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Attachments		Total Number of Pages						
A – Microsoft Excel 97 Spreadsheets for the Calculation of the Respirable Fraction of Commercial SNF		30						
B – Microsoft Excel 97 Spreadsheets for the Calculation of the Respirable Fraction of Crud		28						
C – Gravitational Deposition Confirmatory Analysis		4						
D – Summary of Release Fractions from Other NRC Licensed Facilities/Casks		6						
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ACRONYMS

AED	aerodynamic equivalent diameter
AMAD	activity median aerodynamic diameter
ARF	airborne release fraction
BWR	boiling water reactor
CSF	crud spallation fraction
DOE	U.S. Department of Energy
DR	damage ratio
EPA	U.S. Environmental Protection Agency
EPF	energy partition factor
FHF	Fuel Handling Facility
ICRP	International Commission on Radiological Protection
INEL	Idaho National Engineering Laboratory
ISFSI	independent spent fuel storage installation
LPF	leak path factor
MAR	material at risk
MGD	mean geometric diameter
MMD	mass median diameter
NRC	U.S. Nuclear Regulatory Commission
PULF	pulverization fraction
PWR	pressurized water reactor
RF	respirable fraction
SAR	safety analysis report
SNF	spent nuclear fuel

ELEMENTAL SYMBOLS AND RELEVANT UNITS

°C	degrees Celsius (unit of temperature)
Ci	Curie (unit of activity)
cm ²	square centimeters (unit of area)
cm/s ²	centimeters per square second (unit of gravitational acceleration)
Co	Cobalt
Cs	Cesium
CsI	Cesium iodide
CsO ₂	Cesium oxide
CsOH	Cesium hydroxide
dps	disintegrations per second (unit of activity)
g/cm ³	grams per cubic centimeter (unit of density)
GWd/MTU	Gigawatt - days per metric tons of uranium (unit of fuel burnup)
³ H	Tritium
I	Iodine
in ²	square inches (unit of area)
IO ₂	Iodine dioxide
I ₂ O ₄	Iodine tetroxide
J/cm ³	Joules per cubic centimeter (unit of energy density)
Kr	Krypton
MPa	Mega-Pascal (unit of pressure)
MWd/MTU	Megawatt - days per metric tons of uranium (unit of fuel burnup)
psig	pounds per square inch, gauge (unit of pressure)
Ru	Ruthenium
RuO ₂	Ruthenium dioxide
RuO ₄	Ruthenium tetroxide
s	second
Sr	Strontium
SrI ₂	Strontium iodide
SrO	Strontium oxide
SrO ₂	Strontium peroxide
UO ₂	Uranium dioxide
μCi	micro-Curies (unit of activity)
μCi/cm ²	micro-Curies per square centimeter (unit of activity per unit area)
μm	micro-meters, micron (unit of length/diameter)

1. PURPOSE

The purpose of this analysis is to specify and document the total and respirable fractions for radioactive materials that could be potentially released from an accident at the repository involving commercial spent nuclear fuel (SNF) in a dry environment. The total and respirable release fractions are used to support the preclosure licensing basis for the repository. The total release fraction is defined as the fraction of total commercial SNF assembly inventory, typically expressed as an activity inventory (e.g., curies), of a given radionuclide that is released to the environment from a waste form. Radionuclides are released from the inside of breached fuel rods (or pins) and from the detachment of radioactive material (crud) from the outside surfaces of fuel rods and other components of fuel assemblies.

The total release fraction accounts for several mechanisms that tend to retain, retard, or diminish the amount of radionuclides that are available for transport to dose receptors or otherwise can be shown to reduce exposure of receptors to radiological releases. The total release fraction includes a fraction of airborne material that is respirable and could result in inhalation doses; this subset of the total release fraction is referred to as the respirable release fraction.

Accidents may involve waste forms characterized as: (1) bare unconfined intact fuel assemblies, (2) confined intact fuel assemblies, or (3) canistered failed commercial SNF. Confined intact commercial SNF assemblies at the repository are contained in shipping casks, canisters, or waste packages. Four categories of failed commercial SNF are identified: (1) mechanically and cladding-penetration damaged commercial SNF, (2) consolidated/reconstituted assemblies, (3) fuel rods, pieces, and debris, and (4) nonfuel components. It is assumed that failed commercial SNF is placed into waste packages with a mesh screen at each end (CRWMS M&O 1999). In contrast to bare unconfined fuel assemblies, the container that confines the fuel assemblies could provide an additional barrier for diminishing the total release fraction should the fuel rod cladding breach during an accident. This analysis, however, does not take credit for the additional barrier and establishes only the total release fractions for bare unconfined intact commercial SNF assemblies, which may be conservatively applied to confined intact commercial SNF assemblies.

This analysis does not include the development of the damage ratio (DR), leak path factor, airborne release fraction, and respirable fraction for accidents other than a drop/slapdown of a shipping cask, spent fuel assembly, or waste package. Values recommended for these parameters (Section 6), in general, are only applicable to crush/impact events with an impact energy of 1.2 J/cm^3 (DOE 1994, p. 4-52) or less. A severe fire event resulting in a potential radionuclide release is a beyond Category 2 event sequence (BSC 2004a) and, therefore, is not considered in this analysis.

2. QUALITY ASSURANCE

This analysis is subject to the requirements of DOE/RW-0333P, *Quality Assurance Requirements and Description* (DOE 2004). This analysis is performed in accordance with AP-3.12Q, *Design Calculations and Analyses* and provides input to the design of structures, systems, and components on the *Q-List* (BSC 2004b). Unverified design inputs are identified and tracked in accordance with AP-3.15Q, *Managing Technical Product Inputs*. This analysis is also subject to the requirements of AP-SV.1Q, *Control of the Electronic Management of Information*.

3. COMPUTER SOFTWARE AND MODEL USAGE

No computational support software or other computer software requiring qualification was used in this analysis. The analyses of the respirable fractions for commercial SNF and crud were performed using Microsoft Excel 97 spreadsheets. The use of this software is considered exempt from the requirements of LP-SI.11Q-BSC, *Software Management*.

The variable input parameters used to calculate respirable fractions (i.e., mean geometric diameter, geometric standard deviation, particle density, dynamic shape factor and maximum respirable or cut-off particle diameter) are described in Section 6.2.2. Attachments A and B provide spreadsheets for the calculation of the respirable fraction for commercial SNF and crud.

4. INPUTS

Design inputs and requirements used in this analysis include requirements developed by the U.S. Nuclear Regulatory Commission (NRC), information developed by, and for, the nuclear industry, design codes and standards, and information developed by the management and operating contractor regarding design requirements. Inputs, and their sources and qualification status, are identified and documented in this section in accordance with AP-3.15Q.

4.1 DESIGN PARAMETERS

The following design parameters are used to determine the respirable fraction of commercial SNF in this analysis:

- UO_2 Theoretical Density = 10.96 g/cm^3 (Section 5, Assumption 5.6)
- Dynamic Shape Factor = 1.3 (Section 5, Assumption 5.5)

The following design parameters are used to determine the respirable fraction of crud in this analysis:

- Crud Density (Hematite) = 5.2 g/cm^3 (*CRC Handbook of Chemistry and Physics* [Weast 1972, p. B-99])
- Dynamic Shape Factor = 1.3 (SAND88-1358 [Sandoval et al. 1991, p. II-5])

Table 1 provides melting and boiling points for specific elements considered to be released from breached fuel pins in this analysis. Melting and boiling points are also provided for some compounds that may be expected to form with these elements through common reactions (e.g., oxidation) as they are released from the fuel. These temperatures are used in Section 5 to establish which radionuclides released from commercial SNF may be treated as gases, volatiles, or particulates (e.g., fuel fines). Commercial SNF cladding surface temperatures under accidents considered in this analysis are assumed to be less than 670°C (Section 5, Assumption 5.10).

The conversion factor of $3.7 \times 10^{10} \text{ dps} = 1 \text{ Ci}$, from U.S. Environmental Protection Agency (EPA) Federal Guidance Report No. 11 (Eckerman et al. 1988, Table 2.1), is used to convert disintegrations per second (dps) to curies (Ci) in Section 6.2.2.2.

Table 1. Temperature Characteristics of Various Elements/Compounds in Commercial SNF

Element/ Compound	Melting Temperature (°C)	Boiling Temperature (°C)	State Considered in this Analysis ^a	Page # In Weast ^b
Cesium	28.4	678	Volatile	B-10
CsI	621	1280		B-82
Cs ₂ O	400	-		B-82
CsOH ^c	272.3	-		B-82
Iodine	113	184	Gas	B-17
IO ₂ or I ₂ O ₄	130	-		B-96
Ruthenium	2310	3900	Volatile	B-28
RuO ₂	Decomposes	-		B-131
RuO ₄	25.5	Decomposes, 108		B-131
Strontium	769	1384	Fuel Fine	B-31
SrI ₂	515	Decomposes		B-143
SrO	2430	3000		B-143
SrO ₂	Decomposes	-		B-143

NOTES: ^a The states (e.g., gas, volatile, particulate) of the elements and compounds in this table are established in Assumptions 5.11 to 5.14 (Section 5).

^b This column refers to the page number in Weast (1972) where the melting and boiling temperatures are located.

^c Present only in a steam environment.

4.2 CRITERIA

No design criteria are applicable to this analysis.

4.3 CODES AND STANDARDS

- 10 CFR Part 71. 2004. Energy: Packaging and Transportation of Radioactive Material.
- 10 CFR Part 72. 2004. Energy: Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste.
- 10 CFR Part 961. 2004. Energy: Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste.
- ANSI N13.1-1969. *Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities.*
- ANSI/ANS-5.10-1998. *Airborne Release Fractions at Non-Reactor Nuclear Facilities.*

5. ASSUMPTIONS

- 5.1 The DR and the leak path factor considered in NUREG/CR-6410 (SAIC 1998, pp. 3-30 and 3-31) and in DOE-HDBK-3010-94, *Analysis of Experimental Data*, Volume 1 of *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities* (DOE 1994, pp. 1-2 and 1-3), are both conservatively assumed to be equal to 1.

Rationale: These two parameters are conservatively set to 1 in this analysis because of the lack of applicable experimental data. It is recognized that for confined fuel assemblies, the DR and the leak path factor will likely be much less than 1, depending on the severity of the accident. In addition, the leak path factor will also depend on the particle size distribution of the initially aerosolized particulate. A value of 1 is conservative and bounds the expected values for these two parameters.

Usage: This assumption is used throughout this analysis wherever the total and respirable release fractions are calculated.

- 5.2 A guillotine break or a longitudinal split of a fuel pin(s) is not considered credible in this analysis.

Rationale: This analysis conservatively considers failure of 100 percent of the fuel rods of a fuel assembly from a credible accident. The mechanism of fuel failure in this analysis is consistent with the failure mechanisms considered by Sandia National Laboratories in SAND80-2124 (Wilmot 1981, p. 11), which defines an impact rupture as a rupture of the cladding produced by bending or other deformation of a fuel rod. No mention is made of a guillotine break or longitudinal split. Intact fuel is also considered rugged and capable of sustaining severe impact environments (Wilmot 1981, p. 18; Chun et al. 1987, Section 4.0).¹ A cask breach of greater than 1 in² (6.4 cm²) is not considered credible for fuel loaded in a transportation cask (Wilmot 1981, pp. 8 and 13). Cask breaches smaller than 1 in² (6.4 cm²) are considered unlikely and were not evidenced in severe tests reported in SAND80-2124 (Wilmot 1981, p. 13). Thus, only small breaches of casks are deemed credible for impact events, because the structural integrity of transportation casks mitigates any potential of a guillotine break or longitudinal split of the fuel rods contained therein.

The previously cited documents provide the bases for release fractions in guidance documents used by the engineering community, such as NUREG-1536 (NRC 1997, Table 7.1) and NUREG/CR-6487 (Anderson et al. 1996). This input is considered a generally accepted engineering practice.

¹ Chun et al. (1987, Section 4.0) states that the weakest fuel assembly, that being the Westinghouse 17 × 17, can sustain a static load in bending equivalent to 63g at 380°C without exceeding the cladding yield strength.

Usage: This assumption is used in Section 6.2.1.

- 5.3 The bounding crud surface activity for a pressurized water reactor (PWR) or boiling water reactor (BWR) fuel assembly is conservatively equal to the maximum spot activity given in NUREG-1617 (NRC 2000a, Table 4-1).

Rationale: Sandoval et al. (1991, Figures 3 and 4 on pp. 21 and 22) show that over 60 percent of the PWR fuel rods and over 80 percent of the BWR fuel rods examined had negligible surface activity. Thus, a bounding crud surface activity may be considered equal to the maximum spot surface activity.

Usage: This assumption is used in Section 6.2.1.3.

- 5.4 PWR crud will have approximately the same respirable fraction as determined for BWR crud.

Rationale: This assumption is based on the experimental data cited in Sandoval et al. (1991, pp. 23 to 26). These experimental data indicate a similarity between the sizes of crud particles on the surface of PWR fuel rods (as measured by a scanning electron microscope) with the sizes of crud particles scraped off of BWR fuel rods (as measured with filter paper). Although the PWR crud particles are smaller than those considered in the BWR crud distribution used to determine the respirable fraction, the fraction of respirable PWR crud is not expected to significantly increase. This is because of the smaller particles contributing only a small amount of mass relative to the total. This is based on the previous technical argument and the conservative manner in which PWR crud is treated in this analysis (i.e., PWR and BWR crud are treated identically with respect to release fraction even though PWR crud is tightly bound to fuel rods).

Usage: This assumption is used in Section 6.2.2.4.

- 5.5 The value for the dynamic shape factor (κ) for commercial SNF is assumed to be 1.3. No applicable data exist for this shape factor for commercial SNF aerosols.

Rationale: This assumption is based on the value for crud from a sample of Quad Cities fuel in Sandoval et al. (1991, p. II-5). The crud sample obtained from Quad Cities had a lognormal distribution, which is the type of distribution used to model the commercial SNF in this analysis. A value of 1.3 implies compact, angular shaped particles. This value is close enough to unity that it does not play a decisive role (Sandoval et al. 1991, p. II-5), based on a comparison between the scanning electron microscope pictures in NUREG/CR-0722 (Lorenz et al. 1980, Appendix C) and Sandoval et al. (1991, pp. I-37 and I-38) and the argument that a value close to unity does not play a decisive role. Pictures produced by the scanning electron microscope show that commercial SNF particles and crud particles do not significantly differ in shape.

Usage: This assumption is used in Sections 4.1 and 6.2.2.2.

- 5.6 The particle density of the aerosol in this analysis will be set equal to the theoretical density of UO_2 , which is 10.96 g/cm^3 (Weast 1972, p. B-151).

Rationale: Fuel fines released from accident events at the repository are not likely to contain many voids commonly found in the fuel because of their small size. Hence, the theoretical density of UO_2 is justifiably applied in the calculations of this analysis. These data are taken from Weast (1972, p. B-151), which is generally accepted by the scientific and engineering community and is technically defensible.

Usage: This assumption is used throughout Sections 4.1, 6.2.1.2, and 6.2.2.2 and in Attachment C.

- 5.7 The ^{55}Fe -based crud surface activity for PWR fuel is assumed to be equal to $5,902\text{-}\mu\text{Ci/cm}^2$.

Rationale: This value is cited from Jones (1992, Table 1), however no basis or reference is provided therein. Even though no value of the crud surface activity for this isotope has been cited in other literature on crud, the results of dose calculations are not sensitive to this parameter.

Usage: This assumption is used in Section 6.2.1.3.

- 5.8 The mass median diameter (MMD) of initially aerosolized commercial SNF is assumed to be equal to $150 \mu\text{m}$.

Rationale: This assumption is based on fuel fines collected from burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, p. 105 and Appendix C). The fines were measured with a scanning electron microscope and determined to be "typically $150 \mu\text{m}$ " in the furnace tube near the point of the fuel pin rupture. This value may be considered conservative when applied to drop or impact events because larger particulates are likely to be initially aerosolized in these events because of the brittle nature of the fuel (assuming reasonable drop heights). This is supported by the MMDs measured in impact tests on unclad, depleted, ceramic UO_2 pellets in ANL-81-27 (Mecham et al. 1981, pp. 26, 34 and 35). These tests involved the impaction of two separate samples of depleted UO_2 pellets. The resulting particle-size distributions had measured MMDs of 18 mm and 32 mm (not μm). These MMDs are significantly larger than the $150\text{-}\mu\text{m}$ MMD assumed in this analysis for the initially aerosolized commercial SNF. Because larger particles are essentially irrespirable (based on the rationale presented in Section 6.2.1) and carry a large portion of the total mass, larger MMDs equate to smaller respirable fractions (RFs) with other parameters being equal (e.g., the standard deviation). Thus, the selection of the $150\text{-}\mu\text{m}$ diameter to represent the MMD of the initially aerosolized commercial SNF from a drop or impact event is a conservative assumption. Another set of test data performed on single pellets of UO_2 by Alvarez is cited in SAND90-2406 (Sanders et al. 1992, Section IV-4). Alvarez performed a series of tests on pellets of clad UO_2 that were both depleted and irradiated. These tests involved the detonation of explosive charges near the fuel. This resulted in a significantly greater amount of energy imparted to the fuel than occurred in the burst rupture tests or a drop or impact event considered in this

analysis. Hence, the measured MMDs from these tests, which ranged from approximately 30 to 100 μm , are not considered applicable to this analysis. The relatively small difference, however, between the 100- μm MMD from Alvarez's explosive tests and the 150- μm diameter considered in this analysis, reinforces the conservative arguments made in this analysis for selecting an MMD of 150 μm . This is based on the preceding technical bases and on NUREG/CR-0722 (Lorenz et al. 1980, p. 105 and Appendix C) providing the release fractions used in guidance documents that are used by the engineering community, such as NUREG-1536 (NRC 1997, Table 7.1) and NUREG/CR-6487 (Anderson et al. 1996).

Usage: This assumption is used throughout Sections 6.2.2 and 7.

- 5.9 Three percent of the total mass of initially aerosolized commercial SNF fuel fines is assumed to have geometric diameters of less than 12 μm .

Rationale: This assumption is based on fuel fines collected from burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, p. 105). These tests provide the best currently available data for the release of fuel fines from commercial SNF. It is recognized that pellet fragmentation increases with fuel burnup. Because the commercial SNF, potentially accepted at the repository, may have burnups that are higher than the fuel tested in NUREG/CR-0722 (Lorenz et al. 1980) (approximately 30 GWd/MTU), then there may be more fuel fines with diameters less than 12- μm available for release.

In these burst rupture tests, it was determined that only a small fraction, 0.8 to 2.9 percent, of the fuel mass ejected from the fuel was carried out of the furnace tube into the thermal gradient tube and filter pack (Lorenz et al. 1980, Table 42).² Considering the deposition of the released fuel particles from gravity, fuel particles of diameters greater than 12 to 15 μm are considered to have settled out before reaching the thermal gradient tube. The most conservative interpretation of these data with respect to the respirable fraction is to select the highest release fraction (i.e., 3 percent) and the smallest diameter (i.e., 12 μm). This will result in the calculation of a conservative respirable fraction. This is based on the preceding technical arguments, the confirmatory analysis in Attachment C, and the fact that these data come from a source (Lorenz et al. 1980, p. 105) that is commonly cited for establishing release fractions for commercial SNF (Assumption 5.8).

Usage: This assumption is used throughout Sections 6.2.2 and 7.

² Small fractions (0.8 to 2.9 percent) in Lorenz et al. (1980, Table 42) were determined by dividing the mass in the thermal gradient tube and the filter packs by the total mass released.

- 5.10 Accidents at the repository, involving dropping or impacting of commercial SNF assemblies or containers loaded with commercial SNF assemblies, will occur at temperatures that ensure that elemental forms of Sr, Ru, and Cs are below their boiling points at the fuel cladding surface (i.e., cladding surface temperature below approximately 670°C).

Rationale: The boiling temperatures of Sr, Ru, and Cs are listed in Table 1 (Section 4). These temperatures establish a cladding surface limiting temperature of 670°C. Because cladding surface temperatures are limited to approximately 400°C for fuel discharged at least 5 years from a reactor under normal conditions in shipping casks (Levy et al. 1987), this assumption disallows these drop event release fractions to be used unless a significant fire occurs in the immediate vicinity of the drop. This assumption is generally accepted and commonly applied to accident conditions for licensed cask systems as recommended in NUREG-1536 (NRC 1997, p. 4-3).

Usage: This assumption is used in Sections 4.1 and 6.2.1.2 to establish the release fractions from the fuel for ^{90}Sr , ^{106}Ru , ^{134}Cs , and ^{137}Cs and in Assumptions 5.11, 5.12, 5.13, and 5.14.

- 5.11 In this analysis cesium and its compounds are conservatively treated as volatiles because of the low melting temperature of elemental cesium.

Rationale: The boiling temperature of elemental cesium (Section 4, Table 1) is above the maximum fuel cladding surface temperature of 400°C assumed in this analysis (Assumption 5.10); hence, it is probable that cesium released from the commercial SNF would exist in the vapor phase because of the higher temperatures within a fuel pin with this surface temperature. This is confirmed by each of the burst rupture and diffusion tests performed in NUREG/CR-0722 (Lorenz et al. 1980). In each test, the cesium purged from a breached fuel pin was in the form of either condensed CsI or Cs_2UO_4 (fuel fine) or gaseous elemental cesium, CsI, Cs_2O or CsOH (the latter, only in the presence of a flowing steam environment). When released to the cooler environment outside of the fuel, however, the elemental cesium and gaseous cesium compounds: (1) quickly condensed and were removed by fuel fines, (2) condensed in a thermal gradient tube, (3) reacted with some nearby quartz to form a cesium silicate (particle), (4) the remainder of the released cesium was found deposited on the HEPA filters as particulates.

Usage: This assumption is used in Section 6.2.1.2.

- 5.12 Iodine and its oxides (if present) are conservatively treated as gases because of iodine's low boiling temperature.

Rationale: The boiling temperature of elemental iodine in Table 1 (Section 4) is clearly below the assumed maximum fuel cladding surface temperature of 400°C (Assumption 5.10). No boiling temperatures were found for iodine oxides; the melting temperatures of these compounds, however, are comparable to that of elemental iodine. Hence, these oxides are considered to be in a gaseous state. In the commercial SNF burst rupture tests performed in NUREG/CR-0722 (Lorenz et al. 1980, pp. 117 to 119, Tests HBU-7 to

HBU-10), it was determined that iodine was released from breached fuel in either elemental form or as CsI. Although CsI is unlikely to be in a gaseous form when released from the fuel matrix, because of its high boiling point, the treatment of the iodine in this compound as a gas is as conservative as the treatment of the Cs in this compound as a volatile (Assumption 5.11). This is based on the preceding technical argument, which is based on established melting and boiling temperatures.

Usage: This assumption is used in Section 6.2.1.1.

5.13 In this analysis, ruthenium and its compound are treated as volatiles.

Rationale: The melting and boiling temperatures of ruthenium (Section 4, Table 1) are clearly above the maximum fuel cladding surface temperature of 670°C assumed in this analysis (Assumption 5.10). In addition, the burst rupture tests performed in NUREG/CR-0722 (Lorenz et al. 1980, pp. 117 to 119, Tests HBU-7 to HBU-10) determined that the vaporized ruthenium, in the form of RuO_2 and RuO_4 , was negligible compared to the ruthenium captured in the fuel fines. The ruthenium in the fuel fines is considered to be in an elemental form and in a condensed state because of the existing temperatures. The formation and vaporization of RuO_2 and RuO_4 begins at approximately 500°C and 600°C (Lorenz et al. 1980, pp. 116 and 117). These temperatures are under the maximum fuel cladding surface temperature of 670°C assumed in this analysis (Assumption 5.10). RuO_4 is volatile. After these compounds have been purged from the fuel pin, they cool to temperatures where the RuO_4 reverts to RuO_2 and the RuO_2 decomposes to its elemental components. The elemental ruthenium resulting from this decomposition is in a solid/particulate form because of its high melting and boiling temperatures. Because of the presence of RuO_4 , ruthenium and its compounds are conservatively treated as volatiles in accordance with ISG-5 (NRC 2003, Table 7.1).

Usage: This assumption is used in Section 6.2.1.2.

5.14 In this analysis, strontium and its oxides (if present) are treated as particulate (e.g., fuel fine) because of their high melting and boiling temperatures.

Rationale: The melting and boiling temperatures of strontium and SrO (Section 4, Table 1) are clearly above the maximum fuel cladding surface temperature of 670°C assumed in this analysis (Assumption 5.10). Any formation of SrO_2 decomposes back to SrO (Weast 1972 p. B-143); thus, the state of this compound is not considered. Similarly, in the commercial SNF burst rupture tests performed in NUREG/CR-0722 (Lorenz et al. 1980, pp. 117 to 119, Tests HBU-7 to HBU-10), iodine was released from breached fuel in either an elemental form or as CsI; no SrI_2 was mentioned. Thus, there is no consideration of the volatility of this compound, based on the preceding technical argument, which is based on established melting and boiling temperatures.

Usage: This assumption is used in Section 6.2.1.2.

5.15 Mechanically damaged commercial SNF and cladding-penetration damaged commercial SNF are assumed contained in a canister with some assembly-like structure inside the

canister. Fuel rods, pieces, and debris, and non-fuel components are only assumed contained in a canister.

Rationale: The results are not sensitive to the assumption.

Usage: This assumption is used in Section 6.3.

- 5.16 Failed fuel that has some assembly-like structure is assumed not to pulverize under a drop or impact event. In this assumption, credit is taken for the canister structure, cladding, and grids/spacers providing sufficient structural support to prevent the fuel from undergoing any significant amount of pulverization.

Rationale: The results are not sensitive to the assumption.

Usage: This assumption is used in Section 6.3.

- 5.17 The contents of a failed fuel canister without any assembly-like structure is assumed to be up to 20 percent pulverized following a drop or impact event. In this assumption, credit is taken only for the structural support provided by the canister to minimize the amount of fuel to be pulverized. The value of 20 percent is selected based on the same conservative assumption made in SAND84-2641 (MacDougall et al. 1987, pp. 5-15 to 5-26).

Rationale: The results are not sensitive to the assumption.

Usage: This assumption is used in Section 6.3.

6. ANALYSIS

Commercial SNF assemblies or confinement systems (e.g., casks, canisters, or waste packages) that contain assemblies may become involved in an accident at the repository that could potentially compromise the confinement boundaries that prevent or reduce the amount of radioactive material released from fuel assemblies. Confinement boundaries include fuel structure, fuel cladding, container confinement boundaries, and facility confinement boundaries. Radioactive material may be released in the form of gases, volatiles, or particulates.

In addition to the confinement boundaries, the physical properties of commercial SNF fuel fines and crud (surface deposits) can have an effect on the calculated dose consequences resulting from event sequences involving commercial SNF assemblies. In particular, the distribution of particle sizes (diameters and masses) affect the fractions of material that are locally deposited versus the fraction that remains airborne (as an aerosol) long enough to reach potential offsite or onsite receptors. Further, only the respirable fraction of the aerosolized fuel fines and crud that reach a receptor significantly contributes to internal organ doses.

Section 6.1 discusses the method for determining the airborne release fractions (ARFs) and respirable fraction (RFs) for the intact and failed commercial SNF.

Section 6.2.1 establishes the ARFs of specific radionuclides released from commercial SNF or from the surface of commercial SNF (e.g., crud). These ARFs are based on experimental data, analyses, or a conservative estimate accepted in license applications approved by the NRC in cases where insufficient experimental and theoretical data are available.

Section 6.2.2 establishes the RFs of released radionuclides from commercial SNF and any associated crud. Four distinct steps are performed to establish the RFs of these particulate matters (Sections 6.1 and 6.2.2). Spreadsheets are provided in Attachments A and B. Different methods for determining the RFs are also discussed in Section 6.2.2.

Section 6.3 discusses the ARFs and RFs determined for failed commercial SNF.

6.1 METHOD

The analysis first addresses the ARFs of commercial SNF following an event at the repository that involves either a drop or an impact of a shipping cask, canister, or waste package loaded with commercial SNF or an uncanistered, unconfined commercial SNF assembly, or canistered failed commercial SNF. In this analysis, this event occurs in a dry environment (i.e., not in a pool). After the ARFs have been established for commercial SNF, the fraction of the airborne material that is respirable, denoted as the RF, is established. Finally, the ARFs and RFs are combined to establish the respirable release fraction for commercial SNF at the repository. The methodology applied in this analysis is consistent with those presented in NUREG/CR-6410 (SAIC 1998, Section 3.2.5.2) and DOE-HDBK-3010-94 (DOE 1994, Section 1.2), for example:

$$\text{Total Release Fraction (all pathways)} = \text{DR} \times \text{LPF} \times \text{ARF} \quad (\text{Eq. 1})$$

$$\text{Respirable Release Fraction (inhalation)} = \text{DR} \times \text{LPF} \times \text{ARF} \times \text{RF} \quad (\text{Eq. 2})$$

where

DR is the damage ratio, assumed to be 1 in this analysis (Section 5, Assumption 5.1).

LPF is the leak path factor, assumed to be 1 in this analysis (Section 5, Assumption 5.1).

The ARF is the fraction of material at risk³ that can be suspended to become available for airborne transport following a specific set of induced physical or thermal stresses. An ARF for each radionuclide, or appropriate grouping of radionuclides (e.g., fuel fines), released from commercial SNF is determined from experimental data, analyses, or previous precedents established in documents approved by the NRC or conservative estimates, or both.

Attachment D includes a summary of some of the fractions used in licensing documents for other nuclear facilities.

³ Material at risk specific to commercial SNF is typically expressed as “curies” of radionuclide inventory associated with a unit assembly of fuel rods.

The RF is the fraction of the initially suspended airborne material that can be inhaled and result in inhalation doses.

The respirable release fraction calculated using Equation 2 may subsequently be used in inhalation dose calculations. The total release fraction calculated using Equation 1 is used as input for other dose calculations (e.g., submersion, groundshine, and ingestion) at the repository. Equation 2 can also be used to calculate submersion, groundshine, and ingestion doses for radionuclide releases from a dry transfer facility at the repository because it is expected that only particles of respirable sizes (i.e., less than or equal to 10 μm aerodynamic equivalent diameter [(AED)]) are released to the environment. Non-respirable particles coming out of a ruptured fuel rod, with a high terminal velocity of approximately 3 cm/s (Attachment C) or larger, would deposit on the surfaces of adjacent fuel rods within a fuel assembly, deposit inside a transportation cask or waste package, or deposit inside the ventilation ductwork.

Intact Commercial SNF

For intact commercial SNF, an analytical method was developed to quantify the RF of the aerosolized particulate measured in various experiments (Lorenz et al. 1980; Mecham et al. 1981, pp. 26, 34, and 35, Table 2; Sandoval et al. 1991, pp. 23 to 26). In Section 6.2.2, the method used to determine the RF for particulate from commercial SNF fuel fines and crud is presented. Four distinct steps are followed to establish the RF of particulates:

- Establish the maximum size of respirable particulates that contribute to the inhalation doses.
- Determine the relationships between the mean geometric diameter (MGD), the MMD, and the activity median aerodynamic diameter (AMAD) for a given particulate size distribution.
- Characterize the particulate geometric size and mass distributions of commercial SNF and crud.
- Establish a method to calculate the RF based on the definition of a respirable aerosol.

Information on the size of respirable particulate is found in International Commission on Radiological Protection (ICRP) Publication 30 (1979, Figure 5.1) and Federal Guidance Report No. 11 (Eckerman et al. 1988, p. 14). The establishment of relationships between the MGD, MMD, and AMAD are based on definitions and equations provided in the *Handbook on Aerosols* (Dennis 1976, p. 111). The characteristics of the particulate size distribution for commercial SNF are based on experimental data provided in NUREG/CR-0722 (Lorenz et al. 1980) and in ANL-81-27 (Mecham et al. 1981, pp. 26, 34, and 35, and Table 2). Experimental data provided by Sandoval et al. (1991, pp. 23 to 26) established the characteristics of the particulate size distribution for crud. For intact commercial SNF, an iterative method is used to calculate the RF of a particulate aerosol. This method is based on the definition of a respirable aerosol as established in Publication 30 (ICRP 1979) and Federal Guidance Report No. 11 (Eckerman et al. 1988) and is judged to provide the most accurate values for commercial SNF and crud. Two other methods to calculate the respirable fraction of a particulate aerosol are

discussed in Section 6.2.2: the AMAD-10 method and the AED method. These methods are based on different interpretations of the definition of a respirable aerosol that have been made in some documents used in this analysis, such as SAND80-2124 (Wilmot 1981 p. 38) and ANL-81-27 (Mecham et al. 1981, pp. 26, 34, and 35, and Table 2). The results from these other methods are provided, however, for comparison purposes only.

Failed Commercial SNF

There are four categories of failed commercial SNF, which include: (1) mechanically and cladding-penetration damaged fuel, (2) consolidated/reconstituted assemblies, (3) fuel rods, pieces, and debris, (4) non-fuel components. Non-fuel components are not important contributors to radiological consequences and therefore are not considered in this analysis.

Experiments reported in ANL-81-27 (Mecham et al. 1981, pp. 26, 34, and 35, and Table 2) and ANL-82-39 (Jardine et al. 1982) provide data that may be applicable to failed fuel damaged by a drop or impact event that involves fuel pulverization. The ARFs and RFs produced from these experiments involve unconfined (i.e., no cladding) glass and UO_2 ceramic specimens impacted by a dropping weight. The applicability and details of these tests are described in Section 6.2.1. These test data and their associated pulverization fraction (PULF), which is equal to $\text{ARF} \times \text{RF}$, were deemed not appropriate for application to dropped or impacted intact fuel assemblies. Because some of the failed fuel exists, however, as small unclad fuel pieces and debris, this data may be considered applicable.

6.2 ARFS AND RFS FOR INTACT COMMERCIAL SNF

6.2.1 ARFs for Intact Commercial SNF

The ARFs from commercial SNF account for the fact that some of the commercial SNF radionuclides are retained in the fuel matrix or exist in a chemical or physical form that is not capable of release under credible accident conditions. Table 2 lists the documents containing ARFs reviewed for this analysis and their sources for the ARFs. A review of this table reveals two primary groups of experimental data that produced the majority of the cited ARFs for commercial SNF:

- Four experiments that burst ruptured highly irradiated commercial SNF rod segments in a flowing steam environment. These experiments quantified and characterized fission product release under conditions postulated for a spent-fuel transportation accident (Lorenz et al. 1980).
- Two single energy density impact tests on three unconfined UO_2 pellets. These tests characterized the size distribution and the RF of the fragments generated (Mecham et al. 1981, pp. 26, 34, and 35, and Table 2; Jardine et al. 1982).

Burst Rupture Tests

NUREG-1567 (NRC 2000b, Table 9.2), NUREG-1536 (NRC 1997, p. 7-5), NUREG-1617 (NRC 2000a, Table 4-1), NUREG/CR-6487 (Anderson et al. 1996, pp. 31 and 32), and SAND80-2124 (Wilmot 1981, p. 36 and Table XVIII) use the burst rupture data in the same

manner to produce their cited ARFs. Thus, although a burst rupture event is not necessarily equivalent to a drop event, these documents do provide strong NRC precedents supporting use of the burst rupture data as a basis for analysis of a wide range of accidents involving commercial SNF.

Impact Rupture Tests

Release fractions based on unconfined (i.e., no cladding) impact tests involving glass and UO_2 ceramic specimens are cited in NUREG/CR-6410 (SAIC 1998, Table 3-1, 3.3.4.10.d), which provides guidance on how to calculate the characteristics of releases of radioactive materials and/or hazardous chemicals from nonreactor nuclear facilities. Although NUREG/CR-6410 (SAIC 1998) is generally applicable to repository operations, the applicability of release fractions derived from impact tests involving unconfined test specimens to accidents involving clad commercial SNF is questionable without further consideration of the potential for large scale gross cladding damage (i.e., guillotine breaks or longitudinal splits).

Table 2. References Containing Airborne Release Fractions

Source Document	Radionuclides Given ARFs	Comments
ANL-81-27 (Mecham et al. 1981, pp. 26, 34, and 35, Table 2) and ANL-82-39 (Jardine et al. 1982)	Fuel fines	Measured release fractions from two impact tests on bare unclad UO ₂ pellets
ANSI/ANS-5.10-1998 (Table A1)	Gases, fuel fines, volatiles, crud	ARFs for gases and volatiles are conservatively set equal to 1 and ARFs for fuel fines and crud come from several different sources (ANSI/ANS-5.10-1998, Table A1)
DOE-HDBK-3010-94 (DOE 1994)	Gases, fuel fines	ARFs for gases are conservatively set equal to 1, ARFs for fuel fines are based on a linear relationship produced from the ARFs determined in ANL-81-27 (Mecham et al. 1981, pp. 26, 34, and 35, Table 2)
ISG-5 (NRC 2003, Table 7.1)	Gases, fuel fines, volatiles, crud	Values cited from NUREG/CR-6487 (Anderson et al. 1996)
NUREG-1536 (NRC 1997, Table 7.1)	Gases, fuel fines, volatiles, crud	ISG-5 (NRC 2003) indicates that NUREG-1536 will be revised to be consistent with NUREG/CR-6487 (Anderson et al. 1996)
NUREG-1567 (NRC 2000b, Table 9.2)	Gases, fuel fines, volatiles, crud	Values cited from NUREG/CR-6487 (Anderson et al. 1996)
NUREG-1617 (NRC 2000a, Table 4-1)	Gases, fuel fines, volatiles, crud	Values cited from NUREG/CR-6487 (Anderson et al. 1996)
NUREG/CR-0722 (Lorenz et al. 1980)	Cs, I, Ru, fuel fines	Measured release fractions from four burst rupture tests on 1-foot fuel segments
NUREG/CR-6410 (SAIC 1998)	Noble gases, iodine, tritium, fuel fines	ARFs for fuel fines from NUREG/CR-0722 (Lorenz et al. 1980), other ARFs from impact tests
NUREG/CR-6487 (Anderson et al. 1996)	Gases, fuel fines, volatiles, crud	Does not state source of ARFs, however, ARFs for gases appear to be from Regulatory Guide 1.25; ARFs for fuel fines and crud from SAND80-2124 (Wilmot 1981, p. 36, Table XVIII); ARFs for volatiles from NUREG/CR-0722 (Lorenz et al. 1980)
NUREG/CR-6672 (Sprung et al. 2000, Table 7.31)	Kr, Cs, Ru, Co (crud), particulates	PWR and BWR release fractions for five chemical element classes and four types of transportation casks in NUREG/CR-6672 (Sprung et al. 2000, Table 7.31)
Regulatory Guide 1.25	³ H, ⁸⁵ Kr, ¹²⁹ I	Presents ARFs for gas releases from fuel handling accidents (no source of ARFs presented, regulatory position)
SAND80-2124 (Wilmot 1981, p. 36, Table XVIII)	⁸⁵ Kr, ¹²⁹ I, ¹³⁴ Cs, ¹³⁷ Cs, ⁹⁰ Sr, ¹⁰⁶ Ru, ⁶⁰ Co (crud), actinides	ARFs for noble gases from light water reactor fuel design data, for fuel fines (Cs, Sr, Ru, and actinides) from NUREG/CR-0722 (Lorenz et al. 1980)

NOTES: ARFs = airborne release fractions; BWR = boiling water reactor; PWR = pressurized water reactor.

In addition to the assumption for severe clad damage (Section 5, Assumption 5.2), application of test data in the determination of ARF and RF for large masses of commercial SNF (e.g., bare unconfined fuel assemblies) dropped from substantial heights (i.e., those that have an impact energy density greater than 1.2 J/cm^3) may be considered excessively conservative (DOE 1994, p. 4-52). This is supported, albeit for a different brittle material, by a simple test showing that a 160-g glass cylinder bounces off a steel plate in a 10-m drop, rather than fracturing as would have been predicted by a similar correlation (Jardine et al. 1982, Section 8 of Appendix D). This reveals the largest deficiency potentially associated with the use of these test data in the determination of ARF and RF for large masses of commercial SNF: can the physical phenomena associated with damage produced by dropping a weight on an unclad fuel pellet be equated to the damage produced by dropping a fuel assembly onto a potentially unyielding surface?

The PULF correlation, which is the fraction of airborne material that is respirable, is not applicable to conditions where the surface area of the impacting component (i.e., the fuel assemblies) is smaller than the surface impacted (i.e., the ground) (SAIC 1998, p. 3-87); a condition that is clearly not applicable to the one considered in this analysis. Thus, unless more experimental tests can be performed, it appears that this correlation has limited applicability to fuel assembly drops and when used in these instances will provide grossly conservative fractions of respirable fuel fines.

DOE-HDBK-3010-94 (DOE 1994, pp. 4-52 to 4-54) presents a numerical analysis that fits the unconfined specimen impact test data to an equation that estimates the PULF of commercial SNF particulate (i.e., the ARF multiplied by the RF):

$$\text{PULF} = (A)(\rho)(g)(h) \quad (\text{Eq. 3})$$

where

A is an empirical correlation equal to $2 \times 10^{-11} \text{ cm-s}^2/\text{g}$
 ρ is the particle density (g/cm^3)
g is gravitational acceleration (980 cm/s^2)
h is the fall height (cm).

For UO_2 , the value of the empirical correlation is based on two experimental data points from single energy density (1.2 J/cm^3) impaction tests on three unconfined UO_2 pellets (Mecham et al. 1981, Table 2 and pp. 30 to 35). The linearity of the correlation with respect to fall height is not based on data for UO_2 , but is based on impaction tests for Pyrex and SRL 131 (Savannah River Site glass frit) over the range of energy densities of 1.2 to 10 J/cm^3 (Jardine et al. 1982, Figure 13 and pp. 28 to 31). For Pyrex, the linearity is poor at low energy densities.

In an attempt to correct some of the conservatism associated with extrapolating small specimen impact test data to large masses of glass or ceramic materials, SAND84-2641 (MacDougall et al. 1987, pp. 5-15 to 5-26) modified the PULF correlation by including an energy partition factor (EPF) to account for the energy absorbed by components of a fuel assembly (e.g., cladding, spacer grids, nozzles) and the non-uniform energy density impact applied to a dropped fuel assembly.

The value of the EPF can be derived from analysis or experiment. SAND84-2641 (MacDougall et al. 1987, pp. 5-15 to 5-26), however, assumed this factor to be 0.2 for a fuel assembly without any defensible basis, although it was considered to be conservative.

Summary

Based on the applicability of the data and previous licensing precedent, the burst rupture ARFs are considered applicable to accidents involving commercial SNF. ARFs derived from burst rupture experimental data referenced in technical guidance documents are summarized in Table 3. As seen in Table 3, however, the burst rupture ARFs may be interpreted or corrected in different manners to produce a range of ARFs for specific radionuclides released from commercial SNF, which depend on the range of conditions, such as the temperature range.

In the following sections, the ARFs for commercial SNF radionuclides are conservatively examined and values recommended for application to the repository.

6.2.1.1 ARFs for CSNF Gases

Iodine, Hydrogen and Noble Gases

As fuel is irradiated in a nuclear power reactor, fission product atoms, of which approximately 15 percent are inert gases, are produced and buildup within the cladding of the fuel pins. Release of these fission gases from the fuel matrix to the plenum and the gap region between the fuel and the cladding is directly related to fuel pellet swelling which is a strong function of linear power density. According to p. 25.2 of Regulatory Guide 1.25, all of the gap activity in the damaged rods is released and consists of 30 percent ^{85}Kr , 10 percent of the total noble gases other than ^{85}Kr , and 10 percent of the total radioactive iodine in the rods. These values are cited by the NRC (1997, Table 7.1; 2000b, Table 9.2) for use in potential accident releases. Page 25.2 of Regulatory Guide 1.25 also states that 30 percent of the ^{127}I and ^{129}I inventory may be assumed released for the purpose of sizing filters.

The release fractions from p. 25.2 of Regulatory Guide 1.25 are assumed for oxide fuels and in cases where the following conditions are not exceeded:

- Peak linear power density of 20.5 kW/ft (67.25 kW/m) for highest power assembly discharged
- Maximum center-line operating fuel temperature less than 4,500°F (2,482°C) for this assembly
- Average burnup for the peak assembly of 25,000 MWd/MTU or less (this corresponds to a peak local burnup of about 45,000 MWd/MTU).

Table 3. Airborne Release Fractions From Fuel Retention

Radionuclide	ISG-5 (NRC 2003, Table 7.1)	NUREG-1536 ^a (NRC 1997, Table 7.1)	NUREG-1567 (NRC 2000b, Table 9.2)	NUREG-1617 (NRC 2000a, Table 4-1)	NUREG/CR-6410 (SAIC 1998, Table 3-1)	NUREG/CR-6487 (Anderson et al. 1996, pp. 30, 31, and 32)	SAND80-2124 ^b (Wilmot 1981, p. 36, Table XVIII)	Regulatory Guide 1.25 (p. 25.2)	Recommended Repository Values
³ H	0.30	0.30	0.30	0.30	—	0.30	—	—	0.30
⁸⁵ Kr	0.30	0.30	0.30	0.30	—	0.30	0.22	0.30	0.30
¹²⁹ I	0.30	0.10	0.30	0.30	—	0.30	0.087	0.30	0.30
¹³⁴ Cs & ¹³⁷ Cs	2.0×10^{-4c}	2.3×10^{-5}	2.0×10^{-4}	2.0×10^{-4c}	2.0×10^{-4d}	2.0×10^{-4c}	0.034	—	2.0×10^{-4}
⁹⁰ Sr	2.0×10^{-4c}	2.3×10^{-5}	2.0×10^{-4}	2.0×10^{-4c}	2.0×10^{-4d}	2.0×10^{-4c}	2.0×10^{-5}	—	3.0×10^{-5e}
¹⁰⁶ Ru	2.0×10^{-4c}	1.5×10^{-5}	2.0×10^{-4}	2.0×10^{-4c}	2.0×10^{-4d}	2.0×10^{-4c}	8.2×10^{-4}	—	2.0×10^{-4}
Fuel Fines	3.0×10^{-5f}	2.3×10^{-5g}	3.0×10^{-5}	3.0×10^{-5g}	2.0×10^{-4d}	3.0×10^{-5g}	2.0×10^{-5h}	—	3.0×10^{-5}
Crud	$0.15/1.00^i$	0.15	$0.15/1.00^i$	$0.15/1.00^i$	1.0×10^{-3d}	$0.15/1.00^i$	0.25	—	1.5×10^{-2j}

NOTES: ^a Values include cask retention and respirable fraction assumptions. Also, ISG-5 (NRC 2003, Table 7.1) indicates that this document will be revised to be consistent with NUREG-1617 (NRC 2000a, Table 4-1) and NUREG/CR-6487 (Anderson et al. 1996, pp. 30, 31, and 32).

^b Values are from SAND80-2124 (Wilmot 1981, Table XVIII) and are a combination of burst rupture data and oxidation data.

^c This value is consistent with the release fraction for volatiles.

^d The values are from NUREG/CR-6410 (SAIC 1998, Table 3-1, 3.3.4.10d and 3.3.4.12a). The crud value represents the ARF for loose surface contamination.

^e ⁹⁰Sr is being treated as a fuel fine. See Section 6.2.1.2

^f This value is consistent with the release fraction for fuel fines.

^g ARF for fuel fines is not provided by NUREG-1536 (NRC 1997, Table 7.1), but is assumed consistent with other listed particulates.

^h This value is the ARF for actinides.

ⁱ 0.15 for normal and off-normal conditions, 1.0 for accident conditions.

^j This value is the effective crud ARF. The effective crud ARF consists of the product of the CSF with the ARF as described in Section 6.2.1.3.

CSF = crud spallation fraction.

Although some of the potential commercial SNF handled at the repository exceeds some of the values in these assumptions, the conservatism built into these release fractions allows them to be applied to accidents involving commercial SNF handled at the repository. For example, according to Graves (1979, p. 177 and Figure 8-9), peak power density rods of light water reactors will typically release 5 to 10 percent of the fission-product gases to the gap, significantly less than the 30 percent recommended on p. 25.2 of Regulatory Guide 1.25. Furthermore, the suggested design release fraction for the linear power density equivalent to the peak power density of 20.5 kW/ft (i.e., 53.5 W/cm) is approximately 5 percent less than the value recommended by p. 25.2 of Regulatory Guide 1.25 according to Figure 8-9 in Graves (1979).

Other results provided in NUREG/CR-0722 (Lorenz et al. 1980, Table 5) indicate lower release fractions than are provided by p. 25.2 of Regulatory Guide 1.25 for Xe and Kr based on diffusional migration through the fuel matrix (i.e., 1.27 percent calculated fission gas gap inventory versus 8 percent as recommended in WASH-1400 (NRC 1975, p. VII-13 and Table VII-1-1). Similarly, the value in SAND80-2124 (Wilmot 1981, Table XVIII, p. 36) for burst ruptures shows lower release fractions for ^{85}Kr (22 percent) than are established on p. 25.2 of Regulatory Guide 1.25 (30 percent) for commercial SNF.

In NUREG/CR-5009 (Baker et al. 1988, Table 3.6), the release fraction of ^{131}I is shown to increase with burnup and for a fuel rod with a burnup of 60,000 MWd/MTU the release fraction is stated to be 0.12, which illustrates the conservative nature of the 0.3 value on p. 25.2 of Regulatory Guide 1.25. Thus, these points illustrate the conservatism associated with the release fractions stipulated on p. 25.2 of Regulatory Guide 1.25.

Although not specifically addressed on p. 25.2 of Regulatory Guide 1.25 or in SAND80-2124 (Wilmot 1981, Table XVIII, p. 36), the ARF for ^3H is conservatively assumed to be equal to the maximum ARF for a gas (i.e., the noble gas release fraction) as ^3H will be released in a gaseous form. In addition, ^{129}I is conservatively treated as a gas (Section 5, Assumption 5.12) and the ARF for ^{129}I is conservatively assumed to be equal to 0.3, as noted in Regulatory Guide 1.25 and reasoned in NUREG/CR-6487 (Anderson et al. 1996, p. 30), because of its low boiling temperature of 184°C (Weast 1972, p. B-17).

Summary for Gases

The recommended ARFs for the gaseous radionuclides ^{85}Kr , ^3H , and ^{129}I are summarized in the last column of Table 3. These values, deemed conservative, are based on values from p. 25.2 of Regulatory Guide 1.25 and in NUREG/CR-6487 (Anderson et al. 1996, p. 30), and are consistent with the values used to evaluate transportation packages containing spent nuclear fuel as stated in NUREG-1617 (NRC 2000a, Table 4-1). In addition, with the exception of the ARF for ^{129}I , these values are also consistent with the ARFs used to evaluate dry storage cask systems in NUREG-1536 (NRC 1997, Table 7.1) and spent fuel dry storage facilities in NUREG-1567 (NRC 2000b, Table 9.2).

6.2.1.2 ARFs for Commercial SNF Volatiles and Fuel Fines

Fuel fines and volatiles could also be liberated/created from fuel pellets because of the shaking of the rod and grinding action between fuel pellets that occurs during handling and transport of the fuel. Fuel fines exist as residual from the fuel manufacturing process and are produced during irradiation from pellet cracking that is associated with thermal distortion caused while the fuel was at high temperatures. In the latter case, the higher temperature at the center of a fuel pellet than at the periphery produces circumferential tensile stresses that produce radial pellet cracks.

In this analysis, the high melting and boiling temperatures of elemental Sr and of common compounds associated with the element in commercial SNF allow ^{90}Sr to be treated as particulate (i.e., fuel fines) (Section 5, Assumption 5.14). Because of the presence of RuO_4 , ^{106}Ru is treated as a volatile (Section 5, Assumption 5.13). The low melting point of elemental Cs means that the radionuclides ^{134}Cs and ^{137}Cs will be treated as volatiles in this analysis in order to address volatile Cs that may exist in partial pressure chemical equilibrium (Section 5, Assumption 5.11).

ARFs for Fuel Fines

For fuel fines, an average of the release fractions from the four burst rupture tests performed in NUREG/CR-0722 (Lorenz et al. 1980, p. 101, Table 40)⁴ is equal to 2.42×10^{-4} . This value is based on release measurements from the bursting of 1-ft segments of fuel rods. Assuming that the same amount of mass is released from a full-length fuel rod as was released from the test segment, SAND80-2124 (Wilmot 1981, pp. 34 and 35) divided the average release fraction by a factor of 10, because a typical spent fuel rod would have roughly ten times the mass of fission products as would the 1-foot test section.

Identical adjustments to the burst rupture data are made in NUREG-1536 (NRC 1997, Table 7.1), NUREG-1617 (NRC 2000a, Table 4-1), NUREG-1567 (NRC 2000b, Table 9.2), and NUREG/CR-6487 (Anderson et al. 1996, Table 6-2) to arrive at the comparable release fractions for fuel fines cited in those references. The validity of this correction may be considered unjustified based on the following arguments:

- The released internal pressure of the full-length fuel rod is expected to entrain particles from regions other than those directly near the burst point and carry them out of the fuel rod. Hence, the release fractions for these particles from the full-length fuel rod could be larger than the fractions from the 1-ft test segment if all particles were to escape.

⁴ Burst rupture data was accumulated from tests performed at temperatures between 900°C and 1200°C and the internal pressure of the helium inserted into the fuel pin at the time of rupture was approximately 2.0 MPa.

- The larger volume of a full-length fuel rod is expected to result in a gas exhaust that is sustained over a longer period of time, albeit a very short time, than the exhaust of the 1-foot fuel rod segment. Although the pressure in a full-length fuel rod is less than the fuel rod pressure that causes a burst rupture, the larger volume of the full-length fuel rod will likely sustain a gas exhaust over a longer period of time, which may allow for more particles to be transported through the fuel pellet-clad gap and released out the break.
- A guillotine break or a longitudinal split of a fuel rod would produce a significant increase in the breach of the confinement compared to the breach caused in a burst rupture. This has the potential to significantly increase the amount of fuel fines that may escape a fuel rod.

The first two preceding arguments may be countered based on the trends of particle deposition in turbulent flow through vertical tubes from Table B3 of ANSI N13.1-1969, and characteristics of the flow paths these particles must travel through. The following arguments were considered to validate this interpretation (Wilmot 1981, pp. 34 and 35) of the rod burst data and to ensure that it is conservative:

- The fraction of particle deposition (independent of particle size) increases as tube diameter decreases (ANSI N13.1-1969, Table B). For a fuel rod, the flow paths for exhausted gases consist of an annular gap (formed by the fuel pellet on the inside and the cladding on the outside) and any penetrating cracks and/or crevices through the fuel. The equivalent diameter of these flow paths is expected to be very small (e.g., less than approximately 0.03 cm for typical commercial SNF). Thus, the fraction of deposition is expected to be high for both the full-length fuel rod and the 1-ft fuel rod segment with only particles local to the breach being released. This suggests that there will be no difference in the mass released from the full-length and 1-ft fuel rod segments.
- The fraction of particle deposition (independent of particle size) increases with the length of the tube (ANSI N13.1-1969, Table B). Thus, the further a particle is from a cladding breach the larger its probability is for being deposited along the tube before it can be released. For a full-length fuel rod, this trend reduces the amount of mass (theorized to be released from the unadjusted burst rupture data) released through a cladding breach. The actual deposition fraction cannot be established because the density of the fuel fines released in this analysis is assumed to be 10.96 g/cm³ (Section 5, Assumption 5.6), which is greater than the values presented in Table B3 of ANSI N13.1-1969. This characteristic of particle transport in a flowing gas stream supports the assumption that higher proportions of particulate present near a break will be released relative to particulate present at large distances from the break location.

- The fraction of particle deposition increases with the size of the particle (ANSI N13.1-1969, Table B). Thus, the larger fuel fines released in the burst rupture experiments, which comprise the vast majority of the mass of the released fuel, were likely located in the immediate vicinity of the cladding breach. For the full-length fuel rod, the larger diameter, high-density fuel fines are not likely to escape the fuel rod and hence, no significant change in the released mass from the burst rupture data is expected.⁵ This further supports the reduction in the burst rupture release fractions.
- The internal gas pressure of a cool fuel rod is less than the pressure that occurred during the burst rupture tests. Thus at the onset of an event that breaches the fuel cladding, the 1-ft fuel rod segment will have a higher exhaust velocity than the full-length fuel rod.⁶ Because velocity and the Reynolds number are directly proportional, this higher velocity results in a larger Reynolds number which, based on the general trends for turbulent flow through vertical tubes in Table B3 of ANSI N13.1-1969, results in less particles being deposited. Thus, more particles are expected to be exhausted resulting in a higher release fraction for the 1-foot fuel rod segment.
- The flow paths in a fuel rod are not likely to be smooth and continuous. Fuel pellet irradiation induced cracking produces non-smooth flow paths for the mixture of fill gases and fission gases and the particles entrained in those gases and pellet-to-clad interference is likely to occur randomly over the length of a fuel rod segment. Deposition is expected to increase per unit flow length through these paths because of the affinity of the deposited particles and the larger particles to adhere to or plate-out on these surfaces.

The final argument against dividing the experimental burst rupture release fractions by a factor of 10 concerns the potential of radionuclide releases that are equal to or larger than the burst rupture from a guillotine break or a longitudinal split of a fuel rod. In this analysis, 100 percent of the fuel rods are assumed to fail because of a credible accident event. The failure of 100 percent of the fuel rods involved in an event by a guillotine break or a longitudinal split is not considered credible within the scope of this analysis (Section 5, Assumption 5.2).

⁵ Page 36 of ANSI N13.1-1969 states that for particles larger than those given in Table B3 (i.e., greater than 10 μm), significant re-entrainment is expected at higher flow rates. Neither the inner clad nor pellet surfaces, however, are expected to be smooth. In addition, the pressure transient time history is characterized by rapidly reducing pressure and flow. Hence, any particle that is deposited on internal surfaces is likely to remain adhered to it during the short duration of the pressure transient, making re-entrainment an insignificant consideration.

⁶ In the worst-case condition of a large break or rupture (i.e., pinhole leaks or hairline cracks would not produce significant flow rate to promote particulate entrainment), the pressure difference between the full-length fuel rod and 1-ft fuel rod segment would be short-lived, as eventually both pressures would quickly equilibrate with the environment outside of the fuel rod.

In SAND80-2124 (Wilmot 1981, p. 11), an impact rupture is defined as a rupture of the cladding produced by bending or other deformation of a fuel rod; no mention is made of a guillotine break or longitudinal split. Intact irradiated fuel is considered quite rugged and capable of sustaining severe impact environments according to SAND80-2124 (Wilmot 1981, p. 18).

Based on these arguments, dividing the experimental burst rupture release fractions by a factor of 10 is justified based on regulatory precedents, physical trends evident in Table B3 of ANSI N13.1-1969, and Assumption 5.2 (Section 5).

Burst Rupture ARFs Applied to Impact Accidents

The release fractions for burst rupture are also expected to produce conservative results when applied to repository accidents, which are of an impact nature. In SAND80-2124 (Wilmot 1981, p. 33), it is stated that an impact rupture is expected to produce more particles (through pulverization and grinding between pellets) than were present in the spent fuel before a burst rupture. There will be less pressure, however, to exhaust these particles after an impact versus a burst rupture and it is expected that an impact rupture would have a more restricted release pathway because of the cladding deformation (Wilmot 1981, p. 33). Indeed, as reported in SAND80-2124 (Wilmot 1981, p. 33), burst rupture release fractions were arbitrarily reduced by a factor of 10 to account for this physical expectation. It is apparent, however, that in more recent NRC guidance, such as (NRC 1997, Table 7.1), release fractions associated with burst ruptures (corrected for fuel rod length) should not be reduced if applied to impact accidents.

ISG-5 and NUREG/CR-6487

ISG-5 (NRC 2003, Table 7.1), NUREG-1617 (NRC 2000a, Table 4-1), and NUREG/CR-6487 (Anderson et al. 1996, pp. 30 and 31) provide release fractions to evaluate normal, off-normal, and hypothetical accident doses for storage casks. These release fractions for fuel fines are the average ARFs (corrected for fuel rod length) from the burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, Table 40) conservatively rounded-up (i.e., 2.4×10^{-5} is rounded up to 3×10^{-5}). This use of the burst rupture ARFs for both the transportation cask (NRC 2000a, Table 4-1) and the storage cask (NRC 2003, Table 7.1) further demonstrates the applicability of these data to credible accidents involving commercial SNF. Based on these arguments, an ARF of 3×10^{-5} is recommended to be conservatively applied to estimate the release of non-volatile fuel fines during accidents at the repository.

NUREG/CR-6487 (Anderson et al. 1996, p. 30) stated that Sr, Cs, and Ru are treated as volatiles in accidents involving transportation packages. For this analysis, with the exception of Cs and Ru, Sr is considered as fuel fines (Section 5, Assumptions 5.13 and 5.14). Event sequences involving fuel assemblies at the repository surface facilities are not expected to involve high enough temperatures for melting or volatilizing of these elements to be of concern, unlike some potential transportation accidents, such as the fire described in 10 CFR 71.73(c)(4) (Section 5, Assumption 5.10). Thus, the ARF associated with Sr (Table 3), is consistent with the ARF values associated with the fuel fines in NUREG-1617 (NRC 2000a, Table 4-1) and NUREG/CR-6487 (Anderson et al. 1996, p. 31).⁷

ARF for Cs

The ARF value for the Cs radioisotopes ¹³⁴Cs and ¹³⁷Cs in NUREG/CR-6487 (Anderson et al. 1996, p. 30) and in NUREG-1617 (NRC 2000a, Table 4-1) is the burst rupture test data for Cs from NUREG/CR-0722 (Lorenz et al. 1980, Table 40)⁸ uncorrected for fuel rod length. Because Cs is considered a volatile in these NUREGs, it is treated similar to the fission and fill gases found in the fuel pin (Section 5, Assumption 5.11). These gases are considered to be fully purged from the gap and plenum regions during an event that breaches the cladding. Thus, no correction for fuel rod length to the measured release fraction is made for the potentially volatile Cs radioisotopes. Because this burst rupture value is uncorrected for fuel rod length or for impact rupture, meaning that the value is reduced by an additional 90 percent according to SAND80-2124 (Wilmot 1981, p. 33), its use to estimate the release of Cs during accidents at the repository is recommended and considered conservative.

In comparison, the Cs ARF values in NUREG-1536 (NRC 1997) are derived from the burst rupture data for fuel fines presented in NUREG/CR-0722 (Lorenz et al. 1980, Table 40) and are corrected for fuel rod length (i.e., divided by a factor of 10). These data were not used in SAND80-2124 (Wilmot 1981, Table XII) for burst rupture release fractions, as shown in Table 2, but were used in SAND80-2124 (Wilmot 1981, Table XII) to determine the release fractions for an impact rupture.⁹

⁷ Although volatile ruthenium was detected as a volatile in some tests reported in NUREG/CR-0722 (Lorenz 1980, pp. 116 to 119), in the burst rupture tests, the volatile ruthenium was negligible compared to the ruthenium contained in the fuel fines (Lorenz 1980, p. 119). Given the results from these tests, ruthenium is considered a volatile in this analysis per Assumption 5.13 and ISG-5 (NRC 2003, Table 7.1).

⁸ An average of the Cs released in these burst rupture tests (Lorenz et al. 1980, Table 40) is determined to be 0.0306 percent, which is higher than the 0.02 percent used in NUREG/CR-6487 (Anderson et al. 1996, Table 6-2, pp. 30 and 31).

⁹ The release fractions for impact rupture are the release fractions from burst rupture reduced by 90 percent to 10 percent of the burst rupture release fractions. SAND80-2124 (Wilmot 1981, Table XII) provides burst rupture experiments from NUREG/CR-0722 (Lorenz et al. 1980, Table 40).

The burst release fractions for ^{134}Cs and ^{137}Cs in SAND80-2124 are calculated using "Fission Product Source Terms for the Light Water Reactor Loss-of-Coolant Accident" (Lorenz et al. 1979, p. 406, equation 1), which has several parameters that were evaluated using data from pressure rupture tests. The tests were performed at temperatures (700°C to 900°C) greater than those that exist for commercial SNF discharged from a reactor core a minimum of five years (cladding surface temperatures are limited to approximately 400°C in shipping casks under normal handling conditions). Hence, the ARFs produced in Lorenz et al. (1979, p. 406) are higher than those expected at the repository.

Summary for Fuel Fines and Volatiles

The recommended ARF values for fuel fines and volatiles are summarized in the last column of Table 3. These values are consistent with the ARF values presented in NUREG-1617 (NRC 2000a, Table 4-1), which are based on the ARF values for transportation casks listed in NUREG/CR-6487 (Anderson et al. 1996, p. 31). Although Cs is treated as a volatile, the recommended ARF values assume accidents at the repository occur at temperatures where Sr does not melt or boil (i.e., temperatures below approximately 670°C) (Section 5, Assumptions 5.10 and 5.14).

6.2.1.3 ARFs for Commercial SNF Crud

Crud releases originate from the surface of a fuel rod. In contrast to fuel fines, gases, and volatiles released from a fuel rod, the crud release fraction is not based on the fraction of fuel rods that are breached. The release mechanism involves surface spallation rather than leakage past fuel cladding barriers. Crud is primarily composed of iron-based compounds and some nickel, copper, cobalt, chromium, manganese, zinc and zircalloy. The actual amount and type of crud varies from reactor to reactor and from cycle to cycle.

Crud becomes radioactive through neutron activation. The nuclear industry recognizes that excessive crud negatively affects fuel performance and it is making a concerted effort to control factors that contribute to crud formation. Thus, crud accumulation on older fuel rods is expected to be greater than the crud on fuel discharged over the last several years. The crud activity on older fuel rods, however, is less than that on freshly discharged fuel rods because of the relatively short half life of the radionuclides that contribute to crud activity.

In general, PWR fuel has less crud activity than BWR fuel (Sandoval et al. 1991, p. 2). Crud can also be classified into two general categories: (1) fluffy, easily removed crud composed mostly of hematite (Fe_2O_3) and (2) a tenacious crud that is tightly bound to the rods composed mostly of spinel (NiFe_2O_4). PWR crud is primarily of the second category while BWR crud is composed of both types.

ARFs for Crud

Mishima and Olson (1990, p. 1134) examined measured data on crud spalling as a result of various mechanical forces during the fuel rod consolidation process and derived values of $4.1\text{E-}04$ for the crud spallation fraction (CSF) during rod consolidation and handling, and $2.2\text{E-}07$ for the fraction of crud airborne (i.e., $\text{CSF} \times \text{ARF}$). This suggests that only a small

fraction of the crud that spalls off rods becomes airborne during the rod consolidation process. The crud ARF is equal to $5.4\text{E-}04$ ($= 2.2\text{E-}07/4.1\text{E-}04$). This value is bounded by an ARF of $1.0\text{E-}01$ for venting gases in a pressurized volume in which loose powder of surface contamination exists (DOE 1994, p. 5-22). The ARF of $1.0\text{E-}01$ is also a bounding value for the suspension of loose surface contamination by vibration shock (DOE 1994, Section 4.4.3.3.1).

Sandoval et al. (1991, pp. 21 to 22, Table 1, p. I-50) provides measured release fractions for the crud located on the outer surface of fuel rods. Sandoval et al. (1991, Table 4 on p. 24) shows spallation fractions for transportation conditions. The maximum crud spallation fraction for both PWR and BWR fuel occurs at elevated fuel temperatures (450°C) where a 0.15-m long region of crud is assumed to bubble up and spall off, resulting in a crud spallation fraction of 15 percent. The elevated fuel temperatures are caused by exposing fuel to a fire at a temperature of 800°C for 30 minutes. At lower temperature conditions (i.e., fuel rod surface temperature of 300°C), a maximum of 8 percent of the crud may spall off. Therefore, the bounding CSF value is 0.15, which is much larger than the CSF of $4.1\text{E-}04$ for the rod consolidation process.

The release fraction for crud found in SAND80-2124 (Wilmot 1981, p. 34) was an estimate that has no experimental basis. This estimate is based on an assumption that 25 percent of the crud that plates on spent fuel assemblies during reactor operation and contaminates the transportation cask cavity surface is loosely adhering. The remainder adheres tightly and requires abrasion and chemical treatment for removal. SAND80-2124 (Wilmot 1981, p. 34) assumes that this 25 percent release fraction includes not only the crud on the cladding surface, but also crud on the assembly structure and the cask interior. This report goes on to state that the 25 percent release fraction from the cask is comparable to the release of all the crud located on the surface of the fuel rod cladding (Wilmot 1981, p. 34). Thus, the 25 percent crud release fraction from SAND80-2124 (Wilmot 1981, p. 34) equates to 100 percent release of the crud on the fuel rod cladding surfaces.

In NUREG-1617 (NRC 2000a, Table 4-1), the crud spallation fraction under hypothetical accident conditions is unity. This value is based on assumptions made in NUREG/CR-6487 (Anderson et al. 1996, p. 28). No justification is given for this assumption in either document. Therefore, the bounding CSF value of 0.15 instead of 1.0 will be recommended for use at the repository.

Using a CSF of 0.15, a crud ARF of $1.0\text{E-}01$, the crud effective ARF for an event sequence is:

$$\text{Crud effective ARF} = \text{CSF} \times \text{ARF} = 0.15 \times 1.0\text{E-}01 = 1.5\text{E-}02 \quad (\text{Eq. 4a})$$

Using a crud RF of 1.0, the crud respirable release fraction is $1.5\text{E-}02$. This crud respirable release fraction is much larger than crud respirable release fractions of $1.3\text{E-}06$ and $4.7\text{E-}08$ found in SAND99-0963 (Luna et al. 1999, p. 7) calculated for sabotage attacks of rail casks employing high energy density devices. These devices have energy densities approximately one thousand times higher than potential cask drops at the repository.

Co-60 Crud Surface Activities

A summary of the crud surface activities found in the literature is summarized in Table 4. The crud surface activities in NUREG-1617 (NRC 2000a, Table 4-1) and NUREG-1536 (NRC 1997, Table 7.1)¹⁰ are based on data in Sandoval et al. (1991, Table 1 on p. 15). These values are in turn based on measured maximum spot/local surface (vs. total surface average) activities of ⁶⁰Co on fuel rods freshly discharged from the reactor. These values may be considered conservative in two manners:

- At the repository, fuel must be cooled a minimum of 5 years following discharge from the reactor core before it will be accepted as required by 10 CFR Part 961. Thus, the surface activity should be approximately half of the cited values, based on ⁶⁰Co being the principal radionuclide in the crud and its 5.271-year half life (Parrington et al. 1996, p. 25).
- The average fuel rod will not have the maximum spot/local surface activity. In fact, Sandoval et al. (1991, Figures 3 and 4 on pp. 21 and 22) show that the majority of examined fuel rods (greater than 60 percent) had little or no crud activity associated with them at fuel discharge. In addition, the maximum spot/local activity density is approximately 7 times the value of the average activity density (Sandoval et al. 1991, p. I-50). Thus, using the maximum spot/local surface activity for a typical fuel assembly is conservative (Section 5, Assumption 5.3).

Thus, a reasonably conservative treatment of the amount of crud released should include an approximate 50 percent reduction in the maximum spot/local activity density cited in NUREG-1617 (NRC 2000a, Table 4-1). The 50 percent reduction is justified based on an approximately 50 percent reduction because of the fuel discharge age. The crud surface activity density is a function of time after discharge from the reactor. The time-dependent crud surface activity is based on the following radioactive decay equation (BSC 2004c, p. 23):

$$N(t) = N(0) \exp (-t \times \ln 2 / t_{1/2}) \quad (\text{Eq. 4b})$$

where,

$$\begin{aligned} N(t) &= \text{crud surface activity at time } t, \\ N(0) &= \text{crud surface activity at time } 0, \end{aligned}$$

¹⁰ Crud surface activity is 140 $\mu\text{Ci}/\text{cm}^2$ for PWRs in NRC (2000a, Table 4-1; 1997, Table 7.1). Crud surface activity, however, is 600 $\mu\text{Ci}/\text{cm}^2$ for BWRs in NRC (1997, Table 7.1), which ignores data from the Tsuruga reactor and 1254 $\mu\text{Ci}/\text{cm}^2$ in NRC (2000a, Table 4-1), which includes data from the Tsuruga reactor.

