Office of Compensation Analysis and Support **Technical Information Bulletin**	Document Number: OCAS-TIB-0011 Effective Date: 1/13/2006 Revision No. 2
Lung Dose Conversion Factor for Thoron WLM	Page 1 of 8
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RECORD OF ISSUE/REVISIONS			
ISSUE AUTHORIZATION DATE	**EFFECTIVE DATE**	**REV. NO.**	**DESCRIPTION**
3/16/2005	3/16/2005	0	New document to provide a basis for the conversion factor.
4/15/2005	4/15/2005	1	Correction factors added for ET1 and ET2 regions
1/13/2006	1/13/2006	2	Correction factors added for ET1 and ET2 regions for Radon 222

1.0 PURPOSE

This Technical Information Bulletin provides the conversion factor for calculating lung dose from Rn-220 decay products measured in working level months (WLM).

2.0 Background

EEOICPA uses the Interactive RadioEpidemiological Program (IREP) to determine the Probability of Causation (POC) that a cancer was caused by occupationally related radiation exposure. Annual radiation dose is the normal IREP input but in the case of radon, a direct exposure model is also included for lung cancers. The exposure model was based on studies performed at uranium mines and thus applies to Rn-222 and its associated decay products. Rn-220 (also known as thoron) decay products have characteristics that are sufficiently different from Rn-222 so that the exposure model is not applicable to thoron. However, thoron decay products are often measured in units of working levels. This requires the development of a conversion factor to express thoron working level exposures in terms of lung dose in rem.

3.0 Working Level Definition

The majority of dose received from radon is actually derived from energy emitted by the decay products rather than the gas itself. Because of this, the dose per unit radon gas activity is greatly dependent on the state of equilibrium of the decay products. To better describe the hazard associated with radon, worker exposure has historically been expressed in terms of the decay product activity. The unit developed for this is the

Working Level. A Working Level is described as the amount of short lived radon decay products in one liter of air that will ultimately decay with 1.3E5 MeV of alpha energy.

When the decay chain reaches 100% equilibrium, one Working Level is equivalent to approximately 100 pCi/L of Rn-222 or 7.5 pCi/L of Rn-220. While this is a significant difference in the gas concentrations, by definition of the working level, the decay products will ultimately emit the same amount of alpha energy. This, however, does not lead to the same lung dose. This is caused largely by the difference in the half-lives of the decay products. Since Rn-220 products have longer half lives, the body has longer to transport the activity from one compartment to another and thus deliver dose to different areas of the lung.

Since the working level is an air concentration, it is analogous to an exposure rate. To describe exposure, the unit working level month (WLM) is normally used. A WLM is described as the exposure equivalent to breathing one WL for 170 hours (one working month).

4.0 Calculation Method

The ICRP 66[1] lung model was used to determine the proper conversion factor of dose per WLM Rn-220. The model consists of 14 compartments. Material deposited in the lung is moved among these compartments as well as removed to the blood stream, the GI tract, and via extrinsic means. No absorption occurs in one compartment, (ET1).

Default absorption rates are described as a combination of two rates, a rapid rate and a slow rate as well as the fraction of material that is absorbed rapidly. This requires the model to use 2 compartments for each of the 13 lung compartment from which absorption occurs. Therefore, the mathematical model consists of 13 rapid absorbing compartments, 13 slowly absorbing compartments, and one other compartment for a total of 27 compartments.

To further complicate the model, Rn-220 decays to 5 important decay products and the model must be solved for each. This then requires a total of 135 mathematical compartments in order to solve the model.

Each compartment can be solved analytically using simple first order differential equations. The solution to these equations becomes tedious when the compartment receives material that has passed through several compartments previously or has decayed through a chain of several nuclides to reach that point. Therefore, several simplifying assumptions have been made. Two of the decay products (Po-216 and Po-212) have very short half-lives (<1sec). Po-216 was considered to be in equilibrium with Rn-220 gas. Po-212 is produced in 64% of the Bi-212 disintegrations and was therefore each Bi-212 decay was considered to also immediately produce a Po-212 decay.

5.0 Model Parameters

The choice of parameters for the model is an important issue. There are numerous parameters to define. The ICRP defines default parameters for the majority and these are to be used unless more specific information is known about the particular situation. Parameters chosen specifically for Rn-220 decay product inhalation are discussed in more detail below. The remaining parameters used the ICRP defaults.

a) Absorption

The ICRP 66[1] lung model defines three default categories for particulate lung absorption. These defaults are to be used unless more specific information is known about the situation at hand. In the case of radon decay products, a number of references are available indicating an absorption half-life of approximately 10 hours. Marsh and Birchall[2] describe an evaluation while Nikezic[3] lists four separate references to this value. Therefore, the 10 hour half-life is used in this calculation.

b) Unattached Fraction

Radon decay products are normally electrically charged. This causes the products to quickly attach to particles normally in the air. This greatly affects the aerodynamic characteristics of these particles which in turn affects the deposition of the particles in the lungs. While unattached fraction is not specifically a parameter of the ICRP 66 lung model, the aerodynamic parameters are.

