July 24, 1996

EPA-SAB-RAC-COM-96-003

Ms. Carol M Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, S. W.
Washington, DC 20460

RE: Radiation Advisory Committee Commentary on the Scientific Basis for Apportioning Risk Among the ICRP Publication 66 Regions of the Respiratory Tract

Dear Ms. Browner:

This Commentary was developed by the Radiation Advisory Committee (RAC) of the Science Advisory Board (SAB) in response to a request from the Office of Radiation and Indoor Air (ORIA) within the Office of Air and Radiation (OAR). At a RAC public meeting on May 25, 1995 Dr. Jerome Puskin and Dr. Neal Nelson from the Office of Indoor Air briefed the RAC on their concerns about the scientific basis for apportioning risk among regions of the respiratory tract in the new ICRP Human Respiratory Tract Model for Radiological Protection, published in International Commission on Radiological Protection (ICRP) Publication 66 (ICRP, 1994). ORIA is considering using the new ICRP model in Federal Guidance Report Number 13. Subsequently the RAC discussed this topic at public meetings on January 25, 1996, April 30, 1996 and May 21-22, 1996.

This Commentary concludes that the use of default values to apportion the tissue weighting factor for lungs in calculating effective doses from inhaled radionuclides, recommended by the ICRP in the absence of published data supporting specific values, would not have a major impact on radiation protection. A small measure of conservatism would be added to dose calculations for certain insoluble radionuclides. The RAC recommends that EPA use the model as adopted by the ICRP and NCRP and that it also undertake an effort to provide, for consideration by the ICRP and NCRP, a more scientifically acceptable basis for apportioning the tissue weighting factor for the lungs. Such an effort could strengthen the credibility

of the ICRP model among those familiar with respiratory tract pathology, although not necessarily improve its usefulness for radiation protection. In the meantime the use of the default values would be an appropriate topic for EPA to consider in addressing the uncertainties of radionuclide dose calculations such as are required for clean-up of sites contaminated with radionuclides. However, uncertainties in other aspects of the model, including morphometry (dimensions of the anatomical and histological features of the respiratory tract), quantitative and qualitative deposition of inhaled particles and the rates of clearance of inhaled material from the lungs, likely have a greater impact on the results obtained with the ICRP model and with any other model developed with the existing data base than the default values for apportioning the tissue weighting factor.

BACKGROUND

The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) adopted the concept of "effective dose (E)" which is designed to predict the same probability of the occurrence of cancer and genetic effects whether the whole body is uniformly irradiated or non-uniformly irradiated. Uniform exposures can occur from external x-rays, gamma-rays and neutrons and also from soluble radionuclides uniformly distributed throughout the body. Non-uniform exposures usually occur from non-uniform distribution of internally deposited radionuclides and by partial body irradiation from external sources of x-rays, gamma rays and neutrons. Because organs and tissues of the body are not all equally sensitive, the calculated doses received by individual organs and tissues must be adjusted to account for these differences to obtain expressions of effective dose. Drawing from studies of health effects observed in populations exposed to relatively uniform irradiation, such as the Japanese atomic bomb survivors, the ICRP and NCRP developed tissue weighting factors (w_T) to be applied to the doses calculated for each tissue and organ in the body. For gonads w_T is 0.20; for red bone marrow, colon, lung and stomach it is 0.12; for bladder, breast, liver, esophagus and thyroid it is 0.05; and for skin and bone surface it is 0.01, for a total of 0.95. An additional w_T of 0.05 is applied to all remainder tissues. For each tissue the calculated equivalent dose (H_T), product of the averaged absorbed dose and the radiation weighting factor (w_R) for the radiation type, is multiplied by the appropriate tissue weighting factor (w_T) to obtain the weighted equivalent dose. The effective dose is the sum of these weighted equiva-

lent doses for all tissues and organs in the body[1] (ICRP, 1991; ICRP,1995; NCRP, 1993).

Earlier dosimetric models for the respiratory tract (Taylor, 1984; ICRP, 1960; TGLD, 1966; ICRP, 1979) ignored the extrathoracic tissues and also the differences in the relative sensitivity of the numerous tissues within the lungs, simply averaging the radiation dose over the total mass of the lungs and associated lymph nodes, with the assumption that the radionuclide contents of these tissues were uniformly distributed[2]. In ICRP Publication 30 (ICRP, 1979) this calculated averaged dose was multiplied by the tissue weighting factor for lungs of 0.12 and added to similar doses calculated for other tissues in the body to give the effective dose equivalent, later renamed the effective dose (ICRP, 1991). This approach is especially subject to criticism because inhaled radionuclides are rarely if ever deposited and retained uniformly throughout all lung tissues. Thus, the dose may be very non-uniform among the several different lung tissues which may vary considerably in their sensitivity to radiation. For example, highly insoluble inhaled radionuclides with long half-lives tend to accumulate in the lymphatic tissues, which are relatively insensitive to radiation. The very high doses these tissues can accumulate have little bearing on the potential for health effects to occur. On the other hand, doses from radionuclides with very short retention times in the lungs, because of rapid decay or fast absorption into the blood, tend to be higher in the more sensitive tissues of the airways.

