ICRP ref 4836-9756-8598
January 26, 2018

Summary of ICRP Recommendations on Radon

Radon is a natural part of the air we breathe. Radon levels outdoors are generally very low, but can be considerably higher inside buildings, and especially underground such as in caves and mines. The International Commission on Radiological Protection (ICRP) makes recommendations for protection of people against exposure to radon at home and at work.

ICRP's first recommendations specifically on this subject were published in 1977, focusing on protection in uranium and other mines (ICRP *Publication 24* Radiation Protection in Uranium and Other Mines). These recommendations were updated and expanded to include protection at home in 1993 (ICRP *Publication 65* Protection Against Radon-222 at Home and at Work).

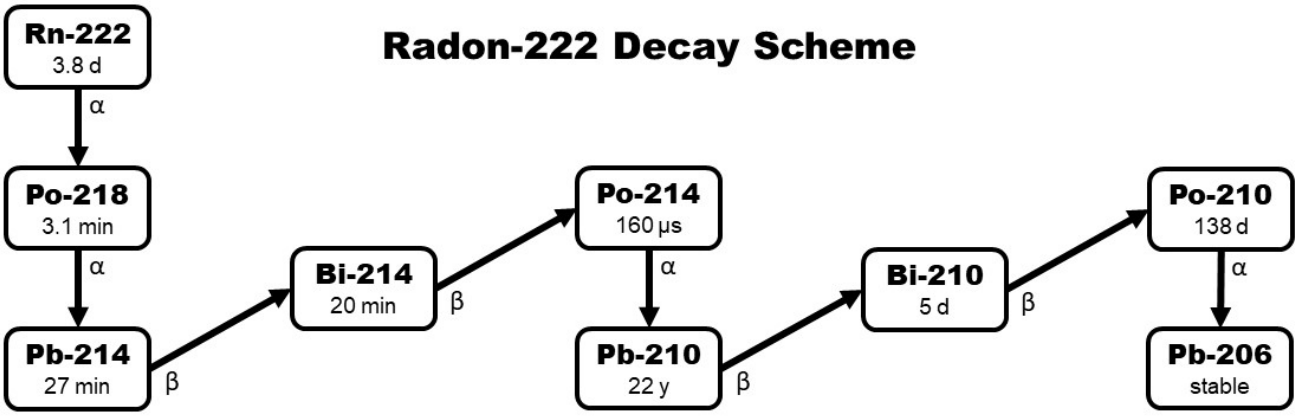
In 2010, ICRP published a comprehensive review of the science relating lung cancer to radon exposure (ICRP *Publication 115* Lung Cancer Risk from Radon and Progeny & Statement on Radon). Based on the latest scientific evidence, the recommended maximum reference level, a key figure driving public health policy for indoor radon, was reduced to 300 Bq m^{-3}.

In 2014, recommendations on radon were updated (ICRP *Publication 126* Radiological Protection against Radon Exposure) considering the key scientific findings of ICRP *Publication 115*, and the most recent ICRP principles and methodology (ICRP *Publication 103* The 2007 Recommendations of the International Commission on Radiological Protection). These recommendations confirmed that authorities should set a national reference level as low as reasonably achievable in the range of 100 – 300 Bq m^{-3}. Radon concentrations are compared to the reference level to help control radon in homes and most workplaces.

Sometimes, it is necessary to calculate the effective dose due to radon exposure in workplaces. A series of ICRP reports provides dose coefficients to aid in these types of calculations. New dose coefficients for radon have just been published (ICRP *Publication 137* Occupational Intakes of Radionuclides: Part 3). Using standard assumptions, exposure to radon at the upper end of the recommended range for a national reference level of 300 Bq m^{-3} corresponds to an annual effective dose of 4 mSv at work and 14 mSv at home.

Background

Uranium (uranium-238) is naturally present in all rocks and soils. Radon (radon-222) is part of the uranium decay chain and, being a noble gas, can escape the matrix of the rock and soil in which it is formed. As a gas or dissolved in water, it moves through fractures in rock or pore spaces in soil. Radon decays with a half-life of 3.8 days to a series of radionuclides referred to as radon progeny. Most of the dose from exposure to radon is delivered by the alpha emissions of the short-lived progeny.



When radon reaches open air, it disperses quickly. Typically, the average radon concentration in outdoor air is around 10 Bq m^{-3}, although it is as low as 1 Bq m^{-3} in some places and higher than 100 Bq m^{-3} in others (UNEP, 2016).