Birchall and James[4] used an unattached fraction of 1% based on a report by Samet et. al.[5] Nikezic et. al.[3] used 8% apparently based on the same report. The largest difference appear to be that Birchall and James attempted to describe typical mine air while Nikezic attempted to describe typical household air. It should also be noted that both reports were describing Rn-222 decay products. The unattached fraction of Rn-220 decay products can be different due to the greatly different half-lives of the products. The Rn-220 products have longer half-lives and thus a longer period of time for the attachment to occur.

Yamasaki et. al.[6] performed a theoretical calculation that showed the unattached fraction for Rn-220 decay products to be approximately 1.6% for indoor air.

Porstendorfer[7] demonstrated showed the unattached fraction depends on the concentration of particulates in the air. He also showed that the unattached fraction of Rn-220 decay products is smaller than that of Rn-222 decay products. His values match well with each of the references above therefore, this calculation will use a value of 2%. It is likely that the dust concentration in a work environment is higher than in a dwelling and thus the unattached fraction should be lower for the work environment. Therefore, when Yamasaki’s value of 1.6% is considered, the 2% unattached fraction should be slightly high for a standard work environment. This can be shown to be a slight overestimate of dose conversion factors but with the percentages so low, it appears to be a reasonable.

c) Particle Size

The ICRP recommends a default particle size of 5 micron for a working environment and 1 micron for members of the public exposed to environmental releases. In both cases, these particle sizes are the median of a lognormal distribution of particle sizes. The default geometric standard deviation (GSD) is 2.5, the default density is 3 g/cc and the default shape factor is 1.5. This calculation uses all these defaults with the exception of the particle size.

The particle size distribution affects the regional deposition of the aerosol in the lungs. This size is greatly affected by the unattached fraction. The fraction that is attached to other particulates can exhibit the aerodynamic characteristics of the larger particle to which it is attached. The unattached fraction, on the other hand, represents very small particles produced from the noble gas (radon).

Nikezic et. al.[3] indicated a particle size distribution for the attached fraction of 0.2 micron with a GSD of 2.35 while the unattached fraction was 0.0015 micron with a GSD of 1.1.

Porstendorfer[7] indicated particle sizes for various environments. The unattached median particle sizes ranged from 0.00013 micron to 0.0013 micron with GSDs ranging from 1.1 to 1.3. For the attached fraction, the major contribution (~86%) exhibited median particle sizes of 0.33 micron for outdoor air and 0.217 micron for indoor air. Most of the remaining distribution exhibited a median size of ~0.040 micron. The GSD for these distributions varied from 1.5 to 2.2.

Birchall and James[4] indicated that the available data of attached aerosol size in underground uranium mines indicates a particle size between 0.15 micron and 0.5 micron with Samet et. al.[5] considering the best estimate to be 0.25 micron.

ICRP 32[8] indicates the value between 0.2 and 0.3 micron.

Based on the references above, this calculation will use a median particle size of 0.25 micron for the attached fraction. A size of 0.0015 micron will be used for the unattached fraction. The ICRP 66 default value of 2.5 will be used for the geometric standard deviation.

d) Equilibrium

The last major factor to consider is the state of equilibrium exhibited by the decay chain inhaled. The decay chain of Rn-220 is shown below.

Rn-220	55.6 sec	Alpha decay
Po-216	0.15 sec	Alpha decay
Pb-212	10.64 hours	Beta decay
Bi-212	60.6 min	Alpha decay (36%), Beta dcay (64%)
Po-212	304 nsec	Alpha decay
Tl-208	3 min	Beta decay

When the chain is in 100% equilibrium, the activity of each generation is equal. However, the number of atoms required to reach this equilibrium activity varies depending on the half-life. Since the working level is defined by the ultimate energy released, it is affected by the number of atoms more than the total activity in a mixture. The alpha energy is emitted only by Po-216 and essentially Bi-212. In reality Bi-212 emits an alpha only 36% of the time but the other 64% of the time it emits a beta then an alpha almost immediately through the decay of Po-212 (304 nsec half-life). The average alpha energy released by a Bi-212 decay is then 7.8 MeV (6.07 Mev * 0.36 + 8.785 MeV * 0.64). Since Po-216 ultimately decays by two alphas (Po-216 and Bi-212) the alpha energy released per Po-216 atom is 14.6 MeV. Pb-212 and Bi-212 both decay with an effective alpha energy of 7.8 MeV. Po-212 decays with an energy of 8.785 MeV and Tl-208 decays by beta decay only.

The largest number of atoms associated with the chain in equilibrium are Pb-212 and Bi-212 due to the relatively long half-lives. The remaining nuclides contribute little to the WL measurement or the lung dose.