The new ICRP model (ICRP,1994) was designed to accommodate the potentially large differences in the doses received and the differences in radiation sensitivities of the various tissues comprising the respiratory tract as well as being compatible with the ICRP dosimetry system (ICRP, 1991). The model provides for the calculation of quantities of inhaled material deposited in the several tissues and

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[1] Because radionuclides may remain in body tissues and organs for years after an intake, it is useful to calculate the total radiation doses received during the residence time of radionuclides in the body. This committed weighted equivalent dose ($H_T(\tau)$) is the time integral of the equivalent dose rate in a particular tissue or organ that will be received by an individual following intake of radioactive material into the body where τ is the integration time in years following intake, 50 years for adults and from intake to age 70 years for children. The sum of the committed weighted equivalent doses for all tissues in the body is the committed effective dose ($E(\tau)$) (ICRP, 1995).

[2] Both the ICRP and the NCRP have recognized the non-uniform irradiation of the lungs following inhalation of radon and its decay products. The ICRP proposed assigning half of the tissue weighting factor of 0.12 to the basal cell layer of the tracheo-bronchial region and half to the pulmonary region (ICRP, 1981). The NCRP calculated doses to the bronchial epithelium as well as to the whole lung (NCRP, 1987).

the residence times in these tissues. Using the mass of each tissue the radiation dose can be calculated.[3] As noted above, the ICRP (ICRP, 1991) assigned a tissue weighting factor, w_T, of 0.12 to the lungs, the tissues within the thorax. In the new model (ICRP, 1994) the w_T is to be apportioned among the tissues of the lungs in relation to their radiation sensitivity, in conformity with the ICRP system. The apportionment of the 0.12 tissue weighting factor among the various tissues of the lungs is the issue addressed by this Commentary.[4] To achieve this apportionment correctly, it is necessary to know the relative sensitivity of the different lung tissues to the induction of cancer by radiation or to know the relative probability of cancers arising in the various lung tissues after the total lungs receive a uniform dose of radiation. In estimating radiogenic cancer risks, the EPA (EPA, 1994) assigned 80% of the lung weighting factor to the tracheo-bronchial region and 20% to the pulmonary region. However, the basis for this apportionment of the weighting factor was not given. After a thorough review of all the available information, the ICRP determined that there are no data from either animal experiments or human epidemiology studies to answer this question unequivocally.

Autopsies only provide information about the location of cancer tissues at the time of death, which may or may not have any relation to the site of origin. Lung cancers have been labeled as to cell type which may suggest the cell of origin and possibly give a clue as to the tissue of origin. However, the ICRP (ICRP, 1994) determined that such data from experimental animals and from humans in which lungs received uniform exposures to radiation, are not of sufficient quality and quantity to derive estimates of relative sensitivity suitable for apportioning the 0.12 weighting factor among the several regions of the lungs.[5]

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[3] The tissues identified by the ICRP (ICRP, 1994) for dose calculations are the anterior nose and the posterior nasal passages including the larynx, pharynx and mouth in the extrathoracic part of the respiratory tract. The tissues identified in the thorax are the tracheal and bronchial epithelium (the latter being divided into the mass of basal cells and the mass of secretory cells, specified separately because these appear to be the radiation sensitive cells), designated the Bronchial Region; the bronchiolar epithelium and respiratory bronchioles, designated the Bronchiolar Region; and the alveolar ducts and sacs and the interstitial connective tissues, designated the Alveolar-interstitial Region. Lymph nodes associated with the respiratory tract were also identified for dose calculations.

[4] According to the ICRP (ICRP, 1994) dose calculation scheme, the extrathoracic tissues were included in a category of "other tissues" for assignment of a tissue weighting factor. The extrathoracic tissues are not among the more radiation sensitive tissues in the body and the assignment of weighting factors to these tissues was not identified as an issue to be addressed by this Commentary.

[5] In the studies in which lung cancers appeared to be disproportionally distributed among lung regions, the radiation exposures were non-uniform and the regions where cancers were observed generally received the highest doses. Also it is uncertain whether tumor types observed in experimental animals will occur in humans. As a result, definitive conclusions about differences in radiation sensitivity could not be drawn.

