TECHNICAL EVALUATION REPORT

CONTAINMENT LEAKAGE RATE TESTING

NEBRASKA PUBLIC POWER DISTRICT
COOPER NUCLEAR STATION

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Prepared by

Franklin Research Center
The Parkway at Twentieth Street
Philadelphia, PA 19103

Author: J.E. Kaucher

FRC Group Leader: T. J. DelGaizo

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

Lead NRC Engineer: Y. S. Huang

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Franklin Research Center
A Division of The Franklin Institute
The Benjamin Franklin Parkway, Phila., Pa. 19103 (215) 448-1000

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1. BACKGROUND

On August 5, 1975 [1], the NRC requested Nebraska Public Power District (NPPD) to review the containment leakage testing program for Cooper Nuclear Station and to provide a plan for achieving full compliance with 10CFR50, Appendix J, including appropriate design modifications, changes to technical specifications, and requests for exemption from the requirements pursuant to 10CFR50.12, where necessary.

NPPD's response dated September 10, 1975 [2], included five requests for exemption from the requirements of Appendix J. On September 16, 1977 [3], the NRC issued Amendment No. 38 to Facility Operating License No. DPR-46, authorizing three of the five exemption requests. At the same time, the NRC requested that NPPD provide additional information regarding the two remaining exemption requests. This additional information was forwarded by NPPD on October 30, 1978 [4].

The purpose of this report is to provide technical evaluations of all outstanding requests for exemption from the requirements of 10CFR50, Appendix J, for Cooper Nuclear Station. Consequently, technical evaluations of the two remaining exemption requests of Reference 2, as amplified by Reference 4, are included.

2. EVALUATION CRITERIA

Code of Federal Regulations, Title 10, Part 50 (10CFR50), Appendix J, Containment Leakage Testing, contains the criteria used for the evaluation of the exemption requests. The criteria are either referenced or briefly stated, where necessary, to support the results of the evaluations. Furthermore, in recognition of plant-specific conditions which could lead to requests for exemption not explicitly covered by the regulations, the NRC directed that the technical review constantly emphasize the basic intent of Appendix J, that potential containment atmospheric leakage paths be identified, monitored, and maintained below established limits.

3. TECHNICAL EVALUATION

3.1 EXEMPTION FROM AIRLOCK TESTING REQUIREMENTS

In References 2 and 4, NPPD requested an exemption from the requirements of Appendix J to test personnel airlocks at intervals of no longer than 1 year at 58 psig (Pa), at least every 6 months at 3 psig, and after each opening at 3 psig. NPPD stated that to conduct airlock tests at Pa, strongbacks must be used, which can only be applied in a shutdown condition. Further, NPPD stated that frequent airlock tests at Pa increase the risk of permanent deformation of the airlock doors and that yearly tests at Pa are sufficient to show physical integrity.

Evaluation. Sections III.B.2 and III.D.2 of Appendix J require that containment airlocks be tested at peak calculated accident pressure (Pa, at 6-month intervals and after each opening in the interim between 6-month tests. These requirements were imposed because airlocks represent potentially large leakage paths which are more subject to human error than other containment penetrations. Type B penetrations (other than airlocks) require testing in accordance with Appendix J at intervals not to exceed 2 years.

Appendix J was published in 1973. A compilation of airlock events from Licensee Event Reports submitted since 1969 shows that airlock testing in accordance with Appendix J has been effective in prompt identification of airlock leakage, but that rigid adherence to the after-each-opening requirement may not be necessary.

Since 1969, there have been approximately 70 reported airlock leakage tests in which measured leakage exceeded allowable limits. Of these events, 25 percent were the result of leakage other than that resulting from improper seating of airlock door seals. These failures were generally caused by leakage past door operating mechanism handwheel packing, door operating cylinder shaft seals, equalizer valves, or test lines. These penetrations resemble other Type B or C containment penetrations except that they may be operated more frequently. Since airlocks are tested at a pressure of Pa every 6 months, these penetrations are tested, at a minimum, four times more frequently than typical Type B or C penetrations. The 6-month test is, therefore, considered to be both justified and adequate for the prompt identification of this leakage.

