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CONTAINMENT SYSTEM LEAKAGE TESTING

A. INTRODUCTION

General Design Criteria 1, "Quality Standards and Records," 16, "Containment Design," 50, "Containment Design Basis," 52, "Capability for Containment Leakage Rate Testing," 53, "Provisions for Containment Testing and Inspection," 54, "Piping Systems Penetrating Containment," 55, "Reactor Coolant Pressure Boundary Penetrating Containment," 56, "Primary Containment Isolation," and 57, "Closed System Isolation Valves," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," require, in part, that the containment system be designed and constructed for periodic integrated and local leakage rate testing at containment design pressure. The Commission has published proposed amendments to Appendix J, "Leakage Tests for Containments of Light-Water-Cooled Nuclear Power Plants," to 10 CFR Part 50 that define the criteria for such testing. This draft guide describes a method acceptable to the NRC staff for complying with these proposed regulations if they are promulgated as published.

Any information collection activities mentioned in this draft regulatory guide are contained as requirements in the proposed amendments to Appendix J of 10 CFR Part 50 that would provide the regulatory basis for this guide. The proposed amendments have been submitted to the Office of Management and Budget for clearance that may be appropriate under the Paperwork Reduction Act. Such clearance, if obtained, would also apply to any information collection activities mentioned in this guide.

B. DISCUSSION

BACKGROUND

ANSI/ANS-56.8-1981,[1] "Containment System Leakage Testing Requirements," was prepared by the American Nuclear Society Standards Committee, Working Group ANS 56.8, and published in 1981 as a replacement to ANSI N45.4-1972, "Leakage Rate Testing of Containment Structures for Nuclear Reactors" (ANS-7.60).

ANSI N45.4-1972 was endorsed and referenced without exceptions in Appendix J to 10 CFR Part 50. ANSI/ANS-56.8-1981 has been considerably expanded and updated, and it has become difficult to endorse this standard without some exceptions. As a result, the new standard is being endorsed in this regulatory guide instead of in the revised Appendix J to facilitate the listing of exceptions to the standard and their modification as the standard is revised or errata sheets are issued.

Appendix J to 10 CFR Part 50 limits the regulation to general test criteria and leaves detailed testing techniques and analyses in the ANSI standard. Therefore the standard and the regulatory guide endorsing it can be revised as the testing technology changes without affecting the basic test criteria in the regulation and without requiring frequent revision of the regulation to keep it up to date with testing technology.

There will always be some debate over whether certain positions are properly regulatory criteria or details of the testing procedures. However, this division of requirements and procedures is believed to provide the most responsive arrangement; it will ensure safe limits on containment system leakage while keeping current with technical advances in testing procedures and analysis methods. Also, by having the regulation address general test criteria and leaving the details of implementation to the standard and regulatory guide, it is expected that fewer license exemptions will have to be filed than have been necessary under the previous regulation, thereby reducing an unproductive administrative burden on both licensees and the NRC staff.

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[1]Copies of ANSI/ANS-56.8-1981 may be obtained from the American Nuclear Society, 555 North Kensington Avenue, La Grange Park, IL 60525. It may be inspected at the Nuclear Regulatory Commission's Public Document Room, 1717 H Street NW., Washington, DC.

DISCUSSION OF REGULATORY POSITIONS

When the provisions of the standard are insufficient for licensing or when special emphasis is desired, the staff has provided supplementary guidelines or recommendations in the regulatory position. Reasons for including them are given below.

1. Conflict. This position eliminates the need to identify every difference between the standard and the regulation and specifies how such differences should be handled.

2. Type A Test Requirement. Paragraph 3.3.7 of the standard requires that the evaluation of the leakage rate include a computation of an upper confidence limit (UCL). Since the Type A test results being reported are at the UCL, the correction being applied to instrument error should also be at the UCL. For clarity, minimum pathway leakage is mentioned explicitly.

