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Equilibrium factor of radon and progenies in Norwegian homes

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Abstract

Several hundred deaths each year are caused by radon-induced lung cancer in Norway. Lung cancers are mainly caused by the inhalation of radon and alpha radiation from the airborne short-lived radon or progenies but not by the radon gas itself. Since radon progenies measurements are limited, a value known as the equilibrium factor can estimate radon progeny's contribution to lung dose. UNSCEAR suggests a worldwide value of 0.4 for the equilibrium factor. Stranden measured an equilibrium factor mean of 0.5 in Norway in 1979. A new in-situ instrument from SARAD, EQF 3220, was used to determine indoor radon concentration, equilibrium factor, and unattached fraction. Fourteen dwellings in Bærum, Oslo, Ski, and Ås were used for radon measurements from October 2020 to April 2021. Still, only results of 12 homes in Oslo, Ski, and Ås were used. Indoor radon measurements in the 12 homes were performed using a 24hours-cycle. The excluded dwellings had 1hour, 3hours, 6hours, and 12hours-cycles of the sampling period. Low sampling cycles result in high error and uncertainty. As a brand-new instrument, many measures were carried out as a test before the actual measurements took place- the study's first phase. The measurements started with an instrument that belongs to DSA, and months later, NMBU acquired a new instrument like the one from DSA.

The instruments were used in parallel in the same room. The study used a paired sample t-test to compare the results of the devices. It was observed that the results of both instruments in parallel were not statistically different, and therefore, the instruments were used separately in the second phase of the study. Most of the dwellings were selected because they were close to the DSA and NMBU. Most owners are DSA or NMBU employees or students willing to make their homes available for measurements. Within 12 houses, of which 2 of Oslo, 1 of Ski, and 9 of Ås, radon means varied from 24 Bq/m^3 to 178 Bq/m^3. The overall regional radon mean value is 145 Bq/m3. The equilibrium factor means varied from 0.21 to 0.26 with an overall equilibrium factor mean value of 0.25. The equilibrium factor mean is a lot lower than the value found in the previous measurements by Stranden in 1979 and the international value suggested by The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The unattached fraction means varied from 0.3 to 0.53. The unattached regional fraction mean value is 0.5. A positive correlation between radon concentration was observed, and a negative one between equilibrium factor and unattached fraction was also observed. The study found a low mean value of the equilibrium factor in the indoor air of the measured dwellings.

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1-Introduction

Radon is the second largest cause of lung cancer after cigarette smoking (WHO 2009) and the first cause of lung cancer among non-smokers (USEPA 2012). Norwegian dwellings have some of the highest radon concentrations in the world (DSA 2000). The Norwegian radon concentration mean is 88 Bq/m^3 and, it is higher than the mean of many Western countries and worldwide. For instance, the average for the 29 OECD (Organisation for Economic Co-operation and Development) countries is 67 Bq/m^3. The world radon mean is less than half the Norwegian values and is reported to be 39 Bq/m^3 (WHO 2009). Geological and climatic conditions, type of housing, and building traditions in Norway are the main reasons for the country's higher indoor radon values (Hassfjell 2017). Higher radon concentrations in Norway are found in areas with uranium-rich granites and gneiss such as Østfold, Vestfold, Aust-Agder, and Hordaland (DSA 2021).

As a result of high indoor radon concentration, several hundred deaths each year are caused by radon-induced lung cancer in the country (Watson et al. 2017). Moreover, it was demonstrated in 2015 that radon exposure contributes to 12%, equivalent to about 373 of all lung cancers cases in Norway. This estimation was made with the help of data from 2001 from Darby and Sarah. Smokers and formers smokers are more affected by radon exposure than non-smokers. This difference can be seen as evidence that radon is an extra influence that induces lung cancer (Hassfjell 2017). Overall, smoking and alcohol consumptions are the known lung cancer risk factors associated with indoor radon exposure (Salgado-Espinosa & Tommasino 2015). Radon is also related to other diseases such as oral and pharyngeal cancer (Salgado-Espinhosa and Tommasino, 2015; Taeger 2011), chronic lymphocytic leukemia, myeloid leukemia, and Hodgkin lymphoma, oncogenic problems (WHO, 2009), stomach cancer (National Research Council -U.S. 1999) (EPA n.d.), skin cancer (Wheeler et at., 2012) and oesophageal cancer (Ruano-Ravina et al. 2014) even with lack or absence of evidence (Taeger 2011).