Improper seating of the airlock door seals, however, is not only the most frequent cause of airlock failures (the remaining 75 percent), but also represents a potentially large leakage path. While testing at a pressure of Pa after each opening will identify seal leakage, it can also be identified by alternative methods, such as pressurizing between double-gasketed door seals (for airlocks designed with this type of seal) or pressurizing the airlock to pressures other than Pa. Furthermore, experience gained in testing airlocks since the issuance of Appendix J indicates that the use of one of these alternative methods may be preferable to the full-pressure test of the entire airlock.

Reactor plants designed prior to the issuance of Appendix J often do not have the capability to test airlocks at Pa without the installation of strongbacks or the performance of mechanical adjustments to the operating mechanisms of the inner doors. The reason for this is that the inner doors are designed to seat with accident pressure on the containment side of the door, and therefore, the operating mechanisms were not designed to withstand accident pressure in the opposite direction. When the airlock is pressurized for a local airlock test (i.e., pressurized between the doors), pressure is exerted on the airlock side of the inner door, causing the door to unseat and preventing the conduct of a meaningful test. The strongback or mechanical adjustments prevent the unseating of the inner door, allowing the test to proceed. The installation of strongbacks or performance of mechanical adjustments is time consuming (often taking several hours), may result in additional radiation exposure to operating personnel, and may also cause degradation of the operating mechanism of the inner door, with consequential loss of reliability of the airlock. In addition, when conditions require frequent openings over a short period of time, testing at Pa after each opening becomes both impractical (tests often take from 8 hours to several days) and accelerates the rate of exposure of personnel and the degradation of mechanical equipment.

For these reasons, the intent of Appendix J is satisified, and the undesirable effects of testing after each opening are reduced if a satisfactory test of the airlock door seals is performed within 3 days of each opening or every 3 days during periods of frequent openings, whenever containment integrity is required. The test of the airlock door seals may be performed by pressurizing the space between the double-gasketed seals (if so equipped) or by pressurizing the entire airlock to a pressure of less than Pa that does not require the installation of strongbacks or performance of other mechanical adjustments. If the reduced pressure airlock test is to be employed, the results of the leakage test must be conservatively extrapolated to equivalent Pa test results. An evaluation of NPPD's proposed method of extrapolation of these test results from 3 to 58 psig is discussed in Section 3.1.1 of this report.

NPPD contends that the requirement to test the airlocks at Cooper Nuclear Station at Pa every 6 months is excessive, since the installation of the strongback necessary to perform the test requires shutting down the reactor to gain access to the containment. NPPD proposes to perform an airlock test at Pa once per year, at reduced pressure (3 psig) every 6 months, and at 3 psig after each opening. In view of the above discussion, this proposal is unacceptable because it does not meet the requirements of Appendix J nor does it satisfy the objective of the regulation.

Since NPPD submitted its request, the NRC has revised Section III.D.2 of Appendix J, effective October 22, 1980. Essentially, the revised rule requires testing of airlocks as follows:

1. Every 6 months at a pressure of Pa (and after periods when the airlock is opened and containment integrity is not required).
2. Within 3 days of opening (or every 3 days during periods of frequent opening) when containment integrity is required, at a pressure of Pa or at a reduced pressure as stated in the Technical Specifications.

NPPD should establish an airlock testing program to conform to the requirements of the revised Section III.D.2. No exemption from the requirements of Appendix J is necessary.

3.1.1 Extrapolation of Reduced Pressure Leakage Test Results

In Reference 4, NPPD stated that the results of reduced pressure airlock tests (3 psig) and also reduced pressure bellows leakage tests (5 psig) are extrapolated to 58 psig using the criteria of ASME Section XI, Winter 1976 Addendum, Article IWV-3000, "Test Procedure," paragraph IWV-3420, which states:

> When leakage tests are made in such cases using pressures lower than function maximum pressure differential, the observed leakage shall be adjusted to function maximum pressure differential value by calculation appropriate to the test media and the ratio between test and function pressure differential assuming leakage to be directly proportional to the pressure differential to the one-half power.

