.56	1.74	28.68	0.06
16	735435.3	735429.65	5.65	28.70	0.20
17	735409.1	735428.73	-19.63	28.71	-0.68
18	735423.5	735427.82	-4.32	28.72	-0.15
19	735436.4	735426.90	9.50	28.72	0.33
20	735436.4	735425.99	10.41	28.71	0.36
21	735391.8	735425.07	-33.27	28.70	-1.16
22	735392.1	735424.16	-32.06	28.68	-1.12
23	735452.8	735423.24	29.56	28.64	1.03
24	735455.5	735422.33	33.17	28.61	1.16
25	735448.9	735421.41	27.49	28.56	0.96
26	735371.3	735420.50	-49.20	28.51	-1.73
27	735387.9	735419.58	-31.68	28.45	-1.11
28	735359.6	735418.67	-59.07	28.35	-2.08
29	735395.4	735417.75	-22.35	28.30	-0.79
30	735375.0	735416.84	-41.84	28.21	-1.48
31	735407.8	735415.92	-8.12	28.12	-0.29
32	735445.5	735415.01	30.49	28.02	1.09
33	735446.5	735414.09	32.41	27.91	1.16
34	735447.0	735413.18	33.82	27.79	1.22
35	735464.2	735412.26	51.94	27.67	1.88
36	735437.0	735411.35	25.65	27.53	0.93

Table D2

Critical Deviation Ratio for Data Rejection for a One-Sided Statistical Test

Observations n	5% Critical Ratio	1% Critical Ratio	Observations n	5% Critical Ratio	1% Critical Ratio
			53	3.19	3.54
6	1.93	1.98	54	3.19	3.55
7	2.08	2.17	55	3.20	3.56
8	2.19	2.32	56	3.21	3.56
9	2.29	2.44	57	3.21	3.57
10	2.37	2.54	58	3.22	3.58
11	2.43	2.63	59	3.22	3.58
12	2.49	2.70	60	3.23	3.59
13	2.54	2.77	61	3.24	3.60
14	2.59	2.82	62	3.24	3.60
15	2.62	2.88	63	3.25	3.61
16	2.66	2.92	64	3.25	3.62
17	2.69	2.96	65	3.26	3.62
18	2.72	3.00	66	3.26	3.63
19	2.75	3.03	67	3.27	3.63
20	2.77	3.06	68	3.27	3.64
21	2.80	3.09	69	3.28	3.64
22	2.82	3.12	70	3.28	3.65
23	2.84	3.14	71	3.29	3.65
24	2.86	3.17	72	3.29	3.66
25	2.88	3.19	73	3.30	3.66
26	2.89	3.21	74	3.30	3.67
27	2.91	3.23	75	3.31	3.67
28	2.93	3.25	76	3.31	3.68
29	2.94	3.27	77	3.31	3.68
30	2.96	3.28	78	3.32	3.69
31	2.97	3.30	79	3.32	3.69
32	2.98	3.32	80	3.33	3.69
33	3.00	3.33	81	3.33	3.70
34	3.01	3.34	82	3.34	3.70
35	3.02	3.36	83	3.34	3.71
36	3.03	3.37	84	3.34	3.71
37	3.04	3.38	85	3.35	3.72
38	3.05	3.40	86	3.35	3.72
39	3.06	3.41	87	3.36	3.72
40	3.08	3.42	88	3.36	3.73
41	3.09	3.43	89	3.36	3.73
42	3.09	3.44	90	3.37	3.74
43	3.10	3.45	91	3.37	3.74
44	3.11	3.46	92	3.38	3.74
45	3.12	3.47	93	3.38	3.75
46	3.13	3.48	94	3.38	3.75
47	3.14	3.49	95	3.39	3.76
48	3.15	3.50	96	3.39	3.76
49	3.16	3.51	97	3.40	3.76
50	3.16	3.52	98	3.40	3.77
51	3.17	3.53	99	3.41	3.77
52	3.18	3.53	100	3.41	3.78

NOTES on Table D2 Values

- The critical deviation ratios (rejection points) listed above are approximations derived from entries given in Table 1 of "The Accuracy of Bonferroni Significance Level for Detecting Outliers in Linear Models," by D.R. Cook and P. Prescott, *Technometrics*, Vol.23, No.1, 1981.

