BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

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Monitored Geologic Repository	000-00C-MGR0-01500-000-00A

5. Title

Leak Path Factors for Radionuclide Releases from Breached Confinement Barriers and Confinement Areas

6. Group

Preclosure Safety Analyses

7. Document Status Designation

☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

This calculation supersedes *Leakpath Factors For Radionuclide Releases From Breached Confinement Barriers*, MOL.20000901.0021.

Attachments	Total Number of Pages
Attachment I	12

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
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DISCLAIMER

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ACRONYMS

ASME	American Society of Mechanical Engineers
BSC	Bechtel SAIC Company, LLC
CFR	Code of Federal Regulations
DF	decontamination factor
DOE	Department of Energy
DPC	dual-purpose canister
DUO	depleted uranium oxide
DWPF	Defense Waste Processing Facility
HEPA	high-efficiency particulate air
HLW	high-level waste
HVAC	heating, ventilation and air conditioning
LPF	leak path factor
MAR	material at risk
MMD	mass median diameter
NRC	Nuclear Regulatory Commission
PNNL	Pacific Northwest National Laboratory
SNL	Sandia National Laboratories
SNF	spent nuclear fuel
SRS	Savannah River Site
TAD	transportation, aging and disposal

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1. PURPOSE

The purpose of this calculation is to develop leak path factors (LPF) to be used in evaluating the consequences of normal operations and potential event sequences at the Yucca Mountain Repository. The leak path factors developed in this calculation can be used to calculate the potential radiation dose to an individual who is onsite or lives in the vicinity of the Yucca Mountain site.

The LPF is the fraction of airborne material-at-risk (MAR) that leaves a confinement barrier after the action of depletion mechanisms such as precipitation, gravitational settling of the released particulate material, filtration, or agglomeration, through the confinement barrier. Confinement barriers could be spent fuel cladding, canisters, shipping casks, waste packages, buildings, spent fuel pools, or filters that prevent or mitigate releases of radionuclides. The leak path factor for each of the confinement barriers except for buildings is defined in this calculation as the fraction of airborne MAR that leaves that barrier. Building leak path factors are not addressed in this calculation.

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2.3 DESIGN CONSTRAINTS

None

2.4 DESIGN OUTPUTS

This calculation will be used as input for other calculations.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

No assumption in this analysis requires verification.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1. Small Leak Area

Assumption: Following a postulated event at the repository, a small leak area in a transportation, aging and disposal (TAD) canister, dual-purpose canister (DPC), waste package, shielded-transfer cask or transportations cask is assumed. See the discussion in Sections 6.3.3.3, 6.3.3.4, and 6.3.4 for further information.

Rationale: The canisters (TADs and DPCs) and their containers (waste packages, shielded-transfer casks, aging overpacks, and transportation casks) are large robust items. The TAD canister is handled inside an aging overpack, shielded-transfer cask, waste package or transportation cask at all times except for the actual transfer of the TAD canister from one overpack to another. Likewise, a DPC can be handled inside an aging overpack, a shielded-transfer cask or a transportation cask (Reference 2.2.1, Sections 1.2.2, 5.1.1 and 6.1.1). All of these items, except for the aging overpacks, provide confinement of their contents. Therefore, not only do the TAD canisters and DPCs provide confinement for their contents, they are also protected by the overpack in which they reside.

A transportation package is required to meet the hypothetical accident conditions in accordance with title 10 of the Code of Federal Regulations (CFR) part 71.73 (Reference 2.2.2 [DIRS 176575]), which include a 30-ft free drop in several orientations, a crush test, puncture test, a fully engulfing fire, and immersion. Confinement must be maintained following the hypothetical accident conditions. The TAD canister is required to be designed to a maximum leak rate of 1.5×10^{-12} fraction of canister free volume per second following a 12-inch flat-bottom drop onto a solid carbon steel plate and a maximum leak rate of 9.3×10^{-10} fraction of canister free volume per second following a 3-ft drop while inside an aging overpack (Reference 2.2.3 [DIRS 181403], Sections 3.1.6 and 3.3.6). The leak rate of 1.5×10^{-12} fraction of canister free volume per second is essentially equivalent to the criteria for establishing leak tightness following closure and sealing of the vessel (Reference 2.2.3 [DIRS 181403], Section 3.1.6, and Reference 2.2.4, Section 6.3.1). The waste packages are to be welded vessels and back filled with helium, similar to the TAD canisters (Reference 2.2.1, Sections 4.1.1 and 29.1.1). Since these casks and canisters are robust and are designed to stringent confinement criteria, assuming a small leak area following a postulated event at the repository is conservative. See the discussion in Sections 6.3.3.3, 6.3.3.4, and 6.3.4 for further justification.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1) and LS-PRO-0201, *Preclosure Safety Analyses Process* (Reference 2.1.2). Therefore, the approved version is designated as QA:QA.

4.2 USE OF SOFTWARE

The commercially available Microsoft® Office Excel 2003 spreadsheet code, which is a component of Microsoft® Office 2003 Professional, is used to perform standard mathematical and plotting functions, which do not depend on the particular software program. The mathematical results are verified by checks using hand calculations and the graphical representations of the results are visually inspected for verification. Usage of Microsoft® Office 2003 Professional in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Reference 2.1.3, Attachment 12). Microsoft® Office 2003 Professional is listed in the current *Level 2 Usage Controlled Software Report*. Microsoft Office® Excel 2003 was executed on a PC running the Microsoft® Windows 2003 Service Pack 2 operating system.

4.3 METHODOLOGY

At the Yucca Mountain repository, a consequence analysis is performed to estimate radiation doses to workers and the public as a result of a postulated release of radioactivity following an event sequence. The radiological source term is an input to the dose consequences. The amount of respirable radionuclides released to the ambient environment as a result of an event sequence is defined as the source term and is estimated by a five-component equation (Reference 2.2.5 [DIRS 103756], p. 1-2, Equation 1-1):

$$ST_j = MAR_j \times DR_j \times ARF_j \times RF_j \times LPF_j \qquad \text{(Eq. 1)}$$

where,

- ST_j - the total amount of the j^th nuclide that is released to the environment [Ci]
- MAR_j - the material at risk of the j^th nuclide [Ci]
- DR_j - the damage ratio of the j^th nuclide (i.e., the fraction of MAR_j that is affected by the event sequence) [unitless]
- ARF_j - the airborne release fraction of the j^th nuclide applicable to the event sequence [unitless]
- RF_j - the respirable fraction of the j^th nuclide applicable to the event sequence [unitless]
- LPF_j - the leak path factor for the j^th nuclide applicable to the event sequence [unitless].

For normal operations and event sequences that have the potential of occurring at the Yucca Mountain repository, more than one LPF can be defined. For example, if a shipping cask loaded with a canister with commercial spent fuel is dropped inside a building and the drop results in a breach of confinement, the radioactive material contents of the package can be released from the fuel cladding to the canister, from the canister to the shipping cask, from the shipping cask to the room within the building, and from the building through high efficiency particulate air (HEPA) filters to the atmosphere. In this case, a potential of five LPFs can be defined. $(LPF)_{cladding}$ is defined as the fraction of radioactive material transported from the fuel matrix past the fuel cladding to the cavity of the canister. $(LPF)_{canister}$ is defined as the fraction of radioactive material transported from the canister to the cavity of the shipping cask. $(LPF)_{cask}$ is defined as the fraction of radioactive material transported from the cavity of the cask to the room. $(LPF)_{bldg}$ is defined as the fraction of radioactive material transported from the room or building, and is available to be released to the environment through the heating, ventilation and air conditioning (HVAC) system HEPA filters. And $(LPF)_{HEPA}$ is defined as the fraction of radioactive material released to the environment after passing through the HEPA filters. When multiple LPFs are used, their cumulative effect may be expressed in a single value that combines all LPFs as follows:

$$(LPF)_{sys} = (LPF)_i \times (LPF)_{i+1} \times (LPF)_{i+2} \times .... \qquad \text{(Eq. 2)}$$

where

$(LPF)_i$ = leak path factor for i^{th} confinement barrier (unitless)

This calculation provides leak path factors for casks, DPCs, TAD canisters, waste packages, HEPA filters and fuel pools.

5. LIST OF ATTACHMENTS

Number of Pages

6. CALCULATION

The leak path factors for each of the depletion mechanisms are addressed in separate sections.

6.1 HEPA FILTER LEAK PATH FACTORS

Filters are widely used in nuclear ventilation, air cleanup, and confinement systems to remove particulate matter from air and gas streams. High-efficiency particulate air (HEPA) filters are, by definition, throwaway, extended-medium, dry-type filters with:

1. a minimum particle removal efficiency of no less than 99.97 percent for 0.3-μm particles,
2. a maximum pressure drop of 1.0-inch water gauge or 1.3-inch water gauge when clean and operated at its rated airflow capacity, and
3. a rigid casing enclosing the full depth of the pleats. (Reference 2.2.6 [DIRS 167097], Glossary)

The dust-holding capacity of a filter is a function of the type, shape, size, and porosity of the filter as well as the aerosol size, shape, and concentration characteristics to which the filter is exposed. As HEPA filters are designed to filter out the smallest particles, they can accommodate only extremely light particulate loadings without experiencing a rapid pressure drop. Thus, a HEPA filter may be protected by a pre-filter capable of removing the bulk of large particles and fibers, a sprinkler to further reduce particulates, and a demister to prevent water damage to the HEPA filters (Reference 2.2.6 [DIRS 167097], Section 3.3.6).

Theory predicts that the primary mechanisms in filtering particles are diffusion and inertia. Direct interception or impaction is a secondary mechanism (Reference 2.2.6 [DIRS 167097], Section 2.5.2). The particle size of fuel fines that is expected to be typical for the fuel to be received at the Yucca Mountain repository is represented by a lognormal distribution with a mass median diameter (MMD) of 150 μm, a mean geometric diameter of 0.715 μm and a standard deviation (σ) of 3.8 (Reference 2.2.7, Section 6.2.2.4.1). Thus, the HEPA filtration efficiencies are applicable to the service conditions expected at the repository.

A decontamination factor (DF) is a measure of air cleaning effectiveness. It is the ratio of the concentration of a contaminant in the untreated air to the concentration in the treated air (Reference 2.2.6 [DIRS 167097], Glossary). The DF is related to filter efficiency, expressed as a fraction, by:

$$DF = \frac{1}{(1-\eta)} \qquad \text{(Eq. 3)}$$

where

η = filter efficiency (unitless)

A leak path factor is the fraction of material that leaves the barrier, or for a filter, it is one minus the filter efficiency.

$$LPF = (1 - \eta) \qquad \text{(Eq. 4)}$$

where

η = filter efficiency (unitless)

Thus, the DF is the reciprocal of the LPF.

$$DF = \frac{1}{LPF} \qquad \text{(Eq. 5)}$$

Therefore, a filter efficiency of 99.97 percent is equivalent to a DF of 3,333, which is equivalent to a LPF of 3×10^{-4}.

To increase the DF of a system, multiple HEPA filters are used in series. Tests at Los Alamos National Laboratory resulted in DFs of 10^4 for stages one and two and somewhat less than 5.0×10^3 for the third stage of a three-stage system, with an average DF of 5.0×10^3 for each of the three stages (Reference 2.2.6 [DIRS 167097], Section 2.5.2). A DF of 5.0×10^3 is equivalent to a filter efficiency of 99.98%. Thus, the tests at Los Alamos National Laboratory resulted in an average filter efficiency of 99.98% or a LPF of 2×10^{-4} for each of the three HEPA filter stages in the three-stage filter system.

The *Nuclear Air Cleaning Handbook* (Reference 2.2.6 [DIRS 167097], Section 2.5.2) states that for purposes of estimating the capability of a multistage HEPA filter installation under normal operating conditions, a DF of $(3.0 \times 10^3)^n$ can be safely used with systems that adhere to the design, construction, testability, and maintainability principles of the *Nuclear Air Cleaning Handbook* or American Society of Mechanical Engineers (ASME) N509 (Reference 2.2.8 [DIRS 176247]). Applying this, the DF of a two stage HEPA filter system would be 9×10^6, which is equivalent to a LPF of 1.1×10^{-7}. Thus, for a two-stage HEPA filter system, the *Nuclear Air Cleaning Handbook* (Reference 2.2.6 [DIRS 167097], Section 2.5.2) recommends a DF of 9×10^6, which is equivalent to a LPF of 1.1×10^{-7}.

The *Nuclear Fuel Cycle Facility Accident Analysis Handbook,* NUREG/CR-6410 (Reference 2.2.9 [DIRS 103695], Section F.2.1.3), states that if a series of HEPA filters is protected by pre-filters, sprinklers, and demisters, efficiencies of 99.9 percent for the first filter and 99.8 percent for all subsequent filters is recommended for accident analysis. This gives a LPF of 0.001 for the first stage and 0.002 for the second stage with a combined LPF of 2.0×10^{-6} for the two-stage system.