Evaluation. This correlation, namely that the leakage results are proportional to the ratio of the test pressures to the one-half power, is appropriate when the characteristic of the leakage is essentially orifice-like. However, when the flow characteristic of the leakage approaches capillary-like flow, this correlation becomes less conservative. As can be seen by applying equation A-3 (Appendix A to this report) for capillary-like flow, the correlation proposed by NPPD is less conservative by a factor of 11.9 for the airlock test and 8.7 for the bellows test. Although the actual leakage path characteristic is some unknown combination of orifice and capillary-like flow, the correlation proposed by NPPD, particularly for the situation in which the reduced pressure is a small percentage of the full pressure test, is unacceptably non-conservative. It is recommended that equation A-3 be used to correlate leakage results as follows:

$$\frac{\dot{m}a}{\dot{m}t} = \frac{(Pa + Pat)^2 - (Pat)^2}{(Pt + Pat)^2 - (Pat)^2}$$

(Note: $\dot{m}$ is in terms of mass flow rate and Pat is atmospheric pressure.)

3.2 HYDRAULIC TESTING OF FEEDWATER CHECK VALVES

In Reference 2, NPPD requested an exemption from the requirements of Appendix J to test the feedwater check valves with water as a test medium in lieu of air or nitrogen. In Reference 4, NPPD provided analyses to demonstrate that the feedwater check valves remained water covered following a postulated accident and that feedwater system check valve leakage following a LOCA will not exceed that established by 10CFR100.

Evaluation. Sections II.H.4 and III.C.2 of Appendix J require that containment isolation valves in main steam and feedwater systems of direct-cycle boiling water reactors be tested with air or nitrogen as a medium. Section II.B of Appendix J defines containment isolation valves as those valves relied upon to perform a containment isolation function. It is clear that the feedwater check valves are relied upon to perform a containment isolation function, and therefore, Appendix J requires that they be tested with air or nitrogen.

For operating reactors designed or constructed prior to the issuance of Appendix J, the substitution of a hydraulic test for the required pneumatic test may be an acceptable exemption from Appendix J where the hydraulic test is used to demonstrate that the valves will remain water covered throughout the post-accident period. By using the hydraulic test to demonstrate this fact, the possibility of leakage of containment atmosphere is eliminated. Therefore, a determination of the pneumatic leakage rate is unnecessary since the valves are not being relied upon to isolate air leakage.

NPPD's submittal demonstrating that the valves will remain water covered [4], however, fails to demonstrate that they will be water covered throughout the post-accident period. In fact, this analysis demonstrates that at the average leakage rates of these check valves experienced at Cooper Nuclear Station (8.3 ft^3/hr), the initial water inventory in a feedwater line at the start of an accident will be depleted after 421 minutes. At this time, unless reactor water level has been restored above the level of the feedwater nozzles or the piping has been otherwise refilled, the check valves will be relied upon to prevent the leakage of containment air. This situation may be mitigated by cooling water being injected by the HPCI or RCIC systems, which are initiated at the start of the accident. However, a single active failure in either of these systems could result in one of the feedwater lines being water filled only by its initial water volume, which would be rapidly depleted by a combination of flashing to steam and the average leakage rate of the check valves.

Consequently, NPPD's proposal to test these valves with water in lieu of air or nitrogen is not acceptable. The feedwater check valves should be pneumatically tested, with the leakage results added to the total pneumatic leakage of the local leakage rate tests to determine acceptability in accordance with Section III.C.3 of Appendix J. However, if liquid leakage limits are established which demonstrate that the valves will remain water covered for 30 days following a LOCA, hydraulic testing with acceptability based on these limits would be acceptable as an exemption to the pneumatic testing requirements of Appendix J.