$t_{1/2}$ = radionuclide half-life in years
 t = the decay time in years.

Using Equation 4b for PWR assemblies, the ^{60}Co crud surface activity after 5 years decay is:

$$N(t) = 140 \mu\text{Ci}/\text{cm}^2 \exp(-5 \text{ y} \times \ln 2 / 5.271 \text{ y}) = 72.5 \mu\text{Ci}/\text{cm}^2$$

Using Equation 4b for BWR assemblies, the ^{60}Co crud surface activity after 5 years decay is:

$$N(t) = 1,254 \mu\text{Ci}/\text{cm}^2 \exp(-5 \text{ y} \times \ln 2 / 5.271 \text{ y}) = 649.7 \mu\text{Ci}/\text{cm}^2$$

Fe-55 Crud Surface Activities

In the vast majority of the literature (e.g., NRC guidance documents, Sandia National Laboratories reports, safety analysis reports [SARs] for storage casks, and SARs for independent spent fuel storage installation), the principal radionuclide in the crud of fuel that has been discharged for a minimum of 5-years is ^{60}Co . However there is some evidence that ^{55}Fe may also be a large component of the crud activity. An isotopic analysis of crud from the Carolina Power & Light Brunswick nuclear power plant (BWR SNF) revealed the presence of a significant amount of ^{55}Fe (Jones 1992, pp. 6-7 and cited Ref. 6). The presence of this isotope is plausible because of the significant presence of iron in crud, usually as hematite. Specifically, the production of ^{55}Fe is through neutron activation of ^{54}Fe (5.9 percent natural abundance). Thus, consideration of this isotope in the crud is justified.

At the time of discharge, the surface activity of ^{55}Fe present was determined to be $7,415 \mu\text{Ci}/\text{cm}^2$ (Jones 1992, Table 2). This value is significantly greater than the BWR values of $600 \mu\text{Ci}/\text{cm}^2$ given in NUREG-1536 (NRC 1997, Table 7.1) and $1,254 \mu\text{Ci}/\text{cm}^2$ given in NUREG-1617 (NRC 2000a, Table 4-1). The half life of ^{55}Fe , 2.73 years (Parrington et al. 1996, p. 25), is about half of the half life of ^{60}Co (5.271 years). So approximately a reduction of 72 percent can be assumed for ^{55}Fe crud. This reduction is based solely on the half life argument as used previously for the ^{60}Co -based crud and therefore is applicable to bare unconfined fuel assemblies and confined fuel assemblies. For PWR fuel, the ^{55}Fe -based crud surface activity at the time of discharge from the core is assumed equal to $5,902 \mu\text{Ci}/\text{cm}^2$ (Section 5, Assumption 5.7).

Using Equation 4b for PWR assemblies, the ^{55}Fe crud surface activity after 5 years decay is:

$$N(t) = 5,902 \mu\text{Ci}/\text{cm}^2 \exp(-5 \text{ y} \times \ln 2 / 2.73 \text{ y}) = 1,658 \mu\text{Ci}/\text{cm}^2$$

Using Equation 4b for BWR assemblies, the ^{55}Fe crud surface activity after 5 years decay is:

$$N(t) = 7,415 \mu\text{Ci}/\text{cm}^2 \exp(-5 \text{ y} \times \ln 2 / 2.73 \text{ y}) = 2,083 \mu\text{Ci}/\text{cm}^2$$

Table 4. Crud Surface Activities

Isotope	Reactor Type	Crud Surface Activity (μCi/cm ²)						Recommended Repository Values	
		NUREG-1536 (NRC 1997, Table 7.1)	NUREG-1567 (NRC 2000b, Table 9.2)	NUREG-1617 (NRC 2000a, Table 4-1)	NUREG/CR-6487 (Anderson et al. 1996, p. 28)	ISG-5 ^a (NRC 2003, Table 7.1)	SAND88-1358 ^b (Sandoval et al. 1991, Table I-12)		Jones 1992
⁶⁰ Co Crud	PWR	140	140	140	140	140	140	51 ^e	72.5 ^c
	BWR	600	1,254	1,254	1,254	1,254	1,250	477 ^f	649.7 ^c
⁵⁵ Fe Crud	PWR	—	—	—	—	—	—	5,902 ^e	1,658 ^d
	BWR	—	—	—	—	—	—	7,415 ^f	2,083 ^d

NOTES: ^a Data are taken from ISG-5 (NRC 2003, Table 7.1).

^b Data are taken from SAND88-1358 (Sandoval et al. 1991, Table I-12).

^c These values have been corrected for half life of ⁶⁰Co over 5 years.

^d These values have been reduced using the half life of ⁵⁵Fe over 5 years.

^e Jones 1992, Table 1, T = 0 (fresh discharge)

^f Jones 1992, Table 2, T = 0 (fresh discharge)

BWR = boiling water reactor; PWR = pressurized water reactor.

Summary for Crud

The recommended ARF for crud, which consider ^{60}Co and ^{55}Fe as the principal radionuclides present, is assumed to be $1.5\text{E-}02$, and is summarized in the last column of Table 3. Table 4 summarizes the surface activities to be used with each crud isotope. NUREG/CR-6487 (Anderson et al. 1996, p. 28) states that these surface activities should be multiplied by the surface area associated with a rod to obtain the crud activity. Thus, the surface area associated with the assembly hardware (e.g., fuel rod spacers, nozzles, etc.) is neglected.

6.2.2 RF for Intact Commercial SNF

The RF is the fraction of the initially suspended airborne material (material at risk multiplied by the ARF) that can be inhaled. The actual fraction of commercial SNF that is respirable depends on the particulate size distribution of the aerosolized commercial SNF. For nuclides in the form of a gas or a volatile, 100 percent are considered respirable because they are assumed to be gases (i.e., 100 percent aerosolized).

The extent of fuel fines and crud that are respirable is dependent on the size distribution of the aerosolized particulate. For consistency with the dose conversion factors used in dose analyses for the repository, the fraction of respirable particulate will be based on the fraction of a distribution with an AMAD less than a specified value. The dose conversion factors are based on an AMAD of $1\text{ }\mu\text{m}$, however the RF will be conservatively based on the fraction of particulate with an AMAD of $10\text{ }\mu\text{m}$ or less. The combination of dose conversion factors based on an AMAD of $1\text{ }\mu\text{m}$ and an RF based on an AMAD of $10\text{ }\mu\text{m}$ will ensure that inhalation doses are conservatively calculated (Section 6.2.2.1). Establishing the RF for commercial SNF fuel fines is limited to analyzing the same two primary groups of experimental data that produced the majority of the cited ARFs for commercial SNF (Table 2) as follows:

- Four experiments that burst ruptured highly irradiated commercial SNF rod segments in a flowing steam environment. These experiments quantified and characterized fission product release under conditions postulated for a spent-fuel transportation accident (Lorenz et al. 1980).
- Two single energy density impaction tests on three unconfined UO_2 pellets. These tests characterized the size distribution and the RF of the fragments generated (Mecham et al. 1981; Jardine et al. 1982).

In this section, a methodology to produce an RF for particulate with a given lognormal size/mass distribution is established. First, an estimate of the respirable particulate size is established for an aerosol (i.e., an AMAD of less than $10\text{ }\mu\text{m}$). Based on this particulate size, relationships are then established between a distribution's MGD, MMD, and AMAD. Finally, the distribution of a typical aerosol of commercial SNF fuel fines is characterized to allow for the calculation of the commercial SNF RF. A similar analysis to determine the RF for crud is performed using experimental data in Sandoval et al. (1991, pp. 23 to 26).

6.2.2.1 Size of Respirable Particulate

When radioactive aerosols are inhaled, parts of the respiratory system are irradiated. Other organs and tissues of the body are also irradiated by radiation originating from the lungs and as a result of translocation of inhaled material to body tissues from the respiratory system. After inhalation of radioactive aerosols, the doses received by various regions of the respiratory system will differ widely, depending on the size distribution of the inhaled material.

ICRP, DOE Handbook, and American Nuclear Society Standard Respirable Definitions

Figure 1 is reproduced from Publication 30 (ICRP 1979, Figure 5.1) that is applicable to aerosol distributions with AMADs between 0.2 and 10 μm and with a geometric standard deviation of less than 4.5.¹¹ Figure 1 shows the effect aerosol size distributions have on their deposition in the respiratory system. Aerosol distributions with an AMAD of less than 10 μm have significant deposition in the lungs (line labeled D_p in Figure 1) and, hence, may significantly contribute to internal doses. Aerosol distributions with an AMAD distribution greater than 10 μm do not deposit as readily in the lungs (deposition occurs almost entirely in the nasal passage) and, hence, do not contribute as readily to lung doses. This trend can be seen in the lung dose conversion factors, which decrease as the AMAD increases from 1 to 10 μm (ICRP 1979, Figure 5.1). Thus, the combined use of an AMAD of 10 μm and a dose conversion factor based on an AMAD of 1 μm represents a conservative methodology, when compared to RFs and dose conversion factors both based on 10 μm (or both based on 1 μm). According to DOE-HDBK-3010-94 (DOE 1994, pp.1-4 to 1-6), several other definitions of respirable particles have been presented by various groups at different times, as follows:

- Particles with terminal velocities equal to that of a 5- μm diameter particle were considered respirable dust by the British Medical Research Council in 1952.
- Particles with a 50 percent respirable cut-size of 3.5- μm AED were considered respirable dust by the U.S. Atomic Energy Commission.
- Particles with a 50 percent respirable cut-size of 2- μm AED were considered respirable dust by the American Conference of Governmental Industrial Hygienists.

¹¹ The only data considered in this analysis that have a standard deviation greater than 4.5 is the pulverization data for brittle materials (Mecham et al. 1981; Jardine et al. 1982). These data are not used in the calculation of the RFs for commercial SNF or crud aerosols.

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Source: ICRP 1979, Figure 5.1

NOTE: D_P is the deposition in the pulmonary parenchyma (lungs), D_{T-B} is the deposition in the trachea and bronchial tree (throat), and D_{N-P} is the deposition in the nasal passage. The dashed lines are provisional estimates of deposition outside the size range of 0.2 to 10 μm.

Figure 1. Deposition of Dust in the Respiratory System

- Particles with a 50 percent respirable cut-off at 15- μm AED were considered inhalable dust (particles entering the upper respiratory airway and entering the thorax) by the EPA.
- Particles with a 50 percent respirable cut-size at 10- μm AED were considered inhalable dust (particles entering the nasal or oral passages) by the International Standards Organization-Europe.

An AED of 10 μm adequately represents the cut-off diameter for respirable particulate (DOE 1994, pp. 1-4 to 1-6). This value is further supported by Appendix B2.1.4, p. 19, of ANSI/ANS-5.10-1998, which states that the respirable fraction "is commonly assumed to include particles 10 μm Aerodynamic Equivalent Diameter (AED) and less as a conservative approximation."

AMAD versus AED

If AMAD and AED were equivalent, then a diameter of 10 μm would conservatively represent the cut-off diameter for respirable particulate. According to DOE-HDBK-3010-94 (DOE 1994, p. xviii), however, the AED is equivalent to the diameter of a sphere of density 1 g/cm^3 that exhibits the same terminal velocity as the particle in question. In this case, the particle in question represents the cut-off diameter for respirable particles ($d_{c/o}$). In terms of the terminal settling velocity (v_{term}), this definition can be written as:

$$v_{\text{term}}(\rho=\rho_{\text{part}}, d=d_{c/o}) = v_{\text{term}}(\rho=1 \text{ g}/\text{cm}^3, d=\text{AED}) \quad (\text{Eq. 5})$$

where

ρ_{part} is the density of the particulate in the aerosol

Whereas, according to Publication 30 (ICRP 1979, p. vii), the AMAD is equivalent to the diameter of a unit sphere (1 g/cm^3) with the same terminal velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol.¹² This activity median diameter will be shown in the next section to be equivalent to the MMD assuming that activity and mass of the particle are proportional. In terms of the terminal settling velocity (v_{term}), this definition can be written as:

$$v_{\text{term}}(\rho=\rho_{\text{part}}, d=\text{MMD}) = v_{\text{term}}(\rho=1 \text{ g}/\text{cm}^3, d=\text{AMAD}) \quad (\text{Eq. 6})$$

¹² The definition of AMAD in DOE (1994, p. xviii) is not the same as the definition of AMAD in ICRP (1979, p. vii). The DOE (1994, p. xviii) defines AMAD as the diameter of the particle for which half of the activity is associated with particles larger than and half the activity associated with particles smaller than this size particle. No mention is made of the unit density sphere in this definition and this definition is actually equivalent to the aerodynamic mass median diameter because activity and mass are proportional.

Thus, these two characteristic diameters, AED and AMAD, are similar in definition (i.e., both are based on unit density). The only difference between AMAD and AED is the particles they share terminal velocities with (i.e., the respirable particle cut-off diameter versus the diameter representative of the median activity for the entire aerosol). Hence, by selecting a diameter of 10 μm for AED and AMAD, the preceding relationships indicate that the value of the respirable particle cut-off diameter must be equivalent to the diameter of the particle representing the median activity of the entire aerosol. However this does not necessarily indicate the RF from these two interpretations (AMAD vs. AED) are equivalent. In fact, it will be shown that the RF from the AED method will be equal to or less than the RF associated with the AMAD method. Consider a lognormally distributed aerosol with a density of 10 g/cm^3 and an MMD of 3.16 μm . Using the expression for the terminal settling velocity in the next section, the preceding relationships reduce to:

$$\text{AED} = d_{c/o} \sqrt{\rho_{part}} \quad (\text{Eq. 7})$$

$$\text{AMAD} = \text{MMD} \sqrt{\rho_{part}} \quad (\text{Eq. 8})$$

Hence, if AMAD and AED are set equal to the maximum respirable diameter of 10 μm , then MMD and $d_{c/o}$ calculated from the preceding expressions are equal to approximately 3.16 μm . Because this value is equal to the MMD of the entire distribution, 100 percent of this aerosol is considered respirable according to the AMAD method and 50 percent of this aerosol is considered respirable according to the AED method (50 percent of the total mass has a diameter less than 3.16 μm , because 3.16 μm is the mass median diameter of the distribution).

If the MMD of the whole distribution in the preceding example had been less than the calculated values for MMD and $d_{c/o}$, then the AMAD method would still have an RF of 100 percent because the AMAD of the whole distribution is less than 10 μm . The RF for the AED method would increase in this case (i.e., greater than 50 percent) because the AED would be greater than the MMD of the whole distribution. Obviously, however, the RF from the AED method would never exceed the RF of 1 from the AMAD method. On the other hand, if the MMD of the whole distribution in the preceding example had been greater than the calculated values for MMD and $d_{c/o}$, then the RFs for both methods would decrease. However, the RF from the AMAD method would always be greater than the RF from the AED method, because the AMAD method will determine the fraction of the whole distribution that has an AMAD of 10 μm and less. This fraction of the whole distribution will almost always include particles with diameters greater than 3.16 μm (except in cases with extremely large MMDs), whereas the AED method will only include those particles with diameters less than 3.16 μm .

Summary of Respirable Diameter

Therefore, for this analysis, respirable particulates are those with a particulate size distribution or any fraction thereof, with an AMAD of less than 10 μm . This ensures consistency with the inhalation dose conversion factors used in dose analyses for the repository, which are also based on a maximum AMAD. These factors are calculated in Federal Guidance Report No. 11 (Eckerman et al. 1988, p. 14) and are conservatively based on an AMAD of 1 μm .¹³ Thus, the combination of dose conversion factors based on an AMAD of 1 μm and an RF based on the mass fraction of particulate that have an AMAD of less than 10 μm are considered to produce a conservative methodology for inhalation dose calculations.

6.2.2.2 Relationships between MGD, MMD, and AMAD

Definitions

Before relationships can be established between the MGD, the MMD, and the AMAD, these quantities are defined as follows as they are used in this analysis:

AMAD-the diameter of a unit density sphere (1 g/cm^3) with the same terminal settling velocity in air as that of the aerosol particle whose activity (radioactivity) is the median for the entire aerosol (ICRP 1979, p. vii).

MGD-the mean or average geometric diameter of the particle number distribution for an entire aerosol and for a lognormal distribution, it represents the size occurring with the greatest frequency (Dennis 1976, p. 111).

MMD-the geometric diameter of the particles in a distribution for which half the mass is associated with particles greater and half the mass associated with particles less than the stated size (DOE 1994, p. xix).

AMAD and MMD Relationship

To establish a relationship between AMAD and MMD, it must first be recognized that the mass (m, grams) and activity (A, curies) of a distribution are proportional (Lamarsh 1983, p. 22), for example:

$$A = 3.7 \times 10^{10} \lambda N = 3.7 \times 10^{10} \lambda m N_A/M \quad (\text{Eq. 9})$$

$$A \propto m$$

¹³ If an AMAD of 10 μm were used instead of an AMAD of 1 μm , then the inhalation dose factors for the lung would decrease.

where

λ is the decay constant (sec^{-1})

N is the number of nuclei present (nuclei)

N_A is Avogadro's number (atoms/mole)

M is the gram atomic weight (g/mole)

3.7×10^{10} is the conversion factor from disintegrations per second to curies.

Equation 9 shows that the particle activity is directly proportional to its mass when all particles contain the same radionuclide. This relationship establishes the equivalency between the aerosol particle whose activity is the median for the entire aerosol with the aerosol particle whose mass is the median for the entire aerosol. Thus, the diameter of the activity median particle is equal to the diameter of the MMD. Using this relationship and the preceding definitions, the following relationship between the terminal settling velocities (v_{term}) of the particulate representing the MMD and the AMAD of a distribution can be established:

$$v_{\text{term}}(\rho=\rho_{\text{part}}, d=\text{MMD}) = v_{\text{term}}(\rho=1 \text{ g/cm}^3, d=\text{AMAD}) \quad (\text{Eq. 10})$$

where

ρ_{part} is the density of the particulate in the aerosol.

The terminal settling velocity is determined from Stoke's solution for the drag on a sphere in creeping flow with correction factors for particulate shape and slip (Sandoval et al. 1991, p. 11):

$$v_{\text{term}}(\rho, d) = \rho g d^2 C(\text{Kn}) / (18 \mu_{\text{air}} \kappa) \quad (\text{Eq. 11})$$

where

ρ is the aerosol particulate density (g/cm^3)

g is gravitational acceleration (980 cm/s^2)

d is the aerosol diameter (cm)

$C(\text{Kn})$ is the Cunningham-Knudsen-Weber slip correction factor (dimensionless)

Kn is the Knudsen number (dimensionless)

μ_{air} is the bulk gas viscosity (g/(cm-s))

κ is the dynamic shape factor (dimensionless). $\kappa = 1$ for a unit density sphere.

Substituting this equation into the previous equation yields:

$$\rho_{\text{part}} g (\text{MMD})^2 C(\text{Kn}_{\text{part}}) / (18 \mu_{\text{air}} \kappa_{\text{part}}) = g (\text{AMAD})^2 C(\text{Kn}_{\text{AMAD}}) / (18 \mu_{\text{air}}) \quad (\text{Eq. 12})$$

$$\rho_{\text{part}} (\text{MMD})^2 C(\text{Kn}_{\text{part}}) / \kappa_{\text{part}} = (\text{AMAD})^2 C(\text{Kn}_{\text{AMAD}}) \quad (\text{Eq. 13})$$

$$\text{AMAD} = \text{MMD} \sqrt{\left[\frac{\rho_{\text{part}}}{\kappa_{\text{part}}} \right] \left[\frac{C(\text{Kn}_{\text{part}})}{C(\text{Kn}_{\text{AMAD}})} \right]} \quad (\text{Eq. 14})$$

Correction Factor and Density Effects

The Cunningham-Knudsen-Weber slip correction factor has the following form (Sandoval et al. 1991, p. 33):

$$C(Kn) = 1 + 1.246Kn + 0.42e^{-0.87/Kn} \quad (\text{Eq. 15})$$

where

Kn is the mean free path of the particle divided by the particle volume equivalent diameter.

The mean free path of a particle in air is (Holman 1990, p. 632 and equation 12-45):

$$\lambda = 2.27 \times 10^{-5} T / P \quad (\text{Eq. 16})$$

where

λ is the mean free path in meters
T is the temperature in Kelvin
P is the pressure in pascals.

Figure 2 shows the Cunningham-Knudsen-Weber correction factor (Sandoval et al. 1991, p. II-5) as a function of particulate diameter at a temperature of 300 K and a pressure of 10^5 Pa. Except for particulate with diameters less than 2 μm , the Cunningham-Knudsen-Weber correction factor is nearly equal to unity and hence, the ratio of $C(Kn_{\text{part}})$ to $C(Kn_{\text{AMAD}})$ is approximately unity.

Thus the relationship between AMAD and MMD reduces to:

$$\text{AMAD} = \text{MMD} \sqrt{\left[\frac{\rho_{\text{part}}}{\kappa} \right]} \quad (\text{Eq. 17})$$

AMAD Relationship for Commercial SNF

The value for the dynamic shape factor (κ) for UO_2 is assumed to be 1.3 (Section 5, Assumption 5.5). The particulate density of the aerosol in this analysis will be set equal to the theoretical density of the SNF (UO_2) which is 10.96 g/cm^3 (Section 5, Assumption 5.6).

Figure 3 illustrates the effect density has on the MMD for a fixed value of AMAD of 10 μm . The density sensitivity of the relationship between AMAD and MMD is insignificant over the range of densities considered acceptable for fuel particulate (i.e., between 9.5 and 11 g/cm^3). Thus this relationship can be reduced to:

$$\text{AMAD} = 2.9 \text{ MMD (for UO}_2\text{)} \quad (\text{Eq. 18})$$

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NOTE: The three diamonds in this figure represent points presented in Table B3 of ANSI N13.1-1969.

Figure 2. Cunningham-Knudsen-Weber Slip Correction Factor in Air at 300 K and 10^5 Pa

NOTE: The large square symbol represents the value associated with the theoretical density of UO_2 .

Figure 3. Effect of Particulate Density on the MMD for an AMAD fixed at 10 μm

AMAD Relationship for Crud

For aerosols of crud, the dynamic shape factor (κ) is equal to 1.3 (Sandoval et al. 1991, p. II-5). This value is based on visual examination of two scanning electron microscope microphotographs of Quad Cities crud and implies compact, angular shaped particles. This value is close enough to unity that it does not have a significant effect on the results (Sandoval et al. 1991, pp. 31 and 32). The density of crud is equal to 5.2 g/cm^3 (Sandoval et al. 1991, Table 9 on p. 33). This value is equal to the density of hematite (e.g., Fe_2O_3) (Weast 1972, p. B-99) that is commonly found on BWR fuel rods and is approximately the density of spinel (e.g., of the form $\text{Ni}_x\text{Fe}_{3-x}\text{O}_4$) that is commonly found on PWR fuel rods. Thus, the relationship between AMAD and MMD for crud reduces to:

$$\text{AMAD} = 2.0 \text{ MMD (for crud)} \quad (\text{Eq. 19})$$

Standard Deviation, MMD, and MGD Relationship

The geometric standard deviation, σ , is a unitless quantity defined as the ratio between the size associated with the cumulative mass of 84.1 percent and the median size (50 percent cumulative mass) or between the median and the 15.9 percent cumulative mass size (DOE 1994, p. xix, and Dennis 1976, p. 113), for example:

$$\sigma = d_{84\%} / d_{50\%} = d_{50\%} / d_{16\%} \quad (\text{Eq. 20})$$

Thus for distributions with small geometric standard deviations (approximately equal to 1), the MMD and the MGD are nearly equivalent (i.e., $\text{MMD} \cong \text{MGD}$). The relationship between the MGD and MMD for an aerosol with a lognormal distribution can be represented as (Dennis 1976, p. 113):

$$\ln(\text{MMD}) = \ln(\text{MGD}) + 3.0 \ln^2(\sigma) \quad (\text{Eq. 21})$$

6.2.2.3 Characterization of a Commercial SNF Aerosol Particulate Distribution

Having established the size characteristic of respirable particulate, it must now be determined what fraction of an aerosol produced from an accident involving commercial SNF is respirable. To perform this task, the type (e.g., lognormal, bimodal) and characteristics (e.g., MGD, standard deviation) of a particulate distribution must be established for commercial SNF.

6.2.2.3.1 Lognormal Distribution Function

Aerosol particle sizes are usually reasonably well described by one of several mathematical distribution functions: the normal, lognormal, bimodal and multimodal distribution functions (Dennis 1976, p. 112). Particles of depleted UO_2 pellets from pulverization tests in ANL-81-27 (Mecham et al. 1981, Figures 16 and 17, p. 30) showed distributions that were characterized as

lognormal functions with some departure from lognormal at the end of the spectrum.¹⁴ Other brittle materials (similar to UO_2), pulverized in ANL-81-27 (Mecham et al. 1981, Figures 16 and 17, p. 30) and ANL-82-39 (Jardine et al. 1982), demonstrated similar lognormal distributions, indicating that brittle materials often exhibit lognormal distributions when pulverized.

In addition, Publication 30 (ICRP 1979, p. 24) states that a lognormal distribution of diameters is typical for aerosols. This assumption is used to calculate the inhalation dose factors tabulated therein and in Federal Guidance Report No. 11 (Eckerman et al. 1988, p. 14). These tabulated values are used to calculate doses for the repository.

The lognormal distribution function often represents aerosols produced by attrition processes (i.e., a wearing away or rubbing-off process that liberates particulate) (Dennis 1976, p. 113). At the repository, the process of releasing and aerosolizing commercial SNF after a drop or impact event may best be described as an attrition process. Thus, the particulate distribution of an aerosol produced from commercial SNF will be represented by a lognormal distribution function. The lognormal probability distribution function for particle diameters can be written (Dennis 1976, p. 113):

$$P(d) = \frac{1}{\sqrt{2\pi} \ln(\sigma)} \exp \left\{ -\frac{[\ln(d) - \ln(\text{MGD})]^2}{2 \ln^2(\sigma)} \right\} \quad (\text{Eq. 22})$$

where

- $P(d)$ is the probability distribution function
- d is a geometric diameter
- MGD is the mean geometric diameter of the distribution
- σ is the geometric standard deviation.

$[P(d) \Delta d / d]$ is the probability that a particle has a diameter in the range $(d - \Delta d/2)$ to $(d + \Delta d/2)$. The number distribution function is given by (Dennis 1976, p. 113):

$$\frac{n_i}{N} = \frac{1}{\sqrt{2\pi} \ln(\sigma)} \int_{d_1/\ln \sigma}^{d_2/\ln \sigma} \exp \left\{ -\frac{[\ln(d) - \ln(\text{MGD})]^2}{2 \ln^2(\sigma)} \right\} d(\ln d) \quad (\text{Eq. 23})$$

¹⁴ The deviation at the end of the spectrum (i.e., for larger particles) is attributed to: (1) uneven stresses in the impacted specimens with impact energy being absorbed in highly stressed zones, leaving the low-stressed zones nearly intact and (2) gross discontinuities at the grain boundaries allowing for a lot of energy to be absorbed and only creating microcracks (Mecham et al. 1981, p. 30).

$$\frac{n_i}{N} = \int P(d) d(\ln d) = \int \frac{P(d)}{d} d(d) \quad (\text{Eq. 24})$$

Figure 4 illustrates a typical differential $[n^D]$ and integrated $[n^I]$ lognormal number distribution:

$$n_i^D = \frac{d(n_i)}{N} = \frac{P(d_i)}{d_i} \quad (\text{Eq. 25})$$

$$n^I = \sum_{i=1}^I \frac{n_i}{N} = \frac{P(d_1)\Delta d}{2d_1} + \sum_{i=2}^{I-1} \left[\frac{P(d_i)\Delta d}{d_i} \right] + \frac{P(d_I)\Delta d}{2d_I} \quad (\text{Eq. 26})$$

where

the extended trapezoidal rule (Press et al. 1992, p. 127) was used to numerically integrate the preceding integral from zero to some diameter d_I where:

$I = 1, 2, \dots, K-1, K$.

K is the total number of integration points¹⁵

In addition, the various diameters discussed in Section 6.2.2.2 and the count mode diameter (i.e., the most frequent count diameter) are shown on Figure 4 as well.

¹⁵ Because of the large range of diameters considered in this analysis (i.e., 10^{-4} to 10^{+8} - μm diameters are used for the fuel fines), a non-uniform mesh spacing was used to perform the numerical integration. A fine mesh was used at the smaller diameters with the meshing becoming coarser as the diameter increased and the value of the integrand diminished (at the tail of the particle/mass distribution, Figures 4 and 5). The use of non-uniform mesh spacing is permitted for this form of numerical integration because of its relative simplicity (i.e., simply summing the area of trapezoids formed by the integrand and each set of two bounding mesh points [Atkinson 1989, p. 253]).

Figure 4. Typical Normalized and Integrated Lognormal Particle Distribution Function (MGD = 1 μm and $\sigma = 2$)

Because the respirable particle diameter is defined in terms of the median activity or the median mass (Section 6.2.2.1), the probability distribution function is converted to a mass distribution function $[P_m(d)]$ using the following equations:

$$m = \frac{4}{3} \pi \left(\frac{d}{2} \right)^3 \rho \quad (\text{Eq. 27})$$

$$P_m(d) = m P(d) = \frac{m}{\sqrt{2\pi} \ln(\sigma)} \exp \left\{ -\frac{[\ln(d) - \ln(\text{MGD})]^2}{2 \ln^2(\sigma)} \right\} \quad (\text{Eq. 28})$$

where

ρ is the theoretical density of UO_2 (10.96 g/cm³).

Figure 5 illustrates a typical normalized differential $[m^D]$ and integrated $[m^I]$ lognormal mass distribution and shows the various diameters discussed in Section 6.2.2.2.

$$m_i^D = \frac{d(m_i)}{M} = \left[\frac{m_i P(d_i) \Delta d}{d_i} \right] / \left[\sum_{j=1}^K \frac{m_j P(d_j) \Delta d}{d_j} \right] \quad (\text{Eq. 29})$$

$$m^I = \sum_{i=1}^I \frac{m_i}{M} = \frac{1}{M} \left\{ \frac{P(d_1) m_1 \Delta d}{2 d_1} + \sum_{i=2}^{I-1} \left[\frac{P(d_i) m_i \Delta d}{d_i} \right] + \frac{P(d_I) m_I \Delta d}{2 d_I} \right\} \quad (\text{Eq. 30})$$

where again the extended trapezoidal rule (Press et al. 1992, p. 127) was used to numerically integrate the probability integral from zero to some diameter, d_I , where:

$I = 1, 2, \dots, K-1, K$. K is the total number of integration points.

With these relationships established, now only the standard deviation and the MGD of the aerosol are needed to determine the RF of an aerosol distribution of commercial SNF and crud.

6.2.2.3.2 Characteristics of a Commercial SNF Aerosol

The two variables in the lognormal probability distribution function that are required to calculate number and mass distributions for an aerosol are the standard deviation and the MGD. In Section 6.2.2.2, relationships between MGD, MMD, and AMAD are shown in terms of the standard deviation. Thus, if any two of these properties (i.e., MGD, MMD, AMAD, and standard deviation) are known for a commercial SNF aerosol, then the lognormal probability distribution function can be solved and the number and mass distributions calculated.

Figure 5. Typical Normalized and Integrated Lognormal Mass Distribution Function (MGD = 1 μm and $\sigma = 2$)

An alternative method of establishing a lognormal distribution is to determine any one of these properties and a single point on any of the curves discussed in Section 6.2.2.3.1. Then an iterative method can be applied where another variable is varied in a logical manner until the known point is captured on the curve. For example, say the MGD of a distribution is known and a point on the differential lognormal number distribution is known, then the standard deviation can be calculated using the differential lognormal number equation (n') in the previous section.¹⁶

The burst rupture data used to establish the release fractions for fuel fines in Section 6.2.1.3 (Lorenz et al. 1980, p. 105 and Appendix C) provide data that can be interpreted as the MMD of the initially released particulate and also, provide a point on the integrated mass curve. The burst rupture test data do not provide a standard deviation or the MGD for the initially released particulate.

The impact test data on unclad UO_2 fuel pellets, discussed in Section 6.2.1, may be used to establish an RF for ceramic UO_2 , as an MMD and standard deviation have been established for these data. In fact, the RF for ceramic UO_2 is reported from these tests in ANL-81-27 (Mecham et al. 1981, pp. 26, 34, and 35, and Table 2) and ANL-82-39 (Jardine et al. 1982). This RF is based on the fraction of mass associated with the lognormally-distributed particles that have diameters less than 10 μm . This is a conservative interpretation of the RF relative to the interpretation of the RF established in Section 6.2.2.1, because the mass fraction of particles with diameters less than 10 μm is greater than the fraction of particles with an AMAD of 10 μm .

In addition, the particulate smaller than 90 μm were separated by wet sieving which effectively detaches smaller particles from larger fragments that would not ordinarily be considered respirable, thereby artificially increasing the respirable fraction. Furthermore, the quantity of respirable particulate is based on the amount measured from the material that had settled on to the bottom of the test apparatus. This quantity is likely inaccurate, because the actual respirable particulate were likely still airborne and could only be measured after being collected onto a filter, as was done for the burst rupture data. Nevertheless, the applicability of these impact data towards drop accidents involving commercial SNF was discounted in Section 6.2.1 and hence, the burst rupture data will be used to establish the RF for commercial SNF.

MMD of Commercial SNF Fuel Fines Aerosol

Fuel fines collected from burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, p. 105 and Appendix C) were measured with a scanning electron microscope and determined to be "typically 150 μm " in the furnace tube near the rupture point on the fuel pin. This 150- μm diameter is interpreted to be the MMD of initially aerosolized commercial SNF (Section 5, Assumption 5.8). This value may be considered conservative when applied to drop or impact events because larger particulates are likely to be initially aerosolized in these events because of

¹⁶ This is a non-linear equation and hence, solving for the standard deviation will require either applying a root finding scheme (e.g., conjugate gradient or bisection method) or simply iterating on the standard deviation until the correct solution is obtained.

the brittle nature of the fuel (assuming reasonable drop heights). This is supported by the MMDs measured in impact tests on unclad, depleted, ceramic UO_2 pellets in ANL-81-27 (Mecham et al. 1981, pp. 26, 34 and 35). These tests involved the impaction of two separate samples of depleted UO_2 pellets. The resulting particle-size distributions had measured MMDs of 18 μm and 32 μm (not μm). These MMDs are significantly larger than the 150- μm MMD assumed in this analysis for the initially aerosolized commercial SNF because these MMDs are based on particles resting on the bottom of the test apparatus while 150- μm MMD is based on airborne particles. These MMDs would become smaller when only airborne particles are used to determine MMDs. Because larger particles are essentially irrespirable (based on the rationale presented in Section 6.2.2.1) and carry a large portion of the total mass, larger MMDs will equate to smaller RFs, with all other parameters being equal (e.g., the standard deviation). Thus, the selection of the 150- μm diameter to represent the MMD of the initially aerosolized commercial SNF from a drop or impact event is believed to be a conservative assumption.

Another set of test data performed on single pellets of UO_2 by Alvarez is cited in Sanders et al. (1992, Section IV-4). Alvarez performed a series of tests on pellets of clad UO_2 that were both depleted and irradiated. These tests involved the detonation of explosive charges near the fuel. This would result in a significantly greater amount of energy imparted to the fuel than occurred in the burst rupture tests or a drop or impact event considered in this analysis. This energy imparted to the fuel would likely to create more small particles (given the brittle nature of the fuel) relative to the number created by a burst rupture or an impact event that would likely have some damage dampening to the upper sections of the fuel rod. Hence, the measured MMDs from these tests, which ranged from approximately 30 to 100 μm , are not considered applicable to this analysis. However, the relatively small difference between the upper range value of 100- μm MMD from Alvarez's explosive tests and the 150- μm diameter considered in this analysis, reinforces the conservative arguments made in this analysis for selecting an MMD of 150 μm .

The only potential drawback of considering the 150- μm MMD of initially aerosolized commercial SNF, in the analysis of the RF, is that this value is based on burst ruptures at high temperatures and not on an impact rupture caused by a drop event. Thus, it is not necessarily an accurate value for modeling the RFs for the considered accident events. However, the use of the burst rupture data towards impact rupture is supported in SAND80-2124 (Wilmot 1981, pp. 32 and 33). The basic tenet is that although an impact rupture is expected to produce more particles than were present in the spent fuel before a burst rupture, there will be less pressure to exhaust these particles after an impact than a burst rupture (Wilmot 1981, pp. 32 and 33). In addition, it is expected that an impact rupture would have a more restricted release pathway because of the cladding deformation (Wilmot 1981, p. 33). These arguments provide additional justification for applying the burst rupture test results to impact ruptures and hence, the 150- μm burst rupture MMD to the initially aerosolized commercial SNF from a drop or impact event at the repository.

Additional Data Point for Commercial SNF Fuel Fines

The other data point used from the burst rupture test data in NUREG/CR-0722 (Lorenz et al. 1980, p. 105) involves the fraction of the total mass less than a specified diameter. According to the masses summarized for each of the burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, Table 42 on p. 105), the largest fraction of UO_2 found in the thermal gradient tube and the filter pack was 0.0293, conservatively 0.03.¹⁷ Considering the deposition of the released fuel particles from gravity, fuel particles of diameters greater than 12 to 15 μm are considered to have settled out before reaching the thermal gradient tube (Lorenz et al. 1980, p. 105), and Attachment C of this analysis for separate confirmation of this settling calculation). Thus, the fraction of UO_2 collected in the thermal gradient tube and filter packs is considered to have diameters less than 12 to 15 μm . This has been confirmed by sampling (albeit somewhat randomly and sparsely) some of the particulate collected in the filters with a scanning electron microscope and determining that these particulate had diameters of typically 10 μm (Lorenz et al. 1980, p. 105 and Appendix C). Summarily, approximately 0.03 of the total mass of commercial SNF released from the burst rupture tests has a diameter of less than 12 to 15 μm (Section 5, Assumption 5.9).

6.2.2.4 Calculated Respirable Fractions

Calculation Methods

In Section 6.2.2.1, the RF of an aerosol that contributes to the inhalation dose is defined as a distribution or a portion of a distribution with an AMAD of 10 μm and less in this analysis. In instances when the AMAD of a whole distribution is greater than 10 μm , the RF is interpreted to be the mass fraction of particles below a cut-off diameter that has an AMAD of 10 μm . To determine this cut-off diameter, an iterative scheme must be applied with the objective of obtaining an MMD of 3.5 μm for commercial SNF particulate and 5.0 μm for crud particulate (each MMD is approximately equal to an AMAD of 10 μm) for the mass distribution below the cut-off diameter. The following steps, henceforth referred to as the iterative method, were used to determine the cut-off diameter:

1. Select a cut-off diameter greater than 3.5 μm for UO_2 (or 5.0 μm for crud).
2. Normalize the mass distribution less than the selected cut-off diameter.
3. Determine the MMD of the normalized distribution (the geometric diameter associated with 50 percent of the cumulative mass).

¹⁷ This value is calculated from data for test HBU-10 in Lorenz et al. (1980, Table 42 on p. 105). According to this table, a total of 46.03 mg of UO_2 was released from the burst fuel pin and 1.35 mg of this was measured in the thermal gradient tube and filter pack. Hence, the fraction of UO_2 collected in the thermal gradient tube and filter pack is 1.35/46.03 or 0.0293.

4. If the MMD of the normalized distribution is greater than 3.5 μm (5.0 μm for crud), then select a lower cut-off diameter and repeat steps 2 and 3.
5. If the MMD of the normalized distribution is less than 3.5 μm (5.0 μm for crud), then select a higher cut-off diameter and repeat steps 2 and 3.
6. When the MMD of the normalized distribution is approximately equal to 3.5 μm (5.0 μm for crud), then the respirable fraction is equal to the cumulative mass fraction of the entire aerosol distribution less than the cut-off diameter.

There are, however, several other methods of interpreting the RF that are not as arduous and were considered in this analysis:

- A conservative method, applied in ANL-81-27 (Mecham et al. 1981, pp. 4 and 5), henceforth referred to as the AMAD-10 Method, is to assume the mass fraction of aerosol particulate with geometric diameters less than 10 μm are respirable. This respirable cut-off diameter is based on equating the maximum respirable AMAD of 10 μm to a geometric diameter (essentially neglecting the AMAD and particle density differences). However, the AMAD of the fraction of the aerosol with a geometric diameter less than 10 μm is likely to be greater than 10 μm , thereby over-predicting the respirable fraction.
- A non-conservative method (relative to the previously described method), henceforth referred to as the AED Method, is to assume the mass fraction of commercial SNF aerosol particulates with geometric diameters less than 3.5 μm (5.0 μm for crud aerosols) are respirable. This respirable cut-off diameter is based on the relationship between the respirable cut-off particle diameter ($d_{c/o}$) and the AED shown in Section 6.2.2.1 (DOE 1994, p. 1-4). According to this relationship, a commercial SNF aerosol with an AED of 10 μm has a $d_{c/o}$ of approximately 3.5 μm (5.0 μm for crud aerosols). The AMAD of the commercial SNF aerosol mass fraction less than 3.5 μm (5.0 μm for crud aerosols) will be less than 10 μm , thereby under-predicting the respirable fraction.

Example Problem Implementing RF Methods

Consider a lognormal commercial SNF mass fraction distribution (Section 6.2.2.3) with an MGD of 1 μm and a standard deviation of 2 as shown in Figures 4 and 5. From Figure 5, the MMD of this distribution is established as 4.2 μm (the geometric diameter associated with 50 percent of the total mass of the distribution). Using the relationship between MMD and AMAD from Section 6.2.2.2, the AMAD of this distribution is equal to 12 μm . According to the AMAD-10 method, 89.9 percent of this aerosol is respirable and this respirable fraction of the aerosol has an AMAD of 11.1 μm . According to the AED method, 40.2 percent of this aerosol is respirable and the AMAD of this respirable fraction of the aerosol is 6.5 μm . The actual fraction of the aerosol that has an AMAD of 10 μm (the iterative method), and would be considered respirable in this analysis, is 80.2 percent. Table 5 summarizes the results from these different methods and notes the cut-off diameter (the assumed maximum respirable particle diameter) in the final column.

This example shows the large variance in the RF because of the different interpretations of the definition of respirable particles in Section 6.2.2.1. In this analysis, the iterative method is judged to provide the most accurate results and is used to establish the RF of the commercial SNF aerosol.

Table 5. Respirable Fractions (Expressed as Percent) of Lognormal Distribution with an MGD of 1 μm and a Standard Deviation of 2 (For Example Purposes Only)

Method	Respirable Percent	AMAD	Cut-Off Diameter
AMAD-10	89.9%	11.1 μm	10 μm
AED	40.2%	6.5 μm	3.5 μm
Iterative	80.2%	10 μm	7.5 μm

NOTES: AED = aerodynamic equivalent diameter; AMAD = activity median aerodynamic diameter.

Verification of RF Methods

To verify the application of lognormal distributions to determine respirable fractions for commercial SNF aerosols, the experimental pulverization data collected in ANL-81-27 (Mecham et al. 1981, pp. 23 to 35, UO_2 Specimen 1) is simulated. The minimum amount of input data needed to perform an accurate calculation of the respirable fraction is the MGD or MMD of the aerosol distribution, the standard deviation or a point on one of the number or mass distribution curves, the particle density, and the dynamic shape factor. For commercial SNF, Section 6.2.2.2 establishes the particle density and dynamic shape factor as 10.96 g/cm^3 and 1.3 (Section 5, Assumption 5.5), respectively. ANL-81-27 (Mecham et al. 1981, Table 2) determined that the MMD is 18 μm and the standard deviation for UO_2 (Specimen 1) is 8.18 μm .

By fixing the standard deviation, the MGD was varied until the calculated MMD of the distribution equaled 18 μm . The resulting MGD of this distribution was 0.032 μm .¹⁸ Figure 6 compares the measured cumulative mass fraction with the cumulative mass fraction calculated using the lognormal distribution. The fit is very good. The respirable fraction for this distribution is 2.0×10^{-4} , with the inherent assumption that the airborne release fraction is 1 for these data (Mecham et al. 1981, Table 2). This RF is based on the mass fraction of particulate with diameters less than 10 μm (Mecham et al. 1981, pp. 4 and 5), which is equivalent to using the AMAD-10 method. Using the AMAD-10 method and the calculated lognormal distribution, an RF of 1.84×10^{-4} is obtained. This value and the measured value are very close, thus verifying the method.

¹⁸ The MGD could also be calculated from $\ln(\text{MMD}) = \ln(\text{MGD}) + 3\ln^2(\sigma)$. The MGD calculated, using this method, is equal to 0.032 μm (identical to the presented value).

NOTE: Circles represent measured data from ANL-81-27 (Mecham et al. 1981, Figure 16).

Figure 6. Fitted Lognormal Aerosol Distribution for UO_2 to Data

Applying the iterative method to data from ANL-81-27 (Mecham et al. 1981, Table 2) yields an RF of approximately 4.83×10^{-5} with a cut-off diameter (maximum respirable diameter) of 4.95 μm . The AED method determines an RF of 2.41×10^{-5} .

6.2.2.4.1 Respirable Fraction for Commercial SNF

The MMD of an initially released commercial SNF aerosol of fines was conservatively established to be 150 μm (Section 6.2.2.3.2), based on burst rupture data in NUREG/CR-0722 (Lorenz et al. 1980, p. 105 and Appendix C) (Section 5, Assumption 5.8). In addition, these burst rupture data also provided a data point on the integrated mass curve: 0.03 of the total mass of released commercial SNF has a maximum diameter between 12 and 15 μm (Section 5, Assumption 5.9). These two characteristics of commercial SNF fuel fines released from a burst ruptured fuel pin allow for the RF to be calculated.

Determination of MGD

First, solving the relationship between MGD, MMD, and the geometric standard deviation provided in Section 6.2.2.2 for MGD, allows for the calculation of MGD given MMD and the standard deviation:

$$\ln(MMD) = \ln(MGD) + 3 \ln^2(\sigma) \quad (\text{Eq. 31})$$

$$MGD = \exp\{\ln(MMD) - 3 \ln^2(\sigma)\} \quad (\text{Eq. 32})$$

However a standard deviation was not established for these data. Thus another iterative process must be established such that the selection of the standard deviation results in an MGD that correlates to an MMD of 150 μm and 0.03 of the total mass has a maximum diameter between 12 and 15 μm . The process steps are as follows:

1. Select a standard deviation, σ .
2. Calculate the MGD using Equation 32 with an MMD of 150 μm .
3. Calculate the integrated lognormal mass distribution using the MGD and σ .
4. Determine whether 0.03 of the total mass has a maximum diameter of either 12 μm or 15 μm .
5. If the fraction of the total mass is less than 0.03 at 12 or 15 μm increase the standard deviation and repeat steps 2, 3, and 4.
6. If the fraction of the total mass is greater than 0.03 at 12 or 15 μm decrease the standard deviation and repeat steps 2, 3, and 4.
7. If the fraction of the total mass is approximately 0.03 at 12 or 15 μm , record the RF from the various methods described earlier (e.g., the iterative method).

Figure 7 shows how the fraction of mass that has a maximum diameter of 12 and 15 μm varies with the standard deviation using the preceding iterative scheme; these results are produced for an MMD fixed at 150 μm . In addition, Figure 7 also shows how the iterative method RF varies with the standard deviation. Each standard deviation has only one RF associated with it from each of the methods previously described because the MMD of this aerosol distribution is fixed at 150 μm , which in turn fixes the value of the MGD to the standard deviation through the Equation 32.

Determination of RF

Figure 7 also shows how the RF from the iterative method is established for this distribution with an MMD fixed at 150 μm . First, the standard deviation that produces a total mass fraction of 0.03 for particles with diameters less than 12 and 15 μm must be established. This is done in Figure 7 with the horizontal solid line leading from the left abscissa value of 0.03 to the dashed lines representing the mass fraction for 12 and 15 μm . At the intersection of the horizontal line with the mass fraction lines a vertical line is drawn to the ordinate. The intersection between the vertical line and the ordinate establishes the standard deviations.

For particles with a maximum diameter of 15 μm , the standard deviation and corresponding MGD are 3.4 and 1.678 μm , respectively. For particles with a maximum diameter of 12 μm , the standard deviation and corresponding MGD are 3.8 and 0.715 μm , respectively. The vertical lines drawn to the ordinate also intersect the iterative method RF line which establishes the RFs for the diameter limits of 12 and 15 μm (two horizontal lines drawn to the right abscissa). The iterative method RF for particles with a maximum diameter of 15 μm is 2.17×10^{-3} and for particles with a maximum diameter of 12 μm the RF is 4.90×10^{-3} .

Table 6 summarizes the RFs for these two limiting diameters using the other RF methods. This table also summarizes the cut-off diameters and AMADs for each of the methods. The RF results from the iterative method, which is considered to provide the most concise RFs relative to the other methods, indicate that for commercial SNF aerosols the RF should conservatively be 0.005. This result is the rounded-up value for the case with particles with a maximum diameter of 12 μm (an MMD of 150 μm , an MGD of 0.715 μm , and a standard deviation of 3.8).

Comparison between Burst Rupture and Impact Rupture Distributions

Figure 8 compares the lognormal distributions produced for the burst rupture data (MMD = 150 μm , MGD = 0.715 μm and $\sigma = 3.8$) from NUREG/CR-0722 (Lorenz et al. 1980, p. 105 and Appendix C) and the impact rupture data (MMD = 18 μm and $\sigma = 8.18$) from ANL-81-27 (Mecham et al. 1981, Table 2). The resulting distributions show that, as expected, the attrition process for commercial SNF escaping through a hole in the clad produced by a burst rupture has fewer large particulates relative to the commercial SNF particulates produced by the impaction of a tup onto unclad fuel pellets. Thus, the RF for the burst rupture data (0.005) is higher than the RF for the impact rupture (0.0002). This is expected because the RF for the impact rupture (0.0002) is based on the entire inventory of particles resting on the bottom of the test apparatus while the RF for the burst rupture (0.005) is based on airborne particles only. These airborne particles were collected on filters, baths, etc. located away from the point of release.

NOTE: The respirable fraction (RF) in this figure was calculated using the *Iterative Method* for a Lognormal Distribution with an MMD of 150 μm .

Figure 7. Fraction of Mass that has a Diameter less than 12 and 15 μm and Respirable Fraction as a Function of the Standard Deviation

NOTE: Burst rupture data is from NUREG/CR-0722 (Lorenz et al. 1980) and impact rupture data is from ANL-81-27 (Mecham et al. 1981).

Figure 8. Comparison of the Cumulative Mass Fraction Lognormal Distributions for Commercial SNF Aerosols Produced by Burst and Impact Ruptures

Table 6. Respirable Fractions of Lognormal Distributions with MMDs of 150 μm

Data Set	Method	Respirable Fraction	AMAD	Cut-Off Diameter
Particles with Diameters < 12 μm and make-up 3% of total mass ^a	AMAD-10	0.0224	20.1 μm	10 μm
	AED	0.00253	7.6 μm	3.5 μm
	Iterative	0.00490	10 μm	4.7 μm
Particles with Diameters < 15 μm and make-up 3% of total mass ^b	AMAD-10	0.0139	21.3 μm	10 μm
	AED	0.00111	8.0 μm	3.5 μm
	Iterative	0.00217	10 μm	4.5 μm

NOTES:

^a These particles have an MGD of 0.715 μm and a standard deviation of 3.8.^b These particles have an MGD of 1.678 μm and a standard deviation of 3.4.

AED = aerodynamic equivalent diameter; AMAD = activity median aerodynamic diameter; MMDs = mass median diameters.

Sensitivity of Results

The calculated RFs that led to the conservative selection of 0.005 as the RF for accident events at the repository involving commercial SNF are sensitive to:

- Density of the particulate (10.96 g/cm³) through the MMD and AMAD relationship established in Section 6.2.2.2
- Dynamic shape factor (1.3) through the MMD and AMAD relationship established in Section 6.2.2.2
- MGD/MMD of the lognormal distribution (0.715 μm /150 μm) through the lognormal distribution function in Section 6.2.2.3.1
- Standard deviation of the lognormal distribution (3.8) through the lognormal distribution function in Section 6.2.2.3.1
- Definition of the respirable AMAD (10 μm) through the definition of a respirable particle as established in Section 6.2.2.1.

A decrease in the density or the MGD/MMD will result in an increase of the RF. An increase in the dynamic shape factor, the standard deviation, or the respirable AMAD will also result in an increase of the RF for commercial SNF.

6.2.2.4.2 Respirable Fraction for Crud

The analysis to determine the RF of crud is much simpler than the analysis performed for commercial SNF fuel fines because experimental data presented in Sandoval et al. (1991, pp. 23 to 26) provide specific characteristics of the lognormal distribution of crud. Specifically, the MGD, MMD, and standard deviation of a crud particle distribution were determined from photographs of a Quad Cities BWR fuel rod using a scanning electron microscope. A plot of the collected data illustrated a precise lognormal distribution with an MMD of $9.7\ \mu\text{m}$, an MGD of $3\ \mu\text{m}$ and a standard deviation of 1.87 (Sandoval et al. 1991, p. 24 and p. 26).

These data resulted in a distribution of particle diameters that are somewhat larger than those observed for crud scraped from fuel rods. However, the scraping action of these tests likely produced smaller particles than are observed intact on a fuel rod. In addition, during an accident hypothesized for the repository, the majority of intact crud particles are likely to spall off of fuel rods rather than be pulverized, because the crud is not in a constricting volume. Hence, larger and likely less respirable crud particles may be produced during an accident event than were measured using the scanning electron microscope and scraped from the surface of a fuel rod.

Using the iterative method discussed earlier, a respirable fraction of 0.30 for BWR crud was established. The cut-off diameter or maximum respirable particle diameter size was established to be $6.9\ \mu\text{m}$. No database for PWR crud number distributions is presently available (Sandoval et al. 1991, p. 25). However, there are some data on particle sizes determined for crud on the cladding surface of a H.B. Robinson PWR fuel rod in Sandoval et al. (1991, p. 24). The PWR crud has a comparable size range with BWR crud (Sandoval et al. 1991, p. 24). Thus, assuming the PWR crud particles also exhibits lognormal behavior, then it may be assumed that PWR crud will have the same RF to that of BWR crud (Section 5, Assumption 5.4).

Table 7 summarizes the results from the different methods to calculate the RF that were discussed earlier. In addition, this table gives the cut-off diameter (or the maximum respirable particle diameter) and AMAD for each method.

Table 7. Respirable Fractions for the Lognormal Distribution of Crud (MGD = $3.0\ \mu\text{m}$ and $\sigma = 1.87$)

Method	Respirable Fraction	AMAD	Cut-Off Diameter
AMAD-10	0.54	$13.0\ \mu\text{m}$	$10.0\ \mu\text{m}$
AED	0.15	$7.88\ \mu\text{m}$	$5.0\ \mu\text{m}$
Iterative	0.30	$10.0\ \mu\text{m}$	$6.9\ \mu\text{m}$

NOTES: AED = aerodynamic equivalent diameter; AMAD = activity median aerodynamic diameter; MGD = mean geometric diameter.

The calculated RFs are sensitive to:

- The density of the particulate (5.2 g/cm^3) through the MMD and AMAD relationship established in Section 6.2.2.2.
- The dynamic shape factor (1.3) through the MMD and AMAD relationship established in Section 6.2.2.2.
- The MGD/MMD of the lognormal distribution ($3 \text{ }\mu\text{m}/9.7 \text{ }\mu\text{m}$) through the lognormal distribution function in Section 6.2.2.3.1.
- The standard deviation of the lognormal distribution (1.87) through the lognormal distribution function in Section 6.2.2.3.1.
- The definition of the respirable AMAD ($10 \text{ }\mu\text{m}$) through the definition of a respirable particle as established in Section 6.2.2.1.

A decrease in the density or the MGD/MMD will result in an increase of the RF. An increase in the dynamic shape factor, the standard deviation, or the respirable AMAD will also result in an increase of the RF for crud. Because of this sensitivity, a conservative value of 1.0 was selected as the RF for accident events at the repository involving commercial SNF crud.

6.2.2.4.3 Summary of Respirable Fractions

To be consistent with the assumptions (i.e., $\text{AMAD} = 1 \text{ }\mu\text{m}$) used to calculate the inhalation dose conversion factors in Federal Guidance Report No. 11 (Eckerman et al. 1988, Table 2.1) and Publication 30 (ICRP 1979, Figure 5.1), the RFs from the iterative method are recommended for use in repository accident analysis involving commercial SNF. This method establishes the RF based on a respirable particle size distribution with an AMAD of $10 \text{ }\mu\text{m}$ or less. The combination of dose conversion factors based on an AMAD of $1 \text{ }\mu\text{m}$ and an RF based on an AMAD of $10 \text{ }\mu\text{m}$ or less are considered to produce a conservative methodology for inhalation dose calculations.

For commercial SNF fuel fines, an RF of 0.005 is recommended. This value is produced for lognormally-distributed particulates with the following characteristics: an MMD of $150 \text{ }\mu\text{m}$, an MGD of $0.715 \text{ }\mu\text{m}$, and a standard deviation of 3.8. For crud from the cladding surface of commercial SNF, a conservative RF of 1.0 is recommended. For gases and volatiles, an RF of 1.0 is recommended.

6.2.3 Comparison of Respirable Release Fractions

The respirable release fractions have been calculated for rail casks and truck casks under hypothetical accident conditions in NUREG/CR-6672 (Sprung et al. 2000, pp. 7-74 and 7-75). These values are compared with the values recommended in this analysis in Table 8.

Table 8. Respirable Release Fractions for Commercial SNF

Nuclide	Recommended Respirable Release Fractions (ARF $\times$ RF)	Truck Casks ^a		Rail Casks ^a	
		PWR Release Fractions	BWR Release Fractions	PWR Release Fractions	BWR Release Fractions
³ H	0.30	1.4×10^{-1}	5.4×10^{-3}	1.8×10^{-1}	1.5×10^{-2}
⁸⁵ Kr	0.30	1.4×10^{-1}	5.4×10^{-3}	1.8×10^{-1}	1.5×10^{-2}
¹²⁹ I	0.30	4.1×10^{-9}	1.6×10^{-10}	5.4×10^{-9}	4.5×10^{-10}
¹³⁴ Cs & ¹³⁷ Cs	2.0×10^{-4}	4.1×10^{-9}	1.6×10^{-10}	5.4×10^{-9}	4.5×10^{-10}
⁹⁰ Sr	1.5×10^{-7}	1.0×10^{-7}	4.0×10^{-9}	1.3×10^{-7}	1.1×10^{-8}
¹⁰⁶ Ru	2.0×10^{-4}	1.0×10^{-7}	4.0×10^{-9}	1.3×10^{-7}	1.1×10^{-8}
Fuel Fines	1.5×10^{-7}	1.0×10^{-7}	4.0×10^{-9}	1.3×10^{-7}	1.1×10^{-8}
Crud (⁶⁰ Co)	1.5×10^{-2}	1.4×10^{-3}	4.5×10^{-4}	1.8×10^{-3}	1.3×10^{-3}
Crud (⁵⁵ Fe)	1.5×10^{-2}	1.4×10^{-3}	4.5×10^{-4}	1.8×10^{-3}	1.3×10^{-3}

NOTES: ^a NUREG/CR-6672 (Sprung et al. 2000, p. 7-74 and 7-75) Case 2 for truck casks and Case 5 for rail casks.

ARF = airborne release fraction; BWR = boiling water reactor; PWR = pressurized water reactor; RF = respirable fraction.

Table 8 shows that the respirable release fractions, ARF multiplied by RF, for gases, Cs, Sr, Ru, and fuel fines recommended in this analysis are more conservative than the corresponding values given in NUREG/CR-6672 (Sprung et al. 2000, pp. 7-74 and 7-75) for cases with impact speeds ranging from 30 to 60 mph and interior cask temperatures ranging from the ambient temperature to 350°C. The crud respirable release fraction of 1.5×10^{-2} , recommended in Table 8, is comparable to the values given in NUREG/CR-6672 (Sprung et al. 2000, pp. 7-74 and 7-75).

6.3 ARFS AND RFS FOR FAILED COMMERCIAL SNF

This section examines and establishes the ARFs and the RFs for failed commercial SNF. This section first examines the applicability of the ARFs and RFs established for intact commercial SNF in Section 6.2 to failed commercial SNF. For cases where the intact commercial SNF values do not bound those of the failed commercial SNF, a preliminary attempt has been made to establish a bounding value for the failed commercial SNF.

According to the report *1999 Design Basis Waste Input Report for Commercial Spent Nuclear Fuel* (CRWMS M&O 1999, p. C-1), there are four categories of "problematic" commercial SNF projected to be placed into disposable canisters (defined as canisters that can be placed into disposal containers without being repackaged). These four categories include:

1. *Mechanically and Cladding-Penetration Damaged SNF*, which includes: (1) fuel that is mechanically damaged such that it can not be vertically lifted or fit within a standard dimension and/or (2) fuel that has lost containment as a result of cladding damage.

Note: It is assumed that the fuel in this category is made-up of intact fuel assemblies and fuel pins/rods. The fuel pins/rods are stored in some grid-like structure within a canister that provides the pins/rods structural support equivalent to an assembly (Section 5, Assumption 5.15).

2. *Consolidated/Reconstituted Assemblies*, which includes fuel that was disassembled and when reassembled has a form that is dimensionally different from the original.

Note: It is assumed that the fuel in this category is made-up of intact fuel assemblies. If the fuel assembly is a reassembled assembly, then its structural support is considered equivalent to an un-reassembled assembly (Section 5, Assumption 5.15).

3. *Fuel Rods, Pieces, and Debris*, which includes variable-sized pieces of fuel and debris combining fuel and nonfuel materials.

Note: It is assumed that the fuel in this category is in the form of stray fuel rods, pieces, and debris that do not have any structural support system while in a canister (Section 5, Assumption 5.15).

4. *Nonfuel Components*, which includes in-core assembly components physically separated from the assemblies and shipped separately.

Results for the final category, Nonfuel Components, is considered out of scope for this report, but it is expected that potential doses created from an accident event involving this material will be bounded by those from the other categories. This is due principally to the lack of fuel material included with the components of this category. The source term from this category is likely be dominated by the surface crud source term.

The ARFs and RFs for specific isotopes identified in Section 6.2 for intact commercial SNF involved in drop or impact events are examined to establish whether they bound the potential ARFs for each of the three remaining categories of failed commercial SNF. The identified groups of specific isotopes are gases (^3H , ^{85}Kr , and ^{129}I), volatiles (^{134}Cs , ^{137}Cs , and ^{106}Ru), fuel fines (^{90}Sr , etc.), and crud (^{60}Co and ^{55}Fe). Crud also includes a surface activity that will be examined for each of these failed commercial SNF categories.

The failed fuel analyzed in this analysis is assumed always contained within an annular canister with mesh screen caps at each end. Fuel handling at the repository will not involve removing this fuel from these canisters. Fuel classified as failed but maintaining the form of an assembly or group of fuel pins placed in some grid-like spacers provided within the canister (matrixed) are considered to withstand a drop or impact event without any pulverization. This essentially means that the structural support of the fuel assembly/fuel pins and the canister wall act monolithically to mitigate any pulverization of the fuel.

6.3.1 ARFs and RFs for Gases

As fuel is irradiated in a nuclear power reactor, fission product atoms, of which approximately 15 percent are inert gases, are produced and buildup within the cladding of the fuel pins. Release of these fission gases from the fuel matrix to the plenum and the gap region between the fuel and the cladding is directly related to fuel pellet swelling which is a strong function of linear power density. The primary fission gases released to this gap region for commercial SNF are noble gases, iodines, and tritium. The recommended ARF values for these gases for intact commercial SNF are based on p. 25.2 of Regulatory Guide 1.25, which states that the release fractions of these fission gases from the gap region of a fuel rod are conservatively assumed to consist of 30 percent ^{85}Kr , 10 percent of other noble gases, and 10 percent of the radioactive iodine. Page 25.2 of Regulatory Guide 1.25 further states that 30 percent of the ^{127}I and ^{129}I inventory may be assumed released for the purpose of sizing filters. These ARFs for gases are also consistent with values cited in NUREG-1617 (NRC 2000a) and NUREG/CR-6487 (Anderson et al. 1996) for use in potential accident releases involving intact fuel rods (SAIC 1998, Table 4-1; Anderson et al. 1996, Table 6-2). These ARFs for gases also bound ARFs cited in other literature: NUREG-1536 (NRC 1997, Table 7.1), NUREG-1567 (NRC 2000b, Table 9.2), and SAND80-2124 (Wilmot 1981, Table XVIII). Table 3 summarizes the ARFs for gases associated with each category of failed commercial SNF and the intact commercial SNF. A discussion of how these values were established follows. RF for gases is equal to 1.0, as 100 percent are considered aerosolized.

6.3.1.1 Mechanically and Cladding-Penetration Damaged SNF

The release of fission gases from mechanically and cladding-penetration damaged SNF will only occur from the plenum and from the gap region between the cladding and the fuel of a fuel pin. An impact or drop event may result in the cladding of this failed fuel category to be punctured, penetrated, or cracked resulting in the release of the gap fission gases. Fission gases from the fuel matrix, excluding the fraction considered released to the gap, are not expected to be released as a result of an impact or drop event. The additional structural support provided to the assemblies or matrixed fuel pins of this failed fuel by the canister will mitigate the potential release of additional gases from the fuel matrix by preventing fuel pulverization potentially caused by a drop or impact event.

Thus, for the mechanically and cladding-penetration damaged SNF category of failed fuel, the ARFs for fission gases will be bounded by those established in Table 3. This is clearly true for the cladding-penetrated commercial SNF where the majority of the fission gases originally in the gap have been purged through the leak paths provided by the cladding penetrations prior to an impact or drop event, thereby removing the motive force contributing to the expulsion of these fission products from the irradiated fuel. These penetrations also ensure that no more fission gases accumulate in the gap. The cladding of mechanically damaged commercial SNF prior to an impact or drop event may be either intact or failed. For the portion of this fuel that has previously failed cladding, the majority of the fission gases in the gap will have been purged through the paths provided by the clad penetrations prior to an impact or drop event. These leak paths will also ensure little or no further fission gas accumulation in the gap. Thus, the gas ARFs for this fuel are clearly bounded by those from Table 3. For the fraction of this fuel that has intact cladding, the differences between it and the fuel analyzed in Section 6.2 are insignificant.

Thus, the gas ARFs established in this analysis for intact fuel are considered bounding for the mechanically damaged commercial SNF with intact cladding.

6.3.1.2 Consolidated/Reconstituted Assemblies

The release of fission gases from consolidated and reconstituted assemblies will only occur from the gap between the cladding and the fuel of a fuel pin. An impact or drop event may result in the cladding of this failed fuel category to be punctured, penetrated, or cracked resulting in the release of the gap fission gases. Fission gases from the fuel matrix, excluding the fraction considered released to the gap, are not expected to be released as a result of an impact or drop event. The additional structural support provide to the assemblies (or matrixed fuel pins) of this failed fuel by the canister will mitigate the potential release of additional gases from the fuel matrix by preventing fuel pulverization potentially caused by a drop or impact event. Furthermore, the differences between this category of failed fuel and the fuel analyzed in Section 6.2 are insignificant with respect to the ARFs for fission gases. Thus, for the consolidated/reconstituted assemblies category of commercial SNF failed fuel, the ARFs for the fission gases will be bounded by those established in Table 3.

6.3.1.3 Fuel Rods, Pieces, and Debris

The release of fission gases from fuel rods, pieces, and debris will occur from the fuel matrix and for a fuel rod with intact cladding, from the gap. An impact or drop event may result in the cladding of a fuel rod in this failed fuel category to be punctured, penetrated, or cracked resulting in the release of the gap fission gases. In addition, because this category of failed fuel is not considered to have any assembly-like structure while in a canister, an impact or drop event is assumed to pulverize up to 20 percent (Section 5, Assumption 5.17) of the fuel thereby releasing fission gases from the fuel matrix.

Thus, for the fuel rods, pieces, and debris category of failed commercial SNF, the ARFs for the fission gases are bounded by the values listed in Section 6.2 for intact commercial SNF. In this report, the ARFs for the fission gases are conservatively established to be 0.3 for fuel rods with intact cladding. Because fuel rods in this group may include rods with intact cladding that are conservatively assumed to be pulverized in the event of a drop or impact, fission gases in the gap (less than 0.005) (Lorenz et al. 1980, Tables 4 and 5) and the fraction of the fuel matrix pulverized (0.2) are conservatively assumed released.

However, if the fuel rods in this failed fuel category are considered to have previously failed cladding, then the fraction of fission gases released (i.e., the ARF) can be reduced to a value of 0.2. This ARF can also be applied to fuel pieces and debris, which are considered to be devoid of any intact cladding and thus do not contain gap fission gases. This value is equal to the fraction of fuel assumed pulverized (see Section 6.3.2.3). It does not include fission gases released from a fuel rod prior to the rods placement into a canister or the fission gases that remain in the particulate created by pulverization which equate to about 30 percent of the total fission gas inventory. Page 25.2 of Regulatory Guide 1.25 conservatively estimates that 30 percent of the fission gases are released to the gap. Considering this fraction and also making allowance for the fission gases that remain captured in the smaller particulate following pulverization, the use of a fission gas ARF of 0.3 is conservative, as shown in Table 9.

Table 9. ARFs and RFs for Gap Gases

Fuel Category	ARF / RF		
	³ H	⁸⁵ Kr	¹²⁹ I
1. Mechanical/Cladding Damaged	0.30 / 1.0	0.30 / 1.0	0.30 / 1.0
2. Consolidated/Reconstituted	0.30 / 1.0	0.30 / 1.0	0.30 / 1.0
3a. Fuel Rods with Intact Cladding	0.30 / 1.0	0.30 / 1.0	0.30 / 1.0
3b. Other Fuel Rods, Pieces, and Debris	0.30 / 1.0	0.30 / 1.0	0.30 / 1.0
Intact Commercial SNF	0.30 / 1.0	0.30 / 1.0	0.30 / 1.0

NOTES: ARF = airborne release fraction; RF = respirable fraction; SNF = spent nuclear fuel.

6.3.2 ARFs and RFs for Volatiles and Fuel Fines

Fuel fines and volatiles found in the gap are liberated or created from fuel pellets because of the shaking of the rod and grinding action between fuel pellets that occurs during handling and transport of the fuel. Fuel fines exist as residue from the fuel manufacturing process and are produced during irradiation from pellet cracking that is associated with thermal distortion caused while the fuel was at high temperatures. In the latter case, the higher temperature at the center of a fuel pellet than at the periphery produces circumferential tensile stress that produce radial pellet cracks.

Some of the primary constituents that makeup fuel fines and volatiles of commercial SNF, as specifically noted in NUREG-1536 (NRC 1997, Table 7.1) and NUREG-1567 (NRC 2000b, Table 9.2), are ⁹⁰Sr, ¹⁰⁶Ru, ¹³⁴Cs, and ¹³⁷Cs. As discussed in Section 6.2.1.2, the only volatiles potentially present in a credible accident at the repository are Cs and Ru. Volatiles are assumed to be 100 percent respirable.

The recommended ARF values for these nuclides, and fuel fines in Section 6.2 are based on data collected from burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, Table 40). These ARFs are also consistent with values cited in NUREG/CR-6487 (Anderson et al. 1996, pp. 31 and 32) and NUREG/CR-6410 (SAIC 1998, Table 4-1) for use in potential accident releases from intact fuel rods. An extensive analysis of the RF in Section 6.2 for fuel fines released in the burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, Table 40), established an RF of 0.005.