However, when radon enters an enclosed space, such as a cave, mine, or building, it can't disperse as easily, so is usually found at higher levels than outdoors. The worldwide average indoor radon concentration is about 50 Bq m^{-3}, although there is a wide variation. In some countries national averages are less than 10 Bq m^{-3} or over 100 m^{-3}. In rare cases radon levels in individual homes can be as high as 10,000 Bq m^{-3} (UNEP, 2016).

Mining has been taking place for thousands of years, with the Egyptians mining gold as long as 4,000 years ago. As described in ICRP *Publication 65*, the existence of a high mortality rate among miners in central Europe was recognised before 1600. In the late 19th century the main cause was identified as a disease of the lung later recognised as cancer. It was first suggested in 1924 that this cancer could be attributed to radon exposure. Further information on 'The History of the Radon Problem in Mines and Homes' can be found in a paper of this title by W Jacobi in ICRP *Publication 65*.

Units

The concentration of radon-222 in air is often measured in becquerels per cubic metre (Bq m^{-3}).

Working Level (WL) is also a measure of concentration in air, but here it's the concentration of radon progeny. This better reflects exposures especially in complex environments like underground mines.

Working Level Month (WLM) is a measure of accumulated exposure, calculated by multiplying the WL by the number of working hours (170h) in a month.

A modern unit similar to WL is millijoule per cubic metre (mJ m^{-3}). Both reflect the concentration of radon progeny in air. Accumulated exposure is calculated by multiplying the concentration in mJ m^{-3} by hours of exposure, resulting in units of mJ h m^{-3}.

ICRP *Publication 24* Radiation Protection in Uranium and Other Mines

In 1970, ICRP established a Task group to investigate radiation exposures in uranium mines and issued ICRP *Publication 24* in 1977. Although the focus was on uranium mining, it was noted that radium-226 is part of the uranium decay chain which is found almost everywhere, and hence not limited to uranium mines. Noting the rapid development of radon epidemiology, an annual limit on the exposure to radon progeny of 12 WLM was recommended.

ICRP *Publication 65* Protection Against Radon-222 at Home and at Work

In 1993, ICRP *Publication 65* established the use of action levels in terms of radon concentrations. For protection against radon in dwellings, selection of an action level in the range of 200 – 600 Bq m^{-3} was recommended, corresponding to an annual effective dose of about 3 – 10 mSv, assuming 7000 h per year spent at home.

Protection in workplaces was considered separately from protection in dwellings, and protection against radon was considered separately from protection against other exposures to radiation. Action levels were recommended in the range of 500 – 1500 Bq m^{-3}, using the same annual effective dose basis of 3 – 10 mSv as used for dwellings, but with a different dose conversion factor for workers, and an annual exposure time of 2000 h at work.

Furthermore, for occupational exposures, there was a reminder that a limit on effective dose also applied: 20 mSv per year averaged over five years, and 50 mSv in any one year. This corresponded to 4 WLM per year averaged over five years, and 10 WLM in any one year.

ICRP *Publication 115* Lung Cancer Risk from Radon and Progeny & Statement on Radon

In 2010, ICRP *Publication 115* updated estimates of the risk of lung cancer associated with exposure to radon and its progeny. This was based on epidemiological results from cohorts of miners exposed to low-levels of radon, and for the first time, from studies of lung cancer risk associated to indoor radon.

The cumulative risk of lung cancer up to 75 years of age was estimated for lifelong non-smokers in a large European study as 0.4%, 0.5%, and 0.7% for radon concentrations of 0, 100, and 400 Bq m^{-3}, respectively. The risk to smokers was about 25 times higher; the same figures for lifelong smokers were 10%, 12%, and 16%. Cigarette smoking is the most important cause of lung cancer. (Darby et al., 2005, 2006)

An important conclusion of Publication 115 was that the detriment-adjusted nominal risk coefficient for lung cancer in a mixed adult population of non-smokers and smokers should be increased to 3×10^{-10} per Bq h m^{-3} (1.4×10^{-4} per mJ h m^{-3}), close to twice the figure recommended in ICRP *Publication 65*.

Taking account of these new findings, the upper value for radon reference levels was lowered from 600 Bq m^{-3} to 300 Bq m^{-3}.

ICRP *Publication 126* Radiological Protection against Radon Exposure

The most recent set of fundamental recommendations on radiological protection were published in 2007 as ICRP *Publication 103*. In 2014, ICRP *Publication 126* provided updated recommendations on protection against radon exposure using the 2007 principles and methodology, and reflecting the new scientific evaluation of radon risk from ICRP *Publication 115*.

An integrated approach for protection against radon exposure in all buildings is recommended. Whatever the purpose of the building, and regardless of whether the occupants are at work or not, the same reference level applies and protection should be optimised in all circumstances.