4. CONCLUSIONS

Technical evaluations of requests for exemption from the requirements of Appendix J for Cooper Nuclear Station, submitted in Reference 4, were conducted. The conclusions are summarized below:

- NPPD's proposal to test containment airlocks annually at a pressure of Pa, every 6 months at a pressure of 3 psig, and after each opening at a pressure of 3 psig is not acceptable. Airlocks should be tested in accordance with the requirements of Section III.D.2 of Appendix J, revised October 1980.
- NPPD's proposed method for correlating reduced pressure leakage rates to full pressure leakage rates is not sufficiently conservative. A correlation assuming capillary-like flow characteristics should be used.
- NPPD's proposal to test feedwater check valves with water in lieu of air or nitrogen as a test medium is not acceptable because these valves may be exposed to containment atmosphere during the post-accident period. These valves must be tested in accordance with Appendix J unless they meet liquid leakage limits which demonstrate that they will remain water covered for 30 days following an accident.

5. REFERENCES

1. K. R. Goller (NRC)
   Letter to J. M. Pilant (NPPD)
   August 5, 1975

2. J. M. Pilant (NPPD)
   Letter to K. R. Goller (NRC)
   September 10, 1975

3. V. Stello, Jr. (NRC)
   Letter to J. M. Pilant (NPPD)
   September 16, 1977

4. J. M. Pilant (NPPD)
   Letter to T. A. Ippolito (NRC)
   October 30, 1978

APPENDIX A

CONVERSION OF REDUCED PRESSURE AIR LEAKAGE MEASUREMENTS TO EQUIVALENT FULL PRESSURE AIR LEAKAGE

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Dr. G. P. Wachtell
Franklin Research Center

APPENDIX A. AIR TO AIR LEAKAGE CONVERSION

In pneumatic leakage testing in which application of Pa psig is called for by Appendix J, it is sometimes necessary to request an exemption that permits pneumatic testing at a lower pressure, Pt psig. The leakage rate, Lt, measured under test conditions must then be converted mathematically to the leakage rate, La, that would occur if the pressure were equal to Pa. It is essential that the conversion be conservative. That is, the calculated value of La must not be lower than the actual leakage rate at Pa would be. On the other hand, the conversion should not be more conservative than necessary in the light of available data, because excessive conservatism could frequently result in the interpretation that a given leak exceeds its maximum allowable limit when in fact it would not exceed that limit if Pa were actually applied.

The meaning of the expression "if Pa were actually applied" should be carefully considered. The assumption is made that the geometry and dimensions of the leakage path would be the same with Pa applied as with Pt applied, or that any changes in geometry would not increase the leakage rate. In the case of airlock doors in which Pt is applied in the reverse direction, opposite to the direction in which Pa would be applied under function conditions, the use of the reverse direction of application of pressure is expected to tend to open the seal and increase the leakage rate. Under function conditions, in which pressure is applied in the forward direction, the seal should be improved if it changes at all. The expression "if Pa were actually applied" in this case means "if Pa were actually applied in the forward (normal for function) direction." In the case of valves and other penetrations, it is essential that increasing the applied pressure from Pt to Pa not change the geometry so as to increase the leakage rate. For example, increasing the pressure on a closed valve should tend to improve its sealing at the surfaces that provide the seal, and also in any other potential leakage paths such as valve stem or packing that may have a connection to the applied pressure. Such other potential leakage paths are of course absent in valve designs in which the stem and packing have a connection only to the downstream side of the valve.

Reference 1, which is ASME Code, Section XI, paragraph IWV-3423 (e), states the following rule for tests at less than function differential pressure:

> "Leakage tests involving pressure differentials lower than function pressure differentials are permitted in those types of valves in which service pressure will tend to diminish the overall leakage channel opening, as by pressing the disk into or onto the seat with greater force. Gate valves, check valves, and globe-type valves having function pressure differential applied over the seat, are examples of valve applications satisfying this requirement. When leakage tests are made in such cases using pressures lower than function maximum pressure differential, the observed leakage shall be adjusted to function maximum pressure differential value. This adjustment shall be made by calculation appropriate to the test media and the ratio between test and function pressure differential, assuming leakage to be directly proportional to the pressure differential to the one-half power."

In the discussion below, it is shown that if (a) the test medium is air, (b) Pa is appreciable compared to one atmosphere, and (c) the leakage path is such as to produce laminar viscous flow (i.e., capillary-like rather than orifice-like), the calculation appropriate to this test medium yields a substantially higher calculated value of Pa than would be obtained by assuming leakage to be directly proportional to the pressure differential to the one-half power.