Another set of experiments by ANL-81-27 (Mecham 1981) and ANL-82-39 (Jardine 1982) that were not used to establish the ARFs for fuel fines in Section 6.2, provides alternative data that may be applicable to failed fuel damaged by a drop or impact event that involves fuel pulverization. The ARFs and RFs produced from these experiments involve unconfined (i.e., no cladding) glass and UO₂ ceramic specimens impacted by a dropping weight. The applicability and details of these tests are described in further detail in Section 6.2. In summary, these test data and their associated PULF were deemed not appropriate for application to dropped or impacted intact commercial SNF assemblies. These data are considered applicable, however, because some of the failed fuel exists as small unclad fuel pieces and debris.

Thus, the equation for the PULF fraction is rewritten here:

$$\text{PULF} = (A) (\rho) (g) (h) \quad (\text{Eq. 33})$$

where

A is an empirical correlation equal to $2 \times 10^{-11} \text{ cm-s}^2/\text{g}$
 ρ is the UO_2 particle density (10.96 g/cm^3)
 g is gravitational acceleration (980 cm/s^2)
 h is the fall height (cm).

Table 10 summarizes the ARFs and RFs for volatiles (i.e., Cs and Ru) and fuel fines associated with each category of failed commercial SNF and the intact commercial SNF.

Table 10. ARFs and RFs for Volatiles and Fuel Fines †

Fuel Category	ARF / RF		
	¹³⁴ Cs & ¹³⁷ Cs & ¹⁰⁶ Ru	⁹⁰ Sr	Fuel Fines
1. Mechanical/Cladding Damaged	2.0E-04 / 1.0	3.0E-05 / 5.0E-03	3.0E-05 / 5.0E-03
2. Consolidated/Reconstituted	2.0E-04 / 1.0	3.0E-05 / 5.0E-03	3.0E-05 / 5.0E-03
3a. Fuel Rods with Intact Cladding	2.0E-04 / 1.0	5.9E-07 / 1.0	5.9E-07 / 1.0
3b. Other Fuel Rods, Pieces, & Debris	2.0E-04 / 1.0	5.8E-07 / 1.0	5.8E-07 / 1.0
Intact Commercial SNF	2.0E-04 / 1.0	3.0E-05 / 5.0E-03	3.0E-05 / 5.0E-03

NOTES: † These values assume a cask drop from 80 inches (203.2 cm).

ARF = airborne release fraction; RF = respirable fraction; SNF = commercial spent nuclear fuel.

6.3.2.1 Mechanically and Cladding-Penetration Damaged SNF

The release of volatiles and fuel fines from mechanically and cladding-penetration damaged SNF will occur from the fuel surface and gap between the cladding and the fuel of a fuel pin. An impact or drop event may result in the cladding of this failed fuel category to be punctured, penetrated, or cracked resulting in the release of the volatiles and fuel fines captured by the exhausting gases in the gap. Volatiles and fuel fines in the fuel matrix are not expected to be released as a result of an impact or drop event.

The additional structural support provide to the assemblies or matrixed fuel pins of this failed fuel by the canister will mitigate the potential release of additional volatile and fuel fine quantities from the fuel matrix by preventing fuel pulverization potentially caused by a drop or impact event (Section 5, Assumption 5.16).

Thus, for the mechanically and cladding-penetration damaged SNF category of failed fuel, the ARFs for the volatiles and fuel fines on the surface of the fuel and in the gap will be bounded by those established in Table 3. This is clearly true for the cladding-penetrated commercial SNF where the majority of the fission gases originally in the gap have been purged through the leak paths provided by the cladding penetrations prior to an impact or drop event, thereby removing the motive force contributing to the expulsion of these fission products from the irradiated fuel.

For the mechanically damaged commercial SNF, the ARFs are bounded for the same reasons the intact commercial SNF is bounded by these ARFs: high deposition through narrow, often long, and tortuous paths to the breach point especially for larger particulate which carry a majority of the total released fuel. Furthermore, the canister walls increase the amount of surface area where local deposition of fuel fines/volatiles can take place, effectively increasing the tortuous paths they pass prior to escaping to the environment. These characteristics provide sufficient justification that the fuel fine and volatile ARFs for intact commercial SNF bound the same ARFs for this category of failed commercial SNF.

6.3.2.2 Consolidated/Reconstituted Assemblies

The release of volatiles and fuel fines from consolidated and reconstituted assemblies will only occur from the fuel surface and gap between the cladding and the fuel of a fuel pin. An impact or drop event may result in the cladding of this failed fuel category to be punctured, penetrated, or cracked resulting in the release of the volatiles and fuel fines captured by the exhausting gases in the gap. Volatiles and fuel fines in the fuel matrix are not expected to be released as a result of an impact or drop event. The additional structural support provide to the assemblies (or matrixed fuel pins) of this failed fuel by the canister will mitigate the potential release of additional volatile and fuel fine quantities from the fuel matrix by preventing fuel pulverization potentially caused by a drop or impact event (Section 5, Assumption 5.16).

Thus, for the consolidated/reconstituted assemblies category of commercial SNF failed fuel, the ARFs for the volatiles and fuel fines in the gap will be bounded by those established in Table 3. This is because of the same reasons the intact commercial SNF is bounded by these ARFs: high deposition through narrow, often long, and tortuous paths to the breach point especially for larger particulate which carry a majority of the total release mass (see Section 6.2). The canister walls also increase the amount of surface area where local deposition of fuel fines/volatiles can take place, effectively increasing the tortuous paths the fuel fines/volatiles pass prior to escaping to the environment. These characteristics provide justification that the fuel fine and volatile ARFs for intact commercial SNF bound the same ARFs for this category of failed commercial SNF.

6.3.2.3 Fuel Rods, Pieces, and Debris

The release of fuel fines and volatiles from fuel rods, pieces, and debris will occur from the fuel matrix and for fuel rods with intact cladding, from the gap. An impact or drop event may result in the cladding of a fuel rod in this failed fuel category to be punctured, penetrated, or cracked resulting in the release of the volatiles and fuel fines captured by the exhausting gases in the gap. In addition, because this category of failed fuel is not considered to have any assembly-like structure while in a canister, an impact or drop event may pulverize some fraction of the fuel, thereby releasing fuel fines and volatiles from the fuel matrix.

Thus, for the fuel rods, pieces, and debris category of commercial SNF failed fuel, the product of the ARF and the RF for the fuel fines are conservatively assumed equal to the PULF from DOE-HDBK-3010-94 (DOE 1994, Section 4.3.3):

$$\text{PULF} = \text{ARF} \times \text{RF} = (A) (\rho) (g) (h) \quad (\text{Eq. 34})$$

where

A is an empirical correlation equal to $2 \times 10^{-11} \text{ cm-s}^2/\text{g}$
 ρ is the UO_2 particle density (10.96 g/cm^3)
 g is gravitational acceleration (980 cm/s^2)
 h is the height the fuel falls (cm).

Because this equation was derived from data involving small specimens (i.e., three pellets), there may be a large degree of conservatism built into this equation when its use is extrapolated to masses greater than a few pellets. This conservatism is due in a large part to a cushioning effect created by the pulverization of the fuel at the bottom of a stack of fuel (e.g., pellets in a fuel rod). The fuel at the bottom of the dropped stack is pulverized into a powder and then acts as a cushion to the fuel dropping over it. In addition, this equation does not take into account the structural credit provided by the presence of cladding or the canister.

In an attempt to correct for some of this conservatism, SAND84-2641 (MacDougall et al. 1987, pp. 5-16 to 5-26) modified the PULF correlation by including an EPF. Unfortunately, values for EPF are not available from analysis or experiment, however, SAND84-2641 (MacDougall et al. 1987, pp. 5-16 to 5-26) assumed that this factor is conservatively 0.2. This is equivalent to assuming that approximately only 20 percent of the total fuel will be pulverized, most likely the bottom 20 percent of the fuel.

The respirable fraction of particulate is based on the mass of particles less than $10 \text{ }\mu\text{m}$ in geometric size. For uranium oxide particles with a density of 10.96 g/cm^3 , the respirable size is about $3 \text{ }\mu\text{m}$ (see Section 6.2.2.1). In a 1.2 J/cm^3 drop-weight impact on a set of three UO_2 pellets, the fractions of particles smaller than $10 \text{ }\mu\text{m}$ and $3 \text{ }\mu\text{m}$ are 2×10^{-4} and 2×10^{-5} (Mecham et al. 1981, Figures 16 and 17). Because the PULF equation is based on a respirable particle size of $10 \text{ }\mu\text{m}$, the PULF value will be reduced by an additional factor of 0.1 ($= 2 \times 10^{-5} / 2 \times 10^{-4}$) to correct for the fraction of respirable fuel fines.

Three rocks (1.29 kg, 1.17 kg, and 1.82 kg) (DOE 1994, p. 4-87) were dropped from a height of 3.7-m onto sand held in an open-lid steel quart can in a vented metal box placed on a plywood sheet or onto unconfined sand placed on a plywood sheet. The rocks were dropped from the same distance onto this can. Three experiments were performed. The first experiment involved sand screened to be less than 2 mm ($2000 \text{ }\mu\text{m}$) in diameter, while the second experiment used sand screened to be less than 0.5 mm ($500 \text{ }\mu\text{m}$) in diameter with 1.8 percent less than 0.025 mm ($25 \text{ }\mu\text{m}$). The third experiment was performed with the same powder used in the second experiment, except that the sand is unconfined.

The measured ARF and RF for the first experiment with confined sand were $3.0\text{E-}04$ and 0.01 (DOE 1994, p. 4-87), respectively. The measured ARF and RF for the second experiment with confined sand were $3.0\text{E-}04$ and 0.07 (DOE 1994, p. 4-87), respectively. The ARF and RF for the third experiment with unconfined sand were $8.7\text{E-}04$ and 0.36 (DOE 1994, p. 4-87), respectively. The experiments showed that the RF was significantly reduced by the presence of an open-lid can. The ARF multiplied by the RF reduction factor (RED) because of the presence of a can is defined as $(\text{ARF} \times \text{RF})_{\text{confined}}/(\text{ARF} \times \text{RF})_{\text{unconfined}}$:

$$(\text{RED})_1 = (3.0\text{E-}04 \times 0.01)/(8.7\text{E-}04 \times 0.36) = 9.6\text{E-}03 \quad (\text{Eq. 35})$$

$$(\text{RED})_2 = (3.0\text{E-}04 \times 0.07)/(8.7\text{E-}04 \times 0.36) = 6.7\text{E-}02 \quad (\text{Eq. 36})$$

The larger of the two calculated RED values (0.067) because of the presence of a can is chosen to conservatively reduce the $\text{ARF} \times \text{RF}$ calculated from the PULF correlation. A failed fuel canister is expected to provide the same degree or better confinement than an open-lid can. Therefore, the application of an $\text{ARF} \times \text{RF}$ reduction factor of 0.067 to the failed fuel canister is conservative.

One of the most important processes affecting the concentration of airborne particulate within a plume is depletion by deposition of aerosols (particulates and vapors) onto the ground, vegetation, and structures. The source term depletion fraction, DEP, is defined as $Q(x)/Q(0)$, where $Q(x)$ and $Q(0)$ are airborne particulate source strength at distance x and at the release point, respectively. The source term depletion fraction at a distance of 5 km has been calculated for five sample materials including UO_2 and defense high level waste glass (MacDougall et al. 1987, Table 5-12). The calculated values of DEP range from 3.4×10^{-2} to 5.8×10^{-2} . A conservative DEP value of 1.0 instead of 0.05 was chosen for repository consequence analysis (MacDougall et al. 1987, p. 5-49).

By including a source term depletion fraction of 1.0 , a reduction factor (RED) of 0.067 because of the presence of a confining surface (i.e., failed fuel canister), and an EPF of 0.2 , the PULF equation can be rewritten as:

$$\begin{aligned} \text{Failed Fuel Release Fraction} &= \text{DEP} \times \text{RED} \times \text{EPF} \times \text{PULF} \\ &= (1.0) (0.067) (0.2) (A) (\rho) (g) (h) \\ &= (1.0) (0.067) (0.2) (2 \times 10^{-11} \text{ cm-s}^2/\text{g}) (10.96 \text{ g/cm}^3) (980 \text{ cm/s}^2) (h) \\ &= 2.88 \times 10^{-9} (h) (\text{cm}) \end{aligned} \quad (\text{Eq. 37})$$

For a drop from 80 inches (203.2 cm), the normal handling height of a shipping cask at the repository (CRWMS M&O 1998, p. 14), the corrected PULF is 5.8×10^{-7} . This value does not include any releases of fuel fines from the gap.

For fuel rods with intact cladding, the additional fraction of respirable fuel fines located in the gap between the cladding and the fuel must be included. Therefore, for these fuel rods, the fraction of respirable fuel fines ($\text{ARF} \times \text{RF}$) is 5.9×10^{-7} . This value includes the fraction 5.8×10^{-7} for the fuel fines from the fuel matrix plus the fraction 1.0×10^{-8} ($=3.0 \times 10^{-5}$ (ARF) $\times 5.0 \times 10^{-3}$ (RF) $\times 0.067$) for the fuel fines from the gap.

The preceding calculations show that the fuel fine ARF $\times$ RF for failed fuel in a canister is bounded by the ARF $\times$ RF of 1.5×10^{-7} for intact commercial SNF.

For the volatile nuclides released from failed fuel in the category of fuel rods, pieces, and debris, the use of ARF/RF of 2.0E-04/1.0 for intact commercial SNF is conservative. The ARF/RF values of 2.0E-04/1.0 are bounding for the release of Cs isotopes from failed fuel.

6.3.3 ARFs, RFs, and Surface Activities for Crud

Crud releases originate from the surface of a fuel rod and associated components (e.g., grid spacers). In contrast to the fuel fines, gases, and volatiles released from a fuel rod, the crud release fraction is not based on the fraction of fuel rods that are breached and the release mechanism involves surface spallation rather than leakage past fuel cladding barriers. Crud is primarily composed of iron-based compounds and some nickel, copper, cobalt, chromium, manganese, zinc, and zircalloy. The actual amount varies from reactor to reactor and cycle to cycle. Crud has become radioactive through neutron activation and has a relatively short half life. In general, pressurized water reactor fuel is found to have less crud activity than boiling water reactor fuel (Sandoval et al. 1991, p. 2).

In Section 6.2.1.3, the crud effective ARF on intact commercial SNF fuel assemblies is conservatively assumed equal to 1.5E-02, which is recommended for use for failed commercial SNF categories with cladding. Similarly, the RF for crud is conservatively established in Section 6.2.4.2 to be equal to 1.0, which is also recommended for use for failed commercial SNF categories. In addition, the surface activities established in Section 6.2.1.3 as bounding for intact commercial SNF are considered bounding for each failed commercial SNF category. According to NUREG/CR-6487 (Anderson et al. 1996, p. 28), these surface activities should be multiplied by the surface area associated with a rod or pin to obtain the total crud activity. Thus, the surface area associated with the assembly hardware (e.g., fuel rod spacers, grids, nozzles) is neglected. Table 4 lists the surface activity densities ($\mu\text{Ci}/\text{cm}^2$) for the constituents of crud recommended to be applied to each category of failed commercial SNF (and intact commercial SNF) by origin of the fuel (i.e., BWR vs. PWR).

6.3.3.1 Mechanically and Cladding-Penetration Damaged SNF

A crud effective ARF of 1.5E-02 and an RF of 1.0 applied to this failed fuel category are considered bounding, because this fuel is unlikely to have crud characteristics significantly different from intact commercial SNF. In addition, mechanically deformed fuel may have lost some crud from its surface because of the deformation and potentially have been in the reactor core for a period insufficient to build-up a crud surface density equivalent to the value established in Section 6.2 as bounding. Hence, the bounding crud surface activities recommended in Table 4 are deemed sufficient for application to the failed commercial SNF in this category. The surface areas applied to this crud surface activity for this failed fuel category are those associated with each fuel rod within an assembly.

6.3.3.2 Consolidated/Reconstituted Assemblies

Application of a crud effective ARF of $1.5\text{E-}02$ and an RF of 1.0 is clearly conservative for the consolidated/reconstituted assemblies because a significant amount of crud on the surfaces of the fuel pins was removed when the pins were pulled through the grid structures. Any remaining crud on the pin surfaces is likely to be tightly adhering and unlikely to flake off during a drop or impact event. In addition, removal of the crud also reduces the crud surface activity to a value significantly less than the values cited in Table 4. Thus, the crud surface activity for this failed fuel category is bounded by the value for intact commercial SNF. The surface areas applied to this crud surface activity for this failed fuel category are those associated with each fuel rod within an assembly.

6.3.3.3 Fuel Rods, Pieces, and Debris

For fuel rods, pieces, and debris, a crud effective ARF of $1.5\text{E-}02$ and an RF of 1.0 are likely to be conservative. Fuel rods will have been likely pulled through grid structures, which removes the majority of loosely adhering crud leaving only tightly adhering crud, hence a crud effective ARF of $1.5\text{E-}02$ is certainly conservative. Similarly, pieces and debris are likely to have only a small amount of crud or no crud depending on the origin of fuel. For example, fuel pellets that have only been exposed to a spent fuel pool environment are likely to have no crud on their surfaces. In addition, this lack of crud will also reduce the crud surface activity to a value significantly less than the values cited in Table 4. Thus, the crud surface activity for this failed fuel category will be bounded by the value for intact commercial SNF. The surface areas applied to this crud surface activity for this failed fuel category are those associated with each fuel rod and no crud adherence to pellets is assumed.

6.3.4 Fuel Oxidation ARF

Failed commercial SNF will be shipped to the repository in screen-end or closed-end canisters in a transportation cask. Failed commercial SNF canisters will be transferred from the cask to a waste package in a waste transfer cell in the Fuel Handling Facility (FHF) or the dry transfer facilities during normal operations. Exposing the failed fuel in air while in the FHF or dry transfer facilities could cause oxidation of the fuel (UO_2) to higher oxides, such as U_3O_8 . When U_3O_8 starts to form, the fuel pellet volume expands and eventually cladding could unzip. Test data have shown that when cladding temperatures exceed 350°C (Einziger 1991, Figure 4), the time to start forming U_3O_8 is short as compared to the time it takes to fully unzip the cladding.

In an accident involving failed fuel, releases would be due to the impact or drop and subsequent oxidation of the exposed fuel. The release due to oxidation is bounded by the release due to the impact or drop event. During the fuel oxidation period, only fission product gases and volatile species are released. Release fractions of fission product gases from oxidation have been shown to be less than 30 percent by Einziger (1991, Figure 8) and NUREG/CR-0722 (Lorenz et al. 1980 p. 34). Therefore the values presented on Table 9 bound the release fractions from oxidation. The volatile species release fraction data on ^{137}Cs and ^{106}Ru taken from NUREG/CR-6672 (Sprung et al. 2000, p. 7-46) is 1.4×10^{-5} for ^{137}Cs , and 7.27×10^{-6} for ^{106}Ru . These release fractions are bounded by the values presented on Table 10. No release of U_3O_8 was observed in existing fuel rod oxidation tests (Lorenz et al. 1980; Einziger 1991).

7. CONCLUSIONS

In this analysis, the total and respirable fractions of radioactive materials that are released from an accident at the repository involving commercial SNF in a dry environment are specified and documented. These total release fractions are defined as the fraction of total inventory of a given radionuclide that is released to the environment from a waste form. The radionuclides are released from the inside of breached fuel rods (or pins) and from the detachment of radioactive material (crud) from the outside surfaces of fuel rods and other components of fuel assemblies. The total release fraction accounts for several mechanisms that tend to retain, retard, or diminish the amount of radionuclides that are available for transport to dose receptors or otherwise can be shown to reduce exposure of receptors to radiological releases. The total and respirable release fractions in this analysis are calculated from the following relationships:

$$\text{Total Release Fraction (all pathways)} = \text{DR} \times \text{LPF} \times \text{ARF} \quad (\text{Eq. 38})$$

$$\text{Respirable Release Fraction (inhalation)} = \text{DR} \times \text{LPF} \times \text{ARF} \times \text{RF} \quad (\text{Eq. 39})$$

where

DR is the damage ratio
LPF the leak path factor
ARF the airborne release fraction
RF the respirable fraction.

The total and respirable release fractions established for commercial SNF in this analysis may be applied to drop or impact accidents involving either a bare unconfined fuel assembly or a confined fuel assembly contained in a shipping cask, a canister, or a waste package. This analysis does not take credit, however, for the container that confines the fuel assemblies, potentially providing an additional barrier for diminishing the total release fraction should the fuel rod cladding breach during an accident. This implies that the DR and the LPF in the preceding relationship for the total release fraction were assumed to be equal to one (Section 5, Assumption 5.1). Thus, applying the total and respirable release fractions from this analysis to confined commercial SNF assemblies may be considered conservative.

Table 11 summarizes the recommended respirable release fractions associated with intact or failed commercial SNF, confined or unconfined. The total release fractions for commercial SNF that may be applied in calculations of other doses (e.g., submersion) is essentially equal to the ARFs in Table 11 because the LPF and DR are assumed equal to one in this analysis (Section 5, Assumption 5.1). In addition to these parameters, Table 12 shows the recommended values for the surface activity per unit area of crud as established in this analysis. The unit area of crud for a fuel assembly is stated in NUREG/CR-6487 (Anderson et al. 1996, p. 28) to be equal to the surface area associated with the rods or pins contained in the assembly. Thus, the surface area associated with the assembly hardware (e.g., fuel rod spacers, nozzles, etc.) is neglected.

Respirable release fractions, $ARF \times RF$, for gases, Cs, Sr, Ru, fuel fines, and crud given in Table 11 are more conservative than corresponding values given in NUREG/CR-6672 (Sprung et al. 2000, p. 7-74 and 7-75) for cases with impact speeds ranging from 30 to 60 mph and cask temperatures ranging from ambient to 750°C.

ARFs for the volatiles Cs and Ru, and the fuel fines (e.g., Sr) established by this analysis are based primarily on data collected from several burst rupture tests in NUREG/CR-0722 (Lorenz et al. 1980, p. 101). ARFs for the noble gases iodine and tritium are based on p. 25.2 of Regulatory Guide 1.25. These ARFs are consistent with the ARFs used to evaluate transportation packages containing SNF as stated in NUREG-1617 (NRC 2000a, Table 4-1). In addition, these values are also fairly consistent with the ARFs used to evaluate dry storage cask systems (NRC 1997, Table 7.1).

Table 11. Respirable Release Fractions for Commercial SNF

Radionuclide	ARF / RF				
	Category 1: Mechanical/ Cladding Damaged	Category 2: Consolidated/ Reconstituted	Category 3a: Fuel Rods with Intact Cladding	Category 3b: Other Fuel Rods, Pieces, and Debris	Intact Commercial SNF
^3H	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0
^{85}Kr	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0
^{129}I	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0	0.3 / 1.0
^{134}Cs & ^{137}Cs (v)	2.0E-04 / 1.0	2.0E-04 / 1.0	2.0E-04 / 1.0	2.0E-04 / 1.0	2.0E-04 / 1.0
^{134}Cs and ^{137}Cs (p)	0	0	0	0	0
^{90}Sr	3.0E-05/5.0E-03	3.0E-05/5.0E-03	5.9E-07 / 1.0 ^a	5.8E-07 / 1.0 ^a	3.0E-05/5.0E-03
^{106}Ru	2.0E-04/1.0	2.0E-04/1.0	2.0E-04 / 1.0 ^a	2.0E-04 / 1.0 ^a	2.0E-04/1.0
Fuel Fines	3.0E-05/5.0E-03	3.0E-05/5.0E-03	5.9E-07 / 1.0 ^a	5.8E-07 / 1.0 ^a	3.0E-05/5.0E-03
Crud	1.5E-02 / 1.0 ^b	1.5E-02 / 1.0 ^b	1.5E-02 / 1.0 ^b	1.5E-02 / 1.0 ^b	1.5E-02 / 1.0 ^b

NOTES: ^a These values assume a cask drop from 80 inches (203.2 cm) for fuel fine and particulate (p) release fractions.

^b The crud ARF/RF values are bounding values. RF is conservatively assumed to be 1.0. The values presented here are the crud effective ARFs. The crud effective ARF consists of the product of the CSF with the ARF as described in Section 6.2.1.3

ARF = airborne release fraction; CSF = crud spallation fraction; SNF = spent nuclear fuel; RF = respirable fraction.

Table 12. Crud Surface Activities ($\mu\text{Ci}/\text{cm}^2$)

Isotope	Reactor Type	Crud Surface Activities ($\mu\text{Ci}/\text{cm}^2$) ^a
⁶⁰ Co Crud ^b	PWR	72.5
	BWR	649.7
⁵⁵ Fe Crud ^c	PWR	1658
	BWR	2083

NOTES: ^a These values are assumed for a single bare unconfined fuel assembly or multiple assemblies.

^b These values have been corrected for half life of ⁶⁰Co over 5 years and for fuel assembly average activity (only in the case of multiple commercial SNF assemblies).

^c These values have been reduced using the half life of ⁵⁵Fe over 5 years.

BWR = boiling water reactor; PWR = pressurized water reactor.

A rigorous evaluation of the RF has also been carried out in this analysis to supplement the sparse existing data for the fraction of commercial SNF and crud that may be considered respirable and contribute to the inhalation doses. This evaluation used measured data presented in NUREG/CR-0722 (Lorenz et al. 1980, p. 101) and Sandoval et al. (1991, pp. 23 to 26) to determine the RFs for commercial SNF fuel fines and for crud found on the fuel surface and other components of fuel assemblies. Alternative methods to determine the RF were also examined and results from these methods are presented in Tables 6 and 7 (Section 6).

Key assumptions to attaining the RF for commercial SNF are that the initially aerosolized commercial SNF fuel fines released from the burst rupture tests had a mass median diameter of 150 μm (Section 5, Assumption 5.8) and that 3 percent of the total mass of released commercial SNF had a maximum diameter somewhere between 12 and 15 μm (Section 5, Assumption 5.9). The combination of dose conversion factors based on an AMAD of 1 μm and an RF based on the mass fraction of particulate that have an AMAD of less than 10 μm are considered to produce a conservative methodology for inhalation dose calculations.

With these recommended parameters and given the potential material at risk per fuel assembly and site meteorological conditions, doses to workers and members of the public can be calculated for the drop and impact accidents involving commercial SNF that may occur in the repository surface facilities.

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8.3 PROCEDURES

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AP-SV.1Q, Rev. 1, ICN 1. *Control of the Electronic Management of Information.*
ACC: DOC.20040308.0001.

LP-SI.11Q-BSC, Rev. 0, ICN 1. *Software Management.* ACC: DOC.20041005.0008.

ATTACHMENT A**Microsoft Excel 97 Spreadsheets for the Calculation of the Respirable Fraction of Commercial SNF**

The following Excel Spreadsheet consists of three separate worksheets: the controller worksheet, which basically controls the inputs, the particle distribution calculations worksheet, which performs the respirable fraction calculations, and the results worksheet.

The controller worksheet is the worksheet where the user inputs specific parameters that are used in the calculation of the respirable fraction. Under the column with the heading "Use User Input (Y/N)," the user may select to either use the default values in the worksheet by placing an "n" in this column or input his/her own inputs for a specific parameter by placing a "y" in this column. The user-supplied input would be placed under the column labeled "User Input" and will be used in the calculation provided a "y" has been placed under the previous column. The default values in the final column represent the values that produce the respirable fraction for commercial SNF in this analysis. By allowing the users to supply their own input parameters, this spreadsheet can be generically used to determine respirable fractions for other fuel types or materials. Attachment B illustrates how user supplied inputs into this controller worksheet can be used to establish the respirable fraction for crud using this same spreadsheet.

The following is a brief discussion of the inputs into the controller worksheet that are needed to calculate the respirable fraction for commercial SNF and for crud:

1. Input: Multiplier to Increment
Default Value: 1.03 (good for commercial SNF particle distributions)
Description: This parameter is equal to a constant that is multiplied by the particle diameter to create the non-uniform mesh as discussed in Section 6.2.2.3.1.
2. Input Mean
Default Value: 0.715 μm (good for commercial SNF particle distributions)
Description: This parameter is equal to the MGD of the whole particle distribution in the unit of μm as discussed in Section 6.2.2.4.1.
3. Input: Standard Deviation
Default Value: 3.8 (good for commercial SNF particle distributions)
Description: This parameter is equal to the standard deviation of the whole particle distribution, σ as discussed in Section 6.2.2.4.1.
4. Input: Density
Default Value: 10.96 g/cm^3 (good for commercial SNF particle distributions)
Description: This parameter is equal to the density of the particulate in the aerosol in the units of g/cm^3 as discussed for Assumption 5.6 (Section 5).

5. Input: Dynamic Shape Factor

Default Value: 1.3 (good for crud & commercial SNF particle distributions)

Description: This parameter is equal to the dynamic shape factor of the particulate in the aerosol as discussed for Assumption 5.5 (Section 5).

6. Input: Respirable Fraction Cut-Off MMD

Default Value: 3.5 μm (good for commercial SNF particle distributions)

Description: This parameter is equivalent to the maximum MMD that provides for an AMAD of 10 μm . For commercial SNF and crud the value of this parameter should be 3.5 μm and 5.0 μm , respectively. The unit of this input is μm as discussed in Section 6.2.2.4.

7. Input: Maximum Respirable Particle Size

Default Value: 4.7 μm (good for commercial SNF particle distributions)

Description: This parameter is used only for the iterative method described in Section 6.2.2.4. It is equal to the diameter that is considered the maximum respirable size, below which the distribution has an AMAD of 10 μm (or an MMD of 3.5 μm for fuel or 5.0 μm for crud). The unit of this input is μm . If this value is too high or too low, then the results worksheet will indicate so (i.e., when the AMAD is not equal to 10 μm).

The results worksheet summarizes the inputs and presents the following results:

1. Output: Respirable Percent

Description: This is the respirable percent calculated using the iterative method. Note 1 below the results states whether this is the actual respirable percent. It is based on the “% of Sum at Particle Diameter of Interest” being approximately equal to 50 percent. This will also indicate whether the Maximum Respirable Particle Size must be changed, and how it should be changed (i.e., reduced or increased). This is part of the iterative scheme and has the units of percent as discussed in Section 6.2.2.4.

2. Output: Conservative Respirable Percent

Description: This is the respirable percent calculated using the AMAD-10 method described in Section 6.2.2. Basically, this is the fraction of the mass of particulate with diameters less than 10 μm and it is expressed as a percent. If the AMAD is less than 10 μm , then the resulting respirable percent is not conservative.

3. Output: Non-Conservative Respirable Percent

Description: This is the respirable percent calculated using the MMD method (non-conservative compared to the AMAD-10 method) described in Section 6.2.2. Basically, this is the fraction of the mass of particulate with diameters less than the respirable fraction cut-off MMD previously described. It is expressed as a percent. If the AMAD is less than 10 μm , then the resulting respirable percent is very non-conservative.

4. Output: Mass Median Diameter

Description: This is the median diameter of the entire mass distribution calculated using Equation 31. It is used as a check of the MMD calculated using the iterative process shown in item 5 below. It has the unit of μm .

5. Output: MMD

Description: This is the median diameter of the entire mass distribution and it is used to calculate the AMAD for the whole distribution. It has the unit of μm .

6. Output: AMAD

Description: This is the activity median aerodynamic diameter of the entire mass distribution. It has the unit of μm .

7. Output: Percent of Sum at Particle Diameter of Interest

Description: For a particle distribution with an AMAD greater than $10 \mu\text{m}$, this value is used by the iterative method to determine the respirable fraction. It is desired that this sum should be approximately 50 percent.

The particle distribution calculation worksheet performs the respirable fraction calculations. The first column of this sheet contains the particle diameters that are used to determine the lognormal particle distribution probability in column two. Column three divides this lognormal probability by the diameter thereby creating the normalized lognormal probability function. The fourth column multiplies the third column by the change in the diameter (Δd). The fifth column sums the normalized probabilities providing the integrated particle distribution. The sixth column calculates the particle volume assuming the particles are spheres. Using the inputted density, the mass of each particle is established in column seven by multiplying the particle volume and density. The lognormal distribution probability and particle mass are multiplied in column eight. The ninth column normalizes the particle mass lognormal distribution probability with the total mass providing the differential mass particle distribution. The tenth column re-normalizes the mass distribution that is less than maximum respirable particle size to establish the AMAD of this fraction of the distribution. The final column sums the differential mass particle distribution in column nine, providing the integral mass distribution.

USER INPUTS: Change only non-highlighted columns

Parameter Description:	Parameter	Units	Use User Input (Y/N)?	User Input	Default
Multiplier to increment particle diameters	1.03		n	1.03	1.03
Mean Geometric Diameter (MGD)	0.7458863	µm	n	1.678	0.745
Standard Deviation (GSD)	3.8		(based on MGD)	3.4	3.8
Density (g/cc)	10.96	g/cc	n	10.96	10.96
Dynamic Shape Factor (DSF)	1.3		n	1.3	1.3
Respirable Fraction (Outflow/MMD)	3.6	µm	n	3.5	3.6
Maximum Respirable Particle Diameter	4.7	µm	n	4.5	4.7
The maximum respirable particle diameter cannot be greater than the mean of the distribution unless overridden as used in "Use User Input (Y/N)" column.					

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	$V \rho$	P(d)* $\Delta d^m/d$	P(d)* $\Delta d^m/(d^m P_{\text{ref}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{ref}}$
0.000100	7.588E-11	7.588E-07	3.794E-11	3.794E-11	5.236E-25	5.739E-18	2.177E-28	3.46952E-26	7.075E-24	3.470E-26
0.000103	8.789E-11	8.533E-07	2.560E-12	4.050E-11	5.722E-25	6.271E-18	1.605E-29	2.55805E-27	7.596E-24	3.725E-26
0.000106	1.018E-10	9.591E-07	2.964E-12	4.346E-11	6.252E-25	6.852E-18	2.031E-29	3.2361E-27	8.256E-24	4.049E-26
0.000109	1.177E-10	1.078E-06	3.429E-12	4.689E-11	6.832E-25	7.488E-18	2.568E-29	4.09188E-27	9.090E-24	4.458E-26
0.000113	1.362E-10	1.210E-06	3.966E-12	5.086E-11	7.465E-25	8.192E-18	3.245E-29	5.17142E-27	1.014E-23	4.975E-26
0.000116	1.574E-10	1.358E-06	4.585E-12	5.544E-11	8.157E-25	8.941E-18	4.099E-29	6.53257E-27	1.148E-23	5.629E-26
0.000119	1.819E-10	1.523E-06	5.298E-12	6.074E-11	8.914E-25	9.770E-18	5.176E-29	8.24794E-27	1.316E-23	6.453E-26
0.000123	2.101E-10	1.708E-06	6.118E-12	6.686E-11	9.740E-25	1.068E-17	6.532E-29	1.04086E-26	1.528E-23	7.494E-26
0.000127	2.425E-10	1.914E-06	7.063E-12	7.392E-11	1.064E-24	1.167E-17	8.239E-29	1.31289E-26	1.796E-23	8.807E-26
0.000130	2.798E-10	2.144E-06	8.148E-12	8.207E-11	1.163E-24	1.275E-17	1.039E-28	1.65621E-26	2.133E-23	1.046E-25
0.000134	3.226E-10	2.401E-06	9.397E-12	9.147E-11	1.271E-24	1.393E-17	1.309E-28	2.08575E-26	2.559E-23	1.255E-25
0.000138	3.719E-10	2.686E-06	1.083E-11	1.023E-10	1.389E-24	1.522E-17	1.649E-28	2.62699E-26	3.094E-23	1.518E-25
0.000143	4.284E-10	3.005E-06	1.248E-11	1.148E-10	1.518E-24	1.663E-17	2.075E-28	3.30707E-26	3.769E-23	1.848E-25
0.000147	4.933E-10	3.359E-06	1.437E-11	1.291E-10	1.658E-24	1.817E-17	2.611E-28	4.16115E-26	4.617E-23	2.264E-25
0.000151	5.677E-10	3.753E-06	1.654E-11	1.457E-10	1.812E-24	1.986E-17	3.284E-28	5.2326E-26	5.684E-23	2.788E-25
0.000156	6.531E-10	4.192E-06	1.902E-11	1.647E-10	1.980E-24	2.170E-17	4.128E-28	6.57835E-26	7.026E-23	3.445E-25
0.000160	7.509E-10	4.680E-06	2.167E-11	1.866E-10	2.164E-24	2.371E-17	5.187E-28	8.26513E-26	8.711E-23	4.272E-25
0.000165	8.630E-10	5.221E-06	2.514E-11	2.117E-10	2.364E-24	2.591E-17	6.513E-28	1.03793E-25	1.083E-22	5.310E-25
0.000170	9.913E-10	5.823E-06	2.867E-11	2.406E-10	2.584E-24	2.832E-17	8.175E-28	1.30279E-25	1.348E-22	6.613E-25
0.000175	1.138E-09	6.491E-06	3.315E-11	2.737E-10	2.823E-24	3.094E-17	1.026E-27	1.63444E-25	1.682E-22	8.247E-25
0.000181	1.306E-09	7.231E-06	3.804E-11	3.118E-10	3.085E-24	3.381E-17	1.286E-27	2.04951E-25	2.100E-22	1.030E-24
0.000186	1.498E-09	8.053E-06	4.363E-11	3.554E-10	3.371E-24	3.694E-17	1.612E-27	2.56872E-25	2.623E-22	1.287E-24
0.000192	1.717E-09	8.963E-06	5.002E-11	4.054E-10	3.683E-24	4.037E-17	2.019E-27	3.2179E-25	3.280E-22	1.608E-24
0.000197	1.968E-09	9.971E-06	5.732E-11	4.627E-10	4.025E-24	4.411E-17	2.528E-27	4.02916E-25	4.101E-22	2.011E-24
0.000203	2.254E-09	1.109E-05	6.564E-11	5.284E-10	4.398E-24	4.820E-17	3.184E-27	5.04247E-25	5.129E-22	2.515E-24
0.000209	2.580E-09	1.232E-05	7.514E-11	6.035E-10	4.806E-24	5.267E-17	3.958E-27	6.30753E-25	6.415E-22	3.146E-24
0.000216	2.952E-09	1.369E-05	8.598E-11	6.895E-10	5.252E-24	5.766E-17	4.949E-27	7.8861E-25	8.024E-22	3.935E-24
0.000222	3.376E-09	1.520E-05	9.833E-11	7.878E-10	5.739E-24	6.290E-17	6.184E-27	9.85491E-25	1.003E-21	4.920E-24
0.000229	3.859E-09	1.687E-05	1.124E-10	9.002E-10	6.271E-24	6.873E-17	7.724E-27	1.23092E-24	1.254E-21	6.151E-24
0.000236	4.409E-09	1.871E-05	1.284E-10	1.029E-09	6.852E-24	7.510E-17	9.643E-27	1.53672E-24	1.568E-21	7.688E-24
0.000243	5.034E-09	2.074E-05	1.466E-10	1.175E-09	7.488E-24	8.207E-17	1.203E-26	1.91755E-24	1.959E-21	9.606E-24
0.000250	5.746E-09	2.298E-05	1.674E-10	1.343E-09	8.182E-24	8.967E-17	1.501E-26	2.39158E-24	2.446E-21	1.200E-23
0.000258	6.555E-09	2.546E-05	1.909E-10	1.534E-09	8.941E-24	9.799E-17	1.871E-26	2.98133E-24	3.054E-21	1.498E-23
0.000265	7.475E-09	2.818E-05	2.177E-10	1.751E-09	9.770E-24	1.071E-16	2.331E-26	3.7147E-24	3.812E-21	1.869E-23
0.000273	8.519E-09	3.118E-05	2.481E-10	1.999E-09	1.068E-23	1.170E-16	2.903E-26	4.62619E-24	4.755E-21	2.332E-23
0.000281	9.704E-09	3.449E-05	2.826E-10	2.282E-09	1.167E-23	1.279E-16	3.614E-26	5.75851E-24	5.929E-21	2.908E-23
0.000290	1.105E-08	3.812E-05	3.218E-10	2.604E-09	1.275E-23	1.397E-16	4.496E-26	7.16448E-24	7.390E-21	3.624E-23
0.000298	1.257E-08	4.212E-05	3.662E-10	2.970E-09	1.393E-23	1.527E-16	5.591E-26	8.90934E-24	9.207E-21	4.515E-23
0.000307	1.430E-08	4.651E-05	4.166E-10	3.387E-09	1.522E-23	1.668E-16	6.949E-26	1.10737E-23	1.146E-20	5.623E-23
0.000317	1.626E-08	5.134E-05	4.736E-10	3.860E-09	1.683E-23	1.823E-16	8.633E-26	1.37572E-23	1.427E-20	6.998E-23
0.000326	1.848E-08	5.664E-05	5.382E-10	4.398E-09	1.817E-23	1.992E-16	1.072E-25	1.70825E-23	1.775E-20	8.707E-23
0.000336	2.099E-08	6.246E-05	6.112E-10	5.010E-09	1.986E-23	2.177E-16	1.330E-25	2.12012E-23	2.208E-20	1.083E-22
0.000346	2.382E-08	6.884E-05	6.939E-10	5.703E-09	2.170E-23	2.378E-16	1.650E-25	2.63001E-23	2.744E-20	1.346E-22

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	$V \rho$	P(d)* $\Delta d^m/d$	P(d)* $\Delta d^m/d$ (d ^m mP ₅₀)	d < 4.7	$\Sigma P(d) m/(P m)_{50}$
0.000356	2.703E-08	7.584E-05	7.874E-10	6.491E-09	2.371E-23	2.599E-16	2.046E-25	3.26093E-23	3.409E-20	1.672E-22
0.000367	3.066E-08	8.350E-05	8.930E-10	7.384E-09	2.591E-23	2.840E-16	2.336E-25	4.04122E-23	4.233E-20	2.076E-22
0.000378	3.475E-08	9.190E-05	1.012E-09	8.396E-09	2.832E-23	3.103E-16	3.141E-25	5.00577E-23	5.254E-20	2.576E-22
0.000390	3.938E-08	1.011E-04	1.147E-09	9.543E-09	3.094E-23	3.391E-16	3.889E-25	6.19749E-23	6.517E-20	3.198E-22
0.000401	4.459E-08	1.111E-04	1.299E-09	1.084E-08	3.381E-23	3.706E-16	4.813E-25	7.66916E-23	8.081E-20	3.963E-22
0.000413	5.047E-08	1.221E-04	1.470E-09	1.231E-08	3.695E-23	4.049E-16	5.953E-25	9.48564E-23	1.002E-19	4.912E-22
0.000426	5.710E-08	1.342E-04	1.663E-09	1.397E-08	4.037E-23	4.425E-16	7.359E-25	1.12686E-22	1.241E-19	6.084E-22
0.000438	6.457E-08	1.473E-04	1.881E-09	1.586E-08	4.411E-23	4.835E-16	9.093E-25	1.44899E-22	1.536E-19	7.533E-22
0.000452	7.298E-08	1.616E-04	2.126E-09	1.798E-08	4.821E-23	5.283E-16	1.123E-24	1.78956E-22	1.901E-19	9.323E-22
0.000465	8.244E-08	1.773E-04	2.401E-09	2.038E-08	5.268E-23	5.773E-16	1.386E-24	2.2091E-22	2.351E-19	1.153E-21
0.000479	9.309E-08	1.943E-04	2.711E-09	2.309E-08	5.756E-23	6.309E-16	1.710E-24	2.72564E-22	2.907E-19	1.426E-21
0.000493	1.051E-07	2.129E-04	3.060E-09	2.615E-08	6.290E-23	6.893E-16	2.109E-24	3.36133E-22	3.593E-19	1.762E-21
0.000508	1.185E-07	2.332E-04	3.452E-09	2.961E-08	6.873E-23	7.533E-16	2.600E-24	4.14324E-22	4.438E-19	2.176E-21
0.000523	1.336E-07	2.552E-04	3.892E-09	3.350E-08	7.510E-23	8.231E-16	3.203E-24	5.10453E-22	5.478E-19	2.687E-21
0.000539	1.506E-07	2.793E-04	4.386E-09	3.788E-08	8.207E-23	8.994E-16	3.945E-24	6.28577E-22	6.760E-19	3.315E-21
0.000555	1.696E-07	3.054E-04	4.940E-09	4.282E-08	8.968E-23	9.828E-16	4.855E-24	7.76658E-22	8.338E-19	4.089E-21
0.000572	1.909E-07	3.338E-04	5.561E-09	4.838E-08	9.799E-23	1.074E-15	5.973E-24	9.51757E-22	1.028E-18	5.041E-21
0.000589	2.148E-07	3.647E-04	6.258E-09	5.464E-08	1.071E-22	1.174E-15	7.344E-24	1.17028E-21	1.266E-18	6.211E-21
0.000607	2.416E-07	3.982E-04	7.038E-09	6.168E-08	1.170E-22	1.282E-15	9.026E-24	1.43827E-21	1.580E-18	7.649E-21
0.000625	2.716E-07	4.346E-04	7.912E-09	6.959E-08	1.279E-22	1.401E-15	1.109E-23	1.76677E-21	1.920E-18	9.416E-21
0.000644	3.052E-07	4.741E-04	8.890E-09	7.848E-08	1.397E-22	1.531E-15	1.361E-23	2.16823E-21	2.362E-18	1.159E-20
0.000663	3.428E-07	5.169E-04	9.984E-09	8.847E-08	1.527E-22	1.673E-15	1.671E-23	2.66208E-21	2.905E-18	1.425E-20
0.000683	3.848E-07	5.634E-04	1.121E-08	9.967E-08	1.668E-22	1.828E-15	2.049E-23	3.26526E-21	3.571E-18	1.751E-20
0.000703	4.317E-07	6.137E-04	1.257E-08	1.122E-07	1.823E-22	1.998E-15	2.512E-23	4.00318E-21	4.387E-18	2.152E-20
0.000725	4.841E-07	6.691E-04	1.410E-08	1.263E-07	1.992E-22	2.183E-15	3.078E-23	4.90545E-21	5.388E-18	2.642E-20
0.000746	5.426E-07	7.270E-04	1.580E-08	1.422E-07	2.177E-22	2.386E-15	3.770E-23	6.00814E-21	6.613E-18	3.243E-20
0.000769	6.079E-07	7.908E-04	1.771E-08	1.599E-07	2.379E-22	2.507E-15	4.616E-23	7.35509E-21	8.112E-18	3.978E-20
0.000792	6.807E-07	8.597E-04	1.983E-08	1.797E-07	2.599E-22	2.849E-15	5.648E-23	8.996E-21	9.947E-18	4.878E-20
0.000816	7.618E-07	9.342E-04	2.219E-08	2.019E-07	2.840E-22	3.113E-15	6.907E-23	1.10064E-20	1.219E-17	5.979E-20
0.000840	8.522E-07	1.015E-03	2.482E-08	2.267E-07	3.103E-22	3.401E-15	8.443E-23	1.34541E-20	1.494E-17	7.324E-20
0.000865	9.529E-07	1.101E-03	2.775E-08	2.544E-07	3.391E-22	3.717E-15	1.032E-22	1.64381E-20	1.829E-17	8.968E-20
0.000891	1.065E-06	1.195E-03	3.102E-08	2.855E-07	3.706E-22	4.061E-15	1.260E-22	2.0074E-20	2.238E-17	1.098E-19
0.000918	1.190E-06	1.296E-03	3.465E-08	3.201E-07	4.049E-22	4.438E-15	1.538E-22	2.45022E-20	2.738E-17	1.343E-19
0.000945	1.328E-06	1.405E-03	3.868E-08	3.588E-07	4.425E-22	4.849E-15	1.876E-22	2.98926E-20	3.347E-17	1.642E-19
0.000974	1.482E-06	1.522E-03	4.317E-08	4.020E-07	4.835E-22	5.299E-15	2.287E-22	3.64509E-20	4.090E-17	2.008E-19
0.001003	1.653E-06	1.648E-03	4.815E-08	4.501E-07	5.283E-22	5.791E-15	2.788E-22	4.44263E-20	4.996E-17	2.450E-19
0.001033	1.843E-06	1.784E-03	5.367E-08	5.038E-07	5.773E-22	6.327E-15	3.396E-22	5.41201E-20	6.100E-17	2.991E-19
0.001064	2.053E-06	1.930E-03	5.981E-08	5.636E-07	6.309E-22	6.914E-15	4.135E-22	6.58969E-20	7.444E-17	3.650E-19
0.001096	2.287E-06	2.087E-03	6.661E-08	6.302E-07	6.894E-22	7.555E-15	5.033E-22	8.0197E-20	9.079E-17	4.452E-19
0.001129	2.546E-06	2.255E-03	7.415E-08	7.043E-07	7.533E-22	8.256E-15	6.122E-22	9.75525E-20	1.107E-16	5.428E-19
0.001163	2.833E-06	2.436E-03	8.250E-08	7.868E-07	8.231E-22	9.021E-15	7.443E-22	1.16608E-19	1.349E-16	6.614E-19
0.001198	3.150E-06	2.630E-03	9.175E-08	8.786E-07	8.995E-22	9.858E-15	9.045E-22	1.44132E-19	1.643E-16	8.055E-19
0.001234	3.502E-06	2.839E-03	1.020E-07	9.806E-07	9.829E-22	1.077E-14	1.099E-21	1.75066E-19	2.000E-16	9.808E-19

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V ρ	P(d)* $\Delta d^3/m/d$	P(d)* $\Delta d^3/m/(d^3 m P_{\text{ref}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{ref}}$
0.001271	3.890E-06	3.062E-03	1.133E-07	1.094E-06	1.074E-21	1.177E-14	1.334E-21	2.12535E-19	2.433E-16	1.193E-18
0.001309	4.320E-06	3.301E-03	1.258E-07	1.220E-06	1.174E-21	1.266E-14	1.618E-21	2.959E-19	2.959E-16	1.451E-18
0.001348	4.795E-06	3.557E-03	1.397E-07	1.359E-06	1.282E-21	1.406E-14	1.963E-21	3.12787E-19	3.597E-16	1.764E-18
0.001388	5.319E-06	3.831E-03	1.549E-07	1.514E-06	1.401E-21	1.566E-14	2.379E-21	3.79174E-19	4.370E-16	2.143E-18
0.001430	5.898E-06	4.124E-03	1.718E-07	1.686E-06	1.531E-21	1.678E-14	2.883E-21	4.59426E-19	5.307E-16	2.602E-18
0.001473	6.537E-06	4.438E-03	1.904E-07	1.878E-06	1.673E-21	1.834E-14	3.492E-21	5.63391E-19	6.441E-16	3.159E-18
0.001517	7.241E-06	4.773E-03	2.109E-07	2.087E-06	1.828E-21	2.004E-14	4.226E-21	6.7349E-19	7.814E-16	3.832E-18
0.001563	8.017E-06	5.131E-03	2.335E-07	2.321E-06	1.998E-21	2.190E-14	5.113E-21	8.14835E-19	9.476E-16	4.647E-18
0.001610	8.872E-06	5.512E-03	2.584E-07	2.579E-06	2.183E-21	2.393E-14	6.183E-21	9.8536E-19	1.149E-15	5.632E-18
0.001658	9.814E-06	5.920E-03	2.858E-07	2.865E-06	2.386E-21	2.615E-14	7.474E-21	1.19099E-18	1.391E-15	6.823E-18
0.001708	1.085E-05	6.354E-03	3.160E-07	3.181E-06	2.607E-21	2.857E-14	9.029E-21	1.43882E-18	1.885E-15	8.262E-18
0.001759	1.199E-05	6.817E-03	3.492E-07	3.530E-06	2.849E-21	3.122E-14	1.090E-20	1.73737E-18	2.039E-15	1.000E-17
0.001812	1.324E-05	7.310E-03	3.857E-07	3.916E-06	3.113E-21	3.412E-14	1.316E-20	2.09685E-18	2.467E-15	1.210E-17
0.001866	1.462E-05	7.835E-03	4.258E-07	4.342E-06	3.401E-21	3.728E-14	1.587E-20	2.52946E-18	2.982E-15	1.463E-17
0.001920	1.613E-05	8.393E-03	4.698E-07	4.812E-06	3.717E-21	4.074E-14	1.914E-20	3.04983E-18	3.604E-15	1.768E-17
0.001980	1.779E-05	8.987E-03	5.182E-07	5.330E-06	4.061E-21	4.451E-14	2.306E-20	3.67545E-18	4.354E-15	2.135E-17
0.002039	1.961E-05	9.618E-03	5.712E-07	5.901E-06	4.438E-21	4.864E-14	2.778E-20	4.42724E-18	5.256E-15	2.578E-17
0.002100	2.161E-05	1.029E-02	6.293E-07	6.530E-06	4.850E-21	5.315E-14	3.345E-20	5.33018E-18	6.343E-15	3.111E-17
0.002163	2.379E-05	1.100E-02	6.930E-07	7.223E-06	5.299E-21	5.808E-14	4.025E-20	6.41414E-18	7.651E-15	3.752E-17
0.002228	2.619E-05	1.176E-02	7.628E-07	7.986E-06	5.791E-21	6.347E-14	4.841E-20	7.71475E-18	9.224E-15	4.524E-17
0.002295	2.881E-05	1.256E-02	8.392E-07	8.825E-06	6.328E-21	6.935E-14	5.820E-20	9.27454E-18	1.112E-14	5.451E-17
0.002364	3.168E-05	1.340E-02	9.228E-07	9.748E-06	6.914E-21	7.578E-14	6.993E-20	1.11442E-17	1.339E-14	6.566E-17
0.002435	3.482E-05	1.430E-02	1.014E-06	1.078E-05	7.555E-21	8.281E-14	8.399E-20	1.33843E-17	1.612E-14	7.904E-17
0.002508	3.828E-05	1.526E-02	1.114E-06	1.188E-05	8.256E-21	9.049E-14	1.008E-19	1.60667E-17	1.939E-14	9.511E-17
0.002583	4.201E-05	1.626E-02	1.223E-06	1.310E-05	9.022E-21	9.888E-14	1.210E-19	1.92772E-17	2.332E-14	1.144E-16
0.002660	4.610E-05	1.733E-02	1.343E-06	1.444E-05	9.888E-21	1.080E-13	1.451E-19	2.3118E-17	2.804E-14	1.375E-16
0.002740	5.057E-05	1.845E-02	1.473E-06	1.592E-05	1.077E-20	1.181E-13	1.739E-19	2.77105E-17	3.369E-14	1.652E-16
0.002822	5.544E-05	1.964E-02	1.615E-06	1.753E-05	1.177E-20	1.290E-13	2.083E-19	3.31989E-17	4.046E-14	1.984E-16
0.002907	6.076E-05	2.090E-02	1.770E-06	1.930E-05	1.286E-20	1.410E-13	2.495E-19	3.97549E-17	4.856E-14	2.382E-16
0.002994	6.655E-05	2.223E-02	1.938E-06	2.124E-05	1.406E-20	1.540E-13	2.986E-19	4.75823E-17	5.827E-14	2.857E-16
0.003084	7.288E-05	2.362E-02	2.122E-06	2.336E-05	1.536E-20	1.683E-13	3.572E-19	5.69229E-17	6.987E-14	3.427E-16
0.003177	7.973E-05	2.510E-02	2.322E-06	2.568E-05	1.678E-20	1.839E-13	4.271E-19	6.80637E-17	8.375E-14	4.107E-16
0.003370	8.720E-05	2.665E-02	2.540E-06	2.822E-05	1.834E-20	2.010E-13	5.105E-19	8.1345E-17	1.003E-13	4.921E-16
0.003471	9.532E-05	2.829E-02	2.776E-06	3.100E-05	2.004E-20	2.196E-13	6.098E-19	9.71703E-17	1.202E-13	5.893E-16
0.003575	1.042E-04	3.001E-02	3.034E-06	3.403E-05	2.190E-20	2.400E-13	7.281E-19	1.16017E-16	1.438E-13	7.053E-16
0.003682	1.124E-04	3.171E-02	3.313E-06	3.735E-05	2.393E-20	2.623E-13	8.688E-19	1.38452E-16	1.720E-13	8.437E-16
0.003793	1.356E-04	3.372E-02	3.616E-06	4.096E-05	2.615E-20	2.866E-13	1.036E-18	1.65144E-16	2.057E-13	1.009E-15
0.003907	1.477E-04	3.571E-02	3.946E-06	4.491E-05	2.857E-20	3.131E-13	1.236E-18	1.96886E-16	2.459E-13	1.206E-15
0.004024	1.610E-04	3.781E-02	4.303E-06	4.921E-05	3.122E-20	3.422E-13	1.472E-18	2.34613E-16	2.937E-13	1.440E-15
0.004145	1.754E-04	4.001E-02	4.690E-06	5.390E-05	3.412E-20	3.739E-13	1.754E-18	2.79433E-16	3.507E-13	1.720E-15
0.004269	1.910E-04	4.232E-02	5.109E-06	5.901E-05	3.728E-20	4.086E-13	2.088E-18	3.2852E-16	4.185E-13	2.052E-15
0.004397	2.079E-04	4.474E-02	5.563E-06	6.457E-05	4.074E-20	4.465E-13	2.494E-18	3.95813E-16	4.992E-13	2.448E-15
		4.728E-02	6.055E-06	7.063E-05	4.451E-20	4.879E-13	2.954E-18	4.70735E-16	5.952E-13	2.919E-15

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) Δ d/d	Σ P(d) Δ d/d	$\pi d^3/6$	$V\rho$	P(d) Δ d π m/d	P(d) Δ d π m/(d π mP $_{50}$)	d < 4.7	Σ P(d) m/(P π) $_{50}$
0.004529	2.261E-04	4.993E-02	6.587E-06	7.721E-05	4.864E-20	5.331E-13	3.511E-18	5.59564E-16	7.093E-13	3.479E-15
0.004665	2.459E-04	5.271E-02	7.102E-06	8.438E-05	5.315E-20	5.825E-13	4.172E-18	6.8483E-16	8.449E-13	4.143E-15
0.004805	2.672E-04	5.562E-02	7.783E-06	9.216E-05	5.808E-20	6.366E-13	4.954E-18	7.8911E-16	1.006E-12	4.933E-15
0.004949	2.903E-04	5.865E-02	8.454E-06	1.006E-04	6.347E-20	6.856E-13	5.881E-18	9.3711E-16	1.197E-12	5.870E-15
0.005097	3.151E-04	6.182E-02	9.179E-06	1.098E-04	6.935E-20	7.401E-13	6.977E-18	1.1117E-15	1.424E-12	6.982E-15
0.005250	3.420E-04	6.514E-02	9.961E-06	1.198E-04	7.578E-20	8.006E-13	8.273E-18	1.3183E-15	1.692E-12	8.300E-15
0.005408	3.709E-04	6.859E-02	1.080E-05	1.306E-04	8.281E-20	9.076E-13	9.805E-18	1.5625E-15	2.011E-12	9.863E-15
0.005570	4.021E-04	7.219E-02	1.171E-05	1.423E-04	9.049E-20	9.917E-13	1.162E-17	1.8509E-15	2.389E-12	1.171E-14
0.005737	4.357E-04	7.595E-02	1.269E-05	1.550E-04	9.868E-20	1.084E-12	1.375E-17	2.1916E-15	2.835E-12	1.391E-14
0.005909	4.719E-04	7.986E-02	1.375E-05	1.687E-04	1.080E-19	1.184E-12	1.628E-17	2.5937E-15	3.364E-12	1.650E-14
0.006087	5.109E-04	8.393E-02	1.488E-05	1.836E-04	1.181E-19	1.294E-12	1.925E-17	3.0681E-15	3.990E-12	1.957E-14
0.006269	5.527E-04	8.817E-02	1.610E-05	1.997E-04	1.290E-19	1.414E-12	2.276E-17	3.6274E-15	4.730E-12	2.319E-14
0.006457	5.978E-04	9.257E-02	1.741E-05	2.171E-04	1.410E-19	1.545E-12	2.690E-17	4.2867E-15	5.604E-12	2.748E-14
0.006651	6.461E-04	9.715E-02	1.882E-05	2.359E-04	1.540E-19	1.688E-12	3.177E-17	5.0632E-15	6.636E-12	3.254E-14
0.006851	6.981E-04	1.019E-01	2.033E-05	2.562E-04	1.683E-19	1.845E-12	3.751E-17	5.9775E-15	7.855E-12	3.852E-14
0.007056	7.538E-04	1.068E-01	2.196E-05	2.782E-04	1.839E-19	2.016E-12	4.426E-17	7.0534E-15	9.293E-12	4.558E-14
0.007268	8.136E-04	1.120E-01	2.370E-05	3.019E-04	2.010E-19	2.203E-12	5.220E-17	8.3189E-15	1.099E-11	5.389E-14
0.007486	8.777E-04	1.173E-01	2.567E-05	3.275E-04	2.196E-19	2.407E-12	6.154E-17	9.8067E-15	1.299E-11	6.370E-14
0.007710	9.464E-04	1.228E-01	2.757E-05	3.550E-04	2.400E-19	2.630E-12	7.251E-17	1.1554E-14	1.535E-11	7.526E-14
0.007942	1.020E-03	1.284E-01	2.971E-05	3.847E-04	2.623E-19	2.874E-12	8.540E-17	1.3608E-14	1.812E-11	8.866E-14
0.008180	1.099E-03	1.343E-01	3.200E-05	4.167E-04	2.866E-19	3.141E-12	1.005E-16	1.6018E-14	2.139E-11	1.049E-13
0.008425	1.183E-03	1.404E-01	3.446E-05	4.512E-04	3.131E-19	3.432E-12	1.183E-16	1.8845E-14	2.523E-11	1.237E-13
0.008678	1.273E-03	1.467E-01	3.708E-05	4.883E-04	3.422E-19	3.750E-12	1.391E-16	2.2161E-14	2.975E-11	1.459E-13
0.008938	1.369E-03	1.532E-01	3.989E-05	5.282E-04	3.739E-19	4.098E-12	1.635E-16	2.6048E-14	3.506E-11	1.719E-13
0.009207	1.472E-03	1.599E-01	4.288E-05	5.711E-04	4.086E-19	4.478E-12	1.920E-16	3.0601E-14	4.130E-11	2.025E-13
0.009483	1.582E-03	1.668E-01	4.608E-05	6.171E-04	4.465E-19	4.893E-12	2.255E-16	3.5932E-14	4.863E-11	2.385E-13
0.009767	1.699E-03	1.740E-01	4.949E-05	6.666E-04	4.879E-19	5.347E-12	2.646E-16	4.2172E-14	5.723E-11	2.806E-13
0.010060	1.824E-03	1.813E-01	5.313E-05	7.198E-04	5.331E-19	5.843E-12	3.105E-16	4.9471E-14	6.731E-11	3.301E-13
0.010362	1.957E-03	1.889E-01	5.701E-05	7.768E-04	5.825E-19	6.385E-12	3.640E-16	5.8003E-14	7.914E-11	3.881E-13
0.010673	2.099E-03	1.967E-01	6.114E-05	8.379E-04	6.366E-19	6.977E-12	4.266E-16	6.7977E-14	9.300E-11	4.561E-13
0.010993	2.250E-03	2.047E-01	6.554E-05	9.035E-04	6.956E-19	7.624E-12	4.997E-16	7.9625E-14	1.092E-10	5.357E-13
0.011323	2.411E-03	2.129E-01	7.022E-05	9.737E-04	7.601E-19	8.331E-12	5.850E-16	9.3223E-14	1.282E-10	6.289E-13
0.011663	2.582E-03	2.214E-01	7.520E-05	1.049E-03	8.306E-19	9.103E-12	6.846E-16	1.0909E-13	1.505E-10	7.360E-13
0.012012	2.764E-03	2.301E-01	8.050E-05	1.129E-03	9.076E-19	9.947E-12	8.007E-16	1.2759E-13	1.765E-10	8.656E-13
0.012373	2.957E-03	2.390E-01	8.612E-05	1.216E-03	9.917E-19	1.087E-11	9.361E-16	1.4916E-13	2.069E-10	1.015E-12
0.012744	3.162E-03	2.481E-01	9.209E-05	1.308E-03	1.084E-18	1.188E-11	1.094E-15	1.7429E-13	2.425E-10	1.189E-12
0.013126	3.379E-03	2.574E-01	9.842E-05	1.406E-03	1.184E-18	1.298E-11	1.277E-15	2.0356E-13	2.840E-10	1.393E-12
0.013520	3.610E-03	2.670E-01	1.051E-04	1.511E-03	1.294E-18	1.418E-11	1.491E-15	2.3762E-13	3.324E-10	1.630E-12
0.013926	3.855E-03	2.768E-01	1.123E-04	1.623E-03	1.414E-18	1.550E-11	1.740E-15	2.7725E-13	3.890E-10	1.908E-12
0.014343	4.114E-03	2.868E-01	1.198E-04	1.743E-03	1.545E-18	1.693E-11	2.029E-15	3.2332E-13	4.549E-10	2.231E-12
0.014774	4.388E-03	2.970E-01	1.278E-04	1.871E-03	1.688E-18	1.850E-11	2.365E-15	3.7688E-13	5.317E-10	2.608E-12
0.015217	4.679E-03	3.075E-01	1.363E-04	2.007E-03	1.845E-18	2.022E-11	2.755E-15	4.3906E-13	6.213E-10	3.047E-12
0.015673	4.986E-03	3.181E-01	1.452E-04	2.153E-03	2.016E-18	2.210E-11	3.209E-15	5.1130E-13	7.255E-10	3.558E-12

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	$P(d)$	$P(d)/d$	$P(d) \cdot \Delta d/d$	$\Sigma P(d) \cdot \Delta d/d$	$\pi d^3/6$	$V \rho$	$P(d) \cdot \Delta d^m/d$	$P(d) \cdot \Delta d^m/d$	$d < 4.7$	$\Sigma P(d) \cdot m/(P \cdot m)_{\text{tot}}$
0.016144	5.311E-03	3.290E-01	1.547E-04	2.307E-03	2.203E-18	2.414E-11	3.735E-15	5.95113E-13	8.469E-10	4.153E-12
0.016628	5.654E-03	3.400E-01	1.647E-04	2.472E-03	2.407E-18	2.638E-11	4.345E-15	6.92317E-13	9.881E-10	4.846E-12
0.017127	6.016E-03	3.513E-01	1.752E-04	2.647E-03	2.630E-18	2.893E-11	5.052E-15	8.05004E-13	1.152E-09	5.851E-12
0.017641	6.399E-03	3.627E-01	1.864E-04	2.833E-03	2.874E-18	3.150E-11	5.871E-15	9.35573E-13	1.343E-09	6.586E-12
0.018170	6.802E-03	3.744E-01	1.981E-04	3.032E-03	3.141E-18	3.442E-11	6.820E-15	1.08679E-12	1.565E-09	7.673E-12
0.018715	7.227E-03	3.862E-01	2.105E-04	3.242E-03	3.432E-18	3.762E-11	7.918E-15	1.26182E-12	1.822E-09	8.935E-12
0.019276	7.675E-03	3.982E-01	2.236E-04	3.466E-03	3.750E-18	4.110E-11	9.189E-15	1.46433E-12	2.120E-09	1.040E-11
0.019855	8.147E-03	4.104E-01	2.373E-04	3.703E-03	4.058E-18	4.492E-11	1.066E-14	1.69851E-12	2.467E-09	1.210E-11
0.020450	8.644E-03	4.227E-01	2.518E-04	3.955E-03	4.478E-18	4.908E-11	1.238E-14	1.96917E-12	2.868E-09	1.407E-11
0.021064	9.167E-03	4.352E-01	2.670E-04	4.222E-03	4.893E-18	5.363E-11	1.432E-14	2.28184E-12	3.334E-09	1.635E-11
0.021696	9.718E-03	4.478E-01	2.830E-04	4.505E-03	5.347E-18	5.860E-11	1.658E-14	2.64286E-12	3.873E-09	1.899E-11
0.022347	1.029E-02	4.606E-01	2.998E-04	4.805E-03	5.843E-18	6.404E-11	1.920E-14	3.0595E-12	4.496E-09	2.205E-11
0.023017	1.090E-02	4.735E-01	3.175E-04	5.122E-03	6.385E-18	6.998E-11	2.222E-14	3.54009E-12	5.218E-09	2.559E-11
0.023708	1.154E-02	4.866E-01	3.360E-04	5.458E-03	6.977E-18	7.647E-11	2.569E-14	4.09418E-12	6.053E-09	2.969E-11
0.024419	1.220E-02	4.997E-01	3.554E-04	5.813E-03	7.624E-18	8.356E-11	2.970E-14	4.73263E-12	7.018E-09	3.442E-11
0.025151	1.290E-02	5.130E-01	3.758E-04	6.189E-03	8.331E-18	9.130E-11	3.431E-14	5.46798E-12	8.133E-09	3.989E-11
0.025906	1.364E-02	5.264E-01	3.972E-04	6.586E-03	9.103E-18	9.977E-11	3.963E-14	6.31445E-12	9.421E-09	4.620E-11
0.026683	1.440E-02	5.398E-01	4.195E-04	7.006E-03	9.947E-18	1.080E-10	4.574E-14	7.2885E-12	1.091E-08	5.349E-11
0.027484	1.521E-02	5.533E-01	4.429E-04	7.449E-03	1.087E-17	1.191E-10	5.277E-14	8.40861E-12	1.262E-08	6.190E-11
0.028308	1.605E-02	5.669E-01	4.674E-04	7.916E-03	1.188E-17	1.302E-10	6.085E-14	9.6961E-12	1.460E-08	7.159E-11
0.029157	1.693E-02	5.805E-01	4.930E-04	8.409E-03	1.298E-17	1.422E-10	7.013E-14	1.11753E-11	1.688E-08	8.277E-11
0.030032	1.784E-02	5.942E-01	5.197E-04	8.929E-03	1.418E-17	1.554E-10	8.079E-14	1.28737E-11	1.950E-08	9.564E-11
0.030933	1.880E-02	6.079E-01	5.477E-04	9.477E-03	1.550E-17	1.699E-10	9.302E-14	1.48231E-11	2.252E-08	1.105E-10
0.031861	1.980E-02	6.215E-01	5.768E-04	1.005E-02	1.693E-17	1.866E-10	1.071E-13	1.70593E-11	2.600E-08	1.275E-10
0.032817	2.085E-02	6.352E-01	6.072E-04	1.066E-02	1.850E-17	2.028E-10	1.231E-13	1.96232E-11	3.000E-08	1.471E-10
0.033801	2.193E-02	6.489E-01	6.388E-04	1.130E-02	2.022E-17	2.216E-10	1.416E-13	2.25613E-11	3.461E-08	1.697E-10
0.034815	2.307E-02	6.625E-01	6.718E-04	1.197E-02	2.210E-17	2.422E-10	1.627E-13	2.59267E-11	3.989E-08	1.956E-10
0.035860	2.425E-02	6.761E-01	7.062E-04	1.268E-02	2.414E-17	2.646E-10	1.869E-13	2.97795E-11	4.596E-08	2.254E-10
0.036936	2.547E-02	6.897E-01	7.419E-04	1.342E-02	2.638E-17	2.892E-10	2.145E-13	3.41881E-11	5.294E-08	2.596E-10
0.038044	2.675E-02	7.031E-01	7.791E-04	1.420E-02	2.883E-17	3.160E-10	2.462E-13	3.923E-11	6.093E-08	2.988E-10
0.039185	2.808E-02	7.165E-01	8.178E-04	1.502E-02	3.150E-17	3.453E-10	2.824E-13	4.49935E-11	7.011E-08	3.438E-10
0.040361	2.945E-02	7.298E-01	8.579E-04	1.587E-02	3.442E-17	3.773E-10	3.237E-13	5.15784E-11	8.063E-08	3.954E-10
0.041571	3.088E-02	7.429E-01	8.995E-04	1.677E-02	3.762E-17	4.123E-10	3.709E-13	5.90881E-11	9.268E-08	4.545E-10
0.042818	3.237E-02	7.559E-01	9.428E-04	1.772E-02	4.110E-17	4.505E-10	4.247E-13	6.76809E-11	1.065E-07	5.222E-10
0.044103	3.391E-02	7.688E-01	9.876E-04	1.870E-02	4.492E-17	4.923E-10	4.862E-13	7.74721E-11	1.223E-07	5.997E-10
0.045426	3.550E-02	7.815E-01	1.034E-03	1.974E-02	4.908E-17	5.379E-10	5.562E-13	8.86364E-11	1.403E-07	6.883E-10
0.046789	3.715E-02	7.940E-01	1.082E-03	2.082E-02	5.363E-17	5.878E-10	6.361E-13	1.0136E-10	1.610E-07	7.897E-10
0.048193	3.886E-02	8.064E-01	1.132E-03	2.195E-02	5.861E-17	6.423E-10	7.270E-13	1.15853E-10	1.846E-07	9.055E-10
0.049638	4.063E-02	8.185E-01	1.183E-03	2.314E-02	6.404E-17	7.019E-10	8.306E-13	1.32353E-10	2.116E-07	1.038E-09
0.051127	4.246E-02	8.304E-01	1.237E-03	2.437E-02	6.998E-17	7.670E-10	9.484E-13	1.5113E-10	2.424E-07	1.189E-09
0.052661	4.434E-02	8.420E-01	1.292E-03	2.566E-02	7.647E-17	8.381E-10	1.082E-12	1.72485E-10	2.776E-07	1.361E-09
0.054241	4.629E-02	8.534E-01	1.348E-03	2.701E-02	8.356E-17	9.158E-10	1.235E-12	1.96762E-10	3.177E-07	1.558E-09
0.055868	4.830E-02	8.646E-01	1.407E-03	2.842E-02	9.131E-17	1.001E-09	1.408E-12	2.24345E-10	3.635E-07	1.783E-09