Regulatory Guide 1.52 (Reference 2.2.10 [DIRS 171692], Section 6.3) allows accident dose evaluations to credit a 99% removal efficiency for particulate matter filter systems that demonstrate aerosol leak test results of less than 0.05% of the challenge aerosol at rated flow ±10%.

For normal operations and event sequences, a $(LPF)_{HEPA}$ of 0.01 per stage for particulate and cesium is recommended, which is equivalent to a HEPA removal efficiency of 99% per stage. For a two-stage HEPA filtration system, this gives a combined efficiency of 99.99%, which is equivalent to a $(LPF)_{HEPA}$ of 10^{-4} when the series of HEPA filters is protected by pre-filters, sprinklers, and demisters. This is consistent with the guidance of Regulatory Guide 1.52 (Reference 2.2.10 [DIRS 171962], Section 6.3) and conservative with respect to the recommendations of Reference 2.2.6 ([DIRS 167097], Section 2.5.2) and Reference 2.2.9 ([DIRS 103695, Section F.2.1.3). In addition, the Nuclear Regulatory Commission found acceptable a LPF for a two-stage HEPA filtrations system of 10^{-4} for the Mixed Oxide Fuel Fabrication Facility (Reference 2.2.11 [DIRS 177722], page 9-10).

6.2 SPENT FUEL CLADDING

The release fractions for commercial spent nuclear fuel (SNF) are provided in *Commercial SNF Accident Release Fractions* (Reference 2.2.7, Section 7). These release fractions are by definition, the fraction of fuel inventory that is released from the fuel cladding to the next confinement barrier (Reference 2.2.7, Section 7). As such, the LPF for spent fuel cladding must equal one (1) when the release fractions from Section 7 of Reference 2.2.7 are used.

6.3 TRANSPORTATION CASKS AND CANISTERS

The Nuclear Regulatory Commission must approve any package used for shipping nuclear material using the provisions of 10 CFR Part 71 (Reference 2.2.2 [DIRS 176575]). A transportation package is required to meet the hypothetical accident conditions, which include a 30-ft free drop, a crush test, puncture test, a fully engulfing fire, and immersion in accordance with 10 CFR 71.73 (Reference 2.2.2 [DIRS 176575]). The purpose of these stringent requirements is to ensure that the transportation packages are robust enough to withstand accident conditions even though it is unlikely they could be exposed to such conditions. While these tests are for the entire transportation package, which can include a canister within a cask with impact limiters, the canister itself provides structural support and confinement within the shipping cask. A leak path factor can be established for the cask as well as the canister inside the cask, if used.

A review of the literature concerning the fraction of particulate released from a shipping cask, canister or container is performed in this section. It includes an overview of cask and canister impact tests, a review of release fractions cited in literature and a review of particulate retention mathematical models.

Waste to be received at the repository can include spent nuclear fuel and high-level waste sealed within canisters. These canisters can include DPCs for commercial SNF, TAD canisters for commercial SNF, and standardized canisters for the Department of Energy (DOE) SNF and high-level waste. A limited amount of spent nuclear fuel may also be shipped bare in a transportation cask without being sealed in a TAD canister or DPC (Reference 2.2.1, Section 1.2.2 and 4.1.1).

The particle size of fuel fines that is expected to be typical for the fuel to be received at the Yucca Mountain repository is represented by a lognormal distribution with a mass median diameter (MMD) of 150 μm, a mean geometric diameter of 0.715 μm and a standard deviation (σ) of 3.8 (Reference 2.2.7, Section 6.2.2.4.1). As shown in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476], Section 7.3.8 and Figure 7.10), deposition processes largely deplete the source distribution of particles with diameters larger than 10 μm. When selecting a LPF value from various LPF models, the most conservative LPF value is taken to develop cask and canister leak path factors. As a result, there is no need for correction factors due to any change of particle size distribution.

Airborne particulate transport is dependent on accident conditions such as structural integrity of the confinement. Depending on the size and location of the breach, the LPF values can range from 0, meaning no release, to 1, meaning all available material is released. Severe accident conditions could result in a gross failure of the confinement. In this case, a conservative LPF of 1 should be used. However, in less severe accident conditions, the impact energy may not be sufficiently large enough to breach the canister and the assumption of a small leak is both appropriate and conservative. A small leak area would result in a small LPF for particulates within the confinement barrier. The LPF as a function of the leak area and pressure is discussed in this section.

As stated earlier, a transportation package is required to meet the hypothetical accident conditions, which include a 30-ft free drop in several orientations, a crush test, puncture test, a fully engulfing fire, and immersion in accordance with 10 CFR 71.73 (Reference 2.2.2 [DIRS 176575]). It is expected that confinement be maintained following the 10 CFR 71.73 hypothetical accident conditions. Therefore, assuming a small leak area following a postulated event at the repository is conservative (Assumption 3.2.1) because no credible repository event has been identified that presents challenges more severe than the 10 CFR 71.73 hypothetical cask accidents.

6.3.1. Impact Tests

Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL) have performed many shipping cask and canister impact tests. Many canister drop tests have been performed to demonstrate the capability of canisters, loaded with vitrified high level waste (HLW) or spent nuclear fuel (SNF), to withstand transportation accidents. The results of these tests are summarized and evaluated in this section.

Peterson et al. (References 2.2.13 and 2.2.14 [DIRS 170829 and DIRS 106578]) at PNNL have performed drop tests on canisters filled with simulated high-level waste glass. Wu et al. (Reference 2.2.15 [DIRS 170936], Section 3.2) reviewed and summarized the test results. In the first set of tests (Reference 2.2.13 [DIRS 170829]), four canisters were each subjected to two vertical drops from a height of 30 feet onto an unyielding surface and a horizontal drop from a height of 40 inches onto a solid steel vertical cylinder in a puncture test. No rupture of any of the canisters occurred. A helium leak test and a liquid dye penetrant test conducted after the impacts revealed no leaks and no significant indications of cracks (Reference 2.2.15 [DIRS 170936], Section 3.2.1). In the second set of tests (Reference 2.2.14 [DIRS 106578]), three Savannah River Laboratory waste containers were tested. Two of the canisters were fabricated from 304L stainless steel, and the third was fabricated from titanium. The impact tests were conducted in the same manner as those in Reference 2.2.13 ([DIRS 170829]). The results indicated no failure and no leak in the stainless steel canisters during a helium leak test. However, a breach did occur in the titanium canister (Reference 2.2.15 [DIRS 170936], Section 3.2.2).

Wu et al. (Reference 2.2.15 [DIRS 170936]) developed a stress analysis model to analyze the effects of a potential drop of a shipping cask and a waste container during waste handling operations. The drop tests from References 2.2.13 and 2.2.14 ([DIRS 170829 and DIRS 106578]) provided technical information about the effects of impact on high-level waste canisters (Reference 2.2.15 [DIRS 170936], Section 3.3). Reasonable agreement was found between the results of a 30 ft drop finite-element analysis using the stress analysis model and the results from the drop test documented in Reference 2.2.14 ([DIRS 106578]) (Reference 2.2.15 [DIRS 170936], Sections 3.2.2 and 3.3.5).

Using the stress analysis model, Wu et al. (Reference 2.2.15 [DIRS 170936], Executive Summary) evaluated several impact scenarios including those for a shipping cask, an empty container, and a loader container. For a shipping cask, the analysis results showed that the maximum stresses occur when the cask rolls off a transfer car and strikes the floor. The maximum stresses do not exceed the allowable stress for the stainless steel, which is the material used in the cask. Therefore, under the test conditions, neither the truck cask nor rail cask should fail. For an empty container, the analysis results show that the maximum stresses occur as the result of a container free-fall of 34 feet or an impact with the hot cell walls. Although the maximum stresses were slightly higher than the allowable stress, the stresses would not result in a fracture of the container. For a loaded container, the analysis results show that the maximum stresses occur when the container falls 2 feet and impacts a 2-inch-diameter object or when it impacts the hot cell walls. Even though the maximum stress is 81,000 psi, which is almost four times as great as the allowable stress for the stainless steel material used, no fracture of the container is expected. The allowable stress for the material is 21,000 psi whereas the ultimate strength is 85,000 psi and the critical fracture strength is 228,000 psi (Reference 2.2.15 [DIRS 170936], Executive Summary).

Drop tests have been performed for full-scale Defense Waste Processing Facility (DWPF) canisters to demonstrate that waste forms in canisters can withstand a 7-meter drop without breach (Reference 2.2.16 [DIRS 101854], Section 8). Seven canisters filled with glass were drop tested from 7 meters by the PNNL personnel in 1988. The canisters were oriented and lifted by a crane until the lowest point on the canister was 7 meters off the ground and then they were released. All seven canisters bounced more than once after the first impact. For those Defense Waste Processing Facility canisters that were dropped on their bottom head, almost no deformation was observed. When these canisters were dropped at an angle on their head, the thicker neck and shoulder buckled and bent. The results of both dye penetrant examinations and helium leak tests demonstrated that no breach of the canisters occurred as a result of the top and bottom drops experienced by each canister.

Drop tests were performed on two full-scale Defense Waste Processing Facility canisters (Reference 2.2.17 [DIRS 141573]). These canisters were filled with simulated high-level waste glass and were dropped from heights of either 0.3 meters or 9.1 meters. The structural integrity of both canisters was not affected by their drop test. Both helium and dye penetrant tests following the drop demonstrated that the integrity of both the fabrication welds and the final closure welds of the canisters were maintained (Reference 2.2.17 [DIRS 141573]). In addition, nineteen drop tests on nine different glass-filled canisters were performed between 1981 and 1984 at the Savannah River Site (SRS) (Reference 2.2.18 [DIRS 170813]). These drops included a drop of 30 feet onto a flat unyielding surface and a drop of 40 inches onto the top end of a 6-inch diameter bar. No breach of any welds on the dropped stainless steel canisters was observed (Reference 2.2.18 [DIRS 170813]).

DOE standard canister drop tests have been performed at Sandia National Laboratories (Reference 2.2.19 [DIRS 169137], Executive Summary). A total of nine 18-inch-diameter test canisters were used in the tests. Seven of the test canisters were 15-ft long and weighted about 6,000 lbs, while two were 10-ft long and weighted 3,000 and 3,800 lbs. In these tests, seven of the test canisters were dropped from a height of 30 ft onto an essentially unyielding surface and one of the test canisters was dropped from a height of 40 inches onto a 6-inch-diameter puncture post. The last test canister was dropped from a height of 24 inches onto a 2-inch thick vertically oriented steel plate, and then tipped over to impact another 2-inches thick vertically oriented steel plate. All nine canisters experienced varying degrees of damage to their skirts, lifting rings, and pressure boundary components (heads and main body). However, all dropped canisters were found to have maintained their pressure boundary and the four canisters that experienced the most damage were found to be leak tight through helium leak testing performed at Idaho National Laboratory (Reference 2.2.19 [DIRS 169137], Executive Summary).

NUREG-0170 (Reference 2.2.20 [DIRS 101892]) summarizes impact tests reported in References 2.2.21 and 2.2.22 ([DIRS 170801 and 170804]) that were performed by Sandia National Laboratories. These tests simulated accidents involving aircraft. The containers were subjected to the same test requirements to which the Federal Aviation Administration subjects flight recorders prior to certification. Per Figure 5-2 of NUREG-0170 (Reference 2.2.20 [DIRS 101892]), aircraft transportation accidents are divided into eight categories (Categories I through VIII) of increasing severity. The severity of aircraft accidents is based on the impact speed and the fire duration at 1300°K. Table 1 summarizes the severity categories for aircraft transportation accidents without fire.

Table 1. Accident Severity Category Classification Scheme - Aircraft

Severity Category Without Fire	Speed of Impact onto Unyielding Surface	
	(kilometers/hour)	(miles/hour)
I	0-17.6	0-11
II	17.6-48	11-55
III	48-88	30-55
IV	88-128	55-80
V	128-224	80-140
VI	224-304	140-190
VII	304-600	190-370
VIII	>600	>370

Source: Reference 2.2.20 [DIRS 101892], Figure 5-2

All containers survived the impact tests with no structural damage to the inner container after impacts onto unyielding targets at speeds up to those typical of a Category V impact accident (Reference 2.2.20 [DIRS 101892], Section 5.2.3). Several containers from the Sandia impact test exhibited some minor structural damages and cracking in Category VI impacts; however, no verified release occurred. In one Category VII impact test, a container lost 6% of its contents (magnesium oxide powder); while others survived Category VIII impacts with no loss of contents (Reference 2.2.20 [DIRS 101892], Section 5.2.3).

The results of the drop tests discussed above are summarized in Table 2.