3. Pressurizing Considerations. Some plant designs have auxiliary steam lines penetrating primary containment for use during outages. Where possible, such lines need to be isolated and vented to prevent the introduction of another energy source that may prove difficult to account for in the calculations.

4. Liquid Level Monitoring. The size of error resulting from the neglect of changes in sump level is not related to the fact that the water condensed from the air. This is because the air mass equations given elsewhere in the standard subtract the effect of the water vapor changes in air mass but make no provision for the volume changes resulting from the conversion to (or from) water.

5. Type A Test Frequency. This position conforms to current practice and represents a practical and logical interpretation of the end of the test interval.

6. Verification Test

6.1. Based upon experience with the existing verification test criteria, several clarifications are needed. For periodic Type A tests, consideration is being given to the future use of a zero-pressure test to verify the ability of the Type A test instrumentation to read the Type A test leakage. This is, however, still in the future, and whether it could supplement or replace the current verification test or current instrument selection guide criteria has yet to be determined.

6.2. The measurement of W_2, as defined in the standard in paragraph 3.2.6, is subject to the same statistical errors as the measurement of the air mass values used in the calculation of the leakage rate. It is not likely that a believable determination of the step change could be made with one air mass data set. Since 20 sets of data points are required to establish the leakage rate (paragraph 5.4 of the standard), it would be appropriate to require a minimum number of data sets for the verification test also. The formula result is reformatted to more clearly represent the preceding text.

7. Data Rejection. A recommendation is provided to continue recording data from faulty or rejected sensors. This has been found to be useful in post-test evaluations.

8. Type B and C Test Pressures. In order for the test results to be valid, either the test differential pressure must be equal to P_{ac} or a method must exist to correctly extrapolate the test results to P_{ac}. At present, controversy exists on how to extrapolate test results to a higher pressure. Until such controversy can be satisfactorily resolved, it is prudent to perform all Type B and C tests at P_{ac}.

9. Type B and C Test Schedule. This position conforms to current practice and represents a practical and logical interpretation of the test interval.

10. Test Medium and Water-Filled Systems. The NRC staff always applies the single-failure criterion in the review of containment-related systems.

11. Calibration. At present, the only calibration requirement is for a one-point in situ check within 6 months of performing the preoperational or periodic test. This is insufficient to ensure system accuracy, sensitivity, and repeatability. The requirements of paragraph 4.2.1 of the standard for initial calibration data do not state when such calibration is to be performed. Therefore, as presently written, the instruments could be initially calibrated

at the time of purchase (perhaps 2 years before performing the preoperational test) and then a one-point check performed within 6 months of each test for the next 40 years. In addition, installing equipment and performing calibrations 6 months prior to the preoperational Type A test will almost guarantee damage to the equipment prior to its use, as considerable construction work is still in progress at this time. Typically, licensees have the instruments calibrated within the 6-month period, and then installed and checked within 2 weeks to a month prior to performing the test.

12. Containment Atmosphere Stabilization, 13. Data Recording and Analysis. Use of these supplementary recommendations 12 and 13 with ANSI/ANS-56.8-1981 will allow discontinuing the use in licensing reviews of Bechtel Topical Report BN-TOP-1, "Testing Criteria for Integrated Leakage Rate Testing of Primary Containment Structures for Nuclear Power Plants," Revision 1, November 7, 1972. It should be noted that these recommendations eliminate the requirement for a 24-hour periodic test. The preoperational test is still intended to be at least 24 hours to be available as a baseline test. Positions 12 and 13, which present recommendations for data collection and analysis, are being considered by the NRC staff for controlling the quality of the data obtained during the Type A and verification tests and for determining test acceptability.

For periodic Type A tests, Position 13.3 establishes additional conditions on the quality of the regression fit obtained using the method in ANSI/ANS-56.8-1981. These conditions are presented in the appendix to this guide as the Extended ANSI Method. Condition 1 in the appendix represents a limit on the deviation of the data from a straight line. Condition 2 gives a limit on the scatter of the data about the regression line. Condition 2 is analogous to the requirement that the ISG (instrument selection guide) does not exceed $0.25L_a$, although Condition 2 is applied to data scatter whereas the ISG applies to instrumentation errors.