Because information from radiation studies was lacking, the ICRP (ICRP, 1994) considered other approaches for apportioning the tissue weighting factor for lungs. For example, in humans not exposed to radiation other than that from natural background, it can be estimated from autopsy information about location of lung tumors and tumor cell types that 60 to 80% of tumors are of bronchial origin, 15 to 30% are of bronchiolar origin and 5 to 10% are of alveolar origin. A complicating factor, though, is cigarette smoking, which is thought to increase the fraction of tumors that originate in the bronchial region. Therefore, for non-smoking populations a distribution of 60% bronchial, 30% bronchiolar and 10% alveolar may be reasonable. However, use of this relative risk approach to apportion the 0.12 tissue weighting factor for lungs requires the assumption that exposure to radiation results in all the naturally occurring lung tumors being increased proportionally. Although there is evidence that radiation induces, in certain other organs and tissues, some of the same kinds of cancers that occur naturally, and for some cancers a relative risk model may be appropriate, application to the different tissues in the lungs did not appear justified to the ICRP. Therefore, as a default, until suitable information becomes available, the ICRP apportioned the 0.12 tissue weighting factor as follows: 33% to the bronchial tissues, equally divided between the basal and secretory cell masses; 33% to the bronchiolar tissues; and 33% to the alveolar-interstitial tissues.

It may be somewhat surprising that the extensive research on radiation-induced lung cancer in experimental animals and in human populations such as underground miners and the Japanese atomic bomb survivors is inadequate to specify the relative radiation sensitivity of the different tissues of the lungs. There is a general belief among researchers in this field of study that in animals and humans exposed to radiation from inhaled radionuclides, more cancers appear in the bronchial region than in other regions except in experimental animals where concentrations of long-lived alpha-emitters induced cancers in the bronchiolar-alveolar tissues.[6] This general observation of a greater frequency of lung cancer in the bronchi than in other regions of the lungs has promoted the idea that the bronchial epithelium is very likely the most radiation sensitive tissue and should be assigned a larger proportion than 33% of the tissue weighting factor for lungs. However, the ICRP (ICRP, 1994) determined that, until the relative sensitivities of lung tissues to

[6] Cancers in humans exposed to long-lived alpha-emitters such as plutonium have not been observed in the United States or elsewhere with the possible exception of the former Soviet Union. Recent unpublished information from Russia describes an increased incidence of lung cancer among plutonium workers, but details including tumor type and tissues of origin are not yet available.

radiation are documented in the scientific literature, the default apportionment values should be used.

While the default values may be objectionable to those who believe the bronchial, bronchiolar and alveolar-interstitial tissues of the lungs are not equally radiation sensitive, the more important radiation protection question is the sensitivity of the dose estimates obtained with the new model to the selection of apportionment values used in the dose calculations. This question is explored in the following examples of lung doses and effective doses calculated for several radionuclides using the default values and also calculated with two sets of apportionment values, Case 1 and Case 2, derived from information about the frequency of naturally occurring, non-radiation-induced, lung cancers. In these calculations the apportionment of the 0.12 weighting factor for lung among the regions of the lungs is as follows:

a) Default: 33% to the bronchial epithelium divided equally (16.67% each) between basal and secretory cell tissues, 33% to the bronchiolar tissues and 33% to the alveolar-interstitial tissues (first column).

b) Case 1: 60% to the bronchial tissues divided equally (30% each) between basal and secretory cell tissues, 30% to the bronchiolar tissues and 10% to the alveolar-interstitial tissues (second column); and

c) Case 2: 80% to the bronchial tissues divided equally (40% each) between basal and secretory cell tissues, 15% to the bronchiolar tissues and 5% to the aveolar-interstitial tissues (third column). (This case is most similar to the EPA's apportioning 80% of the lung weighting factor to the tracheo-bronchial region and 20% to the pulmonary region (EPA, 1994) in calculating doses for estimating radiogenic cancer risks.)

In all cases a value of 0.1% was assigned to lymph nodes. The doses are calculated for a standard worker: 31.3% of the time sitting and 68.7% doing light exercise. The software, LUDEP 1.1 (Personal Computer Program for Calculating Internal Doses Using the New ICRP Respiratory Tract Model) (NRPB, 1994), was used to calculate both committed weighted equivalent doses for lungs and commit-

ted effective doses[7]. The lung doses include contributions from radiation emitted from radionuclides deposited in the lungs and translocated to other tissues and organs in the body. These doses are not significant for alpha emitters.