Table 2. Summary of Cask and Canister Drop Tests

Cask or Canister Drop Test	Organization Performing the Test	Drop Height	Test Results	References*
Glass filled stainless steel canisters	PNNL	30 ft vertical drop, 40-inch horizontal puncture test drop	No canister breach	Reference 2.2.13 [DIRS 170829]
Glass filled canisters; 2 stainless steel, 1 titanium	PNNL	30 ft vertical drop, 40-inch horizontal puncture test drop	No stainless steel canister breach, titanium canister breach	Reference 2.2.14 [DIRS 106578]
DWPF canister drop	PNNL	7 m	No canister breach	Reference 2.2.16 [DIRS 101854]
DWPF canister drop	SNL	0.3 m or 9.1 m	No canister breach	Reference 2.2.17 [DIRS 141573]
Glass-filled canister drop	SRS	30 ft vertical drop, 40-inch horizontal puncture test drop	No canister breach	Reference 2.2.18 [DIRS 170813]
DOE standard canister drop	SNL	30 ft or 2 ft	No canister breach	Reference 2.2.19 [DIRS 169137]
Plutonium shipping container drop onto unyielding targets	SNL	At speeds typical of Category V to VIII impacts	No release for Category V or VI impacts. Only one container breached and lost 6% of its contents in a Category VII impact; others survived Category VIII impact.	Reference 2.2.21 [DIRS 170801] and Reference 2.2.22 [DIRS 170804]

Note: *See text for specific citation in reference.
DOE=Department of Energy, DWPF=Defense Waste Processing Facility, PNNL=Pacific Northwest National Laboratory, SNL=Sandia National Laboratories, SRS=Savannah River Site

In conclusion, the impact tests summarized here show that both casks and glass canisters are robust and would not be expected to fail under credible conditions associated with repository operations. As the table shows, only one stainless steel container breached following a Category

VII impact test, which is defined as an accident that has an impact speed between 190 and 370 mph. The only possible event that could be in the range of these speeds involves an aircraft crash. The frequency of aircraft crashes has been shown to be less than one chance in 10,000 of occurring before permanent closure of the Yucca Mountain repository; thus, an aircraft crash is not a credible event (Reference 2.2.23, Section 7).

6.3.2. Release Fractions Cited In Literature

Several investigators have estimated the degree of resistance against airborne dispersion of particulate provided by spent nuclear fuel cladding, shipping casks, canisters, and containers. MacDougall et al. (Reference 2.2.24 [DIRS 104779], Table 5-8) has recommended escape factors, or leak path factors, for various combinations of confinement barriers, such as fuel cladding, shipping casks, canisters, and/or containers, against an uncontrolled release. MacDougall et al. (Reference 2.2.24 [DIRS 104779], Table 5-8) recommended leak path factors are shown in Table 3.

Table 3. Leak Path Factors Recommended for Various Combinations of Confinement Barriers

Source Term	LPF
Spent fuel cladding	0.1
Cask	0.1
Container or canister	0.1
Spent fuel in cask	(0.1)(0.1) = 0.01
Spent fuel in container	(0.1)(0.1) = 0.01
Spent fuel in container in cask	(0.1)(0.1)(0.1) = 0.001
HLW canister	0.1
HLW canister in cask	(0.1)(0.1) = 0.01
HLW canister in container	(0.1)(0.1) = 0.01
HLW canister in container in cask	(0.1)(0.1)(0.1) = 0.001

Source: Reference 2.2.24 [DIRS 104779], Table 5-8

Table 3 shows a recommended LPF of 0.1 for each confinement barrier. Note that the fuel cladding LPF should be equal to one (1) when using the release fractions from Section 7 of Reference 2.2.7.

Wilmot (Reference 2.2.25 [DIRS 104724], Table XIX) used a release fraction of 0.05 for particulates and volatiles (Cs, I) for the release from the cavity of a gas-cooled cask to the environment. The release fraction was based on the collective judgment of experts.

In 1977, the NRC issued a generic environmental impact statement, NUREG-0170 (Reference 2.2.20 [DIRS 101892]), which covers the transport of all types of radioactive material by all transport modes (road, rail, air, and water). For the purpose of dose calculations, accidents were divided into eight categories (Categories I through VIII) of increasing severity. Two source term models were developed and used in NUREG-0170 to calculate the dose to the public due to a postulated transportation accident. Table 4 shows the cask release fractions for both truck and train accidents from NUREG-0170 (Reference 2.2.20 [DIRS 101892], Tables 5-4, 5-5, 5-8 and 5-9).

Model I release fractions are derived from a total release model that is characterized as somewhat unrealistic but which allows simplistic evaluations (Reference 2.2.20 [DIRS 101892], Section 5.2.3). As can be seen in Table 4, Model I release fractions exhibit a step change from 0 to 1 when the accident category changes from II to III. Model II release fractions are derived from a more realistic model that is characterized as still having inherent conservatisms (Reference 2.2.20 [DIRS 101892], Section 5.2.3). Model II release fractions, which change from 0 to 1 more gradually as seen in Table 4, are based on SNL plutonium shipping container test data (References 2.2.21 and 2.2.22 [DIRS 170801 and 170804).

Table 4. NUREG-0170 Model I and Model II Severity and Cask Release Fractions for Spent Fuel Transport by Truck and Rail

Accident Category	Severity Fractions*		Release Fraction Truck and Rail	
	Truck	Rail	Model I	Model II
I	0.55	0.5	0.0	0.0
II	0.36	0.3	0.0	0.0
III	0.07	0.18	1.0	0.01
IV	0.016	0.018	1.0	0.1
V	0.0028	0.0018	1.0	1.0
VI	0.0011	1.3×10^{-4}	1.0	1.0
VII	8.5×10^{-5}	6.0×10^{-5}	1.0	1.0
VIII	1.5×10^{-5}	1.0×10^{-5}	1.0	1.0

Source: NUREG-0170 (Reference 2.2.20 [DIRS 101892], Tables 5-4, 5-5, 5-8, and 5-9)
NOTE: * Fraction of accidents that fall into this severity range.

In the final supplementary environmental impact statement for the Waste Isolation Pilot Plant (Reference 2.2.26 [DIRS 170805], Section D3.3), a fraction of radioactive material released from failed containers into the package cavity, and a fraction of radioactive material released from the package to the environment were used. These fractions were dependent on the severity of the accident and were based on NUREG-0170 Model I release fractions and some other release fractions derived from experiments. For remotely handled casks, the estimated release fractions are 0 for severity category accidents I-IV, 1×10^{-4} for severity category accidents V and VI, and 2×10^{-4} for severity category accidents VII and VIII (Reference 2.2.26 [DIRS 170805], Table D3.17).

The NRC modal study, NUREG/CR-4829 (Reference 2.2.27 [DIRS 101828], Figure 4-5), categorized the potential damage to shipping containers used to transport PWR or BWR spent nuclear fuel according to the magnitude of thermal and mechanical forces that could result from an accident. The thermal and mechanical forces were categorized into 20 regions. Each region is associated with one of the five cask mid-wall temperature ranges; up to 500°F, 500°F to

600°F, 600°F to 650°F, 650°F to 1050°F, and greater than 1050°F, and one of the four ranges of maximum strain on the inner shell of the cask; up to 0.2%, 0.2% to 2%, 2% to 30%, and greater than 30%. For each region, release fractions for inert gas, iodine, cesium, ruthenium, and particulates were given.

Reference 2.2.28 ([DIRS 101802], Volume 1, Appendix D Section A.7.2.2.4 and Appendix I Section I-5.2.2) used the cask release fractions from NUREG/CR-4829 (Reference 2.2.27 [DIRS 101828]) for inert gas, iodine, cesium, ruthenium, and particulates to calculate the potential dose to the public during transportation accidents involving DOE SNF. The cask release fractions developed in NUREG/CR-4829 (Reference 2.2.27 [DIRS 101828]) for commercial PWR fuel are reported in Table I-27 of Reference 2.2.28 ([DIRS 101802]). For accident region R(1,1), which has up to 0.2% strain and up to 500°F cask temperature, no releases occur. The accident region R(3,4), which has up to 30% strain and up to 1050°F cask temperature, has an inert gas release fraction of 0.39, iodine release fraction of 4.3×10^{-3}, cesium release fraction of 2.0×10^{-4}, ruthenium release fraction of 4.8×10^{-5}, and particulate release fraction of 2.0×10^{-6}.

NUREG-1864 (Reference 2.2.29 [DIRS 181343], Sections D.2.5.2.2. and D.4) provides a recommended fraction of the respirable fuel and crud particles that escape a cask containing commercial spent nuclear fuel. The fraction released, or leak path factor, is less than or equal to 0.1 for particulates and crud. The leak path factor for the particular case evaluated, that being a HI-STORM cask with a 100-foot drop, is 0.1 for particles and crud.

In conclusion, leak path factors have been cited and used in the literature. The recommended leak path factors, even for relatively severe accident conditions, have generally ranged from 0 to 0.1 for casks and canisters.

6.3.3. Particulate Retention Models

This section discusses various models available to calculate the leak path factor. These models are based on the theory of particulate deposition or test data. A comparison of these models is discussed in this section.

6.3.3.1. The Sutter et al. Correlation

Sutter et al. (Reference 2.2.30 [DIRS 170832]) have conducted leak tests using depleted uranium oxide (DUO) powder to simulate PuO_2 powder leaked from a breached container under postulated accident conditions. Three hundred and seventy experimental runs using DUO in the plutonium oxide leak studies were defined by type of apparatus and by type of opening, or leak path, combined with chamber pressure and duration of run. Two sets of apparatus were used: Above Powder Leak Apparatus (APLA) for leaks above the powder level and Under Powder Leak (UPL) apparatus for leaks below the powder level. Leak paths were through three types of openings: orifices, short capillaries, and long capillaries. These openings varied in diameter from 20 to 276 μm. Selection of openings and the appropriate apparatus determined the hardware characteristics for a run (Reference 2.2.30 [DIRS 170832], Summary and Conclusions; Appendix B).

For each run a chamber pressure between 5 and 1000 psig, and duration of run time during which the apparatus was at the selected pressure, was between 0 and 360 minutes. Some runs with multiple openings were made on the APLA. For the UPL, some runs were made using mechanical agitation; others were not. All APLA runs had powder agitation. The tests were conducted with an initial mass of 3 kg (Reference 2.2.30 [DIRS 170832], Introduction). However, a series of test with the UPL apparatus was made to assess the effect of varying the initial amount of DUO between 25 g and 300 g (Reference 2.2.30 [DIRS 170832], page B-36). Test results indicate that as the initial mass increased above 100 g, the amount of DUO that leaked through the aperture did not significantly change (Reference 2.2.30 [DIRS 170832], page B-36).

The DUO powder has a mass median diameter (MMD) of 1 μm, which is a 3.5-μm aerodynamic equivalent diameter, and 95% of its mass was associated with particles of 10-μm or less (Reference 2.2.30 [DIRS 170832], pg. 29). The MMD of fuel fines generated during a spent fuel rod burst event postulated for the Yucca Mountain repository is about 150 μm (Reference 2.2.7, Section 6.2.2.4.1). Because it would be expected that releases for larger particles would be less than for smaller particles, the data for DUO, a fine powder with a MMD of 1 μm, provides conservative estimates for releases of fuel fines during postulated events at the Yucca Mountain repository.

To perform an experiment, an aperture, either an orifice or capillary, was cemented in a filter-loaded collection chamber. The chamber was placed in the apparatus and the upstream pressure was increased to the predetermined level and maintained at that level for the designated time. The experiment was than terminated by turning off the air and allowing the vessel to depressurize. All of the DUO powder that passed through the aperture as a result of the pressurization cycle was sampled and analyzed. Seventeen thin-plate orifices with bore diameters ranging from 20 to 200 μm, and 12 capillaries, 0.76 and 2.54 cm long with nominal diameters of 50 to 250 μm, were used to simulate leaks.

The initial experiments indicated aperture diameter and increasing pressure to be significant parameters for powder transmission, and seemed to indicate a correlation with airflow rate. Further investigation of the data confirmed the significance of the diameter and pressure parameters with the influence of the diameter to be more important than the pressure. The following correlations for the amount of DUO that leaked through the aperture were developed by a statistical analysis of the experimental data.

For low flow cases, $\ell n(A\sqrt{P}) < 10.5$, where A is the area in μm^2 and P is the pressure in psig, the expected average and upper limit values were 33 μg and 46 μg, respectively, for below powder leaks; 5 μg and 6 μg, respectively, for above powder leaks (Reference 2.2.30 [DIRS 170832], Appendix B, Table B1). The report recommends using the average or upper limit for low flow cases.

As stated earlier, the tests were conducted with an initial mass of 3 kg (Reference 2.2.30 [DIRS 170832], Introduction). However, twenty-one tests with the UPL apparatus were made to assess the effect of varying the initial amount of DUO between 25 g and 300 g (Reference 2.2.30 [DIRS

170832], page B-36). Test results indicate that as the initial mass increased above 100 g, the amount of DUO that leaked through the aperture did not significantly change (Reference 2.2.30 [DIRS 170832], Figure B8). The maximum normal internal pressure of a cask or canister is nominally 100 psig (Reference 2.2.2 [DIRS 176575], Part 71.4). Although the amount of material leaking out was generally independent of the mass of the material in the test vessel (Reference 2.2.30 [DIRS 170832], Table B21), these initial values can be used to approximate leak path factors. The initial mass is taken as 3 kg (3×10^9 μg), since only 21 of the 370 tests had different initial masses. For these low flow cases, the upper limit leakage values lead to a LPF for below powder leaks of 2×10^{-8} (46 μg divided by 3×10^9 μg) and a LPF for above powder leaks of 2×10^{-9} (6 μg divided by 3×10^9 μg).