- The 5% critical ratio for n points can be obtained from the equation

$$CR(5\%) = 1.512704 + 0.165416n - 0.000609n^2 + 0.00000170n^3 \\ -2.385636n^{0.5} + 2.954755\log_e(n).$$

- The 1% critical ratio for n points can be obtained from the equation

$$CR(1\%) = 1.168092 + 0.173090n - 0.000577n^2 + 0.00000149n^3 \\ -2.672396n^{0.5} + 3.539676\log_e(n).$$

- Earlier versions of this Appendix give somewhat different values than the Table D2. Both tables, however, are based on approximations, and neither table is necessarily more "correct" than the other.

- Table D2 is applicable to a sequence of 6 to 100 observations. Extrapolation beyond these limits shall be made with caution. The formulas given in notes (2) and (3) above can be shown to be inappropriate for a data set much larger than 100.

  To overcome sample size restrictions, one may examine outliers in non-overlapping sequences of no more than 100 observations. To avoid bias, a determination of whether to employ a rejection criterion, as well as the length of such sequences, shall be made in advance of the test.

- The problem of multiple outliers is still being debated in the statistical literature. The reason for a lack of clear methodology stems from the fact that the methodology would depend on the relation among outliers. If there is a common cause for the outliers then, perhaps, all readings affected by this cause ought to be removed. If the outliers are clearly independent (different time, different sensor type, and different subvolume), then, perhaps, repetitions of the test for outliers are warranted. In the absence of clear knowledge of the nature of the relation among the outliers, the following arguments may be used as a basis for effective policy:

  (a) In advance of the leakage rate test, declare whether you intend to test for outliers.

  (b) When in doubt, practice conservatism and leave the outlier in the sample.

  (c) The statistical test for outliers serves to identify potential readings that do not belong in the data set. Prudent engineering judgment and careful documentation are still required to determine the disposition of any outlier(s).

Appendix E

(This Appendix is not part of American National Standard for Containment System Leakage Rate Testing Requirements, ANSI/ANS-56.8-1994, but it is included for information purposes only.)

Containment Atmosphere Stabilization Criteria

The mass point analysis technique assumes that the leakage rate remains constant with time, such that the data can be analyzed by the method of linear least squares fit. Following containment pressurization to P_{ac}, a period of time is required to allow containment atmospheric conditions to stabilize sufficiently such that the containment air mass decay curve approaches a straight line with respect to time. The effects of ingassing (the absorption of air into scaffolding, insulation, concrete, etc., at the elevated pressure), pressure equalization across penetration test volumes, and temperature decay once the heat of pressurization is removed, can result in a higher initial leakage rate during the initial stages of the stabilization period. The leakage rate generally decreases to a constant value as the stabilization period progresses.

The bases for the given criteria enable passing of the Type A test and the verification test in the shortest duration possible by

(1) ensuring that the containment air mass data has stabilized sufficiently such that the mass decay curve is essentially linear with respect to time with no adverse curvature component,

(2) ensuring that the Type A test data has a high probability of passing the Limit on Curvature and the Limit on Data Scatter conditions required by the Type A test acceptance criteria, and

(3) providing reasonable assurance of successfully passing the verification test.

The stabilization criteria are determined by calculating both one hour and two hour sliding window leakage rates. A valid least squares fit requires a sufficient number of data sets. Therefore, data acquisition intervals of less than or equal to 5 minutes are recommended, such that 13 data sets are available for the one hour window and 25 data sets are available for the two hour window. The data acquisition time interval may be reset to a longer period once the appropriate Type A starting time is determined.

