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Radon Survey of Los Alamos National Laboratory Buildings and Los Alamos County Residential Buildings

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Los Alamos
NATIONAL LABORATORY

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1 Introduction

Radon is a naturally occurring, odorless, colorless radioactive gas arising from the decay of the radium that accompanies natural uranium and thorium. The refined uranium and thorium found at LANL does not contain radium and so does not emit radon. Uranium and thorium are widely distributed in nature and are found in trace quantities in all rocks, sand, and soil. Building materials such as natural stone, adobe, brick, and concrete may also contain trace quantities of uranium and thorium. Radon gas enters the surrounding air by emanating from materials containing radium. Exposure to the decay progeny of radon can result in significant radiation doses, especially to radiosensitive portions of the lung where this exposure has been implicated as a potential contributor to lung cancer (NRC 1999; NCRP 1988, 1989; Pawel and Puskin 2004). Radon concentrations, the associated radiation doses to the lung, and corresponding cancer risk to residents have been extensively studied and reported (NCRP 1988; NRC 1988, 1999; UNSCEAR 2000), but much fewer studies have included measurements in workplaces other than mines (Levine and Strom 1987; Annanmäki et al. 1996; IAEA 2003). While the epidemiology has been argued, it is universally accepted that radiation doses from radon progeny are generally the highest contributor to a person's overall dose from background radiation sources (NRC 1999; UNSCEAR 2000).

The concentrations of radon and its progeny inside structures have been shown to depend on numerous factors (NCRP 1989). Some of the key factors include the amount of uranium and thorium in the surrounding soil and building materials, atmospheric conditions, construction type (i.e., slab, basement, crawl spaces, etc.), porosity of the soil and building, and the ventilation rates. The large variability in the factors listed above contributes to a large range in radon concentrations in homes that spans several orders-of-magnitude, and numerous homes have radon concentrations that are sufficiently high to be a public health concern. In the United States, the U.S. Environmental Protection Agency (U.S. EPA) has put forth guidance to assist homeowners in decisions to mitigate the risks associated with radon gas in the homes (U.S. EPA 2007). While residential radon levels and associated risks have been thoroughly studied and are regulated through a single government agency, less attention has been paid to the measurement and regulatory control of radon in workplaces other than mines (Chen 2005; Lewis 2008†). In the United States, such exposure is controlled through the Occupational Safety and Health Agency (OSHA) through regulation 29 CFR 1910.1096 through references to U.S. Nuclear Regulatory Commission (U.S. NRC) regulation 10 CFR 20 (OSHA 1970; U.S. NRC 1999), which combined establishes an acceptable radon concentration threshold in the workplace at one third of a Working Level (WL), which is about 1,200 Bq m-3. This limit is similar to that proposed in the international documents (IAEA 2003).

2 Purpose and Scope

The workforce in the United States is continuously monitored and reported by the Department of Labor but was about 146 million workers in November of 2008 (U.S. DOL 2009). This amounts to over 200 billion person-hours per year that people spend at work, of which a large fraction of time is spent in office-like spaces. Clearly, the large amount of time people spend at work justifies assessment of indoor air quality, for radiation protection or otherwise. However, radon concentrations in workspaces other than mines are rarely made except for schools (U.S. EPA 1993).

A radon survey of office spaces was of interest to LANL for several reasons. First, exposure to natural radon in LANL office spaces has been considered to be outside the regulatory reach of the federal regulations and the U.S. Department of Energy (U.S. DOE) orders, and thus has not been studied as extensively as occupational exposure to other radionuclides and is not subject to the same rigorous radiological controls. Second, a general survey of radon concentrations in LANL workspaces was of interest to management to ensure safe environments for workers and is in keeping with the intent of OSHA requirements. Though radon in LANL offices would not be derived from enhanced radioactive sources, radon exposure in general office spaces has the potential to significantly impact worker risk.