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	$V\rho$	P(d)* $\Delta d^3/m/d$	P(d)* $\Delta d^3 m/(d^3 m P_{50})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{tot}}$
0.057544	5.038E-02	8.754E-01	1.467E-03	2.989E-02	9.977E-17	1.094E-09	1.604E-12	2.5667E-10	4.156E-07	2.038E-09
0.059271	5.251E-02	8.860E-01	1.529E-03	3.142E-02	1.090E-16	1.195E-09	1.828E-12	2.9122E-10	4.750E-07	2.329E-09
0.061049	5.471E-02	8.962E-01	1.594E-03	3.301E-02	1.191E-16	1.306E-09	2.081E-12	3.3156E-10	5.426E-07	2.661E-09
0.062880	5.698E-02	9.061E-01	1.659E-03	3.467E-02	1.302E-16	1.427E-09	2.368E-12	3.7730E-10	6.195E-07	3.038E-09
0.064767	5.931E-02	9.157E-01	1.727E-03	3.640E-02	1.423E-16	1.559E-09	2.693E-12	4.2914E-10	7.071E-07	3.467E-09
0.066710	6.170E-02	9.249E-01	1.797E-03	3.819E-02	1.554E-16	1.704E-09	3.062E-12	4.8786E-10	8.065E-07	3.955E-09
0.068711	6.416E-02	9.337E-01	1.869E-03	4.006E-02	1.699E-16	1.862E-09	3.479E-12	5.5435E-10	9.196E-07	4.510E-09
0.070772	6.668E-02	9.422E-01	1.942E-03	4.200E-02	1.856E-16	2.034E-09	3.951E-12	6.2959E-10	1.048E-06	5.139E-09
0.072896	6.927E-02	9.503E-01	2.018E-03	4.402E-02	2.028E-16	2.223E-09	4.485E-12	7.1469E-10	1.194E-06	5.854E-09
0.075082	7.193E-02	9.580E-01	2.095E-03	4.612E-02	2.216E-16	2.429E-09	5.089E-12	8.1090E-10	1.359E-06	6.665E-09
0.077335	7.465E-02	9.653E-01	2.174E-03	4.829E-02	2.422E-16	2.654E-09	5.771E-12	9.1981E-10	1.547E-06	7.585E-09
0.079655	7.743E-02	9.721E-01	2.255E-03	5.055E-02	2.646E-16	2.900E-09	6.541E-12	1.0423E-09	1.759E-06	8.627E-09
0.082045	8.028E-02	9.785E-01	2.338E-03	5.288E-02	2.892E-16	3.169E-09	7.411E-12	1.1809E-09	2.000E-06	9.808E-09
0.084506	8.320E-02	9.845E-01	2.423E-03	5.531E-02	3.160E-16	3.463E-09	8.392E-12	1.3373E-09	2.273E-06	1.115E-08
0.087041	8.618E-02	9.901E-01	2.510E-03	5.782E-02	3.453E-16	3.784E-09	9.498E-12	1.5136E-09	2.581E-06	1.266E-08
0.089652	8.922E-02	9.961E-01	2.599E-03	6.042E-02	3.773E-16	4.135E-09	1.075E-11	1.7123E-09	2.930E-06	1.437E-08
0.092342	9.232E-02	9.997E-01	2.689E-03	6.310E-02	4.123E-16	4.519E-09	1.215E-11	1.9361E-09	3.325E-06	1.631E-08
0.095112	9.548E-02	1.004E+00	2.781E-03	6.589E-02	4.505E-16	4.938E-09	1.373E-11	2.1881E-09	3.771E-06	1.850E-08
0.097966	9.870E-02	1.008E+00	2.875E-03	6.876E-02	4.923E-16	5.395E-09	1.551E-11	2.4718E-09	4.275E-06	2.097E-08
0.100905	1.020E-01	1.011E+00	2.970E-03	7.173E-02	5.379E-16	5.896E-09	1.751E-11	2.7908E-09	4.844E-06	2.376E-08
0.103932	1.053E-01	1.013E+00	3.068E-03	7.480E-02	5.878E-16	6.442E-09	1.976E-11	3.1494E-09	5.487E-06	2.691E-08
0.107050	1.087E-01	1.016E+00	3.167E-03	7.797E-02	6.423E-16	7.040E-09	2.229E-11	3.5524E-09	6.211E-06	3.046E-08
0.110261	1.122E-01	1.017E+00	3.267E-03	8.123E-02	7.019E-16	7.693E-09	2.513E-11	4.0050E-09	7.028E-06	3.446E-08
0.113569	1.157E-01	1.019E+00	3.369E-03	8.460E-02	7.670E-16	8.406E-09	2.832E-11	4.5130E-09	7.948E-06	3.898E-08
0.116976	1.192E-01	1.019E+00	3.473E-03	8.807E-02	8.381E-16	9.185E-09	3.190E-11	5.0830E-09	8.984E-06	4.406E-08
0.120485	1.228E-01	1.019E+00	3.578E-03	9.165E-02	9.158E-16	1.004E-08	3.591E-11	5.7222E-09	1.015E-05	4.978E-08
0.124100	1.265E-01	1.019E+00	3.684E-03	9.534E-02	1.001E-15	1.097E-08	4.040E-11	6.4386E-09	1.146E-05	5.622E-08
0.127823	1.302E-01	1.018E+00	3.792E-03	9.913E-02	1.094E-15	1.198E-08	4.544E-11	7.2412E-09	1.294E-05	6.346E-08
0.131657	1.339E-01	1.017E+00	3.900E-03	1.030E-01	1.195E-15	1.310E-08	5.108E-11	8.1397E-09	1.460E-05	7.160E-08
0.135607	1.377E-01	1.015E+00	4.010E-03	1.070E-01	1.306E-15	1.431E-08	5.739E-11	9.1453E-09	1.647E-05	8.075E-08
0.143866	1.453E-01	1.013E+00	4.121E-03	1.112E-01	1.427E-15	1.564E-08	6.445E-11	1.0270E-08	1.856E-05	9.102E-08
0.148182	1.492E-01	1.007E+00	4.233E-03	1.154E-01	1.559E-15	1.709E-08	7.234E-11	1.1527E-08	2.081E-05	1.025E-07
0.152827	1.531E-01	1.003E+00	4.346E-03	1.197E-01	1.704E-15	1.867E-08	8.116E-11	1.2932E-08	2.355E-05	1.155E-07
0.157206	1.571E-01	9.991E-01	4.460E-03	1.242E-01	1.862E-15	2.040E-08	9.101E-11	1.4502E-08	2.650E-05	1.300E-07
0.161922	1.610E-01	9.945E-01	4.575E-03	1.288E-01	2.034E-15	2.230E-08	1.020E-10	1.6253E-08	2.982E-05	1.462E-07
0.166780	1.650E-01	9.893E-01	4.690E-03	1.335E-01	2.223E-15	2.436E-08	1.143E-10	1.8208E-08	3.353E-05	1.644E-07
0.171783	1.690E-01	9.837E-01	4.806E-03	1.383E-01	2.428E-15	2.662E-08	1.279E-10	2.03874E-08	3.769E-05	1.848E-07
0.176937	1.730E-01	9.777E-01	4.922E-03	1.432E-01	2.654E-15	2.909E-08	1.432E-10	2.2816E-08	4.234E-05	2.076E-07
0.182245	1.770E-01	9.712E-01	5.038E-03	1.482E-01	2.900E-15	3.179E-08	1.602E-10	2.5524E-08	4.755E-05	2.332E-07
0.187712	1.810E-01	9.643E-01	5.155E-03	1.534E-01	3.169E-15	3.474E-08	1.791E-10	2.8535E-08	5.336E-05	2.617E-07
0.193343	1.850E-01	9.570E-01	5.272E-03	1.587E-01	3.463E-15	3.786E-08	2.001E-10	3.1888E-08	5.987E-05	2.936E-07
0.199144	1.890E-01	9.492E-01	5.389E-03	1.640E-01	3.784E-15	4.148E-08	2.235E-10	3.58174E-08	6.713E-05	3.292E-07
			5.506E-03	1.696E-01	4.135E-15	4.532E-08	2.495E-10	3.97634E-08	7.524E-05	3.690E-07

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* Δ d/d	Σ P(d)* Δ d/d	$\pi d^3/6$	V ρ	P(d)* Δ d*m/d	P(d)* Δ d*m/(d*mP ₅₀)	d < 4.7	Σ P(d) m/(P m) ₅₀
0.205118	1.930E-01	9.411E-01	5.622E-03	1.752E-01	4.519E-15	4.952E-08	2.784E-10	4.43702E-08	8.428E-05	4.133E-07
0.211272	1.970E-01	9.325E-01	5.738E-03	1.809E-01	4.938E-15	5.412E-08	3.105E-10	4.94865E-08	9.437E-05	4.628E-07
0.217610	2.010E-01	9.236E-01	5.854E-03	1.868E-01	5.396E-15	5.913E-08	3.462E-10	5.51657E-08	1.056E-04	5.180E-07
0.224138	2.049E-01	9.144E-01	5.969E-03	1.927E-01	5.896E-15	6.462E-08	3.857E-10	6.14663E-08	1.182E-04	5.795E-07
0.230862	2.089E-01	9.048E-01	6.084E-03	1.988E-01	6.443E-15	7.061E-08	4.296E-10	6.84534E-08	1.321E-04	6.479E-07
0.237788	2.128E-01	8.948E-01	6.197E-03	2.050E-01	7.040E-15	7.716E-08	4.782E-10	7.61972E-08	1.477E-04	7.241E-07
0.244922	2.168E-01	8.845E-01	6.310E-03	2.113E-01	7.693E-15	8.431E-08	5.320E-10	8.47753E-08	1.649E-04	8.089E-07
0.252269	2.205E-01	8.739E-01	6.421E-03	2.177E-01	8.406E-15	9.213E-08	5.916E-10	9.4273E-08	1.842E-04	9.032E-07
0.259837	2.243E-01	8.630E-01	6.532E-03	2.243E-01	9.186E-15	1.007E-07	6.576E-10	1.04783E-07	2.055E-04	1.008E-06
0.267633	2.280E-01	8.519E-01	6.640E-03	2.309E-01	1.004E-14	1.100E-07	7.305E-10	1.16408E-07	2.293E-04	1.124E-06
0.275662	2.317E-01	8.404E-01	6.748E-03	2.377E-01	1.097E-14	1.202E-07	8.112E-10	1.2926E-07	2.556E-04	1.254E-06
0.283931	2.353E-01	8.287E-01	6.854E-03	2.445E-01	1.198E-14	1.314E-07	9.003E-10	1.4346E-07	2.849E-04	1.397E-06
0.292449	2.389E-01	8.168E-01	6.958E-03	2.515E-01	1.310E-14	1.435E-07	9.987E-10	1.59141E-07	3.173E-04	1.556E-06
0.301223	2.424E-01	8.047E-01	7.060E-03	2.585E-01	1.431E-14	1.568E-07	1.107E-09	1.76451E-07	3.533E-04	1.733E-06
0.319667	2.458E-01	7.923E-01	7.160E-03	2.657E-01	1.564E-14	1.714E-07	1.227E-09	1.9547E-07	3.932E-04	1.928E-06
0.329154	2.492E-01	7.798E-01	7.258E-03	2.730E-01	1.709E-14	1.873E-07	1.359E-09	2.16604E-07	4.373E-04	2.145E-06
0.339029	2.525E-01	7.670E-01	7.354E-03	2.803E-01	1.867E-14	2.046E-07	1.505E-09	2.3981E-07	4.862E-04	2.365E-06
0.349200	2.558E-01	7.541E-01	7.447E-03	2.878E-01	2.040E-14	2.236E-07	1.665E-09	2.6373E-07	5.404E-04	2.600E-06
0.359676	2.618E-01	7.411E-01	7.538E-03	2.953E-01	2.230E-14	2.444E-07	1.842E-09	2.93516E-07	6.002E-04	2.944E-06
0.370466	2.648E-01	7.279E-01	7.626E-03	3.029E-01	2.436E-14	2.670E-07	2.036E-09	3.24485E-07	6.664E-04	3.268E-06
0.381580	2.678E-01	7.147E-01	7.711E-03	3.106E-01	2.662E-14	2.918E-07	2.250E-09	3.58548E-07	7.395E-04	3.627E-06
0.393027	2.678E-01	7.013E-01	7.794E-03	3.184E-01	2.909E-14	3.188E-07	2.485E-09	3.95988E-07	8.202E-04	4.023E-06
0.404818	2.703E-01	6.878E-01	7.873E-03	3.263E-01	3.179E-14	3.484E-07	2.743E-09	4.37126E-07	9.094E-04	4.460E-06
0.416963	2.729E-01	6.743E-01	7.950E-03	3.343E-01	3.474E-14	3.807E-07	3.027E-09	4.823E-07	1.008E-03	4.942E-06
0.429472	2.755E-01	6.607E-01	8.023E-03	3.423E-01	3.796E-14	4.160E-07	3.338E-09	5.31883E-07	1.116E-03	5.474E-06
0.442356	2.779E-01	6.470E-01	8.093E-03	3.504E-01	4.148E-14	4.546E-07	3.679E-09	5.86275E-07	1.236E-03	6.060E-06
0.455827	2.802E-01	6.333E-01	8.160E-03	3.585E-01	4.532E-14	4.967E-07	4.053E-09	6.45913E-07	1.367E-03	6.706E-06
0.469295	2.823E-01	6.196E-01	8.223E-03	3.668E-01	4.953E-14	5.428E-07	4.463E-09	7.11269E-07	1.512E-03	7.417E-06
0.483374	2.844E-01	6.060E-01	8.283E-03	3.750E-01	5.412E-14	5.931E-07	4.913E-09	7.82854E-07	1.672E-03	8.200E-06
0.497875	2.863E-01	5.923E-01	8.339E-03	3.834E-01	5.914E-14	6.481E-07	5.404E-09	8.61221E-07	1.848E-03	9.061E-06
0.512812	2.881E-01	5.786E-01	8.391E-03	3.918E-01	6.462E-14	7.082E-07	5.943E-09	9.46968E-07	2.041E-03	1.001E-05
0.528196	2.897E-01	5.650E-01	8.439E-03	4.002E-01	7.061E-14	7.739E-07	6.531E-09	1.04074E-06	2.253E-03	1.105E-05
0.544042	2.913E-01	5.514E-01	8.484E-03	4.087E-01	7.716E-14	8.457E-07	7.174E-09	1.14324E-06	2.486E-03	1.219E-05
0.560363	2.927E-01	5.379E-01	8.524E-03	4.172E-01	8.431E-14	9.241E-07	7.877E-09	1.25522E-06	2.742E-03	1.345E-05
0.577174	2.939E-01	5.245E-01	8.561E-03	4.258E-01	9.213E-14	1.010E-06	8.644E-09	1.3775E-06	3.023E-03	1.483E-05
0.594489	2.950E-01	5.112E-01	8.593E-03	4.344E-01	1.007E-13	1.103E-06	9.482E-09	1.51094E-06	3.331E-03	1.634E-05
0.612324	2.960E-01	4.979E-01	8.622E-03	4.430E-01	1.100E-13	1.206E-06	1.040E-08	1.65649E-06	3.669E-03	1.799E-05
0.630894	2.968E-01	4.848E-01	8.646E-03	4.516E-01	1.202E-13	1.318E-06	1.139E-08	1.81518E-06	4.039E-03	1.981E-05
0.649615	2.975E-01	4.717E-01	8.666E-03	4.603E-01	1.314E-13	1.440E-06	1.248E-08	1.9881E-06	4.444E-03	2.180E-05
0.669103	2.981E-01	4.588E-01	8.682E-03	4.690E-01	1.435E-13	1.573E-06	1.366E-08	2.17642E-06	4.888E-03	2.397E-05
0.689176	2.985E-01	4.461E-01	8.693E-03	4.777E-01	1.568E-13	1.719E-06	1.494E-08	2.38141E-06	5.374E-03	2.635E-05
0.708851	2.987E-01	4.334E-01	8.701E-03	4.864E-01	1.714E-13	1.878E-06	1.634E-08	2.60444E-06	5.905E-03	2.896E-05
	2.988E-01	4.210E-01	8.704E-03	4.951E-01	1.873E-13	2.053E-06	1.787E-08	2.84695E-06	6.485E-03	3.180E-05

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V ρ	P(d)* $\Delta d^3 m/d$	P(d)* $\Delta d^3 m/(d^3 m P_{\text{ref}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{ref}}$
0.731147	2.988E-01	4.087E-01	8.703E-03	5.038E-01	2.047E-13	2.243E-06	1.952E-08	3.11052E-06	7.120E-03	3.492E-05
0.733081	2.988E-01	3.965E-01	8.697E-03	5.125E-01	2.238E-13	2.451E-06	1.232E-08	3.39883E-06	7.812E-03	3.831E-05
0.775674	2.983E-01	3.845E-01	8.687E-03	5.212E-01	2.444E-13	2.678E-06	2.327E-08	3.70767E-06	8.568E-03	4.202E-05
0.798944	2.978E-01	3.727E-01	8.674E-03	5.298E-01	2.670E-13	2.927E-06	2.538E-08	4.04497E-06	9.393E-03	4.606E-05
0.822912	2.972E-01	3.611E-01	8.655E-03	5.385E-01	2.918E-13	3.198E-06	2.768E-08	4.41079E-06	1.029E-02	5.048E-05
0.847600	2.964E-01	3.497E-01	8.633E-03	5.471E-01	3.188E-13	3.494E-06	3.017E-08	4.80734E-06	1.127E-02	5.528E-05
0.873028	2.955E-01	3.385E-01	8.606E-03	5.557E-01	3.484E-13	3.819E-06	3.286E-08	5.23698E-06	1.234E-02	6.052E-05
0.899218	2.944E-01	3.274E-01	8.576E-03	5.643E-01	3.807E-13	4.173E-06	3.578E-08	5.70221E-06	1.350E-02	6.622E-05
0.926195	2.932E-01	3.166E-01	8.541E-03	5.728E-01	4.160E-13	4.559E-06	3.894E-08	6.20574E-06	1.477E-02	7.243E-05
0.953981	2.919E-01	3.060E-01	8.502E-03	5.814E-01	4.546E-13	4.982E-06	4.236E-08	6.75041E-06	1.615E-02	7.918E-05
0.982600	2.904E-01	2.956E-01	8.460E-03	5.898E-01	4.967E-13	5.444E-06	4.606E-08	7.33929E-06	1.764E-02	8.652E-05
1.012078	2.888E-01	2.854E-01	8.413E-03	5.982E-01	5.428E-13	5.949E-06	5.005E-08	7.97564E-06	1.927E-02	9.449E-05
1.042441	2.871E-01	2.754E-01	8.363E-03	6.066E-01	5.931E-13	6.501E-06	5.436E-08	8.66291E-06	2.103E-02	1.032E-04
1.073714	2.853E-01	2.657E-01	8.308E-03	6.149E-01	6.481E-13	7.104E-06	5.902E-08	9.40479E-06	2.295E-02	1.126E-04
1.105925	2.833E-01	2.561E-01	8.250E-03	6.231E-01	7.082E-13	7.792E-06	6.404E-08	1.02052E-05	2.503E-02	1.228E-04
1.139103	2.811E-01	2.468E-01	8.189E-03	6.313E-01	7.739E-13	8.482E-06	6.946E-08	1.10683E-05	2.729E-02	1.338E-04
1.173276	2.789E-01	2.377E-01	8.124E-03	6.395E-01	8.457E-13	9.269E-06	7.529E-08	1.19985E-05	2.974E-02	1.458E-04
1.208474	2.766E-01	2.289E-01	8.055E-03	6.475E-01	9.241E-13	1.013E-05	8.158E-08	1.30005E-05	3.239E-02	1.588E-04
1.244729	2.741E-01	2.202E-01	7.983E-03	6.555E-01	1.010E-12	1.107E-05	8.355E-08	1.40793E-05	3.526E-02	1.729E-04
1.282070	2.715E-01	2.118E-01	7.908E-03	6.634E-01	1.103E-12	1.209E-05	8.564E-08	1.52402E-05	3.837E-02	1.882E-04
1.320533	2.688E-01	2.036E-01	7.830E-03	6.712E-01	1.206E-12	1.321E-05	1.035E-07	1.64866E-05	4.173E-02	2.046E-04
1.360149	2.660E-01	1.956E-01	7.749E-03	6.790E-01	1.318E-12	1.444E-05	1.119E-07	1.78306E-05	4.536E-02	2.225E-04
1.400953	2.632E-01	1.878E-01	7.665E-03	6.866E-01	1.440E-12	1.578E-05	1.209E-07	1.92724E-05	4.929E-02	2.417E-04
1.442982	2.602E-01	1.803E-01	7.578E-03	6.942E-01	1.573E-12	1.724E-05	1.307E-07	2.08205E-05	5.354E-02	2.626E-04
1.486271	2.571E-01	1.730E-01	7.488E-03	7.017E-01	1.719E-12	1.894E-05	1.411E-07	2.2482E-05	5.812E-02	2.850E-04
1.530859	2.539E-01	1.659E-01	7.396E-03	7.091E-01	1.878E-12	2.089E-05	1.523E-07	2.42642E-05	6.307E-02	3.093E-04
1.576785	2.507E-01	1.590E-01	7.301E-03	7.164E-01	2.053E-12	2.250E-05	1.643E-07	2.61748E-05	6.841E-02	3.355E-04
1.624089	2.473E-01	1.523E-01	7.204E-03	7.236E-01	2.243E-12	2.458E-05	1.771E-07	2.8222E-05	7.416E-02	3.637E-04
1.672811	2.439E-01	1.458E-01	7.105E-03	7.307E-01	2.451E-12	2.686E-05	1.909E-07	3.04144E-05	8.036E-02	3.941E-04
1.722996	2.405E-01	1.396E-01	7.004E-03	7.377E-01	2.678E-12	2.935E-05	2.068E-07	3.27611E-05	8.705E-02	4.269E-04
1.774685	2.369E-01	1.335E-01	6.901E-03	7.446E-01	2.927E-12	3.208E-05	2.213E-07	3.52715E-05	9.424E-02	4.622E-04
1.827926	2.333E-01	1.276E-01	6.796E-03	7.514E-01	3.198E-12	3.505E-05	2.382E-07	3.79557E-05	1.020E-01	5.001E-04
1.882764	2.297E-01	1.220E-01	6.689E-03	7.581E-01	3.495E-12	3.830E-05	2.562E-07	4.08241E-05	1.103E-01	5.409E-04
1.939247	2.259E-01	1.165E-01	6.581E-03	7.647E-01	3.819E-12	4.185E-05	2.754E-07	4.38878E-05	1.193E-01	5.848E-04
1.997424	2.222E-01	1.112E-01	6.471E-03	7.712E-01	4.173E-12	4.573E-05	2.959E-07	4.71583E-05	1.289E-01	6.320E-04
2.057347	2.184E-01	1.061E-01	6.360E-03	7.775E-01	4.560E-12	4.997E-05	3.178E-07	5.06477E-05	1.392E-01	6.826E-04
2.119067	2.145E-01	1.012E-01	6.248E-03	7.838E-01	4.982E-12	5.461E-05	3.412E-07	5.43686E-05	1.503E-01	7.370E-04
2.182639	2.106E-01	9.650E-02	6.135E-03	7.899E-01	5.444E-12	5.967E-05	3.661E-07	5.83342E-05	1.622E-01	7.953E-04
2.248118	2.067E-01	9.195E-02	6.021E-03	7.959E-01	5.949E-12	6.520E-05	3.926E-07	6.25585E-05	1.749E-01	8.579E-04
2.315562	2.028E-01	8.757E-02	5.906E-03	8.018E-01	6.501E-12	7.125E-05	4.208E-07	6.70557E-05	1.886E-01	9.249E-04
2.385029	1.988E-01	8.336E-02	5.791E-03	8.078E-01	7.104E-12	7.766E-05	4.508E-07	7.1941E-05	2.033E-01	9.968E-04
2.456580	1.948E-01	7.931E-02	5.675E-03	8.133E-01	7.762E-12	8.507E-05	4.828E-07	7.69301E-05	2.169E-01	1.074E-03
2.530277	1.908E-01	7.542E-02	5.558E-03	8.189E-01	8.482E-12	9.296E-05	5.167E-07	8.23393E-05	2.357E-01	1.156E-03

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	Vp	P(d) $\Delta d^3/d$	P(d) $\Delta d^3 m/(d^3 m P_{\text{tot}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{tot}}$
2.606185	1.868E-01	7.169E-02	5.442E-03	8.243E-01	9.269E-12	1.016E-04	5.528E-07	8.80857E-05	2.537E-01	1.244E-03
2.684371	1.828E-01	6.810E-02	5.325E-03	8.296E-01	1.013E-11	1.110E-04	5.911E-07	9.41869E-05	2.729E-01	1.338E-03
2.764902	1.788E-01	6.467E-02	5.208E-03	8.348E-01	1.107E-11	1.213E-04	6.317E-07	0.000100661	2.934E-01	1.439E-03
2.847849	1.748E-01	6.138E-02	5.091E-03	8.399E-01	1.209E-11	1.325E-04	6.748E-07	0.000107528	3.153E-01	1.547E-03
2.933285	1.708E-01	5.822E-02	4.974E-03	8.449E-01	1.321E-11	1.448E-04	7.205E-07	0.000114807	3.388E-01	1.661E-03
3.021283	1.668E-01	5.521E-02	4.858E-03	8.498E-01	1.444E-11	1.583E-04	7.688E-07	0.000122519	3.637E-01	1.784E-03
3.111922	1.628E-01	5.232E-02	4.742E-03	8.545E-01	1.578E-11	1.729E-04	8.201E-07	0.000130684	3.904E-01	1.915E-03
3.205279	1.588E-01	4.956E-02	4.627E-03	8.591E-01	1.724E-11	1.890E-04	8.743E-07	0.000139325	4.188E-01	2.054E-03
3.301438	1.549E-01	4.692E-02	4.512E-03	8.636E-01	1.894E-11	2.065E-04	9.317E-07	0.000148465	4.491E-01	2.202E-03
3.400481	1.510E-01	4.440E-02	4.398E-03	8.680E-01	2.059E-11	2.256E-04	9.923E-07	0.000158127	4.813E-01	2.360E-03
3.502495	1.471E-01	4.200E-02	4.284E-03	8.723E-01	2.250E-11	2.466E-04	1.056E-06	0.000168335	5.156E-01	2.529E-03
3.607570	1.432E-01	3.970E-02	4.172E-03	8.765E-01	2.458E-11	2.694E-04	1.124E-06	0.000179115	5.522E-01	2.708E-03
3.715797	1.394E-01	3.752E-02	4.060E-03	8.805E-01	2.686E-11	2.944E-04	1.195E-06	0.000190491	5.910E-01	2.898E-03
3.827271	1.356E-01	3.543E-02	3.950E-03	8.845E-01	2.935E-11	3.217E-04	1.271E-06	0.000202491	6.323E-01	3.101E-03
3.942089	1.319E-01	3.345E-02	3.840E-03	8.883E-01	3.208E-11	3.516E-04	1.350E-06	0.000215141	6.762E-01	3.316E-03
4.060352	1.281E-01	3.156E-02	3.732E-03	8.921E-01	3.505E-11	3.841E-04	1.434E-06	0.000228469	7.228E-01	3.544E-03
4.182162	1.245E-01	2.976E-02	3.625E-03	8.957E-01	3.830E-11	4.198E-04	1.522E-06	0.000242504	7.722E-01	3.787E-03
4.307827	1.208E-01	2.805E-02	3.520E-03	8.992E-01	4.185E-11	4.587E-04	1.614E-06	0.000257274	8.247E-01	4.044E-03
4.436856	1.173E-01	2.643E-02	3.416E-03	9.026E-01	4.573E-11	5.012E-04	1.712E-06	0.000272811	8.803E-01	4.317E-03
4.700000	1.104E-01	2.350E-02	3.117E-03	9.088E-01	5.436E-11	5.988E-04	2.029E-06	0.000587083	1.000E+00	5.228E-03
4.841030	1.070E-01	2.211E-02	3.019E-03	9.119E-01	5.940E-11	6.511E-04	2.148E-06	0.000362045	1.000E+00	5.570E-03
4.986230	1.037E-01	2.079E-02	2.828E-03	9.149E-01	6.491E-11	7.114E-04	2.272E-06	0.000382791	1.000E+00	5.932E-03
5.135817	1.003E-01	1.954E-02	2.735E-03	9.179E-01	7.093E-11	7.774E-04	2.402E-06	0.000404527	1.000E+00	6.315E-03
5.289891	9.709E-02	1.835E-02	2.644E-03	9.207E-01	7.751E-11	8.495E-04	2.539E-06	0.000427288	1.000E+00	6.719E-03
5.448588	9.389E-02	1.723E-02	2.554E-03	9.234E-01	8.469E-11	9.282E-04	2.681E-06	0.000451109	1.000E+00	7.146E-03
5.612046	9.076E-02	1.617E-02	2.466E-03	9.266E-01	9.255E-11	1.014E-03	2.831E-06	0.000476024	1.000E+00	7.598E-03
5.790407	8.769E-02	1.517E-02	2.381E-03	9.286E-01	1.011E-10	1.108E-03	3.015E-06	0.000502069	1.000E+00	8.074E-03
5.953819	8.468E-02	1.422E-02	2.297E-03	9.311E-01	1.105E-10	1.211E-03	3.212E-06	0.000529279	1.000E+00	8.576E-03
6.132434	8.174E-02	1.333E-02	2.215E-03	9.335E-01	1.208E-10	1.323E-03	3.350E-06	0.000557691	1.000E+00	9.105E-03
6.316407	7.885E-02	1.248E-02	2.134E-03	9.358E-01	1.319E-10	1.446E-03	3.500E-06	0.00058734	1.000E+00	9.663E-03
6.505899	7.604E-02	1.169E-02	2.056E-03	9.380E-01	1.442E-10	1.580E-03	3.686E-06	0.000618261	1.000E+00	1.025E-02
6.701076	7.328E-02	1.094E-02	1.980E-03	9.401E-01	1.576E-10	1.727E-03	3.880E-06	0.00064068	1.000E+00	1.087E-02
6.902108	7.059E-02	1.023E-02	1.905E-03	9.422E-01	1.722E-10	1.887E-03	4.082E-06	0.000684068	1.000E+00	1.152E-02
7.097172	6.797E-02	9.561E-03	1.833E-03	9.442E-01	1.881E-10	2.062E-03	4.293E-06	0.000719024	1.000E+00	1.220E-02
7.322447	6.541E-02	8.933E-03	1.762E-03	9.461E-01	2.056E-10	2.253E-03	4.512E-06	0.000755395	1.000E+00	1.292E-02
7.542120	6.292E-02	8.343E-03	1.693E-03	9.479E-01	2.246E-10	2.462E-03	4.740E-06	0.000793218	1.000E+00	1.368E-02
7.768384	6.050E-02	7.787E-03	1.626E-03	9.497E-01	2.455E-10	2.690E-03	4.978E-06	0.000832526	1.000E+00	1.447E-02
8.001435	5.813E-02	7.266E-03	1.561E-03	9.514E-01	2.682E-10	2.940E-03	5.224E-06	0.000873354	1.000E+00	1.530E-02
8.241478	5.584E-02	6.775E-03	1.498E-03	9.530E-01	2.931E-10	3.212E-03	5.491E-06	0.000915735	1.000E+00	1.618E-02
8.498723	5.361E-02	6.315E-03	1.437E-03	9.545E-01	3.203E-10	3.510E-03	5.747E-06	0.000959703	1.000E+00	1.709E-02
8.743394	5.144E-02	5.883E-03	1.377E-03	9.560E-01	3.500E-10	3.836E-03	6.022E-06	0.001005288	1.000E+00	1.805E-02
9.005686	4.933E-02	5.478E-03	1.317E-03	9.575E-01	3.824E-10	4.191E-03	6.309E-06		1.000E+00	1.906E-02
9.275857	4.729E-02	5.098E-03		9.589E-01	4.179E-10	4.580E-03				

