APPENDIX D - Inhalability and Respirability of Airborne Particles and Adjusting the ALI and CEDE for Various Particle Sizes

D.1 Introduction

The inhalation of a contaminant is one of the most important routes of internal exposure. The nature and magnitude of the hazard in a given situation depends on a complex combination of many factors, including:

- Particle size distribution (which governs how the aerosol enters the body via inhalation and how it penetrates into and is subsequently deposited in the respiratory tract).
- The airborne concentration (which governs how much is deposited).
- Chemical form, physical form, and particle morphology (which govern the subsequent fate and biological response to the contaminant with the respiratory tract and other organs of the body).

The first part of the overall process of aerosol exposure is the entry by inhalation of aerosols from the ambient air into the respiratory tract.

Only particles which could pose a potential risk to health by inhalation are those particles which are actually capable of entering the respiratory tract during breathing, not all particles will necessarily have the same probability of entering. The concept of inhalability and respirability are discussed below. The aerosol used in the exposure and intake estimates is 5 μm AMAD.

D.2 Inhalability

Inhalability is the fraction of the suspended material in ambient air that actually enters the nose or mouth with the volume of air inhaled[38]. Inhalability is a function of particle aerodynamic size, inspiratory flow rate, wind speed and wind direction. The inhalable fraction averaged over all wind directions is related to particle aerodynamic size (d_{ae}) by the following relationship[38]:

$$E = 0.50\ (1 + e^{-0.06 d_{ae}})$$

For $0 < d_{ae} \leq 100$ μm AED

Where:

E = The fraction of the airborne particles that are inhalable.

d_{ae} = Particle aerodynamic size (μm).

For particles that are larger than 100 μm, the inhalability is unknown. In the absence of relevant data, the inhalable fraction will be taken as 0.50for particles ≥ 100 μm[38, 39, 40]. Table D-1 summarizes the inhalable fraction versus particle size.

The data presented in Table D-1 does not change for the range of wind speeds from 0.5 meter/sec to 9 meters/sec[40].

Table D-1. Particle Size Versus Inhalable Fraction

d_{ae} (μm)	Inhalable Fraction
0	1.000
1	0.970
2	0.940
5	0.870
10	0.770
20	0.650
30	0.580
40	0.545
50	0.525
≥100	0.500

Table D-2 summarizes the fraction of the particles in the thoracic portion of the respiratory tract versus particle size[40].

Table D-2. Particle Size Versus Thoracic Fraction

d_{ae} (μm)	Thoracic Fraction
0	1.000
2	0.940
4	0.890
5	0.850
6	0.805
8	0.670
10	0.500
12	0.350
14	0.230
16	0.150
18	0.095
20	0.060

D.3 Respirability

Table D-3 summarizes the RF or the fraction of the particles entering the respiratory tract versus particle size.

Table D-3. Particle Size Versus RF

d_{ae} (μm)	Respirable Fraction
0	1.00
1	0.97
2	0.91
3	0.74
4	0.50
5	0.30
6	0.17
7	0.09
8	0.05
10	0.01

D.4 Adjusting the ALI and DAC for Particle Size Distribution

The 10 CFR Part 20 and ICRP-30 have established the ALI and DACs based on a 1 μm AMAD aerosol. For an aerosol with an AMAD between 0 μm and 10 μm and a σ_g less than 4.5, corrections to the ALI or DAC should be made (see ICRP-30).

Each radionuclide will have its own ALI or dose adjustment, due to the differing contributions to CDE of radionuclides deposited in the three respiratory tract compartments: nasopharyngeal region (N-P), tracheobronchial region (T-B), and pulmonary region (P). The following equation expresses the adjustment to the CDE in terms of the changes in particle deposition in the three different respiratory tract compartments (see Appendix J):

$$\frac{H_{50}(AMAD)}{H_{50}(1AMAD)} = f_{N-P}\frac{D_{N-P}(AMAD)}{0.3} + f_{T-B}\frac{D_{T-B}(AMAD)}{0.08} + f_{P}\frac{D_{P}(AMAD)}{0.25}$$

Where:

D_{N-P} = Deposition fraction in the N-P region

D_{T-G} = Deposition fraction in the T-B region

D_{P} = Deposition fraction in the P region

The deposition fraction is obtained from Figure 5.1, ICRP-30, Supplement to Part 1. (See Appendix J.)

f_{N-P} = Fraction of CDE for particles deposited in N-P region

f_{T-B} = Fraction of CDE for particles deposited in T-B region

f_{P} = Fraction of CDE for particles deposited in P region

The fraction of CDE is obtained from ICRP-30, Supplement to Part 1 (pp. 364-380).

It should be noted that the above formula is for deriving stochastic ALIs, not for deriving a nonstochastic ALI.

Table D-4 summarizes the ratios for the deposition fraction for particles of 0.2μm to 10 μm AMAD.

Table D-4. Ratios for Deposited Fractions (AMAD to 1 μm)

Aerosol AMAD (μm)	D_{N-P} (AMAD) / D_{N-P} (1 μm)	D_{T-B} (AMAD) / D_{T-B} (1 μm)	D_P (AMAD) / D_P (1 μm)
0.2	0.17	1.00	2.00
0.5	0.53	1.00	1.40
0.7	0.77	1.00	1.20
1.0	1.00	1.00	1.00
2.0	1.67	1.00	0.68
5.0	2.47	1.00	0.36
7.0	2.70	1.00	0.28
10.0	2.90	1.00	0.20

How to determine the appropriate ALI when adjusting derived air concentration[41].

$$\frac{ALI(1mm)}{Stochastic} = \frac{5\,rem}{\sum_T W_T\, H_{50,T}\, ({}^{rem}/_{mCi})}$$

$$\frac{ALI(1mm)}{Nonstochastic} = \frac{50\,rem}{H_{50,T}({}^{rem}/_{mCi})}$$

Where:

W_T = Tissue or organ weighting factor

$H_{50,T}$ = Dose per unit intake (rem/μCi)

For DU Classes W and Y, the ratio of the CDE and the DAC simplifies to:

$$\frac{H_{50}(AMAD)}{H_{50}(1mm)} = \frac{DAC(1mm)}{DAC(AMAD)}$$

Table D-5 summarizes the ratios of the CDE or DAC (AMAD) to DAC (1 μm) for DU oxides.

Table D-5. Ratio of DAC (AMAD) to DAC (1 μm) DU Oxides

Particle Size (μm)	Ratio of DAC (AMAD) to DAC (: m)		
	Class D	Class W	Class Y
0.2	0.81	0.50	0.50
0.5	0.94	0.71	0.71
1.0	1.00	1.00	1.00
2.0	0.96	1.50	1.50
5.0	0.88	2.80	2.80
7.0	0.84	3.60	3.60
10.0	0.82	5.00	5.00