The upper benchmark of around 10 mSv per year, from ICRP *Publication 65*, continues to be recommended. Based on this, authorities should set a national reference level as low as reasonably achievable in the range of 100 – 300 Bq m^{-3}. Radon levels are compared to the reference level to help prioritise efforts to control levels in homes and most workplaces.

ICRP *Publication 126* recommends a specific graded approach for workplaces for applying occupational protection requirements. Where workers' exposure to radon is not considered as occupational (e.g. office buildings), the first step is to reduce the concentration of radon to a level that is as low as reasonably achievable below the same derived reference level as set for dwellings. The corresponding annual dose is usually lower than that in dwellings, because the time spent in workplaces is usually less than the time spent at home. If difficulties are met in the first step, a more realistic approach is recommended as a second step, consisting of optimising protection using the actual parameters of the exposure situation, such as occupancy, together with a reference level of the order of 10 mSv annual effective dose. If, despite all reasonable efforts to reduce radon exposure in workplaces, the exposure persists above the reference level expressed in effective dose, the workers should be considered as occupationally exposed. In such cases, relevant requirements for occupational exposure should be applied.

For some types of workplaces, national authorities may decide that exposure of workers to radon should be considered occupational regardless of whether concentrations are above or below a reference level, because the workers are inevitably and substantially exposed to radon, and their exposure to radon is more intimately or obviously related to their work activities. Authorities should consider establishing a national list of such workplaces or work activities (e.g. mines and other underground workplaces, thermal spas).

Regardless of whether workers are considered occupationally exposed, effective doses should be kept below the upper value of the range for existing exposure situations (20 mSv per year).

ICRP *Publication 137* Occupational Intakes of Radionuclides: Part 3

Although protection against radon is primarily based on measurement and control of levels of exposure, dose estimates are required in certain situations for workers. Dose estimates are of value for protection purposes when workers are exposed to more than one source of radiation as is the case for underground miners. In addition, dose estimates are required for comparing sources of public exposure.

Using the nominal risk coefficient from ICRP *Publication 115* (1.4×10^{-4} per mJ h m^{-3}), and ICRP *Publication 103* detriment values, a dose conversion convention value of 3.3 mSv per mJ h m^{-3} for adults is obtained. This is fundamentally based on epidemiological evidence.

Using dosimetric models, the dose coefficients are 3.3 mSv per mJ h m^{-3} for workers in mines and 4 mSv per mJ h m^{-3} for sedentary officer workers. Using the same methodology, the dose coefficient for exposure in homes is 3.7 mSv per mJ h m^{-3}.

For tourist caves, and indoor workplaces where workers are assumed to spend two-thirds of time in exercise, the dose coefficients are 6.7 and 5.7 mSv per mJ h m^{-3}, respectively.

There is remarkable consistency between coefficients obtained by dosimetric calculations and conversion coefficients based on epidemiological comparisons. Taking account of both methods and their associated uncertainties, the following rounded dose coefficients, presented in ICRP *Publication 137*, are recommended.

For buildings and underground mines, in most circumstances the recommended dose coefficient is 3 mSv per mJ h m^{-3} (approximately 10 mSv per WLM).

The corresponding dose coefficient expressed in terms of radon-222 gas exposure depends on the equilibrium factor, F, between radon gas and its progeny. Using the standard assumption of F = 0.4 for most indoor situations, this dose coefficient corresponds to 6.7×10^{-6} mSv per Bq h m^{-3}.

While *ICRP Publication 137* does not specifically address public exposures, it is intended that this same dose coefficient applies to exposures in homes. Dose coefficients for radionuclide intakes by members of the public will be published in due course and will include radon.

Using this dose coefficient, exposure to radon at the upper value of the national reference level of 300 Bq m^{-3} recommended in ICRP *Publication 126* corresponds to an annual effective dose of 4 mSv at work and 14 mSv at home.

***To calculate effective dose**, multiply the appropriate coefficient by the radon (or radon progeny) concentration and the time exposed. For example:*
6.7×10^{-6} mSv per Bq h m^{-3} × 300 Bq m^{-3} × 2000 h = 4 mSv

For the specific situations of indoor work involving substantial physical activity, and exposures in tourist caves, the recommended dose coefficient is 6 mSv per mJ h m^{-3} (approximately 20 mSv per WLM).

In cases where aerosol characteristics are significantly different from typical conditions, where sufficient, reliable aerosol data are available, and estimated doses warrant more detailed consideration, it is possible to calculate site-specific dose coefficients using data provided in ICRP *Publication 137*.

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