For high flow cases, $\ell n(A\sqrt{P}) > 10.5$, again with A in μm^2 and P in psig, the amount of DUO leaked through the aperture is predicted by:

$$\ell n(M) = a + b_1 \ell nA + b_2 \sqrt{P} \qquad \text{(Eq. 4)}$$

where

A = area of the aperture (μm^2)
P = pressure (psig)
M = mass of DUO leaked through the aperture (μg)
a, b_1, b_2 = coefficients defined in Table 5

Equation (4) can be transformed into the leak path factor, LPF, as follows:

$$LPF = \frac{M}{M_0} = \frac{1}{M_0} Exp(a + b_1 \ell nA + b_2 \sqrt{P}) \qquad \text{(Eq. 5)}$$

where

LPF = leak path factor or fraction of DUO mass leaked out of the vessel (unitless)
M_0 = initial DUO mass in the vessel (μg)

Coefficients a, b_1, and b_2 in Equations (4) and (5) are dependent on the leak configuration and the location of the leak. Values of these coefficients are given in Table 5. Again, using an initial DUO mass of 3 kg, the LPFs can be determined.

Table 5. Coefficients Used in Equations 4 and 5

Coefficients	UPL Orifices	APLA Orifices	Capillaries	Unspecified Configuration*
a	-10.2848	-14.1959	-17.9875	-14.2790
b_1	1.6080	1.7906	2.1658	1.8280
b_2	0.0449	0.1095	0.1170	0.1052

NOTE: *least squares fit for all observations (UPL orifices, APLA orifices, and capillaries)
UPL=under powder leak, APLA=above powder leak apparatus

Source: Reference 2.2.30 [DIRS 170832], Appendix B

Using Equation 5, leak path factors for orifices and capillaries ranging from 10 to 10,000 μm in diameter and pressures at 0, 25, 50 and 100 psig were determined and the results of the calculations are reported in Attachment I. The maximum normal internal pressure of a cask or canister is nominally 100 psig (Reference 2.2.2 [DIRS 176575], Part 71.4). The results show that the LPF increases with increasing aperture diameters and pressures. The results also show, as indicated in Attachment I, that the capillary configuration results in the highest amount of DUO release out of the vessel and hence the highest LPF.

During some of the test runs, orifices or capillaries either plugged immediately when the sampling system was pressurized, or they became partially plugged with loss of powder flow although without complete cessation of airflow. Six percent of the orifices used became totally plugged and 3% became partially plugged during experiments. Seventeen percent of the capillaries plugged immediately and 10% were suspected of plugging. Capillaries, with more extensive surface area exposed to airborne powder than orifices, can plug at the face, or particles can deposit in the length of the leak path, leading to bridging and eventual flow blockage. This additional area available for deposition could account for the 17% plugging of capillaries compared to 6% for orifices where plugging occurred primarily at the orifice face (Reference 2.2.30 [DIRS 170832], Pages 37 through 39).

The overall conclusions from this study are:

- Diameter and pressure were both significant, although diameter was the most important parameter in powder leakage.
- The opening orifice or capillary types and location above or below the static powder level affected powder transmission.
- The amount of powder covering a leak did not affect the leak below the static powder level because of powder compaction.
- The duration of a run had no statistically discernible effect on powder transmitted in time up to 24 hours.
- Agitation did not influence the flow from a leak below the static powder level.
- Leakage below the static powder level maximized at 100 psig for openings less than 100 μm.
- Plugging was a frequent occurrence, as discussed above.
- Efforts to increase the powder leakage by various procedures were unsuccessful.

6.3.3.2. Vaughan Plugging Model

During several of the PNNL tests (Reference 2.2.30 [DIRS 170832]), orifices or capillaries either plugged immediately when the sampling system was pressurized, or they became partially plugged with loss of powder flow although without complete cessation of airflow. Plugging is an important phenomenon for orifices or capillaries smaller than 1,000 μm in diameter as discussed in and indicated in the figure of Reference 2.2.31 ([DIRS 170836], pp. 507 to 508).

A simple model of plugging of pipes from aerosol deposition is discussed in this section. A simple method (Reference 2.2.31 [DIRS 170836], pp. 507 to 508) was developed to account for the decrease in the flow cross-sectional area as a result of particle deposition inside the pipe and the eventually plugging of the pipe. An expression for the time-dependent mass of the deposited particles as a function of the maximum thickness of the particles deposited on the wall was derived. The deposition rate was related to the suspended mass concentration, the volumetric flow rate, the collection efficiency, and the proportion of the pipe cross-sectional area still open. The two expressions were combined to form a final integrated expression for the total mass of aerosol carried through the pipe prior to complete plugging of the pipe. The simple model estimated the mass of the aerosol that transmitted prior to the pipe plugging to the dimensions of the pipe and a dimensional factor, K. The model given in the text of Reference 2.2.31 ([DIRS 170836], pp. 507 to 508) relates mass to K and the cube of the radius of the pipe, where K is equal to 10 g/cm^3. The figure plots the model, showing mass versus pipe diameter. When using the K equal to 10 g/cm^3, the figure is actually plotting KD^3 (Reference 2.2.31 [DIRS 170836], pp. 507 to 508).

Morewitz (Reference 2.2.32 [DIRS 170827]) also reported pipe plugging test data and attempted to correlate the data with the Vaughan plugging model. Plugging was reported for diameters ranging from 0.002 to 26.5 cm. Of the approximately 30 data points reported by Morewitz (Reference 2.2.32 [DIRS 170827]), about 25 were for pipe diameters of less than 1 cm and most pipe diameters used were less than 0.1 cm. The model used by Morewitz related the mass to the cube of the pipe diameter with a dimensional factor, K, in units of g/cm^3 (KD^3). The data for pipe bend, straight sections, different entrance conditions, and a variety of flow and aerosol conditions were combined to yield a range of values for K, equal to 30 $g/cm^3 \pm 20$. The suggested range of the K values does not include the data points for the very smallest diameters. Reference 2.2.31 ([DIRS 170836], pp. 507 to 508) noted that the simple model was derived under the assumption that the collection efficiency of the particles is independent of the particle size and gas flow rate. The factor K is assumed to be a function of the geometry of the deposited particles, the density of the particles, and the particle collection efficiency.

Reference 2.2.33 ([DIRS 170810]) also compared the Vaughan simple model of plugging, using the cube of the diameter (KD^3), with a turbulent transport model. Thus, the Vaughan plugging model, as depicted in the figure of Reference 2.2.31 ([DIRS 170836], pp. 507 to 508), and used in Reference 2.2.32 ([DIRS 170827]) and Reference 2.2.33 ([DIRS 170810]) is as follows:

$$M = KD^3 \qquad \text{(Eq. 6)}$$

where

M = aerosol mass transmitted prior to plugging (g)
K = dimensional factor (g/cm^3)
D = pipe diameter (cm)

Reference 2.2.31 ([DIRS 170836], pp. 507 to 508) reported a K value of about 10 g/cm^3 and Reference 2.2.32 ([DIRS 170827]) reported a range of K values of 30 $g/cm^3 \pm 20$. Table 6 shows the leak path factors derived using Equation 6 using K values of 10, 30 and 50 g/cm^3 with an initial mass of 3,000 g so that a comparison can be made with the Sutter et al. model in Section 6.3.3.4.

Table 6. Vaughan Plugging Model

D (mm)	K=10 g/cm^3		K=30 g/cm^3		K=50 g/cm^3	
	Mass (g)	LPF[1]	Mass (g)	LPF[1]	Mass (g)	LPF[1]
0.01	1.00×10^{-8}	3.33×10^{-12}	3.00×10^{-8}	1.00×10^{-11}	5.00×10^{-8}	1.67×10^{-11}
0.05	1.25×10^{-6}	4.17×10^{-10}	3.75×10^{-6}	1.25×10^{-9}	6.25×10^{-6}	2.08×10^{-9}
0.1	1.00×10^{-5}	3.33×10^{-9}	3.00×10^{-5}	1.00×10^{-8}	5.00×10^{-5}	1.67×10^{-8}
0.25	1.56×10^{-4}	5.21×10^{-8}	4.69×10^{-4}	1.56×10^{-7}	7.81×10^{-4}	2.60×10^{-7}
0.5	1.25×10^{-3}	4.17×10^{-7}	3.75×10^{-3}	1.25×10^{-6}	6.25×10^{-3}	2.08×10^{-6}
1	1.00×10^{-2}	3.33×10^{-6}	3.00×10^{-2}	1.00×10^{-5}	5.00×10^{-2}	1.67×10^{-5}
1.129	1.44×10^{-2}	4.80×10^{-6}	4.32×10^{-2}	1.44×10^{-5}	7.20×10^{-2}	2.40×10^{-5}
3.568	4.54×10^{-1}	1.51×10^{-4}	1.36	4.54×10^{-4}	2.27	7.57×10^{-4}
5	1.25	4.17×10^{-4}	3.75	1.25×10^{-3}	6.25	2.08×10^{-3}
10	10	3.33×10^{-3}	30	1.00×10^{-2}	50	1.67×10^{-2}

NOTE: [1] LPF is calculated from Equation 6 and an initial mass of 3,000 g.

6.3.3.3. Cask Retention Model Used in NUREG/CR-6672

NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]) documents the methodology and results of the study performed to reexamine the risks of transporting spent fuel that was documented in NUREG-0170 (Reference 2.2.20 [DIRS 101892]). Shipping casks for the transportation of spent nuclear fuel are generally available in three weight classes, legal weight truck, overweight truck, and rail, and with three gamma-shielding materials, steel, lead, and depleted uranium (Reference 2.2.12 [DIRS 152476], Section 4.1).

Finite element analyses of truck and rail casks have been performed and documented in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]). Leakage through elastomeric truck and rail cask seals due to cask impact was predicted. Based on the results of finite element analysis of cask impacting an unyielding surface and a thermal analysis from the resulting fire, a cask leak area of 1 mm^2 was assumed for truck casks with elastomer o-ring seals following a 120 mph impact (Reference 2.2.12 [DIRS 152476], Sections 7.2.5.1 and 7.2.5.2). For rail casks at the impact speed of 60 mph with a resultant fire, a leak area of 0.18 mm^2 was calculated. The leak area was increased to 1 mm^2 to be consistent with the leak area determined for the truck casks

(Reference 2.2.12 [DIRS 152476], Section 7.3.8). Event sequences involving drops or collisions at the Yucca Mountain repository are expected to result in impact forces less than the impact forces following a 60-mph impact without a subsequent fire. Therefore, the release fractions derived in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]) corresponding to a 1 mm^2 leak area can be reasonably applied to potential event sequences at the Yucca Mountain repository.

In NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]), the fractions of Kr, UO_2, TeO, CsOH, and CsI released from the interior of a Type B TN-125 cask were calculated using the MELCOR code (Reference 2.2.12 [DIRS 152476], Section 7.3.8). It was assumed that the cask was pressurized to 5 atm by failure of all of the fuel rods in the cask during a high-speed collision and then depressurizes to atmospheric pressure at a rate determined by the cask seal leak area. The results show that for leak paths with cross-sectional areas of 4 and 100 mm^2, particle deposition largely depleted the source distribution of particles with diameters larger than 10 μm (Reference 2.2.12 [DIRS 152476], Section 7.3.8). The use of the data presented in NUREG/CR-6672 for Yucca Mountain is appropriate because the train and truck casks being evaluated are used for shipping commercial spent nuclear fuel, thus the source distribution of particles would be similar. The cask-to-environment release fraction for UO_2 is plotted as a function of the size of cask seal failure (leak area) as shown in Figure 1, which is a reproduction of Figure 7.11 of Reference 2.2.12 ([DIRS 152476]). The y-axis variable, one minus cask retention fraction, shown in Figure 1, is equivalent to the leak path factor. The cask-to-environment release fraction increases as the leak area increases. This is expected since, after pressurization due to the failure of the fuel rods, cask depressurization times decrease as the cask seal leak area increases. Thus, a large leak area means a short depressurization time, little time for fuel fines and fission products to deposit on cask interior surfaces, and consequently larger cask-to-environment release fractions. In Figure 1, a cask-to-environment release fraction of 0.02 for fuel fines (UO_2) corresponds to a leak area of 1 mm^2. A cask-to-environment release fraction of 0.02, corresponding to a 1-mm^2-leak area, was used in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476], Section 7.3.8) for the releases of fuel fines during a transportation accident.

For the release of crud from a shipping cask, which are corrosion products on fuel rod surfaces, a spallation factor of 0.1 and a cask-to-environment release fraction of 0.02 were used in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476], Section 7.3.6 and 7.3.8).