The purpose of the 2009 radon survey (Whicker 2009) was to measure and document indoor radon levels across a broad spectrum of office-type workspaces and neighboring homes. The measured concentrations were compared against those measured across the United States and across the world. The results were also compared against a wide variety of radiation protection thresholds such as (1) the action levels of 148 Bq m^{-3} (the U.S. EPA action level for public housing), (2) ≈1,200 Bq m^{-3} OSHA threshold for office spaces, (3) effective dose threshold of 1 mSv threshold for defining a radiological worker, (4) 50 mSv occupational effective dose limit, and (5) 0.1 mSv and 1 mSv limits for public exposures from the air pathway and all pathways, respectively.

3 Methods

3.1 Selection of buildings

The buildings selected to be included in the survey are office spaces used by LANL employees. Most of the spaces are owned by LANL, but there are a small number of offices in buildings that are leased from other property owners. In addition, numerous measurements were made in residences, mostly within the boundaries of Los Alamos County. This provided the opportunity to compare radon concentrations at office spaces with residential homes located within the same county.

The criteria for selecting a LANL office location to be monitored included: (1) being an occupied office space or common area, (2) not in a radiologically controlled area, and (3) having easy access to retrieve the monitor. Several office buildings were multi-story and detectors were placed in these on several floors, including basements, to look for effects of radon levels due to floor levels. Offices monitored were mostly on LANL property, but several off-site locations (in the neighboring towns of Los Alamos and White Rock) that are leased by LANL were also included. Residences were selected on a volunteer basis. In all, 65 detectors were placed in LANL offices (58 on LANL property and 7 leased in the surrounding towns) and 47 were placed in residential houses.

3.2 Alpha-track measurement techniques

Measurements of radon were primarily made using alpha-track (AT) detectors using U.S. EPA protocol (U.S. EPA 1992). These are commercially available, inexpensive, and widely accepted as the best method to collect long-term (i.e., >90 days) time-averaged radon concentrations (Nero et al. 1986; Yeager et al. 1994). The AT detectors were deployed and the integration time for the measurements was approximately 90 days, as prescribed by the commercial supplier.

3.3 Analysis of results

Averages, medians, and ranges were calculated categorized by type of building (office or residential), with a further categorization for offices LANL owned or leased. A final categorization was made for office spaces based on floor level. Statistical comparisons were made between residential and office buildings and across. The residential and office concentrations were also compared to regional and national radon concentrations, and, finally, the concentrations were compared against national and international radiation protection regulations.

Many of the residents in Los Alamos County not only reside but also work in the same county. Therefore, it was worthwhile to calculate potential doses received by office workers while at work and then compare that value to potential doses received while at home. In addition, potential doses were calculated for homebound individuals for whom it is assumed spend 85% of their time at home. For these calculations several assumptions were made. Workers are at the offices 8 h per day, 5 d per week, and 50 week per year. Assuming the workers are in the office the whole time while at work, they would be in the office about 2,000 work hours per year. The time workers spent in the home is 0.85 (8,760 h y^{-1} – 2,000 h y^{-1}) = 5,746 h y^{-1}, if 85% of a person's time outside work is spent in the home. We assumed the homebound individual spends 0.85 x 8,760 = 7,446 h y^{-1} at home. The dose conversion factor of 9 nSv h^{-1} (Bq m^{-3})$^{-1}$ published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was used (UNSCEAR 2000; Chen 2005; Vanmarcke 2008) to calculate effective doses. An equilibrium value of 0.4 was assumed and a seasonal correction factor of 1.5 was also used (based on residences; Denman et al. 2007), though the 1.5 correction factor would probably be conservative for office spaces due to year-round ventilation. The general equation used to calculate effective doses is shown in equation (1).

$$H_E = DCF \times EF \times C_{Rn} \times S_W \times T_E \quad (1)$$

Where:

H_E = the annual effective dose in Sv

DCF = dose conversion factor for radon progeny [9 nSv h^{-1} (Bq m^{-3})$^{-1}$]

