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A Possible Alternative to the Water Immersion Test for Type B Fissile Material Packages

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INTRODUCTION

U.S. transportation regulations (10 CFR 71) require that a Type B package certified for the transport of fissile material be capable of withstanding a series of tests that demonstrate package integrity under hypothetical accident conditions (HAC). These tests, which are similar to those specified in IAEA regulations, include a sequence consisting of (1) a 9-m (30-ft.) free drop onto an unyielding surface, (2) a 1-m (40-in.) free drop onto a mild steel puncture bar, (3) an exposure to a 30-minute fire of at least 800°C, and (4) an 8-hour immersion in 0.9 m (3 ft.) of water.

The first three tests are required for all Type B packages. The water immersion test is needed only for fissile material packages, and then only if water inleakage is not assumed in the criticality analysis. (Regulations generally require *one* package remain subcritical with water inleakage, although exceptions provided in §71.55(c) can be approved. On the other hand, if the shipment contains an *array* of packages, the applicant has more flexibility to demonstrate that water inleakage need not be considered for all packages, based on their performance under HAC.)

For many packages, especially those that are small and relatively inexpensive, the method used to demonstrate that these requirements are satisfied is typically to perform the actual tests specified in the regulation on a sample package. Development of a testing plan and execution of the tests represent a considerable effort, and any changes in the package design or specifications implemented after such tests can have significant impact in the certification process. Because the water immersion test discussed above is not required for all Type B.packages, it may not be part of the original test sequence. If at a later date a need is seen to qualify that package for fissile material, or if the criticality analysis without water inleakage is deemed inadequate, a repetition of the testing program would be a very undesirable course of action.

This paper presents a possible alternative to conducting such a test. This alternative would be especially attractive in the case where the water immersion requirement arises after the initial test program, but may also support omission of the immersion test for other cases. In previous Safety Analysis Reports for package certification, applicants have sometimes justified ommission of the immersion test by merely asserting that a structurally sound package which passes the drop, puncture, and fire tests will not permit water inleakage. The method discussed in this paper presents an analytical justification for such a conclusion.

BASIS FOR ALTERNATIVE APPROACH

The *regulatory* basis for such an approach is §71.41 (10 CFR 71), which provides that evaluation by methods other than testing may be used to demonstrate compliance with regulatory requirements. The *technical* basis for the alternative to the water immersion test relies on calculations using experimental data and/or analysis of the drop, puncture, and fire tests. The acceptance criterion for a package that is qualified by an actual testing program is that it passes a containment (leakage) test after the sequence of tests has been completed. Typically the package test specimen is filled with helium gas, and a post-test leakage measurement is shown to satisfy limits specified in §71.51. (If the package is qualified by analysis, an evaluation is generally performed to show that the package does

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not rupture and that no deformation occurs in the region near the package seals when subjected to HAC specifications. Therefore, the leakage rate under HAC is essentially that of the undamaged package.)

Although the allowed leakage rate of a Type B package depends on its contents, these rates are generally very low. The most restrictive leak-rate criterion is that the package be "leak tight" (i.e., leakage is $<10^{-7}$ std cc/s air). Even in cases in which the allowable leakage is larger, leak rates of $<10^{-3}$ std cc/s are not uncommon for typical packages. By comparing the leak rate for air or helium (as demonstrated after the drop and fire tests) to that calculated for water under similar conditions through the same leak hole, a convincing argument can often be made that the package would not permit water inleakage.

As presented in Appendix B of ANSI N14.5 (ANSI 1987), the volumetric leakage rate at the average pressure in the leakage path, L_a, of an unchoked gas through a straight circular tube can be expressed as:

$$L_a = (F_c + F_m)(P_u - P_d) \text{ cc/s, where} \quad (1)$$

$$F_c = 2.49(10^6)D^4/a\mu \text{ cc-atm/s, and} \quad (2)$$

$$F_m = 3.81(10^3)D^3(T/M)^{0.5}/aP_a. \quad (3)$$

P_u, P_d, and P_a are the upstream, downstream, and average pressures (atm); F_c and F_m are the coefficients of continuum and molecular flow conductance per unit pressure, respectively (cc/atm-s); D and a are the leakage hole diameter and length (cm); μ is the gas viscosity (cP); T is the gas absolute temperature (K); and M is the gas molecular weight (grams/mole).

Equation 1 yields the volumetric leakage rate at the average pressure, $(P_u + P_d)/2$. To obtain the leakage rate at the upstream pressure, L_u, Equation 1 must be multiplied by P_a/P_u, or

$$L_u = L_a(P_a/P_u) \text{ cc/s.} \quad (4)$$

The equation for the volumetric leakage rate of water (liquid laminar flow) through the same hole (a, D) is also presented in ANSI N14.5 as

$$L_w = F_c(P_u - P_d) \text{ cc/s,} \quad (5)$$

where the terms are defined similarly to those in Equations 1 and 2, except that μ is now the viscosity of water. In addition, since liquid water is relatively incompressible compared to gas at the relevant conditions, the volumetric leakage rate is essentially the same at either P_u, P_d, or P_a.