By combining equations B.4, B.6, and B.7, from Appendix B, L_{1h} and L_{2h} are determined by the Equation E.1. The appropriate values for n, W_i, and t_i for the one hour leakage window or the two hour window are substituted accordingly.

$$(L_{1h} \text{ or } L_{2h}) = \frac{-2400\ [n\ (\Sigma t_i W_i) - (\Sigma t_i)(\Sigma W_i)]}{(\Sigma W_i)(\Sigma t_i^2) - (\Sigma t_i)(\Sigma t_i W_i)} \tag{E.1}$$

where:

L_{1h} = estimate of the leakage rate, derived from the least squares slope and intercept using the mass data over the last hour (percent/24 h).

L_{2h} = estimate of the leakage rate, derived from the least squares slope and intercept using the mass data over the last two hours (percent/24 h).

The containment may be considered stabilized for Type A test purposes when the following conditions are simultaneously met:

$$0 \leq L_{1h} < L_a \tag{E.2}$$

and

$$| L_{2h} - L_{1h} | \leq 0.25 L_a \ . \tag{E.3}$$

Table E1
Sample Problem

For this sample problem, L_a = 0.25%/24h, $0.25L_a$ = 0.0625%/24h, and data sets are taken every 5 minutes. Therefore, n_{1h} = 13, and n_{2h} = 25.

Time (Hours)	Mass (lbm)	L_{1h} (%/24h)	L_{2h} (%/24h)	$\lvert L_{2h}-L_{1h} \rvert$ (%/24h)	Time (Hours)	Mass (lbm)	L_{1h} (%/24h)	L_{2h} (%/24h)	$\lvert L_{2h}-L_{1h} \rvert$ (%/24h)
00:00	687470	-	-	-	03:10	686166	0.3228	0.5730	0.2502
00:05	687329	-	-	-	03:15	686164	0.3092	0.5409	0.2317
00:10	687189	-	-	-	03:20	686155	0.3154	0.5102	0.1948
00:15	687048	-	-	-	03:25	686146	0.3215	0.4796	0.1581
00:20	686933	-	-	-	03:30	686136	0.3265	0.4494	0.1229
00:25	686818	-	-	-	03:35	686121	0.3379	0.4224	0.0845
00:30	686702	-	-	-	03:40	686106	0.3540	0.4020	0.0480*
00:35	686672	-	-	-	03:45	686090	0.3725	0.3885	0.0159*
00:40	686642	-	-	-	03:50	686085	0.3772	0.3783	0.0011*
00:45	686612	-	-	-	03:55	686080	0.3818	0.3688	0.0129*
00:50	686585	-	-	-	04:00	686075	0.3884	0.3605	0.0279*
00:55	686557	-	-	-	04:05	686074	0.3938	0.3522	0.0416*
01:00	686530	3.2680	-	-	04:10	686072	0.3826	0.3449	0.0377*
01:05	686510	2.7467	-	-	04:15	686071	0.3549	0.3390	0.0159*
01:10	686491	2.2439	-	-	04:20	686057	0.3288	0.3401	0.0113*
01:15	686471	1.7985	-	-	04:25	686043	0.3125	0.3426	0.0300*
01:20	686455	1.4399	-	-	04:30	686028	0.3049	0.3462	0.0413*
01:25	686438	1.1611	-	-	04:35	686021	0.2961	0.3482	0.0521*
01:30	686422	0.9807	-	-	04:40	686013	0.2962	0.3488	0.0525*
01:35	686397	0.9326	-	-	04:45	686005	0.3070	0.3478	0.0408*
01:40	686372	0.8969	-	-	04:50	685994	0.3336	0.3461	0.0125*
01:45	686347	0.8746	-	-	04:55	685984	0.3606	0.3472	0.0134*
01:50	686330	0.8566	-	-	05:00	685973	0.3870	0.3512	0.0358*
01:55	686313	0.8414	-	-	05:05	696985	0.3813	0.3498	0.0315*
02:00	686296	0.8316	1.6810	0.8494	05:10	685996	0.3413	0.3389	0.0023*
02:05	686278	0.8303	1.4690	0.6387	05:15	686008	0.2697	0.3192	0.0495*
02:10	686260	0.8278	1.2842	0.4564	05:20	685987	0.2139*	0.3033	0.0894
02:15	686242	0.8245	1.1312	0.3068	05:25	685967	0.1899*	0.2934	0.1035
02:20	686237	0.8020	1.0086	0.2066	05:30	685946	0.1965*	0.2894	0.0928
02:25	686233	0.7582	0.9107	0.1525	05:35	685950	0.1987*	0.2813	0.0826
02:30	686228	0.6956	0.8407	0.1450	05:40	685953	0.1906*	0.2723	0.0817
02:35	686223	0.6181	0.8027	0.1846	05:45	685957	0.1748*	0.2629	0.0881
02:40	686218	0.5420	0.7638	0.2218	05:50	685959	0.1553*	0.2540	0.0988
02:45	686213	0.4717	0.7247	0.2531	05:55	685962	0.1385*	0.2421	0.1036
02:50	686199	0.4237	0.6898	0.2660	06:00	685965	0.1274*	0.2273	0.1000
02:55	686185	0.3884	0.6583	0.2698	06:05	685943	0.1587**	0.2194	0.0607**
03:00	686171	0.3666	0.6307	0.2641	06:10	685921	0.1945**	0.2161	0.0215**
03:05	686169	0.3431	0.6031	0.2600	06:15	685900	0.2274**	0.2169	0.0105**