For air flow through an orifice, assuming uniform flow velocity over the orifice area, the mass flow rate per unit orifice area is ρv, where ρ is the density of air in the orifice and v is velocity in the orifice. Assuming that the discharge pressure is Pat = 1 atmosphere and the source pressure is Po, where Po and Pat are both absolute pressures, ρv is given by

$$(\rho v)^2 = \frac{2\gamma g}{\gamma - 1} \frac{Pat^2}{R_o T} \left(\frac{Po}{Pat} - 1 \right) G \qquad \text{(A-1)}$$

where $\gamma = 1.4$ is the specific heat ratio for air, $g = 32.2$ ft/sec^2 is the acceleration of gravity, T is source (upstream, at Po) temperature (°R), P is absolute pressure (psf), $R_o = 53.26$ ft-lb/lb°F is the gas constant for air and G is given by

$$G = \left(\frac{Pe}{Pat}\right)^2 \frac{x^{\frac{\gamma-1}{\gamma}}\left(x^{\frac{\gamma-1}{\gamma}}-1\right)}{\left(\frac{Po}{Pat}-1\right)} \quad \text{(A-2)}$$

$$x = \frac{Po}{Pe}$$

Pe = Pat for subsonic flow

Pe = 0.5283 Po for choked flow

Choked flow occurs when

$$\frac{Pat}{Po} \leq \left(\frac{\gamma+1}{2}\right)^{-\frac{\gamma}{\gamma-1}} = 0.5283$$

$\sqrt{G}$ is proportional to $\rho v/\sqrt{Po-Pat}$. Values of $\sqrt{G}$ are listed in Table A-1. $\sqrt{G_o}$, the limiting value of $\sqrt{G}$ for small (Po-Pat), is $\sqrt{(\gamma-1)/\gamma} = 0.5345$.

In Table A-1, inspection of $\sqrt{G}/\sqrt{G_o}$ shows the accuracy of the assumption that for an orifice-like leakage flow resistance, leakage mass flow rate is proportional to pressure difference to the one-half power. For example, if Po = 60 psig (Po-Pat = 60 in Table A-1), $\sqrt{G}/\sqrt{G_o} = 1.210$. Extrapolation of mass flow rate measured with Pt = 15 psig to mass flow rate predicted for Pa = 60 psig will underestimate the mass flow rate by the factor 0.968/1.210 = 0.80, or 20%.

The foregoing argument tacitly assumes that the orifice coefficient is = 1.0. However, the same conclusion concerning extrapolation from low values of Pt to high values of Po can be drawn if the orifice coefficient is assumed to be constant, i.e., independent of Po. Consequently,

Table A-1. $\sqrt{G}$ for Various Values of Po - Pat for Orifice. (Pat taken = 15 psia.)

Po - Pat (psi)	$\sqrt{G}$	$\sqrt{G}/\sqrt{G_o}$
0.01	0.5345	1.000
1	0.5332	0.998
5	0.5282	0.988
13.3	0.5185	0.970
13.4*	0.5184	0.970
15 *	0.5176	0.968
20 *	0.5230	0.978
25 *	0.5346	1.000
30 *	0.5490	1.027
35 *	0.5648	1.057
40 *	0.5811	1.087
45 *	0.5977	1.118
50 *	0.6143	1.149
55 *	0.6307	1.180
60 *	0.6470	1.210

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*Choked flow

for leakage paths that are known to be entirely orifice-like, the assumption that leakage mass flow rate is proportional to pressure difference to the one-half power gives a reasonably accurate correlation, underestimating the leakage mass flow rate by at most 20% for Pa $\leq$ 60 psig. To correct the underestimate, the factor $(\sqrt{G}/\sqrt{G_o})_a/(\sqrt{G}/\sqrt{G_o})_t$ has to be applied, where a and t mean Po = Pa and Pt, respectively. References 2, 3, and 4 discuss the conversion formulas to be applied for various fluids (e.g., air and water) for various types of leakage path. For viscous flow of a gas, the mass flow rate from a source at absolute inlet pressure P_1 to absolute outlet pressure P_2 is proportional to $(P_1^2 - P_2^2)$. The proportionality factor is $C/\mu T$, where C is a function of geometry, T is absolute temperature, and μ is viscosity (which is a function only of temperature).