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* Δd /d	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V ρ	P(d)* Δd /m/d	P(d)* Δd /m/(d*m ρ_{tot})	d < 4.7	$\Sigma P(d)$ m/(P*m) ρ_{tot}
9.554132	4.531E-02	4.743E-03	1.320E-03	9.602E-01	4.566E-10	5.005E-03	6.605E-06	0.001052522	1.000E+00	2.011E-02
9.840756	4.339E-02	4.410E-03	1.284E-03	9.614E-01	4.990E-10	5.469E-03	6.912E-06	0.00101436	1.000E+00	2.121E-02
10.135979	4.154E-02	4.098E-03	1.210E-03	9.626E-01	5.453E-10	5.976E-03	7.230E-06	0.001152057	1.000E+00	2.236E-02
10.440058	3.974E-02	3.806E-03	1.157E-03	9.638E-01	5.958E-10	6.530E-03	7.558E-06	0.001204415	1.000E+00	2.357E-02
10.753260	3.800E-02	3.534E-03	1.107E-03	9.649E-01	6.511E-10	7.136E-03	7.898E-06	0.001256535	1.000E+00	2.483E-02
11.070558	3.632E-02	3.279E-03	1.058E-03	9.660E-01	7.114E-10	7.797E-03	8.249E-06	0.001314443	1.000E+00	2.614E-02
11.408134	3.470E-02	3.042E-03	1.011E-03	9.670E-01	7.774E-10	8.520E-03	8.611E-06	0.001372161	1.000E+00	2.751E-02
12.000000	3.205E-02	2.671E-03	1.581E-03	9.686E-01	9.048E-10	9.916E-03	1.568E-05	0.002496077	1.000E+00	3.001E-02
12.360000	3.058E-02	2.474E-03	8.907E-04	9.695E-01	9.887E-10	1.084E-02	9.651E-06	0.001537919	1.000E+00	3.155E-02
12.730800	2.916E-02	2.290E-03	8.493E-04	9.703E-01	1.080E-09	1.184E-02	1.006E-05	0.001602532	1.000E+00	3.315E-02
13.112724	2.779E-02	2.120E-03	8.095E-04	9.711E-01	1.181E-09	1.294E-02	1.047E-05	0.001669041	1.000E+00	3.482E-02
13.506106	2.648E-02	1.960E-03	7.712E-04	9.719E-01	1.290E-09	1.414E-02	1.090E-05	0.001737459	1.000E+00	3.656E-02
13.911289	2.521E-02	1.812E-03	7.343E-04	9.728E-01	1.410E-09	1.545E-02	1.134E-05	0.001807794	1.000E+00	3.837E-02
14.328628	2.399E-02	1.675E-03	6.989E-04	9.733E-01	1.540E-09	1.688E-02	1.180E-05	0.001880055	1.000E+00	4.025E-02
15.000000	2.220E-02	1.480E-03	6.147E-04	9.743E-01	1.767E-09	1.937E-02	1.925E-05	0.003068954	1.000E+00	4.331E-02
15.450000	2.110E-02	1.366E-03	6.147E-04	9.748E-01	1.931E-09	2.116E-02	1.301E-05	0.002072993	1.000E+00	4.539E-02
15.913500	2.005E-02	1.260E-03	5.840E-04	9.755E-01	2.110E-09	2.313E-02	1.351E-05	0.002152107	1.000E+00	4.754E-02
16.390905	1.904E-02	1.162E-03	5.545E-04	9.761E-01	2.306E-09	2.527E-02	1.401E-05	0.002233145	1.000E+00	4.977E-02
16.882632	1.807E-02	1.070E-03	5.263E-04	9.766E-01	2.520E-09	2.761E-02	1.453E-05	0.002316098	1.000E+00	5.209E-02
17.389111	1.714E-02	9.859E-04	4.993E-04	9.771E-01	2.763E-09	3.017E-02	1.507E-05	0.002400956	1.000E+00	5.449E-02
18.448108	1.626E-02	9.076E-04	4.735E-04	9.776E-01	3.008E-09	3.297E-02	1.561E-05	0.002487703	1.000E+00	5.698E-02
19.001551	1.541E-02	8.351E-04	4.487E-04	9.780E-01	3.287E-09	3.603E-02	1.617E-05	0.002576321	1.000E+00	5.955E-02
19.571598	1.459E-02	7.680E-04	4.251E-04	9.784E-01	3.592E-09	3.937E-02	1.674E-05	0.002666787	1.000E+00	6.222E-02
20.158746	1.382E-02	7.060E-04	4.025E-04	9.788E-01	3.925E-09	4.302E-02	1.731E-05	0.002759078	1.000E+00	6.498E-02
20.763508	1.308E-02	6.487E-04	3.809E-04	9.792E-01	4.289E-09	4.701E-02	1.790E-05	0.002853163	1.000E+00	6.783E-02
21.386413	1.237E-02	5.957E-04	3.602E-04	9.796E-01	4.687E-09	5.137E-02	1.851E-05	0.002949011	1.000E+00	7.078E-02
22.028006	1.169E-02	5.468E-04	3.406E-04	9.799E-01	5.122E-09	5.613E-02	1.912E-05	0.003046585	1.000E+00	7.383E-02
22.688846	1.105E-02	5.016E-04	3.218E-04	9.802E-01	5.597E-09	6.134E-02	1.974E-05	0.003145844	1.000E+00	7.697E-02
23.369511	1.044E-02	4.600E-04	3.040E-04	9.805E-01	6.116E-09	6.703E-02	2.037E-05	0.003246745	1.000E+00	8.022E-02
24.070597	9.852E-03	4.216E-04	2.870E-04	9.808E-01	6.683E-09	7.324E-02	2.102E-05	0.003349241	1.000E+00	8.357E-02
24.792714	9.296E-03	3.882E-04	2.708E-04	9.811E-01	7.302E-09	8.003E-02	2.167E-05	0.003453278	1.000E+00	8.702E-02
25.536496	8.768E-03	3.536E-04	2.554E-04	9.814E-01	7.979E-09	8.745E-02	2.233E-05	0.003558903	1.000E+00	9.068E-02
26.302591	8.265E-03	3.236E-04	2.407E-04	9.816E-01	8.719E-09	9.556E-02	2.300E-05	0.003665754	1.000E+00	9.425E-02
27.091669	7.787E-03	2.980E-04	2.268E-04	9.818E-01	9.528E-09	1.044E-01	2.368E-05	0.003774068	1.000E+00	9.802E-02
27.904419	7.333E-03	2.707E-04	2.136E-04	9.820E-01	1.041E-08	1.141E-01	2.437E-05	0.003883679	1.000E+00	1.019E-01
28.741551	6.902E-03	2.474E-04	2.010E-04	9.822E-01	1.138E-08	1.247E-01	2.507E-05	0.003994515	1.000E+00	1.059E-01
29.603798	6.494E-03	2.259E-04	1.891E-04	9.824E-01	1.243E-08	1.363E-01	2.577E-05	0.0041065	1.000E+00	1.100E-01
30.491912	6.106E-03	2.063E-04	1.778E-04	9.826E-01	1.356E-08	1.489E-01	2.648E-05	0.004219555	1.000E+00	1.142E-01
31.406669	5.739E-03	1.882E-04	1.672E-04	9.828E-01	1.484E-08	1.627E-01	2.719E-05	0.004333597	1.000E+00	1.186E-01
32.348869	5.391E-03	1.717E-04	1.570E-04	9.829E-01	1.622E-08	1.778E-01	2.792E-05	0.004448541	1.000E+00	1.230E-01
33.319335	5.062E-03	1.565E-04	1.474E-04	9.831E-01	1.772E-08	1.943E-01	2.864E-05	0.004564295	1.000E+00	1.276E-01
34.318915	4.751E-03	1.426E-04	1.384E-04	9.832E-01	1.937E-08	2.123E-01	2.937E-05	0.004680766	1.000E+00	1.323E-01
	4.456E-03	1.299E-04	1.298E-04	9.833E-01	2.116E-08	2.320E-01	3.011E-05	0.004797856	1.000E+00	1.370E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*d/d	$\Sigma P(d)*d/d$	$\pi d^3/6$	V ρ	P(d)* Δd^3 /m/d	P(d)* Δd^3 /m/(d ³ *mP _{vd})	d < 4.7	$\Sigma P(d)$ m/(P m) _{het}
35.348483	4.178E-03	1.182E-04	1.217E-04	9.835E-01	2.313E-08	2.535E-01	3.085E-05	0.004915465	1.000E+00	1.420E-01
36.408937	3.916E-03	1.075E-04	1.140E-04	9.836E-01	2.527E-08	2.770E-01	3.159E-05	0.005033489	1.000E+00	1.470E-01
37.501205	3.668E-03	9.780E-05	1.068E-04	9.837E-01	2.761E-08	3.027E-01	3.233E-05	0.005151182	1.000E+00	1.522E-01
38.626241	3.434E-03	8.889E-05	1.000E-04	9.838E-01	3.017E-08	3.307E-01	3.307E-05	0.005270349	1.000E+00	1.574E-01
39.785029	3.213E-03	8.076E-05	9.358E-05	9.839E-01	3.297E-08	3.614E-01	3.382E-05	0.005388962	1.000E+00	1.628E-01
40.978579	3.005E-03	7.333E-05	8.752E-05	9.840E-01	3.603E-08	3.949E-01	3.456E-05	0.005507544	1.000E+00	1.683E-01
42.207937	2.809E-03	6.655E-05	8.182E-05	9.841E-01	3.937E-08	4.315E-01	3.531E-05	0.005625976	1.000E+00	1.739E-01
43.474175	2.625E-03	6.037E-05	7.645E-05	9.841E-01	4.302E-08	4.715E-01	3.605E-05	0.005744139	1.000E+00	1.797E-01
44.778400	2.451E-03	5.474E-05	7.139E-05	9.842E-01	4.701E-08	5.152E-01	3.679E-05	0.005861909	1.000E+00	1.855E-01
46.121752	2.288E-03	4.961E-05	6.664E-05	9.843E-01	5.137E-08	5.630E-01	3.752E-05	0.005979161	1.000E+00	1.915E-01
47.505405	2.135E-03	4.494E-05	6.218E-05	9.843E-01	5.613E-08	6.152E-01	3.825E-05	0.00609577	1.000E+00	1.976E-01
48.930567	1.991E-03	4.068E-05	5.798E-05	9.844E-01	6.134E-08	6.723E-01	3.898E-05	0.006211607	1.000E+00	2.038E-01
50.398484	1.855E-03	3.682E-05	5.404E-05	9.844E-01	6.703E-08	7.346E-01	3.970E-05	0.006326542	1.000E+00	2.102E-01
51.910438	1.729E-03	3.330E-05	5.035E-05	9.845E-01	7.324E-08	8.027E-01	4.042E-05	0.006440447	1.000E+00	2.166E-01
53.467752	1.610E-03	3.010E-05	4.688E-05	9.845E-01	8.003E-08	8.772E-01	4.112E-05	0.006553189	1.000E+00	2.232E-01
55.071794	1.498E-03	2.720E-05	4.363E-05	9.846E-01	8.746E-08	9.595E-01	4.182E-05	0.006664636	1.000E+00	2.298E-01
56.723938	1.394E-03	2.457E-05	4.059E-05	9.846E-01	9.556E-08	1.047E+00	4.251E-05	0.006774656	1.000E+00	2.366E-01
58.425656	1.296E-03	2.218E-05	3.774E-05	9.847E-01	1.044E-07	1.145E+00	4.319E-05	0.006883118	1.000E+00	2.435E-01
60.178425	1.204E-03	2.001E-05	3.507E-05	9.847E-01	1.141E-07	1.251E+00	4.386E-05	0.006989888	1.000E+00	2.505E-01
61.983778	1.119E-03	1.805E-05	3.258E-05	9.847E-01	1.247E-07	1.367E+00	4.452E-05	0.007094836	1.000E+00	2.576E-01
63.843292	1.038E-03	1.627E-05	3.025E-05	9.848E-01	1.363E-07	1.493E+00	4.517E-05	0.007197829	1.000E+00	2.648E-01
65.756590	9.637E-04	1.465E-05	2.807E-05	9.848E-01	1.489E-07	1.632E+00	4.580E-05	0.007298739	1.000E+00	2.721E-01
67.731348	8.938E-04	1.320E-05	2.603E-05	9.848E-01	1.627E-07	1.783E+00	4.642E-05	0.007397436	1.000E+00	2.795E-01
69.763288	8.286E-04	1.188E-05	2.414E-05	9.848E-01	1.778E-07	1.948E+00	4.703E-05	0.007493793	1.000E+00	2.870E-01
71.856187	7.678E-04	1.069E-05	2.236E-05	9.849E-01	1.943E-07	2.129E+00	4.762E-05	0.007587685	1.000E+00	2.945E-01
74.011873	7.111E-04	9.608E-06	2.071E-05	9.849E-01	2.123E-07	2.327E+00	4.819E-05	0.007677579	1.000E+00	3.022E-01
76.232229	6.583E-04	8.635E-06	1.917E-05	9.849E-01	2.320E-07	2.542E+00	4.874E-05	0.007767579	1.000E+00	3.100E-01
78.519196	6.091E-04	7.757E-06	1.774E-05	9.849E-01	2.535E-07	2.778E+00	4.928E-05	0.007853342	1.000E+00	3.178E-01
80.874772	5.633E-04	6.965E-06	1.641E-05	9.849E-01	2.770E-07	3.036E+00	4.980E-05	0.007936161	1.000E+00	3.258E-01
83.301015	5.207E-04	6.250E-06	1.516E-05	9.849E-01	3.027E-07	3.317E+00	5.030E-05	0.008092517	1.000E+00	3.338E-01
85.800045	4.810E-04	5.606E-06	1.401E-05	9.850E-01	3.307E-07	3.625E+00	5.078E-05	0.00815922	1.000E+00	3.419E-01
88.374047	4.442E-04	5.026E-06	1.284E-05	9.850E-01	3.614E-07	3.961E+00	5.124E-05	0.008165839	1.000E+00	3.500E-01
91.025268	4.100E-04	4.504E-06	1.194E-05	9.850E-01	3.949E-07	4.328E+00	5.168E-05	0.008235787	1.000E+00	3.583E-01
93.756026	3.782E-04	4.034E-06	1.102E-05	9.850E-01	4.315E-07	4.729E+00	5.210E-05	0.008302263	1.000E+00	3.666E-01
96.598707	3.487E-04	3.611E-06	1.016E-05	9.850E-01	4.715E-07	5.168E+00	5.249E-05	0.008365174	1.000E+00	3.750E-01
99.465768	3.214E-04	3.231E-06	9.362E-06	9.850E-01	5.153E-07	5.647E+00	5.287E-05	0.008424443	1.000E+00	3.834E-01
102.449741	2.961E-04	2.890E-06	8.624E-06	9.850E-01	5.630E-07	6.171E+00	5.321E-05	0.008479948	1.000E+00	3.919E-01
105.523233	2.726E-04	2.583E-06	7.940E-06	9.850E-01	6.152E-07	6.743E+00	5.354E-05	0.008531648	1.000E+00	4.004E-01
108.688930	2.509E-04	2.308E-06	7.307E-06	9.850E-01	6.723E-07	7.368E+00	5.384E-05	0.008579456	1.000E+00	4.090E-01
111.949598	2.308E-04	2.061E-06	6.721E-06	9.850E-01	7.346E-07	8.051E+00	5.411E-05	0.008623304	1.000E+00	4.176E-01
115.308086	2.121E-04	1.840E-06	6.179E-06	9.851E-01	8.027E-07	8.798E+00	5.436E-05	0.008663128	1.000E+00	4.263E-01
118.767329	1.949E-04	1.641E-06	5.678E-06	9.851E-01	8.772E-07	9.614E+00	5.459E-05	0.00869887	1.000E+00	4.350E-01
122.330349	1.791E-04	1.464E-06	5.215E-06	9.851E-01	9.585E-07	1.051E+01	5.479E-05	0.008730478	1.000E+00	4.437E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) Δ d/d	Σ P(d) Δ d/d	$\pi d^3/6$	V p	P(d) Δ d $\cdot$ m/d	P(d) Δ d $\cdot$ m/(d $\cdot$ mP ₅₀)	d < 4.7	Σ P(d) m/(P m) _{tot}
126.000259	1.644E-04	1.305E-06	4.788E-06	9.851E-01	1.047E-06	1.148E+01	5.496E-05	0.008757907	1.000E+00	4.524E-01
129.780267	1.508E-04	1.162E-06	4.393E-06	9.851E-01	1.145E-06	1.254E+01	5.510E-05	0.008781116	1.000E+00	4.612E-01
133.673675	1.363E-04	1.035E-06	4.029E-06	9.851E-01	1.251E-06	1.371E+01	5.522E-05	0.008800071	1.000E+00	4.700E-01
137.633885	1.268E-04	9.209E-07	3.693E-06	9.851E-01	1.367E-06	1.498E+01	5.532E-05	0.008814745	1.000E+00	4.788E-01
141.814402	1.162E-04	8.192E-07	3.384E-06	9.851E-01	1.493E-06	1.637E+01	5.538E-05	0.008825115	1.000E+00	4.877E-01
146.088834	1.064E-04	7.283E-07	3.099E-06	9.851E-01	1.632E-06	1.788E+01	5.542E-05	0.008831168	1.000E+00	4.968E-01
150.450899	9.738E-05	6.472E-07	2.836E-06	9.851E-01	1.783E-06	1.954E+01	5.543E-05	0.008832893	1.000E+00	5.053E-01
154.994426	8.908E-05	5.749E-07	2.595E-06	9.851E-01	1.948E-06	2.136E+01	5.541E-05	0.008830288	1.000E+00	5.142E-01
159.613358	8.147E-05	5.104E-07	2.373E-06	9.851E-01	2.129E-06	2.334E+01	5.537E-05	0.008823358	1.000E+00	5.230E-01
164.401759	7.446E-05	4.529E-07	2.169E-06	9.851E-01	2.327E-06	2.550E+01	5.530E-05	0.008812112	1.000E+00	5.318E-01
169.333812	6.802E-05	4.017E-07	1.981E-06	9.851E-01	2.542E-06	2.786E+01	5.520E-05	0.008796567	1.000E+00	5.406E-01
174.413826	6.211E-05	3.561E-07	1.809E-06	9.851E-01	2.778E-06	3.045E+01	5.508E-05	0.008776745	1.000E+00	5.494E-01
179.646241	5.668E-05	3.155E-07	1.651E-06	9.851E-01	3.036E-06	3.327E+01	5.493E-05	0.008752677	1.000E+00	5.581E-01
185.035628	5.170E-05	2.794E-07	1.506E-06	9.851E-01	3.317E-06	3.636E+01	5.475E-05	0.008724396	1.000E+00	5.668E-01
190.566697	4.714E-05	2.473E-07	1.373E-06	9.851E-01	3.625E-06	3.973E+01	5.455E-05	0.008691944	1.000E+00	5.755E-01
196.304298	4.296E-05	2.188E-07	1.251E-06	9.851E-01	3.961E-06	4.341E+01	5.432E-05	0.008655368	1.000E+00	5.842E-01
202.193427	3.913E-05	1.935E-07	1.140E-06	9.851E-01	4.328E-06	4.744E+01	5.406E-05	0.008614723	1.000E+00	5.928E-01
208.259230	3.562E-05	1.710E-07	1.038E-06	9.851E-01	4.729E-06	5.183E+01	5.378E-05	0.008570085	1.000E+00	6.014E-01
214.507007	3.241E-05	1.511E-07	9.441E-07	9.851E-01	5.168E-06	5.664E+01	5.348E-05	0.008521461	1.000E+00	6.099E-01
220.942217	2.948E-05	1.334E-07	8.587E-07	9.851E-01	5.647E-06	6.189E+01	5.315E-05	0.008468979	1.000E+00	6.184E-01
227.570483	2.680E-05	1.178E-07	7.806E-07	9.851E-01	6.171E-06	6.763E+01	5.279E-05	0.008412696	1.000E+00	6.268E-01
234.397598	2.435E-05	1.039E-07	7.092E-07	9.851E-01	6.743E-06	7.390E+01	5.242E-05	0.00835269	1.000E+00	6.351E-01
241.429526	2.211E-05	9.160E-08	6.441E-07	9.851E-01	7.368E-06	8.076E+01	5.202E-05	0.008289048	1.000E+00	6.434E-01
248.672412	2.007E-05	8.072E-08	5.847E-07	9.851E-01	8.052E-06	8.825E+01	5.160E-05	0.008221859	1.000E+00	6.516E-01
256.132584	1.821E-05	7.111E-08	5.305E-07	9.851E-01	8.798E-06	9.643E+01	5.115E-05	0.008151218	1.000E+00	6.598E-01
263.816561	1.652E-05	6.260E-08	4.810E-07	9.851E-01	9.614E-06	1.054E+02	5.069E-05	0.008077223	1.000E+00	6.679E-01
271.731058	1.497E-05	5.509E-08	4.360E-07	9.851E-01	1.051E-05	1.151E+02	5.020E-05	0.007999976	1.000E+00	6.759E-01
279.882990	1.356E-05	4.846E-08	3.950E-07	9.851E-01	1.148E-05	1.258E+02	4.970E-05	0.007919585	1.000E+00	6.838E-01
288.279480	1.228E-05	4.260E-08	3.577E-07	9.851E-01	1.254E-05	1.375E+02	4.917E-05	0.00783616	1.000E+00	6.916E-01
296.927864	1.111E-05	3.743E-08	3.237E-07	9.851E-01	1.371E-05	1.502E+02	4.863E-05	0.007749812	1.000E+00	6.994E-01
305.835700	1.005E-05	3.287E-08	2.928E-07	9.851E-01	1.498E-05	1.642E+02	4.807E-05	0.00766066	1.000E+00	7.070E-01
315.010771	9.091E-06	2.886E-08	2.648E-07	9.851E-01	1.637E-05	1.794E+02	4.750E-05	0.007568822	1.000E+00	7.146E-01
324.461094	8.216E-06	2.532E-08	2.393E-07	9.851E-01	1.788E-05	1.960E+02	4.690E-05	0.00747442	1.000E+00	7.221E-01
334.194927	7.421E-06	2.221E-08	2.161E-07	9.851E-01	1.854E-05	2.142E+02	4.630E-05	0.007377578	1.000E+00	7.295E-01
344.220775	6.700E-06	1.946E-08	1.951E-07	9.851E-01	2.136E-05	2.341E+02	4.570E-05	0.007278421	1.000E+00	7.367E-01
354.547398	6.046E-06	1.705E-08	1.761E-07	9.851E-01	2.334E-05	2.558E+02	4.504E-05	0.007177077	1.000E+00	7.439E-01
365.183820	5.453E-06	1.493E-08	1.588E-07	9.851E-01	2.550E-05	2.795E+02	4.439E-05	0.007073876	1.000E+00	7.510E-01
376.139335	4.916E-06	1.307E-08	1.432E-07	9.851E-01	2.786E-05	3.054E+02	4.373E-05	0.006966348	1.000E+00	7.580E-01
387.423515	4.430E-06	1.143E-08	1.290E-07	9.851E-01	3.045E-05	3.337E+02	4.308E-05	0.006861223	1.000E+00	7.648E-01
399.046220	3.990E-06	9.998E-09	1.162E-07	9.851E-01	3.327E-05	3.647E+02	4.237E-05	0.006752435	1.000E+00	7.716E-01
411.017607	3.591E-06	8.738E-09	1.046E-07	9.851E-01	3.636E-05	3.985E+02	4.168E-05	0.006642114	1.000E+00	7.782E-01
423.348135	3.231E-06	7.633E-09	9.412E-08	9.851E-01	3.973E-05	4.354E+02	4.098E-05	0.006530393	1.000E+00	7.847E-01
436.048579	2.906E-06	6.664E-09	8.464E-08	9.851E-01	4.341E-05	4.758E+02	4.027E-05	0.006417404	1.000E+00	7.912E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)^*\Delta d/d$	$\pi d^3/6$	V p	P(d)* $\Delta d^*m/d$	P(d)* $\Delta d^*m/(d^*mP_{\text{tot}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{tot}}$
449.130036	2.612E-06	5.816E-09	7.608E-08	9.851E-01	4.744E-05	5.199E+02	3.956E-05	0.00630328	1.000E+00	7.975E-01
462.603937	2.347E-06	5.073E-09	6.835E-08	9.851E-01	5.184E-05	5.681E+02	3.883E-05	0.006188151	1.000E+00	8.036E-01
476.482055	2.107E-06	4.423E-09	6.138E-08	9.851E-01	5.664E-05	6.208E+02	3.810E-05	0.006072147	1.000E+00	8.097E-01
490.776517	1.891E-06	3.854E-09	5.509E-08	9.851E-01	6.189E-05	6.784E+02	3.737E-05	0.005955397	1.000E+00	8.157E-01
505.498813	1.697E-06	3.357E-09	4.942E-08	9.851E-01	6.763E-05	7.413E+02	3.664E-05	0.005838029	1.000E+00	8.215E-01
520.664807	1.522E-06	2.922E-09	4.432E-08	9.851E-01	7.390E-05	8.100E+02	3.590E-05	0.005720169	1.000E+00	8.272E-01
536.284751	1.364E-06	2.543E-09	3.972E-08	9.851E-01	8.076E-05	8.851E+02	3.515E-05	0.005601942	1.000E+00	8.328E-01
552.373294	1.222E-06	2.211E-09	3.558E-08	9.851E-01	8.825E-05	9.672E+02	3.441E-05	0.00548347	1.000E+00	8.383E-01
568.944493	1.094E-06	1.922E-09	3.186E-08	9.851E-01	9.643E-05	1.057E+03	3.367E-05	0.005364872	1.000E+00	8.437E-01
586.012827	9.788E-07	1.670E-09	2.851E-08	9.851E-01	1.054E-04	1.155E+03	3.292E-05	0.005246267	1.000E+00	8.489E-01
603.593212	8.755E-07	1.450E-09	2.550E-08	9.851E-01	1.151E-04	1.262E+03	3.218E-05	0.005127769	1.000E+00	8.541E-01
621.701009	7.827E-07	1.259E-09	2.280E-08	9.851E-01	1.258E-04	1.379E+03	3.144E-05	0.005009492	1.000E+00	8.591E-01
640.352039	6.994E-07	1.092E-09	2.037E-08	9.851E-01	1.375E-04	1.507E+03	3.070E-05	0.004891544	1.000E+00	8.640E-01
659.582600	6.247E-07	9.471E-10	1.819E-08	9.851E-01	1.502E-04	1.647E+03	2.996E-05	0.004774032	1.000E+00	8.687E-01
679.349478	5.577E-07	8.209E-10	1.624E-08	9.851E-01	1.642E-04	1.799E+03	2.922E-05	0.004657059	1.000E+00	8.734E-01
699.729982	4.976E-07	7.111E-10	1.449E-08	9.851E-01	1.794E-04	1.968E+03	2.849E-05	0.004540726	1.000E+00	8.779E-01
720.721861	4.438E-07	6.157E-10	1.293E-08	9.851E-01	1.960E-04	2.148E+03	2.777E-05	0.004425129	1.000E+00	8.824E-01
742.343517	3.958E-07	5.329E-10	1.152E-08	9.851E-01	2.142E-04	2.348E+03	2.705E-05	0.004310361	1.000E+00	8.867E-01
764.613823	3.525E-07	4.610E-10	1.027E-08	9.851E-01	2.341E-04	2.565E+03	2.633E-05	0.004196512	1.000E+00	8.909E-01
787.552237	3.139E-07	3.985E-10	9.142E-09	9.851E-01	2.558E-04	2.803E+03	2.563E-05	0.004083668	1.000E+00	8.949E-01
811.178804	2.794E-07	3.444E-10	8.137E-09	9.851E-01	2.795E-04	3.063E+03	2.493E-05	0.00397191	1.000E+00	8.989E-01
835.514168	2.486E-07	2.975E-10	7.239E-09	9.851E-01	3.054E-04	3.347E+03	2.423E-05	0.003861317	1.000E+00	9.028E-01
860.579594	2.210E-07	2.588E-10	6.437E-09	9.851E-01	3.337E-04	3.657E+03	2.354E-05	0.003751964	1.000E+00	9.065E-01
886.396981	1.964E-07	2.216E-10	5.722E-09	9.851E-01	3.647E-04	3.997E+03	2.287E-05	0.003643921	1.000E+00	9.102E-01
912.988891	1.745E-07	1.911E-10	5.083E-09	9.851E-01	3.985E-04	4.367E+03	2.220E-05	0.003537255	1.000E+00	9.137E-01
940.378557	1.549E-07	1.648E-10	4.513E-09	9.851E-01	4.354E-04	4.772E+03	2.154E-05	0.003432028	1.000E+00	9.171E-01
968.589914	1.375E-07	1.420E-10	4.005E-09	9.851E-01	4.768E-04	5.215E+03	2.089E-05	0.003328299	1.000E+00	9.205E-01
997.647612	1.220E-07	1.223E-10	3.553E-09	9.851E-01	5.199E-04	5.698E+03	2.025E-05	0.003226123	1.000E+00	9.237E-01
1027.577040	1.082E-07	1.052E-10	3.150E-09	9.851E-01	5.681E-04	6.227E+03	1.961E-05	0.003125552	1.000E+00	9.268E-01
1058.404351	9.584E-08	9.055E-11	2.791E-09	9.851E-01	6.208E-04	6.804E+03	1.899E-05	0.003026631	1.000E+00	9.299E-01
1090.156482	8.489E-08	7.787E-11	2.473E-09	9.851E-01	6.784E-04	7.435E+03	1.838E-05	0.002929405	1.000E+00	9.328E-01
1122.861176	7.515E-08	6.693E-11	2.189E-09	9.851E-01	7.413E-04	8.124E+03	1.778E-05	0.002833912	1.000E+00	9.356E-01
1156.547011	6.650E-08	5.750E-11	1.937E-09	9.851E-01	8.100E-04	8.878E+03	1.720E-05	0.002740189	1.000E+00	9.384E-01
1191.243422	5.882E-08	4.937E-11	1.713E-09	9.851E-01	8.851E-04	9.701E+03	1.662E-05	0.002648266	1.000E+00	9.410E-01
1226.980724	5.200E-08	4.238E-11	1.514E-09	9.851E-01	9.672E-04	1.060E+04	1.605E-05	0.002558173	1.000E+00	9.436E-01
1263.790146	4.594E-08	3.635E-11	1.338E-09	9.851E-01	1.057E-03	1.158E+04	1.550E-05	0.002469934	1.000E+00	9.460E-01
1301.703851	4.057E-08	3.117E-11	1.162E-09	9.851E-01	1.155E-03	1.266E+04	1.496E-05	0.002383569	1.000E+00	9.484E-01
1340.754966	3.581E-08	2.671E-11	1.043E-09	9.851E-01	1.262E-03	1.383E+04	1.443E-05	0.002299097	1.000E+00	9.507E-01
1380.977615	3.160E-08	2.288E-11	9.203E-10	9.851E-01	1.379E-03	1.511E+04	1.391E-05	0.002216532	1.000E+00	9.529E-01
1422.405944	2.786E-08	1.959E-11	8.116E-10	9.851E-01	1.507E-03	1.652E+04	1.340E-05	0.002135884	1.000E+00	9.551E-01
1465.079152	2.456E-08	1.676E-11	7.153E-10	9.851E-01	1.647E-03	1.805E+04	1.291E-05	0.002057162	1.000E+00	9.571E-01
1509.031526	2.164E-08	1.434E-11	6.302E-10	9.851E-01	1.799E-03	1.972E+04	1.243E-05	0.00198037	1.000E+00	9.591E-01
1554.302472	1.905E-08	1.226E-11	5.549E-10	9.851E-01	1.966E-03	2.155E+04	1.196E-05	0.001905511	1.000E+00	9.610E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V ρ	P(d) $\Delta d^3/d$	P(d) $\Delta d^3 m/(d^4 m P_{\text{ref}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{ref}}$
1600.991546	1.677E-08	1.047E-11	4.884E-10	9.851E-01	2.148E-03	2.355E+04	1.150E-05	0.001832582	1.000E+00	9.628E-01
1648.959493	1.475E-08	8.946E-12	4.296E-10	9.851E-01	2.348E-03	2.573E+04	1.105E-05	0.001761581	1.000E+00	9.646E-01
1698.9428278	1.297E-08	7.636E-12	3.778E-10	9.851E-01	2.585E-03	2.812E+04	1.062E-05	0.001692501	1.000E+00	9.663E-01
1749.381126	1.140E-08	6.516E-12	3.320E-10	9.851E-01	2.803E-03	3.072E+04	1.020E-05	0.001625333	1.000E+00	9.679E-01
1801.862560	1.001E-08	5.557E-12	2.916E-10	9.851E-01	3.063E-03	3.357E+04	9.790E-06	0.001560065	1.000E+00	9.695E-01
1855.918436	8.790E-09	4.736E-12	2.560E-10	9.851E-01	3.347E-03	3.668E+04	9.392E-06	0.001496685	1.000E+00	9.710E-01
1911.595989	7.714E-09	4.035E-12	2.247E-10	9.851E-01	3.658E-03	4.009E+04	9.006E-06	0.001435175	1.000E+00	9.724E-01
1968.943869	6.766E-09	3.436E-12	1.971E-10	9.851E-01	3.997E-03	4.380E+04	8.632E-06	0.001375519	1.000E+00	9.738E-01
2028.012185	5.931E-09	2.925E-12	1.728E-10	9.851E-01	4.367E-03	4.767E+04	8.269E-06	0.001317697	1.000E+00	9.751E-01
2088.852551	5.197E-09	2.488E-12	1.514E-10	9.851E-01	4.772E-03	5.230E+04	7.918E-06	0.001261686	1.000E+00	9.764E-01
2151.518127	4.552E-09	2.116E-12	1.326E-10	9.851E-01	5.215E-03	5.715E+04	7.577E-06	0.001207464	1.000E+00	9.776E-01
2216.063671	3.985E-09	1.798E-12	1.161E-10	9.851E-01	5.698E-03	6.245E+04	7.248E-06	0.001155008	1.000E+00	9.787E-01
2282.545581	3.486E-09	1.527E-12	1.015E-10	9.851E-01	6.227E-03	6.824E+04	6.930E-06	0.001104286	1.000E+00	9.798E-01
2351.021949	3.049E-09	1.297E-12	8.880E-11	9.851E-01	6.804E-03	7.457E+04	6.622E-06	0.001055275	1.000E+00	9.809E-01
2421.552607	2.665E-09	1.101E-12	7.762E-11	9.851E-01	7.435E-03	8.149E+04	6.325E-06	0.001007946	1.000E+00	9.819E-01
2494.199185	2.328E-09	9.335E-13	6.782E-11	9.851E-01	8.124E-03	8.904E+04	6.039E-06	0.000962267	1.000E+00	9.829E-01
2569.025161	2.033E-09	7.914E-13	5.922E-11	9.851E-01	8.878E-03	9.730E+04	5.762E-06	0.000918208	1.000E+00	9.838E-01
2646.095916	1.775E-09	6.707E-13	5.169E-11	9.851E-01	9.701E-03	1.063E+05	5.496E-06	0.000875737	1.000E+00	9.847E-01
2725.478793	1.548E-09	5.680E-13	4.509E-11	9.851E-01	1.060E-02	1.162E+05	5.239E-06	0.000834821	1.000E+00	9.855E-01
2807.243157	1.350E-09	4.809E-13	3.932E-11	9.851E-01	1.158E-02	1.270E+05	4.992E-06	0.000795427	1.000E+00	9.863E-01
2891.460452	1.176E-09	4.069E-13	3.427E-11	9.851E-01	1.266E-02	1.387E+05	4.754E-06	0.00075752	1.000E+00	9.870E-01
2978.204265	1.025E-09	3.441E-13	2.985E-11	9.851E-01	1.383E-02	1.516E+05	4.525E-06	0.000721066	1.000E+00	9.878E-01
3067.550393	8.923E-10	2.909E-13	2.599E-11	9.851E-01	1.511E-02	1.656E+05	4.305E-06	0.00068603	1.000E+00	9.885E-01
3159.576905	7.765E-10	2.458E-13	2.262E-11	9.851E-01	1.652E-02	1.810E+05	4.094E-06	0.000652377	1.000E+00	9.891E-01
3254.364212	6.754E-10	2.075E-13	1.967E-11	9.851E-01	1.805E-02	1.978E+05	3.891E-06	0.00062007	1.000E+00	9.897E-01
3351.995139	5.872E-10	1.752E-13	1.710E-11	9.851E-01	1.972E-02	2.161E+05	3.697E-06	0.000589074	1.000E+00	9.903E-01
3452.554993	5.103E-10	1.478E-13	1.486E-11	9.851E-01	2.155E-02	2.362E+05	3.510E-06	0.000559354	1.000E+00	9.909E-01
3556.131643	4.432E-10	1.246E-13	1.291E-11	9.851E-01	2.355E-02	2.581E+05	3.331E-06	0.000530872	1.000E+00	9.919E-01
3662.815592	3.848E-10	1.050E-13	1.121E-11	9.851E-01	2.573E-02	2.820E+05	3.160E-06	0.000503594	1.000E+00	9.924E-01
3772.700060	3.338E-10	8.849E-14	9.724E-12	9.851E-01	2.812E-02	3.082E+05	2.996E-06	0.000477484	1.000E+00	9.928E-01
3885.881061	2.895E-10	7.451E-14	8.433E-12	9.851E-01	3.072E-02	3.367E+05	2.840E-06	0.000452505	1.000E+00	9.933E-01
4002.457493	2.510E-10	6.271E-14	7.310E-12	9.851E-01	3.357E-02	3.680E+05	2.690E-06	0.000428623	1.000E+00	9.937E-01
4122.531218	2.175E-10	5.275E-14	6.334E-12	9.851E-01	3.669E-02	4.021E+05	2.547E-06	0.000405802	1.000E+00	9.941E-01
4246.207155	1.883E-10	4.435E-14	5.485E-12	9.851E-01	4.009E-02	4.394E+05	2.410E-06	0.000384008	1.000E+00	9.944E-01
4373.593369	1.630E-10	3.727E-14	4.748E-12	9.851E-01	4.380E-02	4.801E+05	2.279E-06	0.000363206	1.000E+00	9.948E-01
4504.801170	1.410E-10	3.130E-14	4.107E-12	9.851E-01	4.787E-02	5.246E+05	2.155E-06	0.000343363	1.000E+00	9.951E-01
4639.945205	1.218E-10	2.628E-14	3.552E-12	9.851E-01	5.230E-02	5.733E+05	2.036E-06	0.000324445	1.000E+00	9.954E-01
4779.143562	1.054E-10	2.205E-14	3.070E-12	9.851E-01	5.715E-02	6.264E+05	1.923E-06	0.000306419	1.000E+00	9.957E-01
4922.517868	9.105E-11	1.850E-14	2.652E-12	9.851E-01	6.245E-02	6.845E+05	1.815E-06	0.000289252	1.000E+00	9.960E-01
5070.193404	7.861E-11	1.551E-14	2.280E-12	9.851E-01	6.825E-02	7.480E+05	1.713E-06	0.000272914	1.000E+00	9.962E-01
5222.299207	6.785E-11	1.299E-14	1.976E-12	9.851E-01	7.457E-02	8.173E+05	1.615E-06	0.000257372	1.000E+00	9.965E-01
5378.968183	5.852E-11	1.088E-14	1.705E-12	9.851E-01	8.149E-02	8.931E+05	1.522E-06	0.000242596	1.000E+00	9.967E-01
5540.337228	5.046E-11	9.107E-15	1.470E-12	9.851E-01	8.904E-02	9.759E+05	1.434E-06	0.000228557	1.000E+00	9.967E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) Δ d/d	Σ P(d) Δ d/d	$\pi d^3/6$	V ρ	P(d) Δ d $\cdot$ m/d	P(d) Δ d $\cdot$ m/(d $\cdot$ mP $_{50}$)	d < 4.7	Σ P(d) m/(P m) $_{50}$
5706.547345	4.348E-11	7.620E-15	1.266E-12	9.851E-01	9.730E-02	1.066E+06	1.351E-08	0.000215224	1.000E+00	9.969E-01
5877.743765	3.745E-11	6.372E-15	1.091E-12	9.851E-01	1.063E-01	1.165E+06	1.271E-06	0.00020257	1.000E+00	9.971E-01
6054.076078	3.224E-11	5.326E-15	9.391E-13	9.851E-01	1.162E-01	1.273E+06	1.196E-06	0.000190566	1.000E+00	9.973E-01
6235.698361	2.775E-11	4.449E-15	8.081E-13	9.851E-01	1.270E-01	1.391E+06	1.124E-06	0.000179186	1.000E+00	9.975E-01
6422.769312	2.386E-11	3.715E-15	6.950E-13	9.851E-01	1.387E-01	1.520E+06	1.057E-06	0.000168403	1.000E+00	9.976E-01
6615.452391	2.051E-11	3.101E-15	5.975E-13	9.851E-01	1.516E-01	1.661E+06	9.927E-07	0.000158191	1.000E+00	9.978E-01
6813.915963	1.763E-11	2.587E-15	5.134E-13	9.851E-01	1.656E-01	1.816E+06	9.321E-07	0.000148526	1.000E+00	9.979E-01
7018.333442	1.514E-11	2.157E-15	4.409E-13	9.851E-01	1.810E-01	1.984E+06	8.747E-07	0.000139383	1.000E+00	9.981E-01
7228.983445	1.299E-11	1.797E-15	3.785E-13	9.851E-01	1.978E-01	2.168E+06	8.204E-07	0.000130738	1.000E+00	9.982E-01
7445.749948	1.115E-11	1.497E-15	3.247E-13	9.851E-01	2.161E-01	2.369E+06	7.692E-07	0.00012257	1.000E+00	9.983E-01
7669.122447	9.560E-12	1.247E-15	2.784E-13	9.851E-01	2.362E-01	2.588E+06	7.208E-07	0.000114855	1.000E+00	9.985E-01
7899.196120	8.194E-12	1.037E-15	2.387E-13	9.851E-01	2.561E-01	2.829E+06	6.751E-07	0.000107574	1.000E+00	9.986E-01
8136.172004	7.020E-12	8.628E-16	2.045E-13	9.851E-01	2.820E-01	3.091E+06	6.320E-07	0.000100704	1.000E+00	9.987E-01
8380.257164	6.011E-12	7.173E-16	1.751E-13	9.851E-01	3.082E-01	3.377E+06	5.913E-07	9.42274E-05	1.000E+00	9.988E-01
8631.664879	5.145E-12	5.960E-16	1.498E-13	9.851E-01	3.367E-01	3.691E+06	5.530E-07	8.81238E-05	1.000E+00	9.988E-01
8890.614825	4.401E-12	4.950E-16	1.282E-13	9.851E-01	3.680E-01	4.033E+06	5.169E-07	8.23752E-05	1.000E+00	9.989E-01
9157.333270	3.763E-12	4.109E-16	1.096E-13	9.851E-01	4.021E-01	4.407E+06	4.830E-07	7.69639E-05	1.000E+00	9.990E-01
9432.053268	3.216E-12	3.409E-16	9.366E-14	9.851E-01	4.394E-01	4.815E+06	4.510E-07	7.18728E-05	1.000E+00	9.991E-01
9715.014866	2.747E-12	2.827E-16	8.001E-14	9.851E-01	4.801E-01	5.262E+06	4.210E-07	6.70856E-05	1.000E+00	9.991E-01
10006.465312	2.345E-12	2.344E-16	6.831E-14	9.851E-01	5.246E-01	5.750E+06	3.928E-07	6.25865E-05	1.000E+00	9.992E-01
10306.659271	2.001E-12	1.942E-16	5.829E-14	9.851E-01	5.733E-01	6.283E+06	3.662E-07	5.83606E-05	1.000E+00	9.993E-01
10515.859049	1.707E-12	1.608E-16	4.972E-14	9.851E-01	6.264E-01	6.866E+06	3.413E-07	5.43933E-05	1.000E+00	9.993E-01
10934.334821	1.455E-12	1.331E-16	4.238E-14	9.851E-01	6.845E-01	7.502E+06	3.180E-07	5.06709E-05	1.000E+00	9.994E-01
11262.364865	1.240E-12	1.101E-16	3.612E-14	9.851E-01	7.480E-01	8.198E+06	2.961E-07	4.71801E-05	1.000E+00	9.994E-01
11600.235811	1.056E-12	9.104E-17	3.076E-14	9.851E-01	8.173E-01	8.958E+06	2.755E-07	4.39082E-05	1.000E+00	9.995E-01
11948.242886	8.990E-13	7.524E-17	2.618E-14	9.851E-01	8.931E-01	9.789E+06	2.563E-07	4.08432E-05	1.000E+00	9.995E-01
12306.690172	7.649E-13	6.215E-17	2.228E-14	9.851E-01	9.759E-01	1.070E+07	2.393E-07	3.79736E-05	1.000E+00	9.995E-01
12675.890877	6.505E-13	5.132E-17	1.895E-14	9.851E-01	1.066E+00	1.169E+07	2.214E-07	3.52882E-05	1.000E+00	9.996E-01
13056.167604	5.529E-13	4.235E-17	1.610E-14	9.851E-01	1.165E+00	1.277E+07	2.057E-07	3.27767E-05	1.000E+00	9.996E-01
13447.852632	4.698E-13	3.493E-17	1.368E-14	9.851E-01	1.273E+00	1.396E+07	1.910E-07	3.0429E-05	1.000E+00	9.996E-01
13851.288211	3.989E-13	2.860E-17	1.162E-14	9.851E-01	1.391E+00	1.525E+07	1.772E-07	2.82356E-05	1.000E+00	9.997E-01
14266.826857	3.386E-13	2.373E-17	9.861E-15	9.851E-01	1.520E+00	1.666E+07	1.643E-07	2.61875E-05	1.000E+00	9.997E-01
14694.831663	2.872E-13	1.955E-17	8.366E-15	9.851E-01	1.661E+00	1.821E+07	1.523E-07	2.42761E-05	1.000E+00	9.997E-01
15135.676613	2.436E-13	1.609E-17	7.094E-15	9.851E-01	1.816E+00	1.990E+07	1.412E-07	2.24931E-05	1.000E+00	9.997E-01
15589.746911	2.064E-13	1.324E-17	6.012E-15	9.851E-01	1.984E+00	2.174E+07	1.307E-07	2.08309E-05	1.000E+00	9.998E-01
16057.439318	1.749E-13	1.089E-17	5.093E-15	9.851E-01	2.168E+00	2.376E+07	1.210E-07	1.9282E-05	1.000E+00	9.998E-01
16539.162498	1.480E-13	8.951E-18	4.312E-15	9.851E-01	2.369E+00	2.596E+07	1.119E-07	1.78398E-05	1.000E+00	9.998E-01
17035.337373	1.253E-13	7.354E-18	3.649E-15	9.851E-01	2.589E+00	2.837E+07	1.035E-07	1.6497E-05	1.000E+00	9.998E-01
17546.397494	1.060E-13	6.040E-18	3.087E-15	9.851E-01	2.829E+00	3.100E+07	9.569E-08	1.52479E-05	1.000E+00	9.998E-01
18072.799419	8.959E-14	4.967E-18	2.610E-15	9.851E-01	3.091E+00	3.388E+07	8.840E-08	1.40868E-05	1.000E+00	9.998E-01
18614.973101	7.571E-14	4.067E-18	2.205E-15	9.851E-01	3.377E+00	3.702E+07	8.163E-08	1.30072E-05	1.000E+00	9.999E-01
19173.422295	6.394E-14	3.335E-18	1.862E-15	9.851E-01	3.691E+00	4.045E+07	7.533E-08	1.20047E-05	1.000E+00	9.999E-01
19748.624963	5.398E-14	2.733E-18	1.572E-15	9.851E-01	4.033E+00	4.420E+07	6.949E-08	1.10741E-05	1.000E+00	9.999E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	$P(d)$	$P(d)/d$	$P(d)\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V_p	$P(d)\Delta d^3m/d$	$P(d)\Delta d^3m/(d^3mP_{\text{ref}})$	$d < 4.7$	$\Sigma P(d) m/(P m)_{\text{ref}}$
20341.083712	4.555E-14	2.239E-18	1.327E-15	9.851E-01	4.407E+00	4.830E+07	6.407E-08	1.02105E-05	1.000E+00	9.999E-01
20951.316224	3.841E-14	1.833E-18	1.119E-15	9.851E-01	4.815E+00	5.278E+07	5.905E-08	9.40975E-06	1.000E+00	9.999E-01
21579.855710	3.238E-14	1.501E-18	9.431E-16	9.851E-01	5.262E+00	5.767E+07	5.439E-08	8.6675E-06	1.000E+00	9.999E-01
22227.251382	2.728E-14	1.227E-18	7.948E-16	9.851E-01	5.750E+00	6.302E+07	5.008E-08	7.9799E-06	1.000E+00	9.999E-01
22894.068923	2.298E-14	1.004E-18	6.692E-16	9.851E-01	6.283E+00	6.866E+07	4.608E-08	7.34324E-06	1.000E+00	9.999E-01
23580.880991	1.934E-14	8.201E-19	5.633E-16	9.851E-01	6.866E+00	7.525E+07	4.238E-08	6.75406E-06	1.000E+00	9.999E-01
24288.317721	1.627E-14	6.699E-19	4.739E-16	9.851E-01	7.502E+00	8.222E+07	3.896E-08	6.20911E-06	1.000E+00	9.999E-01
25016.967252	1.368E-14	5.468E-19	3.985E-16	9.851E-01	8.198E+00	8.985E+07	3.580E-08	5.70533E-06	1.000E+00	9.999E-01
25767.476270	1.150E-14	4.462E-19	3.349E-16	9.851E-01	8.958E+00	9.818E+07	3.288E-08	5.23986E-06	1.000E+00	9.999E-01
26540.500558	9.600E-15	3.640E-19	2.814E-16	9.851E-01	9.789E+00	1.073E+08	3.018E-08	4.81E-06	1.000E+00	9.999E-01
27336.715575	8.111E-15	2.967E-19	2.362E-16	9.851E-01	1.070E+01	1.172E+08	2.769E-08	4.41324E-06	1.000E+00	1.000E+00
28156.817042	6.807E-15	2.418E-19	1.983E-16	9.851E-01	1.169E+01	1.281E+08	2.540E-08	4.04723E-06	1.000E+00	1.000E+00
29001.521553	5.710E-15	1.969E-19	1.663E-16	9.851E-01	1.277E+01	1.400E+08	2.328E-08	3.70975E-06	1.000E+00	1.000E+00
29871.567200	4.787E-15	1.603E-19	1.394E-16	9.851E-01	1.396E+01	1.530E+08	2.133E-08	3.39875E-06	1.000E+00	1.000E+00
30767.714216	4.012E-15	1.304E-19	1.168E-16	9.851E-01	1.525E+01	1.671E+08	1.953E-08	3.11229E-06	1.000E+00	1.000E+00
31690.745642	3.360E-15	1.080E-19	9.787E-17	9.851E-01	1.686E+01	1.826E+08	1.788E-08	2.84858E-06	1.000E+00	1.000E+00
32641.468011	2.813E-15	8.618E-20	8.194E-17	9.851E-01	1.821E+01	1.996E+08	1.635E-08	2.60593E-06	1.000E+00	1.000E+00
33620.712052	2.354E-15	7.002E-20	6.856E-17	9.851E-01	1.890E+01	2.181E+08	1.495E-08	2.38279E-06	1.000E+00	1.000E+00
34629.333413	1.969E-15	5.685E-20	5.734E-17	9.851E-01	2.174E+01	2.383E+08	1.367E-08	2.17769E-06	1.000E+00	1.000E+00
35668.213416	1.646E-15	4.614E-20	4.794E-17	9.851E-01	2.376E+01	2.604E+08	1.248E-08	1.98926E-06	1.000E+00	1.000E+00
36738.259818	1.375E-15	3.743E-20	4.003E-17	9.851E-01	2.596E+01	2.846E+08	1.140E-08	1.81625E-06	1.000E+00	1.000E+00
37840.407613	1.148E-15	3.035E-20	3.345E-17	9.851E-01	2.837E+01	3.109E+08	1.040E-08	1.65747E-06	1.000E+00	1.000E+00
38975.619841	9.587E-16	2.460E-20	2.792E-17	9.851E-01	3.100E+01	3.398E+08	9.487E-09	1.51183E-06	1.000E+00	1.000E+00
40144.888436	7.998E-16	1.992E-20	2.330E-17	9.851E-01	3.388E+01	3.713E+08	8.649E-09	1.37832E-06	1.000E+00	1.000E+00
41349.235089	6.670E-16	1.613E-20	1.943E-17	9.851E-01	3.702E+01	4.057E+08	7.882E-09	1.25598E-06	1.000E+00	1.000E+00
42589.712142	5.559E-16	1.305E-20	1.619E-17	9.851E-01	4.045E+01	4.433E+08	7.179E-09	1.14393E-06	1.000E+00	1.000E+00
45183.425811	4.632E-16	1.056E-20	1.349E-17	9.851E-01	4.420E+01	4.844E+08	6.535E-09	1.04137E-06	1.000E+00	1.000E+00
46538.928380	3.857E-16	8.539E-21	1.123E-17	9.851E-01	4.830E+01	5.294E+08	5.948E-09	9.47546E-07	1.000E+00	1.000E+00
47935.096231	3.210E-16	6.897E-21	9.349E-18	9.851E-01	5.278E+01	5.784E+08	5.408E-09	8.61748E-07	1.000E+00	1.000E+00
49373.149118	2.670E-16	5.570E-21	7.777E-18	9.851E-01	5.767E+01	6.321E+08	4.916E-09	7.83336E-07	1.000E+00	1.000E+00
50854.343592	2.220E-16	4.497E-21	6.466E-18	9.851E-01	6.302E+01	6.907E+08	4.466E-09	7.11709E-07	1.000E+00	1.000E+00
52379.973899	1.845E-16	3.628E-21	5.374E-18	9.851E-01	6.886E+01	7.547E+08	4.056E-09	6.46315E-07	1.000E+00	1.000E+00
53951.373116	1.533E-16	2.926E-21	4.464E-18	9.851E-01	7.525E+01	8.247E+08	3.681E-09	5.86642E-07	1.000E+00	1.000E+00
55569.914310	1.272E-16	2.358E-21	3.706E-18	9.851E-01	8.223E+01	9.012E+08	3.340E-09	5.32217E-07	1.000E+00	1.000E+00
57237.011739	1.058E-16	1.900E-21	3.075E-18	9.851E-01	8.985E+01	9.848E+08	3.029E-09	4.82605E-07	1.000E+00	1.000E+00
58954.122091	8.759E-17	1.530E-21	2.551E-18	9.851E-01	9.818E+01	1.076E+09	2.745E-09	4.37403E-07	1.000E+00	1.000E+00
60722.745764	7.260E-17	1.232E-21	2.115E-18	9.851E-01	1.073E+02	1.176E+09	2.487E-09	3.96241E-07	1.000E+00	1.000E+00
62544.428127	6.016E-17	9.907E-22	1.752E-18	9.851E-01	1.172E+02	1.285E+09	2.251E-09	3.58776E-07	1.000E+00	1.000E+00
64420.760971	4.983E-17	7.966E-22	1.451E-18	9.851E-01	1.281E+02	1.404E+09	2.038E-09	3.24694E-07	1.000E+00	1.000E+00
66353.383800	4.125E-17	6.403E-22	1.201E-18	9.851E-01	1.530E+02	1.534E+09	1.843E-09	2.93706E-07	1.000E+00	1.000E+00
68343.985314	3.413E-17	5.143E-22	9.940E-19	9.851E-01	1.530E+02	1.676E+09	1.666E-09	2.65545E-07	1.000E+00	1.000E+00
70394.304873	2.822E-17	4.129E-22	8.220E-19	9.851E-01	1.671E+02	1.832E+09	1.506E-09	2.39967E-07	1.000E+00	1.000E+00
	2.333E-17	3.314E-22	6.795E-19	9.851E-01	1.826E+02	2.002E+09	1.360E-09	2.16746E-07	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particle Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*d/d	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	Vp	P(d)*d ³ m/d	P(d)*d ³ m/(d ³ mP _{td})	d < 4.7	$\Sigma P(d) m/(P m)_{\text{tot}}$
72506.134019	1.927E-17	2.658E-22	5.614E-19	9.851E-01	1.996E+02	2.187E+09	1.228E-09	1.95676E-07	1.000E+00	1.000E+00
74681.318040	1.592E-17	2.131E-22	4.636E-19	9.851E-01	2.181E+02	2.390E+09	1.108E-09	1.76568E-07	1.000E+00	1.000E+00
76921.757581	1.314E-17	1.708E-22	3.826E-19	9.851E-01	2.383E+02	2.612E+09	9.993E-10	1.59247E-07	1.000E+00	1.000E+00
79229.410308	1.084E-17	1.368E-22	3.156E-19	9.851E-01	2.604E+02	2.854E+09	9.009E-10	1.43566E-07	1.000E+00	1.000E+00
81606.292618	8.936E-18	1.095E-22	2.603E-19	9.851E-01	2.846E+02	3.119E+09	8.117E-10	1.29347E-07	1.000E+00	1.000E+00
84054.481396	7.364E-18	8.762E-23	2.145E-19	9.851E-01	3.109E+02	3.408E+09	7.310E-10	1.16487E-07	1.000E+00	1.000E+00
86576.115838	6.067E-18	7.007E-23	1.767E-19	9.851E-01	3.398E+02	3.724E+09	6.580E-10	1.04855E-07	1.000E+00	1.000E+00
89173.399313	4.995E-18	5.601E-23	1.455E-19	9.851E-01	3.713E+02	4.069E+09	5.920E-10	9.43374E-08	1.000E+00	1.000E+00
91848.601293	4.111E-18	4.475E-23	1.197E-19	9.851E-01	4.057E+02	4.447E+09	5.324E-10	8.48335E-08	1.000E+00	1.000E+00
94604.059331	3.381E-18	3.574E-23	9.848E-20	9.851E-01	4.433E+02	4.859E+09	4.785E-10	7.62496E-08	1.000E+00	1.000E+00
97442.181111	2.780E-18	2.853E-23	8.096E-20	9.851E-01	4.844E+02	5.309E+09	4.299E-10	6.85008E-08	1.000E+00	1.000E+00
100365.446545	2.284E-18	2.276E-23	6.653E-20	9.851E-01	5.294E+02	5.802E+09	3.860E-10	6.15092E-08	1.000E+00	1.000E+00
103376.409941	1.876E-18	1.815E-23	5.484E-20	9.851E-01	5.784E+02	6.340E+09	3.484E-10	5.52042E-08	1.000E+00	1.000E+00
106477.702239	1.540E-18	1.446E-23	4.486E-20	9.851E-01	6.321E+02	6.928E+09	3.108E-10	4.95212E-08	1.000E+00	1.000E+00
109672.033306	1.264E-18	1.152E-23	3.681E-20	9.851E-01	6.907E+02	7.570E+09	2.786E-10	4.44014E-08	1.000E+00	1.000E+00
112962.194308	1.036E-18	9.175E-24	3.019E-20	9.851E-01	7.547E+02	8.272E+09	2.497E-10	3.97915E-08	1.000E+00	1.000E+00
116351.060135	8.496E-19	7.302E-24	2.475E-20	9.851E-01	8.247E+02	9.039E+09	2.237E-10	3.56427E-08	1.000E+00	1.000E+00
119841.591939	6.961E-19	5.808E-24	2.027E-20	9.851E-01	9.012E+02	9.877E+09	2.003E-10	3.19108E-08	1.000E+00	1.000E+00
123436.839697	5.700E-19	4.618E-24	1.660E-20	9.851E-01	9.848E+02	1.079E+10	1.792E-10	2.85557E-08	1.000E+00	1.000E+00
127139.944888	4.666E-19	3.670E-24	1.359E-20	9.851E-01	1.076E+03	1.179E+10	1.603E-10	2.55408E-08	1.000E+00	1.000E+00
130954.143235	3.817E-19	2.915E-24	1.112E-20	9.851E-01	1.176E+03	1.289E+10	1.433E-10	2.2833E-08	1.000E+00	1.000E+00
134882.767532	3.121E-19	2.314E-24	9.092E-21	9.851E-01	1.285E+03	1.408E+10	1.280E-10	2.04022E-08	1.000E+00	1.000E+00
138929.250558	2.551E-19	1.836E-24	7.431E-21	9.851E-01	1.404E+03	1.539E+10	1.143E-10	1.82214E-08	1.000E+00	1.000E+00
143097.128074	2.084E-19	1.456E-24	6.070E-21	9.851E-01	1.534E+03	1.682E+10	1.021E-10	1.62656E-08	1.000E+00	1.000E+00
147390.041917	1.702E-19	1.155E-24	4.956E-21	9.851E-01	1.676E+03	1.837E+10	9.107E-11	1.45127E-08	1.000E+00	1.000E+00
151811.743174	1.389E-19	9.148E-25	4.045E-21	9.851E-01	1.832E+03	2.008E+10	8.122E-11	1.29423E-08	1.000E+00	1.000E+00
156366.095469	1.133E-19	7.245E-25	3.300E-21	9.851E-01	2.002E+03	2.194E+10	7.239E-11	1.15362E-08	1.000E+00	1.000E+00
161057.078333	9.236E-20	5.735E-25	2.690E-21	9.851E-01	2.187E+03	2.397E+10	6.450E-11	1.02778E-08	1.000E+00	1.000E+00
165888.780683	7.527E-20	4.537E-25	2.192E-21	9.851E-01	2.390E+03	2.620E+10	5.743E-11	9.15222E-09	1.000E+00	1.000E+00
170865.454404	6.131E-20	3.588E-25	1.766E-21	9.851E-01	2.612E+03	2.863E+10	5.112E-11	8.14589E-09	1.000E+00	1.000E+00
175991.418036	4.991E-20	2.836E-25	1.454E-21	9.851E-01	2.854E+03	3.128E+10	4.548E-11	7.24667E-09	1.000E+00	1.000E+00
181271.160577	4.061E-20	2.241E-25	1.183E-21	9.851E-01	3.119E+03	3.418E+10	4.044E-11	6.44354E-09	1.000E+00	1.000E+00
186709.295394	3.303E-20	1.769E-25	9.621E-22	9.851E-01	3.408E+03	3.735E+10	3.594E-11	5.72662E-09	1.000E+00	1.000E+00
192310.574256	2.685E-20	1.396E-25	7.821E-22	9.851E-01	3.724E+03	4.081E+10	3.192E-11	5.08697E-09	1.000E+00	1.000E+00
198079.891484	2.182E-20	1.102E-25	6.355E-22	9.851E-01	4.069E+03	4.460E+10	2.834E-11	4.51655E-09	1.000E+00	1.000E+00
204022.288228	1.772E-20	8.685E-26	5.161E-22	9.851E-01	4.447E+03	4.874E+10	2.515E-11	4.00813E-09	1.000E+00	1.000E+00
210142.956875	1.438E-20	6.845E-26	4.189E-22	9.851E-01	4.859E+03	5.325E+10	2.231E-11	3.5552E-09	1.000E+00	1.000E+00
216447.245581	1.167E-20	5.392E-26	3.399E-22	9.851E-01	5.310E+03	5.819E+10	1.978E-11	3.15191E-09	1.000E+00	1.000E+00
222940.662949	9.463E-21	4.245E-26	2.756E-22	9.851E-01	5.802E+03	6.359E+10	1.753E-11	2.79298E-09	1.000E+00	1.000E+00
229628.882837	7.670E-21	3.340E-26	2.234E-22	9.851E-01	6.340E+03	6.948E+10	1.552E-11	2.47373E-09	1.000E+00	1.000E+00
236517.749322	6.214E-21	2.627E-26	1.810E-22	9.851E-01	6.928E+03	7.593E+10	1.374E-11	2.18989E-09	1.000E+00	1.000E+00
243613.281802	5.032E-21	2.065E-26	1.466E-22	9.851E-01	7.570E+03	8.297E+10	1.216E-11	1.93767E-09	1.000E+00	1.000E+00
250921.680256	4.072E-21	1.623E-26	1.188E-22	9.851E-01	8.272E+03	9.066E+10	1.075E-11	1.71366E-09	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle $\pi d^3/6$	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V_p	P(d) $\Delta d^3 m/d$	P(d) $\Delta d^3 m/d$	P(d) $\Delta d^3 m/(d^3 m P_{90})$	$d < 4.7$	$\Sigma P(d) m/(P m)_{90}$
258449.330684	3.294E-21	1.275E-26	9.595E-23	9.851E-01	9.039E+03	9.907E+10	9.506E-12	9.506E-12	1.51481E-09	1.000E+00	1.000E+00
266202.810584	2.664E-21	1.001E-26	7.758E-23	9.851E-01	9.877E+03	1.083E+11	8.399E-12	8.399E-12	1.33837E-09	1.000E+00	1.000E+00
274188.894901	2.153E-21	7.851E-27	6.270E-23	9.851E-01	1.079E+04	1.183E+11	7.417E-12	7.417E-12	1.1819E-09	1.000E+00	1.000E+00
282414.561748	1.739E-21	6.157E-27	5.065E-23	9.851E-01	1.179E+04	1.293E+11	6.547E-12	6.547E-12	1.04322E-09	1.000E+00	1.000E+00
290886.998601	1.404E-21	4.826E-27	4.089E-23	9.851E-01	1.289E+04	1.412E+11	5.776E-12	5.776E-12	9.20353E-10	1.000E+00	1.000E+00
299613.608559	1.133E-21	3.781E-27	3.300E-23	9.851E-01	1.408E+04	1.543E+11	5.083E-12	5.083E-12	8.11562E-10	1.000E+00	1.000E+00
308602.016816	9.137E-22	2.961E-27	2.661E-23	9.851E-01	1.539E+04	1.687E+11	4.489E-12	4.489E-12	7.1528E-10	1.000E+00	1.000E+00
317860.077320	7.366E-22	2.317E-27	2.146E-23	9.851E-01	1.682E+04	1.843E+11	3.954E-12	3.954E-12	6.30111E-10	1.000E+00	1.000E+00
327395.879640	5.936E-22	1.813E-27	1.729E-23	9.851E-01	1.837E+04	2.014E+11	3.482E-12	3.482E-12	5.54812E-10	1.000E+00	1.000E+00
337217.756029	4.781E-22	1.418E-27	1.392E-23	9.851E-01	2.008E+04	2.201E+11	3.064E-12	3.064E-12	4.88271E-10	1.000E+00	1.000E+00
347334.288710	3.848E-22	1.108E-27	1.121E-23	9.851E-01	2.194E+04	2.405E+11	2.695E-12	2.695E-12	4.29501E-10	1.000E+00	1.000E+00
357754.317371	3.096E-22	8.655E-28	9.018E-24	9.851E-01	2.397E+04	2.628E+11	2.370E-12	2.370E-12	3.77619E-10	1.000E+00	1.000E+00
368486.946892	2.490E-22	6.758E-28	7.253E-24	9.851E-01	2.620E+04	2.871E+11	2.082E-12	2.082E-12	3.31841E-10	1.000E+00	1.000E+00
379541.555299	2.002E-22	5.274E-28	5.830E-24	9.851E-01	2.863E+04	3.138E+11	1.829E-12	1.829E-12	2.9147E-10	1.000E+00	1.000E+00
390927.801958	1.608E-22	4.113E-28	4.684E-24	9.851E-01	3.128E+04	3.428E+11	1.606E-12	1.606E-12	2.55885E-10	1.000E+00	1.000E+00
402655.636017	1.291E-22	3.207E-28	3.761E-24	9.851E-01	3.418E+04	3.746E+11	1.409E-12	1.409E-12	2.24534E-10	1.000E+00	1.000E+00
414735.305097	1.036E-22	2.499E-28	3.019E-24	9.851E-01	3.735E+04	4.094E+11	1.236E-12	1.236E-12	1.96928E-10	1.000E+00	1.000E+00
427177.364250	8.315E-23	1.946E-28	2.422E-24	9.851E-01	4.082E+04	4.473E+11	1.093E-12	1.093E-12	1.72632E-10	1.000E+00	1.000E+00
439992.685178	6.667E-23	1.515E-28	1.942E-24	9.851E-01	4.460E+04	4.888E+11	9.492E-13	9.492E-13	1.51258E-10	1.000E+00	1.000E+00
453192.465733	5.343E-23	1.179E-28	1.556E-24	9.851E-01	4.874E+04	5.341E+11	8.313E-13	8.313E-13	1.32486E-10	1.000E+00	1.000E+00
466788.239705	4.280E-23	9.169E-29	1.247E-24	9.851E-01	5.325E+04	5.837E+11	7.276E-13	7.276E-13	1.15952E-10	1.000E+00	1.000E+00
480791.866896	3.427E-23	7.128E-29	9.982E-25	9.851E-01	5.819E+04	6.378E+11	6.366E-13	6.366E-13	1.01447E-10	1.000E+00	1.000E+00
495215.643503	2.743E-23	5.538E-29	7.988E-25	9.851E-01	6.359E+04	6.969E+11	5.567E-13	5.567E-13	8.87131E-11	1.000E+00	1.000E+00
510072.112808	2.194E-23	4.301E-29	6.399E-25	9.851E-01	6.949E+04	7.616E+11	4.866E-13	4.866E-13	7.75394E-11	1.000E+00	1.000E+00
525374.276192	1.754E-23	3.338E-29	5.108E-25	9.851E-01	7.593E+04	8.322E+11	4.251E-13	4.251E-13	6.77399E-11	1.000E+00	1.000E+00
541135.504478	1.401E-23	2.590E-29	4.082E-25	9.851E-01	8.297E+04	9.093E+11	3.712E-13	3.712E-13	5.91498E-11	1.000E+00	1.000E+00
557369.569612	1.119E-23	2.008E-29	3.260E-25	9.851E-01	9.066E+04	9.937E+11	3.240E-13	3.240E-13	5.16237E-11	1.000E+00	1.000E+00
574090.666701	8.936E-24	1.557E-29	2.603E-25	9.851E-01	9.907E+04	1.086E+12	2.826E-13	2.826E-13	4.50332E-11	1.000E+00	1.000E+00
591313.376402	7.130E-24	1.206E-29	2.077E-25	9.851E-01	1.083E+05	1.186E+12	2.464E-13	2.464E-13	3.92647E-11	1.000E+00	1.000E+00
609052.777694	5.686E-24	9.337E-30	1.656E-25	9.851E-01	1.183E+05	1.297E+12	2.147E-13	2.147E-13	3.42184E-11	1.000E+00	1.000E+00
627324.361025	4.533E-24	7.226E-30	1.320E-25	9.851E-01	1.293E+05	1.417E+12	1.870E-13	1.870E-13	2.9806E-11	1.000E+00	1.000E+00
646144.091855	3.612E-24	5.589E-30	1.052E-25	9.851E-01	1.412E+05	1.548E+12	1.628E-13	1.628E-13	2.59499E-11	1.000E+00	1.000E+00
665528.414611	2.876E-24	4.321E-30	8.377E-26	9.851E-01	1.543E+05	1.692E+12	1.417E-13	1.417E-13	2.25816E-11	1.000E+00	1.000E+00
685494.267049	2.289E-24	3.340E-30	6.668E-26	9.851E-01	1.687E+05	1.849E+12	1.233E-13	1.233E-13	1.96408E-11	1.000E+00	1.000E+00
706059.095061	1.821E-24	2.579E-30	5.305E-26	9.851E-01	1.843E+05	2.020E+12	1.071E-13	1.071E-13	1.70747E-11	1.000E+00	1.000E+00
727240.867913	1.448E-24	1.991E-30	4.218E-26	9.851E-01	2.014E+05	2.207E+12	9.310E-14	9.310E-14	1.48365E-11	1.000E+00	1.000E+00
749058.093950	1.151E-24	1.537E-30	3.353E-26	9.851E-01	2.201E+05	2.412E+12	8.086E-14	8.086E-14	1.28855E-11	1.000E+00	1.000E+00
771529.836768	9.144E-25	1.185E-30	2.663E-26	9.851E-01	2.405E+05	2.636E+12	7.019E-14	7.019E-14	1.11855E-11	1.000E+00	1.000E+00
794675.718771	7.261E-25	9.137E-31	2.115E-26	9.851E-01	2.628E+05	2.880E+12	6.090E-14	6.090E-14	9.70498E-12	1.000E+00	1.000E+00
818516.003828	5.762E-25	7.040E-31	1.678E-26	9.851E-01	2.871E+05	3.147E+12	5.282E-14	5.282E-14	8.41634E-12	1.000E+00	1.000E+00
843071.483942	4.571E-25	5.422E-31	1.331E-26	9.851E-01	3.138E+05	3.439E+12	4.578E-14	4.578E-14	7.29522E-12	1.000E+00	1.000E+00
868363.628461	3.624E-25	4.173E-31	1.066E-26	9.851E-01	3.428E+05	3.758E+12	3.966E-14	3.966E-14	6.32034E-12	1.000E+00	1.000E+00
894414.537315	2.872E-25	3.211E-31	8.365E-27	9.851E-01	3.746E+05	4.108E+12	3.435E-14	3.435E-14	5.47306E-12	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V ρ	P(d)* $\Delta d^m/d$	P(d)* $\Delta d^m/(d^m \rho P_{\text{tot}})$	d < 4.7	$\Sigma P(d) m/(P m)_{\text{tot}}$
921246.973434	2.275E-25	2.469E-31	6.625E-27	9.851E-01	4.094E+05	4.487E+12	2.973E-14	4.73704E-12	1.000E+00	1.000E+00
948884.362637	1.801E-25	1.898E-31	5.245E-27	9.851E-01	4.473E+05	4.903E+12	2.572E-14	4.09799E-12	1.000E+00	1.000E+00
977350.914116	1.425E-25	1.458E-31	4.150E-27	9.851E-01	4.488E+05	5.357E+12	2.224E-14	3.54341E-12	1.000E+00	1.000E+00
1006671.441540	1.127E-25	1.120E-31	3.283E-27	9.851E-01	5.341E+05	5.854E+12	1.922E-14	3.06238E-12	1.000E+00	1.000E+00
1036871.584786	8.910E-26	8.593E-32	2.595E-27	9.851E-01	5.837E+05	6.397E+12	1.680E-14	2.64536E-12	1.000E+00	1.000E+00
1067977.732329	7.040E-26	6.592E-32	2.050E-27	9.851E-01	6.378E+05	6.990E+12	1.433E-14	2.284E-12	1.000E+00	1.000E+00
1100017.064299	5.560E-26	5.054E-32	1.619E-27	9.851E-01	6.969E+05	7.638E+12	1.237E-14	1.97104E-12	1.000E+00	1.000E+00
1133017.576228	4.389E-26	3.873E-32	1.278E-27	9.851E-01	7.616E+05	8.347E+12	1.067E-14	1.70013E-12	1.000E+00	1.000E+00
1167008.103515	3.462E-26	2.967E-32	1.008E-27	9.851E-01	8.322E+05	9.121E+12	9.198E-15	1.46573E-12	1.000E+00	1.000E+00
1202018.346620	2.730E-26	2.272E-32	7.953E-28	9.851E-01	9.094E+05	9.966E+12	7.926E-15	1.26303E-12	1.000E+00	1.000E+00
1238078.897019	2.152E-26	1.738E-32	6.268E-28	9.851E-01	9.937E+05	1.089E+13	6.827E-15	1.08783E-12	1.000E+00	1.000E+00
1275221.263930	1.695E-26	1.330E-32	4.938E-28	9.851E-01	1.086E+06	1.190E+13	5.877E-15	9.36477E-13	1.000E+00	1.000E+00
1313477.901848	1.335E-26	1.016E-32	3.888E-28	9.851E-01	1.186E+06	1.300E+13	5.057E-15	8.05784E-13	1.000E+00	1.000E+00
1352882.238903	1.051E-26	7.767E-33	3.060E-28	9.851E-01	1.297E+06	1.421E+13	4.349E-15	6.92991E-13	1.000E+00	1.000E+00
1393468.706070	8.266E-27	5.932E-33	2.407E-28	9.851E-01	1.417E+06	1.553E+13	3.738E-15	5.95694E-13	1.000E+00	1.000E+00
1435272.767252	6.499E-27	4.528E-33	1.893E-28	9.851E-01	1.548E+06	1.694E+13	3.212E-15	5.11807E-13	1.000E+00	1.000E+00
1478330.950270	5.107E-27	3.455E-33	1.488E-28	9.851E-01	1.692E+06	1.854E+13	2.758E-15	4.39518E-13	1.000E+00	1.000E+00
1522680.878778	4.012E-27	2.635E-33	1.169E-28	9.851E-01	1.849E+06	2.026E+13	2.367E-15	3.77254E-13	1.000E+00	1.000E+00
1568361.305141	3.150E-27	2.008E-33	9.174E-29	9.851E-01	2.020E+06	2.214E+13	2.031E-15	3.23652E-13	1.000E+00	1.000E+00
1615412.144295	2.472E-27	1.530E-33	7.199E-29	9.851E-01	2.207E+06	2.419E+13	1.742E-15	2.77529E-13	1.000E+00	1.000E+00
1663874.508624	1.939E-27	1.165E-33	5.647E-29	9.851E-01	2.412E+06	2.643E+13	1.493E-15	2.37863E-13	1.000E+00	1.000E+00
1713790.743883	1.520E-27	8.868E-34	4.427E-29	9.851E-01	2.636E+06	2.869E+13	1.279E-15	2.03767E-13	1.000E+00	1.000E+00
1765204.466199	1.191E-27	6.747E-34	3.469E-29	9.851E-01	2.880E+06	3.156E+13	1.095E-15	1.74472E-13	1.000E+00	1.000E+00
1818160.600185	9.327E-28	5.130E-34	2.717E-29	9.851E-01	3.147E+06	3.449E+13	9.370E-16	1.49316E-13	1.000E+00	1.000E+00
1872705.418191	7.301E-28	3.899E-34	2.127E-29	9.851E-01	3.439E+06	3.769E+13	8.015E-16	1.27724E-13	1.000E+00	1.000E+00
1928886.580737	5.713E-28	2.962E-34	1.664E-29	9.851E-01	3.758E+06	4.118E+13	6.853E-16	1.09201E-13	1.000E+00	1.000E+00
1986753.178159	4.468E-28	2.249E-34	1.301E-29	9.851E-01	4.106E+06	4.500E+13	5.856E-16	9.33182E-14	1.000E+00	1.000E+00
2046355.773504	3.492E-28	1.707E-34	1.017E-29	9.851E-01	4.487E+06	4.918E+13	5.002E-16	7.97067E-14	1.000E+00	1.000E+00
2107746.46709	2.728E-28	1.294E-34	7.947E-30	9.851E-01	4.903E+06	5.374E+13	4.270E-16	6.80471E-14	1.000E+00	1.000E+00
2170978.840110	2.131E-28	9.814E-35	6.205E-30	9.851E-01	5.358E+06	5.872E+13	3.644E-16	5.80647E-14	1.000E+00	1.000E+00
2236108.205313	1.663E-28	7.437E-35	4.843E-30	9.851E-01	5.854E+06	6.416E+13	3.108E-16	4.95223E-14	1.000E+00	1.000E+00
2303191.451473	1.297E-28	5.633E-35	3.778E-30	9.851E-01	6.397E+06	7.011E+13	2.649E-16	4.2216E-14	1.000E+00	1.000E+00
2372287.195017	1.012E-28	4.264E-35	2.946E-30	9.851E-01	6.990E+06	7.661E+13	2.257E-16	3.59701E-14	1.000E+00	1.000E+00
2443455.810867	7.884E-29	3.226E-35	2.296E-30	9.851E-01	7.639E+06	8.372E+13	1.922E-16	3.06331E-14	1.000E+00	1.000E+00
2516759.485193	6.141E-29	2.440E-35	1.789E-30	9.851E-01	8.347E+06	9.148E+13	1.636E-16	2.60753E-14	1.000E+00	1.000E+00
2592262.269749	4.781E-29	1.845E-35	1.393E-30	9.851E-01	9.121E+06	9.996E+13	1.392E-16	2.21847E-14	1.000E+00	1.000E+00
2670030.137842	3.721E-29	1.394E-35	1.064E-30	9.851E-01	9.967E+06	1.092E+14	1.194E-16	1.88654E-14	1.000E+00	1.000E+00
2750131.041977	2.894E-29	1.052E-35	8.430E-31	9.851E-01	1.089E+07	1.194E+14	1.006E-16	1.60348E-14	1.000E+00	1.000E+00
2832634.973236	2.250E-29	7.944E-36	6.554E-31	9.851E-01	1.190E+07	1.304E+14	8.548E-17	1.36223E-14	1.000E+00	1.000E+00
2917614.022433	1.749E-29	5.993E-36	5.093E-31	9.851E-01	1.300E+07	1.425E+14	7.259E-17	1.15671E-14	1.000E+00	1.000E+00
3005142.443106	1.358E-29	4.519E-36	3.956E-31	9.851E-01	1.421E+07	1.557E+14	6.161E-17	9.81712E-15	1.000E+00	1.000E+00
3095296.716400	1.054E-29	3.406E-36	3.071E-31	9.851E-01	1.553E+07	1.702E+14	5.226E-17	8.32782E-15	1.000E+00	1.000E+00
3188155.617892	8.181E-30	2.566E-36	2.383E-31	9.851E-01	1.697E+07	1.860E+14	4.431E-17	7.06099E-15	1.000E+00	1.000E+00

Particle Geometric Diameter (µm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (µg)	Log Normal Mass Distribution (µg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*Δd/d	Σ P(d)*Δd/d	π d ³ /6	V ρ	P(d)*Δd*md	P(d)*Δd*md/(d ³ mP _{tot})	d < 4.7	Σ P(d) m/(P m) _{tot}
3283800.286428	6.345E-30	1.932E-36	1.848E-31	9.851E-01	1.854E-07	2.032E+14	3.755E-17	5.98394E-15	1.000E+00	1.000E+00
3382314.295021	4.918E-30	1.454E-36	1.432E-31	9.851E-01	2.026E-07	2.221E+14	3.481E-17	5.06869E-15	1.000E+00	1.000E+00
3483783.723872	3.811E-30	1.094E-36	1.110E-31	9.851E-01	2.214E-07	2.426E+14	2.693E-17	4.29133E-15	1.000E+00	1.000E+00
3588297.235598	2.951E-30	8.224E-37	8.595E-32	9.851E-01	2.419E-07	2.651E+14	2.279E-17	3.6314E-15	1.000E+00	1.000E+00
3695946.152656	2.284E-30	6.180E-37	6.553E-32	9.851E-01	2.643E-07	2.897E+14	1.927E-17	3.07145E-15	1.000E+00	1.000E+00
3806824.537235	1.767E-30	4.642E-37	5.147E-32	9.851E-01	2.889E-07	3.166E+14	1.629E-17	2.59658E-15	1.000E+00	1.000E+00
3921029.273352	1.366E-30	3.485E-37	3.980E-32	9.851E-01	3.156E-07	3.459E+14	1.377E-17	2.19404E-15	1.000E+00	1.000E+00
4038860.151553	1.056E-30	2.615E-37	3.076E-32	9.851E-01	3.449E-07	3.780E+14	1.163E-17	1.853E-15	1.000E+00	1.000E+00
4159819.956099	8.159E-31	1.961E-37	2.376E-32	9.851E-01	3.769E-07	4.131E+14	9.816E-18	1.56421E-15	1.000E+00	1.000E+00
4284614.554782	6.300E-31	1.470E-37	1.835E-32	9.851E-01	4.118E-07	4.514E+14	8.282E-18	1.31977E-15	1.000E+00	1.000E+00
4413152.991426	4.862E-31	1.102E-37	1.416E-32	9.851E-01	4.500E-07	4.932E+14	6.984E-18	1.11299E-15	1.000E+00	1.000E+00
4545547.581199	3.750E-31	8.250E-38	1.092E-32	9.851E-01	4.918E-07	5.390E+14	5.887E-18	9.38148E-16	1.000E+00	1.000E+00
4681914.008604	2.891E-31	6.176E-38	8.422E-33	9.851E-01	5.374E-07	5.890E+14	4.960E-18	7.90384E-16	1.000E+00	1.000E+00
4822371.248862	2.228E-31	4.621E-38	6.490E-33	9.851E-01	5.872E-07	6.436E+14	4.177E-18	6.65667E-16	1.000E+00	1.000E+00
4967042.571728	1.716E-31	3.455E-38	4.999E-33	9.851E-01	6.416E-07	7.032E+14	3.515E-18	5.60186E-16	1.000E+00	1.000E+00
5116053.848879	1.321E-31	2.583E-38	3.848E-33	9.851E-01	7.011E-07	7.684E+14	2.957E-18	4.7126E-16	1.000E+00	1.000E+00
5269535.464346	1.017E-31	1.929E-38	2.961E-33	9.851E-01	7.662E-07	8.397E+14	2.487E-18	3.96255E-16	1.000E+00	1.000E+00
5427621.528276	7.820E-32	1.441E-38	2.278E-33	9.851E-01	8.372E-07	9.176E+14	2.090E-18	3.3025E-16	1.000E+00	1.000E+00
5590450.174125	6.011E-32	1.075E-38	1.751E-33	9.851E-01	9.148E-07	1.003E+15	1.756E-18	2.79748E-16	1.000E+00	1.000E+00
5758163.679348	4.619E-32	8.021E-39	1.345E-33	9.851E-01	9.997E-07	1.098E+15	1.474E-18	2.34878E-16	1.000E+00	1.000E+00
5930908.599729	3.547E-32	5.981E-39	1.033E-33	9.851E-01	1.092E-08	1.197E+15	1.237E-18	1.97109E-16	1.000E+00	1.000E+00
6108835.847421	2.723E-32	4.457E-39	7.931E-34	9.851E-01	1.194E-08	1.308E+15	1.038E-18	1.65332E-16	1.000E+00	1.000E+00
6292100.922843	2.089E-32	3.320E-39	6.085E-34	9.851E-01	1.304E-08	1.430E+15	8.698E-19	1.3861E-16	1.000E+00	1.000E+00
6480863.950528	1.602E-32	2.472E-39	4.866E-34	9.851E-01	1.425E-08	1.562E+15	7.289E-19	1.1619E-16	1.000E+00	1.000E+00
6675289.859044	1.228E-32	1.839E-39	3.576E-34	9.851E-01	1.557E-08	1.707E+15	6.105E-19	9.72814E-17	1.000E+00	1.000E+00
6875548.565116	9.407E-33	1.368E-39	2.740E-34	9.851E-01	1.702E-08	1.865E+15	5.111E-19	8.14363E-17	1.000E+00	1.000E+00
7081815.022069	7.203E-33	1.017E-39	2.098E-34	9.851E-01	1.860E-08	2.038E+15	4.276E-19	6.81419E-17	1.000E+00	1.000E+00
7294269.472731	5.513E-33	7.558E-40	1.606E-34	9.851E-01	2.032E-08	2.227E+15	3.576E-19	5.69885E-17	1.000E+00	1.000E+00
7513097.556913	4.217E-33	5.613E-40	1.228E-34	9.851E-01	2.221E-08	2.434E+15	2.989E-19	4.76373E-17	1.000E+00	1.000E+00
7738490.483621	3.225E-33	4.167E-40	9.392E-35	9.851E-01	2.426E-08	2.659E+15	2.498E-19	3.9601E-17	1.000E+00	1.000E+00
7970845.198129	2.464E-33	3.092E-40	7.178E-35	9.851E-01	2.651E-08	2.906E+15	2.086E-19	3.32375E-17	1.000E+00	1.000E+00
8209764.554073	1.882E-33	2.293E-40	5.483E-35	9.851E-01	2.897E-08	3.175E+15	1.741E-19	2.77428E-17	1.000E+00	1.000E+00
8456057.406995	1.437E-33	1.700E-40	4.186E-35	9.851E-01	3.168E-08	3.470E+15	1.452E-19	2.31451E-17	1.000E+00	1.000E+00
8709739.215416	1.097E-33	1.259E-40	3.194E-35	9.851E-01	3.460E-08	3.792E+15	1.211E-19	1.92998E-17	1.000E+00	1.000E+00
8971031.391879	8.365E-34	9.324E-41	2.436E-35	9.851E-01	3.780E-08	4.143E+15	1.009E-19	1.60856E-17	1.000E+00	1.000E+00
9240162.333635	6.377E-34	6.901E-41	1.857E-35	9.851E-01	4.131E-08	4.527E+15	8.409E-20	1.34E-17	1.000E+00	1.000E+00
9517367.203844	4.859E-34	5.108E-41	1.415E-35	9.851E-01	4.514E-08	4.947E+15	7.002E-20	1.11574E-17	1.000E+00	1.000E+00
9802888.219753	3.701E-34	3.775E-41	1.078E-35	9.851E-01	4.932E-08	5.406E+15	5.827E-20	9.28553E-18	1.000E+00	1.000E+00
10096974.866346	2.817E-34	2.790E-41	8.205E-36	9.851E-01	5.390E-08	5.907E+15	4.847E-20	7.72391E-18	1.000E+00	1.000E+00
10399884.112336	2.143E-34	2.061E-41	6.243E-36	9.851E-01	5.890E-08	6.455E+15	4.030E-20	6.42178E-18	1.000E+00	1.000E+00
10711880.635706	1.630E-34	1.522E-41	4.748E-36	9.851E-01	6.436E-08	7.054E+15	3.349E-20	5.33655E-18	1.000E+00	1.000E+00
11033237.054778	1.239E-34	1.123E-41	3.609E-36	9.851E-01	7.032E-08	7.708E+15	2.782E-20	4.43254E-18	1.000E+00	1.000E+00
11364234.168421	9.414E-35	8.284E-42	2.742E-36	9.851E-01	7.685E-08	8.422E+15	2.309E-20	3.67987E-18	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V ρ	P(d) $\Delta d^3 m/d$	P(d) $\Delta d^3 m/(d^3 m P_{90})$	d < 4.7	$\Sigma P(d) m/(P m)_{90}$
11705161.191414	7.148E-35	6.107E-42	2.082E-36	9.851E-01	8.397E+08	9.203E+15	1.916E-20	3.0535E-18	1.000E+00	1.000E+00
12056316.027156	5.426E-35	4.500E-42	1.580E-36	9.851E-01	9.176E+08	1.006E+16	1.589E-20	2.5325E-18	1.000E+00	1.000E+00
12418005.507971	4.116E-35	3.315E-42	1.199E-36	9.851E-01	1.003E+09	1.098E+16	1.317E-20	2.09939E-18	1.000E+00	1.000E+00
12790545.673210	3.121E-35	2.440E-42	9.090E-37	9.851E-01	1.096E+09	1.201E+16	1.092E-20	1.73948E-18	1.000E+00	1.000E+00
13174262.043406	2.365E-35	1.795E-42	6.889E-37	9.851E-01	1.197E+09	1.312E+16	9.040E-21	1.44057E-18	1.000E+00	1.000E+00
13569489.904708	1.792E-35	1.320E-42	5.219E-37	9.851E-01	1.308E+09	1.434E+16	7.483E-21	1.19244E-18	1.000E+00	1.000E+00
13976574.601849	1.357E-35	9.707E-43	3.951E-37	9.851E-01	1.430E+09	1.567E+16	6.191E-21	9.86564E-19	1.000E+00	1.000E+00
14395871.839905	1.027E-35	7.132E-43	2.990E-37	9.851E-01	1.562E+09	1.712E+16	5.120E-21	8.15833E-19	1.000E+00	1.000E+00
14827747.995102	7.766E-36	5.237E-43	2.262E-37	9.851E-01	1.707E+09	1.871E+16	4.232E-21	6.74318E-19	1.000E+00	1.000E+00
15272580.434955	5.871E-36	3.844E-43	1.710E-37	9.851E-01	1.865E+09	2.044E+16	3.496E-21	5.57076E-19	1.000E+00	1.000E+00
15730757.848004	4.437E-36	2.820E-43	1.292E-37	9.851E-01	2.038E+09	2.234E+16	2.887E-21	4.59994E-19	1.000E+00	1.000E+00
16202680.583444	3.351E-36	2.068E-43	9.760E-38	9.851E-01	2.227E+09	2.441E+16	2.382E-21	3.79644E-19	1.000E+00	1.000E+00
16888761.000947	2.500E-36	1.516E-43	7.368E-38	9.851E-01	2.434E+09	2.677E+16	1.985E-21	3.13176E-19	1.000E+00	1.000E+00
17189423.830976	1.909E-36	1.110E-43	5.559E-38	9.851E-01	2.659E+09	2.915E+16	1.620E-21	2.58218E-19	1.000E+00	1.000E+00
17705106.545905	1.440E-36	8.131E-44	4.193E-38	9.851E-01	2.906E+09	3.185E+16	1.335E-21	2.128E-19	1.000E+00	1.000E+00
18236259.742282	1.085E-36	5.950E-44	3.161E-38	9.851E-01	3.175E+09	3.480E+16	1.100E-21	1.75285E-19	1.000E+00	1.000E+00
18783347.534551	8.176E-37	4.353E-44	2.381E-38	9.851E-01	3.470E+09	3.803E+16	9.056E-22	1.44313E-19	1.000E+00	1.000E+00
19346847.960587	6.157E-37	3.182E-44	1.793E-38	9.851E-01	3.792E+09	4.156E+16	7.452E-22	1.18755E-19	1.000E+00	1.000E+00
19827253.399405	4.634E-37	2.326E-44	1.350E-38	9.851E-01	4.143E+09	4.541E+16	6.129E-22	9.76755E-20	1.000E+00	1.000E+00
20525071.001387	3.487E-37	1.699E-44	1.016E-38	9.851E-01	4.527E+09	4.962E+16	5.039E-22	8.02983E-20	1.000E+00	1.000E+00
21140823.131428	2.622E-37	1.240E-44	7.636E-39	9.851E-01	4.947E+09	5.422E+16	4.141E-22	6.59804E-20	1.000E+00	1.000E+00
2175047.425371	1.971E-37	9.049E-45	5.739E-39	9.851E-01	5.406E+09	5.925E+16	3.401E-22	5.41889E-20	1.000E+00	1.000E+00
22428299.260132	1.480E-37	6.600E-45	4.312E-39	9.851E-01	5.907E+09	6.474E+16	2.791E-22	4.44828E-20	1.000E+00	1.000E+00
23101148.237936	1.111E-37	4.811E-45	3.237E-39	9.851E-01	6.455E+09	7.075E+16	2.290E-22	3.64974E-20	1.000E+00	1.000E+00
23794182.685074	8.342E-38	3.506E-45	2.430E-39	9.851E-01	7.054E+09	7.731E+16	1.878E-22	2.99308E-20	1.000E+00	1.000E+00
24508008.165627	6.257E-38	2.553E-45	1.822E-39	9.851E-01	7.708E+09	8.448E+16	1.540E-22	2.45336E-20	1.000E+00	1.000E+00
25243248.410595	4.691E-38	1.858E-45	1.368E-39	9.851E-01	8.422E+09	9.231E+16	1.261E-22	2.00998E-20	1.000E+00	1.000E+00
26000545.862913	3.516E-38	1.352E-45	1.024E-39	9.851E-01	9.203E+09	1.009E+17	1.033E-22	1.64593E-20	1.000E+00	1.000E+00
26780562.238801	2.633E-38	9.833E-46	7.670E-40	9.851E-01	1.006E+10	1.102E+17	8.454E-23	1.34715E-20	1.000E+00	1.000E+00
27583979.105965	1.971E-38	7.147E-46	5.742E-40	9.851E-01	1.099E+10	1.204E+17	6.916E-23	1.10207E-20	1.000E+00	1.000E+00
28411498.479144	1.475E-38	5.192E-46	4.297E-40	9.851E-01	1.201E+10	1.316E+17	5.655E-23	9.01128E-21	1.000E+00	1.000E+00
29263843.433518	1.103E-38	3.770E-46	3.214E-40	9.851E-01	1.312E+10	1.438E+17	4.622E-23	7.36466E-21	1.000E+00	1.000E+00
30141758.736524	8.248E-39	2.736E-46	2.402E-40	9.851E-01	1.434E+10	1.572E+17	3.775E-23	6.01598E-21	1.000E+00	1.000E+00
31046011.498619	6.163E-39	1.985E-46	1.795E-40	9.851E-01	1.567E+10	1.717E+17	3.082E-23	4.91186E-21	1.000E+00	1.000E+00
31977391.843578	4.602E-39	1.439E-46	1.341E-40	9.851E-01	1.712E+10	1.876E+17	2.515E-23	4.00843E-21	1.000E+00	1.000E+00
32936713.598885	3.436E-39	1.043E-46	1.001E-40	9.851E-01	1.871E+10	2.050E+17	2.052E-23	3.26955E-21	1.000E+00	1.000E+00
33924815.006852	2.563E-39	7.556E-47	7.466E-41	9.851E-01	2.044E+10	2.241E+17	1.673E-23	2.66557E-21	1.000E+00	1.000E+00
34942559.457057	1.911E-39	5.470E-47	5.567E-41	9.851E-01	2.234E+10	2.448E+17	1.363E-23	2.17209E-21	1.000E+00	1.000E+00
35980836.240769	1.425E-39	3.959E-47	4.150E-41	9.851E-01	2.441E+10	2.675E+17	1.110E-23	1.76911E-21	1.000E+00	1.000E+00
37070561.327992	1.061E-39	2.863E-47	3.091E-41	9.851E-01	2.667E+10	2.923E+17	9.038E-24	1.44018E-21	1.000E+00	1.000E+00
38182878.167832	7.903E-40	2.070E-47	2.302E-41	9.851E-01	2.915E+10	3.195E+17	7.354E-24	1.17184E-21	1.000E+00	1.000E+00
39328158.512867	5.882E-40	1.496E-47	1.713E-41	9.851E-01	3.185E+10	3.491E+17	5.981E-24	9.53026E-22	1.000E+00	1.000E+00
40508003.268253	4.376E-40	1.080E-47	1.274E-41	9.851E-01	3.480E+10	3.814E+17	4.861E-24	7.74691E-22	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
	$P(d)$	$P(d)/d$	$P(d)\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	$V\rho$	$P(d)\gamma\Delta d^2m/d$	$P(d)\Delta d^2m/(d^2mP_{0d})$	$d < 4.7$	$\Sigma P(d) m/(P m)_{\text{tot}}$
41723243.366300	3.254E-40	7.798E-48	9.476E-42	9.851E-01	3.803E+10	4.168E+17	3.950E-24	6.29419E-22	1.000E+00	1.000E+00
42974940.667289	2.418E-40	5.626E-48	7.042E-42	9.851E-01	4.156E+10	4.555E+17	3.208E-24	5.11138E-22	1.000E+00	1.000E+00
44264188.887308	1.796E-40	4.058E-48	5.231E-42	9.851E-01	4.541E+10	4.977E+17	2.604E-24	4.14881E-22	1.000E+00	1.000E+00
45592114.553927	1.333E-40	2.925E-48	3.864E-42	9.851E-01	4.962E+10	5.438E+17	2.112E-24	3.36586E-22	1.000E+00	1.000E+00
46959877.990545	9.895E-41	2.107E-48	2.802E-42	9.851E-01	5.422E+10	5.943E+17	1.713E-24	2.72933E-22	1.000E+00	1.000E+00
48368674.330261	7.339E-41	1.517E-48	2.138E-42	9.851E-01	5.925E+10	6.494E+17	1.388E-24	2.21208E-22	1.000E+00	1.000E+00
49819734.560169	5.441E-41	1.092E-48	1.585E-42	9.851E-01	6.474E+10	7.096E+17	1.125E-24	1.79199E-22	1.000E+00	1.000E+00
51314326.596974	4.032E-41	7.857E-49	1.174E-42	9.851E-01	7.075E+10	7.754E+17	9.105E-25	1.45097E-22	1.000E+00	1.000E+00
52853756.394884	2.986E-41	5.649E-49	8.697E-43	9.851E-01	7.731E+10	8.473E+17	7.369E-25	1.17426E-22	1.000E+00	1.000E+00
54439369.086730	2.210E-41	4.060E-49	6.438E-43	9.851E-01	8.448E+10	9.259E+17	5.981E-25	9.49862E-23	1.000E+00	1.000E+00
56072550.159332	1.635E-41	2.917E-49	4.763E-43	9.851E-01	9.231E+10	1.012E+18	4.819E-25	7.67967E-23	1.000E+00	1.000E+00
57754726.664112	1.209E-41	2.094E-49	3.523E-43	9.851E-01	1.009E+11	1.106E+18	3.894E-25	6.206E-23	1.000E+00	1.000E+00
59487368.464035	8.940E-42	1.503E-49	2.604E-43	9.851E-01	1.102E+11	1.208E+18	3.146E-25	5.01266E-23	1.000E+00	1.000E+00
61271989.517956	6.605E-42	1.078E-49	1.924E-43	9.851E-01	1.204E+11	1.320E+18	2.540E-25	4.0468E-23	1.000E+00	1.000E+00
63110149.203495	4.877E-42	7.728E-50	1.421E-43	9.851E-01	1.316E+11	1.442E+18	2.049E-25	3.26544E-23	1.000E+00	1.000E+00
65003453.879600	3.600E-42	5.538E-50	1.048E-43	9.851E-01	1.438E+11	1.576E+18	1.653E-25	2.63366E-23	1.000E+00	1.000E+00
66953557.289988	2.686E-42	3.967E-50	7.735E-44	9.851E-01	1.572E+11	1.722E+18	1.332E-25	2.12307E-23	1.000E+00	1.000E+00
68962164.008687	1.958E-42	2.840E-50	5.704E-44	9.851E-01	1.717E+11	1.882E+18	1.073E-25	1.71063E-23	1.000E+00	1.000E+00
71031028.928948	1.443E-42	2.032E-50	4.204E-44	9.851E-01	1.876E+11	2.057E+18	8.645E-26	1.37764E-23	1.000E+00	1.000E+00
73161959.796817	1.063E-42	1.453E-50	3.097E-44	9.851E-01	2.050E+11	2.247E+18	6.959E-26	1.10892E-23	1.000E+00	1.000E+00
75355818.590721	7.828E-43	1.039E-50	2.280E-44	9.851E-01	2.241E+11	2.456E+18	5.599E-26	8.92184E-24	1.000E+00	1.000E+00
77617523.148443	5.761E-43	7.422E-51	1.678E-44	9.851E-01	2.448E+11	2.683E+18	4.502E-26	7.17455E-24	1.000E+00	1.000E+00
79948048.842896	4.237E-43	5.300E-51	1.234E-44	9.851E-01	2.675E+11	2.932E+18	3.619E-26	5.76663E-24	1.000E+00	1.000E+00
82344430.308183	3.115E-43	3.763E-51	9.073E-45	9.851E-01	2.923E+11	3.204E+18	2.907E-26	4.63272E-24	1.000E+00	1.000E+00
84814763.217428	2.289E-43	2.699E-51	6.667E-45	9.851E-01	3.195E+11	3.501E+18	2.334E-26	3.71995E-24	1.000E+00	1.000E+00
87359206.113951	1.681E-43	1.925E-51	4.897E-45	9.851E-01	3.491E+11	3.826E+18	1.874E-26	2.98556E-24	1.000E+00	1.000E+00
89979982.297370	1.234E-43	1.372E-51	3.595E-45	9.851E-01	3.814E+11	4.161E+18	1.503E-26	2.39498E-24	1.000E+00	1.000E+00
92679381.766291	9.057E-44	9.772E-52	2.638E-45	9.851E-01	4.168E+11	4.568E+18	1.205E-26	1.92028E-24	1.000E+00	1.000E+00
95459763.219280	6.642E-44	6.958E-52	1.935E-45	9.851E-01	4.555E+11	4.992E+18	9.857E-27	1.53891E-24	1.000E+00	1.000E+00
98323556.115858	4.869E-44	4.952E-52	1.418E-45	9.851E-01	4.977E+11	5.455E+18	7.736E-27	1.23268E-24	1.000E+00	1.000E+00
101273262.799334	3.567E-44	3.522E-52	1.039E-45	9.851E-01	5.439E+11	5.961E+18	6.193E-27	9.86905E-25	1.000E+00	1.000E+00
104311460.683314	2.612E-44	2.504E-52	7.609E-46	9.851E-01	5.943E+11	6.513E+18	4.966E-27	7.89744E-25	1.000E+00	1.000E+00
107440804.503813	1.912E-44	1.780E-52	5.569E-46	9.851E-01	6.494E+11	7.117E+18	3.964E-27	6.31662E-25	1.000E+00	1.000E+00
110664028.638927	1.399E-44	1.264E-52	4.075E-46	9.851E-01	7.096E+11	7.777E+18	3.169E-27	5.04975E-25	1.000E+00	1.000E+00
113983949.498095	1.023E-44	8.975E-53	2.979E-46	9.851E-01	7.754E+11	8.498E+18	2.532E-27	4.03498E-25	1.000E+00	1.000E+00
117403467.983038	7.477E-45	6.368E-53	2.178E-46	9.851E-01	8.473E+11	9.286E+18	2.022E-27	3.22256E-25	1.000E+00	1.000E+00
120925572.022529	5.462E-45	4.517E-53	1.591E-46	9.851E-01	9.259E+11	1.015E+19	1.614E-27	2.57246E-25	1.000E+00	1.000E+00
124553339.183205	3.988E-45	3.202E-53	1.162E-46	9.851E-01	1.066E+12	1.109E+19	1.288E-27	2.05249E-25	1.000E+00	1.000E+00
128289939.358701	2.911E-45	2.269E-53	8.477E-47	9.851E-01	1.212E+19	1.212E+19	1.027E-27	1.63683E-25	1.000E+00	1.000E+00
132138637.539462	2.123E-45	1.607E-53	6.184E-47	9.851E-01	1.208E+12	1.324E+19	8.187E-28	1.3047E-25	1.000E+00	1.000E+00
136102796.665846	1.548E-45	1.137E-53	4.509E-47	9.851E-01	1.320E+12	1.447E+19	6.523E-28	1.03945E-25	1.000E+00	1.000E+00
140185880.565816	1.128E-45	8.047E-54	3.286E-47	9.851E-01	1.442E+12	1.581E+19	5.194E-28	8.27727E-26	1.000E+00	1.000E+00
144391456.982584	8.216E-46	5.690E-54	2.393E-47	9.851E-01	1.576E+12	1.728E+19	4.134E-28	6.58804E-26	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (∞)	Particle $\pi d^3/6$	Log Normal Mass Distribution	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	$P(d)$	$P(d)/d$	$P(d)\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V_p	$P(d)\Delta d^3/m/d$	$P(d)\Delta d^3/m/(d^3mP_{td})$	$d < 4.7$	$\Sigma P(d) m/(P m)_{td}$
148723200.692062	5.982E-46	4.022E-54	1.742E-47	9.851E-01	1.722E+12	1.888E+19	3.289E-28	5.24098E-26	1.000E+00	1.000E+00
153184896.712823	4.353E-46	2.841E-54	1.268E-47	9.851E-01	1.882E+12	2.063E+19	2.615E-28	4.16731E-26	1.000E+00	1.000E+00
157780443.614208	3.166E-46	2.006E-54	9.221E-48	9.851E-01	2.057E+12	2.254E+19	2.075E-28	3.31197E-26	1.000E+00	1.000E+00
162513856.922634	2.301E-46	1.416E-54	6.703E-48	9.851E-01	2.247E+12	2.463E+19	1.651E-28	2.63089E-26	1.000E+00	1.000E+00
167389272.630313	1.672E-46	9.989E-55	4.870E-48	9.851E-01	2.456E+12	2.691E+19	1.311E-28	2.08885E-26	1.000E+00	1.000E+00
172410950.809223	1.214E-46	7.043E-55	3.537E-48	9.851E-01	2.683E+12	2.941E+19	1.040E-28	1.65788E-26	1.000E+00	1.000E+00
177583279.333500	8.815E-47	4.964E-55	2.567E-48	9.851E-01	2.932E+12	3.214E+19	8.251E-29	1.31486E-26	1.000E+00	1.000E+00
182910777.713505	6.395E-47	3.498E-55	1.863E-48	9.851E-01	3.204E+12	3.512E+19	6.542E-29	1.04242E-26	1.000E+00	1.000E+00
188398101.044910	4.638E-47	2.462E-55	1.351E-48	9.851E-01	3.501E+12	3.837E+19	5.184E-29	8.26032E-27	1.000E+00	1.000E+00
194050044.076257	3.362E-47	1.732E-55	9.791E-49	9.851E-01	3.826E+12	4.193E+19	4.108E-29	6.5424E-27	1.000E+00	1.000E+00
198871545.398545	2.435E-47	1.218E-55	7.093E-49	9.851E-01	4.181E+12	4.582E+19	3.250E-29	5.17921E-27	1.000E+00	1.000E+00
205867691.760501	1.763E-47	8.566E-56	5.138E-49	9.851E-01	4.568E+12	5.007E+19	2.572E-29	4.09806E-27	1.000E+00	1.000E+00
212043722.513316	1.276E-47	6.019E-56	3.717E-49	9.851E-01	4.992E+12	5.471E+19	2.034E-29	3.241E-27	1.000E+00	1.000E+00
218405034.188716	9.233E-48	4.227E-56	2.689E-49	9.851E-01	5.455E+12	5.979E+19	1.608E-29	2.56193E-27	1.000E+00	1.000E+00
224957185.214377	6.676E-48	2.967E-56	1.944E-49	9.851E-01	5.961E+12	6.533E+19	1.270E-29	2.02415E-27	1.000E+00	1.000E+00
231705900.770808	4.824E-48	2.082E-56	1.405E-49	9.851E-01	6.513E+12	7.139E+19	1.003E-29	1.59847E-27	1.000E+00	1.000E+00
238657077.793933	3.485E-48	1.460E-56	1.015E-49	9.851E-01	7.177E+12	7.801E+19	7.918E-30	1.2617E-27	1.000E+00	1.000E+00
245816790.127751	2.516E-48	1.024E-56	7.328E-50	9.851E-01	7.777E+12	8.524E+19	6.248E-30	9.95387E-28	1.000E+00	1.000E+00
253191293.831583	1.816E-48	7.171E-57	5.288E-50	9.851E-01	8.499E+12	9.314E+19	4.926E-30	7.84903E-28	1.000E+00	1.000E+00
260787032.646531	1.310E-48	5.021E-57	3.814E-50	9.851E-01	9.287E+12	1.018E+20	3.882E-30	6.18624E-28	1.000E+00	1.000E+00
268610643.628927	9.441E-49	3.515E-57	2.750E-50	9.851E-01	1.015E+13	1.112E+20	3.058E-30	4.87332E-28	1.000E+00	1.000E+00
276688992.934704	6.803E-49	2.459E-57	1.981E-50	9.851E-01	1.109E+13	1.215E+20	2.408E-30	3.83716E-28	1.000E+00	1.000E+00
284969031.822746	4.899E-49	1.719E-57	1.427E-50	9.851E-01	1.212E+13	1.328E+20	1.895E-30	3.01983E-28	1.000E+00	1.000E+00
293518102.777428	3.527E-49	1.202E-57	1.027E-50	9.851E-01	1.324E+13	1.451E+20	1.491E-30	2.37642E-28	1.000E+00	1.000E+00
302323645.860751	2.538E-49	8.394E-58	7.391E-51	9.851E-01	1.447E+13	1.586E+20	1.172E-30	1.86762E-28	1.000E+00	1.000E+00
311393355.236573	1.825E-49	5.860E-58	5.315E-51	9.851E-01	1.581E+13	1.733E+20	9.210E-31	1.46764E-28	1.000E+00	1.000E+00
320735155.893670	1.312E-49	4.090E-58	3.821E-51	9.851E-01	1.728E+13	1.893E+20	7.234E-31	1.15277E-28	1.000E+00	1.000E+00
330357210.570481	9.424E-50	2.853E-58	2.745E-51	9.851E-01	1.888E+13	2.069E+20	5.679E-31	9.05001E-29	1.000E+00	1.000E+00
340267926.887595	6.767E-50	1.989E-58	1.971E-51	9.851E-01	2.063E+13	2.261E+20	4.456E-31	7.1014E-29	1.000E+00	1.000E+00
350475984.694223	4.857E-50	1.386E-58	1.415E-51	9.851E-01	2.254E+13	2.470E+20	3.495E-31	5.56962E-29	1.000E+00	1.000E+00
360990243.635050	3.485E-50	9.653E-59	1.015E-51	9.851E-01	2.463E+13	2.700E+20	2.740E-31	4.36611E-29	1.000E+00	1.000E+00
371819980.944101	2.499E-50	6.720E-59	7.277E-52	9.851E-01	2.692E+13	2.950E+20	2.147E-31	3.42098E-29	1.000E+00	1.000E+00
382874549.472424	1.791E-50	4.676E-59	5.216E-52	9.851E-01	2.941E+13	3.223E+20	1.681E-31	2.67913E-29	1.000E+00	1.000E+00
394463785.956597	1.283E-50	3.252E-59	3.736E-52	9.851E-01	3.214E+13	3.522E+20	1.316E-31	2.09712E-29	1.000E+00	1.000E+00
406287699.536295	9.184E-51	2.261E-59	2.675E-52	9.851E-01	3.512E+13	3.849E+20	1.030E-31	1.64074E-29	1.000E+00	1.000E+00
418486630.521354	6.573E-51	1.571E-59	1.914E-52	9.851E-01	3.837E+13	4.206E+20	8.052E-32	1.28305E-29	1.000E+00	1.000E+00
431041229.436984	4.701E-51	1.091E-59	1.369E-52	9.851E-01	4.193E+13	4.586E+20	6.293E-32	1.00285E-29	1.000E+00	1.000E+00
443972486.320104	3.361E-51	7.571E-60	9.790E-53	9.851E-01	4.582E+13	5.022E+20	4.916E-32	7.83457E-30	1.000E+00	1.000E+00
457291640.309707	2.402E-51	5.252E-60	6.996E-53	9.851E-01	5.007E+13	5.488E+20	3.839E-32	6.11759E-30	1.000E+00	1.000E+00
471010389.518899	1.715E-51	3.642E-60	4.997E-53	9.851E-01	5.471E+13	5.997E+20	2.996E-32	4.77456E-30	1.000E+00	1.000E+00
485140701.204569	1.225E-51	2.524E-60	3.567E-53	9.851E-01	5.979E+13	6.553E+20	2.337E-32	3.72454E-30	1.000E+00	1.000E+00
499694922.240706	8.738E-52	1.749E-60	2.545E-53	9.851E-01	6.533E+13	7.160E+20	1.822E-32	2.90402E-30	1.000E+00	1.000E+00
514685769.907927	6.232E-52	1.211E-60	1.815E-53	9.851E-01	7.139E+13	7.824E+20	1.420E-32	2.26315E-30	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V ρ	P(d)* $\Delta d^3/m/d$	P(d)* $\Delta d^3 m/(d^3 m P_{tot})$	d < 4.7	$\Sigma P(d) m/(P m)_{tot}$
530126343.005165	4.442E-52	8.380E-61	1.294E-53	9.851E-01	7.801E+13	8.550E+20	1.106E-32	1.76285E-30	1.000E+00	1.000E+00
546030133.295320	3.165E-52	5.797E-61	9.219E-54	9.851E-01	8.524E+13	9.342E+20	8.613E-33	1.37247E-30	1.000E+00	1.000E+00
562411037.294179	2.254E-52	4.008E-61	6.565E-54	9.851E-01	9.315E+13	1.021E+21	6.702E-33	1.06802E-30	1.000E+00	1.000E+00
579283368.413005	1.604E-52	2.770E-61	4.673E-54	9.851E-01	1.018E+14	1.116E+21	5.213E-33	8.30694E-31	1.000E+00	1.000E+00
596861869.465395	1.141E-52	1.913E-61	3.325E-54	9.851E-01	1.112E+14	1.219E+21	4.053E-33	6.45788E-31	1.000E+00	1.000E+00
614561725.549357	8.117E-53	1.321E-61	2.364E-54	9.851E-01	1.215E+14	1.332E+21	3.149E-33	5.01796E-31	1.000E+00	1.000E+00
632998577.315837	5.769E-53	9.113E-62	1.680E-54	9.851E-01	1.328E+14	1.456E+21	2.446E-33	3.89718E-31	1.000E+00	1.000E+00
651988534.635312	4.098E-53	6.286E-62	1.194E-54	9.851E-01	1.451E+14	1.590E+21	1.898E-33	3.02525E-31	1.000E+00	1.000E+00
671548190.674372	2.910E-53	4.333E-62	8.475E-55	9.851E-01	1.586E+14	1.738E+21	1.473E-33	2.34725E-31	1.000E+00	1.000E+00
691694636.394603	2.065E-53	2.986E-62	6.015E-55	9.851E-01	1.733E+14	1.899E+21	1.142E-33	1.8203E-31	1.000E+00	1.000E+00
712445475.486441	1.465E-53	2.056E-62	2.133E-55	9.851E-01	1.893E+14	2.075E+21	4.427E-34	7.05482E-32	1.000E+00	1.000E+00
sum =	3.369E+01					mP _{tot} =	6.275E-03			

Summary of Results			
[All Values Automatically Updated]		See	[All Values Automatically Updated]
Results:		Note	Inputs:
Respirable Percent = 0.490416 %	1		Geometric Mean (d) = 0.714589 μm
Conservative Respirable Percent = 2.236305 %	2		Standard Deviation (σ) = 3.8
Non-Conservative Respirable Percent = 0.252878 %	3		Maximum Respirable Particle Diameter = 4.7 μm
Mass Median Diameter = 150.000 μm	4		Particulate Density (ρ) = 10.96 g/cc
Mass Median Diameter (MMD) = 146.0688 μm	5		Dynamic Shape Factor (κ) = 1.3
AMAD = 424.1224 μm	6		
% of Sum at Particle Diam. Of Interest = 51.56401 %	7		
<p>Note 1: Fraction of Distribution with MMD ~3.5 microns (i.e., 10 microns AMAD).</p> <p>Note 2: Fraction of Distribution less than 10 microns (if AMAD < 10 microns value is non-conservative).</p> <p>Note 3: Fraction of Distribution less than 3 microns (if AMAD < 10 microns value is non-conservative).</p> <p>Note 4: Mass Median Diameter for entire distribution - used to check the MMD note 5</p> <p>Note 5: MMD for entire distribution.</p> <p>Note 6: AMAD for entire distribution (if < 10 microns then 100% respirable, if > 10 microns could be 0% respirable).</p> <p>Note 7: Desire to be ~50% which means particles with diameter < Max Respirable Particle Diam. have an MMD of 3.5 mm.</p>			

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Attachment B

Microsoft Excel 97 Spreadsheets for the Calculation of the Respirable Fraction of Crud

The following Excel Spreadsheet is nearly identical to the spreadsheet presented in Attachment A. It consists of three separate worksheets: (1) the controller worksheet, which basically controls the inputs, (2) the particle distribution calculations worksheet, which performs the respirable fraction calculations, and the (3) results worksheet. A brief discussion of the inputs and outputs and calculations performed in this spreadsheet are discussed in Attachment A. The values calculated in this spreadsheet are for crud that has the characteristics noted in Section 6.2 of this analysis. The user supplied inputs option has been used in the controller worksheet to establish the crud respirable fraction.