Lung cancers are mainly caused by the inhalation of alpha radiation from the airborne short-lived radon daughters or progenies and not by the radon gas (ICRU 2012). In general, the dose from radon progenies is a hundred times higher than the one from radon inhalation (UNSCEAR 2000). Unlike in this study, radon gas is the one that is commonly measured instead of its progenies because radon measurements are much easier to carry out, require less expensive equipment, and are appropriate for long-term sampling or measurements (ICRU 2012).

Since radon progenies measurements are limited, a value called equilibrium factor, F, can be used to estimate the contribution of radon progenies to lung dose. Moreover, it is not possible to use measured radon activity concentrations alone to obtain information on unattached fractions and size distributions of radon progeny (Stranden, Berteig et al. 1979). Equivalent equilibrium concentration (EEC) is the activity concentration of radon gas when it is in equilibrium with its short-lived daughter, which can have the same potential alpha concentration (PAEC) as the available initially emitted mixture (ICRU 2012). This study uses EEC of radon, EEC of unattached fraction, EEC of the cluster, and radon concentration of slow mode to determine the equilibrium factor and unattached fraction.

The objective of the study is to analyze indoor radon and progeny concentration and equilibrium factor in Bærum, Oslo, Ski, and Ås by using a new in-situ instrument from SARAD, EQF 3230. The study is also essential for the Norwegian radiation and nuclear safety authority (DSA) to gain experience with the newly purchased device and develop knowledge of the measurement method for future studies. The results of the measurements will be to fill a gap of available DSA data and, thus, a better assessment of risks of indoor radon exposure in the selected area. This research could be considered a pilot study, in fact, this is the second study of equilibrium factor made in Norway. Stranden and his collaborators in 1979 carried out the first study regarding equilibrium factor in indoor air. The following research question was formulated:

- Is the equilibrium factor value of the measured area in this study the same as the previous one measured by Stranden et al. in 1979 and the worldwide suggested by The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2008?

The study came out with the following hypothesis:

- The equilibrium factor in the study area is the same as the previous one measured in Norway in 1979 by Stranden and the worldwide suggested by UNCSEAR in 2008.

1.1.Theory

1.1.2. Radon

There are 40 different radon isotopes, but ^{222}Rn, ^{220}Rn, and ^{219}Rn are common and naturally abundant. The Isotopes are daughters of radium isotopes ^{226}Ra, ^{224}Ra, and ^{223}Ra and named radon, thoron, and actinon. The names were attributed to their origin from three natural radioactive decay series of primordial radionuclides 238U, 232Th, and 235U, respectively. ^{222}Rn is the most studied one because of its slightly long half-life of 3.8 days (ICRP 2016) and the one that will be discussed in this study.

^{222}Rn is a colorless, odorless, tasteless, chemically inert, and radioactive gas formed by the naturally occurring uranium-238 decay chain. Uranium-238 can be found in many rocks and minerals (Fig.1). Because of these properties, many people live or work in a place with very high radon levels without knowing about its existence (Taeger 2011; 2017). Physically, radon dissolves well in water, has a boiling point of -61.8 °C and a density of 9.72 g/L (Abu-Khader, Shawaqfeh et al. 2018).

Norway is a country that contains many uranium-rich bedrocks. The uranium-rich bedrocks contributes to very high radon concentrations (DSA 2004). Radon decays forming short and long-lived decay products (ICRU 2012). The short-lived decay products are the ones that will be discussed in this study and are known as progenies. The progenies are isotopes of polonium, lead, bismuth, and thallium. Radon is an alpha-particle emitter. However, its short-lived decay products ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po decay to others products emitting alpha particles, beta particles, and gamma-rays (Taeger 2017), contributing to natural radioactivity of indoor-outdoor air and water (Stacks 2015).