Highly insoluble compounds of relatively long-lived radionuclides of elements such as plutonium and strontium are only slowly absorbed into the blood from the respiratory tract. The calculated doses given in Table 1 for ^{239}Pu and for ^{90}Sr show that both the total lung doses (committed weighted equivalent doses) and the effective doses (committed effective doses) are greatest (up to more than two times for 0.02 and 0.1 µm AMAD (Activity Median Aerodynamic Diameter) ^{239}Pu aerosols) when the default values for apportioning the tissue weighting factor are used, Column 1. For more soluble 1 µm AMAD aerosols absorbed from the lungs at a moderate rate, ^{238}Pu and ^{210}Po (alpha emitters), the calculated lung doses are slightly less when the default values are used, but the effective doses are about the same for all cases. However, for smaller particle size ^{210}Po aerosols, 0.1 µm AMAD, the default values lead to somewhat higher calculated lung and effective doses. The calculated lung and effective doses for soluble compounds of such radionuclides as ^{137}Cs and ^{131}I (beta-gamma emitters) that are rapidly translocated from the lungs to other tissues in the body are not sensitive to the choice of factors used for apportioning the risk among the different regions of the lungs.

It is debatable whether even the largest differences, slightly more than a factor of two in these example calculations, would have any significant impact on limiting exposures or estimating risks from exposures to air-borne radionuclides. Although these examples are limited in number, they include the radionuclides likely to be among the most sensitive to how the tissue weighting factor is apportioned, *i.e.*, alpha-emitting, long-lived insoluble radionuclides which are retained in the lungs sufficiently long to result in the lung dose being a substantial contribution to the effective dose. Radon and its decay products are not included in these example calculations because the ICRP (ICRP, 1993) advises using risk estimates directly from epidemiology data rather than calculating lung and effective doses.

CONCLUSION & RECOMMENDATIONS

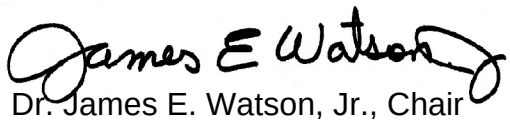
[7] This version of LUDEP, LUDEP 1.1, uses ICRP Publication 30 biokinetic models (ICRP, 1979). LUDEP 2.0, available in June 1996, uses updated biokinetic models from ICRP Publications 56 (ICRP, 1989), 67 (ICRP, 1993a) and 69 (ICRP, 1995). Inhalation dose coefficients in recent ICRP Publications 68 (ICRP, 1994a) and 71 (ICRP, 1995a) are based on the newer biokinetic models and, thus, differ slightly from the values calculated in Table 1 in this commentary.

The use of default values to apportion the tissue weighting factor for lungs in calculating effective doses from inhaled radionuclides would not appear to have a major impact on radiation protection. For certain insoluble radionuclides, but unlikely for soluble radionuclides, the use of the default values could add a small measure of conservatism to dose calculations. Neither the ICRP nor the NCRP believes the use of the default values poses a barrier to the adoption of the new dosimetric model for the human respiratory tract. When more acceptable values for apportioning the tissue weighting factor for lungs are obtained, the default values can be readily replaced. In the interim the RAC recommends the EPA use the new dosimetric model for the human respiratory tract as adopted by the ICRP and NCRP to calculate lung doses for inhaled radionuclides such as in the preparation of Federal Guidance Number 13 and in clean-up of sites contaminated with radionuclides.

However, the need to use default values indicates a lack of scientific information that, if corrected, could improve the credibility of the ICRP model among some of those familiar with respiratory tract pathology. The use of default values does not appear to weaken the usefulness of the model for radiation protection. For this purpose then, the RAC recommends EPA continue an effort to provide for adoption by the ICRP and NCRP a more scientifically acceptable basis for apportioning the tissue weighting factor for lungs. This effort could involve reexamining the literature for data on the relative radiation sensitivity of the several regions of the lungs including more recent results of epidemiology studies and animal experiments as well as studies that might identify the frequency distribution of radiation sensitive cells in the various regions of the lungs. Lacking success identifying scientifically credible published information that would justify replacement of the default values, the EPA might consider supporting the necessary research to do so. An EPA effort that resulted in a scheme for apportioning the lung tissue weighting factor that could be adopted by the ICRP and NCRP would be welcomed by the radiation protection community. The adoption of values by the EPA independent of the ICRP and NCRP would cause confusion in the calculation of effective doses in the U.S.

We trust this Commentary will offer some insights on the issues associated with apportioning the tissue weighting factor for the lungs in the new ICRP Dosimetric Model for the Human Respiratory Tract and on the opportunity for the EPA to contribute to improving the scientific basis for that aspect of the model.