* Individual criteria met.
** Both criteria met.

The containment atmosphere stabilization criteria are first satisfied at 06:05.

Appendix F

(This Appendix is not part of American National Standard for Containment System Leakage Rate Testing Requirements, ANSI/ANS-56.8-1994, but it is included for information purposes only.)

Vapor Pressure and Volume Change Calculations

The equations used to calculate the vapor pressure and volume changes are listed below.

F1. Symbols and Subscripts

a - Free volume per inch of vessel level (ft^3)
b - Base level of the vessel (in.)
c - Actual water level in the vessel (in.)
f_i - The volume fraction of the i^{th} subvolume
N - Number of subvolumes
Pv - The average vapor pressure over water or ice in psi
RH - The relative humidity of air in percent
T - The drybulb air temperature in °F
T_d - The dew temperature in °F
V_c - Total containment free air volume
V_i - Free volume in subvolume i
V_{ko} - Volume of the subvolume k when c equals b

F2. Calculation of Vapor Pressure From Dew Temperature. Vapor Pressure is a function of Dew Temperature. The most accurate correlation is found in the *ASME Steam Tables: Thermodynamic and Transport Properties of Steam,* published by the American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10018. A simpler, yet accurate, formula is given below:

For vapor over water this formula[17] is valid in the range of dew temperatures from 32°F to 122°F. For ice, temperature shall be between -58°F to 32°F.

$$Pv = A\ \exp\left(\frac{B\ (T_d - 32)}{(T_d - 32) + C}\right) \qquad (F.1)$$

	Water	Ice
A =	0.0886804589	0.0886717535
B =	17.368	22.452
C =	429.984	490.59

If relative humidity (RH) sensors are used in place of sensors that measure dew temperature, then the correlation below may be used to calculate the dew temperature.

NOTE: The temperature used shall be located close to the RH sensor, so that its temperature is within 2.0°F of the RH sensor's temperature.

$$T_d = \frac{C \times \ln\left[\frac{RH}{100} \times \exp\left(\frac{B\ (T - 32)}{(T - 32) + C}\right)\right]}{B - \ln\left[\frac{RH}{100} \times \exp\left(\frac{B\ (T - 32)}{(T - 32) + C}\right)\right]} + 32 \qquad (F.2)$$

[17] Arnold Wexler, "Vapor Pressure Formulations for Water in the Range of 0° - 120°C, A Revision," *Journal of Research for National Bureau of Standards*, Vol. 80A, 1976, page 775.