COMPARISON OF AIR AND WATER LEAKAGE RATES

As an example of the above correlation, consider a package with an upstream volumetric leakage rate, L_u, of 10^{-7} std cc/s (air). At standard leak-test conditions, T = 298 K, μ = 0.185 cP, P_u = 1 atm, and P_d = 0.01 atm. For a leak hole of length a = 1 cm, Equations 1 through 4 can be solved to yield a leak hole diameter of $1.63(10^{-4})$ cm. If this same package is tested for water leakage at a depth of 0.9 m (1.087 atm), the expected leakage rate for water, using Equation 5, is

$$L_w = 1.7(10^{-10}) \text{ cc/s,}$$

where $\mu = 0.89$ cP, and the inside pressure of the package is assumed to be 1 atm. Consequently, for the above case it is seen that the leakage rate for water is approximately three orders of magnitude less than that for air at standard leak test conditions.

Figure 1 depicts the leakage rate of water as a function of the standard air leakage rate. Also shown is the total volume of water inleakage that would occur during an 8-hour water immersion test in which the leak hole was submerged 0.9 m below the water surface. Note that even for air leakage rates as large as 10^{-3} std cc/s, the water leakage is negligible.

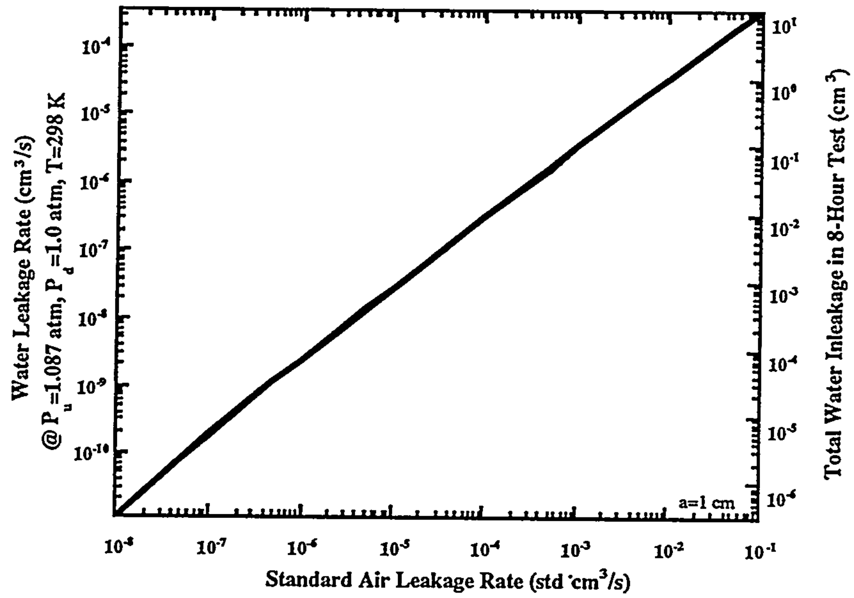

Figure 1. Water leakage rate as a function of standard air leakage rate for a leak-path length of 1 cm. Also shown is the total water leakage that would occur during 8 hours. The upstream water pressure is assumed to be 1.087 atm (0.9-m depth), and the downstream (internal containment) pressure is 1 atm. Surface tension of the water is not considered.

OTHER CONSIDERATIONS

Three additional factors should be considered in estimating the water leakage rage by correlating it with that for standard air.

First, the relationships illustrated in Figure 1 assume that the internal pressure of the package is 1 atm. If the contents are at subatmospheric pressure, the water leakage rates will be somewhat larger, as shown by Equation 5. On the other hand, if the internal pressure is greater than that of the water (~1.09 atm), water leakage will not occur.

Second, the leakage rate of Equation 5 neglects the surface tension of water. According to ANSI N14.5, the surface tension will prevent water leakage unless

$$(P_u - P_d) > 3.95(10^{-6})\sigma/D, \qquad (6)$$

where σ is the water surface tension (72 dyne/cm for pure water). For reasonable estimates of the surface tension for water encountered in a real water-immersion accident and typical leak-hole diameters, it is apparent that neglecting surface tension results in very conservative estimates for water inleakage. For example, if the surface tension of water with some impurities is only half that of pure water (36 dyne/cm) and the leak hole diameter is 10^{-3} cm ($L_u \approx 10^{-4}$ std cc/s), then water leakage can occur only if

$$(P_u - P_d) > 1.4 \text{ atm.}$$

Third, the comparison of air and water leakage discussed thus far has neglected that the air leakage is *outward*, while water leakage is *inward*. According to ANSI N14.5, Appendix A, the leakage flow during testing should be the same as in operation; flow in the reverse direction must be justified. In this case, the pressure drops across the seals under HAC for typical packages are small, and any disturbance of the seals is expected to be negligible. Consequently, no significant difference in leakage rates due to the direction of flow should occur.

CONCLUSION

Leakage rates that demonstrate compliance with §71.51 containment limits can often be used to show by calculation that a package satisfies the water immersion requirements of §71.73(c)(4). Straightforward analysis using ANSI N14.5 principles can correlate the gas leakage to water leakage. Typical containment requirements are generally more stringent than those for water leakage. Other factors, such as internal pressure of the package and water surface tension, will further inhibit water inleakage. Although details of the analysis will depend on the specific package under evaluation, the calculational procedures discussed represents an possible alternative to demonstrating that significant water inleakage will not occur.

REFERENCES

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