Inequality (1.1) is a standard statistical test used to investigate whether a second order term in the model relating mass to time is warranted. If (1.1) is satisfied, it is concluded that a parabola does not fit the data significantly better than a straight line; therefore the test passed the first condition. If (1.1) is not satisfied, inequality (1.2) must be satisfied in order to pass Condition 1. Inequality (1.2) sets a limit on the ratio of the quadratic term to a function of the allowable leakage rate (L_a).

The left-hand side of inequality (2.1) is the coefficient of determination (the square of the correlation coefficient between mass and time). The corresponding limit on the right-hand side is derived using the following considerations: the standard deviation of the data scatter about the regression line is compared to the estimate made of the instrumentation errors; the resultant chi-square is allowed to vary up to the 95th percentile of the chi-square distribution with n - 2 degrees of freedom; and the condition is imposed that a function of the data scatter is less than $0.25L_a$.

In summary, this method does not change the way the leakage rate or upper confidence level are calculated. It imposes two additional conditions on the data behavior and puts limits on curvature and data scatter.

14. Temperature Measurement

14.1. The fraction of the containment volume assigned to each sensor needs to be confirmed. Recommendations are provided for the basis for such confirmation.

14.2, 14.3. ANSI/ANS-56.8-1981 addresses temperature surveys, but clarification is needed regarding the use of fans and when dewpoint temperature surveys should be made. It is essential that the temperature surveys be made with the ventilation configuration to be used in the tests. Since operational heat sources are so different from preoperational conditions, the surveys should be rerun at least for the first periodic Type A leakage rate test, as is stated for drybulb temperature surveys.

15. Absolute Test Method. The absolute test method should reflect spatial temperature variability over the containment volume when it exists. The current mass equation inadequately defines the mean temperature term. As a result, the mean temperatures are frequently calculated using an approximation formula. Although this approximation yields similar acceptable results with temperature distributions normally experienced, it is still not technically correct. Therefore, the derivation of the temperature value, T_i, to be used in the equation for the mass, W_i, is shown, which accommodates spatial temperature variations throughout the containment.

16. Reporting of Results. A uniform format for reporting Type A, B, and C test results is being encouraged in order to make better use of the data history being generated.

17. Flow Rate (Air, Water, Nitrogen). These recommendations are being made to avoid the use of an air discharge test method since there are many inherent inaccuracies in trying to capture and measure discharged air, e.g., leak paths from the tested volume other than that being metered.

18. Water Collection. The best determinant of leakage rate, whether for air or water, is to measure the makeup required to maintain test pressure. In addition, certain piping configurations will not permit the collection of valve (water) leakage, thus requiring that makeup be monitored.

19. Vacuum Retention. Pressure buildup or vacuum decay is not considered to be an equivalent alternative to measuring a flow rate because of the added complexity of varying parameters (temperature, etc.) and loss of accuracy as the pressure differential disappears. Also, the formula in the standard does not provide the same results for positive or negative pressures.

20. Recording of Leakage Rates. Clarification is provided for a prior concern on packing leakage.

C. REGULATORY POSITION

The procedures, requirements, measurements, and analytical techniques recommended by ANSI/ANS-56.8-1981, "Containment System Leakage Testing Requirements," together with its appendices, are generally acceptable to the NRC staff. They provide an adequate basis for complying with the Commission's regulations with regard to the leakage testing of containment systems, subject to the following:

1. Conflict. If any provisions of the standard conflict with the requirements of Appendix J to 10 CFR Part 50, the requirements of Appendix J govern.

* 2. Type A Test Requirement. Paragraphs 3.2.1.2, 3.2.1.3, and 3.2.6(a) should be supplemented by:

> The leakages shall be based on the minimum pathway and shall include instrumentation system error.