F3. Ideal Gas Law (Changing Volume). For uncorrected dry air mass, the following definitions apply:

$$V_c = \sum_{i=1}^{N} V_i \qquad f_i = \frac{V_i}{V_c} \; . \tag{F.3}$$

For corrected dry air mass, the same definitions for V_c and f_i apply, except that one of the subvolumes is corrected for changes in a vessel's water level. If k is the subvolume number of the corrected subvolume, then

$$V_k = V_{ko} - a(c - b) \; . \tag{F.4}$$

The volume fractions (f_i) are then calculated with the corrected volume, and all other calculations are subsequently performed as previously specified for Type 1 dry air mass.

Appendix G

(This appendix is not a part of American National Standard for Containment System Leakage Testing Requirements, ANSI/ANS-56.8-1994, but is included for information purposes only.)

Termination Limit Criteria

Two termination limits[18] shall be met before a Type A test is considered successful. This limit on curvature assures that the function relating containment air mass to time is either linear or the curvature of that function is within acceptable bounds.

G1. Symbols and Notation

A'	- Coefficient of linear component in the least square parabola, lbm/h (kg/h)
B'	- Intercept of least squares parabola, lbm (kg)
C'	- Quadratic coefficient of least squares parabola, lbm/h^2 (kg/h^2)
$F(1, n\text{-}3, .95)$	- Table value for the 95th percentile of the F distribution with 1 and n-3 degrees of freedom
r	- Coefficient of linear correlation between the time and mass
t	- Length of test (same as t_n), h
t_i	- Time since the beginning of the test to the i^{th} time, h
$\bar{t}$	- Average of n time readings, h
$\overline{W}$	- Average of n air mass readings, lbm (kg)
$\chi^2(n\text{-}2, .95)$	- Table value for the 95th percentile of the Chi-Square distribution with n–2 degrees of freedom

G2. Limit on Curvature. Three inequalities are listed under this limit. The limit on curvature is met if any of these inequalities is met.

G2.1 The First Inequality. This inequality examines the contribution of a second degree polynomial beyond the contribution of a straight line to the fit of a straight line[19]. If that contribution is not statistically significant, the assumption of linearity is confirmed and the limit on curvature is met.

In order to develop the statistical test, some intermediate calculations are

$$\begin{aligned}
Stt &= \Sigma t_i^2 - (\Sigma t_i)^2/n \\
Sww &= \Sigma W_i^2 - (\Sigma W_i)^2/n \\
Stw &= \Sigma t_i W_i - (\Sigma t_i)(\Sigma W_i)/n \\
Sttt &= \Sigma t_i^3 - (\Sigma t_i)(\Sigma t_i^2)/n \\
Stttt &= \Sigma t_i^4 - (\Sigma t_i^2)^2/n \\
Sttw &= \Sigma t_i^2 W_i - (\Sigma t_i^2)(\Sigma W_i)/n
\end{aligned} \qquad (G.1)$$

NOTE: The summation sign Σ indicates summing across the i subscript, from 1 to n. The notations after S are consistent with the standard statistical notations. The notation tt in Stt indicates that the right hand expression is a second degree polynomial in t. Other subscripts follow similar logic.

Using the above expression, the coefficients of the least square fit to the second degree polynomial

$$\hat{W}_i = B' + A't_i + C't_i^2$$

are calculated as

$$B' = (\Sigma W_i)/n - A'(\Sigma t_i)/n - C'(\Sigma t_i^2)/n \qquad (G.2)$$

[18] The historical development of the termination limits may be found in the appendix of the NRC Draft Regulatory Guide MS 021-5, "Containment System Leakage Testing," filed April, 1990.