Sincerely,



Dr. James E. Watson, Jr., Chair
Radiation Advisory Committee
Science Advisory Board

Dr. Genevieve M. Matanoski, Chair
Executive Committee
Science Advisory Board

APPENDIX A

TABLE 1: THE SENSITIVITY OF TOTAL LUNG AND EFFECTIVE DOSE CALCULATIONS TO THE CHOICE OF VALUES USED TO APPORTION RISK AMONG THE REGIONS OF THE LUNGS (Refer to Footnote to Table 1, p. A-4)

A. ^{238}Pu (moderate rate of absorption), 1 μm AMAD, $T_{1/2}$ = 87.7 years (an alpha emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	1.02 E-07	1.84 E-07	2.45 E-07
Bronchial, secretory cells	1.23 E-06	2.21 E-06	2.95 E-06
Bronchiolar	1.69 E-06	1.52 E-06	7.62 E-07
Alveolar-iterstitial	6.93 E-07	2.08 E-07	1.04 E-07
Lymph nodes	3.84 E-10	3.84 E-10	3.84 E-10
Total Lung Dose (Sv/Bq)	**3.72 E-06**	**4.13 E-06**	**4.06 E-06**
Effective Dose (Sv/Bq)	**4.83 E-05**	**4.87 E-05**	**4.86 E-05**

B. ^{239}Pu (slow rate of absorption), 0.02 μm AMAD, $T_{1/2}$ = 24,065 years (an alpha emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	1.98 E-07	3.56 E-07	4.75 E-07
Bronchial, secretory cells	3.43 E-06	6.17 E-06	8.22 E-06
Bronchiolar	2.45 E-05	2.21 E-05	1.11 E-05
Alveolar-interstitial	2.48 E-05	7.44 E-06	3.72 E-06
Lymph nodes	4.96 E-07	4.96 E-07	4.96 E-07
Total Lung Dose (Sv/Bq)	**5.34 E-05**	**3.66 E-05**	**2.40 E-05**
Effective Dose (Sv/Bq)	**8.46 E-05**	**6.77 E-05**	**5.51 E-05**

C. ^{239}Pu (slow rate of absorption), 0.1 μm AMAD, $T_{1/2}$ = 24,065 years (an alpha emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	6.48 E-08	1.16 E-07	1.55 E-07
Bronchial, secretory cells	1.18 E-06	2.12 E-06	2.83 E-06
Bronchiolar	9.48 E-06	8.54 E-06	4.27 E-06
Alveolar-interstitial	1.51 E-05	4.52 E-06	2.26 E-06
Lymph nodes	2.66 E-07	2.66 E-07	2.66 E-07
Total Lung Dose (Sv/Bq)	**2.60 E-05**	**1.56 E-05**	**9.78 E-06**

Effective Dose (Sv/Bq)	**4.47 E-05**	**3.43 E-05**	**2.85 E-05**

D. ^{239}Pu (slow rate of absorption), 1 µm AMAD, $T_{1/2}$ = 24,065 years (an alpha emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	8.29 E-08	1.49 E-07	1.99 E-07
Bronchial, secretory cells	1.30 E-06	2.34 E-06	3.12 E-06
Bronchiolar	2.46 E-06	2.22 E-06	1.11 E-06
Alveolar-interstitial	5.54 E-06	1.66 E-06	8.32 E-07
Lymph nodes	9.83 E-08	9.83 E-08	9.83 E-08
Total Lung Dose (Sv/Bq)	**9.48 E-06**	**6.47 E-06**	**5.36 E-06**
Effective Dose (Sv/Bq)	**1.65 E-05**	**1.35 E-05**	**1.23 E-05**

E. ^{239}Pu (slow rate of absorption), 5 µm AMAD, $T_{1/2}$ = 24,065 years (an alpha emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	1.16 E-07	2.09 E-07	2.78 E-07
Bronchial, secretory cells	1.30 E-06	2.34 E-06	3.12 E-06
Bronchiolar	1.32 E-06	1.19 E-06	5.96 E-07
Alveolar-interstitial	2.76 E-06	8.30 E-07	4.15 E-07
Lymph nodes	5.85 E-08	5.85 E-08	5.85 E-08
Total Lung Dose (Sv/Bq)	**5.56 E-06**	**4.63 E-06**	**4.47 E-06**
Effective Dose (Sv/Bq)	**9.26 E-06**	**8.33 E-06**	**8.17 E-06**