* 3. Pressurizing Considerations. In paragraph 3.2.1.7 (page 4), use the following instead of the second sentence:

> All possible sources of gas leakage (such as air, nitrogen, steam) into the containment from any system shall be isolated and vented or disconnected during the Type A test.

* 4. Liquid Level Monitoring. In paragraph 3.2.1.8 (page 4), the second paragraph should not be used.

* 5. Type A Test Frequency. Paragraph 3.2.3 (page 4) should be supplemented by:

> If the test interval ends while primary containment integrity is not required, the test interval may be extended provided a successful Type A test is completed before containment integrity is required in the plant.

6. Verification Test

6.1. Paragraph 3.2.6(b) (page 5) should be supplemented by the following:

(3) The purpose of the verification test is to verify the ability of the Type A test instrumentation to detect leakage rates approaching L_a.

(4) The verification test should measure a change in the leakage rate or a change in the mass. However, a "one-point check" is insufficient; sufficient points should be used to establish a continuous definitive line slope extension following directly from the Type A test line plot.

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*It is expected that a forthcoming revision to ANSI/ANS-56.8-1981 will include this position.

* (5) The start time for the verification test should be as soon as possible following each Type A test.

(6) Data acquisition should not be interrupted without justification from the end of the successful Type A test to the start of the verification test. In some cases, this period of time could be several hours and should then be considered to be part of the Type A test. Data acquisition, of course, should also not be interrupted without justification from the start to the finish of the verification test.

* (7) The Type A test leakage rate to be used for comparison with the verification test is the leakage rate obtained through the latest recorded Type A data point.

6.2. The method described in paragraph 3.2.6(b)(2) (page 5) is acceptable only if it is supplemented by a requirement for a sufficient number of air mass measurement data sets for the measurement of W_2 used in the equation for the step-change verification test and if the resultant value is less than or equal to $0.25t_p/24$, where t_p is the time required to pump daily allowable leakage at the rate being pumped.

* 7. Data Rejection. Paragraph 3.2.6(c) (page 5, last paragraph) should be supplemented by:

> For sensors rejected or suspected of being faulty, data should be recorded for the duration of the test (Type A test plus verification test) so that it is available if needed for post-test evaluation.

* 8. Type B and C Test Pressures. In paragraph 3.3.2 (page 6), the following should be used in place of the last sentence of the first paragraph:

> Substituting a vacuum test for pressurization to P_{ac} is permitted provided the differential pressure across the item under test is at least P_{ac}.

* 9. Type B and C Test Schedule. Paragraph 3.3.4(a) (page 6) should be supplemented by the following sentence:

If the two-year interval ends while primary containment integrity is not required, the test interval may be extended provided all deferred testing is successfully completed before containment integrity is required in the plant.

10. Test Medium and Water-Filled Systems. The accident referred to in the first sentence of 3.3.5(b) (page 6) and the first sentence of 6.4 (page 14) should be assumed to be a single active failure in the affected system.

* 11. Calibration

11.1. In paragraph 4.2.2 (page 7), the following should be used in place of the first sentence:

Instrumentation used for Type A, B, or C tests shall be individually calibrated no more than six months prior to use.

11.2. In paragraph 4.2.3.2 (page 8), the following should be used in place of the last sentence:

The check shall be done not more than one month prior to the ILRT.

11.3. Throughout paragraph 4.2.4 (page 8), the words "calibration checks," "checks," and "checked," should not be used; the words "calibration," "calibrations," or "calibrated" should be substituted as appropriate.

12. Containment Atmosphere Stabilization

12.1. Paragraph 5.2.1 should be supplemented by the following statistical limitation on the determination of stabilization:

The 95% upper confidence limit of containment leakage should be equal to or greater than zero prior to declaring the start of the test.