C_{Rn} = average of measured concentrations in Bq m^{-3}

EF = equilibrium factor (0.4)

S_w = seasonal correction factor of 1.5 (for a start time in July)

T_E = time of exposure, 2,000 h for occupational exposure alone, 5,746 h for office worker while at home, and 7,446 h for 85% residential exposure

4 Results

Table 1 provides the summary statistics for the radon concentration measurements. A comparison of radon concentrations between office and residential spaces is shown in Fig. 1. The distributions of the radon concentrations for the office spaces were skewed with a median value of 18.5 Bq m^{-3} and with minimum and maximum concentrations of 11.1 and 107.3 Bq m^{-3}, respectively. The office measurements were internally consistent, with the average range for detectors placed at the same locations of 2.6 Bq m^{-3}. In contrast, the average concentrations for residential structures were about three times those measured for the office building. The median radon concentration for residences was 55.5 Bq m^{-3}, with minimum and maximum concentrations being 22.2 and 233.1 Bq m^{-3}, respectively. The data in the residences were also self-consistent with perfect correlation in measured radon concentrations among collocated detectors.

Table 1. Summary statistics for radon concentrations in the office spaces and homes are provided at the top of the table, and the associated effective dose rates are provided at the bottom of the table.

Radon concentrations (Bq m^{-3})

	Mean	Median	Maximum
Location			
Office Space	24.3	18.5	107.3
Home	75.0	55.5	233.1

Effective dose rates (mSv y^{-1})

	Exposure Time (h)	Mean	Median	Maximum
Exposure scenario				
Office work only	2,000	0.3	0.2	1.1
Office worker while at home	5,746	2.3	1.7	7.2
Homebound individual	7,446	3.0	2.2	9.3