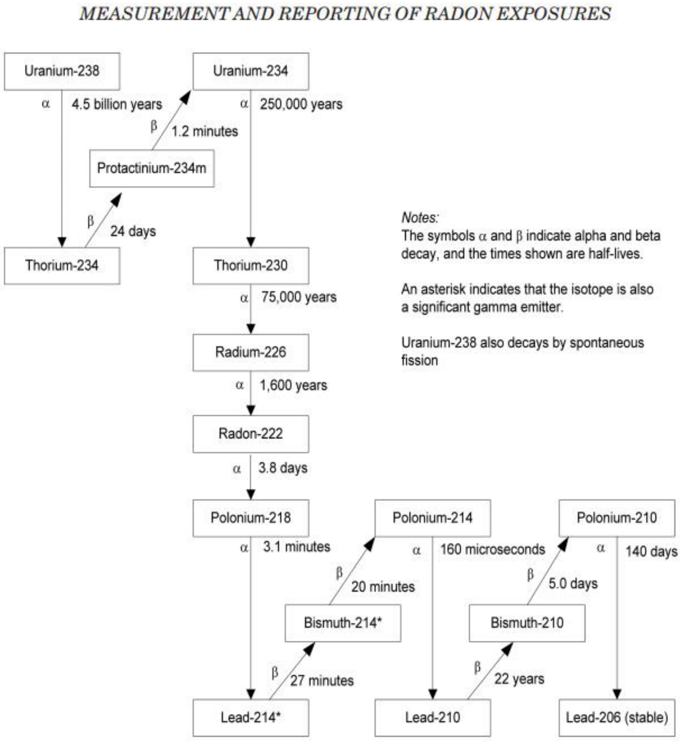

Figure 1: Decay chain of uranium-238 and the formed radon long-lived daughters ^{210}Pb, ^{210}Bi, ^{210}Po, ^{206}Pb, and short-lived daughter ^{218}Po,^{214} Pb,^{214} Bi,^{214}Po.

1.1.3. Radon in air

Radon is present everywhere, but its abundance is relatively low. Radon escapes from the uranium-rich rocks and enters a dwelling from the ground by cracks and unsealed openings in the walls of the building. Radon can accumulate over time if the building is not well ventilated. Radon in the outdoor environment is about 5 Bq/m^3 to 15 Bq/m^3 and much lower than the indoor. Radon is naturally ventilated and diluted in the outdoor air (Taeger 2017) (ICRU 2012). Radon can accumulate from 10 Bq/m^3 to more than 10 000 Bq/m^3 indoors over time, mainly in dwellings, schools, and offices. In mines, caves, and water treatment facilities, the levels can be even higher (WHO, 2009).

The geological conditions of the region, type of ventilation, people's lifestyle, building material, heating habits in winter will determine indoor radon values (DSA 2004). When a dwelling is heated, a negative pressure is created inside, forcing radon into the building if a crack or unsealed openings are present in the walls (Fig.2). The accumulation over time can result in high radiation dose and risk of lung cancer (WHO 2009). Radon can also be found in drinking water (Taeger 2017).