12.2. In paragraph 5.3.1.3, the following should be used in place of the second sentence:

After reaching test pressure, the containment air temperature is stabilized when (a) the slope of the temperature vs. time curve is less than 0.5°F/hr (0.3°C/hr) averaged over the last two hours and (b) the rate of change of the slope of the temperature vs. time curve is less than 0.5°F/hr^2 (0.3°C/hr^2) averaged over the last two hours.

12.3. Paragraph 5.3.1 should be supplemented with the following:

5.3.1.4 Containment air temperature should remain stabilized over the entire test period, including the verification test, and the tests should be continued only so long as the temperature is stabilized. If the unstable temperature appears to be due to a problem with the test procedures (such as a mechanical error/failure) rather than leakage, the test may be continued if the problem has been identified and corrected.

13. Data Recording and Analysis

13.1. In place of the last paragraph in 5.4, the following should be used:

The start time of the containment integrated leakage rate test should be declared following a determination that test conditions have stabilized and the start time is not subject to change during or after data collection. If any test is restarted, the restart time should be selected as "time forward" not as "time backward." The minimum test duration after the containment atmosphere and instrument readings have stabilized should be 24 hours for a preoperational Type A test and 8 hours for periodic Type A tests.

13.2. Paragraph 5.6 should be supplemented by:

Instantaneous (unaveraged) sensor readings should be recorded at approximately equal intervals but in no case at intervals greater than one hour.

13.3. In paragraph 5.7.4, additional conditions should be applied to limit nonlinearity and data scatter when a Type A test is conducted, regardless of the test duration. These additional conditions apply to the verification test as well as to the Type A test. The application of these additional conditions is to control the quality of the least squares fit obtained from the mass point technique of ANSI/ANS-56.8-1981. Such conditions are recommended in the appendix to this guide, but the use of alternative conditions will also be considered if demonstrated to be adequate.

* 14. Temperature Measurement

14.1. Paragraph 5.5 (page 11) should be supplemented by:

5.5.3 Volume Fractions. The temperature and humidity pretest surveys shall be used to confirm assigned volume fractions. The calculated volume fractions combined with the placement of the sensors will ensure that each sensor represents the assigned volume. The sum of the volume fractions must add to unity. If during the conduct of a test a sensor fails or is deleted, that sensor's volume fraction should be reassigned to other sensors on the basis of the survey results. For subsequent tests the volume fractions shall be reviewed to determine their continued validity.

14.2. In paragraph 5.5.1, the following should be used instead of the first two sentences:

Area surveys within the containment structure shall be made in advance of preoperational and the initial periodic leakage rate tests to establish any areas of regional variation in temperature with the ventilation configuration planned for each test. Fans or other means of air circulation may be used to equalize temperatures in any region where representative temperature measurements are taken and appreciable temperature variations exist.

14.3. In paragraph 5.5.2, the following should be used instead of the second and third sentences:

Psychrometric readings should be taken throughout the containment before conducting the preoperational and the initial periodic leakage rate tests to determine the correct location of the sensors for the ventilation configuration planned for each test.

* 15. Absolute Test Method. Paragraph 5.7.3 (page 12) should be supplemented by an explicit definition of the temperature term T_i at time i to be used in its equation as being derived from

$$T_i = \frac{1}{\sum_{j=1}^{m} \frac{w_j}{T_{ij}}}$$

where w_j is a weighting factor or the percentage of overall containment volume assigned to a temperature sensor j, m is the number of temperature sensors used in the test, and T_{ij} is the temperature recorded by sensor j at time i.

16. Reporting of Results The format and content of paragraph 5.8 (page 12) should be used for submitting reports that would be required by the proposed Appendix J to 10 CFR Part 50, including the individual Type A, B, and C "as found" and "as left" leakage readings that would be required by Appendix J.

17. Flow Rate (Air, Water, Nitrogen)

17.1. In paragraph 6.5.2 (page 14), the following should be used in place of the second sentence:

> Makeup fluid to the test volume required to maintain test pressure shall be the same as the test fluid or a less viscous fluid and shall be measured using a flowmeter that directly measures valve leakage rate.