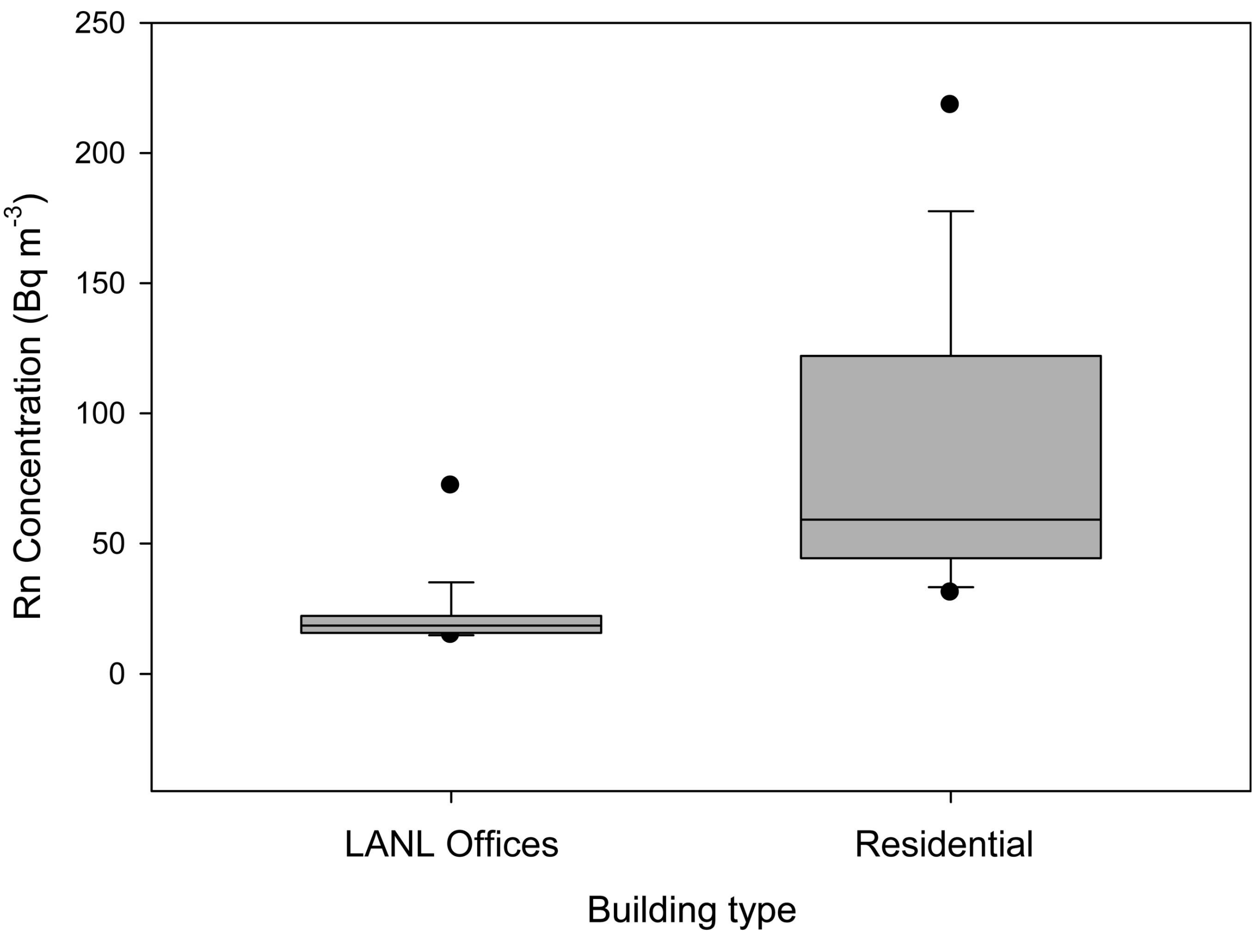

Figure 1. A comparison of the distributions of radon concentrations between LANL office spaces and residential homes in Los Alamos County. The boxes represent 25–75% of the values and whiskers represent the range of 95% of the values. Outliers are represented by the dots outside the range of 95%. Median concentrations are represented by the line inside the boxes.

Data for radon concentrations in office spaces were further subdivided into two categories, LANL-owned or LANL-leased buildings, and both were compared to the concentrations measured in residences and shown in Fig. 2. The distributions appear shifted because several of the highest radon concentrations were measured in a leased building (107.3 Bq m-3). The higher measurement in the leased buildings elevated the average concentration to 40.7 Bq m-3 as compared to the 22.2 Bq m-3 measured in the LANL-owned offices, but the median concentration of the LANL-operated buildings was equal to that measured for the leased buildings (18.5 Bq m-3). A non-parametric Mann Whitney rank sum test was not statistically significant at the 0.05 probability level between the LANL-owned and leased buildings, and both these were significantly lower than the radon concentrations found in the residential homes.

