A Review of Radon Doses

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Abstract

Radon is radioactive; therefore, a radiation dose is associated with radon exposure. In the literature, values of radon dose conversion factor vary widely, and the meanings of radon dose can be quite different. It is important to understand what is really meant by a value of radon dose. A review of radon doses is given here. A summary table of different radon doses should be helpful to radon protection practitioners for better communication of radon risk to the public.

Key words

cancer risk
lung dose
radiation dose
radon

Introduction

Radon (^{222}Rn) is an inert radioactive gas produced by the decay of natural uranium in rocks and soils throughout the earth's crust. A certain fraction of the radon escapes into the air where, in the outdoors, it is quickly diluted and is of no further concern. However, in confined spaces such as homes and office buildings, radon can accumulate to harmful levels. Radon is an alpha-emitter that decays with a half-life of 3.8 days into a short-lived series of progeny. A certain fraction of radon progeny becomes attached to aerosol particles. By inhalation, these can be deposited in the lungs and bombard sensitive lung tissue with alpha radiation. Over a period of time, this may lead to malignant transformation and the formation of lung cancer. Indoor radon has been determined to be the second leading cause of lung cancer after tobacco smoking.[1]

Radon is radioactive; therefore, a radiation dose is associated with radon exposure. Radon concentration and radon dose are two terms we use in our routine communication to the members of the public regarding radon and its health risk. Radon concentration is normally given in the unit of Bq/m^3. Radon dose is another quantity which gives energy deposition from radon and its progeny per unit mass of the absorber, such as human body or human lung. Radon dose is usually expressed in the unit of mSv which could be a radiation weighted and/or tissue weighted quantity. Because radon concentration and radon dose are two different physical quantities, a conversion factor is used to assess radon dose for unit radon exposure. In the literature, values of radon dose conversion factor vary widely and the meanings of radon dose can be quite different.[2-9] It is important to understand what is really meant by a value of radon dose.

In summary, there are two main categories of radon dose: the dose from epidemiological assessment and that from physical dosimetry.

Radon Dose from Epidemiological Assessments

Radon doses given in ICRP publications belong to this category. The ICRP has not provided values of the doses per unit intake for radon and its decay products from application of the respiratory tract model. Because lung cancer has been observed and studied extensively in miners exposed to radon-222, the ICRP has adopted a conversion convention for radon exposures that is based on *equality of detriments from epidemiological determinations*. As stated in ICRP Publication 65,[2] a conversion from radon exposure to effective dose was obtained by a direct comparison of the detriment associated with a unit effective dose and a unit radon exposure. The detriment per unit effective dose is 7.3×10^{-5} per mSv for the general public based mainly on studies of A-bomb survivors.[3] The detriment per unit exposure to radon progeny is 8.0×10^{-5} per mJ h m^{-3} (1 mJ h m^{-3} = 0.282 WLM, where WLM is the exposure unit of Working Level Month commonly used in workplaces).[2] In terms of detriment, an exposure to radon progeny of 1 mJ h m^{-3} is equivalent to an effective dose of 1.10 mSv for members of the public ($8.0 \times 10^{-5}/7.3 \times 10^{-5} = 1.10$). The ICRP conversion from radon exposure to effective dose has nothing to do with any dosimetric parameters and does not rely on tissue or radiation weighting factors. This is not a dose in the sense of dosimetry. It is solely based on equality of detriments resulting from two totally different exposure scenarios. A better name for this type of dose should be "risk equivalent dose."

Assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4, then 1 Bq/m^3 is equivalent to 1.56×10^{-2} mJ h m^{-3}. Based on the ICRP radon dose conversion, exposure to radon at 100 Bq/m^3 will be equivalent to an annual effective dose of 1.72 mSv.