Since Pb-212 has a half-life approximately 10 times larger than Bi-212, the number of Pb-212 atoms in an 100% equilibrium mixture is approximately 10 times that of Bi-212. This causes Pb-212 to be the primary contributor to the WL measurement regardless of the degree of equilibrium. On the other hand, Pb-212 atoms inhaled have more time to be removed from the lungs prior to emitting all energy that will ultimately be emitted by the remainder of the decay chain. This causes Pb-212 to produce less lung dose per unit activity inhaled than that of Bi-212. Therefore, while the amount of Pb-212 in air drives the WL measurement, the amount of Bi-212 in air is a large contributor to lung dose. This causes the degree of equilibrium to be an important parameter. A good measurement of this degree of disequilibrium is the ratio of Bi-212 to Pb-212.

The degree of equilibrium depends entirely on the circumstances surrounding the production and movement of the Rn-220 gas in the breathing zone. This cannot be easily predetermined but a range of likely values can.

ICRP 32[8] indicates this ratio (Bi-212 to Pb-212) is between 0.2 and 0.8. Pillai and Paul[9] indicate the ratio is between 0.11 and 0.37 in a monazite mine and 0.24 to 0.84 in open air. This calculation will use 0.8 as a default value but also provide values for a range of equilibrium values. This will allow the most appropriate value to be used for the particular circumstances.

6.0 Thoron Results

The ICRP 66 lung model was solved using the assumptions described above. Under the default assumptions used in this report, a dose of 7.61 rem to the lungs will be assigned per WLM of Rn-220 decay products inhaled. Similarly, the default doses to the ET1 region will be 1750.33 rem and 2.90 rem to ET2. This value should be considered to be received entirely in the year the material was inhaled.

The values for different degrees of equilibrium were also calculated and are provided in the table below. The degree of equilibrium is specified by the ratio of Bi-212 activity to Pb-212 activity. These values can be used is information for the specific situation is available.

Table 1 - Dose per WLM inhaled for various degrees of Equilibrium

% equilibrium (Bi-212/Pb-212)	Lung dose (rem) per WLM	ET1 dose (rem) per WLM	ET2 dose (rem) per WLM
20%	4.04	932.99	0.17
40%	5.27	1215.58	1.11
60%	6.46	1487.84	2.03
80%	7.61	1750.33	2.90

7.0 Radon

Radon 222 conversion factors were determined only for the ET1 and ET2 compartments. The dose to the lungs was not determined because a direct exposure cancer model is available for use. The LNet compartment was determined but not listed here. Due to the fact that there is no direct deposition in the lymph nodes and the short half-life of the radon progeny, no significant dose is received by the lymph nodes. The progeny undergoes significant decay before any of the material can reach the lymph nodes.

The Po-214 decay was not modeled separately. The energy emitted from this decay was added to the Bi-214 decays. This is due to the very short half-life of Po-214 (approximately 0.16 msec).

a) Model Parameters

The absorption rate and particle size used for radon 220 were again used for radon 222. The unattached fractions used were 0.18, 0.021, and 0.0007 for Po-218, Pb-214, and Bi-214 respectively. This was taken from a formula in NCRP Report 78[10] that equates unattached fractions to dust particle concentrations in the air. The particle concentration used was $1x10^4$ particles per cm^3, which equate to an overall unattached fraction of 8%. This fraction is the same reported by Nikezic et. al.[3] for indoor air. By comparison, Birchall and James[4] reported an unattached fraction of 1% for mine air. The dose conversion factor was determined to be higher for higher unattached fractions. Since the dust concentration is difficult to determine and the difference is not large (~15%) the 8% assumption was used. This should be an overestimate for most work sites.

The equilibrium of the various radon 222 progeny also affects the conversion factor. However, this also affects the number of working levels the activity in the air will represent. These tend to be competing factors and cause the affect on this conversion factor to be relatively small. Three equilibrium fractions were investigated. Two from NCRP Report 78[10] and the third from Domanski[11]. The factors along with the associated overall equilibrium factor are shown in the table below.

Table 2 – Equilibrium Factors for Radon 222

	NCRP 78 outdoor	NCRP 78 indoor	Domanski
Po-218	0.9	0.5	0.656
Pb-214	0.7	0.3	0.446
Bi-214	0.7	0.2	0.259
Overall	0.72	0.28	0.40

The highest conversion factor for the ET2 compartment was produced by the NCRP 78 outdoor factors. These factors were approximately 6% higher than the lowest values calculated. Given the small difference in factors, these fractions will be used as a slightly favorable assumption for all values of equilibrium.

b) Radon Results

As a result of these parameters, the radon 222 conversion factors are listed in the table below.

Table 3 – Dose Conversion Factors for Radon 222

	Conversion Factor (Rem/WLM)
ET1 compartment	2077
ET2 compartment	8.35

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