F. ^{90}Sr (slow rate of absorption), 1 µm AMAD, $T_{1/2}$ = 29.12 years (a beta emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	1.87 E-08	3.37 E-08	4.49 E-08
Bronchial, secretory cells	1.91 E-08	3.44 E-08	4.58 E-08
Bronchiolar	5.18 E-08	4.66 E-08	2.33 E-08
Alveolar-interstitial	5.47 E-08	1.64 E-08	8.21 E-08
Lymph nodes	3.24 E-10	3.24 E-10	3.24 E-10
Total Lung Dose (Sv/Bq)	**1.45 E-07**	**1.31 E-07**	**1.23 E-07**
Effective Dose (Sv/Bq)	**1.49 E-07**	**1.36 E-07**	**1.27 E-07**

G. ^{137}Cs (fast rate of absorption), 0.1 µm AMAD, $T_{1/2}$ = 30.0 years (a beta-gamma emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	9.88 E-11	1.77 E-10	2.37 E-10
Bronchial, secretory cells	9.89 E-11	1.78 E-10	2.37 E-10
Bronchiolar	1.98 E-10	1.78 E-10	8.90 E-11
Alveolar-interstitial	1.96 E-10	5.88 E-11	2.94 E-11
Lymph nodes	5.87 E-13	5.87 E-13	5.87 E-13
Total Lung Dose (Sv/Bq)	**5.92 E-10**	**5.92 E-10**	**5.92 E-10**
Effective Dose (Sv/Bq)	**5.33 E-09**	**5.33 E-09**	**5.33 E-09**

H. ^{137}Cs (fast rate of absorption), 1 µm AMAD, $T_{1/2}$ = 30.0 years (a beta-gamma emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	8.59 E-11	1.55 E-10	2.06 E-10
Bronchial, secretory cells	8.61 E-11	1.55 E-10	2.07 E-10
Bronchiolar	1.71 E-10	1.54 E-10	7.68 E-11
Alveolar-interstitial	1.70 E-10	5.11 E-11	2.56 E-11
Lymph nodes	5.11 E-13	5.11 E-13	5.11 E-13
Total Lung Dose (Sv/Bq)	**5.13 E-10**	**5.15 E-10**	**5.16 E-10**
Effective Dose (Sv/Bq)	**4.72 E-09**	**4.72 E-09**	**4.72 E-09**

I. ^{131}I (fast rate of absorption), 1 µm AMAD, $T_{1/2}$ = 8.04 days (a beta-gamma emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	1.77 E-12	3.20 E-12	4.26 E-12
Bronchial, secretory cells	1.99 E-12	3.58 E-12	4.78 E-12
Bronchiolar	2.46 E-12	2.21 E-12	1.11 E-12
Alveolar-interstitial	2.04 E-12	6.14 E-13	3.07 E-13
Lymph nodes	5.83 E-15	5.83 E-15	5.83 E-15
Total Lung Dose (Sv/Bq)	**8.27 E-12**	**9.61 E-12**	**1.05 E-11**
Effective Dose (Sv/Bq)	**1.14 E-08**	**1.14 E-08**	**1.14 E-08**

J. ^{210}Po (moderate rate of absorption), 0.1 µm AMAD, $T_{1/2}$ = 138.38 days (an alpha emitter)

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	4.27 E-08	7.68 E-08	1.02.E-07
Bronchial, secretory cells	8.36 E-07	1.50 E-06	2.00 E-06
Bronchiolar	5.80 E-06	5.23 E-06	2.61 E-06
Alveolar-interstitial	1.04 E-06	3.12 E-07	1.56 E-07
Lymph nodes	3.60 E-10	3.60 E-10	3.60 E-10
Total Lung Dose (Sv/Bq)	**7.72 E-06**	**7.12 E-06**	**4.87 E-06**
Effective Dose (Sv/Bq)	**7.86 E-06**	**7.26 E-06**	**5.02 E-06**

K.**^{210}Po (moderate rate of absorption), 1 µm AMAD, $T_{1/2}$ = 138.38 days (an alpha emitter)**

Regional Lung Dose (Sv/Bq)

Lung Region	*Default*	*Case 1*	Case 2
Bronchial, basal cells	5.24 E-08	9.41 E-08	1.25 E-07
Bronchial, secretory cells	9.55 E-07	1.72 E-06	2.29 E-06
Bronchiolar	1.43 E-06	1.29 E-06	6.44 E-07
Alveolar-interstitial	3.83 E-07	1.15 E-07	5.75 E-08
Lymph nodes	1.37 E-10	1.37 E-10	1.37 E-10
Total Lung Dose (Sv/Bq)	**2.82 E-06**	**3.21 E-06**	**3.11 E-06**
Effective Dose (Sv/Bq)	**2.90 E-06**	**3.29 E-06**	**3.20 E-06**

Footnote to Table 1.