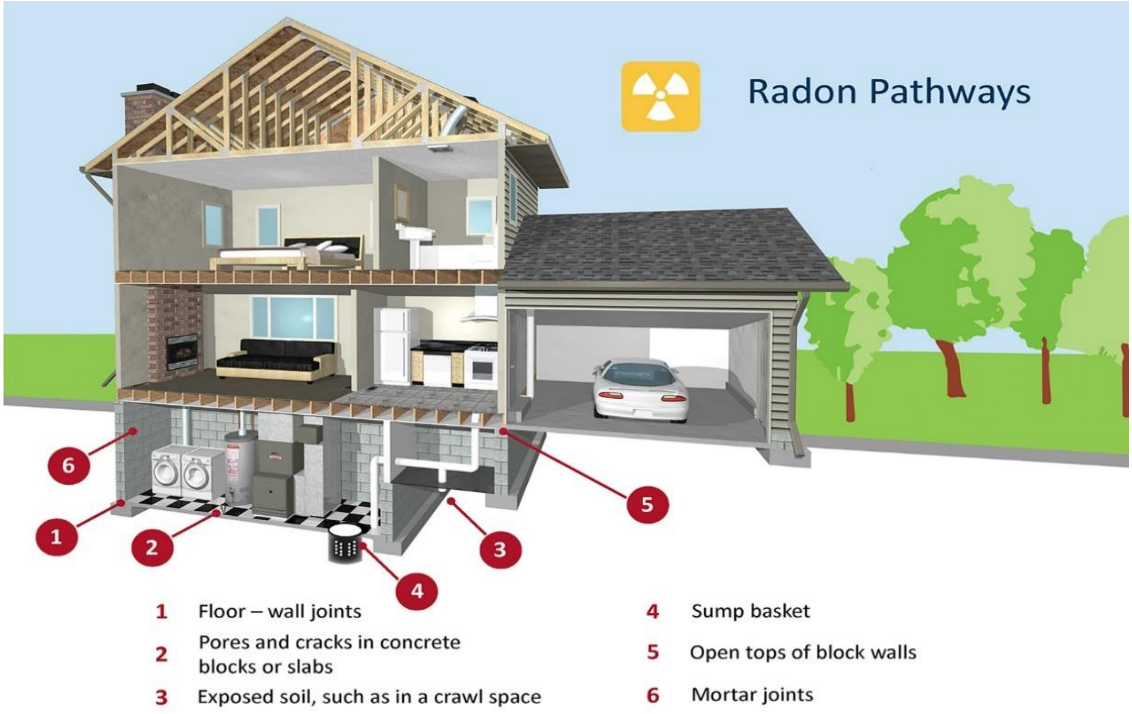

Figure 2. Different radon pathways from the outside to the inside environment (Minnesota department of health (n.d.).

1.1.4. Radon in water

Radon can seep from soil, granites, basalts, and sand to water. Since radon dissolves well in water, it can be consumed while ingesting water. Drinking water contributes very litle to radon doses in the lungs, but in some water contain high radon levels mostly the one from private wells drilled in solid rock (DSA 2021). For instance, 3.7 Bq/l to 37000 Bq/l have been found in deep wells (USGS 1998). Water containing radon can be consumed in 2 different ways: ingestion and inhalation. For instance, water from wells drilled in uranium-rich rock can contribute to high indoor radon when used in water taps, showers, and washing machines (DSA 2021). In some cases, water-containing radon consumption is associated with stomach cancer (EPA n.d.) (National Research Council -U.S. 1999), but there is no evidence (Taeger 2011).

High radon concentrations coming from the water used for domestic activities can increase indoor radon and lung cancer risk. Lung cancer risk will depend on the radon concentration, the amount of water consumed in a dwelling, the time spent indoors, and how ventilated the home is. In general, the radon concentration in the water of 1000 Bq/l can add about 100 Bq/m^3 to the indoor air. Consumption of water containing radon can also give radiation doses to the body. However, the radiation dose from water consumption is usually low compared to the one from inhalation of radon in the air (DSA 2021). It is recommended to implement mitigation actions if your domestic water has a radon concentration above 500 Bq/l in private wells and 100 Bq/l for waterworks (DSA 2021). Overall, radon exposure from drinking water is more of a problem and concern in other European countries than in Norway. In Serbia, for example, a high radon concentration of about 1463±316 Bq/ was found. This value exceeds the 100Bq/l from the European commission recommendation level in drinking water (Todorovich et al., 2012) and the recommended value in Norway (DSA 2021).