Radon Dose from Physical Dosimetry

Many publications have dealt with radon dose to the lung determined from physical dosimetry.[4-8] There are absorbed dose, equivalent dose and effective dose. Typically, estimates of absorbed dose to the critical cells of the respiratory tract per unit of radon exposure are derived from the analysis of information on aerosol size distribution, unattached fraction, breathing rate, fractional deposition in the airways, mucous clearance rate, and location of the target cells in the airways.[9–12] Such estimates are strongly model-dependent and subject to many uncertainties associated with the input data as well as the assumptions built into particular computing models. Literature values of absorbed doses to lung vary from 5 to 71 nGy per (Bq h m^{-3}) as summarized in Table 26 of the UNSCEAR 2000 report.[9] The central value is estimated to be 9 nGy per (Bq h m^{-3}).

Again assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4 as used in ICRP publications, the annual absorbed dose to lung at a radon concentration of 100 Bq/m^3 will be 2.5 mGy.

The equivalent dose is the radiation-weighted absorbed dose. The radiation weighting factor for alpha particles is 20 as recommended by ICRP.[3] Applying the weighting factor of 20, the annual equivalent dose to lung at a radon concentration of 100 Bq/m^3 will then be 50 mSv.

When concerned with effective dose, one has to apply a tissue weighting factor in addition to the radiation weighting factor. According to ICRP,[3] the tissue weighting factor for lung is 0.12; the radiation weighting factor for alpha particles is 20. With these two weighting factors, the absorbed dose of 2.5 mGy to lung for one year exposure at 100 Bq/m^3 becomes an annual effective dose of 6 mSv.

In terms of effective dose, for one year of radon exposure at 100 Bq/m^3, the estimate from a dosimetric approach is 6 mSv, while the estimate from an epidemiological approach is 1.7 mSv. The dosimetric estimate is thus about 3.5 times higher than the epidemiological estimate.

However, as indicated in the BEIR VI report,[10] there are biological experimental studies showing that a quality factor of 10 seems appropriate for cells at depth in the bronchial epithelium.[13, 14] There is general agreement among scientists that alpha irradiation of cells in the bronchial epithelium is responsible for the development of lung cancer.[1,10] If we use a radiation weighting factor of 10, the discrepancy is reduced to a factor of 1.7.

UNSCEAR's Compromise on Radon Effective Dose Conversion

In the literature, there are discussions on the discrepancy between dosimetric and epidemiological effective doses for radon exposure.[15,16] UNSCEAR, in its last report UNSCEAR 2000,[9] noted the difference in radon doses and recommended a radon effective dose conversion factor of 9 nSv per (Bq h m^{-3}). Note that this is a conversion factor for an effective dose, not for the dose to lung. This conversion factor lies between dosimetric and epidemiological dose conversions and is somewhat closer to the dose conversion from epidemiological assessments.

Assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4, using UNSCEAR recommendation of 9 nSv per (Bq h m^{-3}), the effective dose for one-year radon exposure at 100 Bq/m^3 is 2.5 mSv.

Summary and Conclusion

As discussed above, there are radon doses with different meanings. For radiation dose due to radon exposure, there are absorbed dose, equivalent dose and effective dose. The absorbed dose is given in the unit of Gray while the equivalent dose and the effective dose have the same unit of Sievert. Besides their different meanings, those radon doses derived from

Table 1. *Summary of estimated radon doses at different radon concentrations, assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4.*

Radon concentration, Bq/m^3	100	200	400	600	800
ICRP "risk equivalent" radon dose, mSv	1.7	3.4	6.9	10	14
UNSCEAR recommended radon dose, mSv	2.5	5	10	15	20
Radon effective dose (dosimetric), mSv	6	12	24	36	48
Radon equivalent dose to lung (w_R=20), mSv	50	100	200	300	400
Radon equivalent dose to lung (w_R=10), mSv	25	50	100	150	200

physical dosimetry vary widely in numerical values. In the practice of radiation protection, it is important to know the meaning of a radon dose and the uncertainty associated with it.

Another approach to assessing radon dose is the epidemiological approach. By com-paring epidemiological studies of A-bomb survivors and underground miners, exposure to radon is converted to an effective dose in the unit of Sieverts, based on equality of detriments. This approach gives a radiation dose which hardly relates to radiation dosimetry. Since the same unit is used for this type of radon dose, the "risk equivalent" dose, it causes confusion in communication of radon risk to the public. A new unit should be adopted for "risk equivalent dose."