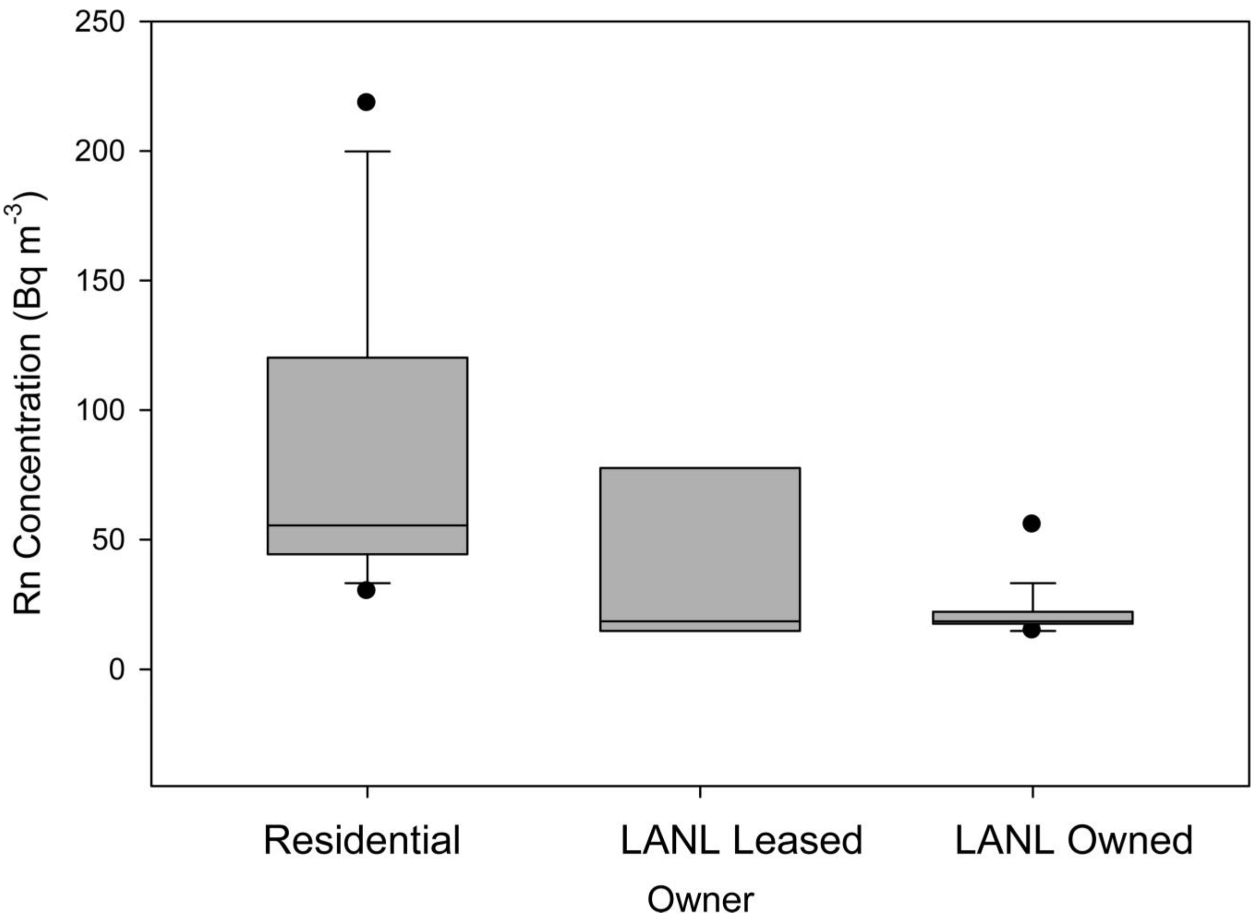

Figure 2. Distributions of radon concentrations by building type and owner. The boxes represent 25–75% of the values and whiskers represent the range of 95% of the values. Outliers are represented by the dots outside the range of 95%. Median concentrations are represented by the line inside the boxes. Not enough measurements were made for the LANL-leased buildings to determine whiskers.

Fig. 3 shows radon concentrations in office spaces categorized by floor, including measurements in basements. No statistical differences were found in radon concentrations across floors. The concentrations for the basement floors ranged from 18.5 to 33.3 Bq m-3, with a median of 24.1 Bq m-3. For the first floor, the median concentration was 18.5 Bq m-3 and ranged from 11.1 to 107.3 Bq m-3. The median concentration on the second floor was 18.5 Bq m-3 and ranged from 14.8 to 29.6 Bq m-3, and, finally, the concentrations on the third floor ranged from 14.8 to 18.5 Bq m-3, with a median concentration of 14.8 Bq m-3.