[19] *Applied Regression Analysis*, by Norman Draper and H. Smith, John Wiley & Sons, NY, 1966; Chapter 4.

$$A' = \frac{(Stw)(Sttt) - (Sttw)(Sttt)}{(Stt)(Stttt) - (Sttt)^2} \tag{G.3}$$

$$C' = \frac{(Stt)(Sttw) - (Sttt)(Stw)}{(Stt)(Stttt) - (Sttt)^2}\ . \tag{G.4}$$

For the sake of completeness, the least square coefficients for the linear fit are provided below using similar terminology to (G.1) as follows:

$$A = Stw/Stt \tag{G.5}$$

$$B = (\Sigma W_i)/n - A\ (\Sigma t_i)/n \tag{G.6}$$

Next, calculate

$$F = \frac{(B' - B)\Sigma W_i + (A' - A)\Sigma W_i\ t_i + C'\Sigma W_i\ t_i^2}{\Sigma W_i^2 - B'W_i - A'\Sigma W_i\ t_i - C'\Sigma W_i\ t_i^2}\ (n - 3) \tag{G.7}$$

Finally, compare the value obtained above to the 95th percentile of the F distribution with 1 and n-3 degrees of freedom, F(1, n-3, .95). The last value may be obtained from most statistics texts[20], or approximated by

$$F\ (1,\ n\text{-}3,\ .95) = \frac{3.8414\ (n^2 - 5.3n + 8.0394)}{n^2 - 7.7098n + 14.9069} \tag{G.8}$$

If $F < F(1, n\text{-}3, .95)$, the quadratic component of the second degree polynomial is determined not significant and the limit on curvature is met.

G2.2 The Second Inequality. This inequality may be used to meet the limit on curvature, is that the curve describing air mass behavior over time is concave upwards. Mathematically, this property is written as an inequality:

$$C' > 0. \tag{G.9}$$

G2.3 The Third Inequality. This inequality could satisfy the limit on curvature; it is represented by

$$2400 \left(\frac{24\ C'}{B'\ (L_a - L_{am})} \right) < 0.25. \tag{G.10}$$

This equation sets a 25% limit on the ratio of the quadratic term to a function of the difference between the calculated leakage rate and the allowable leakage rate.

NOTE: The B′ (estimate of containment air mass at the beginning of the test) in the denominator is always positive. The expression (L_a- L_{am}) is also positive since (L_a - L_{am}) > .25L_a is a condition for passing the Type A test.

[20] *Handbook of Mathematical Tables,* by D. B. Owen, Addison-Wesley, Reading, MA, 1962; Table 4.1.

G3. Limit on Data Scatter. This limits the scatter of the air mass about the regression line. The square of the linear correlation coefficient, r^2, can be written as

$$r^2 = \frac{[n(\sum t_i W_i) - (\sum t_i)(\sum W_i)]^2}{[n\sum t_i^2 - (\sum t_i)^2][n\sum W_i^2 - (\sum W_i)^2]} . \tag{G.11}$$

The limit on data scatter is met if the following inequality is met:

$$r^2 > \frac{(L_{am})^2 (Stt)}{(L_{am})^2 (Stt) + (L_a)^2 t_n^2 \chi^2 (n-2, .95)/122.93} , \tag{G.12}$$

where $\chi^2(n-2, .95)$ is the 95th percentile of the Chi-Square distribution with n–2 degrees of freedom. The 95th percentile may be found in most texts on applied statistics or approximated by[21]

$$\chi^2(n-2, .95) \approx 1.08916 \frac{(n + 1.33)(n + 42.603)}{(n - 1.202)(n + 28.155)} (n-2) . \tag{G.13}$$

[21] "The Distribution of Chi-square," by E. B. Wilson and M. M. Hilferty, *Proceedings of the National Academy of Science*, Vol. 17, pp. 684-688, 1931.

Table G1
Sample Problem

The G2.1 Limit is satisfied when equation (G.7) divided by equation (G.8) is less than one. The G2.2 Limit is satisfied when inequality (G.9) is greater than zero. The G2.3 Limit is satisfied when the ratio of the left side of the inequality (G.10) over the right side is less than one. The G3 Limit is satisfied when the ratio of the left side of inequality G.12 over the right side is greater than one. For this sample problem, L_a = 0.30 %/24h and $0.75L_a$ = 0.225 %/24h.