USER INPUTS: Change only non-highlighted columns

Parameter Description	Parameter	Units	Use User Input (Y/N)?	User Input	Default
Multiplier to increment particle diameters =	1.03	-	n	1.03	1.03
Mean Geometric Diameter (MGD) =	5	µm	y	3.000	0.715
Standard Deviation (σ) =	1.67	-	based on MGD	1.87	2.3
Density (ρ) =	5.2	g/cc	y	5.2	10.98
Dynamic Shape Factor (χ) =	4.3	-	y	1.3	1.3
Respirable Fraction Cutoff (MMD) _R =	5	µm	y	5	3.5
Maximum Respirable Particle Diameter =	6.9	µm	o	6.9	4.7
The maximum respirable particle diameter may not be greater than the mean of the distribution unless a (override) is used in User Input (Y/N) column.					

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particle Distribution	Particle Volume, V (cc)	Particle $\pi d^3/6$	Particle Mass, m (μg)	Log Normal Mass Distribution	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	$V \rho$	P(d) $\Delta d^2 m/d$	P(d) $\Delta d^2 m/d$	P(d) $\Delta d^2 m/d^4 m P_{50}$	d < 6.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
0.000100	8.012E-60	8.012E-56	4.006E-60	4.006E-60	5.238E-25	2.723E-18	1.091E-77	1.091E-77	2.58477E-74	8.601E-74	2.585E-74
0.000103	1.742E-59	1.691E-55	5.073E-61	4.513E-60	5.722E-25	2.975E-18	1.509E-78	1.509E-78	3.57712E-75	9.791E-74	2.942E-74
0.000106	3.779E-59	3.562E-55	1.101E-60	5.614E-60	6.252E-25	3.251E-18	3.578E-78	3.578E-78	8.47938E-75	1.281E-73	3.790E-74
0.000109	8.178E-59	7.484E-55	2.382E-60	7.966E-60	6.832E-25	3.553E-18	8.462E-78	8.462E-78	2.00551E-74	1.929E-73	5.796E-74
0.000113	1.766E-58	1.569E-54	5.144E-60	1.314E-59	7.465E-25	3.882E-18	1.997E-77	1.997E-77	4.7328E-74	3.504E-73	1.053E-73
0.000116	3.806E-58	3.283E-54	1.109E-59	2.423E-59	8.157E-25	4.242E-18	4.702E-77	4.702E-77	1.1144E-73	7.212E-73	2.167E-73
0.000119	8.183E-58	6.853E-54	2.383E-59	4.806E-59	8.914E-25	4.635E-18	1.105E-76	1.105E-76	2.61818E-73	1.592E-72	4.785E-73
0.000123	1.755E-57	1.427E-53	5.113E-59	9.919E-59	9.740E-25	5.065E-18	2.590E-76	2.590E-76	6.13743E-73	3.635E-72	1.092E-72
0.000127	3.757E-57	2.966E-53	1.094E-58	2.086E-58	1.064E-24	5.535E-18	6.057E-76	6.057E-76	1.43551E-72	8.411E-72	2.528E-72
0.000130	8.025E-57	6.150E-53	2.337E-58	4.424E-58	1.163E-24	6.048E-18	1.414E-75	1.414E-75	3.35009E-72	1.956E-71	5.878E-72
0.000134	1.710E-56	1.272E-52	4.981E-58	9.404E-58	1.271E-24	6.609E-18	3.292E-75	3.292E-75	7.80079E-72	4.552E-71	1.368E-71
0.000138	3.636E-56	2.627E-52	1.069E-57	1.999E-57	1.389E-24	7.222E-18	7.648E-75	7.648E-75	1.81239E-71	1.058E-70	3.180E-71
0.000143	7.713E-56	5.410E-52	2.247E-57	4.246E-57	1.518E-24	7.891E-18	1.773E-74	1.773E-74	4.20143E-71	2.456E-70	7.382E-71
0.000147	1.633E-55	1.112E-51	4.755E-57	9.001E-57	1.658E-24	8.623E-18	4.101E-74	4.101E-74	9.71793E-71	5.690E-70	1.710E-70
0.000151	3.448E-55	2.280E-51	1.004E-56	1.812E-56	1.812E-24	9.422E-18	9.463E-74	9.463E-74	2.24276E-70	1.315E-69	3.953E-70
0.000156	7.267E-55	4.664E-51	2.116E-56	4.021E-56	1.980E-24	1.030E-17	2.179E-73	2.179E-73	5.16442E-70	3.034E-69	9.117E-70
0.000165	1.528E-54	9.521E-51	4.450E-56	8.471E-56	2.164E-24	1.125E-17	5.007E-73	5.007E-73	1.18657E-69	6.982E-69	2.098E-69
0.000170	3.205E-54	1.939E-50	9.336E-56	1.781E-55	2.364E-24	1.229E-17	1.148E-72	1.148E-72	2.72017E-69	1.603E-68	4.818E-69
0.000175	6.710E-54	3.941E-50	1.954E-55	3.735E-55	2.584E-24	1.343E-17	2.625E-72	2.625E-72	6.22199E-69	3.674E-68	1.104E-68
0.000181	1.401E-53	7.992E-50	4.082E-55	7.817E-55	2.823E-24	1.468E-17	5.992E-72	5.992E-72	1.42002E-68	8.399E-68	2.524E-68
0.000186	2.920E-53	1.617E-49	8.508E-55	1.632E-54	3.085E-24	1.604E-17	1.384E-71	1.384E-71	3.23365E-68	1.916E-67	5.758E-68
0.000192	6.072E-53	3.264E-49	1.769E-54	3.371E-54	3.371E-24	1.753E-17	3.100E-71	3.100E-71	7.34719E-68	4.361E-67	1.310E-67
0.000197	1.260E-52	5.575E-49	3.669E-54	7.070E-54	3.683E-24	1.915E-17	7.028E-71	7.028E-71	1.68684E-67	9.903E-67	2.976E-67
0.000199	2.608E-52	1.321E-48	7.596E-54	1.467E-53	4.025E-24	2.093E-17	1.590E-70	1.590E-70	3.76767E-67	2.244E-66	6.744E-67
0.000203	5.386E-52	2.650E-48	1.569E-53	3.035E-53	4.398E-24	2.287E-17	3.588E-70	3.588E-70	8.50348E-67	5.074E-66	1.525E-66
0.000208	1.110E-51	5.302E-48	3.233E-53	6.269E-53	4.806E-24	2.498E-17	8.080E-70	8.080E-70	1.91492E-66	1.145E-65	3.440E-66
0.000216	2.283E-51	1.058E-47	6.648E-53	1.292E-52	5.252E-24	2.731E-17	1.816E-69	1.816E-69	4.30267E-66	2.576E-65	7.742E-66
0.000222	4.683E-51	2.108E-47	1.364E-52	2.656E-52	5.739E-24	2.984E-17	4.070E-69	4.070E-69	9.64618E-66	5.786E-65	1.739E-65
0.000236	1.958E-50	8.309E-47	5.703E-52	1.115E-51	6.271E-24	3.261E-17	9.103E-69	9.103E-69	2.15777E-65	1.297E-64	3.897E-65
0.000243	3.991E-50	1.644E-46	1.162E-51	2.277E-51	7.488E-24	3.894E-17	4.525E-68	4.525E-68	4.81599E-65	2.899E-64	8.713E-65
0.000250	8.114E-50	3.246E-46	2.363E-51	4.641E-51	8.182E-24	4.255E-17	1.008E-67	1.008E-67	2.3831E-64	1.440E-63	4.327E-64
0.000256	1.846E-49	6.393E-46	4.785E-51	9.436E-51	8.941E-24	4.649E-17	2.229E-67	2.229E-67	5.28344E-64	3.198E-63	9.610E-64
0.000265	3.333E-49	1.257E-45	8.707E-51	1.914E-50	9.770E-24	5.080E-17	4.932E-67	4.932E-67	1.16876E-63	7.087E-63	2.130E-63
0.000273	6.732E-49	2.464E-45	1.961E-50	3.875E-50	1.069E-23	5.551E-17	1.089E-66	1.089E-66	2.57968E-63	1.567E-62	4.709E-63
0.000281	1.357E-48	4.822E-45	3.952E-50	7.827E-50	1.167E-23	6.066E-17	2.397E-66	2.397E-66	5.68109E-63	3.458E-62	1.039E-62
0.000290	2.728E-48	9.414E-45	7.947E-50	1.577E-49	1.275E-23	6.629E-17	5.267E-66	5.267E-66	1.24834E-62	7.612E-62	2.287E-62
0.000299	5.474E-48	1.834E-44	1.594E-49	3.172E-49	1.393E-23	7.243E-17	1.158E-65	1.158E-65	2.73695E-62	1.672E-61	5.024E-62
0.000307	1.096E-47	3.564E-44	3.192E-49	6.364E-49	1.522E-23	7.915E-17	2.526E-65	2.526E-65	5.9873E-62	3.684E-61	1.101E-61
0.000317	2.189E-47	6.912E-44	6.376E-49	1.274E-48	1.663E-23	8.649E-17	5.514E-65	5.514E-65	1.30685E-61	8.013E-61	2.408E-61
0.000326	4.363E-47	1.337E-43	1.271E-48	2.545E-48	1.817E-23	9.451E-17	1.201E-64	1.201E-64	2.84613E-61	1.748E-60	5.254E-61
0.000336	8.676E-47	2.582E-43	2.527E-48	5.072E-48	1.986E-23	1.033E-16	2.810E-64	2.810E-64	6.18462E-61	3.806E-60	1.144E-60
0.000346	1.721E-46	4.974E-43	5.014E-48	1.009E-47	2.170E-23	1.128E-16	5.658E-64	5.658E-64	1.34092E-60	8.268E-60	2.485E-60

Commercial SNF Accident Release Fractions

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V_p	P(d)* $\Delta d^m/d$	P(d)* $\Delta d^m/(d^m P_{\text{ref}})$	d < 6.9	$\Sigma P(d) \text{ m/(P m)}_{\text{ref}}$
0.000356	3.408E-46	9.561E-43	9.926E-48	2.001E-47	2.371E-23	1.233E-16	1.224E-63	2.90085E-60	1.792E-59	5.386E-60
0.000367	6.732E-46	1.834E-42	1.961E-47	3.962E-47	2.591E-23	1.347E-16	2.642E-63	5.6151E-60	3.876E-59	1.165E-59
0.000378	1.327E-45	3.509E-42	3.865E-47	7.827E-47	2.832E-23	1.472E-16	5.690E-63	1.34854E-59	8.363E-59	2.513E-59
0.000390	2.608E-45	6.999E-42	7.600E-47	1.543E-46	3.094E-23	1.609E-16	1.223E-62	2.89788E-59	1.801E-58	5.411E-58
0.000401	5.120E-45	1.276E-41	1.491E-46	3.034E-46	3.361E-23	1.758E-16	2.622E-62	6.21339E-59	3.868E-58	1.162E-58
0.000413	1.002E-44	2.426E-41	2.920E-46	5.953E-46	3.695E-23	1.921E-16	5.609E-62	1.32925E-58	8.291E-58	2.492E-58
0.000426	1.958E-44	4.600E-41	5.703E-46	1.166E-45	4.037E-23	2.099E-16	1.197E-61	2.83739E-58	1.773E-57	5.329E-58
0.000438	3.816E-44	8.706E-41	1.112E-45	2.277E-45	4.411E-23	2.294E-16	2.550E-61	6.04312E-58	3.784E-57	1.137E-57
0.000452	7.422E-44	1.644E-40	2.162E-45	4.439E-45	4.821E-23	2.507E-16	5.419E-61	1.28421E-57	8.058E-57	2.421E-57
0.000465	1.440E-43	3.097E-40	4.195E-45	8.634E-45	5.268E-23	2.739E-16	1.149E-60	2.72296E-57	1.712E-56	5.144E-57
0.000479	2.788E-43	5.821E-40	8.121E-45	1.675E-44	5.756E-23	2.993E-16	2.431E-60	5.76074E-57	3.629E-56	1.091E-56
0.000493	5.386E-43	1.092E-39	1.569E-44	3.244E-44	6.290E-23	3.271E-16	5.131E-60	1.21604E-56	7.675E-56	2.307E-56
0.000508	1.038E-42	2.043E-39	3.024E-44	6.288E-44	6.873E-23	3.574E-16	1.081E-59	2.56122E-56	1.620E-55	4.868E-56
0.000539	1.997E-42	3.814E-39	5.816E-44	1.208E-43	7.510E-23	3.905E-16	2.271E-59	5.38243E-56	3.411E-55	1.025E-55
0.000572	3.831E-42	7.106E-39	1.116E-43	2.324E-43	8.207E-23	4.267E-16	4.762E-59	1.1286E-55	7.166E-55	2.154E-55
0.000589	7.336E-42	1.321E-38	2.137E-43	4.481E-43	8.968E-23	4.663E-16	9.963E-59	2.36122E-55	1.502E-54	4.515E-55
0.000607	1.401E-41	2.450E-38	4.082E-43	8.543E-43	9.799E-23	5.096E-16	2.080E-58	4.92904E-55	3.143E-54	9.444E-55
0.000625	2.671E-41	4.534E-38	7.780E-43	1.632E-42	1.071E-22	5.568E-16	4.332E-58	1.02664E-54	6.559E-54	1.971E-54
0.000644	5.080E-41	8.372E-38	1.480E-42	3.112E-42	1.170E-22	6.084E-16	9.003E-58	2.13358E-54	1.366E-53	4.105E-54
0.000663	9.840E-41	1.542E-37	2.808E-42	5.920E-42	1.279E-22	6.849E-16	1.867E-57	4.42415E-54	2.386E-53	8.529E-54
0.000683	1.825E-40	2.835E-37	5.316E-42	1.124E-41	1.397E-22	7.265E-16	3.862E-57	9.15339E-54	5.894E-53	1.768E-53
0.000703	3.448E-40	5.200E-37	1.004E-41	2.128E-41	1.527E-22	7.939E-16	7.973E-57	1.88958E-53	1.217E-52	3.658E-53
0.000725	6.500E-40	9.517E-37	1.893E-41	4.021E-41	1.668E-22	8.675E-16	1.642E-56	3.89207E-53	2.512E-52	7.550E-53
0.000746	1.222E-39	1.738E-36	3.561E-41	7.582E-41	1.823E-22	9.479E-16	3.375E-56	7.99885E-53	5.174E-52	1.555E-52
0.000769	2.294E-39	3.166E-36	6.682E-41	1.428E-40	1.992E-22	1.038E-15	6.921E-56	1.64023E-52	1.063E-51	3.195E-52
0.000792	4.295E-39	5.755E-36	1.251E-40	2.677E-40	2.177E-22	1.132E-15	1.416E-55	3.35595E-52	2.180E-51	6.551E-52
0.000816	8.025E-39	1.044E-35	2.337E-40	5.015E-40	2.379E-22	1.237E-15	2.891E-55	6.85104E-52	4.460E-51	1.340E-51
0.000840	1.496E-38	1.889E-35	4.357E-40	9.372E-40	2.599E-22	1.352E-15	5.888E-55	1.3955E-51	9.103E-51	2.736E-51
0.000865	2.782E-38	3.411E-35	8.103E-40	1.748E-39	2.840E-22	1.477E-15	1.197E-54	2.83618E-51	1.854E-50	5.572E-51
0.000891	5.163E-38	6.147E-35	1.504E-39	3.251E-39	3.103E-22	1.614E-15	2.427E-54	5.75135E-51	3.768E-50	1.132E-50
0.000918	9.560E-38	1.105E-34	2.785E-39	6.038E-39	3.391E-22	1.763E-15	4.910E-54	1.16369E-50	7.640E-50	2.298E-50
0.000945	1.766E-37	1.982E-34	5.144E-39	1.118E-38	3.706E-22	1.927E-15	9.913E-54	2.34928E-50	1.546E-49	4.645E-50
0.000974	3.256E-37	3.547E-34	9.483E-39	2.066E-38	4.049E-22	2.106E-15	1.997E-53	4.73223E-50	3.120E-49	9.378E-50
0.001003	5.989E-37	6.334E-34	1.744E-38	3.811E-38	4.425E-22	2.301E-15	4.013E-53	9.51103E-50	6.285E-49	1.889E-49
0.001033	1.099E-36	1.129E-33	3.201E-38	7.012E-38	4.835E-22	2.514E-15	8.048E-53	1.90731E-49	1.263E-48	3.796E-49
0.001064	2.012E-36	2.006E-33	5.861E-38	1.287E-37	5.283E-22	2.747E-15	1.610E-52	3.81633E-49	2.533E-48	7.612E-49
0.001096	3.677E-36	3.559E-33	1.071E-37	2.359E-37	5.773E-22	3.002E-15	3.215E-52	7.61907E-49	5.068E-48	1.523E-48
0.001129	6.703E-36	6.299E-33	1.952E-37	4.310E-37	6.309E-22	3.280E-15	6.404E-52	1.51771E-48	1.012E-47	3.041E-48
0.001163	1.219E-35	1.112E-32	3.551E-37	7.861E-37	6.894E-22	3.585E-15	1.273E-51	3.01654E-48	2.016E-47	6.057E-48
0.001198	2.213E-35	1.960E-32	6.444E-37	1.431E-36	7.533E-22	3.917E-15	2.524E-51	5.98219E-48	4.006E-47	1.204E-47
0.001234	4.006E-35	3.446E-32	1.167E-36	2.597E-36	8.231E-22	4.280E-15	4.965E-51	1.1937E-47	7.945E-47	2.388E-47
	7.239E-35	6.044E-32	2.108E-36	4.706E-36	8.995E-22	4.677E-15	9.861E-51	2.33699E-47	1.572E-46	4.725E-47
	1.305E-34	1.058E-31	3.801E-36	8.507E-36	9.829E-22	5.111E-15	1.943E-50	4.80365E-47	3.104E-46	9.328E-47

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V p	P(d)* $\Delta d^3/d$	P(d)* $\Delta d^3 m/(d^3 m P_{90})$	d < 6.9	$\Sigma P(d) m/(P m)_{90}$
0.001271	2.347E-34	1.847E-31	6.837E-36	1.534E-35	1.074E-21	5.585E-15	3.818E-50	9.04855E-47	6.115E-46	1.838E-46
0.001309	4.213E-34	3.219E-31	1.227E-35	2.761E-35	1.174E-21	6.103E-15	7.488E-50	1.77455E-46	1.202E-45	3.612E-46
0.001348	7.544E-34	5.598E-31	2.197E-35	4.958E-35	1.282E-21	6.669E-15	1.465E-49	3.47238E-46	2.357E-45	7.085E-46
0.001388	1.348E-33	9.708E-31	3.928E-35	8.884E-35	1.401E-21	7.287E-15	2.861E-49	6.77952E-46	4.613E-45	1.386E-45
0.001430	2.403E-33	1.680E-30	6.999E-35	1.588E-34	1.531E-21	7.963E-15	5.573E-49	1.32089E-45	9.008E-45	2.707E-45
0.001473	4.274E-33	2.802E-30	1.245E-34	2.833E-34	1.673E-21	8.701E-15	1.083E-48	2.56706E-45	1.755E-44	5.274E-45
0.001517	7.566E-33	5.000E-30	2.209E-34	5.043E-34	1.828E-21	9.508E-15	2.101E-48	4.97854E-45	3.412E-44	1.025E-44
0.001563	1.343E-32	8.597E-30	3.913E-34	8.955E-34	1.998E-21	1.039E-14	4.065E-48	9.63358E-45	6.617E-44	1.989E-44
0.001610	2.374E-32	1.475E-29	6.913E-34	1.587E-33	2.183E-21	1.135E-14	7.849E-48	1.86007E-44	1.281E-43	3.849E-44
0.001658	4.185E-32	2.524E-29	1.218E-33	2.806E-33	2.386E-21	1.241E-14	1.512E-47	3.58335E-44	2.473E-43	7.432E-44
0.001708	7.361E-32	4.311E-29	2.144E-33	4.950E-33	2.607E-21	1.356E-14	2.906E-47	6.89781E-44	4.765E-43	1.432E-43
0.001759	1.292E-31	7.348E-29	3.763E-33	8.713E-33	2.849E-21	1.481E-14	5.574E-47	1.32101E-43	9.161E-43	2.753E-43
0.001812	2.263E-31	1.249E-28	6.590E-33	1.530E-32	3.113E-21	1.619E-14	1.067E-46	2.5279E-43	1.757E-42	5.281E-43
0.001866	3.953E-31	2.119E-28	1.151E-32	2.682E-32	3.401E-21	1.769E-14	2.037E-46	4.82668E-43	3.363E-42	1.011E-42
0.001922	6.893E-31	3.586E-28	2.008E-32	4.689E-32	3.717E-21	1.933E-14	3.880E-46	9.19527E-43	6.423E-42	1.930E-42
0.001980	1.199E-30	6.057E-28	3.492E-32	8.181E-32	4.061E-21	2.112E-14	7.375E-46	1.74789E-42	1.224E-41	3.678E-42
0.002039	2.081E-30	1.021E-27	6.061E-32	1.424E-31	4.438E-21	2.322E-14	1.399E-45	3.31509E-42	2.327E-41	6.993E-42
0.002100	3.604E-30	1.716E-27	1.050E-31	2.474E-31	4.850E-21	2.522E-14	2.647E-45	6.27347E-42	4.415E-41	1.327E-41
0.002163	6.228E-30	2.879E-27	1.814E-31	4.288E-31	5.299E-21	2.756E-14	4.998E-45	1.18455E-41	8.356E-41	2.511E-41
0.002228	1.074E-29	4.819E-27	3.127E-31	7.415E-31	5.791E-21	3.011E-14	9.417E-45	2.23166E-41	1.578E-40	4.743E-41
0.002295	1.847E-29	8.049E-27	5.380E-31	1.279E-30	6.328E-21	3.290E-14	1.770E-44	4.19503E-41	2.974E-40	8.938E-41
0.002364	3.170E-29	1.341E-26	9.234E-31	2.203E-30	6.914E-21	3.595E-14	3.320E-44	7.86817E-41	5.592E-40	1.681E-40
0.002435	5.430E-29	2.230E-26	1.581E-30	3.784E-30	7.555E-21	3.928E-14	6.213E-44	1.47246E-40	1.049E-39	3.153E-40
0.002508	9.278E-29	3.700E-26	2.702E-30	6.487E-30	8.256E-21	4.293E-14	1.160E-43	2.74945E-40	1.964E-39	5.903E-40
0.002583	1.582E-28	6.125E-26	4.607E-30	1.109E-29	9.022E-21	4.691E-14	2.161E-43	5.12246E-40	3.669E-39	1.102E-39
0.002660	2.691E-28	1.012E-25	7.838E-30	1.893E-29	9.858E-21	5.126E-14	4.018E-43	9.52233E-40	6.837E-39	2.058E-39
0.002740	4.568E-28	1.667E-25	1.330E-29	3.224E-29	1.077E-20	5.602E-14	7.453E-43	1.7682E-39	1.271E-38	3.821E-39
0.002822	7.736E-28	2.741E-25	2.253E-29	5.477E-29	1.177E-20	6.121E-14	1.379E-42	3.28864E-39	2.359E-38	7.090E-39
0.002894	2.204E-27	7.362E-25	6.420E-29	1.570E-28	1.406E-20	7.309E-14	4.692E-42	1.11203E-38	8.086E-38	2.425E-38
0.003004	3.708E-27	1.202E-24	1.080E-28	2.651E-28	1.536E-20	7.986E-14	8.626E-42	2.04428E-38	1.487E-37	4.469E-38
0.003177	6.225E-27	1.960E-24	1.813E-28	4.464E-28	1.678E-20	8.727E-14	1.582E-41	3.74967E-38	2.735E-37	8.219E-38
0.003272	1.043E-26	3.186E-24	3.036E-28	7.500E-28	1.894E-20	9.538E-14	2.896E-41	6.86244E-38	5.018E-37	1.508E-37
0.003370	1.742E-26	5.170E-24	5.074E-28	1.257E-27	2.004E-20	1.042E-13	5.288E-41	1.25313E-37	9.188E-37	2.761E-37
0.003471	2.905E-26	8.369E-24	8.461E-28	2.103E-27	2.190E-20	1.139E-13	9.634E-41	2.2832E-37	1.679E-37	5.044E-37
0.003575	4.833E-26	1.352E-23	1.408E-27	3.511E-27	2.393E-20	1.244E-13	1.751E-40	4.15072E-37	3.060E-36	9.195E-37
0.003682	8.022E-26	2.178E-23	2.337E-27	5.848E-27	2.615E-20	1.360E-13	3.177E-40	7.52896E-37	5.563E-36	1.672E-36
0.003793	1.329E-25	3.503E-23	3.870E-27	9.718E-27	2.857E-20	1.486E-13	5.750E-40	1.36263E-36	1.010E-35	3.035E-36
0.003907	2.186E-25	5.620E-23	6.395E-27	1.611E-26	3.122E-20	1.623E-13	1.038E-39	2.46066E-36	1.829E-35	5.486E-36
0.004024	3.621E-25	8.998E-23	1.055E-26	2.666E-26	3.412E-20	1.774E-13	1.871E-39	4.43361E-36	3.304E-35	9.929E-36
0.004145	5.957E-25	1.437E-22	1.735E-26	4.401E-26	3.728E-20	1.939E-13	3.363E-39	7.97088E-36	5.956E-35	1.790E-35
0.004269	9.778E-25	2.291E-22	2.848E-26	7.249E-26	4.074E-20	2.118E-13	6.033E-39	1.42976E-35	1.071E-34	3.220E-35
0.004397	1.602E-24	3.642E-22	4.665E-26	1.191E-25	4.451E-20	2.315E-13	1.080E-38	2.55897E-35	1.923E-34	5.779E-35

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)	P(d) Δd	$\Sigma P(d)\Delta d$	$\pi d^3/6$	$V\rho$	P(d) Δd /m(d)	P(d) Δd /m(d) ΔP_{50}	d < 6.9	$\Sigma P(d)$ m(P m) ΔP_{50}
0.004529	2.617E-24	5.779E-22	7.624E-26	1.954E-25	4.864E-20	2.529E-13	1.928E-38	4.56979E-35	3.444E-34	1.035E-34
0.004685	4.268E-24	9.149E-22	1.243E-25	3.197E-25	5.315E-20	2.784E-13	3.436E-38	8.14254E-35	6.163E-34	1.849E-34
0.004805	6.944E-24	1.445E-21	2.023E-25	5.219E-25	5.808E-20	3.020E-13	6.108E-38	1.44762E-34	1.097E-33	3.297E-34
0.004949	1.127E-23	2.278E-21	3.283E-25	8.503E-25	6.347E-20	3.300E-13	1.094E-37	2.56792E-34	1.992E-33	5.865E-34
0.005067	1.826E-23	3.582E-21	5.318E-25	1.382E-24	6.935E-20	3.606E-13	1.918E-37	4.54505E-34	3.464E-33	1.041E-33
0.005250	2.951E-23	5.620E-21	8.595E-25	2.242E-24	7.578E-20	3.941E-13	3.387E-37	8.02654E-34	6.135E-33	1.844E-33
0.005408	4.758E-23	8.789E-21	1.386E-24	3.627E-24	8.281E-20	4.306E-13	5.968E-37	1.41433E-33	1.084E-32	3.258E-33
0.005570	7.656E-23	1.374E-20	2.230E-24	5.857E-24	9.049E-20	4.705E-13	1.049E-36	2.48658E-33	1.912E-32	5.745E-33
0.005737	1.229E-22	2.142E-20	3.580E-24	9.437E-24	9.888E-20	5.142E-13	1.841E-36	4.362E-33	3.363E-32	1.011E-32
0.005909	1.969E-22	3.331E-20	5.734E-24	1.517E-23	1.080E-19	5.618E-13	3.222E-36	7.63486E-33	5.904E-32	1.774E-32
0.006087	3.146E-22	5.169E-20	9.164E-24	2.434E-23	1.181E-19	6.139E-13	5.626E-36	1.33336E-32	1.034E-31	3.108E-32
0.006269	5.017E-22	8.003E-20	1.461E-23	3.895E-23	1.290E-19	6.709E-13	9.804E-36	2.32342E-32	1.807E-31	5.431E-32
0.006457	7.983E-22	1.236E-19	2.325E-23	6.220E-23	1.410E-19	7.331E-13	1.705E-35	4.03959E-32	3.151E-31	9.471E-32
0.006651	1.267E-21	1.906E-19	3.691E-23	9.911E-23	1.540E-19	8.011E-13	2.957E-35	7.00775E-32	5.483E-31	1.648E-31
0.006851	2.008E-21	2.930E-19	5.847E-23	1.576E-22	1.683E-19	8.759E-13	5.118E-35	1.21297E-31	9.520E-31	2.861E-31
0.007056	3.173E-21	4.497E-19	9.241E-23	2.500E-22	1.839E-19	9.569E-13	8.839E-35	2.09487E-31	1.649E-30	4.956E-31
0.007268	5.004E-21	6.885E-19	1.457E-22	3.957E-22	2.010E-19	1.045E-12	1.523E-34	3.60987E-31	2.850E-30	8.566E-31
0.007486	7.873E-21	1.052E-18	2.293E-22	6.250E-22	2.198E-19	1.142E-12	2.618E-34	6.20689E-31	4.916E-30	1.477E-30
0.007710	1.236E-20	1.603E-18	3.600E-22	9.850E-22	2.400E-19	1.248E-12	4.493E-34	1.06478E-30	8.459E-30	2.542E-30
0.007842	1.936E-20	2.438E-18	5.639E-22	1.549E-21	2.623E-19	1.364E-12	7.691E-34	1.82259E-30	1.452E-29	4.365E-30
0.008180	3.026E-20	3.700E-18	8.814E-22	2.430E-21	2.866E-19	1.490E-12	1.313E-33	3.1128E-30	2.488E-29	7.477E-30
0.008425	4.719E-20	5.601E-18	1.375E-21	3.805E-21	3.131E-19	1.628E-12	2.238E-33	5.30451E-30	4.253E-29	1.278E-29
0.008678	7.343E-20	8.462E-18	2.139E-21	5.944E-21	3.422E-19	1.779E-12	3.806E-33	9.01925E-30	7.255E-29	2.180E-29
0.008938	1.140E-19	1.275E-17	3.321E-21	9.264E-21	3.739E-19	1.944E-12	6.456E-33	1.53013E-29	1.235E-28	3.710E-29
0.009207	1.768E-19	1.918E-17	5.144E-21	1.441E-20	4.086E-19	2.125E-12	1.093E-32	2.59009E-29	2.098E-28	6.300E-29
0.009483	2.730E-19	2.879E-17	7.951E-21	2.236E-20	4.465E-19	2.322E-12	1.846E-32	4.37456E-29	3.552E-28	1.067E-28
0.009767	4.210E-19	4.310E-17	1.226E-20	3.462E-20	4.879E-19	2.537E-12	3.111E-32	7.37201E-29	6.008E-28	1.805E-28
0.010060	6.478E-19	6.439E-17	1.887E-20	5.349E-20	5.331E-19	2.772E-12	5.230E-32	1.23956E-28	1.013E-27	3.044E-28
0.010362	9.946E-19	9.598E-17	2.897E-20	8.248E-20	5.825E-19	3.029E-12	8.775E-32	2.07961E-28	1.705E-27	5.124E-28
0.010673	1.524E-18	1.428E-16	4.438E-20	1.269E-19	6.366E-19	3.310E-12	1.469E-31	3.4812E-28	2.863E-27	8.605E-28
0.010993	2.329E-18	2.118E-16	6.783E-20	1.947E-19	6.956E-19	3.617E-12	2.453E-31	5.81441E-28	4.798E-27	1.442E-27
0.011323	3.552E-18	3.137E-16	1.034E-19	2.981E-19	7.601E-19	3.952E-12	4.089E-31	9.68979E-28	8.023E-27	2.411E-27
0.011663	5.405E-18	4.634E-16	1.574E-19	4.555E-19	8.306E-19	4.319E-12	6.799E-31	1.61122E-27	1.338E-26	4.022E-27
0.012012	8.206E-18	6.831E-16	2.390E-19	6.945E-19	9.076E-19	4.719E-12	1.128E-30	2.67317E-27	2.228E-26	6.695E-27
0.012373	1.243E-17	1.005E-15	3.621E-19	1.057E-18	9.917E-19	5.157E-12	1.867E-30	4.42517E-27	3.700E-26	1.112E-26
0.012744	1.879E-17	1.474E-15	5.473E-19	1.604E-18	1.084E-18	5.635E-12	3.084E-30	7.30911E-27	6.133E-26	1.843E-26
0.013126	2.834E-17	2.159E-15	8.254E-19	2.429E-18	1.194E-18	6.158E-12	5.083E-30	1.20457E-26	1.014E-25	3.048E-26
0.013520	4.265E-17	3.154E-15	1.242E-18	3.671E-18	1.294E-18	6.729E-12	8.358E-30	1.98075E-26	1.673E-25	5.028E-26
0.013926	6.403E-17	4.598E-15	1.865E-18	5.536E-18	1.414E-18	7.353E-12	1.371E-29	3.24981E-26	2.755E-25	8.278E-26
0.014343	9.593E-17	6.888E-15	2.794E-18	8.330E-18	1.545E-18	8.035E-12	2.245E-29	5.32009E-26	4.525E-25	1.360E-25
0.014774	1.434E-16	9.706E-15	4.176E-18	1.251E-17	1.688E-18	8.780E-12	3.667E-29	8.68983E-26	7.417E-25	2.229E-25
0.015217	2.139E-16	1.405E-14	6.229E-18	1.874E-17	1.845E-18	9.594E-12	5.976E-29	1.41623E-25	1.213E-24	3.645E-25
0.015673	3.183E-16	2.031E-14	9.270E-18	2.801E-17	2.016E-18	1.048E-11	9.718E-29	2.30298E-25	1.979E-24	5.948E-25

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	$V\rho$	P(d)* $\Delta d^3/d$	P(d)* $\Delta d^3 m/(d^3 m P_{90})$	d < 6.9	$\Sigma P(d) m/(P m)_{90}$
0.016144	4.726E-16	2.927E-14	1.376E-17	4.177E-17	2.203E-18	1.146E-11	1.577E-28	3.736E-25	3.223E-24	9.685E-25
0.016628	7.001E-16	4.210E-14	2.039E-17	6.218E-17	2.407E-18	1.252E-11	2.552E-28	6.04917E-25	5.236E-24	1.573E-24
0.017127	1.035E-15	6.043E-14	3.014E-17	9.230E-17	2.630E-18	1.368E-11	4.123E-28	9.77144E-25	8.487E-24	2.550E-24
0.017641	1.526E-15	8.653E-14	4.446E-17	1.368E-16	2.874E-18	1.495E-11	6.645E-28	1.57481E-24	1.373E-23	4.125E-24
0.018170	2.246E-15	1.236E-13	6.543E-17	2.022E-16	3.141E-18	1.633E-11	1.069E-27	2.53244E-24	2.215E-23	6.658E-24
0.018715	3.298E-15	1.762E-13	9.607E-17	2.993E-16	3.432E-18	1.785E-11	1.715E-27	4.06335E-24	3.568E-23	1.072E-23
0.019276	4.832E-15	2.507E-13	1.407E-16	4.390E-16	3.750E-18	1.950E-11	2.745E-27	6.50519E-24	5.732E-23	1.723E-23
0.019855	7.064E-15	3.558E-13	2.058E-16	6.448E-16	4.098E-18	2.131E-11	4.385E-27	1.03912E-23	9.190E-23	2.762E-23
0.020450	1.030E-14	5.038E-13	3.001E-16	9.449E-16	4.478E-18	2.329E-11	6.988E-27	1.65618E-23	1.470E-22	4.418E-23
0.021064	1.499E-14	7.119E-13	4.367E-16	1.382E-15	4.893E-18	2.548E-11	1.111E-26	2.63370E-23	2.347E-22	7.052E-23
0.021696	2.177E-14	1.004E-12	6.342E-16	2.016E-15	5.347E-18	2.781E-11	1.763E-26	4.17908E-23	3.737E-22	1.123E-22
0.022347	3.155E-14	1.412E-12	9.188E-16	2.935E-15	5.843E-18	3.038E-11	2.792E-26	6.61628E-23	5.939E-22	1.785E-22
0.023017	4.560E-14	1.981E-12	1.328E-15	4.263E-15	6.385E-18	3.320E-11	4.410E-26	1.04515E-22	9.417E-22	2.830E-22
0.023708	6.578E-14	2.775E-12	1.916E-15	6.179E-15	6.977E-18	3.628E-11	6.951E-26	1.6473E-22	1.490E-21	4.477E-22
0.024419	9.487E-14	3.877E-12	2.757E-15	8.936E-15	7.624E-18	3.964E-11	1.093E-25	2.59061E-22	2.352E-21	7.068E-22
0.025151	1.359E-13	5.405E-12	3.960E-15	1.290E-14	8.331E-18	4.332E-11	1.715E-25	4.06501E-22	3.705E-21	1.113E-21
0.025906	1.948E-13	7.519E-12	5.673E-15	1.857E-14	9.103E-18	4.734E-11	2.685E-25	6.36433E-22	5.822E-21	1.750E-21
0.026693	2.785E-13	1.044E-11	8.110E-15	2.688E-14	9.947E-18	5.173E-11	4.195E-25	9.94203E-22	9.131E-21	2.744E-21
0.027484	3.972E-13	1.445E-11	1.157E-14	3.825E-14	1.087E-17	5.652E-11	6.539E-25	1.54983E-21	1.429E-20	4.294E-21
0.028308	5.653E-13	1.997E-11	1.646E-14	5.471E-14	1.188E-17	6.176E-11	1.017E-24	2.40898E-21	2.231E-20	6.704E-21
0.029157	8.027E-13	2.753E-11	2.338E-14	7.809E-14	1.298E-17	6.749E-11	1.578E-24	3.73968E-21	3.475E-20	1.044E-20
0.030032	1.137E-12	3.787E-11	3.313E-14	1.112E-13	1.418E-17	7.375E-11	2.443E-24	5.79002E-21	5.402E-20	1.623E-20
0.030933	1.608E-12	5.198E-11	4.683E-14	1.581E-13	1.550E-17	8.059E-11	3.774E-24	8.94459E-21	8.378E-20	2.518E-20
0.031861	2.268E-12	7.119E-11	6.606E-14	2.241E-13	1.693E-17	8.808E-11	5.818E-24	1.37871E-20	1.297E-19	3.896E-20
0.032817	3.192E-12	9.728E-11	9.298E-14	3.171E-13	1.850E-17	9.623E-11	8.947E-24	2.12039E-20	2.002E-19	6.017E-20
0.033801	4.483E-12	1.326E-10	1.308E-13	4.477E-13	2.022E-17	1.051E-10	1.373E-23	3.26379E-20	3.085E-19	9.271E-20
0.034810	6.282E-12	1.804E-10	1.830E-13	6.306E-13	2.210E-17	1.149E-10	2.102E-23	4.98191E-20	4.743E-19	1.425E-19
0.035860	8.792E-12	2.449E-10	2.558E-13	8.864E-13	2.414E-17	1.258E-10	3.211E-23	7.61086E-20	7.275E-19	2.186E-19
0.036936	1.225E-11	3.317E-10	3.568E-13	1.243E-12	2.638E-17	1.372E-10	4.895E-23	1.16012E-19	1.114E-18	3.346E-19
0.038044	1.705E-11	4.482E-10	4.986E-13	1.740E-12	2.883E-17	1.499E-10	7.445E-23	1.76443E-19	1.701E-18	5.111E-19
0.039185	2.368E-11	6.043E-10	6.897E-13	2.430E-12	3.150E-17	1.638E-10	1.130E-22	2.67754E-19	2.592E-18	7.788E-19
0.040361	3.281E-11	8.129E-10	9.556E-13	3.385E-12	3.442E-17	1.790E-10	1.711E-22	4.05415E-19	3.941E-18	1.184E-18
0.041571	4.536E-11	1.091E-09	1.321E-12	4.706E-12	3.762E-17	1.958E-10	2.584E-22	6.12484E-19	5.979E-18	1.797E-18
0.042818	6.258E-11	1.461E-09	1.823E-12	6.529E-12	4.110E-17	2.137E-10	3.896E-22	9.23254E-19	9.051E-18	2.720E-18
0.044103	8.613E-11	1.953E-09	2.509E-12	9.038E-12	4.492E-17	2.338E-10	5.859E-22	1.38881E-18	1.367E-17	4.109E-18
0.045426	1.183E-10	2.604E-09	3.445E-12	1.248E-11	4.908E-17	2.552E-10	8.793E-22	2.08386E-18	2.061E-17	6.192E-18
0.046789	1.621E-10	3.464E-09	4.721E-12	1.720E-11	5.363E-17	2.789E-10	1.317E-21	3.12028E-18	3.099E-17	9.313E-18
0.048193	2.216E-10	4.598E-09	6.455E-12	2.366E-11	5.861E-17	3.047E-10	1.967E-21	4.66169E-18	4.650E-17	1.397E-17
0.049638	3.023E-10	6.090E-09	8.805E-12	3.246E-11	6.404E-17	3.330E-10	2.932E-21	6.94909E-18	6.963E-17	2.092E-17
0.051127	4.115E-10	8.048E-09	1.199E-11	4.445E-11	6.998E-17	3.639E-10	4.361E-21	1.03358E-17	1.040E-16	3.126E-17
0.052661	5.589E-10	1.061E-08	1.628E-11	6.073E-11	7.647E-17	3.976E-10	6.472E-21	1.53388E-17	1.551E-16	4.660E-17
0.054241	7.573E-10	1.396E-08	2.206E-11	8.278E-11	8.356E-17	4.345E-10	9.594E-21	2.27127E-17	2.306E-16	6.931E-17
0.055868	1.024E-09	1.833E-08	2.982E-11	1.126E-10	9.131E-17	4.748E-10	1.416E-20	3.35567E-17	3.423E-16	1.029E-16

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	$P(d)$	$P(d)/d$	$P(d)/d^3$	$\Sigma P(d)/d$	$\pi d^3/6$	$V \rho$	$P(d)/d^3$	$P(d)/d^3 \cdot m/(d^3 \cdot P_{\text{ref}})$	$d < 6.9$	$\Sigma P(d) \cdot m/(P \cdot m)_{\text{ref}}$
0.057544	1.381E-09	2.400E-08	4.023E-11	1.528E-10	9.977E-17	5.189E-10	2.087E-20	4.94677E-17	5.089E-16	1.923E-16
0.059271	1.859E-09	3.137E-08	5.416E-11	2.070E-10	1.090E-16	5.669E-10	3.070E-20	7.27604E-17	7.490E-16	2.251E-16
0.061049	2.497E-09	4.090E-08	7.273E-11	2.797E-10	1.191E-16	6.195E-10	4.506E-20	1.06782E-16	1.104E-15	3.319E-16
0.062880	3.346E-09	5.322E-08	9.747E-11	3.772E-10	1.302E-16	6.789E-10	6.598E-20	1.56364E-16	1.625E-15	4.882E-16
0.064767	4.474E-09	6.908E-08	1.303E-10	5.075E-10	1.423E-16	7.397E-10	9.640E-20	2.28457E-16	2.385E-15	7.167E-16
0.066710	5.969E-09	8.948E-08	1.739E-10	6.814E-10	1.554E-16	8.032E-10	1.405E-19	3.33045E-16	3.493E-15	1.050E-15
0.068711	7.946E-09	1.156E-07	2.314E-10	9.128E-10	1.699E-16	8.832E-10	2.044E-19	4.84434E-16	5.105E-15	1.534E-15
0.070772	1.055E-08	1.491E-07	3.074E-10	1.220E-09	1.856E-16	9.651E-10	2.867E-19	7.03067E-16	7.445E-15	2.237E-15
0.072896	1.399E-08	1.919E-07	4.073E-10	1.628E-09	2.028E-16	1.058E-09	4.296E-19	1.0181E-15	1.083E-14	3.255E-15
0.075082	1.849E-08	2.463E-07	5.386E-10	2.168E-09	2.216E-16	1.152E-09	6.207E-19	1.47101E-15	1.573E-14	4.726E-15
0.077335	2.440E-08	3.155E-07	7.106E-10	2.877E-09	2.422E-16	1.259E-09	8.948E-19	2.12067E-15	2.278E-14	6.847E-15
0.079655	3.211E-08	4.032E-07	9.354E-10	3.812E-09	2.646E-16	1.376E-09	1.287E-18	3.05043E-15	3.293E-14	9.897E-15
0.082045	4.218E-08	5.141E-07	1.229E-09	5.041E-09	2.892E-16	1.504E-09	1.847E-18	4.37806E-15	4.750E-14	1.428E-14
0.084508	5.528E-08	6.541E-07	1.610E-09	6.651E-09	3.160E-16	1.643E-09	2.645E-18	6.2895E-15	6.837E-14	2.055E-14
0.087041	7.228E-08	8.304E-07	2.105E-09	8.768E-09	3.453E-16	1.795E-09	3.780E-18	8.981E-15	9.817E-14	2.850E-14
0.089652	9.430E-08	1.052E-06	2.747E-09	1.150E-08	3.773E-16	1.962E-09	5.389E-18	1.27712E-14	1.407E-13	4.227E-14
0.092342	1.228E-07	1.329E-06	3.576E-09	1.508E-08	4.123E-16	2.144E-09	7.866E-18	1.81667E-14	2.011E-13	6.044E-14
0.095112	1.595E-07	1.676E-06	4.644E-09	1.972E-08	4.505E-16	2.343E-09	1.088E-17	2.57842E-14	2.869E-13	8.623E-14
0.097966	2.066E-07	2.109E-06	6.019E-09	2.574E-08	4.923E-16	2.560E-09	1.541E-17	3.65143E-14	4.084E-13	1.227E-13
0.100905	2.672E-07	2.648E-06	7.783E-09	3.352E-08	5.378E-16	2.797E-09	2.177E-17	5.15945E-14	5.801E-13	1.743E-13
0.103932	3.448E-07	3.317E-06	1.004E-08	4.357E-08	5.878E-16	3.057E-09	3.069E-17	7.27404E-14	8.222E-13	2.471E-13
0.107050	4.438E-07	4.146E-06	1.293E-08	5.649E-08	6.423E-16	3.340E-09	4.318E-17	1.02324E-13	1.163E-12	3.494E-13
0.110281	5.701E-07	5.170E-06	1.660E-08	7.310E-08	7.019E-16	3.650E-09	6.060E-17	1.4362E-13	1.641E-12	4.930E-13
0.113589	7.306E-07	6.433E-06	2.128E-08	9.438E-08	7.670E-16	3.988E-09	8.487E-17	2.01132E-13	2.310E-12	6.942E-13
0.116976	9.343E-07	7.987E-06	2.721E-08	1.216E-07	8.381E-16	4.358E-09	1.186E-16	2.81047E-13	3.245E-12	9.752E-13
0.120485	1.192E-06	9.894E-06	3.472E-08	1.563E-07	9.158E-16	4.762E-09	1.653E-16	3.9184E-13	4.549E-12	1.367E-12
0.124100	1.518E-06	1.223E-05	4.420E-08	2.005E-07	1.001E-15	5.204E-09	2.300E-16	5.45092E-13	6.383E-12	1.912E-12
0.127823	1.928E-06	1.508E-05	5.614E-08	2.567E-07	1.094E-15	5.689E-09	3.192E-16	7.56593E-13	8.880E-12	2.869E-12
0.131657	2.443E-06	1.856E-05	7.116E-08	3.278E-07	1.195E-15	6.214E-09	4.421E-16	1.04782E-12	1.237E-11	3.717E-12
0.135607	3.089E-06	2.278E-05	8.998E-08	4.178E-07	1.306E-15	6.790E-09	6.110E-16	1.44791E-12	1.719E-11	5.164E-12
0.139675	3.898E-06	2.791E-05	1.135E-07	5.313E-07	1.427E-15	7.419E-09	8.424E-16	1.99632E-12	2.383E-11	7.161E-12
0.143866	4.907E-06	3.411E-05	1.429E-07	6.743E-07	1.559E-15	8.107E-09	1.159E-15	2.7463E-12	3.297E-11	9.907E-12
0.148182	6.164E-06	4.160E-05	1.795E-07	8.538E-07	1.704E-15	8.859E-09	1.591E-15	3.76963E-12	4.551E-11	1.368E-11
0.152627	7.726E-06	5.062E-05	2.250E-07	1.079E-06	1.862E-15	9.680E-09	2.178E-15	5.16274E-12	6.289E-11	1.884E-11
0.157206	9.662E-06	6.146E-05	2.814E-07	1.360E-06	2.034E-15	1.058E-08	2.977E-15	7.05494E-12	8.617E-11	2.589E-11
0.161922	1.206E-05	7.446E-05	3.511E-07	1.711E-06	2.223E-15	1.156E-08	4.059E-15	9.61917E-12	1.182E-10	3.551E-11
0.166780	1.501E-05	9.000E-05	4.372E-07	2.149E-06	2.429E-15	1.263E-08	5.522E-15	1.30862E-11	1.617E-10	4.860E-11
0.171793	1.864E-05	1.085E-04	5.431E-07	2.692E-06	2.654E-15	1.380E-08	7.495E-15	1.77632E-11	2.208E-10	6.636E-11
0.176937	2.311E-05	1.306E-04	6.731E-07	3.365E-06	2.900E-15	1.508E-08	1.015E-14	2.40581E-11	3.009E-10	9.042E-11
0.182245	2.858E-05	1.568E-04	8.324E-07	4.197E-06	3.169E-15	1.648E-08	1.372E-14	3.25111E-11	4.091E-10	1.229E-10
0.187712	3.526E-05	1.878E-04	1.027E-06	5.224E-06	3.483E-15	1.801E-08	1.850E-14	4.38363E-11	5.549E-10	1.668E-10
0.193343	4.342E-05	2.246E-04	1.265E-06	6.489E-06	3.784E-15	1.968E-08	2.488E-14	5.8975E-11	7.512E-10	2.257E-10
0.199144	5.334E-05	2.678E-04	1.553E-06	8.042E-06	4.135E-15	2.150E-08	3.340E-14	7.9165E-11	1.015E-09	3.049E-10

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	$V\rho$	P(d) $\Delta d^3/d$	P(d) $\Delta d^3 m/(d^3 m P_{50})$	d < 6.9	$\Sigma P(d) m/(P m)_{50}$
0.205118	6.537E-05	3.187E-04	1.904E-06	9.946E-06	4.519E-15	2.350E-08	4.474E-14	1.0603E-10	1.367E-09	4.109E-10
0.211272	7.995E-05	3.784E-04	2.329E-06	1.227E-05	4.938E-15	2.568E-08	5.979E-14	1.4169E-10	1.839E-09	5.526E-10
0.217610	9.756E-05	4.483E-04	2.842E-06	1.512E-05	5.396E-15	2.808E-08	7.972E-14	1.8937E-10	2.468E-09	7.416E-10
0.224138	1.188E-04	5.299E-04	3.460E-06	1.858E-05	5.896E-15	3.066E-08	1.061E-13	2.5136E-10	3.304E-09	9.929E-10
0.230862	1.443E-04	6.250E-04	4.203E-06	2.278E-05	6.443E-15	3.350E-08	1.408E-13	3.3682E-10	4.414E-09	1.327E-09
0.237788	1.749E-04	7.355E-04	5.094E-06	2.787E-05	7.040E-15	3.661E-08	1.865E-13	4.4196E-10	5.885E-09	1.769E-09
0.244922	2.115E-04	8.637E-04	6.161E-06	3.403E-05	7.893E-15	4.000E-08	2.465E-13	5.8408E-10	7.829E-09	2.353E-09
0.252269	2.553E-04	1.012E-03	7.435E-06	4.147E-05	8.406E-15	4.371E-08	3.250E-13	7.7017E-10	1.039E-08	3.123E-09
0.259837	3.073E-04	1.183E-03	8.952E-06	5.042E-05	9.186E-15	4.776E-08	4.276E-13	1.0133E-09	1.376E-08	4.136E-09
0.267633	3.692E-04	1.605E-03	1.079E-05	6.117E-05	1.004E-14	5.219E-08	5.613E-13	1.33021E-09	1.819E-08	5.486E-09
0.275662	4.26E-04	1.805E-03	1.289E-05	7.406E-05	1.097E-14	5.703E-08	7.352E-13	1.74233E-09	2.399E-08	7.209E-09
0.283931	5.293E-04	1.864E-03	1.542E-05	8.948E-05	1.199E-14	6.232E-08	9.608E-13	2.2770E-09	3.168E-08	9.486E-09
0.292449	6.317E-04	2.160E-03	1.840E-05	1.079E-04	1.310E-14	6.810E-08	1.253E-12	2.96927E-09	4.145E-08	1.246E-08
0.301223	7.521E-04	2.497E-03	2.191E-05	1.298E-04	1.431E-14	7.442E-08	1.630E-12	3.86328E-09	5.430E-08	1.632E-08
0.310260	8.935E-04	2.880E-03	2.602E-05	1.558E-04	1.564E-14	8.132E-08	2.116E-12	5.01528E-09	7.099E-08	2.133E-08
0.319587	1.059E-03	3.314E-03	3.085E-05	1.867E-04	1.709E-14	8.888E-08	2.741E-12	6.49628E-09	9.261E-08	2.783E-08
0.329154	1.253E-03	3.806E-03	3.649E-05	2.231E-04	1.867E-14	9.710E-08	3.543E-12	8.33584E-09	1.205E-07	3.623E-08
0.339029	1.478E-03	4.360E-03	4.306E-05	2.682E-04	2.040E-14	1.061E-07	4.588E-12	1.08267E-08	1.566E-07	4.705E-08
0.349200	1.741E-03	4.985E-03	5.070E-05	3.169E-04	2.230E-14	1.159E-07	5.878E-12	1.39303E-08	2.029E-07	6.098E-08
0.359676	2.045E-03	5.686E-03	5.956E-05	3.765E-04	2.436E-14	1.267E-07	7.546E-12	1.78837E-08	2.624E-07	7.887E-08
0.370466	2.397E-03	6.471E-03	6.982E-05	4.463E-04	2.682E-14	1.384E-07	9.666E-12	2.29078E-08	3.387E-07	1.018E-07
0.381580	2.804E-03	7.348E-03	8.167E-05	5.280E-04	2.909E-14	1.513E-07	1.235E-11	2.9278E-08	4.361E-07	1.311E-07
0.393027	3.272E-03	8.328E-03	9.531E-05	6.233E-04	3.179E-14	1.653E-07	1.575E-11	3.73363E-08	5.603E-07	1.684E-07
0.404818	3.810E-03	9.412E-03	1.110E-04	7.342E-04	3.474E-14	1.806E-07	2.005E-11	4.75065E-08	7.184E-07	2.159E-07
0.416963	4.427E-03	1.062E-02	1.289E-04	8.632E-04	3.798E-14	1.974E-07	2.545E-11	6.03124E-08	9.191E-07	2.762E-07
0.429472	5.132E-03	1.195E-02	1.495E-04	1.013E-03	4.148E-14	2.157E-07	3.224E-11	7.63998E-08	1.173E-06	3.526E-07
0.442356	5.936E-03	1.342E-02	1.729E-04	1.186E-03	4.532E-14	2.357E-07	4.075E-11	9.65622E-08	1.495E-06	4.492E-07
0.455627	6.850E-03	1.503E-02	1.995E-04	1.385E-03	4.953E-14	2.575E-07	5.138E-11	1.21774E-07	1.900E-06	5.709E-07
0.469285	7.888E-03	1.681E-02	2.298E-04	1.615E-03	5.412E-14	2.814E-07	6.465E-11	1.53226E-07	2.410E-06	7.242E-07
0.483374	9.063E-03	1.875E-02	2.640E-04	1.878E-03	5.914E-14	3.075E-07	8.117E-11	1.92373E-07	3.050E-06	9.165E-07
0.497875	1.039E-02	2.087E-02	3.026E-04	2.181E-03	6.462E-14	3.360E-07	1.017E-10	2.40983E-07	3.852E-06	1.158E-06
0.512812	1.188E-02	2.317E-02	3.461E-04	2.528E-03	7.061E-14	3.672E-07	1.271E-10	3.01204E-07	4.854E-06	1.459E-06
0.528196	1.366E-02	2.568E-02	3.950E-04	2.923E-03	7.716E-14	4.012E-07	1.585E-10	3.75634E-07	6.104E-06	1.834E-06
0.544042	1.544E-02	2.839E-02	4.499E-04	3.372E-03	8.431E-14	4.384E-07	1.972E-10	4.67414E-07	7.859E-06	2.302E-06
0.560363	1.755E-02	3.132E-02	5.111E-04	3.894E-03	9.213E-14	4.791E-07	2.449E-10	5.80324E-07	9.590E-06	2.882E-06
0.577174	1.989E-02	3.447E-02	5.794E-04	4.463E-03	1.007E-13	5.235E-07	3.033E-10	7.18902E-07	1.198E-05	3.601E-06
0.594489	2.250E-02	3.785E-02	6.564E-04	5.118E-03	1.100E-13	5.721E-07	3.749E-10	8.88589E-07	1.494E-05	4.430E-06
0.612324	2.540E-02	4.148E-02	7.398E-04	5.858E-03	1.202E-13	6.251E-07	4.624E-10	1.08588E-06	1.898E-05	5.585E-06
0.630694	2.860E-02	4.535E-02	8.330E-04	6.691E-03	1.314E-13	6.831E-07	5.690E-10	1.34852E-06	2.307E-05	6.934E-06
0.649615	3.214E-02	4.947E-02	9.360E-04	7.627E-03	1.435E-13	7.484E-07	6.966E-10	1.65571E-06	2.858E-05	8.590E-06
0.669103	3.603E-02	5.385E-02	1.049E-03	8.677E-03	1.568E-13	8.156E-07	8.559E-10	2.02834E-06	3.533E-05	1.062E-05
0.689176	4.030E-02	5.848E-02	1.174E-03	9.850E-03	1.714E-13	8.912E-07	1.046E-09	2.4793E-06	4.358E-05	1.310E-05
0.709851	4.498E-02	6.337E-02	1.310E-03	1.116E-02	1.873E-13	9.739E-07	1.276E-09	3.02378E-06	5.364E-05	1.612E-05

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V ρ	P(d) $\Delta d^3/m/d$	P(d) $\Delta d^3 m/(d^3 m P_{50})$	d < 6.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
0.731147	5.009E-02	6.851E-02	1.459E-03	1.262E-02	2.047E-13	1.064E-06	1.553E-09	3.67961E-06	6.589E-05	1.980E-05
0.753081	5.566E-02	7.391E-02	1.621E-03	1.424E-02	2.236E-13	1.163E-06	1.885E-09	4.46771E-06	8.076E-05	2.427E-05
0.775674	6.171E-02	7.955E-02	1.797E-03	1.604E-02	2.444E-13	1.271E-06	2.284E-09	5.41252E-06	9.877E-05	2.968E-05
0.798944	6.828E-02	8.544E-02	1.988E-03	1.803E-02	2.670E-13	1.389E-06	2.761E-09	6.54254E-06	1.208E-04	3.622E-05
0.822912	7.534E-02	9.156E-02	2.194E-03	2.022E-02	2.918E-13	1.517E-06	3.330E-09	7.89085E-06	1.468E-04	4.411E-05
0.847600	8.297E-02	9.789E-02	2.417E-03	2.264E-02	3.188E-13	1.658E-06	4.007E-09	9.49584E-06	1.784E-04	5.361E-05
0.873028	9.117E-02	1.044E-01	2.656E-03	2.529E-02	3.484E-13	1.812E-06	4.811E-09	1.14018E-05	2.163E-04	6.501E-05
0.899218	9.996E-02	1.112E-01	2.911E-03	2.820E-02	3.807E-13	1.980E-06	5.784E-09	1.36599E-05	2.618E-04	7.867E-05
0.926195	1.094E-01	1.181E-01	3.185E-03	3.139E-02	4.160E-13	2.163E-06	6.890E-09	1.63286E-05	3.161E-04	9.500E-05
0.953981	1.194E-01	1.251E-01	3.476E-03	3.487E-02	4.546E-13	2.364E-06	8.218E-09	1.94754E-05	3.809E-04	1.145E-04
0.982600	1.300E-01	1.323E-01	3.786E-03	3.865E-02	4.967E-13	2.583E-06	9.780E-09	2.31767E-05	4.581E-04	1.377E-04
1.012078	1.413E-01	1.396E-01	4.114E-03	4.277E-02	5.428E-13	2.823E-06	1.161E-08	2.75202E-05	5.496E-04	1.652E-04
1.042441	1.531E-01	1.469E-01	4.461E-03	4.723E-02	5.931E-13	3.084E-06	1.378E-08	3.26047E-05	6.581E-04	1.978E-04
1.073714	1.657E-01	1.543E-01	4.825E-03	5.205E-02	6.481E-13	3.370E-06	1.626E-08	3.85427E-05	7.864E-04	2.363E-04
1.105925	1.788E-01	1.617E-01	5.209E-03	5.726E-02	7.082E-13	3.683E-06	1.918E-08	4.54806E-05	9.377E-04	2.818E-04
1.139103	1.926E-01	1.691E-01	5.610E-03	6.287E-02	7.739E-13	4.024E-06	2.257E-08	5.35007E-05	1.116E-03	3.363E-04
1.173276	2.070E-01	1.764E-01	6.028E-03	6.890E-02	8.457E-13	4.397E-06	2.651E-08	6.28225E-05	1.325E-03	3.981E-04
1.208474	2.219E-01	1.836E-01	6.463E-03	7.536E-02	9.241E-13	4.805E-06	3.108E-08	7.36043E-05	1.570E-03	4.717E-04
1.244729	2.374E-01	1.907E-01	6.915E-03	8.228E-02	1.010E-12	5.251E-06	3.631E-08	8.60443E-05	1.856E-03	5.578E-04
1.282070	2.534E-01	1.977E-01	7.381E-03	8.966E-02	1.103E-12	5.738E-06	4.233E-08	0.000100363	2.190E-03	6.581E-04
1.320533	2.699E-01	2.044E-01	7.861E-03	9.752E-02	1.206E-12	6.270E-06	4.929E-08	0.000118803	2.579E-03	7.749E-04
1.360149	2.868E-01	2.109E-01	8.354E-03	1.059E-01	1.318E-12	6.851E-06	5.723E-08	0.000135634	3.030E-03	9.106E-04
1.400953	3.041E-01	2.171E-01	8.857E-03	1.147E-01	1.440E-12	7.486E-06	6.631E-08	0.000157149	3.553E-03	1.068E-03
1.442982	3.217E-01	2.230E-01	9.371E-03	1.241E-01	1.573E-12	8.181E-06	7.686E-08	0.000181673	4.157E-03	1.249E-03
1.486271	3.396E-01	2.285E-01	9.892E-03	1.340E-01	1.719E-12	8.939E-06	8.842E-08	0.000209555	4.855E-03	1.459E-03
1.530859	3.577E-01	2.337E-01	1.042E-02	1.444E-01	1.878E-12	9.768E-06	1.018E-07	0.000241178	5.657E-03	1.700E-03
1.576785	3.759E-01	2.384E-01	1.095E-02	1.554E-01	2.053E-12	1.067E-05	1.169E-07	0.000278954	6.579E-03	1.977E-03
1.624089	3.942E-01	2.427E-01	1.148E-02	1.688E-01	2.243E-12	1.166E-05	1.339E-07	0.00031733	7.635E-03	2.294E-03
1.672811	4.124E-01	2.465E-01	1.201E-02	1.788E-01	2.451E-12	1.275E-05	1.531E-07	0.000362781	8.842E-03	2.657E-03
1.722996	4.305E-01	2.498E-01	1.254E-02	1.914E-01	2.678E-12	1.393E-05	1.748E-07	0.000413819	1.022E-02	3.071E-03
1.774685	4.484E-01	2.526E-01	1.306E-02	2.044E-01	2.927E-12	1.522E-05	1.987E-07	0.000470985	1.179E-02	3.542E-03
1.827926	4.660E-01	2.549E-01	1.357E-02	2.180E-01	3.198E-12	1.663E-05	2.257E-07	0.000534855	1.357E-02	4.077E-03
1.882764	4.832E-01	2.566E-01	1.407E-02	2.321E-01	3.495E-12	1.817E-05	2.557E-07	0.000608033	1.558E-02	4.683E-03
1.939247	4.999E-01	2.578E-01	1.456E-02	2.466E-01	3.819E-12	1.986E-05	2.891E-07	0.000688153	1.786E-02	5.368E-03
1.997424	5.160E-01	2.584E-01	1.503E-02	2.617E-01	4.173E-12	2.170E-05	3.261E-07	0.000772878	2.043E-02	6.141E-03
2.057347	5.315E-01	2.584E-01	1.548E-02	2.772E-01	4.560E-12	2.371E-05	3.671E-07	0.000869892	2.333E-02	7.011E-03
2.119067	5.463E-01	2.578E-01	1.591E-02	2.931E-01	4.982E-12	2.591E-05	4.122E-07	0.000976904	2.658E-02	7.988E-03
2.182639	5.602E-01	2.566E-01	1.632E-02	3.094E-01	5.444E-12	2.831E-05	4.619E-07	0.001094635	3.022E-02	9.082E-03
2.248118	5.731E-01	2.549E-01	1.669E-02	3.261E-01	5.949E-12	3.094E-05	5.164E-07	0.001223823	3.429E-02	1.031E-02
2.315562	5.851E-01	2.527E-01	1.704E-02	3.431E-01	6.501E-12	3.380E-05	5.761E-07	0.001365209	3.884E-02	1.167E-02
2.385029	5.960E-01	2.499E-01	1.736E-02	3.605E-01	7.104E-12	3.694E-05	6.412E-07	0.001519538	4.389E-02	1.319E-02
2.456580	6.057E-01	2.467E-01	1.764E-02	3.781E-01	7.762E-12	4.036E-05	7.121E-07	0.001687544	4.951E-02	1.488E-02
2.530277	6.142E-01	2.422E-01	1.789E-02	3.960E-01	8.482E-12	4.411E-05	7.890E-07	0.001869952	5.573E-02	1.675E-02