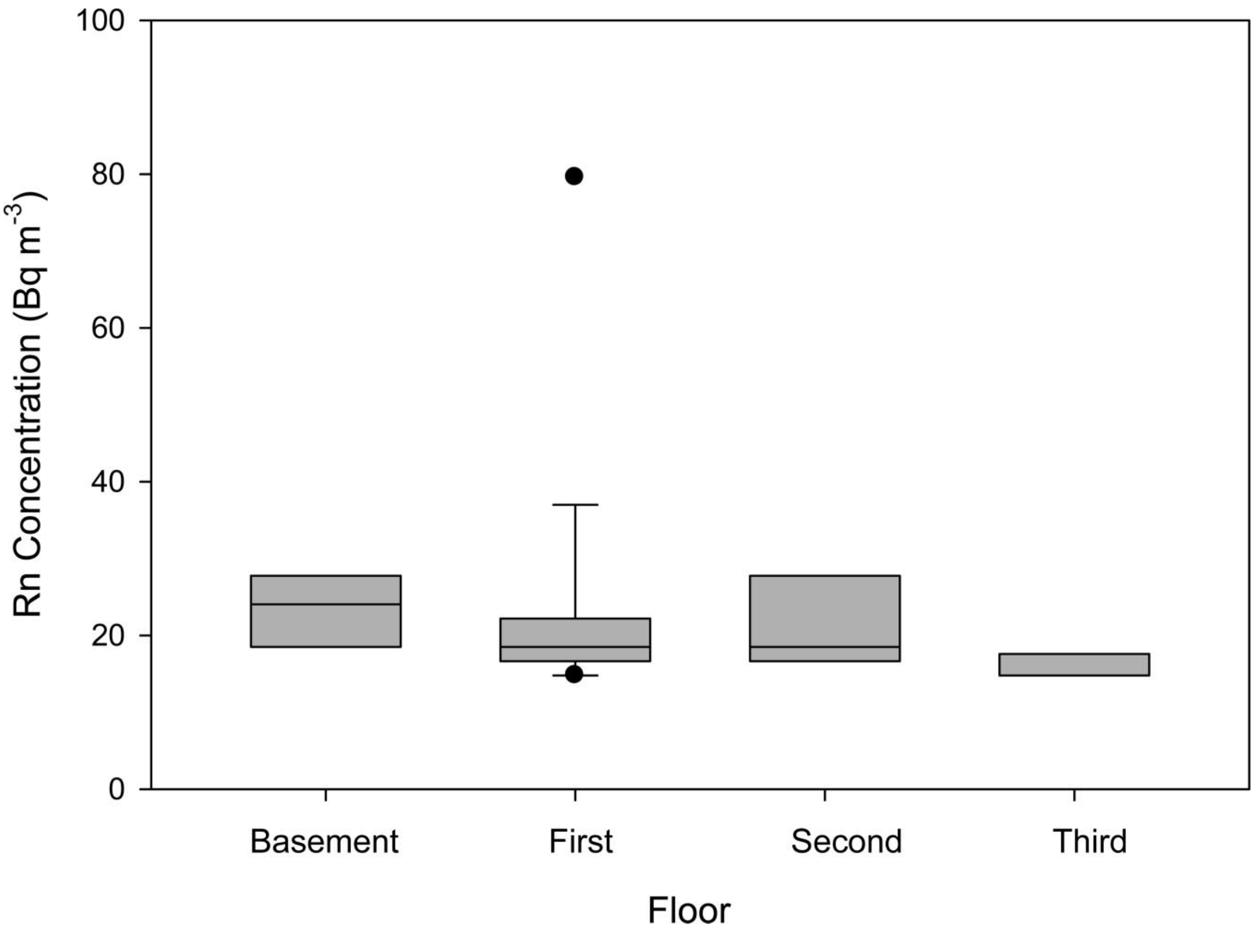

Figure 3. Distributions of radon concentrations in office building categorized by floor. The boxes represent 25–75% of the values and whiskers represent the range of 95% of the values. Outliers are represented by the dots outside the range of 95%. Median concentrations are represented by the line inside the boxes. Not enough measurements were made for the basement, second and third floors to determine whiskers.

The concentrations in the Los Alamos residences appear to be generally in the range and near central values for radon concentrations in buildings across the United States and neighboring countries (NCRP 1984; Cohen and Shah 1991; Marcinowski et al. 1994) and are slightly, but not statistically significantly, above the world-wide geometric mean of 44.4 Bq m-3 (UNSCEAR 2000). There were only a few homes in the survey that exceeded the U.S. EPA recommended threshold of 148 Bq m-3.