Data Point	Time Hours	Mass (lbm)	MP UCL (%/day)	G2.1 Limit (<1)	G2.2 Limit (>0)	G2.3 Limit (<1)	G3. Limit (>1)
1	00:00	173825.2857	-	-	-	-	0.0000
2	00:15	173814.0484	-	-	-	-	1.0000
3	00:30	173813.8596	1.7956	-	-	-	0.8102
4	00:45	173817.0412	0.5153	0.1153*	56.8316	463.8451	0.5177
5	01:00	173813.5221	0.2913	0.0881*	21.3352	151.5345	0.7347
6	01:15	173818.8850	0.1808	0.5488*	19.7891	104.112	0.6870
7	01:30	173814.5110	0.1342	0.2422*	9.2564	48.1961	1.0592
8	01:45	173801.9477	0.1853	0.0277*	-2.9781	19.5612	0.9393
9	02:00	173807.7360	0.1610	0.0109*	-1.2144	7.8537	1.1431*
10	02:15	173814.9946	0.1265	0.0923*	2.7339	15.5151	1.2189*
11	02:30	173809.6252	0.1099	0.1222*	2.2588	12.5416	1.4869*
12	02:45	173805.3536	0.1052	0.0468*	1.0691	6.0300	1.7016*
13	03:00	173804.6627	0.1001	0.0234*	0.5817	3.3001	1.9091*
14	03:15	173796.2768	0.1098	0.0471*	-0.7002	4.1909	1.7861*
15	03:30	173805.3873	0.0997	0.0006*	0.0673	0.3912	1.9904*
16	03:45	173801.1720	0.0952	0.0030*	0.1192	0.6902	2.1542*
17	04:00	173802.1613	0.0894	0.0321*	0.3211	1.8345	2.3503*
18	04:15	173800.2013	0.0856	0.0538*	0.3455	1.9616	2.5199*
19	04:30	173795.6392	0.0855	0.0110*	0.1332	0.7624	2.5639*
20	04:45	173790.6529	0.0887	0.0265*	-0.1817	1.0600	2.4683*
21	05:00	173790.2450	0.0899	0.0989*	-0.3028	1.7865	2.4460*
22	05:15	173799.4702	0.0844	0.0048*	0.0623	0.3596	2.6157*
23	05:30	173783.2095	0.0893	0.0898*	-0.2497	1.4739	2.4336*
24	05:45	173781.1511	0.0932	0.3507*	-0.4447	2.6773	2.3130*
25	06:00	173779.5430	0.0961	0.6772*	-0.5499	3.3641	2.2351*
26	06:15	173781.1456	0.0964	0.7650*	-0.5173	3.1837	2.2381*
27	06:30	173777.9538	0.0974	0.9596*	-0.5148	3.1936	2.2185*
28	06:45	173782.9008	0.0954	0.5677*	-0.3678	2.2684	2.2744*
29	07:00	173781.9810	0.0935	0.3069*	-0.2497	1.5311	2.3297*
30	07:15	173786.2918	0.0902	0.0259*	-0.0705	0.4260	2.4173*
31	07:30	173779.0298	0.0890	0.0071*	-0.0335	0.2018	2.4600*
32	07:45	173781.0346	0.0870	0.0112*	0.0386	0.2313	2.5272*
33	08:00	173769.3171	0.0884	0.0128*	-0.0384	0.2319	2.4784*

* Individual criteria met.

In this sample, the G2.1 Limit criterion is continuously satisfied from data point 4 through 33. The G3 Limit criterion is continuously satisfied from data point 9 through 33. At the minimum time of eight hours, both the curvature and the scatter limits are satisfied for a minimum of one hour or four data points, whichever is greater; therefore, the Type A test could be terminated at eight hours.