Assuming that test pressure Pt psig is applied at the same temperature as that at which function pressure Pa psig is applied, and assuming further that the downstream pressure is one atmosphere, Pat psia, then the ratio of the mass flow rates is

$$\frac{\dot{m}a}{\dot{m}t} = \frac{(Pa + Pat)^2 - (Pat)^2}{(Pt + Pat)^2 - (Pat)^2} \qquad (A-3)$$

If the temperatures are not the same, the right side of Equation (A-3) has to be multiplied by

$$\frac{\mu(Tt) \cdot Tt}{\mu(Ta) \cdot Ta} \qquad (A-4)$$

Assuming that Tt = Ta, Table A-2 shows the ratio $\dot{m}a/\dot{m}t$ for various values of Pa and Pt, along with values of $(Pa\ psig/Pt\ psig)^{1/2}$. Pat is taken to be 15 psia in calculating $\dot{m}a/\dot{m}t$.

Table A-2. $\dot{m}a/\dot{m}t$ for Various Values of Pa and Pt.

	$\dot{m}a/\dot{m}t$			$(Pa/Pt)^{1/2}$			$\frac{(\dot{m}a/\dot{m}t)}{(Pa/Pt)^{1/2}}$		
Pt (psig)	Pa=50	55 (psig)	60	50	55	60	50	55	60
5	22.86	26.71	30.86	3.16	3.32	3.46	7.2	8.1	8.9
15	5.93	6.93	8.00	1.83	1.91	2.00	3.2	3.6	4.0
25	2.91	3.40	3.93	1.41	1.48	1.55	2.1	2.3	2.5
35	1.76	2.05	2.37	1.20	1.25	1.31	1.5	1.6	1.8
45	1.19	1.39	1.60	1.05	1.11	1.15	1.1	1.3	1.4

In all cases, the assumption that mass flow rate is proportional to pressure differential to the one-half power is unconservative for purely viscous flow. For Pa = 60 psig and Pt = 5 psig, it is unconservative by a factor of 8.9.

RECOMMENDED PROCEDURE

Any one of the following procedures, A, B, or C should be adopted.

A. Test Program

An extensive test program, covering several components of each type for which a correlation from Pt to Pa is sought, should be performed, in which sufficient experimental data showing the relation between Pt and leakage mass flow rate are obtained to permit a conservative empirical correlation to be established. Care must be taken to ensure that experimental orifice-like leaks are not used to represent actual, potentially capillary-like or viscous leaks.

B. Conservative Theoretical Correlation

Use Equation (A-3) as the correlation formula, including the factor (A-4) if necessary.

C. Measure Leakage Characteristic

For a given penetration, several values of Pt may be applied, so that an empirical correlation can be established. A statistical analysis of the data would be required to ensure at a 95% confidence level, that the predicted value of $\dot{m}a$ is not exceeded by the actual value of $\dot{m}a$.

REFERENCES

1. ASME Code, Section XI, paragraph IWV-3423(e).

2. Amesz, J., "Conversion of Leak Flow-Rates for Various Fluids and Different Pressure Conditions," 1966, EUR 2982.e, ORGEL Program, Ispra Establishment, Italy.

3. Maccary, R.R., DiNunno, J.J., Holt, A.E., and Arlotto, G.A., "Leakage Characteristics of Steel Containment Vessels and the Analysis of Leakage Rate Determinations," May, 1964, Division of Safety Standards, AEC, TID-20583.

4. Cottrell, Wm. B., and Savolainen, A.W., editors, "U.S. Reactor Containment Technology," ORNL-NSIC-5, Aug. 1965. Chapter 10, "Performance Tests," R.F. Griffin and G.H. Dyer. Sections 10.4.5 and 10.4.6 adapted from Reference 3.