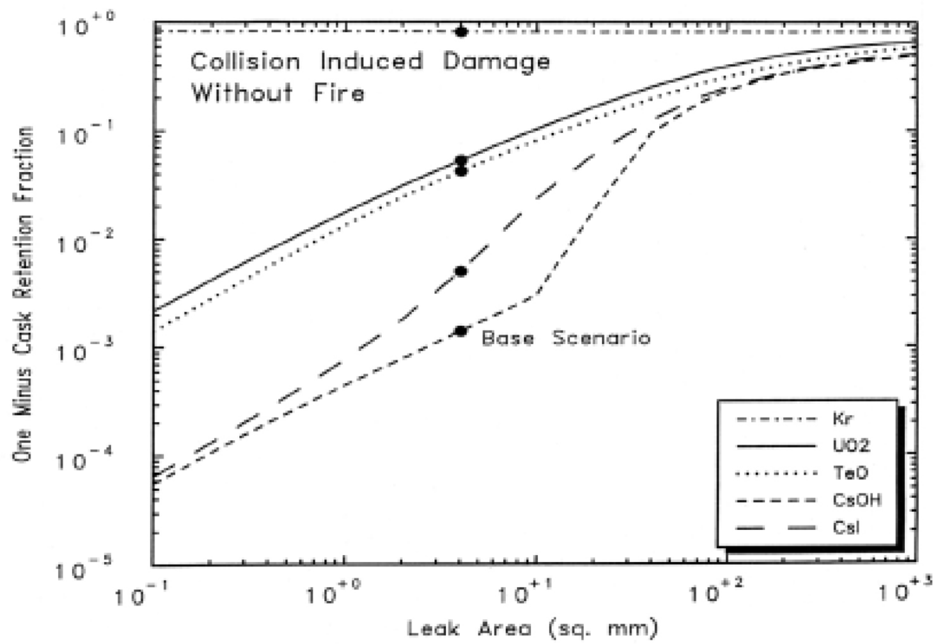
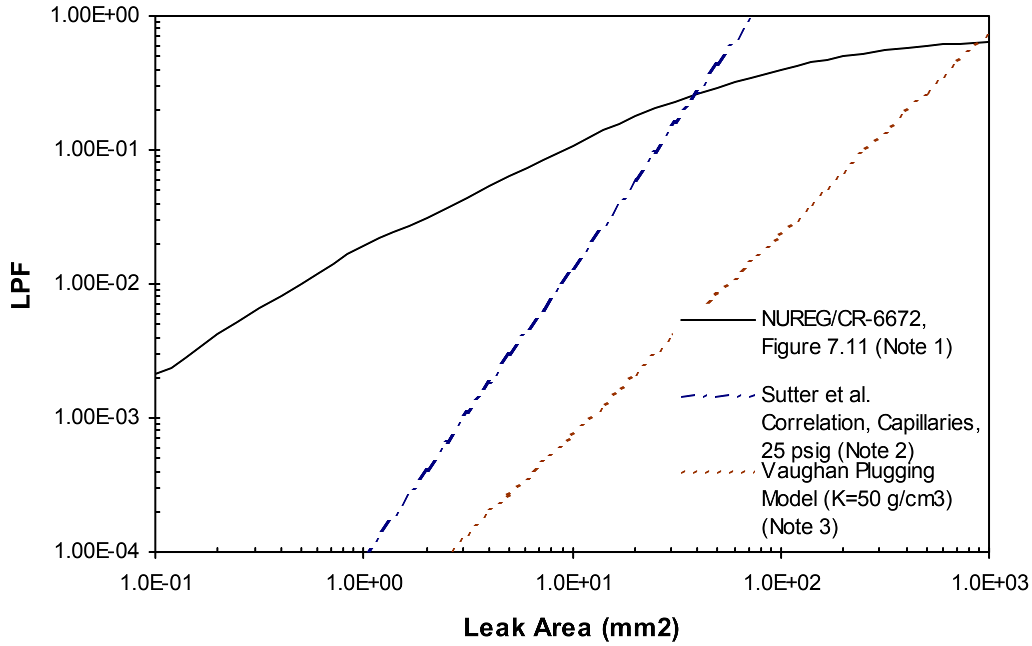


Figure 1. Dependence of Cask-to-Environment Release Fractions (leak path factors) on the Size of the Cask Failure (leak area)

As stated earlier, event sequences involving drops or collisions at the Yucca Mountain repository are expected to result in impact forces less than the impact forces following a 60-mph impact. Therefore, the release fractions derived in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]) corresponding to a 1 mm^2 leak area can be reasonably applied to potential event sequences at the Yucca Mountain repository.

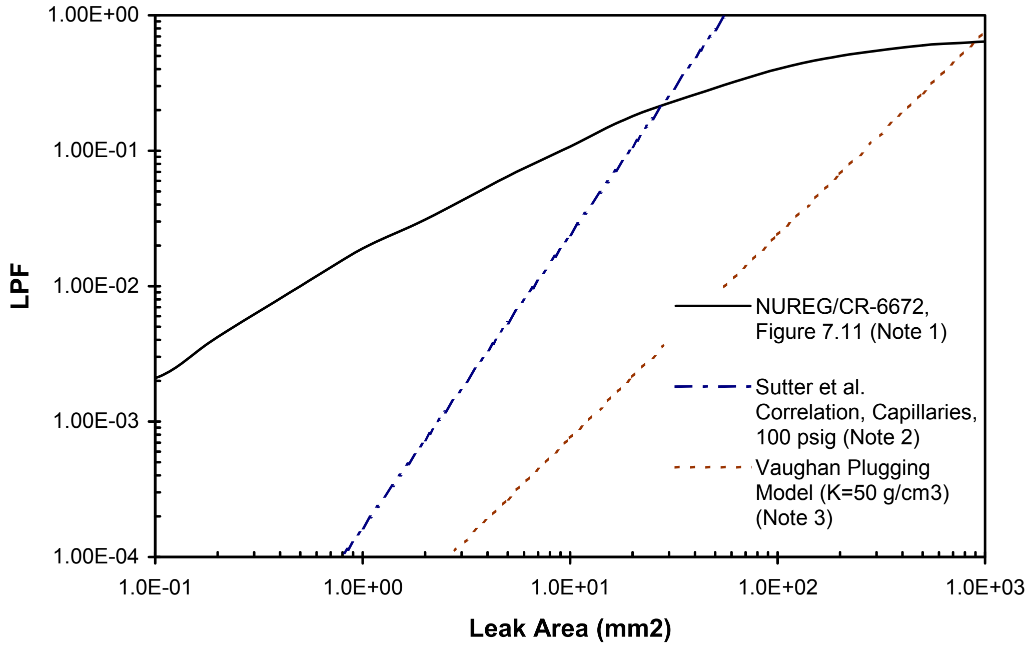
6.3.3.4. Comparisons of Models

A plot of LPF, or one minus the cask retention fraction, as a function of the leak area taken from NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476], Figure 7.11) for UO_2, as shown in Figure 1, is shown in Figure 2 and Figure 3, together with the Sutter et al. correlation using the configuration that results in the largest LPF (capillaries) (Section 6.3.3.1) and the Vaughan plugging model using the K value that gives the highest LPF (K=50 g/cm^3) (Section 6.3.3.2). The LPF reported in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]) as a function of the leak area was calculated using the MELCOR code (Reference 2.2.12 [DIRS 152476], Section 7.3.8). All three models predict that LPF increases with the increasing leak area. For the cask leak area of 1 mm^2 or smaller, the LPF reported in NUREG/CR-6672 is at least two orders of magnitude larger than the LPF values calculated by the Sutter et al. correlation or the Vaughan plugging model. The NUREG/CR-6672 LPF model is more conservative than the Sutter et al. correlation or the Vaughan plugging model primarily because the plugging phenomenon frequently observed in small orifices or capillaries are not modeled in the MELCOR code. Because of the conservatism in the MELCOR code results, a LPF calculated by the MELCOR code as reported in NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476], Section 7.3.8), is used in selecting LPF values for a shipping cask, a plutonium can, a disposable canister, a TAD canister or a waste package.



NOTES: (1) Reference 2.2.12 [DIRS 152476], Figure 7.11
(2) Reference 2.2.30 [DIRS 170832], Summary and Conclusions; Appendix B
(3) Reference 2.2.31 [DIRS 170836], pp. 507 to 508

Figure 2. Comparison of Models at 25 psig



NOTES: (1) Reference 2.2.12 [DIRS 152476], Figure 7.11
(2) Reference 2.2.30 [DIRS 170832], Summary and Conclusions; Appendix B
(3) Reference 2.2.31 [DIRS 170836], pp. 507 to 508

Figure 3. Comparison of Models at 100 psig

6.3.4. Recommendation for Casks and Canisters

Welded canisters and mechanically closed casks are used at the Yucca Mountain repository. NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476], Section 7.3.6 and 7.3.8) recommends a 1 mm^2 leak area for both a mechanically sealed, that is, bolted, train cask following a 60-mph impact with a resultant fire and a mechanically sealed truck cask following a 120 mph impact with a resultant fire. For conservatism, it is recommended that a leak area 10 times the recommended leak area of NUREG/CR-6672 (Reference 2.2.12 [DIRS 152476]) be used for potential event sequences at the repository. Applying a LPF to welded canisters that is based on a leak area that is ten times the leak area predicted for bolted casks is very conservative. Using the NUREG/CR-6672 correlation depicted in Figures 2 and 3, a leak area of 10 mm^2 results in a LPF of 0.1, which is more conservative than the LPFs predicted by the Sutter et. al. correlation (Reference 2.2.30 [DIRS 170832]) or the Vaughan Plugging model (Reference 2.2.31 [DIRS 170836], pp. 507 to 508). A LPF of 0.1 is also equal to the recommended LPF for commercial spent nuclear fuel and crud particles cited in NUREG-1864 (Reference 2.2.29 [DIRS 181343], Sections D.2.5.2.2. and D.4).

6.4 SPENT FUEL POOL

If an event occurs in the spent fuel pool of the Wet Handling Facility that results in the release of radionuclides from the fuel, the release will be directly in the pool water. NRC provides guidance to the nuclear utilities on evaluating the radiological consequences of fuel handling accidents. Since the operations involving the spent fuel pool at the repository are similar to operations in the spent fuel pool at utility sites, the NRC guidance on fuel handling accidents can be applied to an event involving the spent fuel pool of the Wet Handling Facility.

Regulatory Guide 1.25, *Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors* (Reference 2.2.34 [DIRS 107691], pg. 25.2), provides criteria for evaluating a fuel handing accident. The regulatory position provided states that all of the gap activity in the damaged rods is released and consists of 10% of the total noble gases other than Kr-85, 30% of the Kr-85, and 10% of the total radioactive iodine in the rods at the time of the accident. The iodine gap inventory is composed of inorganic species (99.75%) and organic species (0.25%). The pool decontamination factors for the inorganic and organic species are 133 and 1, respectively, giving an overall effective decontamination factor of 100, which means that 99% of the total iodine released from the damaged rods is retained by the pool water. This difference in decontamination factors for inorganic and organic iodine species results in the iodine above the fuel pool being composed of 75% inorganic and 25% organic species. The retention of noble gases in the pool is negligible. These decontamination factors are valid if the pool water depth is at least 23 ft above the damaged fuel. A summary of the guidance provided by Regulatory Guide 1.25 (Reference 2.2.34 [DIRS 107691], pg. 25.2) is given in Table 7, which also shows the resulting leak path factors, which are equivalent to one over the decontamination factors, and the fractions released from the pool, which are equivalent to the release fractions times the leak path factors.

Table 7. Recommendations from Regulatory Guide 1.25

Group	Release Fraction (RF)	Decontamination Factor (DF)	Leak Path Factor (LPF) (1/DF)	Fraction Released from Pool (RF ×LPF)
Noble Gases (other than Kr-85)	0.1	1	1	0.1
Kr-85	0.3	1	1	0.3
Iodine	0.1	100	0.01	1.0×10^{-3}
Particulates	N/A	N/A	N/A	N/A

Source: Regulatory Guide 1.25 (Reference 2.2.34 [DIRS 107691], pg. 25.2)

The Nuclear Regulatory Commission's traditional methods for calculating the radiological consequences of design basis accidents are described in a series of regulatory guides and Standard Review Plan chapters, which were developed to be consistent with the TID-14844 (Reference 2.2.35 [DIRS 178858]) source terms and whole body and thyroid dose guidelines (Reference 2.2.36 [DIRS 166293], Section A). Since the publication of TID-14844 (Reference 2.2.35 [DIRS 178858]), significant advances have been made in understanding the timing, magnitude, and chemical form of fission product releases from severe nuclear power plant accidents. In 1995, the NRC published NUREG-1465, *Accident Source Terms for Light-Water Nuclear Power Plants, Final Report* (Reference 2.2.37 [DIRS 169798]), referred to as alternative source terms. The total effective dose criteria (TEDE) are expected to be used with the alternative source terms and not with results calculated with TID-14844 source terms (Reference 2.2.36 [DIRS 166293], Section A).

Regulatory Guide 1.183, *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors* (Reference 2.2.38 [DIRS 173584], Appendix B), provides criteria for evaluating a fuel handling accident when using the alternative source terms, and the total effective dose equivalent criteria.