The doses are calculated for a standard worker: 31.3% of the time sitting and 68.76% doing light exercise. The doses are per unit intake: Sv (Sieverts) per Bq (Becquerel). The software, LUDEP 1.1 (Personal Computer Program for Calculating Internal doses Using the NEW ICRP Respiratory Tract Model) (NRPB,1994), was used to calculate both committed weighted equivalent doses (abbreviated in the Table as Regional Lung Dose and Total Lung Dose) and committed effective doses (abbreviated in the Table as Effective Dose). Total Lung Doses are the sums of the committed weighted equivalent doses to all lung regions given in the Table. The time of integration of the doses was 50 years after intake. The Effective Doses given in the Table are the sums of the products of the committed tissue equivalent doses and the appropriate tissue weighting factors for all tissues and organs in the body, including lungs, also integrated over 50 years. This detail is not given in the Table.

The doses in the first column, *Default*, were calculated using the ICRP default values for apportioning the lung weighting factor, 0.12. These are 16.67% to each the basal and secretory cells of the bronchial epithelium, 33% to the bronchiolar epithelium and 33% to the alveolar-interstitial tissues. The doses in the second column, *Case 1,* were calculated by apportioning the 0.12 weighting factor; 30% to each the basal and secretory cells of the bronchial epithelium, 30% to the bronchiolar epithelium and 10% to the alveolar-interstitial tissues. The doses in the third column, *Case 2*, were calculated by apportioning the 0.12 weighting factor; 40% to each the basal and secretory cells of the bronchial epithelium, 15% to the bronchiolar epithelium and 5% to the alveolar-interstitial tissues.

APPENDIX B

GLOSSARY OF TERMS AND ACRONYMS AS USED IN THIS COMMENTARY

Absorption	Transfer of inhaled material to body fluids such as circulating blood.
AMAD	Activity Median Aerodynamic Diameter. Fifty percent of the activity (aerodynamically classified) in the aerosol is associated with particles of aerodynamic diameter greater than the AMAD. A log-normal distribution of particle sizes is usually assumed.
Apportionment Values	Weighting factors assigned for the partition of tissue weighting factor, 0.12, among regions of the lungs.
Alveolar-Interstitial Region	Consists of the respiratory bronchioles, alveolar ducts and sacs with their alveoli, and the interstitial connective tissues; airway generations 16 and beyond.
Basal Cells	Cuboidal epithelial cells attached to the basement membrane of extrathoracic and bronchial epithelium and not extending to the surface.
Bronchial Region	Consists of the trachea and bronchi; airway generations 1 through 8.
Bronchiolar Region	Consists of the bronchioles and terminal bronchioles; airway generations 9 through 15.
Bq	Becquerel: the special name for the SI (International System of units) unit of radioactivity; 1 Bq = 1 disintegration per second.
Cs	Cesium and its radioactive isotope, ^{137}Cs, a beta-gamma emitter.
Deposition	Refers to the initial processes determining how much of the material in the inspired air remains behind in the respiratory tract after exhalation.
Default Values	Numerical values taken when specific information is deficient.
E	Exponent, expressed here in powers of ten.

Effective Dose	E The sum of the weighted equivalent doses in all tissues of the body.
Committed Effective Dose	$E(\tau)$ The sum of the products of the committed tissue equivalent doses and the appropriate tissue weighting factors (w_T) for all tissues and organs of the body, where τ is the integration time in years following intake of radioactive material into the body, 50 years for adults and from intake to age 70 years for children.
EPA	The United States Environmental Protection Agency
Exposure	Refers to the potential for receiving a radiation dose by being in the presence of airborne radionuclides or near a beam of neutrons, x-or gamma-rays.
Extrathoracic	Refers to regions of the respiratory tract that are outside of the thorax: anterior nose, posterior nasal passages, mouth, pharynx and larynx.
Gy	Gray: the special name for the SI (International System of units) unit of absorbed dose: 1 Gy = 1 joule per kilogram..
Equivalent Dose	H_T The product of the averaged absorbed dose in a tissue or organ T and the radiation weighting factor (w_R) for the radiation type.
Committed Equivalent Dose	$H_T(\tau)$ The time integral of the equivalent dose rate in a particular tissue or organ that will be received by an individual following intake of radioactive material into the body where τ is the integration time in years following intake, 50 years for adults and from intake to age 70 years for children.
Intake	Activity that enters the respiratory tract or gastrointestinal tract from the environment.
I	Iodine and its radioactive isotope, ^{131}I, a beta-gamma emitter.
ICRP	International Commission on Radiological Protection. The ICRP was established in 1928 by the Second International Congress of Radiology to provide general guidance and recommendations on the safe use of radiation and radioactive materials in medicine, education, research and industry. It works closely with its sister organization, the International Commission on Radiation Units and Measurements, and has official

relationships with the World Health Organization and the International Atomic Energy Agency. It also interacts with numerous other international organizations on matters of radiation protection.