4.1 Potential dose implications

The calculated effective dose rates (whole body), based on equation (1), are provided in Table 1. The effective dose rate was 0.3 mSv y-1 for the average office worker while at work and 1.1 mSv y-1 for the maximally exposed office worker. In contrast, the average effective dose rate for these workers while at home would be about 3 mSv y-1 and 9.3 mSv y-1 for the maximally exposed individual. Therefore, the average office worker who lives and works in Los Alamos County will receive about nine times on average more radiation dose from radon progeny at home than in the office with a total effective dose rate of about 3.3 mSv y-1. The effective dose rate for the average homebound individual, or non-office worker, who spends 85% of the time in their home would be about 3 mSv y-1 with the highest dose rate of 9.3 mSv y-1.

This higher effective dose received in homes is predominantly due to the higher concentrations in homes and because people spend relatively more time in their home. The average radiation dose of the office workers from exposure to radon progeny of about 0.3 mSv y-1 and maximum dose of 1.1 mSv y-1 can be compared to those regulated by the U.S. DOE as "radiological workers" (U.S. DOE 2007). A radiological worker, whose job involves working with radioactive materials or working around radiation producing devices, is defined as a worker who has the likely potential of exceeding 1 mSv per year. This value is within the range of the estimated effective doses for workers in LANL offices (Fig. 4). The 0.3 mSv y-1 average dose and the maximum office worker dose of 1.1 mSv y-1 is much lower than the occupational limits for radiological workers of 50 mSv y-1 and the recommended 5-year average of 20 mSv y-1 (ICRP 1990) but is closer to the average occupational dose, not including radon exposure, that radiation workers across LANL receive, which is generally much less than 5 mSv y-1.