Table 1 summarizes radon doses at different radon concentrations. All calculations are based on the assumptions of 7000 hours per year indoor and an equilibrium factor of 0.4.

For the conversion of a radon exposure to a radon dose, there are large uncertainties in dosimetric assessments as well as in epidemiological analysis. UNSCEAR's radon dose conversion factor lies between dosimetric and epidemiological dose conversions. As proposed by Harley et al.[17] at the 6th High Level Nature Radiation and Radon Areas in 2004, one should use the UNSCEAR's conversion convention to avoid confusion and misunderstanding.

References

1. International Agency for Research on Cancer (IARC). Summaries & Evaluations, Vol.43 *Radon.* WHO 1988.
2. International Commission on Radiological Protection. "Protection Against Radon-222 at Home and at Work," ICRP Publication 65. *Annals of the ICRP 23* (1993).
3. International Commission on Radiological Protection. "Recommendations of the International Commission on Radiological Protection," ICRP Publication 60. *Annals of the ICRP 21* (1991).
4. Harley, N.H., and B.S. Pasternack, "Alpha Absorption Measurements Applied to Lung Dose from Radon Daughters," *Health Phys.* **23**:771-782, (1972).
5. Harley, N.H., B.S. Cohen, and E.S. Robbins. "The Variability in Radon Decay Product Bronchial Dose," *Environ. Int.* **22**:S959-964, (1996).
6. Porstendorfer , J., "Physical Parameters and Dose Factors of the Radon and Thoron Decay Products," *Radiat. Prot. Dosim.* **94**:365-373 (2001).
7. Marsh, J.W., and A. Birchall, "Sensitivity Analysis of the Weighted Equivalent Lung Dose Per Unit Exposure from Radon Progeny," *Radiat. Prot. Dosim.* **87**:167-178 (2000).
8. Marsh, J.W., A. Birchall, G. Butterweck, M.-D. Dorrian, C. Huet, X. Ortega, A. Reineking, G. Tymen, Ch. Schuler, A. Vargas, G. Vezzu, and J. Wendt, "Uncertainty Analysis of the Weighted Equivalent Lung Dose Per Unit Exposure to Radon Progeny," *Radiat. Prot. Dosim.* **102**:229-248 (2002).
9. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionizing Radiation.* UNSCEAR 2000 Report to the General Assembly, New York; 2000.
10. National Research Council. Biological Effects of Ionizing Radiation (BEIR) VI Report, *Health Effects of Exposure to Radon,* Washington DC: National Academy Press; 1999.
11. Mohamed, A., "Influence of Radioactive Aerosol and Biological Parameters of Inhaled Radon Progeny on Human Lung Dose," *Radiat. Prot. Dosim.* **113**:115-122 (2005).
12. Hofmann, W., M.G. Menache, D.J. Crawford-Brown, R.S. Caswell, and L.R. Karam, "Modeling Energy Deposition and Cellular Radiation Effects in Human Bronchial Epithelium by Radon Progeny Alpha Particles," *Health Phys.* **78**:377-393 (2000).
13. Brenner, D.J., R.C. Miller, Y. Huang, and E.J. Hall, "The Biological Effectiveness of Radon-Progeny Alpha Particles III Quality Factors," *Radiat. Res.* **142**;61-69 (1995).
14. Hofmann, W., H. Fakir, I. Aubineau, and P. Pihet, "Interaction of Alpha Particles at the Cellular Level – Implications for the Radiation Weighting Factor," *Radiat. Prot. Dosim.* **112**;493-500 (2004).

15. Stabher, J. W., "Dosimetric and Epidemiological Approaches to Assessing Radon Doses – Can the Differences be Reconciled?" *Radiat. Prot. Dosim.* **112**:487-492 (2004).

16. Birchall, A., and J.W. Marsh, "Radon Dosimetry and Its Implication for Risk," *ICS* **1276**:81-84 (2005).

17. Harley, N.H., P. Chittaporn, R. Medora, R. Merrill and W. Wanisooksumbut, "Thoron versus Radon: Measurement and Dosimetry," *ICS* 1276:72-75 (2005).

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