LUDEP — Personal computer program for calculating internal doses using the new ICRP biokinetic respiratory tract model (Version 1.0, 1.1, 2.0, etc.)

Lymph Nodes — Accumulations of lymphatic tissue about 1 to 25 mm in diameter, located along lymphatic vessels between tissues and organs, that filter bacteria and foreign materials from the lymph, a transparent fluid that is drained from tissues and returned to the blood.

mm — millimeter (one thousandth of a meter)

NCRP — National Council on Radiation Protection and Measurements The NCRP was originally established in 1929 as the Advisory Committee on X-ray and Radium Protection to the National Bureau of Standards, at the recommendation of the ICRP, and renamed the National Committee on Radiation Protection in 1946 with the addition of several parent organizations including the armed forces, professional medical societies and the National Electrical Manufacturers Association. In 1964 the NCRP was chartered by Congress as a non-profit organization to collect, analyze, develop and disseminate in the public interest information and recommendations about radiation protection; provide means for cooperation of organizations interested in radiation matters; develop basic concepts about radiation topics and their application; and to cooperate with the ICRP and other international organizations concerned with radiation protection.

NRPB — National Radiological Protection Board of England

ORIA — Office of Radiation and Indoor Air (U.S. EPA)

ORP — Office of Radiation Programs (U.S. EPA) (Forerunner of ORIA)

Pu — Plutonium and its radioactive isotopes, ^{238}Pu and ^{239}Pu, both alpha emitters.

Po — Polonium and its radioactive isotope, ^{210}Po, an alpha emitter.

RAC — Radiation Advisory Committee (U.S. EPA/SAB/RAC)

rem — roentgen equivalent man: the unit of dose equivalent)

SAB — Science Advisory Board (U.S. EPA)

Secretory Cells — Nonciliated epithelial cells that have mucous or serous secretions.

Sr — Strontium and its radioactive isotope, ^{90}Sr, a beta emitter.

Sv — Sievert: the special name for the S.I. (International System of units) unit of equivalent dose (H_T) and effective dose (E): 1 Sv = 1 joule per kilogram), equal to 100 rem.

$T_{1/2}$ — Radioactive Half-life: The time taken for the activity of a radioactive material to lose half its value by decay, generally with the emission of alpha, beta, gamma or neutron radiations.

TGLD — Task Group on Lung Dynamics (1966 task group of ICRP)

Thoracic — Refers to the regions of the respiratory tract that are contained within the thorax: bronchial, bronchiolar and alveolar-interstitial regions.

µm — Micrometer: 10^{-4} mm.

Radiation Weighting Factor — w_R A dimensionless factor to derive the equivalent dose from the absorbed dose averaged over a tissue or organ and is based on the quality of radiation.

Tissue Weighting Factor — w_T The factor by which the equivalent dose in a tissue or organ is weighted to represent the relative contribution of that tissue or organ to the total detriment resulting from uniform irradiation of the body.

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The Radiation Advisory Committee (RAC) wishes to acknowledge with grateful appreciation that the bulk of this commentary was prepared by Dr. William J Bair, a member of the RAC.

ABSTRACT

The Radiation Advisory Committee (RAC) of the Science Advisory Board (SAB) prepared this commentary on the scientific basis for apportioning risk among the International Commission on Radiation Protection (ICRP) Publication 66 regions of the respiratory tract in response to concerns raised by the Office of Radiation and Indoor Air (ORIA) within the Office of Air and Radiation (OAR). In this commentary it is concluded that the current use of the default values recommended by the ICRP would not have a major impact on radiation protection. Nevertheless, the EPA is encouraged to undertake an effort to provide a more scientifically acceptable basis for apportioning the tissue weighting factor for the lungs. This could involve reexamining the literature for data on the relative radiation sensitivity of the several regions of the lungs, including more recent results from epidemiology studies and animal experiments as well as studies that might identify the frequency distribution of radiation sensitive cells in the various tissues in the lungs.

The RAC noted that an EPA Effort that resulted in a scheme for apportioning the lung tissue risk weighting factor that was acceptable to the ICRP and the NCRP (National Council on Radiation Protection and Measurements) would be welcomed by the radiation protection community. The Committee also noted that the adoption of values by the EPA independent of the ICRP and the NCRP would cause unneeded confusion in the calculation of effective doses in the United States.

Key Words: Lung model, ICRP Human Respiratory Tract Model for Radiological Protection, Committed Effective Dose, Committed Equivalent Lung Dose, Dose Calculations, Tissue Weighting Factor.

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