17.2. Paragraph 6.5.2 should be supplemented by:

> The air discharge method shall not be used.

* 18. Water Collection. Paragraph 6.5.3 (page 14) should be supplemented by:

When it is uncertain that all water is being collected, the water makeup provided to the test volume to maintain test pressure shall be measured in accordance with paragraph 6.5.2.

* 19. Vacuum Retention. In paragraph 6.5.4 (page 15), the sentence beginning "Alternately, a pressure (vacuum) gauge may be used...." and the remainder of paragraph 6.5.4 should not be used.

* 20. Recording of Leakage Rates. Paragraph 6.6 (page 15) should be supplemented by:

> Any packing leakage that provides a leakage path outside the primary reactor containment shall be accounted for in Type C test results, but need not be quantified separately. Packing leakage that remains within the containment system need not be included in the Type C test results.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

This draft guide has been released to encourage public participation in its development. Except in those cases in which an applicant proposes an acceptable alternative method, the method to be described in the active guide reflecting public comments will be used by the NRC staff in evaluating procedures for containment system leakage testing for compliance with the amended Appendix J to 10 CFR Part 50 if the amendments are promulgated as proposed.

APPENDIX

Extended ANSI Method

Data generated during Type A and verification tests are analyzed by the mass point method described in Appendix B of ANSI/ANS-56.8-1981. The extension of the ANSI method requires two additional conditions--above and beyond the ANSI requirements--which must be satisfied at time t, the end of the test, by which n points (t_i, W_i) are collected. The Type A and verification tests are not considered acceptable until both Condition 1 and Condition 2 have been satisfied.

Condition 1: A Limit on Curvature

Two inequalities, (1.1) and (1.2), are listed under this condition. If inequality (1.1) is met, Condition 1 is satisified, and (1.2) need not be checked. If inequality (1.1) is not satisfied, (1.2) must be satisfied. If neither (1.1) nor (1.2) is satisified, Condition 1 of the Extended ANSI Method is not met and the test is not acceptable.

$$\frac{(B' - B)\Sigma W_i + (A' - A)\Sigma W_i t_i + C'\Sigma W_i t_i^2}{\Sigma W_i^2 - B'\Sigma W_i - A'\Sigma W_i t_i - C'\Sigma W_i t_i^2}(n - 3) < F(1, n - 3, 0.95) \tag{1.1}$$

$$2400\left|\frac{C't}{B'L_a}\right| < 0.25 \tag{1.2}$$

The symbols A, B, W_i, t_i, and L_a are defined by ANSI/ANS-56.8-1981. The terms A', B', and C' are the solutions to the equations

$$\begin{aligned} \Sigma W_i &= B'n + A'\Sigma t_i + C'\Sigma t_i^2 \\ \Sigma W_i t_i &= B'\Sigma t_i + A'\Sigma t_i^2 + C'\Sigma t_i^3 \\ \Sigma W_i t_i^2 &= B'\Sigma t_i^2 + A'\Sigma t_i^3 + C'\Sigma t_i^4 \end{aligned} \tag{1.3}$$

and are the coefficients for the least squares parabola

$$W_i = B' + A't_i + C't_i^2 \tag{1.4}$$

and F(1, n - 3, 0.95) is the 95th percentile of the F distribution with 1 degree of freedom in the numerator and n - 3 degrees of freedom in the denominator.

The left side of inequality (1.1) can also be written as

$$\frac{\Sigma(W_i - B - At_i)^2 - \Sigma(W_i - B' - A't_i - C't_i^2)^2}{\Sigma(W_i - B' - A't_i - C't_i^2)^2} (n - 3) \tag{1.5}$$

which is the statistic used to test whether the contribution of a quadratic term (above and beyond the contribution of the linear term) in the leakage rate model is statistically significant.

The ancillary inequality (1.2) sets a 25% limit on the ratio of the quadratic term to a function of the allowable leakage rate (L_a).