1.1.5. Radon in Norway

Rocks such as alum shales, granites, pegmatite, and highly permeable grounds with high uranium levels contribute to high radon levels in Norway (DSA 2021). Øvre Salangen, located nearby rich uranium mountain Orrefjell is an example of a Norwegian place where the indoor air in the homes is highly affected by radon. As a result, many homes in this place have radon concentrations above the Norwegian recommendation limit of 200 Bq/m^3 (DSA and NMBU 2018). A data of measurements taken in some dwellings in the wither 2016-2017, shows that 20 to 30% of the homes exceed 200 Bq/m$^{3.}$ However, less than 10% of Norwegian homes reach these values in most areas of Norway (DSA and NMBU 2018). Figure 3 shows how radon is distributed among the country, the most and least affected areas, including areas lacking data.

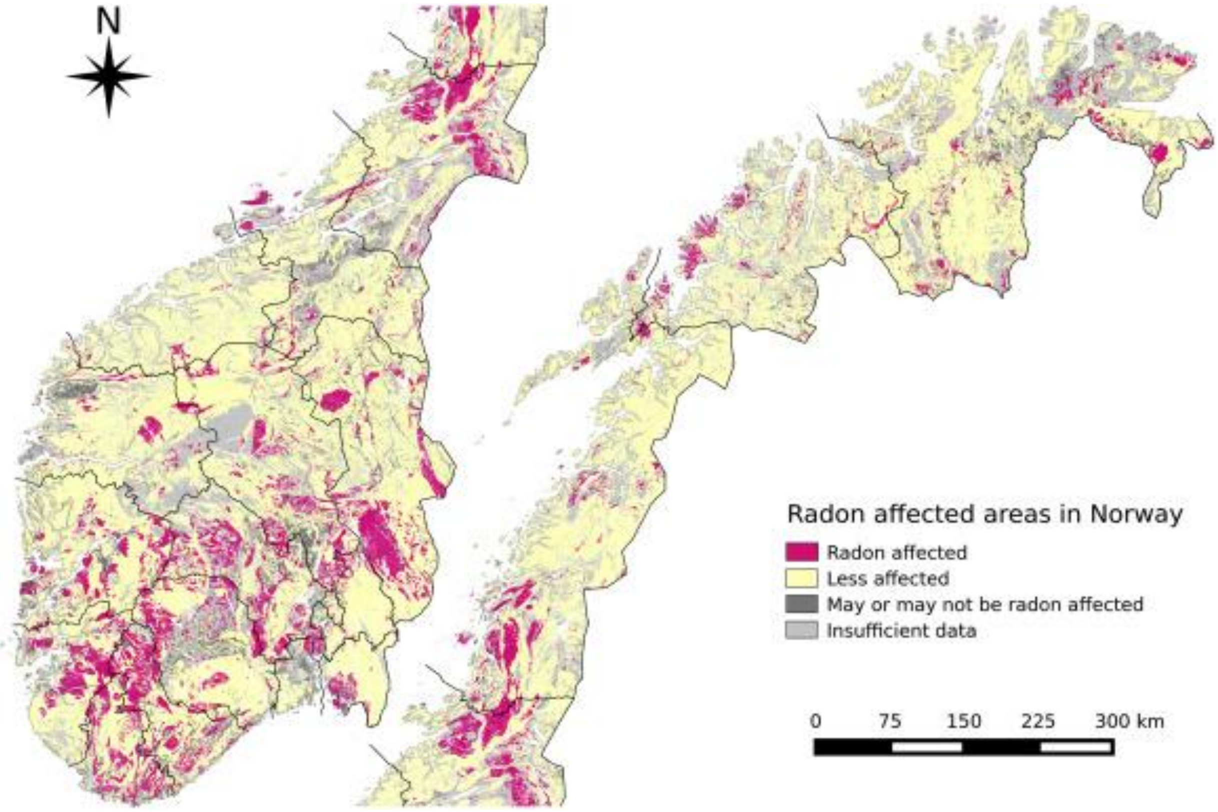

Figure 3. The country's distribution of radon. The more and less affected areas including the ones with insufficient radon data (Watson et al., 2017).