Reference 2.2.38 ([DIRS 173584], Appendix B) states that, upon a fuel handling accident in a pool, all of the gap activity is instantaneously released into the fuel pool. The radionuclides that should be considered include xenons, kryptons, halogens, cesiums, and rubidiums. The chemical form of radioiodine released from the fuel to the spent fuel pool should be assumed to be 95% cesium iodide (CsI), 4.85% elemental iodine, and 0.15% organic iodide. The CsI released to the pool is assumed to completely and instantaneously dissociate in the pool water and re-evolve as elemental iodine. If the depth of water above the damaged fuel is 23 feet or greater, the decontamination factors for the elemental and organic species of are 500 and 1, respectively, giving an overall effective decontamination factor of 200, which means that 99.5% of the total iodine released from the damaged rods is retained by the water. This difference in decontamination factors for elemental (99.85%) and organic (0.15%) species results in the iodine above the water being composed of 57% elemental and 43% organic species. The retention of noble gases in the water is negligible (decontamination factor of 1). The pool water retains all particulate radionuclides.

These retention or decontamination factors given in Regulatory Guide 1.183 (Reference 2.2.38 [DIRS 173584], Appendix B) are applicable only when using the release fractions provided in Section 3 of the Regulatory Guide 1.183. A summary of the guidance provided by Regulatory Guide 1.183 (Reference 2.2.38 [DIRS 173584], Section 3 and Appendix B) is given in Table 8.

Table 8. Recommendations from Regulatory Guide 1.183

Group	Release Fraction (RF)	Decontamination Factor (DF)	Leak Path Factor (LPF) (1/DF)	Fraction Released from Pool (RF ×LPF)
I-131	0.08	200	0.005	4.0×10^{-4}
Kr-85	0.10	1	1	0.10
Other Noble Gases (Xe, Kr)	0.05	1	1	0.05
Other Halogens (I)	0.05	200	0.005	2.5×10^{-4}
Other Halogens (Br)	0.05	1*	1	0.05
Alkali Metals (Cs, Rb)	0.12	Infinite	0	0

NOTE: *Not specified, thus one (1) is used.
Source: Reference 2.2.38 ([DIRS 173584], Section 3 and Appendix B)

Since 10 CFR Part 63 (Reference 2.2.39 [DIRS 176544]) provides dose criteria in terms of TEDE, the guidance of Regulatory Guide 1.25 (Reference 2.2.34 [DIRS 107691]) shown in

Table 7, is not applicable. The guidance of Regulatory Guide 1.183 (Reference 2.2.38 [DIRS 173584], Section 3 and Appendix B) as shown in Table 8 is used since it provides criteria for evaluating a fuel handling accident when using the alternative source terms, and the total effective dose equivalent criteria.

7. RESULTS AND CONCLUSIONS

The following leak path factors are to be used in dose assessments.

7.1 HEPA FILTERS

A $(LPF)_{HEPA}$ of 0.01 per stage for particulate and cesium, which is equivalent to a HEPA removal efficiency of 99% per stage is to be used for normal operations and event sequences. For a two-stage HEPA filtration system, this gives a combined efficiency of 99.99% for two stages or a $(LPF)_{HEPA}$ of 10^{-4} when the series of HEPA filters is protected by pre-filters, sprinklers, and demisters. Refer to Section 6.1 for the discussion of the $(LPF)_{HEPA}$.

7.2 SPENT FUEL CLADDING

No LPF for fuel cladding is given in this calculation. Refer to Section 6.2 for further discussion.

7.3 TRANSPORTATION CASKS AND CANISTERS

It is recommended that a LPF of 0.1 be used for canisters, such as DPCs and TADs, and for transportation casks and waste packages. Refer to Section 6.3 for the rationale.

7.4 SPENT FUEL POOL

The leak path factors for the nuclides potentially released in the spent fuel pool are listed in Table 9. Refer to Section 6.4 for further discussion.

Table 9. Spent Fuel Pool Leak Path Factors

Group	Leak Path Factor (LPF)
I-131	0.005
Kr-85	1
Other Noble Gases (Xe, Kr)	1
Other Halogens (I)	0.005
Other Halogens (Br)	1
Alkali Metals (Cs, Rb)	0

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ATTACHMENT I.

SUTTER ET AL. LEAK PATH FACTOR TABLES

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Microsoft® EXCEL spreadsheet calculations have been performed using Equations (4) and (5) to calculate the mass and fraction of DUO leaked out of the test vessel for leak areas ranging from 0.01 mm to 10 mm and pressures at 0, 25, 50 and 100 psig. The fraction of DOU leaked out of the test vessel is the leak path factor for particulate. The leak path factor is calculated based on an initial DUO inventory of 3 kg. The parameters a, b_1, and b_2 are from Table 5. The calculation results are summarized in Tables I-1 through I-16.

Table I-1. Leak Path Factor for UPL Orifices at 0 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-10.2848	1.608	0.0449	0.01	7.85×10^{-05}	0	3.81×10^{-08}	1.27×10^{-11}
-10.2848	1.608	0.0449	0.03	7.07×10^{-04}	0	1.30×10^{-06}	4.34×10^{-10}
-10.2848	1.608	0.0449	0.05	1.96×10^{-03}	0	6.74×10^{-06}	2.25×10^{-09}
-10.2848	1.608	0.0449	0.07	3.85×10^{-03}	0	1.99×10^{-05}	6.63×10^{-09}
-10.2848	1.608	0.0449	0.1	7.85×10^{-03}	0	6.26×10^{-05}	2.09×10^{-08}
-10.2848	1.608	0.0449	0.25	4.91×10^{-02}	0	1.19×10^{-03}	3.97×10^{-07}
-10.2848	1.608	0.0449	0.3	7.07×10^{-02}	0	2.14×10^{-03}	7.14×10^{-07}
-10.2848	1.608	0.0449	0.5	1.96×10^{-01}	0	1.11×10^{-02}	3.69×10^{-06}
-10.2848	1.608	0.0449	0.7	3.85×10^{-01}	0	3.27×10^{-02}	1.09×10^{-05}
-10.2848	1.608	0.0449	1	7.85×10^{-01}	0	1.03×10^{-01}	3.43×10^{-05}
-10.2848	1.608	0.0449	1.129	$1.00 \times 10^{+00}$	0	1.52×10^{-01}	5.07×10^{-05}
-10.2848	1.608	0.0449	3.568	$1.00 \times 10^{+01}$	0	$6.16 \times 10^{+00}$	2.05×10^{-03}
-10.2848	1.608	0.0449	5	$1.96 \times 10^{+01}$	0	$1.82 \times 10^{+01}$	6.07×10^{-03}
-10.2848	1.608	0.0449	7	$3.85 \times 10^{+01}$	0	$5.38 \times 10^{+01}$	1.79×10^{-02}
-10.2848	1.608	0.0449	10	$7.85 \times 10^{+01}$	0	$1.69 \times 10^{+02}$	5.64×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-2. Leak Path Factor for UPL Orifices at 25 psig

a	b1	b2	D (mm)	A (mm2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-10.2848	1.608	0.0449	0.01	7.85×10^{-05}	25	4.77×10^{-08}	1.59×10^{-11}
-10.2848	1.608	0.0449	0.03	7.07×10^{-04}	25	1.63×10^{-06}	5.44×10^{-10}
-10.2848	1.608	0.0449	0.05	1.96×10^{-03}	25	8.43×10^{-06}	2.81×10^{-09}
-10.2848	1.608	0.0449	0.07	3.85×10^{-03}	25	2.49×10^{-05}	8.30×10^{-09}
-10.2848	1.608	0.0449	0.1	7.85×10^{-03}	25	7.84×10^{-05}	2.61×10^{-08}
-10.2848	1.608	0.0449	0.25	4.91×10^{-02}	25	1.49×10^{-03}	4.98×10^{-07}
-10.2848	1.608	0.0449	0.3	7.07×10^{-02}	25	2.68×10^{-03}	8.94×10^{-07}
-10.2848	1.608	0.0449	0.5	1.96×10^{-01}	25	1.39×10^{-02}	4.62×10^{-06}
-10.2848	1.608	0.0449	0.7	3.85×10^{-01}	25	4.09×10^{-02}	1.36×10^{-05}
-10.2848	1.608	0.0449	1	7.85×10^{-01}	25	1.29×10^{-01}	4.30×10^{-05}
-10.2848	1.608	0.0449	1.129	$1.00 \times 10^{+00}$	25	1.90×10^{-01}	6.35×10^{-05}
-10.2848	1.608	0.0449	3.568	$1.00 \times 10^{+01}$	25	$7.70 \times 10^{+00}$	2.57×10^{-03}
-10.2848	1.608	0.0449	5	$1.96 \times 10^{+01}$	25	$2.28 \times 10^{+01}$	7.60×10^{-03}
-10.2848	1.608	0.0449	7	$3.85 \times 10^{+01}$	25	$6.73 \times 10^{+01}$	2.24×10^{-02}
-10.2848	1.608	0.0449	10	$7.85 \times 10^{+01}$	25	$2.12 \times 10^{+02}$	7.06×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-3. Leak Path Factor for UPL Orifices at 50 psig

a	b1	b2	D (mm)	A (mm2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-10.2848	1.608	0.0449	0.01	7.85×10^{-05}	50	5.23×10^{-08}	1.74×10^{-11}
-10.2848	1.608	0.0449	0.03	7.07×10^{-04}	50	1.79×10^{-06}	5.97×10^{-10}
-10.2848	1.608	0.0449	0.05	1.96×10^{-03}	50	9.26×10^{-06}	3.09×10^{-09}
-10.2848	1.608	0.0449	0.07	3.85×10^{-03}	50	2.73×10^{-05}	9.10×10^{-09}
-10.2848	1.608	0.0449	0.1	7.85×10^{-03}	50	8.60×10^{-05}	2.87×10^{-08}
-10.2848	1.608	0.0449	0.25	4.91×10^{-02}	50	1.64×10^{-03}	5.46×10^{-07}
-10.2848	1.608	0.0449	0.3	7.07×10^{-02}	50	2.94×10^{-03}	9.81×10^{-07}
-10.2848	1.608	0.0449	0.5	1.96×10^{-01}	50	1.52×10^{-02}	5.07×10^{-06}
-10.2848	1.608	0.0449	0.7	3.85×10^{-01}	50	4.49×10^{-02}	1.50×10^{-05}
-10.2848	1.608	0.0449	1	7.85×10^{-01}	50	1.41×10^{-01}	4.71×10^{-05}
-10.2848	1.608	0.0449	1.129	$1.00 \times 10^{+00}$	50	2.09×10^{-01}	6.96×10^{-05}
-10.2848	1.608	0.0449	3.568	$1.00 \times 10^{+01}$	50	$8.46 \times 10^{+00}$	2.82×10^{-03}
-10.2848	1.608	0.0449	5	$1.96 \times 10^{+01}$	50	$2.50 \times 10^{+01}$	8.34×10^{-03}
-10.2848	1.608	0.0449	7	$3.85 \times 10^{+01}$	50	$7.39 \times 10^{+01}$	2.46×10^{-02}
-10.2848	1.608	0.0449	10	$7.85 \times 10^{+01}$	50	$2.33 \times 10^{+02}$	7.75×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-4. Leak Path Factor for UPL Orifices at 100 psig