Finally, F(1, n - 3, 0.95) can be approximated by

$$F(1, n - 3, 0.95) \sim \frac{3.8414(n^2 - 5.3n + 8.0394)}{n^2 - 7.7098n + 14.9069} \tag{1.6}$$

Other approximations to F(1, n - 3, 0.95) can be found in the statistical literature.

<u>Condition 2: Limit on Data Scatter</u>

The second condition for passing the test is satisfaction of inequality (2.1). In order to have an acceptable test, (2.1) must be met.

$$r^2 > \frac{L_{am}^2 \Sigma(t_i - \bar{t})^2}{L_{am}^2 \Sigma(t_i - \bar{t})^2 + L_a^2 t^2\ \chi^2(n - 2, 0.95)/122.93} \tag{2.1}$$

where r^2 is the coefficient of determination (the square of the linear correlation coefficient between time t_i and mass W_i), $\chi^2(n - 2, 0.95)$ is the 95th percentile of the chi-square distribution with n - 2 degrees of freedom, and L_{am} is defined by ANSI/ANS-56.8-1981.

The motivation for criterion (2.1) is that a high r^2 reflects a tight scatter of the points about the regression line.

The coefficient of determination may be written in several forms, some of which are given below.

$$r^2 = \frac{[n(\Sigma t_i W_i) - (\Sigma t_i)(\Sigma W_i)]^2}{[n(\Sigma t_i^2) - (\Sigma t_i)^2][n(\Sigma W_i^2) - (\Sigma W_i)^2]} \tag{2.2}$$

$$r^2 = \frac{\Sigma(\hat{W}_i - \bar{W})^2}{\Sigma(W_i - \hat{W}_i)^2 + \Sigma(\hat{W}_i - \bar{W})^2} \tag{2.3}$$

$$r^2 = \frac{1}{1 + \dfrac{\Sigma(W_i - \hat{W}_i)^2}{\Sigma(W_i - \bar{W}_i)^2}} \tag{2.4}$$

$$r^2 = \frac{1}{1 + \left(\dfrac{S_w}{At}\right)^2 \dfrac{(n - 2)t^2}{\Sigma(t_i - \bar{t})^2}} \tag{2.5}$$

where

$$\hat{W}_i = B + At_i \tag{2.6}$$

$$\bar{W} = \frac{\Sigma W_i}{n} = B + \frac{A\Sigma t_i}{n} = B + A\bar{t} \tag{2.7}$$

$$S_w^2 = \frac{\Sigma(W_i - \hat{W}_i)^2}{(n - 2)} \tag{2.8}$$

S_W^2 is the calculated variance of the mass data points about the regression line and should be related to Θ^2, the instrument reproducibility error used by the Instrument Selection Guide (ISG) in ANSI/ANS-56.8-1981, Appendix G. The relation between S_W^2 and Θ^2 can be investigated by the ratio

$$\chi^2 = \frac{(n - 2)S_W^2}{\Theta^2} \tag{2.9}$$

which is distributed as a chi-square statistic with n - 2 degrees of freedom. Let $\chi^2(n - 2, 0.95)$ denote the upper 95th percentile of this statistic. Then the following inequality holds with 95% probability

$$S_W^2 < \Theta^2\chi^2(n - 2, 0.95)/(n - 2) \tag{2.10}$$

Let e_W denote the error associated with W_i. In analogy to the formulation of the ISG given by ANSI/ANS-56.8-1981 in Appendix G,

$$ISG^2 = \left(\frac{2400}{t}\right)^2\left[2\left(\frac{e_P}{P}\right)^2 + 2\left(\frac{e_{P_V}}{P}\right)^2 + 2\left(\frac{e_T}{T}\right)^2\right] \tag{2.11}$$

write

$$e_W^2 = W_i^2\left[\left(\frac{e_P}{P}\right)^2 + \left(\frac{e_{P_V}}{P}\right)^2 + \left(\frac{e_T}{T}\right)^2\right] \tag{2.12}$$