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	$P(d)$	$P(d)/d$	$P(d)\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V_p	$P(d)\Delta d^3\text{m}/d$	$P(d)\Delta d^3\text{m}/(d^3\text{m}P_{\text{tot}})$	$d < 6.9$	$\Sigma P(d) \text{ m}/(P \text{ m})_{\text{tot}}$
2.606185	6.214E-01	2.385E-01	1.810E-02	4.141E-01	9.269E-12	4.820E-05	8.724E-07	0.00206746	6.261E-02	1.882E-02
2.684371	6.274E-01	2.337E-01	1.827E-02	4.324E-01	1.013E-11	5.267E-05	9.624E-07	0.002280738	7.020E-02	2.110E-02
2.764902	6.320E-01	2.286E-01	1.841E-02	4.508E-01	1.107E-11	5.755E-05	1.059E-06	0.002510413	7.855E-02	2.361E-02
2.847849	6.352E-01	2.230E-01	1.850E-02	4.693E-01	1.209E-11	6.289E-05	1.163E-06	0.002757061	8.773E-02	2.636E-02
2.933285	6.369E-01	2.171E-01	1.858E-02	4.878E-01	1.321E-11	6.872E-05	1.275E-06	0.003021198	9.778E-02	2.939E-02
3.021293	6.373E-01	2.109E-01	1.858E-02	5.064E-01	1.444E-11	7.508E-05	1.394E-06	0.003303266	1.088E-01	3.269E-02
3.112823	6.363E-01	2.045E-01	1.853E-02	5.249E-01	1.578E-11	8.205E-05	1.521E-06	0.003603623	1.208E-01	3.629E-02
3.205279	6.338E-01	1.977E-01	1.848E-02	5.434E-01	1.724E-11	8.966E-05	1.655E-06	0.003922533	1.338E-01	4.021E-02
3.301438	6.299E-01	1.908E-01	1.835E-02	5.617E-01	1.884E-11	9.707E-05	1.798E-06	0.004260156	1.480E-01	4.447E-02
3.400481	6.247E-01	1.837E-01	1.820E-02	5.799E-01	2.059E-11	1.071E-04	1.948E-06	0.004616531	1.634E-01	4.908E-02
3.502495	6.181E-01	1.765E-01	1.800E-02	5.979E-01	2.250E-11	1.170E-04	2.106E-06	0.004991576	1.800E-01	5.408E-02
3.607570	6.103E-01	1.692E-01	1.778E-02	6.157E-01	2.458E-11	1.278E-04	2.272E-06	0.005385066	1.979E-01	5.947E-02
3.715797	6.012E-01	1.618E-01	1.751E-02	6.332E-01	2.686E-11	1.397E-04	2.446E-06	0.005796634	2.172E-01	6.526E-02
3.827271	5.908E-01	1.544E-01	1.721E-02	6.504E-01	2.935E-11	1.526E-04	2.627E-06	0.006225758	2.379E-01	7.149E-02
3.942089	5.795E-01	1.470E-01	1.688E-02	6.673E-01	3.208E-11	1.668E-04	2.815E-06	0.006871756	2.601E-01	7.816E-02
4.060352	5.670E-01	1.397E-01	1.652E-02	6.838E-01	3.505E-11	1.823E-04	3.010E-06	0.007133777	2.838E-01	8.530E-02
4.182162	5.538E-01	1.324E-01	1.612E-02	7.000E-01	3.830E-11	1.992E-04	3.211E-06	0.007610803	3.092E-01	9.291E-02
4.307627	5.393E-01	1.252E-01	1.571E-02	7.157E-01	4.185E-11	2.176E-04	3.419E-06	0.008101639	3.361E-01	1.010E-01
4.436866	5.242E-01	1.181E-01	1.527E-02	7.309E-01	4.573E-11	2.378E-04	3.631E-06	0.00860492	3.647E-01	1.098E-01
4.569962	5.084E-01	1.112E-01	1.481E-02	7.457E-01	4.997E-11	2.599E-04	3.848E-06	0.009119106	3.951E-01	1.187E-01
4.707061	4.920E-01	1.045E-01	1.433E-02	7.601E-01	5.461E-11	2.840E-04	4.069E-06	0.009642491	4.272E-01	1.284E-01
4.848272	4.750E-01	9.797E-02	1.383E-02	7.739E-01	5.967E-11	3.103E-04	4.293E-06	0.010173203	4.610E-01	1.389E-01
4.993721	4.576E-01	9.163E-02	1.333E-02	7.872E-01	6.520E-11	3.391E-04	4.519E-06	0.010709216	4.967E-01	1.493E-01
5.143532	4.398E-01	8.551E-02	1.281E-02	8.000E-01	7.125E-11	3.705E-04	4.746E-06	0.011248359	5.341E-01	1.605E-01
5.297838	4.218E-01	7.962E-02	1.229E-02	8.123E-01	7.786E-11	4.049E-04	4.974E-06	0.011788327	5.733E-01	1.723E-01
5.456773	4.037E-01	7.397E-02	1.176E-02	8.241E-01	8.508E-11	4.424E-04	5.201E-06	0.012326896	6.143E-01	1.846E-01
5.620477	3.854E-01	6.857E-02	1.123E-02	8.353E-01	9.296E-11	4.834E-04	5.427E-06	0.01286094	6.571E-01	1.975E-01
5.789091	3.672E-01	6.343E-02	1.069E-02	8.460E-01	1.016E-10	5.282E-04	5.649E-06	0.013388448	7.017E-01	2.109E-01
5.962764	3.490E-01	5.853E-02	1.017E-02	8.562E-01	1.110E-10	5.772E-04	5.868E-06	0.013906548	7.480E-01	2.248E-01
6.141646	3.310E-01	5.390E-02	9.642E-03	8.658E-01	1.213E-10	6.307E-04	6.081E-06	0.014412517	7.959E-01	2.392E-01
6.325896	3.133E-01	4.952E-02	9.124E-03	8.748E-01	1.325E-10	6.892E-04	6.289E-06	0.014903624	8.455E-01	2.541E-01
6.515673	2.958E-01	4.540E-02	8.615E-03	8.836E-01	1.448E-10	7.531E-04	6.488E-06	0.015377137	8.967E-01	2.695E-01
6.900000	2.630E-01	3.811E-02	1.463E-02	8.982E-01	1.720E-10	8.944E-04	1.310E-05	0.031047107	1.000E+00	3.005E-01
7.107000	2.467E-01	3.471E-02	7.185E-03	9.054E-01	1.880E-10	9.774E-04	7.022E-06	0.016641421	1.000E+00	3.172E-01
7.320210	2.309E-01	3.154E-02	6.724E-03	9.121E-01	2.054E-10	1.068E-03	7.182E-06	0.017019987	1.000E+00	3.342E-01
7.539816	2.156E-01	2.860E-02	6.280E-03	9.184E-01	2.244E-10	1.167E-03	7.329E-06	0.017368389	1.000E+00	3.515E-01
7.766011	2.009E-01	2.587E-02	5.851E-03	9.242E-01	2.452E-10	1.275E-03	7.482E-06	0.017684443	1.000E+00	3.692E-01
7.998991	1.868E-01	2.335E-02	5.440E-03	9.297E-01	2.680E-10	1.394E-03	7.581E-06	0.017966138	1.000E+00	3.872E-01
8.238961	1.733E-01	2.103E-02	5.047E-03	9.347E-01	2.928E-10	1.523E-03	7.685E-06	0.018211662	1.000E+00	4.054E-01
8.486130	1.604E-01	1.890E-02	4.671E-03	9.394E-01	3.200E-10	1.664E-03	7.772E-06	0.01841942	1.000E+00	4.238E-01
8.740714	1.481E-01	1.694E-02	4.314E-03	9.437E-01	3.497E-10	1.818E-03	7.843E-06	0.01858805	1.000E+00	4.424E-01
9.002935	1.365E-01	1.516E-02	3.978E-03	9.477E-01	3.821E-10	1.987E-03	7.898E-06	0.018716439	1.000E+00	4.611E-01
9.273023	1.255E-01	1.353E-02	3.655E-03	9.513E-01	4.175E-10	2.171E-03	7.934E-06	0.018803735	1.000E+00	4.799E-01

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	$V\rho$	P(d)* $\Delta d^m/d$	P(d)* $\Delta d^m/(d^m \cdot m \cdot P_{\text{ref}})$	d < 6.9	$\Sigma P(d) \cdot m/(P \cdot m)_{\text{ref}}$
9.551214	1.151E-01	1.205E-02	3.353E-03	9.547E-01	4.562E-10	2.372E-03	7.954E-06	0.018849357	1.000E+00	4.988E-01
9.837750	1.054E-01	1.071E-02	3.069E-03	9.578E-01	4.985E-10	2.592E-03	7.955E-06	0.018853	1.000E+00	5.176E-01
10.132883	9.622E-02	9.496E-03	2.803E-03	9.606E-01	5.448E-10	2.833E-03	7.939E-06	0.018814639	1.000E+00	5.365E-01
10.436869	8.768E-02	8.401E-03	2.554E-03	9.631E-01	5.953E-10	3.095E-03	7.905E-06	0.018734532	1.000E+00	5.552E-01
10.749975	7.972E-02	7.416E-03	2.322E-03	9.654E-01	6.505E-10	3.382E-03	7.854E-06	0.018613211	1.000E+00	5.738E-01
11.072474	7.232E-02	6.532E-03	2.107E-03	9.675E-01	7.108E-10	3.696E-03	7.786E-06	0.018451483	1.000E+00	5.923E-01
11.404649	6.546E-02	5.740E-03	1.907E-03	9.695E-01	7.767E-10	4.039E-03	7.701E-06	0.018250415	1.000E+00	6.105E-01
12.000000	5.486E-02	4.572E-03	1.722E-03	9.722E-01	9.048E-10	4.705E-03	7.281E-06	0.030347315	1.000E+00	6.409E-01
12.360000	4.936E-02	3.993E-03	1.438E-03	9.736E-01	9.887E-10	5.141E-03	7.391E-06	0.017515315	1.000E+00	6.584E-01
12.730800	4.431E-02	3.480E-03	1.290E-03	9.749E-01	1.080E-09	5.618E-03	7.250E-06	0.017181267	1.000E+00	6.755E-01
13.112724	3.969E-02	3.026E-03	1.156E-03	9.761E-01	1.181E-09	6.139E-03	7.096E-06	0.016816048	1.000E+00	6.924E-01
13.506106	3.547E-02	2.626E-03	1.033E-03	9.771E-01	1.290E-09	6.708E-03	6.929E-06	0.01642193	1.000E+00	7.088E-01
13.911289	3.163E-02	2.273E-03	9.211E-04	9.780E-01	1.410E-09	7.330E-03	6.752E-06	0.016001326	1.000E+00	7.248E-01
14.328628	2.814E-02	1.964E-03	8.195E-04	9.788E-01	1.540E-09	8.010E-03	6.564E-06	0.015556764	1.000E+00	7.403E-01
15.000000	2.338E-02	1.558E-03	1.046E-03	9.799E-01	1.767E-09	9.189E-03	6.141E-06	0.022784464	1.000E+00	7.631E-01
15.450000	2.068E-02	1.338E-03	6.023E-04	9.805E-01	1.931E-09	1.004E-02	5.844E-06	0.014333263	1.000E+00	7.775E-01
15.913500	1.825E-02	1.147E-03	5.317E-04	9.810E-01	2.110E-09	1.097E-02	5.834E-06	0.013825188	1.000E+00	7.913E-01
16.390905	1.608E-02	9.808E-04	4.683E-04	9.815E-01	2.306E-09	1.199E-02	5.591E-06	0.013305419	1.000E+00	8.046E-01
16.873911	1.413E-02	8.368E-04	4.115E-04	9.819E-01	2.520E-09	1.310E-02	5.165E-06	0.012776666	1.000E+00	8.174E-01
17.389111	1.239E-02	7.124E-04	3.608E-04	9.823E-01	2.753E-09	1.432E-02	4.710E-06	0.012241597	1.000E+00	8.296E-01
17.910784	1.084E-02	6.051E-04	3.157E-04	9.826E-01	3.008E-09	1.564E-02	4.338E-06	0.011702808	1.000E+00	8.413E-01
18.448108	9.460E-03	5.128E-04	2.755E-04	9.828E-01	3.287E-09	1.709E-02	4.170E-06	0.011162812	1.000E+00	8.525E-01
19.001551	8.240E-03	4.336E-04	2.400E-04	9.831E-01	3.592E-09	1.868E-02	4.483E-06	0.010624015	1.000E+00	8.631E-01
19.571598	7.160E-03	3.659E-04	2.086E-04	9.833E-01	3.925E-09	2.041E-02	4.257E-06	0.010088701	1.000E+00	8.732E-01
20.158746	6.209E-03	3.080E-04	1.808E-04	9.835E-01	4.289E-09	2.230E-02	4.033E-06	0.009559019	1.000E+00	8.827E-01
20.763508	5.372E-03	2.587E-04	1.565E-04	9.836E-01	4.687E-09	2.437E-02	3.813E-06	0.009036971	1.000E+00	8.918E-01
21.386413	4.637E-03	2.168E-04	1.351E-04	9.838E-01	5.122E-09	2.663E-02	3.597E-06	0.008524403	1.000E+00	9.003E-01
22.028006	3.994E-03	1.813E-04	1.163E-04	9.839E-01	5.597E-09	2.910E-02	3.385E-06	0.008022996	1.000E+00	9.083E-01
22.688846	3.432E-03	1.513E-04	9.997E-05	9.840E-01	6.116E-09	3.180E-02	3.179E-06	0.007534261	1.000E+00	9.159E-01
23.369511	2.943E-03	1.259E-04	8.572E-05	9.841E-01	6.683E-09	3.475E-02	2.979E-06	0.007059539	1.000E+00	9.228E-01
24.070597	2.518E-03	1.046E-04	7.334E-05	9.841E-01	7.302E-09	3.797E-02	2.785E-06	0.006599993	1.000E+00	9.295E-01
24.792714	2.150E-03	8.670E-05	6.261E-05	9.842E-01	7.979E-09	4.149E-02	2.598E-06	0.006156616	1.000E+00	9.357E-01
25.536496	1.831E-03	7.170E-05	5.333E-05	9.843E-01	8.719E-09	4.534E-02	2.418E-06	0.005730233	1.000E+00	9.414E-01
26.302591	1.566E-03	5.916E-05	4.532E-05	9.843E-01	9.528E-09	4.954E-02	2.245E-06	0.005321498	1.000E+00	9.457E-01
27.091669	1.319E-03	4.870E-05	3.843E-05	9.843E-01	1.041E-08	5.414E-02	2.081E-06	0.00493091	1.000E+00	9.517E-01
27.904419	1.118E-03	4.001E-05	3.252E-05	9.844E-01	1.138E-08	5.916E-02	1.924E-06	0.004558813	1.000E+00	9.562E-01
28.741551	9.425E-04	3.279E-05	2.745E-05	9.844E-01	1.243E-08	6.464E-02	1.774E-06	0.004205407	1.000E+00	9.604E-01
29.603798	7.938E-04	2.682E-05	2.312E-05	9.844E-01	1.368E-08	7.064E-02	1.633E-06	0.003870755	1.000E+00	9.643E-01
30.491912	6.672E-04	2.188E-05	1.943E-05	9.844E-01	1.484E-08	7.719E-02	1.500E-06	0.003554798	1.000E+00	9.679E-01
31.406669	5.595E-04	1.781E-05	1.630E-05	9.845E-01	1.622E-08	8.435E-02	1.374E-06	0.003257359	1.000E+00	9.711E-01
32.348869	4.681E-04	1.447E-05	1.363E-05	9.845E-01	1.772E-08	9.217E-02	1.257E-06	0.002978159	1.000E+00	9.741E-01
33.319335	3.908E-04	1.173E-05	1.138E-05	9.845E-01	1.937E-08	1.007E-01	1.146E-06	0.002716825	1.000E+00	9.768E-01
34.318915	3.255E-04	9.485E-06	9.481E-06	9.845E-01	2.116E-08	1.101E-01	1.043E-06	0.002472902	1.000E+00	9.793E-01

Commercial SNF Accident Release Fractions

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Shape, $\pi d^3/6$	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*Δd/d	Σ P(d)*Δd/d	Particle Volume, V (cc)	Particle Shape, $\pi d^3/6$	Particle Mass, m (μg)	P(d)*Δd*mi/d	P(d)*Δd*mi/(d ³ mP ₅₀)	d < 6.9	Σ P(d) m/(P m) ₅₀
35.348483	2.706E-04	7.654E-06	7.880E-06	9.845E-01	2.313E-08	1.203E-01	1.203E-01	9.477E-07	0.002245865	1.000E+00	9.815E-01
36.408937	2.244E-04	6.162E-06	6.535E-06	9.845E-01	2.527E-08	1.314E-01	1.314E-01	8.587E-07	0.002035129	1.000E+00	9.836E-01
37.501205	1.856E-04	4.950E-06	5.407E-06	9.845E-01	2.761E-08	1.436E-01	1.436E-01	7.764E-07	0.001840059	1.000E+00	9.854E-01
38.626241	1.533E-04	3.968E-06	4.464E-06	9.845E-01	3.017E-08	1.569E-01	1.569E-01	7.004E-07	0.001659981	1.000E+00	9.871E-01
39.785029	1.262E-04	3.173E-06	3.677E-06	9.845E-01	3.297E-08	1.715E-01	1.715E-01	6.305E-07	0.00149419	1.000E+00	9.886E-01
40.978759	1.038E-04	2.532E-06	3.022E-06	9.845E-01	3.603E-08	1.874E-01	1.874E-01	5.662E-07	0.001341962	1.000E+00	9.899E-01
42.207937	8.510E-05	2.016E-06	2.479E-06	9.845E-01	3.937E-08	2.047E-01	2.047E-01	5.074E-07	0.001202558	1.000E+00	9.911E-01
43.474175	6.963E-05	1.802E-06	2.028E-06	9.845E-01	4.302E-08	2.237E-01	2.237E-01	4.537E-07	0.001075235	1.000E+00	9.922E-01
44.778400	5.685E-05	1.270E-06	1.656E-06	9.845E-01	4.701E-08	2.445E-01	2.445E-01	4.048E-07	0.000959251	1.000E+00	9.931E-01
46.121752	4.631E-05	1.004E-06	1.349E-06	9.845E-01	5.137E-08	2.671E-01	2.671E-01	3.603E-07	0.000853872	1.000E+00	9.940E-01
47.505405	3.764E-05	7.923E-07	1.096E-06	9.845E-01	5.613E-08	2.919E-01	2.919E-01	3.200E-07	0.000758376	1.000E+00	9.947E-01
48.930567	3.052E-05	6.238E-07	8.891E-07	9.845E-01	6.134E-08	3.190E-01	3.190E-01	2.836E-07	0.00067206	1.000E+00	9.954E-01
50.398484	2.470E-05	4.901E-07	7.194E-07	9.845E-01	6.703E-08	3.485E-01	3.485E-01	2.507E-07	0.000594241	1.000E+00	9.960E-01
51.910438	1.994E-05	3.842E-07	5.808E-07	9.845E-01	7.324E-08	3.809E-01	3.809E-01	2.212E-07	0.000524263	1.000E+00	9.965E-01
53.467752	1.606E-05	3.005E-07	4.679E-07	9.845E-01	8.003E-08	4.162E-01	4.162E-01	1.947E-07	0.000461485	1.000E+00	9.970E-01
55.071784	1.291E-05	2.345E-07	3.761E-07	9.845E-01	8.746E-08	4.548E-01	4.548E-01	1.710E-07	0.000405337	1.000E+00	9.974E-01
56.723938	1.036E-05	1.826E-07	3.016E-07	9.845E-01	9.568E-08	4.989E-01	4.989E-01	1.499E-07	0.00035522	1.000E+00	9.978E-01
58.425656	8.287E-06	1.418E-07	2.414E-07	9.845E-01	1.044E-07	5.430E-01	5.430E-01	1.311E-07	0.000310606	1.000E+00	9.981E-01
60.178425	6.616E-06	1.099E-07	1.927E-07	9.845E-01	1.141E-07	5.934E-01	5.934E-01	1.143E-07	0.00027099	1.000E+00	9.983E-01
61.983778	5.271E-06	8.504E-08	1.535E-07	9.845E-01	1.247E-07	6.484E-01	6.484E-01	9.954E-08	0.000235901	1.000E+00	9.986E-01
63.843292	4.190E-06	5.652E-08	1.220E-07	9.845E-01	1.363E-07	7.085E-01	7.085E-01	8.646E-08	0.000204897	1.000E+00	9.988E-01
65.758590	3.323E-06	5.053E-08	9.678E-08	9.845E-01	1.489E-07	7.742E-01	7.742E-01	7.493E-08	0.000177572	1.000E+00	9.990E-01
67.731348	2.629E-06	3.882E-08	7.658E-08	9.845E-01	1.627E-07	8.460E-01	8.460E-01	6.479E-08	0.000153548	1.000E+00	9.991E-01
69.763288	2.076E-06	2.976E-08	6.047E-08	9.845E-01	1.778E-07	9.244E-01	9.244E-01	5.590E-08	0.000132479	1.000E+00	9.992E-01
71.856187	1.636E-06	2.276E-08	4.764E-08	9.845E-01	1.943E-07	1.010E+00	1.010E+00	4.812E-08	0.000114046	1.000E+00	9.994E-01
74.011873	1.286E-06	1.737E-08	3.745E-08	9.845E-01	2.123E-07	1.104E+00	1.104E+00	4.133E-08	9.7989E-05	1.000E+00	9.995E-01
76.232229	1.008E-06	1.323E-08	2.937E-08	9.845E-01	2.320E-07	1.206E+00	1.206E+00	3.542E-08	8.39538E-05	1.000E+00	9.995E-01
78.519196	7.891E-07	1.005E-08	2.298E-08	9.845E-01	2.535E-07	1.318E+00	1.318E+00	3.029E-08	7.17906E-05	1.000E+00	9.996E-01
80.874772	6.161E-07	7.618E-09	1.795E-08	9.845E-01	2.770E-07	1.440E+00	1.440E+00	2.585E-08	6.12529E-05	1.000E+00	9.997E-01
83.301015	4.800E-07	5.762E-09	1.398E-08	9.845E-01	3.027E-07	1.574E+00	1.574E+00	2.200E-08	5.21456E-05	1.000E+00	9.997E-01
85.800045	3.731E-07	4.349E-09	1.087E-08	9.845E-01	3.307E-07	1.720E+00	1.720E+00	1.869E-08	4.42935E-05	1.000E+00	9.998E-01
88.374047	2.894E-07	3.275E-09	8.429E-09	9.845E-01	3.614E-07	1.879E+00	1.879E+00	1.584E-08	3.75399E-05	1.000E+00	9.998E-01
91.025268	2.240E-07	2.460E-09	6.523E-09	9.845E-01	3.949E-07	2.053E+00	2.053E+00	1.340E-08	3.17452E-05	1.000E+00	9.998E-01
93.756026	1.729E-07	1.845E-09	5.037E-09	9.845E-01	4.315E-07	2.244E+00	2.244E+00	1.130E-08	2.67852E-05	1.000E+00	9.999E-01
96.568707	1.332E-07	1.380E-09	3.881E-09	9.845E-01	4.715E-07	2.452E+00	2.452E+00	9.515E-09	2.25498E-05	1.000E+00	9.999E-01
99.465768	1.024E-07	1.030E-09	2.983E-09	9.845E-01	5.153E-07	2.678E+00	2.678E+00	7.993E-09	1.89419E-05	1.000E+00	9.999E-01
102.449741	7.856E-08	7.668E-10	2.288E-09	9.845E-01	5.630E-07	2.928E+00	2.928E+00	6.699E-09	1.58757E-05	1.000E+00	9.999E-01
105.523233	6.012E-08	5.697E-10	1.751E-09	9.845E-01	6.152E-07	3.199E+00	3.199E+00	5.602E-09	1.32763E-05	1.000E+00	9.999E-01
108.688930	4.591E-08	4.224E-10	1.337E-09	9.845E-01	6.723E-07	3.486E+00	3.486E+00	4.674E-09	1.10777E-05	1.000E+00	9.999E-01
111.949598	3.498E-08	3.124E-10	1.019E-09	9.845E-01	7.346E-07	3.820E+00	3.820E+00	3.892E-09	9.22277E-06	1.000E+00	1.000E+00
115.308086	2.659E-08	2.306E-10	7.744E-10	9.845E-01	8.027E-07	4.174E+00	4.174E+00	3.233E-09	7.68114E-06	1.000E+00	1.000E+00
118.767329	2.017E-08	1.698E-10	5.874E-10	9.845E-01	8.772E-07	4.561E+00	4.561E+00	2.678E-09	6.34983E-06	1.000E+00	1.000E+00
122.330349	1.526E-08	1.248E-10	4.446E-10	9.845E-01	9.585E-07	4.984E+00	4.984E+00	2.216E-09	5.25125E-06	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/\delta$	V ρ	P(d)* $\Delta d^3 m/d$	P(d)* $\Delta d^3 m/(d^3 m F_{50})$	d < 6.9	$\Sigma P(d) m/(P m)_{50}$
126.000259	1.153E-08	9.147E-11	3.357E-10	9.845E-01	1.047E-06	5.448E-00	1.828E-09	4.3300E-06	1.000E+00	1.000E+00
129.780267	8.684E-09	6.691E-11	2.529E-10	9.845E-01	1.145E-06	5.952E-00	1.505E-09	3.5674E-06	1.000E+00	1.000E+00
133.673675	6.528E-09	4.884E-11	1.901E-10	9.845E-01	1.251E-06	6.503E-00	1.237E-09	2.9305E-06	1.000E+00	1.000E+00
137.683885	4.897E-09	3.557E-11	1.426E-10	9.845E-01	1.367E-06	7.106E-00	1.014E-09	2.4020E-06	1.000E+00	1.000E+00
141.814402	3.665E-09	2.584E-11	1.067E-10	9.845E-01	1.493E-06	7.765E-00	8.289E-10	1.9644E-06	1.000E+00	1.000E+00
146.068834	2.737E-09	1.874E-11	7.971E-11	9.845E-01	1.632E-06	8.485E-00	6.764E-10	1.6029E-06	1.000E+00	1.000E+00
150.450899	2.039E-09	1.355E-11	5.939E-11	9.845E-01	1.783E-06	9.272E-00	5.507E-10	1.3051E-06	1.000E+00	1.000E+00
154.964426	1.516E-09	9.783E-12	4.415E-11	9.845E-01	1.948E-06	1.013E-01	4.474E-10	1.0602E-06	1.000E+00	1.000E+00
164.401759	8.323E-10	5.062E-12	2.424E-11	9.845E-01	2.129E-06	1.107E-01	3.626E-10	8.5937E-07	1.000E+00	1.000E+00
169.333812	6.146E-10	3.630E-12	1.780E-11	9.845E-01	2.327E-06	1.210E-01	2.933E-10	6.9502E-07	1.000E+00	1.000E+00
174.413826	4.529E-10	2.596E-12	1.319E-11	9.845E-01	2.542E-06	1.322E-01	2.367E-10	5.6084E-07	1.000E+00	1.000E+00
179.646241	3.329E-10	1.853E-12	9.697E-12	9.845E-01	2.778E-06	1.445E-01	1.905E-10	4.5156E-07	1.000E+00	1.000E+00
185.035628	2.442E-10	1.320E-12	7.113E-12	9.845E-01	3.036E-06	1.579E-01	1.537E-10	3.6277E-07	1.000E+00	1.000E+00
190.586897	1.788E-10	9.379E-13	5.206E-12	9.845E-01	3.317E-06	1.725E-01	1.227E-10	2.9078E-07	1.000E+00	1.000E+00
202.193427	9.512E-11	4.704E-13	2.770E-12	9.845E-01	3.625E-06	1.885E-01	9.813E-11	2.3267E-07	1.000E+00	1.000E+00
208.259230	6.916E-11	3.321E-13	2.014E-12	9.845E-01	3.961E-06	2.080E-01	7.831E-11	1.8558E-07	1.000E+00	1.000E+00
214.507007	5.017E-11	2.339E-13	1.461E-12	9.845E-01	4.328E-06	2.251E-01	6.235E-11	1.4771E-07	1.000E+00	1.000E+00
220.942217	3.831E-11	1.843E-13	1.058E-12	9.845E-01	4.728E-06	2.459E-01	4.954E-11	1.1739E-07	1.000E+00	1.000E+00
227.570483	2.822E-11	1.152E-13	7.638E-13	9.845E-01	5.168E-06	2.687E-01	3.927E-11	9.3058E-08	1.000E+00	1.000E+00
234.397598	1.890E-11	8.061E-14	5.04E-13	9.845E-01	5.647E-06	2.937E-01	3.106E-11	7.3601E-08	1.000E+00	1.000E+00
241.429526	1.359E-11	5.627E-14	3.57E-13	9.845E-01	6.171E-06	3.209E-01	2.451E-11	5.8082E-08	1.000E+00	1.000E+00
248.672412	9.746E-12	3.919E-14	2.839E-13	9.845E-01	6.743E-06	3.506E-01	1.930E-11	4.5734E-08	1.000E+00	1.000E+00
256.132584	6.978E-12	2.724E-14	2.032E-13	9.845E-01	7.368E-06	3.832E-01	1.516E-11	3.5930E-08	1.000E+00	1.000E+00
263.816561	4.982E-12	1.888E-14	1.451E-13	9.845E-01	8.052E-06	4.187E-01	1.188E-11	2.8165E-08	1.000E+00	1.000E+00
271.731058	3.550E-12	1.306E-14	1.034E-13	9.845E-01	8.798E-06	4.575E-01	9.296E-12	2.2028E-08	1.000E+00	1.000E+00
279.882990	2.524E-12	9.019E-15	7.352E-14	9.845E-01	9.614E-06	4.999E-01	7.254E-12	1.7192E-08	1.000E+00	1.000E+00
288.279480	1.791E-12	6.212E-15	5.216E-14	9.845E-01	1.051E-05	5.483E-01	5.849E-12	1.3368E-08	1.000E+00	1.000E+00
296.927864	1.268E-12	4.269E-15	3.692E-14	9.845E-01	1.254E-05	6.523E-01	3.402E-12	8.0626E-09	1.000E+00	1.000E+00
305.335700	8.952E-13	2.927E-15	2.607E-14	9.845E-01	1.371E-05	7.128E-01	2.631E-12	6.2362E-09	1.000E+00	1.000E+00
315.010771	6.308E-13	2.003E-15	1.837E-14	9.845E-01	1.498E-05	7.789E-01	2.031E-12	4.8128E-09	1.000E+00	1.000E+00
324.461094	4.435E-13	1.367E-15	1.292E-14	9.845E-01	1.637E-05	8.511E-01	1.564E-12	3.7060E-09	1.000E+00	1.000E+00
334.194827	3.112E-13	9.311E-16	9.063E-15	9.845E-01	1.788E-05	9.300E-01	1.201E-12	2.8474E-09	1.000E+00	1.000E+00
344.220775	2.178E-13	6.328E-16	6.344E-15	9.845E-01	1.854E-05	1.016E-02	9.211E-13	2.1828E-09	1.000E+00	1.000E+00
354.547388	1.521E-13	4.291E-16	4.431E-15	9.845E-01	2.136E-05	1.110E-02	7.045E-13	1.6696E-09	1.000E+00	1.000E+00
365.183920	1.060E-13	2.903E-16	3.088E-15	9.845E-01	2.334E-05	1.213E-02	5.377E-13	1.2742E-09	1.000E+00	1.000E+00
376.139335	7.372E-14	1.960E-16	2.147E-15	9.845E-01	2.550E-05	1.326E-02	4.094E-13	9.7033E-10	1.000E+00	1.000E+00
387.423515	5.114E-14	1.320E-16	1.490E-15	9.845E-01	2.786E-05	1.448E-02	3.111E-13	7.3726E-10	1.000E+00	1.000E+00
399.046220	3.540E-14	8.872E-17	1.031E-15	9.845E-01	3.045E-05	1.583E-02	2.358E-13	5.5892E-10	1.000E+00	1.000E+00
411.017607	2.445E-14	5.949E-17	7.122E-16	9.845E-01	3.327E-05	1.730E-02	1.784E-13	4.2277E-10	1.000E+00	1.000E+00
423.348135	1.685E-14	3.980E-17	4.908E-16	9.845E-01	3.636E-05	1.891E-02	1.346E-13	3.1908E-10	1.000E+00	1.000E+00
436.048579	1.159E-14	2.657E-17	3.375E-16	9.845E-01	3.973E-05	2.066E-02	1.014E-13	2.4028E-10	1.000E+00	1.000E+00
					4.341E-05	2.257E-02	7.618E-14	1.8054E-10	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particle Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Distribution	Respirable Fraction	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V ρ	P(d) $\Delta d^3/m/d$	P(d) $\Delta d^3 m/d$	d < 6.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
449.130036	7.949E-15	1.770E-17	2.315E-16	9.845E-01	4.744E-05	2.467E+02	5.711E-14	1.35353E-10	1.000E+00	1.000E+00
462.603937	5.442E-15	1.176E-17	1.585E-16	9.845E-01	5.184E-05	2.695E+02	4.272E-14	1.01248E-10	1.000E+00	1.000E+00
476.482055	3.717E-15	7.801E-18	1.083E-16	9.845E-01	5.664E-05	2.945E+02	3.189E-14	7.55678E-11	1.000E+00	1.000E+00
490.776517	2.533E-15	5.161E-18	7.376E-17	9.845E-01	6.189E-05	3.218E+02	2.376E-14	5.62753E-11	1.000E+00	1.000E+00
505.498813	1.722E-15	3.407E-18	5.017E-17	9.845E-01	6.763E-05	3.517E+02	1.764E-14	4.18149E-11	1.000E+00	1.000E+00
520.664807	1.169E-15	2.245E-18	3.404E-17	9.845E-01	7.390E-05	3.843E+02	1.308E-14	3.10009E-11	1.000E+00	1.000E+00
536.284751	7.911E-16	1.475E-18	2.304E-17	9.845E-01	8.076E-05	4.199E+02	9.676E-15	2.29325E-11	1.000E+00	1.000E+00
552.373294	5.344E-16	9.674E-19	1.556E-17	9.845E-01	8.825E-05	4.589E+02	7.142E-15	1.69261E-11	1.000E+00	1.000E+00
568.944493	3.601E-16	6.330E-19	1.049E-17	9.845E-01	9.643E-05	5.014E+02	5.260E-15	1.24651E-11	1.000E+00	1.000E+00
586.012827	2.422E-16	4.133E-19	7.054E-18	9.845E-01	1.054E-04	5.479E+02	3.865E-15	9.1594E-12	1.000E+00	1.000E+00
603.593212	1.625E-16	2.692E-19	4.733E-18	9.845E-01	1.151E-04	5.987E+02	2.834E-15	6.71535E-12	1.000E+00	1.000E+00
621.701009	1.068E-16	1.750E-19	3.169E-18	9.845E-01	1.258E-04	6.543E+02	2.073E-15	4.9125E-12	1.000E+00	1.000E+00
640.352039	7.266E-17	1.135E-19	2.116E-18	9.845E-01	1.375E-04	7.149E+02	1.513E-15	3.58564E-12	1.000E+00	1.000E+00
659.562600	4.843E-17	7.342E-20	1.410E-18	9.845E-01	1.502E-04	7.812E+02	1.102E-15	2.61134E-12	1.000E+00	1.000E+00
679.349478	3.220E-17	4.740E-20	9.379E-19	9.845E-01	1.642E-04	8.537E+02	8.007E-16	1.89754E-12	1.000E+00	1.000E+00
699.729962	2.137E-17	3.054E-20	6.223E-19	9.845E-01	1.794E-04	9.328E+02	5.805E-16	1.37579E-12	1.000E+00	1.000E+00
720.721861	1.415E-17	1.963E-20	4.120E-19	9.845E-01	1.960E-04	1.019E+03	4.200E-16	9.95271E-13	1.000E+00	1.000E+00
742.343517	9.344E-18	1.259E-20	2.722E-19	9.845E-01	2.142E-04	1.114E+03	3.031E-16	7.18396E-13	1.000E+00	1.000E+00
767.613823	6.158E-18	8.054E-21	1.794E-19	9.845E-01	2.341E-04	1.217E+03	2.183E-16	5.1739E-13	1.000E+00	1.000E+00
787.552237	4.050E-18	5.142E-21	1.180E-19	9.845E-01	2.558E-04	1.330E+03	1.569E-16	3.71795E-13	1.000E+00	1.000E+00
811.178804	2.657E-18	3.276E-21	7.740E-20	9.845E-01	2.795E-04	1.453E+03	1.125E-16	2.66575E-13	1.000E+00	1.000E+00
835.514168	1.740E-18	2.082E-21	5.067E-20	9.845E-01	3.054E-04	1.588E+03	8.047E-17	1.90708E-13	1.000E+00	1.000E+00
860.579594	1.136E-18	1.321E-21	3.310E-20	9.845E-01	3.337E-04	1.735E+03	5.744E-17	1.36128E-13	1.000E+00	1.000E+00
886.395981	7.407E-19	8.357E-22	2.157E-20	9.845E-01	3.647E-04	1.896E+03	4.091E-17	9.69527E-14	1.000E+00	1.000E+00
912.988991	4.817E-19	5.276E-22	1.403E-20	9.845E-01	3.986E-04	2.072E+03	2.907E-17	6.8974E-14	1.000E+00	1.000E+00
940.378557	3.126E-19	3.324E-22	9.104E-21	9.845E-01	4.354E-04	2.264E+03	2.061E-17	4.88515E-14	1.000E+00	1.000E+00
968.589914	2.024E-19	2.089E-22	5.894E-21	9.845E-01	4.758E-04	2.474E+03	1.458E-17	3.45808E-14	1.000E+00	1.000E+00
997.647612	1.307E-19	1.310E-22	3.808E-21	9.845E-01	5.199E-04	2.704E+03	1.029E-17	2.43961E-14	1.000E+00	1.000E+00
1027.577040	8.426E-20	8.200E-23	2.454E-21	9.845E-01	5.681E-04	2.954E+03	7.250E-18	1.71826E-14	1.000E+00	1.000E+00
1058.404351	5.419E-20	5.120E-23	1.578E-21	9.845E-01	6.208E-04	3.228E+03	5.095E-18	1.20751E-14	1.000E+00	1.000E+00
1090.156482	3.477E-20	3.190E-23	9.845E-22	9.845E-01	6.794E-04	3.528E+03	3.573E-18	8.46886E-15	1.000E+00	1.000E+00
1122.861176	2.226E-20	1.983E-23	6.484E-22	9.845E-01	7.413E-04	3.855E+03	2.500E-18	5.92381E-15	1.000E+00	1.000E+00
1156.347011	1.422E-20	1.230E-23	4.142E-22	9.845E-01	8.100E-04	4.212E+03	1.745E-18	4.13505E-15	1.000E+00	1.000E+00
1191.243422	9.065E-21	7.610E-24	2.640E-22	9.845E-01	8.851E-04	4.603E+03	1.215E-18	2.8801E-15	1.000E+00	1.000E+00
1226.980724	5.765E-21	4.899E-24	1.679E-22	9.845E-01	9.672E-04	5.029E+03	8.446E-19	2.00155E-15	1.000E+00	1.000E+00
1263.790146	3.659E-21	2.895E-24	1.066E-22	9.845E-01	1.057E-03	5.496E+03	5.856E-19	1.38789E-15	1.000E+00	1.000E+00
1301.703851	2.316E-21	1.780E-24	6.747E-23	9.845E-01	1.155E-03	6.005E+03	4.052E-19	9.60233E-16	1.000E+00	1.000E+00
1340.754966	1.463E-21	1.091E-24	4.262E-23	9.845E-01	1.262E-03	6.562E+03	2.797E-19	6.62871E-16	1.000E+00	1.000E+00
1380.977615	9.224E-22	6.680E-25	2.687E-23	9.845E-01	1.379E-03	7.171E+03	1.927E-19	4.56576E-16	1.000E+00	1.000E+00
1422.406944	5.801E-22	4.079E-25	1.690E-23	9.845E-01	1.507E-03	7.836E+03	1.324E-19	3.13783E-16	1.000E+00	1.000E+00
1465.079152	3.841E-22	2.485E-25	1.060E-23	9.845E-01	1.647E-03	8.562E+03	9.079E-20	2.15167E-16	1.000E+00	1.000E+00
1509.031526	2.280E-22	1.511E-25	6.639E-24	9.845E-01	1.799E-03	9.356E+03	6.212E-20	1.47216E-16	1.000E+00	1.000E+00
1554.302472	1.424E-22	9.162E-26	4.148E-24	9.845E-01	1.966E-03	1.022E+04	4.241E-20	1.005E-16	1.000E+00	1.000E+00

Commercial SNF Accident Release Fractions

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) Δd /d	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	V ρ	P(d) Δd^3 /m/d	P(d) Δd^3 /m/(d Δd P Δd)	d < 6.9	$\Sigma P(d)$ m/(P m) Δd
1600.931546	8.877E-23	5.545E-26	2.586E-24	9.845E-01	2.148E-03	1.117E+04	2.899E-20	6.84552E-17	1.000E+00	1.000E+00
1648.959493	5.521E-23	3.348E-26	1.608E-24	9.845E-01	2.348E-03	1.221E+04	1.963E-20	4.65243E-17	1.000E+00	1.000E+00
1698.428278	3.426E-23	2.017E-26	9.979E-25	9.845E-01	2.565E-03	1.334E+04	1.331E-20	3.15489E-17	1.000E+00	1.000E+00
1749.381126	2.122E-23	1.213E-26	6.179E-25	9.845E-01	2.803E-03	1.458E+04	9.007E-21	2.13462E-17	1.000E+00	1.000E+00
1801.862560	1.311E-23	7.274E-27	3.818E-25	9.845E-01	3.063E-03	1.593E+04	6.081E-21	1.44108E-17	1.000E+00	1.000E+00
1855.918436	8.080E-24	4.353E-27	2.353E-25	9.845E-01	3.347E-03	1.741E+04	4.096E-21	9.70706E-18	1.000E+00	1.000E+00
1911.595989	4.969E-24	2.600E-27	1.447E-25	9.845E-01	3.658E-03	1.902E+04	2.753E-21	6.52407E-18	1.000E+00	1.000E+00
1988.943869	3.050E-24	1.549E-27	8.883E-26	9.845E-01	3.997E-03	2.078E+04	1.846E-21	4.37503E-18	1.000E+00	1.000E+00
2028.012185	1.867E-24	9.208E-28	5.439E-26	9.845E-01	4.367E-03	2.271E+04	1.235E-21	2.92735E-18	1.000E+00	1.000E+00
2088.852551	1.141E-24	5.462E-28	3.323E-26	9.845E-01	4.772E-03	2.482E+04	8.246E-22	1.95434E-18	1.000E+00	1.000E+00
2151.518127	6.955E-25	3.233E-28	2.026E-26	9.845E-01	5.215E-03	2.712E+04	5.493E-22	1.30184E-18	1.000E+00	1.000E+00
2216.063671	4.230E-25	1.909E-28	1.232E-26	9.845E-01	5.698E-03	2.963E+04	3.651E-22	8.65256E-19	1.000E+00	1.000E+00
2282.545581	2.567E-25	1.125E-28	7.478E-27	9.845E-01	6.227E-03	3.238E+04	2.421E-22	5.73805E-19	1.000E+00	1.000E+00
2351.021949	1.555E-25	6.613E-29	4.528E-27	9.845E-01	6.804E-03	3.538E+04	1.602E-22	3.79878E-19	1.000E+00	1.000E+00
2421.552607	9.393E-26	3.879E-29	2.736E-27	9.845E-01	7.435E-03	3.866E+04	1.058E-22	2.50668E-19	1.000E+00	1.000E+00
2494.193185	5.662E-26	2.270E-29	1.649E-27	9.845E-01	8.124E-03	4.225E+04	6.968E-23	1.65125E-19	1.000E+00	1.000E+00
2569.025161	3.408E-26	1.326E-29	9.920E-28	9.845E-01	8.878E-03	4.616E+04	4.580E-23	1.08532E-19	1.000E+00	1.000E+00
2646.095916	2.044E-26	7.725E-30	5.954E-28	9.845E-01	9.701E-03	5.045E+04	3.003E-23	7.11765E-20	1.000E+00	1.000E+00
2725.478793	1.224E-26	4.491E-30	3.565E-28	9.845E-01	1.060E-02	5.512E+04	1.965E-23	4.65742E-20	1.000E+00	1.000E+00
2801.243157	7.314E-27	2.605E-30	2.130E-28	9.845E-01	1.158E-02	6.023E+04	1.283E-23	3.04078E-20	1.000E+00	1.000E+00
2878.204265	4.360E-27	1.508E-30	1.270E-28	9.845E-01	1.266E-02	6.582E+04	8.358E-24	1.98088E-20	1.000E+00	1.000E+00
2978.204265	2.593E-27	8.708E-31	7.554E-29	9.845E-01	1.383E-02	7.192E+04	5.433E-24	1.28754E-20	1.000E+00	1.000E+00
3067.550393	1.539E-27	5.018E-31	4.483E-29	9.845E-01	1.511E-02	7.859E+04	3.523E-24	8.35018E-21	1.000E+00	1.000E+00
3159.576905	9.115E-28	2.885E-31	2.655E-29	9.845E-01	1.652E-02	8.598E+04	2.280E-24	5.40334E-21	1.000E+00	1.000E+00
3254.364212	5.386E-28	1.655E-31	1.569E-29	9.845E-01	1.805E-02	9.384E+04	1.472E-24	3.48867E-21	1.000E+00	1.000E+00
3351.995139	3.175E-28	9.472E-32	9.248E-30	9.845E-01	1.972E-02	1.025E+05	9.483E-25	2.24745E-21	1.000E+00	1.000E+00
3452.554993	1.868E-28	5.410E-32	5.440E-30	9.845E-01	2.155E-02	1.121E+05	6.096E-25	1.44461E-21	1.000E+00	1.000E+00
3556.131643	1.098E-28	3.083E-32	3.193E-30	9.845E-01	2.355E-02	1.224E+05	3.909E-25	9.26495E-22	1.000E+00	1.000E+00
3662.815592	6.420E-29	1.753E-32	1.870E-30	9.845E-01	2.573E-02	1.338E+05	2.502E-25	5.9288E-22	1.000E+00	1.000E+00
3772.700060	3.751E-29	9.942E-33	1.093E-30	9.845E-01	2.812E-02	1.462E+05	1.597E-25	3.78549E-22	1.000E+00	1.000E+00
3885.881061	2.187E-29	5.628E-33	6.370E-31	9.845E-01	3.072E-02	1.598E+05	1.018E-25	2.41162E-22	1.000E+00	1.000E+00
4002.457493	1.272E-29	3.178E-33	3.705E-31	9.845E-01	3.357E-02	1.748E+05	6.488E-26	1.53295E-22	1.000E+00	1.000E+00
4122.531218	7.384E-30	1.791E-33	2.151E-31	9.845E-01	3.669E-02	1.908E+05	4.102E-26	9.7225E-23	1.000E+00	1.000E+00
4246.207155	4.276E-30	1.007E-33	1.245E-31	9.845E-01	4.009E-02	2.085E+05	2.596E-26	6.15261E-23	1.000E+00	1.000E+00
4373.593369	2.471E-30	5.649E-34	7.197E-32	9.845E-01	4.380E-02	2.278E+05	1.639E-26	3.88484E-23	1.000E+00	1.000E+00
4450.801170	1.425E-30	3.162E-34	4.149E-32	9.845E-01	4.787E-02	2.489E+05	1.033E-26	2.44747E-23	1.000E+00	1.000E+00
4504.945205	8.195E-31	1.766E-34	2.387E-32	9.845E-01	5.230E-02	2.720E+05	6.492E-27	1.53849E-23	1.000E+00	1.000E+00
4779.143562	4.704E-31	9.842E-35	1.370E-32	9.845E-01	5.715E-02	2.972E+05	4.072E-27	9.64941E-24	1.000E+00	1.000E+00
4922.517868	2.694E-31	5.472E-35	7.846E-33	9.845E-01	6.245E-02	3.248E+05	2.548E-27	6.03665E-24	1.000E+00	1.000E+00
5070.193404	1.539E-31	3.036E-35	4.483E-33	9.845E-01	6.825E-02	3.549E+05	1.591E-27	3.7706E-24	1.000E+00	1.000E+00
5222.299207	8.776E-32	1.681E-35	2.556E-33	9.845E-01	7.457E-02	3.878E+05	9.912E-28	2.34918E-24	1.000E+00	1.000E+00
5378.968183	4.993E-32	9.282E-36	1.454E-33	9.845E-01	8.148E-02	4.237E+05	6.162E-28	1.46031E-24	1.000E+00	1.000E+00
5540.337228	2.834E-32	5.115E-36	8.254E-34	9.845E-01	8.904E-02	4.630E+05	3.822E-28	9.05757E-25	1.000E+00	1.000E+00

Commercial SNF Accident Release Fractions

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*d/d	$\Sigma P(d)*d/d$	$\pi d^3/6$	V ρ	P(d)*d* $\pi m/d$	P(d)* $\Delta d^3 m/d^3$	d < 6.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
5706.547345	1.805E-32	2.813E-36	4.675E-34	9.845E-01	9.730E-02	5.060E+05	2.365E-28	5.60542E-25	1.000E+00	1.000E+00
5877.743765	9.070E-33	1.543E-36	2.642E-34	9.845E-01	1.063E-01	5.529E+05	1.461E-28	3.46128E-25	1.000E+00	1.000E+00
6054.076078	5.114E-33	8.447E-37	1.489E-34	9.845E-01	1.162E-01	6.042E+05	8.998E-29	2.13253E-25	1.000E+00	1.000E+00
6235.698361	2.877E-33	4.613E-37	8.379E-35	9.845E-01	1.270E-01	6.602E+05	5.532E-29	1.31095E-25	1.000E+00	1.000E+00
6422.769312	1.615E-33	2.514E-37	4.703E-35	9.845E-01	1.387E-01	7.214E+05	3.393E-29	8.041E-26	1.000E+00	1.000E+00
6615.452391	9.044E-34	1.367E-37	2.634E-35	9.845E-01	1.516E-01	7.893E+05	2.076E-29	4.92112E-26	1.000E+00	1.000E+00
6813.915963	5.054E-34	7.417E-38	1.472E-35	9.845E-01	1.656E-01	8.614E+05	1.268E-29	3.00504E-26	1.000E+00	1.000E+00
7018.333442	2.818E-34	4.015E-38	8.208E-36	9.845E-01	1.810E-01	9.412E+05	7.726E-30	1.83091E-26	1.000E+00	1.000E+00
7228.893445	1.568E-34	2.169E-38	4.566E-36	9.845E-01	1.978E-01	1.029E+06	4.697E-30	1.11305E-26	1.000E+00	1.000E+00
7445.749948	8.703E-35	1.169E-38	2.535E-36	9.845E-01	2.161E-01	1.124E+06	2.849E-30	6.75143E-27	1.000E+00	1.000E+00
7689.122447	4.820E-35	6.285E-39	1.404E-36	9.845E-01	2.362E-01	1.228E+06	1.724E-30	4.08609E-27	1.000E+00	1.000E+00
7899.196120	2.664E-35	3.372E-39	7.758E-37	9.845E-01	2.581E-01	1.342E+06	1.041E-30	2.46747E-27	1.000E+00	1.000E+00
8136.172004	1.469E-35	1.809E-39	4.278E-37	9.845E-01	2.820E-01	1.466E+06	6.273E-31	1.48671E-27	1.000E+00	1.000E+00
8380.257164	8.081E-36	9.642E-40	2.354E-37	9.845E-01	3.082E-01	1.602E+06	3.771E-31	8.93783E-28	1.000E+00	1.000E+00
8631.664879	4.438E-36	5.139E-40	1.292E-37	9.845E-01	3.367E-01	1.751E+06	2.262E-31	5.3613E-28	1.000E+00	1.000E+00
8890.614825	2.430E-36	2.733E-40	7.076E-38	9.845E-01	3.680E-01	1.913E+06	1.354E-31	3.20877E-28	1.000E+00	1.000E+00
9157.333270	1.328E-36	1.450E-40	3.867E-38	9.845E-01	4.021E-01	2.091E+06	8.086E-32	1.9162E-28	1.000E+00	1.000E+00
9432.053268	7.240E-37	7.676E-41	2.109E-38	9.845E-01	4.394E-01	2.285E+06	4.818E-32	1.14179E-28	1.000E+00	1.000E+00
9715.014866	3.939E-37	4.055E-41	1.147E-38	9.845E-01	4.801E-01	2.497E+06	2.864E-32	6.78791E-29	1.000E+00	1.000E+00
10006.465312	2.138E-37	2.137E-41	6.228E-39	9.845E-01	5.246E-01	2.728E+06	1.699E-32	4.02654E-29	1.000E+00	1.000E+00
10306.659271	1.158E-37	1.124E-41	3.373E-39	9.845E-01	5.733E-01	2.981E+06	1.006E-32	2.38319E-29	1.000E+00	1.000E+00
10615.859049	6.259E-38	5.896E-42	1.823E-39	9.845E-01	6.264E-01	3.257E+06	5.939E-33	1.4074E-29	1.000E+00	1.000E+00
10934.334821	3.375E-38	3.087E-42	9.831E-40	9.845E-01	6.845E-01	3.559E+06	3.499E-33	8.29291E-30	1.000E+00	1.000E+00
11262.364865	1.816E-38	1.612E-42	5.289E-40	9.845E-01	7.480E-01	3.899E+06	2.057E-33	4.8756E-30	1.000E+00	1.000E+00
11600.235811	9.749E-39	8.404E-43	2.840E-40	9.845E-01	8.173E-01	4.250E+06	1.207E-33	2.8601E-30	1.000E+00	1.000E+00
11948.242886	5.222E-39	4.370E-43	1.521E-40	9.845E-01	8.931E-01	4.644E+06	7.064E-34	1.67404E-30	1.000E+00	1.000E+00
12306.690172	2.791E-39	2.268E-43	8.129E-41	9.845E-01	9.759E-01	5.075E+06	4.125E-34	9.77645E-31	1.000E+00	1.000E+00
12675.890877	1.488E-39	1.174E-43	4.335E-41	9.845E-01	1.068E+00	5.545E+06	2.404E-34	5.69677E-31	1.000E+00	1.000E+00
13056.167604	7.918E-40	6.065E-44	2.306E-41	9.845E-01	1.165E+00	6.060E+06	1.398E-34	3.31213E-31	1.000E+00	1.000E+00
13447.852632	4.204E-40	3.126E-44	1.224E-41	9.845E-01	1.273E+00	6.622E+06	8.107E-35	1.9214E-31	1.000E+00	1.000E+00
13851.288211	2.227E-40	1.608E-44	6.486E-42	9.845E-01	1.391E+00	7.236E+06	4.893E-35	1.11214E-31	1.000E+00	1.000E+00
14266.826857	1.177E-40	8.249E-45	3.428E-42	9.845E-01	1.520E+00	7.906E+06	2.710E-35	6.42294E-32	1.000E+00	1.000E+00
14694.831663	6.206E-41	4.223E-45	1.808E-42	9.845E-01	1.661E+00	8.640E+06	1.562E-35	3.70117E-32	1.000E+00	1.000E+00
15135.676613	3.266E-41	2.157E-45	9.511E-43	9.845E-01	1.816E+00	9.441E+06	8.979E-36	2.12802E-32	1.000E+00	1.000E+00
15589.746911	1.714E-41	1.100E-45	4.993E-43	9.845E-01	1.984E+00	1.032E+07	5.151E-36	1.2208E-32	1.000E+00	1.000E+00
16057.439318	8.980E-42	5.593E-46	2.616E-43	9.845E-01	2.168E+00	1.127E+07	2.594E-36	1.2208E-32	1.000E+00	1.000E+00
16539.162498	4.694E-42	2.838E-46	1.367E-43	9.845E-01	2.369E+00	1.232E+07	1.684E-36	6.99093E-33	1.000E+00	1.000E+00
17035.337373	2.448E-42	1.437E-46	7.129E-44	9.845E-01	2.589E+00	1.346E+07	9.596E-37	2.27424E-33	1.000E+00	1.000E+00
17546.397494	1.274E-42	7.259E-47	3.710E-44	9.845E-01	2.829E+00	1.471E+07	5.456E-37	1.2931E-33	1.000E+00	1.000E+00
18072.789419	6.612E-43	3.659E-47	1.926E-44	9.845E-01	3.091E+00	1.607E+07	3.095E-37	7.33594E-34	1.000E+00	1.000E+00
18614.973101	3.425E-43	1.840E-47	9.977E-45	9.845E-01	3.377E+00	1.756E+07	1.752E-37	4.15253E-34	1.000E+00	1.000E+00
19173.422295	1.770E-43	9.234E-48	5.157E-45	9.845E-01	3.691E+00	1.919E+07	9.896E-38	2.34532E-34	1.000E+00	1.000E+00
19748.624963	9.130E-44	4.623E-48	2.659E-45	9.845E-01	4.033E+00	2.097E+07	5.577E-38	1.32167E-34	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)* $\Delta d/d$	$\Sigma P(d)*\Delta d/d$	$\pi d^3/6$	V ρ	P(d)* $\Delta d^3/m/d$	P(d)* $\Delta d^3 m/(d^3 m P_{\text{ref}})$	d < 6.9	$\Sigma P(d) m/(P m)_{\text{ref}}$
20341.063712	4.698E-44	2.310E-48	1.388E-45	9.845E-01	4.407E+00	2.292E+07	3.136E-38	7.43145E-35	1.000E+00	1.000E+00
20951.316224	2.412E-44	1.151E-48	7.076E-46	9.845E-01	4.815E+00	2.504E+07	1.759E-38	4.16924E-35	1.000E+00	1.000E+00
21579.855710	1.236E-44	5.726E-49	3.599E-46	9.845E-01	5.262E+00	2.736E+07	9.848E-39	2.33384E-35	1.000E+00	1.000E+00
22227.251382	6.316E-45	2.842E-49	1.840E-46	9.845E-01	5.750E+00	2.990E+07	5.500E-39	1.30352E-35	1.000E+00	1.000E+00
22894.068923	3.221E-45	1.407E-49	8.382E-47	9.845E-01	6.283E+00	3.267E+07	3.065E-39	7.26432E-36	1.000E+00	1.000E+00
23580.890991	1.639E-45	6.951E-50	4.774E-47	9.845E-01	6.868E+00	3.570E+07	1.704E-39	4.03928E-36	1.000E+00	1.000E+00
24288.317721	8.322E-46	3.426E-50	2.424E-47	9.845E-01	7.502E+00	3.901E+07	9.456E-40	2.24102E-36	1.000E+00	1.000E+00
25016.967252	4.216E-46	1.685E-50	1.228E-47	9.845E-01	8.198E+00	4.263E+07	5.235E-40	1.24056E-36	1.000E+00	1.000E+00
25767.476270	2.131E-46	8.270E-51	6.207E-48	9.845E-01	8.958E+00	4.688E+07	2.891E-40	6.85205E-37	1.000E+00	1.000E+00
26540.500558	1.075E-46	4.049E-51	3.130E-48	9.845E-01	9.789E+00	5.090E+07	1.593E-40	3.77621E-37	1.000E+00	1.000E+00
27336.715575	5.408E-47	1.978E-51	1.575E-48	9.845E-01	1.070E+01	5.562E+07	8.762E-41	2.07646E-37	1.000E+00	1.000E+00
28156.817042	2.716E-47	9.644E-52	7.909E-49	9.845E-01	1.169E+01	6.078E+07	4.807E-41	1.13925E-37	1.000E+00	1.000E+00
29001.521553	1.360E-47	4.691E-52	3.962E-49	9.845E-01	1.277E+01	6.641E+07	2.632E-41	6.23664E-38	1.000E+00	1.000E+00
29871.567200	6.800E-48	2.276E-52	1.981E-49	9.845E-01	1.396E+01	7.257E+07	1.437E-41	3.40653E-38	1.000E+00	1.000E+00
30767.714216	3.392E-48	1.102E-52	9.878E-50	9.845E-01	1.525E+01	7.930E+07	7.834E-42	1.85654E-38	1.000E+00	1.000E+00
31690.745642	1.688E-48	5.326E-53	4.916E-50	9.845E-01	1.668E+01	8.666E+07	4.260E-42	1.00955E-38	1.000E+00	1.000E+00
32641.468011	8.380E-49	2.567E-53	2.441E-50	9.845E-01	1.821E+01	9.469E+07	2.311E-42	5.47753E-39	1.000E+00	1.000E+00
33620.712052	4.152E-49	1.235E-53	1.209E-50	9.845E-01	1.990E+01	1.035E+08	1.251E-42	2.96532E-39	1.000E+00	1.000E+00
34629.333413	2.052E-49	5.926E-54	5.978E-51	9.845E-01	2.174E+01	1.131E+08	6.759E-43	1.60174E-39	1.000E+00	1.000E+00
35668.213416	1.012E-49	2.838E-54	2.948E-51	9.845E-01	2.376E+01	1.236E+08	3.643E-43	8.63259E-40	1.000E+00	1.000E+00
36738.259818	4.981E-50	1.356E-54	1.451E-51	9.845E-01	2.596E+01	1.350E+08	1.959E-43	6.84219E-40	1.000E+00	1.000E+00
37840.407613	2.446E-50	6.464E-55	7.124E-52	9.845E-01	2.837E+01	1.475E+08	1.051E-43	2.49079E-40	1.000E+00	1.000E+00
38975.619841	1.198E-50	3.075E-55	3.490E-52	9.845E-01	3.100E+01	1.612E+08	5.627E-44	1.33348E-40	1.000E+00	1.000E+00
40144.888436	5.858E-51	1.459E-55	1.706E-52	9.845E-01	3.388E+01	1.762E+08	3.006E-44	7.12291E-41	1.000E+00	1.000E+00
41349.235089	2.857E-51	6.910E-56	8.322E-53	9.845E-01	3.702E+01	1.925E+08	1.602E-44	3.79634E-41	1.000E+00	1.000E+00
42589.712142	1.391E-51	3.265E-56	4.050E-53	9.845E-01	4.045E+01	2.103E+08	8.519E-45	2.01885E-41	1.000E+00	1.000E+00
43867.403506	6.752E-52	1.539E-56	1.987E-53	9.845E-01	4.420E+01	2.298E+08	4.520E-45	1.07121E-41	1.000E+00	1.000E+00
45183.425611	3.271E-52	7.240E-57	9.528E-54	9.845E-01	4.830E+01	2.512E+08	2.393E-45	5.67124E-42	1.000E+00	1.000E+00
46538.928380	1.581E-52	3.398E-57	4.606E-54	9.845E-01	5.278E+01	2.744E+08	1.264E-45	2.9958E-42	1.000E+00	1.000E+00
47935.096231	7.628E-53	1.591E-57	2.222E-54	9.845E-01	5.767E+01	2.999E+08	6.663E-46	1.57898E-42	1.000E+00	1.000E+00
49373.149118	3.671E-53	7.435E-58	1.069E-54	9.845E-01	6.302E+01	3.277E+08	3.504E-46	8.30375E-43	1.000E+00	1.000E+00
50854.343592	1.763E-53	3.466E-58	5.134E-55	9.845E-01	6.886E+01	3.581E+08	1.839E-46	4.35715E-43	1.000E+00	1.000E+00
52379.973899	8.446E-54	1.612E-58	2.460E-55	9.845E-01	7.525E+01	3.913E+08	9.626E-47	2.2812E-43	1.000E+00	1.000E+00
53951.373116	4.038E-54	7.484E-59	1.176E-55	9.845E-01	8.223E+01	4.276E+08	5.028E-47	1.19167E-43	1.000E+00	1.000E+00
55569.914310	1.926E-54	3.466E-59	5.609E-56	9.845E-01	8.985E+01	4.672E+08	2.621E-47	6.21123E-44	1.000E+00	1.000E+00
57237.011739	9.166E-55	1.601E-59	2.670E-56	9.845E-01	9.818E+01	5.105E+08	1.363E-47	3.23022E-44	1.000E+00	1.000E+00
58994.122091	4.353E-55	7.383E-60	1.268E-56	9.845E-01	1.073E+02	5.579E+08	7.073E-48	1.67617E-44	1.000E+00	1.000E+00
60722.745754	2.052E-55	3.396E-60	6.007E-57	9.845E-01	1.172E+02	6.096E+08	3.662E-48	8.67832E-45	1.000E+00	1.000E+00
62544.428127	9.750E-56	1.558E-60	2.840E-57	9.845E-01	1.281E+02	6.661E+08	1.892E-48	4.48316E-45	1.000E+00	1.000E+00
64420.760971	4.599E-56	7.139E-61	1.340E-57	9.845E-01	1.400E+02	7.279E+08	9.751E-49	2.31081E-45	1.000E+00	1.000E+00
66353.393800	2.165E-56	3.262E-61	6.305E-58	9.845E-01	1.530E+02	7.954E+08	5.015E-49	1.18844E-45	1.000E+00	1.000E+00
68343.985314	1.016E-56	1.487E-61	2.961E-58	9.845E-01	1.671E+02	8.692E+08	2.573E-49	6.08647E-46	1.000E+00	1.000E+00
70394.304873	4.763E-57	6.766E-62	1.387E-58	9.845E-01	1.826E+02	9.498E+08	1.318E-49	3.12245E-46	1.000E+00	1.000E+00