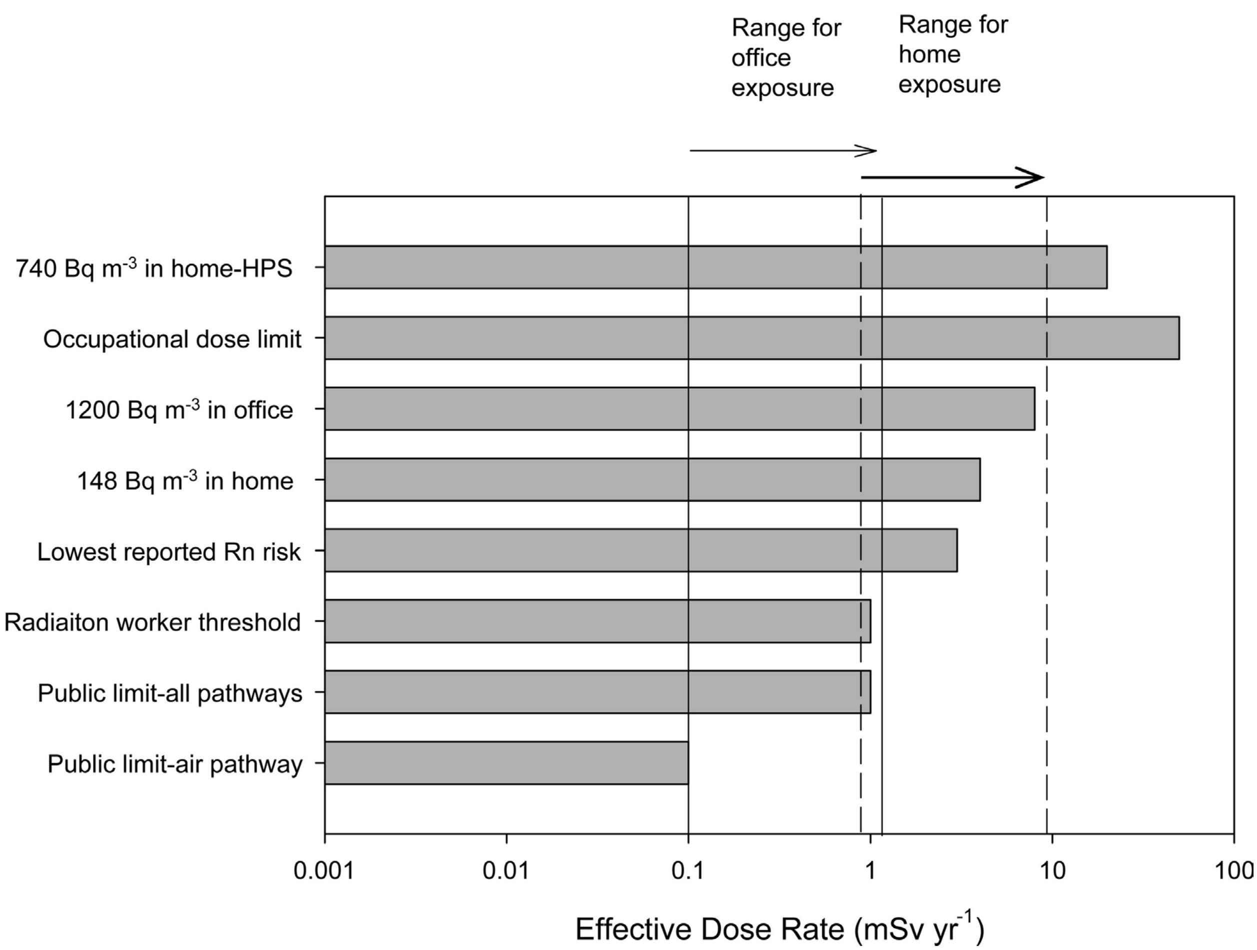

Figure 4. Annual effective dose rates for different radon concentrations and exposure scenarios contrasted against various radiation protection thresholds.

5 Discussion and Conclusion

Radon concentrations were measured in office spaces across LANL and in residences in the same county. None of the office spaces was above the U.S. EPA residence threshold concentration of 148 Bq m^{-3}. These lower concentrations are likely due to relatively high ventilation rates found in the office buildings. While ventilation engineers at LANL do not know the precise air exchange rates of the many buildings surveyed, typical offices have >2 room air changes per hour (ACH) to improve indoor air quality for everything from body odor to CO_2 levels and temperature control (Awbi 1991). In contrast, the mean air exchange rate in homes is about 0.6 ACH (U.S. EPA 1997). Increased ventilation directly lowers radon concentrations in buildings by bringing outdoor air with low radon concentrations inside and flushing out the higher, concentrated air out of the building (NCRP 1984; Awbi 1991).

The potential effective dose rate for the average office worker while at work was about 0.3 mSv y^{-1} and ranged up to 1.1 mSv y^{-1}. These are in range of the 1 mSv y^{-1} effective dose rate that DOE defines as a threshold for classifying a person as being a radiological worker, though the DOE has explicitly excluded radon exposure from regulatory control unless it is a product of anthropogenically enhanced uranium, which these office exposures are not.

The higher ventilation rates in office buildings relative to the typical home were sufficient to keep radon concentrations minimized in offices and additional radon measurements are probably not warranted unless the building has a compromised ventilation system or there are extenuating circumstances. The data also suggest that offices in basements do not have higher concentrations than office spaces on upper floors, assuming the ventilation in the building is functioning well.

5.1 Conclusion

The radon measurements made in the 2009 timeframe would be representative of levels that could be expected currently. The primary driver for this decision is the fact that radon at LANL is not product of anthropogenically enhanced uranium and naturally occurring uranium concentrations in regional building material is relatively stable. The measurements taken at LANL were even less than the average Los Alamos County residences (55.5 Bq m-3) and what would be expected to be observed in the average U.S. home (148 Bq m-3).

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