from which

$$\left(\frac{e_W}{W_i}\right)^2 = \frac{t^2 ISG^2}{2(2400)^2} \tag{2.13}$$

The error e_W is expected to be proportional to Θ. If Θ represents one standard deviation of the instrumentation error, then, under normality assumption, 1.96Θ represents a 95% confidence band on the true value of W_i. Substituting 1.96Θ for e_{W_i} in (2.13) and solving for Θ^2 gives

$$\Theta^2 = \left(\frac{ISG\ W_i t}{\sqrt{2}(1.96)(2400)}\right)^2 \tag{2.14}$$

Since W_i changes very little during the test, it is replaced by B, the intercept of the regression line. Then Θ^2 is substituted into (2.10) to yield

$$S_w^2 < \left(\frac{ISG \cdot B \cdot t}{\sqrt{2}\,(1.96)(2400)}\right)^2 \frac{\chi^2(n - 2,\ 0.95)}{(n - 2)} \tag{2.15}$$

Next divide both sides of (2.15) by $(At)^2$. Replacing $(2400)^2A^2$ by $B^2L_{am}^2$ and Θ by its limit of $0.25L_a$ gives

$$\left(\frac{S_w}{At}\right)^2 < \left(\frac{0.25L_a}{\sqrt{2}\ 1.96L_{am}}\right)^2 \frac{\chi^2(n - 2,\ 0.95)}{(n - 2)} \tag{2.16}$$

for which, after some manipulation,

$$\left(\frac{S_w}{At}\right)^2 \frac{(n - 2)t^2}{\Sigma(t - \bar{t})^2} < \frac{1}{122.93}\left(\frac{L_a}{L_{am}}\right)^2 \frac{t^2}{\Sigma(t - \bar{t})^2}\ \chi^2(n - 2,\ 0.95) \tag{2.17}$$

$$\frac{1}{1 + \left(\frac{S_w}{At}\right)^2 \frac{(n - 2)t^2}{\Sigma(t - \bar{t})^2}} > \frac{1}{1 + \left(\frac{L_a}{L_{am}}\right)^2 \frac{t^2}{\Sigma(t - \bar{t})}\ \chi^2(n - 2,\ 0.95)/122.93} \tag{2.18}$$

By (2.5), the left side of (2.18) is recognized as r^2. Hence, after some further manipulation, obtain

$$r^2 > \frac{L_{am}^2\ \Sigma(t - \bar{t})^2}{L_{am}^2\ \Sigma(t - \bar{t})^2 + L_a^2t^2\ \chi^2(n - 2,\ 0.95)/122.93} \tag{2.19}$$

The numerical entry for $\chi^2(n - 2,\ 0.95)$ can be taken from a statistical table or approximated. One approximation is given by E. B. Wilson and M. M. Hilferty.* Let $Q = 2/[9(n - 2)]$, then

$$\chi^2(n - 2,\ 0.95) \sim (n - 2)\ \{1 - Q + (1.645)\sqrt{Q}\}^3 \tag{2.20}$$

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*Proceedings of the National Academy of Science, Vol. 17, pp. 684-688, 1931.

Another approximation to $\chi^2(n - 2, 0.95)$ is given as

$$\chi^2(n - 2, 0.95) \sim 1.08916 \frac{(n + 1.33)(n + 42.603)}{(n - 1.202)(n + 28.155)} (n - 2) \tag{2.21}$$

Other approximations to χ^2 can be found in the statistical literature.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this draft regulatory guide. A draft regulatory analysis that examines the costs and benefits of the rule as implemented by the guide was prepared for the proposed amendments to Appendix J of 10 CFR Part 50, which provide the regulatory basis for this guide. The draft analysis is available for inspection and copying for a fee in the NRC Public Document Room, 1717 H Street NW., Washington, DC. Free single copies may be obtained upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

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