Commercial SNF Accident Release Fractions

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) Δ d/d	Σ P(d) Δ d/d	$\pi d^3/6$	$V \rho$	P(d) Δ d $\cdot$ m/d	P(d) Δ d $\cdot$ m/(d $\cdot$ mP $_{50}$)	d < 6.9	Σ P(d) m/(P m) $_{50}$
72506.134019	2.227E-57	3.071E-62	6.486E-59	9.845E-01	1.996E-02	1.039E+09	6.731E-50	1.59515E-46	1.000E+00	1.000E+00
74681.318040	1.039E-57	1.391E-62	3.025E-59	9.845E-01	2.181E-02	1.134E+09	3.431E-50	8.13093E-47	1.000E+00	1.000E+00
76921.757581	4.834E-58	6.285E-63	1.408E-59	9.845E-01	2.383E-02	1.239E+09	1.745E-50	4.13533E-47	1.000E+00	1.000E+00
79229.410308	2.245E-58	2.834E-63	6.539E-60	9.845E-01	2.604E-02	1.354E+09	8.855E-51	2.09851E-47	1.000E+00	1.000E+00
81606.292618	1.040E-58	1.275E-63	3.030E-60	9.845E-01	2.846E-02	1.480E+09	4.483E-51	1.08254E-47	1.000E+00	1.000E+00
84054.481396	4.810E-59	5.722E-64	1.401E-60	9.845E-01	3.109E-02	1.617E+09	2.269E-51	5.36794E-48	1.000E+00	1.000E+00
86576.115838	2.219E-59	2.563E-64	6.462E-61	9.845E-01	3.398E-02	1.767E+09	1.142E-51	2.70585E-48	1.000E+00	1.000E+00
89173.399313	1.021E-59	1.145E-64	2.974E-61	9.845E-01	3.713E-02	1.931E+09	5.742E-52	1.36091E-48	1.000E+00	1.000E+00
91848.601293	4.690E-60	5.106E-65	1.366E-61	9.845E-01	4.057E-02	2.110E+09	2.882E-52	8.82951E-49	1.000E+00	1.000E+00
2.149E-60	2.272E-65	6.259E-62	9.845E-01	9.845E-01	4.433E-02	2.305E+09	1.443E-52	3.41963E-49	1.000E+00	1.000E+00
9.825E-61	1.008E-65	2.862E-62	9.845E-01	9.845E-01	4.844E-02	2.519E+09	7.209E-53	1.70845E-49	1.000E+00	1.000E+00
4.482E-61	4.466E-66	1.305E-62	9.845E-01	9.845E-01	5.294E-02	2.753E+09	3.594E-53	8.51637E-50	1.000E+00	1.000E+00
2.040E-61	1.973E-66	5.942E-63	9.845E-01	9.845E-01	5.784E-02	3.008E+09	1.787E-53	4.23584E-50	1.000E+00	1.000E+00
4.199E-62	8.702E-67	2.699E-63	9.845E-01	9.845E-01	6.321E-02	3.287E+09	8.870E-54	2.10211E-50	1.000E+00	1.000E+00
1.898E-62	1.680E-67	5.528E-64	9.845E-01	9.845E-01	6.907E-02	3.592E+09	4.392E-54	1.04089E-50	1.000E+00	1.000E+00
8.564E-63	7.360E-68	2.494E-64	9.845E-01	9.845E-01	7.547E-02	3.925E+09	2.170E-54	5.1428E-51	1.000E+00	1.000E+00
3.855E-63	3.217E-68	1.123E-64	9.845E-01	9.845E-01	8.247E-02	4.289E+09	1.070E-54	2.53509E-51	1.000E+00	1.000E+00
1.731E-63	1.403E-68	5.042E-65	9.845E-01	9.845E-01	9.012E-02	4.686E+09	5.261E-55	1.24691E-51	1.000E+00	1.000E+00
7.758E-64	6.102E-69	2.260E-65	9.845E-01	9.845E-01	9.848E-02	5.121E+09	2.582E-55	6.1194E-52	1.000E+00	1.000E+00
3.469E-64	2.649E-69	1.010E-65	9.845E-01	9.845E-01	1.076E+03	5.596E+09	1.284E-55	2.99695E-52	1.000E+00	1.000E+00
1.548E-64	1.147E-69	4.507E-66	9.845E-01	9.845E-01	1.176E+03	6.114E+09	6.178E-56	1.46403E-52	1.000E+00	1.000E+00
6.888E-65	4.958E-70	2.006E-66	9.845E-01	9.845E-01	1.285E+03	6.681E+09	3.012E-56	7.13706E-53	1.000E+00	1.000E+00
3.059E-65	2.138E-70	8.911E-67	9.845E-01	9.845E-01	1.404E+03	7.301E+09	1.468E-56	3.47152E-53	1.000E+00	1.000E+00
5.995E-66	9.199E-71	3.949E-67	9.845E-01	9.845E-01	1.534E+03	7.978E+09	7.109E-57	1.68481E-53	1.000E+00	1.000E+00
1.356E-66	1.691E-71	1.746E-67	9.845E-01	9.845E-01	1.676E+03	8.718E+09	3.443E-57	8.15856E-54	1.000E+00	1.000E+00
1.184E-66	7.229E-72	3.391E-68	9.845E-01	9.845E-01	1.832E+03	9.528E+09	1.663E-57	3.94192E-54	1.000E+00	1.000E+00
5.113E-67	3.082E-72	1.489E-68	9.845E-01	9.845E-01	2.002E+03	1.041E+10	8.019E-58	1.90035E-54	1.000E+00	1.000E+00
2.241E-67	1.311E-72	6.527E-69	9.845E-01	9.845E-01	2.187E+03	1.137E+10	3.857E-58	9.14095E-55	1.000E+00	1.000E+00
4.275E-68	5.568E-73	2.854E-69	9.845E-01	9.845E-01	2.390E+03	1.243E+10	1.851E-58	4.38713E-55	1.000E+00	1.000E+00
1.861E-68	9.967E-74	5.420E-70	9.845E-01	9.845E-01	2.612E+03	1.358E+10	8.865E-59	2.10088E-55	1.000E+00	1.000E+00
8.083E-69	4.203E-74	2.354E-70	9.845E-01	9.845E-01	2.854E+03	1.484E+10	4.236E-59	1.00381E-55	1.000E+00	1.000E+00
3.503E-69	1.768E-74	1.020E-70	9.845E-01	9.845E-01	3.119E+03	1.622E+10	2.019E-59	4.78559E-56	1.000E+00	1.000E+00
1.515E-69	7.424E-75	4.412E-71	9.845E-01	9.845E-01	3.408E+03	1.772E+10	9.605E-60	2.27641E-56	1.000E+00	1.000E+00
6.535E-70	3.110E-75	1.903E-71	9.845E-01	9.845E-01	3.724E+03	1.936E+10	4.559E-60	1.08043E-56	1.000E+00	1.000E+00
2.813E-70	1.300E-75	8.194E-72	9.845E-01	9.845E-01	4.069E+03	2.116E+10	2.159E-60	5.11653E-57	1.000E+00	1.000E+00
1.208E-70	5.420E-76	3.520E-72	9.845E-01	9.845E-01	4.447E+03	2.312E+10	1.020E-60	2.4178E-57	1.000E+00	1.000E+00
5.179E-71	2.255E-76	1.508E-72	9.845E-01	9.845E-01	4.859E+03	2.527E+10	4.809E-61	1.13979E-57	1.000E+00	1.000E+00
2.215E-71	9.363E-77	6.450E-73	9.845E-01	9.845E-01	5.310E+03	2.761E+10	2.262E-61	5.36165E-58	1.000E+00	1.000E+00
9.449E-72	3.879E-77	2.752E-73	9.845E-01	9.845E-01	5.802E+03	3.017E+10	1.062E-61	2.51653E-58	1.000E+00	1.000E+00
4.023E-72	1.603E-77	1.172E-73	9.845E-01	9.845E-01	6.340E+03	3.297E+10	4.973E-62	1.17852E-58	1.000E+00	1.000E+00
					6.928E+03	3.602E+10	2.324E-62	5.50887E-59	1.000E+00	1.000E+00
					7.570E+03	3.936E+10	1.083E-62	2.56746E-59	1.000E+00	1.000E+00
					8.272E+03	4.301E+10	5.040E-63	1.19435E-59	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution	Normalized Differential Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*d/d	$\Sigma P(d)*d/d$	$\pi d^3/6$	V ρ	P(d)*d*m/d	P(d)*d*m/(d*mP _{tot})	d < 6.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
258449.330664	1.709E-72	6.611E-78	4.977E-74	9.845E-01	9.039E+03	4.700E+10	2.339E-63	5.54364E-60	1.000E+00	1.000E+00
266202.810584	7.242E-73	2.720E-78	2.109E-74	9.845E-01	9.877E+03	5.136E+10	1.083E-63	2.56737E-60	1.000E+00	1.000E+00
274188.864901	3.062E-73	1.117E-78	8.919E-75	9.845E-01	1.079E+04	5.612E+10	5.006E-64	1.18635E-60	1.000E+00	1.000E+00
282414.561748	1.292E-73	4.575E-79	3.763E-75	9.845E-01	1.179E+04	6.132E+10	2.308E-64	5.46976E-61	1.000E+00	1.000E+00
290886.998601	5.440E-74	1.870E-79	1.584E-75	9.845E-01	1.289E+04	6.702E+10	1.062E-64	2.51626E-61	1.000E+00	1.000E+00
299613.608559	2.285E-74	7.626E-80	6.655E-76	9.845E-01	1.408E+04	7.323E+10	4.874E-65	1.15498E-61	1.000E+00	1.000E+00
308602.016816	9.577E-75	3.103E-80	2.789E-76	9.845E-01	1.539E+04	8.002E+10	2.232E-65	5.28964E-62	1.000E+00	1.000E+00
317860.077320	4.005E-75	1.260E-80	1.166E-76	9.845E-01	1.682E+04	8.744E+10	1.020E-65	2.41717E-62	1.000E+00	1.000E+00
327395.879640	1.671E-75	5.104E-81	4.867E-77	9.845E-01	1.837E+04	9.555E+10	4.650E-66	1.1021E-62	1.000E+00	1.000E+00
337217.766029	6.957E-76	2.063E-81	2.026E-77	9.845E-01	2.008E+04	1.044E+11	2.116E-66	5.0138E-63	1.000E+00	1.000E+00
347334.288710	2.890E-76	8.320E-82	8.417E-78	9.845E-01	2.194E+04	1.141E+11	9.603E-67	2.27585E-63	1.000E+00	1.000E+00
358486.946892	1.198E-76	3.348E-82	3.489E-78	9.845E-01	2.397E+04	1.247E+11	4.349E-67	4.65791E-64	1.000E+00	1.000E+00
379541.552299	4.953E-77	1.344E-82	1.443E-78	9.845E-01	2.620E+04	1.362E+11	1.965E-67	8.65791E-64	1.000E+00	1.000E+00
390827.801958	2.044E-77	5.385E-83	5.953E-79	9.845E-01	2.863E+04	1.489E+11	8.862E-68	2.10021E-64	1.000E+00	1.000E+00
402655.636017	8.415E-78	2.153E-83	2.451E-79	9.845E-01	3.128E+04	1.627E+11	3.987E-68	9.44855E-65	1.000E+00	1.000E+00
414735.305097	3.457E-78	8.585E-84	1.007E-79	9.845E-01	3.418E+04	1.777E+11	1.790E-68	4.24173E-65	1.000E+00	1.000E+00
427177.364250	1.417E-78	3.416E-84	4.127E-80	9.845E-01	3.735E+04	1.942E+11	8.016E-69	1.89961E-65	1.000E+00	1.000E+00
439992.685178	5.795E-79	1.356E-84	1.688E-80	9.845E-01	4.082E+04	2.122E+11	3.582E-69	8.48911E-66	1.000E+00	1.000E+00
453192.465733	2.364E-79	5.374E-85	6.887E-81	9.845E-01	4.460E+04	2.319E+11	1.597E-69	3.78522E-66	1.000E+00	1.000E+00
466788.239705	9.627E-80	2.124E-85	2.804E-81	9.845E-01	4.874E+04	2.534E+11	7.106E-70	1.68404E-66	1.000E+00	1.000E+00
480791.886896	3.911E-80	8.378E-86	1.139E-81	9.845E-01	5.325E+04	2.769E+11	3.154E-70	7.47555E-67	1.000E+00	1.000E+00
495215.643503	1.585E-80	3.297E-86	4.617E-82	9.845E-01	5.819E+04	3.026E+11	1.397E-70	3.31106E-67	1.000E+00	1.000E+00
510072.112808	6.411E-81	1.295E-86	1.867E-82	9.845E-01	6.359E+04	3.307E+11	6.174E-71	1.46326E-67	1.000E+00	1.000E+00
525374.276192	2.587E-81	5.072E-87	7.535E-83	9.845E-01	6.949E+04	3.613E+11	2.723E-71	6.4522E-68	1.000E+00	1.000E+00
541135.504478	1.042E-81	1.983E-87	3.034E-83	9.845E-01	7.593E+04	3.948E+11	1.198E-71	2.83874E-68	1.000E+00	1.000E+00
557369.569612	4.184E-82	7.733E-88	1.219E-83	9.845E-01	8.297E+04	4.314E+11	5.258E-72	1.24616E-68	1.000E+00	1.000E+00
574090.656701	1.677E-82	3.009E-88	4.885E-84	9.845E-01	9.066E+04	4.714E+11	2.303E-72	5.45828E-69	1.000E+00	1.000E+00
591313.376402	6.708E-83	1.168E-88	1.954E-84	9.845E-01	9.907E+04	5.152E+11	1.007E-72	2.38544E-69	1.000E+00	1.000E+00
609052.777694	2.677E-83	4.527E-89	7.797E-85	9.845E-01	1.083E+05	5.629E+11	4.389E-73	1.04019E-69	1.000E+00	1.000E+00
627324.361025	1.066E-83	1.750E-89	3.104E-85	9.845E-01	1.183E+05	6.151E+11	1.910E-73	4.52571E-70	1.000E+00	1.000E+00
646144.081855	4.234E-84	6.750E-90	1.233E-85	9.845E-01	1.293E+05	6.722E+11	8.290E-74	1.96469E-70	1.000E+00	1.000E+00
665528.414611	1.679E-84	2.598E-90	4.889E-86	9.845E-01	1.412E+05	7.346E+11	3.591E-74	8.51005E-71	1.000E+00	1.000E+00
685494.267049	6.639E-85	9.975E-91	1.934E-86	9.845E-01	1.543E+05	8.028E+11	1.552E-74	3.87792E-71	1.000E+00	1.000E+00
706059.095061	2.620E-85	3.822E-91	7.631E-87	9.845E-01	1.687E+05	8.770E+11	6.692E-75	1.586E-71	1.000E+00	1.000E+00
727240.867913	1.032E-85	1.461E-91	3.005E-87	9.845E-01	1.843E+05	9.584E+11	2.879E-75	6.82396E-72	1.000E+00	1.000E+00
749058.093950	4.053E-86	5.573E-92	1.180E-87	9.845E-01	2.014E+05	1.047E+12	1.236E-75	2.92955E-72	1.000E+00	1.000E+00
771529.836768	1.588E-86	2.121E-92	4.627E-88	9.845E-01	2.201E+05	1.144E+12	5.295E-76	1.25486E-72	1.000E+00	1.000E+00
794675.731871	6.214E-87	8.054E-93	1.810E-88	9.845E-01	2.405E+05	1.250E+12	2.263E-76	5.36321E-73	1.000E+00	1.000E+00
818516.003828	2.425E-87	3.051E-93	7.063E-89	9.845E-01	2.628E+05	1.368E+12	9.651E-77	2.28709E-73	1.000E+00	1.000E+00
83688.88	9.442E-88	1.154E-93	2.750E-89	9.845E-01	2.871E+05	1.493E+12	4.106E-77	9.73137E-74	1.000E+00	1.000E+00
868363.629461	3.668E-88	4.351E-94	1.068E-89	9.845E-01	3.138E+05	1.632E+12	1.743E-77	4.13139E-74	1.000E+00	1.000E+00
884414.537315	1.422E-88	1.639E-94	4.142E-90	9.845E-01	3.428E+05	1.783E+12	7.384E-78	1.75005E-74	1.000E+00	1.000E+00
	5.500E-89	6.150E-95	1.802E-90	9.845E-01	3.746E+05	1.948E+12	3.121E-78	7.39684E-75	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle $\pi d^3/\delta$	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*Δd/d	Σ P(d)*Δd/d	π d ³ / δ	V ρ	P(d)*Δd ² m/d	P(d)*Δd ² m/(d ² mP ₉₀)	d < 6.9	Σ P(d) m/(P m) ₉₀	
921246.973434	2.123E-89	2.304E-95	6.183E-91	9.845E-01	4.094E+05	2.129E+12	1.316E-78	3.11926E-75	1.000E+00	1.000E+00	
948884.392637	8.174E-90	8.614E-96	2.381E-91	9.845E-01	4.473E+05	2.326E+12	5.538E-79	1.3125E-75	1.000E+00	1.000E+00	
977350.914116	3.141E-90	3.213E-96	8.147E-92	9.845E-01	4.888E+05	2.542E+12	2.325E-79	5.51034E-76	1.000E+00	1.000E+00	
1006671.441540	1.204E-90	1.196E-96	3.507E-92	9.845E-01	5.341E+05	2.778E+12	9.740E-80	2.30829E-76	1.000E+00	1.000E+00	
1036871.584786	4.605E-91	4.441E-97	1.341E-92	9.845E-01	5.837E+05	3.035E+12	4.071E-80	9.64788E-77	1.000E+00	1.000E+00	
1067877.732329	1.758E-91	1.648E-97	5.119E-93	9.845E-01	6.378E+05	3.317E+12	1.698E-80	4.02352E-77	1.000E+00	1.000E+00	
1100017.064299	6.693E-92	6.084E-98	1.949E-93	9.845E-01	6.969E+05	3.624E+12	7.064E-81	1.67422E-77	1.000E+00	1.000E+00	
1133071.576228	2.543E-92	2.244E-98	7.408E-94	9.845E-01	7.618E+05	3.960E+12	2.933E-81	6.95102E-78	1.000E+00	1.000E+00	
1167008.103515	9.640E-93	8.260E-99	2.808E-94	9.845E-01	8.322E+05	4.327E+12	1.215E-81	2.8795E-78	1.000E+00	1.000E+00	
1202018.346620	3.646E-93	3.034E-99	1.062E-94	9.845E-01	9.094E+05	4.729E+12	5.022E-82	1.19019E-78	1.000E+00	1.000E+00	
1233078.897019	1.376E-93	1.112E-99	4.008E-95	9.845E-01	9.937E+05	5.167E+12	2.071E-82	4.9085E-79	1.000E+00	1.000E+00	
1275221.263930	5.182E-94	4.064E-100	1.509E-95	9.845E-01	1.088E+06	5.646E+12	8.523E-83	2.01982E-79	1.000E+00	1.000E+00	
1313477.901848	1.947E-94	1.483E-100	5.672E-96	9.845E-01	1.186E+06	6.170E+12	3.499E-83	8.29291E-80	1.000E+00	1.000E+00	
1352882.238903	7.300E-95	5.396E-101	2.126E-96	9.845E-01	1.297E+06	6.742E+12	1.434E-83	3.39729E-80	1.000E+00	1.000E+00	
1393468.708070	2.731E-95	1.960E-101	7.954E-97	9.845E-01	1.417E+06	7.367E+12	5.859E-84	1.38864E-80	1.000E+00	1.000E+00	
1435272.767252	1.019E-95	7.101E-102	2.969E-97	9.845E-01	1.548E+06	8.050E+12	2.390E-84	5.66344E-81	1.000E+00	1.000E+00	
1476330.950270	3.795E-96	2.567E-102	1.105E-97	9.845E-01	1.692E+06	8.797E+12	9.725E-85	2.30463E-81	1.000E+00	1.000E+00	
1522680.878778	1.410E-96	9.282E-103	4.108E-98	9.845E-01	1.849E+06	9.612E+12	3.948E-85	9.35735E-82	1.000E+00	1.000E+00	
1568361.305141	5.229E-97	3.334E-103	1.523E-98	9.845E-01	2.020E+06	1.050E+13	1.600E-85	3.79089E-82	1.000E+00	1.000E+00	
1615412.144295	1.934E-97	1.197E-103	5.633E-99	9.845E-01	2.207E+06	1.148E+13	6.466E-86	1.53233E-82	1.000E+00	1.000E+00	
1663874.508624	7.139E-98	4.290E-104	2.079E-99	9.845E-01	2.412E+06	1.254E+13	2.689E-86	6.18014E-83	1.000E+00	1.000E+00	
1713790.743683	2.629E-98	1.534E-104	7.657E-100	9.845E-01	2.636E+06	1.370E+13	1.049E-86	2.48701E-83	1.000E+00	1.000E+00	
1765204.466199	9.660E-99	5.473E-105	2.814E-100	9.845E-01	2.880E+06	1.498E+13	4.214E-87	9.9589E-84	1.000E+00	1.000E+00	
1818160.600185	3.542E-99	1.948E-105	1.032E-100	9.845E-01	3.147E+06	1.636E+13	1.688E-87	4.00063E-84	1.000E+00	1.000E+00	
1872705.418191	1.296E-99	6.918E-106	3.774E-101	9.845E-01	3.439E+06	1.788E+13	6.748E-88	1.59919E-84	1.000E+00	1.000E+00	
1928886.580737	4.729E-100	2.452E-106	1.377E-101	9.845E-01	3.758E+06	1.954E+13	2.691E-88	6.3763E-85	1.000E+00	1.000E+00	
1986753.178159	1.722E-100	8.669E-107	5.016E-102	9.845E-01	4.108E+06	2.135E+13	1.071E-88	2.53829E-85	1.000E+00	1.000E+00	
2046355.773504	6.259E-101	3.058E-107	1.823E-102	9.845E-01	4.467E+06	2.333E+13	4.253E-89	1.00788E-85	1.000E+00	1.000E+00	
2107746.446709	2.269E-101	1.077E-107	6.609E-103	9.845E-01	4.903E+06	2.550E+13	1.685E-89	3.99307E-86	1.000E+00	1.000E+00	
2170978.840110	8.208E-102	3.781E-108	2.391E-103	9.845E-01	5.358E+06	2.786E+13	6.660E-90	1.57847E-86	1.000E+00	1.000E+00	
2236108.205313	2.963E-102	1.325E-108	8.630E-104	9.845E-01	5.854E+06	3.044E+13	2.627E-90	6.22586E-87	1.000E+00	1.000E+00	
2303191.451473	1.067E-102	4.633E-109	3.108E-104	9.845E-01	6.397E+06	3.327E+13	1.034E-90	2.45015E-87	1.000E+00	1.000E+00	
2372287.195017	3.834E-103	1.616E-109	1.117E-104	9.845E-01	6.990E+06	3.635E+13	4.060E-91	9.62094E-88	1.000E+00	1.000E+00	
2443455.810867	1.375E-103	5.626E-110	4.004E-105	9.845E-01	7.639E+06	3.972E+13	1.591E-91	3.76947E-88	1.000E+00	1.000E+00	
2516759.485193	4.918E-104	1.954E-110	1.433E-105	9.845E-01	8.347E+06	4.340E+13	6.218E-92	1.47354E-88	1.000E+00	1.000E+00	
2592282.269749	1.756E-104	6.772E-111	5.113E-106	9.845E-01	9.121E+06	4.743E+13	2.425E-92	5.74753E-89	1.000E+00	1.000E+00	
26253E-105	2.623E-105	2.342E-111	1.821E-106	9.845E-01	9.967E+06	5.183E+13	9.438E-93	2.23682E-89	1.000E+00	1.000E+00	
2670030.137842	2.222E-105	8.079E-112	6.472E-107	9.845E-01	1.089E+07	5.663E+13	3.665E-93	8.68589E-90	1.000E+00	1.000E+00	
2750131.041977	7.878E-106	2.781E-112	2.295E-107	9.845E-01	1.190E+07	6.188E+13	1.420E-93	3.36534E-90	1.000E+00	1.000E+00	
2832634.973236	2.787E-106	9.593E-113	8.118E-108	9.845E-01	1.300E+07	6.762E+13	5.490E-94	1.30099E-90	1.000E+00	1.000E+00	
2917614.022433	2.787E-106	9.593E-113	8.118E-108	9.845E-01	1.421E+07	7.399E+13	2.117E-94	5.01823E-91	1.000E+00	1.000E+00	
3005142.443106	9.839E-107	3.274E-113	2.866E-108	9.845E-01	1.553E+07	8.074E+13	8.149E-95	1.93134E-91	1.000E+00	1.000E+00	
3095296.716400	3.465E-107	1.120E-113	1.009E-108	9.845E-01	1.697E+07	8.823E+13	3.129E-95	7.4165E-92	1.000E+00	1.000E+00	
3188155.617892	1.218E-107	3.820E-114	3.547E-109	9.845E-01	1.697E+07	8.823E+13	3.129E-95	7.4165E-92	1.000E+00	1.000E+00	

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*dd/d	$\Sigma P(d)*dd/d$	$\pi d^3/6$	V ρ	P(d)*dd*md/d	P(d)*dd*md/(d* ρ *m ₀)	d < 6.9	$\Sigma P(d) m/(P m)_0$
3283800.286428	4.270E-108	1.300E-114	1.244E-109	9.845E-01	1.854E-07	9.641E+13	1.199E-95	2.84165E-92	1.000E+00	1.000E+00
3382314.295021	1.494E-108	4.417E-115	4.351E-110	9.845E-01	2.026E-07	1.054E+14	4.584E-96	1.08636E-92	1.000E+00	1.000E+00
3483783.723872	5.215E-109	1.497E-115	5.191E-111	9.845E-01	2.214E-07	1.151E+14	1.748E-96	4.14389E-93	1.000E+00	1.000E+00
3589297.235588	1.816E-109	5.062E-116	5.290E-111	9.845E-01	2.419E-07	1.258E+14	6.655E-97	1.57715E-93	1.000E+00	1.000E+00
3695948.152656	6.312E-110	1.708E-116	1.838E-111	9.845E-01	2.643E-07	1.375E+14	2.527E-97	5.86924E-94	1.000E+00	1.000E+00
3809824.537235	2.189E-110	5.750E-117	6.375E-112	9.845E-01	2.869E-07	1.502E+14	9.576E-98	2.26935E-94	1.000E+00	1.000E+00
3921029.273352	7.573E-111	1.931E-117	2.208E-112	9.845E-01	3.156E-07	1.641E+14	3.620E-98	8.57949E-95	1.000E+00	1.000E+00
4038660.151553	2.614E-111	6.473E-118	7.614E-113	9.845E-01	3.449E-07	1.794E+14	1.366E-98	3.23633E-95	1.000E+00	1.000E+00
4109819.956099	9.004E-112	2.165E-118	2.623E-113	9.845E-01	3.769E-07	1.960E+14	5.140E-99	1.21808E-95	1.000E+00	1.000E+00
4284614.554782	3.094E-112	7.222E-119	9.013E-114	9.845E-01	4.118E-07	2.142E+14	1.930E-99	4.57438E-96	1.000E+00	1.000E+00
4545547.581169	3.630E-113	7.987E-120	1.057E-114	9.845E-01	4.918E-07	2.557E+14	2.704E-100	6.40821E-97	1.000E+00	1.000E+00
46822371.428862	1.239E-113	2.647E-120	3.610E-115	9.845E-01	5.374E-07	2.704E+14	1.009E-100	2.39049E-97	1.000E+00	1.000E+00
4967042.571728	4.222E-114	8.754E-121	1.230E-115	9.845E-01	5.872E-07	3.053E+14	3.754E-101	8.89749E-98	1.000E+00	1.000E+00
5116053.848879	1.435E-114	2.888E-121	4.179E-116	9.845E-01	6.416E-07	3.337E+14	1.394E-101	3.30431E-98	1.000E+00	1.000E+00
5269535.464346	4.865E-115	9.510E-122	1.417E-116	9.845E-01	7.011E-07	3.646E+14	5.168E-102	1.2244E-98	1.000E+00	1.000E+00
5427621.528276	1.846E-115	3.124E-122	4.795E-117	9.845E-01	7.862E-07	3.984E+14	1.910E-102	4.5269E-99	1.000E+00	1.000E+00
5590450.174125	1.872E-116	3.348E-123	5.452E-118	9.845E-01	8.372E-07	4.353E+14	7.047E-103	1.67E-99	1.000E+00	1.000E+00
5758163.679348	6.291E-117	1.093E-123	1.832E-118	9.845E-01	9.148E-07	4.757E+14	2.594E-103	6.1468E-100	1.000E+00	1.000E+00
5930908.589729	2.110E-117	3.557E-124	6.145E-119	9.845E-01	9.997E-07	5.198E+14	9.525E-104	2.2574E-100	1.000E+00	1.000E+00
6109835.847421	7.059E-118	1.156E-124	2.056E-119	9.845E-01	1.092E+08	5.680E+14	3.490E-104	8.2721E-101	1.000E+00	1.000E+00
6292100.922843	2.357E-118	3.746E-125	6.864E-120	9.845E-01	1.194E+08	6.207E+14	1.276E-104	3.0245E-101	1.000E+00	1.000E+00
6480863.950528	7.850E-119	1.211E-125	2.287E-121	9.845E-01	1.304E+08	6.782E+14	4.656E-105	1.1034E-101	1.000E+00	1.000E+00
6675289.869044	2.609E-119	3.909E-126	7.600E-121	9.845E-01	1.425E+08	7.411E+14	1.695E-105	4.0162E-102	1.000E+00	1.000E+00
6875548.565116	8.653E-120	1.288E-126	2.520E-121	9.845E-01	1.557E+08	8.099E+14	6.155E-106	1.4586E-102	1.000E+00	1.000E+00
7081815.022069	2.863E-120	4.043E-127	8.339E-122	9.845E-01	1.702E+08	8.850E+14	2.230E-106	5.2857E-103	1.000E+00	1.000E+00
7294269.472731	3.114E-121	1.286E-127	2.753E-122	9.845E-01	1.860E+08	9.670E+14	8.064E-107	1.9117E-103	1.000E+00	1.000E+00
7513097.556913	1.023E-121	1.323E-128	2.981E-123	9.845E-01	2.032E+08	1.057E+15	2.908E-107	6.8948E-104	1.000E+00	1.000E+00
7738490.483621	3.356E-122	4.211E-129	9.776E-124	9.845E-01	2.221E+08	1.155E+15	1.047E-107	2.4818E-104	1.000E+00	1.000E+00
7970645.198129	1.088E-122	1.338E-129	3.199E-124	9.845E-01	2.426E+08	1.262E+15	3.761E-108	8.9138E-105	1.000E+00	1.000E+00
8209764.554073	3.586E-123	4.240E-130	1.044E-124	9.845E-01	2.651E+08	1.379E+15	1.348E-108	3.1942E-105	1.000E+00	1.000E+00
8455057.490695	1.168E-123	1.341E-130	3.402E-125	9.845E-01	2.897E+08	1.507E+15	4.819E-109	1.1421E-105	1.000E+00	1.000E+00
8709739.215416	3.797E-124	4.232E-131	1.108E-125	9.845E-01	3.166E+08	1.646E+15	1.719E-109	4.0747E-106	1.000E+00	1.000E+00
8971031.391879	1.231E-124	1.333E-131	3.588E-126	9.845E-01	3.460E+08	1.799E+15	6.120E-110	1.4505E-106	1.000E+00	1.000E+00
9240162.333635	1.231E-124	1.333E-131	3.588E-126	9.845E-01	3.780E+08	1.966E+15	2.174E-110	5.1517E-107	1.000E+00	1.000E+00
9517367.203644	3.984E-125	4.186E-132	1.161E-126	9.845E-01	4.131E+08	2.148E+15	7.704E-111	1.8257E-107	1.000E+00	1.000E+00
9802888.219753	1.288E-125	1.312E-132	3.747E-127	9.845E-01	4.514E+08	2.347E+15	2.724E-111	6.4555E-108	1.000E+00	1.000E+00
10096974.866346	4.144E-126	4.104E-133	1.207E-127	9.845E-01	4.932E+08	2.565E+15	9.610E-112	2.2776E-108	1.000E+00	1.000E+00
10399884.112336	1.332E-126	1.281E-133	3.880E-128	9.845E-01	5.390E+08	2.803E+15	3.383E-112	6.0175E-109	1.000E+00	1.000E+00
10711880.635706	4.272E-127	3.988E-134	1.244E-128	9.845E-01	5.890E+08	3.083E+15	1.188E-112	2.816E-109	1.000E+00	1.000E+00
11033237.054778	1.367E-127	1.239E-134	3.982E-129	9.845E-01	6.436E+08	3.347E+15	4.164E-113	9.8689E-110	1.000E+00	1.000E+00
11364234.166421	4.365E-128	3.841E-135	1.271E-129	9.845E-01	7.032E+08	3.657E+15	1.456E-113	3.4508E-110	1.000E+00	1.000E+00
					7.685E+08	3.996E+15	5.080E-114	1.204E-110	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*d/d	$\Sigma P(d)*d/d$	$\pi d^3/6$	$V \rho$	P(d)*d*m/d	P(d)*d*m/(d ³ mP _{wt})	d < 6.9	$\Sigma P(d) \text{ m}/(P \text{ m})_{\text{tot}}$
11705161.191414	1.391E-128	1.188E-135	4.050E-130	9.845E-01	8.397E-08	4.367E+15	1.789E-114	4.1914E-111	1.000E+00	1.000E+00
12056316.027156	4.420E-129	3.666E-136	1.287E-130	9.845E-01	9.176E-08	4.771E+15	6.143E-115	1.4558E-111	1.000E+00	1.000E+00
12418005.507971	1.402E-129	1.129E-136	4.083E-131	9.845E-01	1.003E-09	5.214E+15	2.129E-115	5.0455E-112	1.000E+00	1.000E+00
12790545.673210	4.436E-130	3.469E-137	1.292E-131	9.845E-01	1.096E-09	5.697E+15	7.362E-116	1.7447E-112	1.000E+00	1.000E+00
13147262.043406	1.401E-130	1.063E-137	4.080E-132	9.845E-01	1.197E-09	6.226E+15	2.540E-116	6.0197E-113	1.000E+00	1.000E+00
13569489.904708	4.413E-131	3.252E-138	1.285E-132	9.845E-01	1.308E-09	6.803E+15	8.744E-117	2.0723E-113	1.000E+00	1.000E+00
13976574.601849	1.387E-131	9.926E-139	4.041E-133	9.845E-01	1.430E-09	7.434E+15	3.004E-117	7.1189E-114	1.000E+00	1.000E+00
14395871.839905	4.351E-132	3.022E-139	1.267E-133	9.845E-01	1.562E-09	8.123E+15	1.029E-117	2.4396E-114	1.000E+00	1.000E+00
14827747.995102	1.362E-132	9.183E-140	3.968E-134	9.845E-01	1.707E-09	8.876E+15	3.520E-118	8.3428E-115	1.000E+00	1.000E+00
15272580.434955	4.252E-133	2.784E-140	1.238E-134	9.845E-01	1.865E-09	9.699E+15	1.201E-118	2.8463E-115	1.000E+00	1.000E+00
15730757.848004	1.325E-133	8.420E-141	3.888E-135	9.845E-01	2.038E-09	1.060E+16	4.089E-119	9.8908E-116	1.000E+00	1.000E+00
16202680.583444	4.118E-134	2.541E-141	1.199E-135	9.845E-01	2.227E-09	1.158E+16	1.389E-119	3.2917E-116	1.000E+00	1.000E+00
16688761.000947	1.277E-134	7.653E-142	3.720E-136	9.845E-01	2.434E-09	1.266E+16	4.709E-120	1.1157E-116	1.000E+00	1.000E+00
17189423.830976	3.952E-135	2.299E-142	1.151E-136	9.845E-01	2.659E-09	1.363E+16	1.592E-120	3.7728E-117	1.000E+00	1.000E+00
17705106.545905	1.220E-135	6.893E-143	3.555E-137	9.845E-01	2.906E-09	1.511E+16	5.372E-121	1.273E-117	1.000E+00	1.000E+00
18236259.742282	3.760E-136	2.062E-143	1.095E-137	9.845E-01	3.175E-09	1.651E+16	1.808E-121	4.2858E-118	1.000E+00	1.000E+00
18783347.534551	1.156E-136	6.154E-144	3.367E-138	9.845E-01	3.470E-09	1.804E+16	6.075E-122	1.4397E-118	1.000E+00	1.000E+00
19346847.960587	3.545E-137	1.833E-144	1.033E-138	9.845E-01	3.792E-09	1.972E+16	2.036E-122	4.8253E-119	1.000E+00	1.000E+00
19927253.3399405	1.085E-137	5.445E-145	3.160E-139	9.845E-01	4.143E-09	2.154E+16	6.809E-123	1.6137E-119	1.000E+00	1.000E+00
20525071.001387	3.313E-138	1.614E-145	9.651E-140	9.845E-01	4.527E-09	2.354E+16	2.272E-123	5.3845E-120	1.000E+00	1.000E+00
21140823.131428	1.010E-138	4.775E-146	2.940E-140	9.845E-01	4.947E-09	2.573E+16	7.584E-124	1.7927E-120	1.000E+00	1.000E+00
21775047.825371	3.089E-139	1.409E-146	8.939E-141	9.845E-01	5.406E-09	2.811E+16	2.513E-124	5.9551E-121	1.000E+00	1.000E+00
22428298.260132	9.309E-140	4.151E-147	2.711E-141	9.845E-01	5.907E-09	3.072E+16	8.329E-125	1.9738E-121	1.000E+00	1.000E+00
23101148.237938	2.817E-140	1.220E-147	8.208E-142	9.845E-01	6.455E-09	3.357E+16	2.754E-125	6.5277E-122	1.000E+00	1.000E+00
23794182.685074	8.508E-141	3.576E-148	2.478E-142	9.845E-01	7.054E-09	3.668E+16	9.089E-126	2.3297E-123	1.000E+00	1.000E+00
24508008.165627	2.563E-141	1.045E-148	7.468E-143	9.845E-01	7.708E-09	4.008E+16	2.992E-126	7.0918E-123	1.000E+00	1.000E+00
25243248.410595	7.706E-142	3.053E-149	2.245E-143	9.845E-01	8.422E-09	4.380E+16	9.830E-127	2.3297E-123	1.000E+00	1.000E+00
26000545.862913	2.312E-142	8.891E-150	6.733E-144	9.845E-01	9.203E-09	4.786E+16	3.222E-127	7.6362E-124	1.000E+00	1.000E+00
26780562.238801	6.918E-143	2.583E-150	2.015E-144	9.845E-01	1.006E+10	5.230E+16	1.054E-127	2.4974E-124	1.000E+00	1.000E+00
27583379.105955	2.068E-143	7.490E-151	6.018E-145	9.845E-01	1.099E+10	5.714E+16	3.439E-128	8.1495E-125	1.000E+00	1.000E+00
28411498.479144	6.156E-144	2.167E-151	1.793E-145	9.845E-01	1.201E+10	6.244E+16	1.120E-128	2.8534E-125	1.000E+00	1.000E+00
29263843.433518	1.830E-144	6.254E-152	5.331E-146	9.845E-01	1.312E+10	6.823E+16	3.637E-129	8.6199E-126	1.000E+00	1.000E+00
30141758.736524	5.429E-145	1.801E-152	1.581E-146	9.845E-01	1.434E+10	7.456E+16	1.179E-129	2.7941E-126	1.000E+00	1.000E+00
31046011.498619	1.607E-145	5.176E-153	4.680E-147	9.845E-01	1.567E+10	8.147E+16	3.813E-130	9.0368E-127	1.000E+00	1.000E+00
31977391.843578	4.745E-146	1.484E-153	1.332E-147	9.845E-01	1.712E+10	8.903E+16	1.230E-130	2.9161E-127	1.000E+00	1.000E+00
32936713.598885	1.398E-146	4.245E-154	4.072E-148	9.845E-01	1.871E+10	9.728E+16	3.962E-131	9.3893E-128	1.000E+00	1.000E+00
33924815.006852	4.111E-147	1.212E-154	1.197E-148	9.845E-01	2.044E+10	1.063E+17	1.273E-131	3.0164E-128	1.000E+00	1.000E+00
34942559.457057	1.208E-147	3.451E-155	3.512E-149	9.845E-01	2.234E+10	1.162E+17	4.080E-132	9.6691E-129	1.000E+00	1.000E+00
35990836.240769	3.530E-148	9.807E-156	1.028E-149	9.845E-01	2.441E+10	1.269E+17	1.305E-132	3.9925E-129	1.000E+00	1.000E+00
37070561.327992	1.031E-148	2.781E-156	3.002E-150	9.845E-01	2.667E+10	1.387E+17	4.164E-133	9.8688E-130	1.000E+00	1.000E+00
38182678.167832	3.004E-149	7.866E-157	8.748E-151	9.845E-01	2.915E+10	1.516E+17	1.329E-133	3.1423E-130	1.000E+00	1.000E+00
39328158.512867	8.733E-150	2.220E-157	2.543E-151	9.845E-01	3.185E+10	1.656E+17	4.212E-134	9.9832E-131	1.000E+00	1.000E+00
40508003.268253	2.533E-150	6.254E-158	7.378E-152	9.845E-01	3.480E+10	1.810E+17	1.339E-134	3.1646E-131	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) Δd	$\Sigma P(d)\Delta d$	$\pi d^3/6$	V ρ	P(d) Δd m/d	P(d) Δd m/(d ³ mP ₅₀)	d < 5.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
4172343.366300	7.332E-151	1.757E-158	2.136E-152	9.845E-01	3.803E+10	1.978E+17	4.223E-135	1.0009E-131	1.000E+00	1.000E+00
42974940.667289	2.118E-151	4.928E-159	6.168E-153	9.845E-01	4.156E+10	2.161E+17	1.333E-135	3.1587E-132	1.000E+00	1.000E+00
44264198.887308	6.102E-152	1.379E-159	1.777E-153	9.845E-01	4.541E+10	2.361E+17	4.197E-136	9.9462E-133	1.000E+00	1.000E+00
45592114.553927	1.754E-152	3.848E-160	5.110E-154	9.845E-01	4.962E+10	2.580E+17	1.319E-136	3.1249E-133	1.000E+00	1.000E+00
46959877.990545	5.033E-153	1.072E-160	1.466E-154	9.845E-01	5.422E+10	2.820E+17	4.133E-137	9.7958E-134	1.000E+00	1.000E+00
48368674.330261	1.441E-153	2.979E-161	4.196E-155	9.845E-01	5.925E+10	3.081E+17	1.293E-137	3.0639E-134	1.000E+00	1.000E+00
49819734.560169	4.115E-154	8.259E-162	1.198E-155	9.845E-01	6.474E+10	3.367E+17	4.035E-138	9.5621E-135	1.000E+00	1.000E+00
51314326.596974	1.173E-154	2.285E-162	3.415E-156	9.845E-01	7.075E+10	3.679E+17	1.256E-138	2.9775E-135	1.000E+00	1.000E+00
52853756.394884	3.334E-155	6.308E-163	9.710E-157	9.845E-01	7.731E+10	4.020E+17	3.904E-139	9.251E-136	1.000E+00	1.000E+00
54439369.086730	9.458E-156	1.737E-163	2.755E-157	9.845E-01	8.448E+10	4.393E+17	1.210E-139	2.8678E-136	1.000E+00	1.000E+00
56072550.159332	2.677E-156	4.775E-164	7.798E-158	9.845E-01	9.231E+10	4.800E+17	3.743E-140	8.8705E-137	1.000E+00	1.000E+00
57754726.664112	7.561E-157	1.309E-164	2.202E-158	9.845E-01	1.009E+11	5.248E+17	1.155E-140	2.7376E-137	1.000E+00	1.000E+00
59487368.464035	2.131E-157	3.582E-165	6.206E-159	9.845E-01	1.102E+11	5.732E+17	3.557E-141	8.4302E-138	1.000E+00	1.000E+00
61271989.517856	5.981E-158	9.778E-166	1.745E-159	9.845E-01	1.204E+11	6.263E+17	1.093E-141	2.5902E-138	1.000E+00	1.000E+00
63110149.203495	1.681E-158	2.663E-166	4.896E-160	9.845E-01	1.316E+11	6.844E+17	3.351E-142	7.9405E-139	1.000E+00	1.000E+00
65003453.679600	4.705E-159	7.238E-167	1.370E-160	9.845E-01	1.438E+11	7.478E+17	1.025E-142	2.4289E-139	1.000E+00	1.000E+00
66963557.289888	1.314E-159	1.963E-167	3.828E-161	9.845E-01	1.572E+11	8.172E+17	3.128E-143	7.4129E-140	1.000E+00	1.000E+00
68962194.009687	3.662E-160	5.311E-168	1.067E-161	9.845E-01	1.717E+11	8.930E+17	9.525E-144	2.2574E-140	1.000E+00	1.000E+00
71031028.928948	1.018E-160	1.434E-168	2.966E-162	9.845E-01	1.876E+11	9.758E+17	2.894E-144	6.8589E-141	1.000E+00	1.000E+00
73161958.796817	2.825E-161	3.882E-169	8.229E-163	9.845E-01	2.050E+11	1.066E+18	8.774E-145	2.0794E-141	1.000E+00	1.000E+00
75356818.590721	7.821E-162	1.038E-169	2.278E-163	9.845E-01	2.241E+11	1.165E+18	2.654E-145	6.2899E-142	1.000E+00	1.000E+00
77617523.148443	2.160E-162	2.783E-170	6.292E-164	9.845E-01	2.448E+11	1.273E+18	8.012E-146	1.8984E-142	1.000E+00	1.000E+00
79846048.842896	5.953E-163	7.447E-171	1.734E-164	9.845E-01	2.675E+11	1.391E+18	2.410E-146	5.717E-143	1.000E+00	1.000E+00
82344430.308183	1.637E-163	1.988E-171	4.768E-165	9.845E-01	2.923E+11	1.520E+18	7.248E-147	1.7178E-143	1.000E+00	1.000E+00
84814763.217428	4.491E-164	5.295E-172	1.308E-165	9.845E-01	3.195E+11	1.661E+18	2.173E-147	5.15E-144	1.000E+00	1.000E+00
87359205.113951	1.230E-164	1.407E-172	3.581E-166	9.845E-01	3.491E+11	1.815E+18	6.500E-148	1.5406E-144	1.000E+00	1.000E+00
8979982.297370	3.358E-165	3.732E-173	9.782E-167	9.845E-01	3.814E+11	1.984E+18	1.940E-148	4.5981E-145	1.000E+00	1.000E+00
92679381.766291	9.153E-166	9.876E-174	2.668E-167	9.845E-01	4.168E+11	2.167E+18	5.778E-149	1.3693E-145	1.000E+00	1.000E+00
95459763.219280	2.489E-166	2.607E-174	7.249E-168	9.845E-01	4.555E+11	2.368E+18	1.717E-149	4.0689E-146	1.000E+00	1.000E+00
98323556.115858	6.753E-167	6.868E-175	1.967E-168	9.845E-01	4.977E+11	2.588E+18	5.090E-150	1.2063E-146	1.000E+00	1.000E+00
101273262.799334	1.828E-167	1.805E-175	5.324E-169	9.845E-01	5.438E+11	2.828E+18	1.506E-150	3.5686E-147	1.000E+00	1.000E+00
104311460.883314	4.938E-168	4.734E-176	1.438E-169	9.845E-01	5.943E+11	3.090E+18	4.444E-151	1.0533E-147	1.000E+00	1.000E+00
107440804.503813	1.331E-168	1.239E-176	3.876E-170	9.845E-01	6.494E+11	3.377E+18	1.309E-151	3.102E-148	1.000E+00	1.000E+00
110664028.638927	3.579E-169	3.234E-177	1.042E-170	9.845E-01	7.096E+11	3.690E+18	3.846E-152	9.1152E-149	1.000E+00	1.000E+00
113983949.498095	9.602E-170	8.424E-178	2.797E-171	9.845E-01	7.754E+11	4.032E+18	1.128E-152	2.6725E-149	1.000E+00	1.000E+00
117403467.983038	2.571E-170	2.190E-178	7.487E-172	9.845E-01	8.473E+11	4.406E+18	3.299E-153	7.8181E-150	1.000E+00	1.000E+00
120925572.022529	6.867E-171	5.678E-179	2.000E-172	9.845E-01	9.259E+11	4.815E+18	9.629E-154	2.282E-150	1.000E+00	1.000E+00
12455339.183205	1.830E-171	1.469E-179	5.330E-173	9.845E-01	1.012E+12	5.261E+18	2.804E-154	6.6461E-151	1.000E+00	1.000E+00
128289939.358701	4.867E-172	3.794E-180	1.418E-173	9.845E-01	1.106E+12	5.749E+18	8.149E-155	1.9313E-151	1.000E+00	1.000E+00
132138637.539462	1.291E-172	9.773E-181	3.761E-174	9.845E-01	1.208E+12	6.282E+18	2.363E-155	5.5996E-152	1.000E+00	1.000E+00
136102796.865846	3.419E-173	2.512E-181	9.958E-175	9.845E-01	1.320E+12	6.884E+18	6.835E-156	1.6189E-152	1.000E+00	1.000E+00
140185880.565916	9.031E-174	6.442E-182	2.630E-176	9.845E-01	1.442E+12	7.501E+18	1.973E-156	4.676E-153	1.000E+00	1.000E+00
144391456.982584	2.380E-174	1.649E-182	6.933E-176	9.845E-01	1.576E+12	8.196E+18	5.883E-157	1.3467E-153	1.000E+00	1.000E+00

Particle Geometric Diameter (μm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (μg)	Log Normal Mass Distribution (μg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d) $\Delta d/d$	$\Sigma P(d)\Delta d/d$	$\pi d^3/6$	$V\rho$	P(d) $\Delta d^3/d$	P(d) $\Delta d^3 m/(d^3 m P_{\omega})$	d < 6.9	$\Sigma P(d) m/(P m)_{\text{tot}}$
148723200.692062	6.260E-175	4.209E-183	1.823E-176	9.845E-01	1.722E+12	8.956E+18	1.633E-157	3.87E-154	1.000E+00	1.000E+00
153184896.712823	1.643E-175	1.072E-183	4.784E-177	9.845E-01	1.882E+12	9.787E+18	4.682E-158	1.109E-154	1.000E+00	1.000E+00
167780443.614208	4.300E-176	2.726E-184	1.253E-177	9.845E-01	2.057E+12	1.069E+19	1.340E-158	3.174E-155	1.000E+00	1.000E+00
162513856.922634	1.123E-176	6.912E-185	3.272E-178	9.845E-01	2.247E+12	1.169E+19	3.824E-158	9.061E-156	1.000E+00	1.000E+00
167389272.630313	2.928E-177	1.749E-185	8.528E-179	9.845E-01	2.466E+12	1.277E+19	1.089E-159	2.580E-156	1.000E+00	1.000E+00
172410950.809223	7.615E-178	4.417E-186	2.218E-179	9.845E-01	2.683E+12	1.395E+19	3.095E-160	7.334E-157	1.000E+00	1.000E+00
177583279.333500	1.978E-178	1.135E-186	5.755E-180	9.845E-01	2.932E+12	1.525E+19	8.775E-161	2.079E-157	1.000E+00	1.000E+00
182910777.713505	5.116E-179	2.797E-187	1.490E-180	9.845E-01	3.204E+12	1.666E+19	2.483E-161	5.883E-158	1.000E+00	1.000E+00
188398101.044910	1.322E-179	7.016E-188	3.849E-181	9.845E-01	3.501E+12	1.821E+19	7.009E-162	1.660E-158	1.000E+00	1.000E+00
194050044.076257	3.406E-180	1.755E-188	9.922E-182	9.845E-01	3.826E+12	1.989E+19	1.974E-162	4.678E-159	1.000E+00	1.000E+00
198871545.398545	8.761E-181	4.383E-189	2.552E-182	9.845E-01	4.181E+12	2.174E+19	5.547E-163	1.314E-159	1.000E+00	1.000E+00
205867691.760501	2.248E-181	1.092E-189	6.548E-183	9.845E-01	4.568E+12	2.376E+19	1.553E-163	3.686E-160	1.000E+00	1.000E+00
212043722.513316	5.756E-182	2.714E-190	1.676E-183	9.845E-01	4.992E+12	2.596E+19	4.352E-164	1.031E-160	1.000E+00	1.000E+00
218405034.188716	1.470E-182	6.733E-191	4.283E-184	9.845E-01	5.455E+12	2.837E+19	1.215E-164	2.879E-161	1.000E+00	1.000E+00
224957185.214377	3.748E-183	1.666E-191	1.092E-184	9.845E-01	5.961E+12	3.100E+19	3.384E-165	8.019E-162	1.000E+00	1.000E+00
231705900.770808	9.533E-184	4.114E-192	2.776E-185	9.845E-01	6.513E+12	3.367E+19	9.404E-166	2.228E-162	1.000E+00	1.000E+00
236657077.793933	2.419E-184	1.014E-192	7.046E-186	9.845E-01	7.117E+12	3.701E+19	2.609E-166	6.179E-163	1.000E+00	1.000E+00
245816790.127751	6.125E-185	2.492E-193	1.794E-186	9.845E-01	7.777E+12	4.044E+19	7.215E-167	1.709E-163	1.000E+00	1.000E+00
253191293.831593	1.547E-185	6.111E-194	4.507E-187	9.845E-01	8.499E+12	4.419E+19	1.992E-167	4.720E-164	1.000E+00	1.000E+00
260787032.646531	3.900E-186	1.496E-194	1.136E-187	9.845E-01	9.287E+12	4.829E+19	5.486E-168	1.300E-164	1.000E+00	1.000E+00
268610643.625927	9.810E-187	3.652E-195	2.857E-188	9.845E-01	1.015E+13	5.277E+19	1.508E-168	3.573E-165	1.000E+00	1.000E+00
276689692.934704	2.462E-187	8.989E-196	7.170E-189	9.845E-01	1.109E+13	5.766E+19	4.134E-169	9.798E-166	1.000E+00	1.000E+00
284989031.822746	6.164E-188	2.163E-196	1.795E-189	9.845E-01	1.212E+13	6.301E+19	1.131E-169	2.680E-166	1.000E+00	1.000E+00
293518102.777428	1.540E-188	5.247E-197	4.485E-190	9.845E-01	1.324E+13	6.885E+19	3.089E-170	7.318E-167	1.000E+00	1.000E+00
302323645.860761	3.839E-189	1.270E-197	1.118E-190	9.845E-01	1.447E+13	7.523E+19	8.412E-171	1.993E-167	1.000E+00	1.000E+00
320735155.893670	9.548E-190	3.066E-198	2.781E-191	9.845E-01	1.581E+13	8.221E+19	2.286E-171	5.418E-168	1.000E+00	1.000E+00
330357210.570481	2.370E-190	7.388E-199	6.902E-192	9.845E-01	1.728E+13	8.983E+19	6.200E-172	1.469E-168	1.000E+00	1.000E+00
350475964.694223	5.867E-191	1.776E-199	1.709E-192	9.845E-01	1.888E+13	9.816E+19	1.678E-172	3.975E-169	1.000E+00	1.000E+00
340267926.887595	1.450E-191	4.260E-200	4.222E-193	9.845E-01	2.063E+13	1.073E+20	4.529E-173	1.073E-169	1.000E+00	1.000E+00
350990243.635050	3.573E-192	1.020E-200	1.041E-193	9.845E-01	2.254E+13	1.172E+20	1.220E-173	2.891E-170	1.000E+00	1.000E+00
371819950.944101	8.789E-193	2.435E-201	2.560E-194	9.845E-01	2.463E+13	1.281E+20	3.279E-174	7.770E-171	1.000E+00	1.000E+00
382974549.474242	5.282E-194	1.379E-202	1.538E-195	9.845E-01	2.941E+13	1.529E+20	2.353E-175	5.575E-172	1.000E+00	1.000E+00
394463785.956597	1.290E-194	5.801E-202	6.283E-195	9.845E-01	3.214E+13	1.671E+20	6.281E-176	1.488E-172	1.000E+00	1.000E+00
406297699.535295	3.146E-195	7.743E-204	8.163E-197	9.845E-01	3.512E+13	1.826E+20	1.673E-176	3.965E-173	1.000E+00	1.000E+00
418486630.521354	7.652E-196	1.828E-204	2.229E-197	9.845E-01	3.837E+13	1.995E+20	4.447E-177	1.054E-173	1.000E+00	1.000E+00
431041229.436994	1.857E-196	4.308E-205	5.409E-198	9.845E-01	4.193E+13	2.181E+20	1.179E-177	2.795E-174	1.000E+00	1.000E+00
457297246.309104	4.497E-197	1.013E-205	1.310E-198	9.845E-01	4.592E+13	2.363E+20	3.121E-178	7.396E-175	1.000E+00	1.000E+00
471010640.309707	1.087E-197	2.376E-206	3.165E-199	9.845E-01	5.007E+13	2.604E+20	8.240E-179	1.952E-175	1.000E+00	1.000E+00
485140701.204569	2.619E-198	5.561E-207	7.629E-200	9.845E-01	5.471E+13	2.845E+20	2.171E-179	5.144E-176	1.000E+00	1.000E+00
499694922.240706	6.301E-199	1.299E-207	1.835E-200	9.845E-01	5.979E+13	3.109E+20	5.703E-180	1.352E-176	1.000E+00	1.000E+00
514685769.907927	1.512E-199	3.026E-208	4.404E-201	9.845E-01	6.533E+13	3.397E+20	1.496E-180	3.546E-177	1.000E+00	1.000E+00
	3.621E-200	7.036E-209	1.055E-201	9.845E-01	7.139E+13	3.712E+20	3.915E-181	9.278E-178	1.000E+00	1.000E+00

Commercial SNF Accident Release Fractions

Particle Geometric Diameter (µm)	Log-Normal Particle Distribution	Normal Particle Distribution	Differential Particle Distribution	Integral Particulate Distribution	Particle Volume, V (cc)	Particle Mass, m (µg)	Log Normal Mass Distribution (µg)	Normalized Differential Mass Distribution	Respirable Fraction Normalized	Integral Mass Distribution
d	P(d)	P(d)/d	P(d)*Δd/d	Σ P(d)*Δd/d	π d ³ / 6	V ρ	P(d)*Δd*m/d	P(d)*Δd*m/(d ³ *mP _{tot})	d < 6.9	Σ P(d) m/(P m) _{tot}
530126343.005165	8.652E-201	1.632E-209	2.520E-202	9.845E-01	7.801E+13	4.056E+20	1.022E-181	2.4226E-178	1.000E+00	1.000E+00
546030133.295320	2.063E-201	3.778E-210	6.008E-203	9.845E-01	8.524E+13	4.433E+20	2.663E-182	6.3112E-179	1.000E+00	1.000E+00
562411037.294179	4.907E-202	8.724E-211	1.429E-203	9.845E-01	9.315E+13	4.844E+20	6.922E-183	1.6405E-179	1.000E+00	1.000E+00
579283368.413005	1.165E-202	2.010E-211	3.392E-204	9.845E-01	1.018E+14	5.293E+20	1.795E-183	4.2545E-180	1.000E+00	1.000E+00
596681869.465395	2.758E-203	4.822E-212	8.032E-205	9.845E-01	1.112E+14	5.783E+20	4.648E-184	1.1009E-180	1.000E+00	1.000E+00
614561725.549357	6.516E-204	1.060E-212	1.898E-205	9.845E-01	1.215E+14	6.320E+20	1.199E-184	2.8426E-181	1.000E+00	1.000E+00
632988577.315837	1.536E-204	2.427E-213	4.475E-206	9.845E-01	1.328E+14	6.906E+20	3.090E-185	7.3231E-182	1.000E+00	1.000E+00
651988534.635312	3.614E-205	5.543E-214	1.053E-206	9.845E-01	1.451E+14	7.546E+20	7.943E-186	1.8824E-182	1.000E+00	1.000E+00
671548190.674372	8.482E-206	1.263E-214	2.471E-207	9.845E-01	1.586E+14	8.246E+20	2.037E-186	4.8278E-183	1.000E+00	1.000E+00
691694636.394603	1.986E-206	2.872E-215	5.786E-208	9.845E-01	1.733E+14	9.010E+20	5.213E-187	1.2355E-183	1.000E+00	1.000E+00
712445475.486441	4.642E-207	6.515E-216	6.759E-209	9.845E-01	1.893E+14	9.846E+20	6.656E-188	1.5773E-184	1.000E+00	1.000E+00
sum =	3.351E+01					mP _{tot} =	4.220E-04			

Summary of Results			
[All Values Automatically Updated]		See	[All Values Automatically Updated]
Results:		Note	Inputs:
Respirable Percent =	30.0517 %	1	Geometric Mean (d) = 3 μ m
Conservative Respirable Percent =	53.64537 %	2	Standard Deviation (σ) = 1.87
Non-Conservative Respirable Percent =	14.92573 %	3	Maximum Respirable Particle Diameter = 6.9 μ m
Mass Median Diameter =	9.71828 μ m	4	Particulate Density (ρ) = 5.2 g/cc
Mass Median Diameter (MMD) =	9.551214 μ m	5	Dynamic Shape Factor (κ) = 1.3
AMAD =	19.10243 μ m	6	
% of Sum at Particle Diam. Of Interest =	49.66684 %	7	
<p>Note 1: Fraction of Distribution with MMD ~5 microns (i.e., 10 microns AMAD).</p> <p>Note 2: Fraction of Distribution less than 10 microns (if AMAD < 10 microns value is non-conservative).</p> <p>Note 3: Fraction of Distribution less than 3 microns (if AMAD < 10 microns value is non-conservative).</p> <p>Note 4: Mass Median Diameter for entire distribution - used to check the MMD note 5</p> <p>Note 5: MMD for entire distribution.</p> <p>Note 6: AMAD for entire distribution (if < 10 microns then 100% respirable, if > 10 microns could be 0% respirable).</p> <p>Note 7: Desire to be ~50% which means particles with diameter < Max Respirable Particle Diam. have an MMD of 5 mm.</p>			

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Attachment C

GRAVITATIONAL DEPOSITION CONFIRMATORY ANALYSIS

NUREG/CR-0722 (Lorenz et al. 1980, p. 105), states that a small fraction of fuel particles ejected from a burst fuel pin was carried out of the furnace tube into the thermal gradient tube and filter pack. At the time of rupture, the velocity of steam flowing past the rupture point, through the furnace tube and down through the filter pack was 15 cm/s. Thus, for particles to settle out before reaching the thermal gradient tube, they would have to fall at a rate of about 3 cm/s (the terminal settling velocity). NUREG/CR-0722 (Lorenz et al. 1980, p. 105) states that particles with diameters greater than 12 to 15 μm would fall at this rate. This has been confirmed by sampling (albeit somewhat randomly and sparsely) some of the particulate collected in the filters with a scanning electron microscope and determining that these particulates had diameters of typically 10 μm (Lorenz et al. 1980, p. 105 and Appendix C). To confirm that particles with diameters greater than 12 to 15- μm settle out before reaching the thermal gradient tube, gravitational deposition methods, presented in Appendix B of ANSI N13.1-1969, will be applied. The first step is to confirm the terminal settling velocity. According to ANSI N13.1-1969, the length for 100 percent deposition (cm) is:

$$L_{100} = \frac{8rV}{3u_t} \quad (\text{Eq. C-1})$$

where

L_{100} is the length for 100 percent deposition (cm)

r is the radius of the tube (cm)

V is the average velocity in the tube (cm/s)

u_t is the terminal settling velocity (cm/s).

The 100 percent deposition length in this case is assumed to be approximately the length of the furnace tube (i.e., 44 cm). The actual length will be somewhat shorter depending on where the actual rupture point occurred. The average velocity in the tube is stated to be approximately 15 cm/s and the radius of the furnace tube is approximately 3.5 cm based on NUREG/CR-0722 (Lorenz et al. 1980, Figure 4 on p. 105). Thus, the Equation C-1 can be solved for the terminal settling velocity:

$$\begin{aligned} u_t &= \frac{8rV}{3L_{100}} = \frac{8(3.5\text{ cm})(15\text{ cm/s})}{3(44\text{ cm})} \\ &= 3.18\text{ cm/s} \end{aligned} \quad (\text{Eq. C-2})$$

This velocity is very close to the 3 cm/s in NUREG/CR-0722 (Lorenz et al. 1980, p. 105).

With the terminal settling velocity now calculated, the diameter of the particles settling at this velocity can be calculated from Stoke's Law (ANSI N13.1-1969, p. 34):

$$u_t = \frac{gd_p^2(\rho_p - \rho_g)}{18\mu} K_m \quad (\text{Eq. C-3})$$

where

g is the gravitational constant (980 cm/s²)

d_p is the diameter of the particle (cm)

ρ_p is the density of the particle (g/cm³)

ρ_g is the density of the steam (g/cm³)

μ is the steam viscosity (g/cm-s)

K_m is the Cunningham correction for slip (unitless).

This equation can be solved for the diameter of the particle.

The terminal velocity has already been shown to be approximately 3 cm/s, the particle density is assumed to be 10.96 g/cm³ (Section 5, Assumption 5.6), the Cunningham correction factor has been shown to be nearly unity (see Figure 2), and the density of steam and viscosity of steam at 900°C are approximately 1.8×10^{-4} g/cm³ and 2.8×10^{-4} g/cm-s, respectively.¹ Thus, the particle diameter can be calculated from:

$$d_p^2 = \frac{18\mu u_t}{g(\rho_p - \rho_g) K_m} \quad (\text{Eq. C-4})$$

¹ The steam density is from: *Fundamentals of Classical Thermodynamics* (Van Wylen and Sonntag 1986, p. 641). The steam viscosity is from: *Flow of Fluids Through Valves, Fittings, and Pipe* (Crane Company 1988, p. A-2).

$$d_p = \sqrt{\frac{18 \mu u_t}{g(\rho_p - \rho_g)K_m}}$$

$$d_p = \sqrt{\frac{18(2.8 \times 10^{-4} \text{ g/cm-s})(3.0 \text{ cm/s})}{(980 \text{ cm/s}^2)(10.96 \text{ g/cm}^3)(1)}}$$

$$d_p = \sqrt{1.41 \times 10^{-6} \text{ cm}^2}$$

$$d_p = 11.9 \text{ } \mu\text{m}$$

This value is essentially equal to the smallest diameter presented in NUREG/CR-0722 (Lorenz et al. 1980, p. 105) as having settled before reaching the thermal gradient tube (i.e., 12 μm). If shorter 100 percent deposition lengths were considered in this analysis, then the terminal settling velocities would increase which in turn results in a larger diameter. This larger diameter is likely near the 15- μm diameter noted in NUREG/CR-0722 (Lorenz et al. 1980, p. 105).

Thus, both the terminal settling velocity of 3 cm/s and the diameter of the fuel particles which settled out before reaching the thermal gradient tube has been confirmed from NUREG/CR-0722 (Lorenz et al. 1980, p. 105) using methods presented in Appendix B of ANSI N13.1-1969.

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Attachment D**Summary of Release Fractions from Other NRC Licensed Facilities/Casks**

The following SARs for cask systems and independent spent fuel storage installations (ISFSIs) provide valuable information on values of release fractions listed in Table D-1 used in consequence analyses and approved by the NRC. The values of release fractions given in Table D-1 are provided for information only and they do not impact the analysis itself. Each of the following documents is found in the Nuclear Regulatory Commission's Public Document Room, 2120 L Street, NW, Lower Level, Washington, DC 20555-0001, and are cross-referenced by number in Tables D-1, D-2, and D-3.

- (1) *Fort St. Vrain Independent Spent Fuel Storage Installation Safety Analysis Report, Revision 2* (INEL 1998).
- (2) *North Anna Power Station Independent Spent Fuel Storage Installation, License Application* (Virginia Electric and Power Company [VEPCO] 1995).
- (3) "Docket No. 72-11, Rancho Seco Independent Spent Fuel Storage Installation, Revision 1 to the Rancho Seco Independent Spent Fuel Storage Installation License Application and Safety Analysis Report" (Shetler 1993) for the Sacramento Municipal Utility District (SMUD).
- (4) *Safety Analysis Report for the INEL TMI-2 Independent Spent Fuel Storage Installation, Revision 0* (INEL 1996).
- (5) *Trojan Independent Spent Fuel Storage Installation, Safety Analysis Report* (PGE n.d.)
- (6) *10 CFR 72 Topical Safety Analysis Report for the Holtec International Storage, Transport and Repository Cask System (HI-STAR-100 Cask System)* (Holtec International 1995).
- (7) *Safety Analysis Report Large On-Site Transfer and On-Site Storage Segment, CLIN 0004PC* (Westinghouse 1996).
- (8) *Safety Analysis Report for the NUHOMS®-MP187 Multi-Purpose Cask* (Vectra Technologies 1996).
- (9) *Safety Analysis Report for the Standardized NUHOMS® Horizontal Modular Storage System for Irradiated Nuclear Fuel* (Vectra Technologies 1995).
- (10) *TN-24 Dry Storage Cask Topical Report* (Transnuclear 1989).
- (11) *Safety Analysis Report for the TranStor™ Storage Cask System* (SNC 1996).
- (12) *Final Design Package Babcock & Wilcox BR-100, 100 Ton Rail/Barge Spent Fuel Shipping Cask* (B&W Fuel Company 1991).

- (13) *Safety Analysis Report for the NAC Legal Weight Truck Cask* (NAC 1995).
- (14) *Safety Analysis Report for the TranStor™ Shipping Cask System* (SNC 1997).

Independent Spent Fuel Storage Installations (ISFSIs)

Table D-1 summarizes the release fractions used in the preceding SARs of the various ISFSIs. For each ISFSI, a hypothetical loss of confinement accident was analyzed. In each case, 100 percent of the fuel cladding was assumed ruptured and the cask breached in such a manner that the release fraction from the cask to the environment was equal to unity. In nearly each case, except for the Fort St. Vrain and INEL TMI-2 ISFSIs, ^{85}Kr is either the only analyzed radionuclide or the only radionuclide that significantly contributes to the dose at the site boundary. It is also noted in the INEL TMI-2 SAR that the fraction of particulate and solids that are released from the cask to a filtration system is approximately 1 percent. This value is expected to be high compared to releases from originally intact fuel assemblies, because most of the TMI-2 fuel is no longer confined by cladding. The release fractions for the gases ^3H and ^{129}I span the whole spectrum (i.e., a release fraction between 0 and 1). The release fraction for the gas ^{85}Kr ranges from 0.25 to 1.00, with an equal number selecting 0.3 and 1.0.

Storage Cask Systems

Table D-2 summarizes the release fractions used in the preceding SARs of the various storage cask systems. For each storage cask, a hypothetical loss of confinement accident was analyzed. In each case, 100 percent of the fuel cladding was assumed ruptured and the cask breached in such a manner that the release fraction from the cask to the environment was equal to unity. In each case, ^{85}Kr is either the only analyzed radionuclide or the only radionuclide that significantly contributes to the dose at the site boundary. No particulate releases are considered in any of these SARs, as the particulates are expected to locally deposit near their release point. The release fractions for the gases ^3H and ^{129}I ranges from 0 to 0.3. The release fraction for the gas ^{85}Kr is nearly always equal to 0.3 for the storage casks with the exception of the ^{24}TN cask system, which used a release fraction of 0.1.

Transportation Cask Systems

Table D-3 summarizes the release fractions used in the preceding SARs of various transportation cask systems. For each transportation cask, the accident release fractions are analyzed under the Confinement chapter of the SAR. In each case, 100 percent of the fuel cladding was assumed ruptured and the cask breached in such a manner that the release fraction from the cask to the environment was equal to unity. In each case, ^{85}Kr is the only radionuclide that significantly contributes to the dose at the site boundary. No particulate releases are considered in any of these SARs, as the particulates are expected to locally deposit near their release point. However, the Sierra TranStor cask does consider 100 percent of the crud (^{60}Co) to be released from the fuel rod surfaces and 100 percent of this to be aerosolized. The release fractions for tritium ranges from 0.1 to 0.3. The release fraction for ^{129}I ranges from 0 to 0.3, but its contribution to the dose is nearly always ignored. The release fraction for the gas ^{85}Kr is always equal to 0.3 for these transportation casks.

Table D-1. Release Fractions Used in SARs for Independent Spent Fuel Storage Installations

Name (Ref.)	NRC Docket Number	Release Fractions					Source (Page #'s)
		Particulate (Co, Cs, Ru, Sr)	Fission Gases			I-129	
			H-3	Kr-85	I-129		
INEL Fort St. Vrain (1)	72-0009	1.00 × 10 ⁻⁵	0.50	1.00	0.00	A8-9/2	
VEPCO North Anna (2)	72-0016	0.00 ^a	1.00	1.00	0.00 ^a	8.3-2	
SMUD Rancho Seco (3)	72-0011	0.00 ^a	0.30	0.30	0.30	18-32	
INEL TMI-2 (4) ^b	72-0020	1.00 × 10 ⁻³	0.00 ^a	0.10	0.00 ^a	7.2-2	
PGE Trojan (5)	72-0017	0.00 ^a	0.30	0.30	0.30	8-8	

^a Based on the dose calculations performed in these SARs, these radionuclides were not included and hence, their release fractions are assumed to be zero. In actuality, the release fractions are likely to be relatively small compared to fission gases; however, other factors (e.g., local deposition, respirability) are assumed to make their dose contributions negligible.

^b Values for the INEL TMI-2 ISFSI are for damaged fuel from Three Mile Island Unit 2. Hence, fission gases liberated from the fuel are assumed to have escaped. In addition, much of the material stored is made up of filters that contain a large number of particulates.

Table D-2. Release Fractions Used in SARs for Storage Cask Systems

Name (Ref.)	NRC Docket Number	Release Fractions				Source (Page #s)
		Particulate (Co, Cs, Ru, Sr)	Fission Gases		I-129	
			H-3	Kr-85		
Holtec HI-STAR (6)	72-1008	0.00	0.30	0.30	0.30	11.2-6
Westinghouse Large MPC (7)	-	0.00	0.30	0.30	0.30	7.3-1
Vectra NUHOMS (9)	72-1004	0.00 ^a	0.30	0.30	0.30	8.2-40
TN-24 (10)	-	0.00 ^a	0.10	0.10	0.00 ^a	8.1-4
SNC TranStor™ (11)	72-1023	0.00	0.30	0.30	0.30	11-17

^a Based on the dose calculations performed in these SARs, these radionuclides were not included and hence, their release fractions are assumed to be zero. In actuality, the release fractions are likely to be relatively small compared to fission gases, however other factors (e.g., local deposition, respirability) are assumed to make their dose contributions negligible.

Table D-3. Release Fractions used in SARs for Transportation Cask Systems

Name (Ref.)	NRC Docket Number	Release Fractions					Source (Page #'s)
		Particulate (Co, Cs, Ru, Sr)	Fission Gases			I-129	
			H-3	Kr-85			
B&W BR-100 Shipping Cask (12)	71-9230	0.00 ^a	0.10	0.30	0.00 ^a	II 4-10	
Holtec HI-STAR (6)	71-9261	0.00	0.30	0.30	0.30	11.2-6	
NAC Legal Weight Truck (13)	71-9225	0.00 ^a	0.10	0.30	0.00 ^a	4.3-1	
Westinghouse Large MPC (7)	-	0.00	0.30	0.30	0.30	7.3-1	
Vectra NUHOMS®MP-187 (8)	71-9255	0.00 ^a	0.30	0.30	0.30	4-5	
SNC TranStor™ (14)	71-9268	0.00 (100% crud)	0.30	0.30	0.30	4-15	

^a Based on the dose calculations performed in these SARs, these radionuclides were not included and hence, their release fractions are assumed to be zero. In actuality, the release fractions are likely to be relatively small compared to fission gases, however other factors (e.g., local deposition, respirability) are assumed to make their dose contributions negligible.

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