a	b1	b2	D (mm)	A (mm2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-10.2848	1.608	0.0449	0.01	7.85×10^{-05}	100	5.97×10^{-08}	1.99×10^{-11}
-10.2848	1.608	0.0449	0.03	7.07×10^{-04}	100	2.04×10^{-06}	6.81×10^{-10}
-10.2848	1.608	0.0449	0.05	1.96×10^{-03}	100	1.06×10^{-05}	3.52×10^{-09}
-10.2848	1.608	0.0449	0.07	3.85×10^{-03}	100	3.12×10^{-05}	1.04×10^{-08}
-10.2848	1.608	0.0449	0.1	7.85×10^{-03}	100	9.81×10^{-05}	3.27×10^{-08}
-10.2848	1.608	0.0449	0.25	4.91×10^{-02}	100	1.87×10^{-03}	6.23×10^{-07}
-10.2848	1.608	0.0449	0.3	7.07×10^{-02}	100	3.36×10^{-03}	1.12×10^{-06}
-10.2848	1.608	0.0449	0.5	1.96×10^{-01}	100	1.74×10^{-02}	5.79×10^{-06}
-10.2848	1.608	0.0449	0.7	3.85×10^{-01}	100	5.12×10^{-02}	1.71×10^{-05}
-10.2848	1.608	0.0449	1	7.85×10^{-01}	100	1.61×10^{-01}	5.38×10^{-05}
-10.2848	1.608	0.0449	1.129	$1.00 \times 10^{+00}$	100	2.38×10^{-01}	7.94×10^{-05}
-10.2848	1.608	0.0449	3.568	$1.00 \times 10^{+01}$	100	$9.64 \times 10^{+00}$	3.21×10^{-03}
-10.2848	1.608	0.0449	5	$1.96 \times 10^{+01}$	100	$2.85 \times 10^{+01}$	9.52×10^{-03}
-10.2848	1.608	0.0449	7	$3.85 \times 10^{+01}$	100	$8.42 \times 10^{+01}$	2.81×10^{-02}
-10.2848	1.608	0.0449	10	$7.85 \times 10^{+01}$	100	$2.65 \times 10^{+02}$	8.84×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-5. Leak Path Factor for APLA Orifices at 0 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.1959	1.7906	0.1095	0.01	7.85×10^{-05}	0	1.69×10^{-09}	5.64×10^{-13}
-14.1959	1.7906	0.1095	0.03	7.07×10^{-04}	0	8.65×10^{-08}	2.88×10^{-11}
-14.1959	1.7906	0.1095	0.05	1.96×10^{-03}	0	5.39×10^{-07}	1.80×10^{-10}
-14.1959	1.7906	0.1095	0.07	3.85×10^{-03}	0	1.80×10^{-06}	5.99×10^{-10}
-14.1959	1.7906	0.1095	0.1	7.85×10^{-03}	0	6.45×10^{-06}	2.15×10^{-09}
-14.1959	1.7906	0.1095	0.25	4.91×10^{-02}	0	1.72×10^{-04}	5.72×10^{-08}
-14.1959	1.7906	0.1095	0.3	7.07×10^{-02}	0	3.30×10^{-04}	1.10×10^{-07}
-14.1959	1.7906	0.1095	0.5	1.96×10^{-01}	0	2.05×10^{-03}	6.85×10^{-07}
-14.1959	1.7906	0.1095	0.7	3.85×10^{-01}	0	6.85×10^{-03}	2.28×10^{-06}
-14.1959	1.7906	0.1095	1	7.85×10^{-01}	0	2.46×10^{-02}	8.19×10^{-06}
-14.1959	1.7906	0.1095	1.129	$1.00 \times 10^{+00}$	0	3.80×10^{-02}	1.27×10^{-05}
-14.1959	1.7906	0.1095	3.568	$1.00 \times 10^{+01}$	0	$2.34 \times 10^{+00}$	7.79×10^{-04}
-14.1959	1.7906	0.1095	5	$1.96 \times 10^{+01}$	0	$7.83 \times 10^{+00}$	2.61×10^{-03}
-14.1959	1.7906	0.1095	7	$3.85 \times 10^{+01}$	0	$2.61 \times 10^{+01}$	8.71×10^{-03}
-14.1959	1.7906	0.1095	10	$7.85 \times 10^{+01}$	0	$9.37 \times 10^{+01}$	3.12×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-6. Leak Path Factor for APLA Orifices at 25 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.1959	1.7906	0.1095	0.01	7.85×10^{-05}	25	2.92×10^{-09}	9.75×10^{-13}
-14.1959	1.7906	0.1095	0.03	7.07×10^{-04}	25	1.49×10^{-07}	4.98×10^{-11}
-14.1959	1.7906	0.1095	0.05	1.96×10^{-03}	25	9.31×10^{-07}	3.10×10^{-10}
-14.1959	1.7906	0.1095	0.07	3.85×10^{-03}	25	3.11×10^{-06}	1.04×10^{-09}
-14.1959	1.7906	0.1095	0.1	7.85×10^{-03}	25	1.11×10^{-05}	3.72×10^{-09}
-14.1959	1.7906	0.1095	0.25	4.91×10^{-02}	25	2.97×10^{-04}	9.89×10^{-08}
-14.1959	1.7906	0.1095	0.3	7.07×10^{-02}	25	5.70×10^{-04}	1.90×10^{-07}
-14.1959	1.7906	0.1095	0.5	1.96×10^{-01}	25	3.55×10^{-03}	1.18×10^{-06}
-14.1959	1.7906	0.1095	0.7	3.85×10^{-01}	25	1.18×10^{-02}	3.95×10^{-06}
-14.1959	1.7906	0.1095	1	7.85×10^{-01}	25	4.25×10^{-02}	1.42×10^{-05}
-14.1959	1.7906	0.1095	1.129	$1.00 \times 10^{+00}$	25	6.56×10^{-02}	2.19×10^{-05}
-14.1959	1.7906	0.1095	3.568	$1.00 \times 10^{+01}$	25	$4.04 \times 10^{+00}$	1.35×10^{-03}
-14.1959	1.7906	0.1095	5	$1.96 \times 10^{+01}$	25	$1.35 \times 10^{+01}$	4.51×10^{-03}
-14.1959	1.7906	0.1095	7	$3.85 \times 10^{+01}$	25	$4.52 \times 10^{+01}$	1.51×10^{-02}
-14.1959	1.7906	0.1095	10	$7.85 \times 10^{+01}$	25	$1.62 \times 10^{+02}$	5.40×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-7. Leak Path Factor for APLA Orifices at 50 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.1959	1.7906	0.1095	0.01	7.85×10^{-05}	50	3.67×10^{-09}	1.22×10^{-12}
-14.1959	1.7906	0.1095	0.03	7.07×10^{-04}	50	1.88×10^{-07}	6.25×10^{-11}
-14.1959	1.7906	0.1095	0.05	1.96×10^{-03}	50	1.17×10^{-06}	3.89×10^{-10}
-14.1959	1.7906	0.1095	0.07	3.85×10^{-03}	50	3.90×10^{-06}	1.30×10^{-09}
-14.1959	1.7906	0.1095	0.1	7.85×10^{-03}	50	1.40×10^{-05}	4.66×10^{-09}
-14.1959	1.7906	0.1095	0.25	4.91×10^{-02}	50	3.72×10^{-04}	1.24×10^{-07}
-14.1959	1.7906	0.1095	0.3	7.07×10^{-02}	50	7.15×10^{-04}	2.38×10^{-07}
-14.1959	1.7906	0.1095	0.5	1.96×10^{-01}	50	4.45×10^{-03}	1.48×10^{-06}
-14.1959	1.7906	0.1095	0.7	3.85×10^{-01}	50	1.49×10^{-02}	4.95×10^{-06}
-14.1959	1.7906	0.1095	1	7.85×10^{-01}	50	5.33×10^{-02}	1.78×10^{-05}
-14.1959	1.7906	0.1095	1.129	$1.00 \times 10^{+00}$	50	8.23×10^{-02}	2.74×10^{-05}
-14.1959	1.7906	0.1095	3.568	$1.00 \times 10^{+01}$	50	$5.07 \times 10^{+00}$	1.69×10^{-03}
-14.1959	1.7906	0.1095	5	$1.96 \times 10^{+01}$	50	$1.70 \times 10^{+01}$	5.66×10^{-03}
-14.1959	1.7906	0.1095	7	$3.85 \times 10^{+01}$	50	$5.67 \times 10^{+01}$	1.89×10^{-02}
-14.1959	1.7906	0.1095	10	$7.85 \times 10^{+01}$	50	$2.03 \times 10^{+02}$	6.77×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-8. Leak Path Factor for APLA Orifices at 100 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.1959	1.7906	0.1095	0.01	7.85×10^{-05}	100	5.05×10^{-09}	1.68×10^{-12}
-14.1959	1.7906	0.1095	0.03	7.07×10^{-04}	100	2.58×10^{-07}	8.61×10^{-11}
-14.1959	1.7906	0.1095	0.05	1.96×10^{-03}	100	1.61×10^{-06}	5.37×10^{-10}
-14.1959	1.7906	0.1095	0.07	3.85×10^{-03}	100	5.37×10^{-06}	1.79×10^{-09}
-14.1959	1.7906	0.1095	0.1	7.85×10^{-03}	100	1.93×10^{-05}	6.42×10^{-09}
-14.1959	1.7906	0.1095	0.25	4.91×10^{-02}	100	5.13×10^{-04}	1.71×10^{-07}
-14.1959	1.7906	0.1095	0.3	7.07×10^{-02}	100	9.85×10^{-04}	3.28×10^{-07}
-14.1959	1.7906	0.1095	0.5	1.96×10^{-01}	100	6.14×10^{-03}	2.05×10^{-06}
-14.1959	1.7906	0.1095	0.7	3.85×10^{-01}	100	2.05×10^{-02}	6.83×10^{-06}
-14.1959	1.7906	0.1095	1	7.85×10^{-01}	100	7.35×10^{-02}	2.45×10^{-05}
-14.1959	1.7906	0.1095	1.129	$1.00 \times 10^{+00}$	100	1.13×10^{-01}	3.78×10^{-05}
-14.1959	1.7906	0.1095	3.568	$1.00 \times 10^{+01}$	100	$6.99 \times 10^{+00}$	2.33×10^{-03}
-14.1959	1.7906	0.1095	5	$1.96 \times 10^{+01}$	100	$2.34 \times 10^{+01}$	7.80×10^{-03}
-14.1959	1.7906	0.1095	7	$3.85 \times 10^{+01}$	100	$7.81 \times 10^{+01}$	2.60×10^{-02}
-14.1959	1.7906	0.1095	10	$7.85 \times 10^{+01}$	100	$2.80 \times 10^{+02}$	9.34×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-9. Leak Path Factor for Capillaries at 0 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-17.9875	2.1658	0.117	0.01	7.85×10^{-05}	0	1.96×10^{-10}	6.54×10^{-14}
-17.9875	2.1658	0.117	0.03	7.07×10^{-04}	0	2.29×10^{-08}	7.62×10^{-12}
-17.9875	2.1658	0.117	0.05	1.96×10^{-03}	0	2.09×10^{-07}	6.97×10^{-11}
-17.9875	2.1658	0.117	0.07	3.85×10^{-03}	0	8.98×10^{-07}	2.99×10^{-10}
-17.9875	2.1658	0.117	0.1	7.85×10^{-03}	0	4.21×10^{-06}	1.40×10^{-09}
-17.9875	2.1658	0.117	0.25	4.91×10^{-02}	0	2.23×10^{-04}	7.43×10^{-08}
-17.9875	2.1658	0.117	0.3	7.07×10^{-02}	0	4.91×10^{-04}	1.64×10^{-07}
-17.9875	2.1658	0.117	0.5	1.96×10^{-01}	0	4.49×10^{-03}	1.50×10^{-06}
-17.9875	2.1658	0.117	0.7	3.85×10^{-01}	0	1.93×10^{-02}	6.42×10^{-06}
-17.9875	2.1658	0.117	1	7.85×10^{-01}	0	9.03×10^{-02}	3.01×10^{-05}
-17.9875	2.1658	0.117	1.129	$1.00 \times 10^{+00}$	0	1.53×10^{-01}	5.09×10^{-05}
-17.9875	2.1658	0.117	3.568	$1.00 \times 10^{+01}$	0	$2.23 \times 10^{+01}$	7.44×10^{-03}
-17.9875	2.1658	0.117	5	$1.96 \times 10^{+01}$	0	$9.62 \times 10^{+01}$	3.21×10^{-02}
-17.9875	2.1658	0.117	7	$3.85 \times 10^{+01}$	0	$4.13 \times 10^{+02}$	1.38×10^{-01}
-17.9875	2.1658	0.117	10	$7.85 \times 10^{+01}$	0	$1.94 \times 10^{+03}$	6.46×10^{-01}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-10. Leak Path Factor for Capillaries at 25 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-17.9875	2.1658	0.117	0.01	7.85×10^{-05}	25	3.52×10^{-10}	1.17×10^{-13}
-17.9875	2.1658	0.117	0.03	7.07×10^{-04}	25	4.10×10^{-08}	1.37×10^{-11}
-17.9875	2.1658	0.117	0.05	1.96×10^{-03}	25	3.75×10^{-07}	1.25×10^{-10}
-17.9875	2.1658	0.117	0.07	3.85×10^{-03}	25	1.61×10^{-06}	5.37×10^{-10}
-17.9875	2.1658	0.117	0.1	7.85×10^{-03}	25	7.55×10^{-06}	2.52×10^{-09}
-17.9875	2.1658	0.117	0.25	4.91×10^{-02}	25	4.00×10^{-04}	1.33×10^{-07}
-17.9875	2.1658	0.117	0.3	7.07×10^{-02}	25	8.81×10^{-04}	2.94×10^{-07}
-17.9875	2.1658	0.117	0.5	1.96×10^{-01}	25	8.05×10^{-03}	2.68×10^{-06}
-17.9875	2.1658	0.117	0.7	3.85×10^{-01}	25	3.46×10^{-02}	1.15×10^{-05}
-17.9875	2.1658	0.117	1	7.85×10^{-01}	25	1.62×10^{-01}	5.40×10^{-05}
-17.9875	2.1658	0.117	1.129	$1.00 \times 10^{+00}$	25	2.74×10^{-01}	9.14×10^{-05}
-17.9875	2.1658	0.117	3.568	$1.00 \times 10^{+01}$	25	$4.01 \times 10^{+01}$	1.34×10^{-02}
-17.9875	2.1658	0.117	5	$1.96 \times 10^{+01}$	25	$1.73 \times 10^{+02}$	5.76×10^{-02}
-17.9875	2.1658	0.117	7	$3.85 \times 10^{+01}$	25	$7.42 \times 10^{+02}$	2.47×10^{-01}
-17.9875	2.1658	0.117	10	$7.85 \times 10^{+01}$	25	$3.48 \times 10^{+03}$	Not Calculated

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-11. Leak Path Factor for Capillaries at 50 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-17.9875	2.1658	0.117	0.01	7.85×10^{-05}	50	4.49×10^{-10}	1.50×10^{-13}
-17.9875	2.1658	0.117	0.03	7.07×10^{-04}	50	5.23×10^{-08}	1.74×10^{-11}
-17.9875	2.1658	0.117	0.05	1.96×10^{-03}	50	4.78×10^{-07}	1.59×10^{-10}
-17.9875	2.1658	0.117	0.07	3.85×10^{-03}	50	2.05×10^{-06}	6.84×10^{-10}
-17.9875	2.1658	0.117	0.1	7.85×10^{-03}	50	9.63×10^{-06}	3.21×10^{-09}
-17.9875	2.1658	0.117	0.25	4.91×10^{-02}	50	5.09×10^{-04}	1.70×10^{-07}
-17.9875	2.1658	0.117	0.3	7.07×10^{-02}	50	1.12×10^{-03}	3.74×10^{-07}
-17.9875	2.1658	0.117	0.5	1.96×10^{-01}	50	1.03×10^{-02}	3.42×10^{-06}
-17.9875	2.1658	0.117	0.7	3.85×10^{-01}	50	4.41×10^{-02}	1.47×10^{-05}
-17.9875	2.1658	0.117	1	7.85×10^{-01}	50	2.07×10^{-01}	6.88×10^{-05}
-17.9875	2.1658	0.117	1.129	$1.00 \times 10^{+00}$	50	3.49×10^{-01}	1.16×10^{-04}
-17.9875	2.1658	0.117	3.568	$1.00 \times 10^{+01}$	50	$5.10 \times 10^{+01}$	1.70×10^{-02}
-17.9875	2.1658	0.117	5	$1.96 \times 10^{+01}$	50	$2.20 \times 10^{+02}$	7.34×10^{-02}
-17.9875	2.1658	0.117	7	$3.85 \times 10^{+01}$	50	$9.45 \times 10^{+02}$	3.15×10^{-01}
-17.9875	2.1658	0.117	10	$7.85 \times 10^{+01}$	50	$4.43 \times 10^{+03}$	Not Calculated

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-12. Leak Path Factor for Capillaries at 100 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-17.9875	2.1658	0.117	0.01	7.85×10^{-05}	100	6.32×10^{-10}	2.11×10^{-13}
-17.9875	2.1658	0.117	0.03	7.07×10^{-04}	100	7.37×10^{-08}	2.46×10^{-11}
-17.9875	2.1658	0.117	0.05	1.96×10^{-03}	100	6.73×10^{-07}	2.24×10^{-10}
-17.9875	2.1658	0.117	0.07	3.85×10^{-03}	100	2.89×10^{-06}	9.64×10^{-10}
-17.9875	2.1658	0.117	0.1	7.85×10^{-03}	100	1.36×10^{-05}	4.52×10^{-09}
-17.9875	2.1658	0.117	0.25	4.91×10^{-02}	100	7.18×10^{-04}	2.39×10^{-07}
-17.9875	2.1658	0.117	0.3	7.07×10^{-02}	100	1.58×10^{-03}	5.27×10^{-07}
-17.9875	2.1658	0.117	0.5	1.96×10^{-01}	100	1.45×10^{-02}	4.82×10^{-06}
-17.9875	2.1658	0.117	0.7	3.85×10^{-01}	100	6.21×10^{-02}	2.07×10^{-05}
-17.9875	2.1658	0.117	1	7.85×10^{-01}	100	2.91×10^{-01}	9.70×10^{-05}
-17.9875	2.1658	0.117	1.129	$1.00 \times 10^{+00}$	100	4.92×10^{-01}	1.64×10^{-04}
-17.9875	2.1658	0.117	3.568	$1.00 \times 10^{+01}$	100	$7.19 \times 10^{+01}$	2.40×10^{-02}
-17.9875	2.1658	0.117	5	$1.96 \times 10^{+01}$	100	$3.10 \times 10^{+02}$	1.03×10^{-01}
-17.9875	2.1658	0.117	7	$3.85 \times 10^{+01}$	100	$1.33 \times 10^{+03}$	4.44×10^{-01}
-17.9875	2.1658	0.117	10	$7.85 \times 10^{+01}$	100	$6.24 \times 10^{+03}$	Not Calculated

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-13. Leak Path Factor for Unspecified Configuration at 0 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.279	1.828	0.1052	0.01	7.85×10^{-05}	0	1.83×10^{-09}	6.11×10^{-13}
-14.279	1.828	0.1052	0.03	7.07×10^{-04}	0	1.02×10^{-07}	3.39×10^{-11}
-14.279	1.828	0.1052	0.05	1.96×10^{-03}	0	6.58×10^{-07}	2.19×10^{-10}
-14.279	1.828	0.1052	0.07	3.85×10^{-03}	0	2.25×10^{-06}	7.51×10^{-10}
-14.279	1.828	0.1052	0.1	7.85×10^{-03}	0	8.30×10^{-06}	2.77×10^{-09}
-14.279	1.828	0.1052	0.25	4.91×10^{-02}	0	2.36×10^{-04}	7.88×10^{-08}
-14.279	1.828	0.1052	0.3	7.07×10^{-02}	0	4.61×10^{-04}	1.54×10^{-07}
-14.279	1.828	0.1052	0.5	1.96×10^{-01}	0	2.98×10^{-03}	9.94×10^{-07}
-14.279	1.828	0.1052	0.7	3.85×10^{-01}	0	1.02×10^{-02}	3.40×10^{-06}
-14.279	1.828	0.1052	1	7.85×10^{-01}	0	3.76×10^{-02}	1.25×10^{-05}
-14.279	1.828	0.1052	1.129	$1.00 \times 10^{+00}$	0	5.86×10^{-02}	1.95×10^{-05}
-14.279	1.828	0.1052	3.568	$1.00 \times 10^{+01}$	0	$3.93 \times 10^{+00}$	1.31×10^{-03}
-14.279	1.828	0.1052	5	$1.96 \times 10^{+01}$	0	$1.35 \times 10^{+01}$	4.50×10^{-03}
-14.279	1.828	0.1052	7	$3.85 \times 10^{+01}$	0	$4.62 \times 10^{+01}$	1.54×10^{-02}
-14.279	1.828	0.1052	10	$7.85 \times 10^{+01}$	0	$1.70 \times 10^{+02}$	5.67×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-14: Leak Path Factor for Unspecified Configuration at 25 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.279	1.828	0.1052	0.01	7.85×10^{-05}	25	3.10×10^{-09}	1.03×10^{-12}
-14.279	1.828	0.1052	0.03	7.07×10^{-04}	25	1.72×10^{-07}	5.74×10^{-11}
-14.279	1.828	0.1052	0.05	1.96×10^{-03}	25	1.11×10^{-06}	3.71×10^{-10}
-14.279	1.828	0.1052	0.07	3.85×10^{-03}	25	3.81×10^{-06}	1.27×10^{-09}
-14.279	1.828	0.1052	0.1	7.85×10^{-03}	25	1.40×10^{-05}	4.68×10^{-09}
-14.279	1.828	0.1052	0.25	4.91×10^{-02}	25	4.00×10^{-04}	1.33×10^{-07}
-14.279	1.828	0.1052	0.3	7.07×10^{-02}	25	7.79×10^{-04}	2.60×10^{-07}
-14.279	1.828	0.1052	0.5	1.96×10^{-01}	25	5.04×10^{-03}	1.68×10^{-06}
-14.279	1.828	0.1052	0.7	3.85×10^{-01}	25	1.73×10^{-02}	5.75×10^{-06}
-14.279	1.828	0.1052	1	7.85×10^{-01}	25	6.36×10^{-02}	2.12×10^{-05}
-14.279	1.828	0.1052	1.129	$1.00 \times 10^{+00}$	25	9.91×10^{-02}	3.30×10^{-05}
-14.279	1.828	0.1052	3.568	$1.00 \times 10^{+01}$	25	$6.65 \times 10^{+00}$	2.22×10^{-03}
-14.279	1.828	0.1052	5	$1.96 \times 10^{+01}$	25	$2.28 \times 10^{+01}$	$7.6 2 \times 10^{-03}$
-14.279	1.828	0.1052	7	$3.85 \times 10^{+01}$	25	$7.82 \times 10^{+01}$	2.61×10^{-02}
-14.279	1.828	0.1052	10	$7.85 \times 10^{+01}$	25	$2.88 \times 10^{+02}$	9.60×10^{-02}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-15: Leak Path Factor for Unspecified Configuration at 50 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.279	1.828	0.1052	0.01	7.85×10^{-05}	50	3.85×10^{-09}	1.28×10^{-12}
-14.279	1.828	0.1052	0.03	7.07×10^{-04}	50	2.14×10^{-07}	7.13×10^{-11}
-14.279	1.828	0.1052	0.05	1.96×10^{-03}	50	1.38×10^{-06}	4.62×10^{-10}
-14.279	1.828	0.1052	0.07	3.85×10^{-03}	50	4.74×10^{-06}	1.58×10^{-09}
-14.279	1.828	0.1052	0.1	7.85×10^{-03}	50	1.75×10^{-05}	5.82×10^{-09}
-14.279	1.828	0.1052	0.25	4.91×10^{-02}	50	4.98×10^{-04}	1.66×10^{-07}
-14.279	1.828	0.1052	0.3	7.07×10^{-02}	50	9.69×10^{-04}	3.23×10^{-07}
-14.279	1.828	0.1052	0.5	1.96×10^{-01}	50	6.27×10^{-03}	2.09×10^{-06}
-14.279	1.828	0.1052	0.7	3.85×10^{-01}	50	2.15×10^{-02}	7.15×10^{-06}
-14.279	1.828	0.1052	1	7.85×10^{-01}	50	7.91×10^{-02}	2.64×10^{-05}
-14.279	1.828	0.1052	1.129	$1.00 \times 10^{+00}$	50	1.23×10^{-01}	4.11×10^{-05}
-14.279	1.828	0.1052	3.568	$1.00 \times 10^{+01}$	50	$8.27 \times 10^{+00}$	2.76×10^{-03}
-14.279	1.828	0.1052	5	$1.96 \times 10^{+01}$	50	$2.84 \times 10^{+01}$	9.47×10^{-03}
-14.279	1.828	0.1052	7	$3.85 \times 10^{+01}$	50	$9.72 \times 10^{+01}$	3.24×10^{-02}
-14.279	1.828	0.1052	10	$7.85 \times 10^{+01}$	50	$3.58 \times 10^{+02}$	1.19×10^{-01}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

Table I-16: Leak Path Factor for Unspecified Configuration at 100 psig

a	b_1	b_2	D (mm)	A (mm^2)	P (psig)	Amount Leaked (g)	Leak Path Factor
-14.279	1.828	0.1052	0.01	7.85×10^{-05}	100	5.25×10^{-09}	1.75×10^{-12}
-14.279	1.828	0.1052	0.03	7.07×10^{-04}	100	2.91×10^{-07}	9.71×10^{-11}
-14.279	1.828	0.1052	0.05	1.96×10^{-03}	100	1.88×10^{-06}	6.28×10^{-10}
-14.279	1.828	0.1052	0.07	3.85×10^{-03}	100	6.45×10^{-06}	2.15×10^{-09}
-14.279	1.828	0.1052	0.1	7.85×10^{-03}	100	2.38×10^{-05}	7.92×10^{-09}
-14.279	1.828	0.1052	0.25	4.91×10^{-02}	100	6.77×10^{-04}	2.26×10^{-07}
-14.279	1.828	0.1052	0.3	7.07×10^{-02}	100	1.32×10^{-03}	4.40×10^{-07}
-14.279	1.828	0.1052	0.5	1.96×10^{-01}	100	8.54×10^{-03}	2.85×10^{-06}
-14.279	1.828	0.1052	0.7	3.85×10^{-01}	100	2.92×10^{-02}	9.74×10^{-06}
-14.279	1.828	0.1052	1	7.85×10^{-01}	100	1.08×10^{-01}	3.59×10^{-05}
-14.279	1.828	0.1052	1.129	$1.00 \times 10^{+00}$	100	1.68×10^{-01}	5.59×10^{-05}
-14.279	1.828	0.1052	3.568	$1.00 \times 10^{+01}$	100	$1.13\ 10^{+01}$	3.75×10^{-03}
-14.279	1.828	0.1052	5	$1.96 \times 10^{+01}$	100	$3.87 \times 10^{+01}$	1.29×10^{-02}
-14.279	1.828	0.1052	7	$3.85 \times 10^{+01}$	100	$1.32 \times 10^{+02}$	4.41×10^{-02}
-14.279	1.828	0.1052	10	$7.85 \times 10^{+01}$	100	$4.87 \times 10^{+02}$	1.62×10^{-01}

NOTE: A=area, D=diameter, P=pressure, UPL=Upper Powder Leak

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