Norwegian radiation and nuclear safety authority (DSA) and a few private companies conducted large-scale surveys of radon concentrations in Norwegian dwellings from 1984 to 2003 (Table 1). The first one was from 1984 to 1986 in 79 different municipalities, 1600 homes. Twenty (20) homes in each municipality were used for the measurements. The municipalities had an annual mean radon concentration of 80-100 Bq/m^3 (Jensen, Strand et al. 2004). The other large-scale survey was conducted in 114 Norwegian municipalities in more than 29000 homes from October 2000 to May 2001. Oslo, Røyken, Stange had 102 Bq/m^3, 154 Bq/m^3,350 Bq/m^{3,} respectively, and Kinsarvik had the highest mean of 2830 Bq/m^3 (Table 7). In Kinsarvik, more than 200 homes had radon concentrations above the recommended limit of 200 Bq/m^3 (DSA 2001).

Table 1. Surveys of an annual mean of radon in the indoor air of many municipalities in Norway from 1984-2003 by Norwegian Radiation Protection Authorities private companies on a commercial basis (Jensen, C. L., T. Strand, et al. 2004).

Period	Number of dwellings	Numbers of municipalities	Organized by	Mean annual radon concentration (Bq/m^3)	Percentage above 200Bq/m^3
1984-1986	1600	79	NRPA	80-100	10
1987-1989	7530	All	NRPA	55-65	5
1990-1998	5000	31	NRPA	115	>10
2000-2001	29000	114	NRPA	89	9
2002-2003	8400	44	NRPA	150	18
1988-2003	20000	-	Others	-	-

1.1.6. Average ionizing radiation dose in the Norwegian population

Norwegian populations are mainly exposed to 2 types of radiation:

- Radiation originating from artificial sources or human activity
- Radiation originating from natural sources

Radiation originating from artificial sourced or human activities includes medical X-rays, CT imaging, nuclear industry, nuclear weapons testing, produced water from the oil industry, and discharges of radioactive material from factories. Most of the discharged material goes to rivers and the sea (Komperød, Friberg et al. 2015). The impact of the discharge of radioactive material or nuclear accidents is significantly smaller than when compared to the ones provided by other types of radiation (Komperød, Friberg et al. 2015). However, its impact cannot be ignored because this type of radiation is known to attack and harm people from a particular place. For instance, Norway was a victim of Sellafield and Chernobyl discharges, but their effects are still present today. The Chernobyl accident in 1986 was the primary source of radioactive contamination to Norwegian food and water (Komperød, Friberg et al. 2015). Investments were made to attenuate the radiation levels in cattle, fish, and vegetables. Besides, the Norwegian population was mentally and psychologically affected due to stress and anxiety in dealing with these problems.

Natural radiation comes mainly from the naturally occurring elements, background, cosmos, and radon. Radon and the progenies are the primary sources of natural radiation. The Norwegian total average dose from ionizing radiation is about 5.2 mSv/year, and radon contributes to nearly half of the total dose, which is 2,5 mSv/year, to the population, according to a survey from 2000-2001 (Fig 4). UNSCEAR estimates an international mean of about 3.0 mSv/year for radiation dose (European Commission 2014). In Norway, 90% indoor occupancy value (Vaage 2010) is used for radon calculation resulting in radon mean of 88 Bq/m^3 and the 2.5mSv/ year dose (Komperød, Friberg, et al. 2015). However, worldwide radon dose is calculated using a lower indoor occupancy value of 80%. In years before 2000, Norway used the 80% Indoor occupancy value that gave a lower dose of 2.2 mSv/year (Komperød, Friberg et al. 2015). High effective radon dose maybe because the Norwegian population spends most of the time indoors than outdoors during the long and freezing winter period, compared to the rest of the globe. Therefore, 90% indoor occupancy value is more suitable for the Norwegian radon average doses calculations than the 80%. Since Norway has Uranium-rich bedrock, it is not surprising that the Norwegian population is exposed to radon and the health effects caused by radon inhalation its inhalation. However, outdoor values are very low and almost insignificant for dose calculations (Komperød, Friberg et al. 2015)

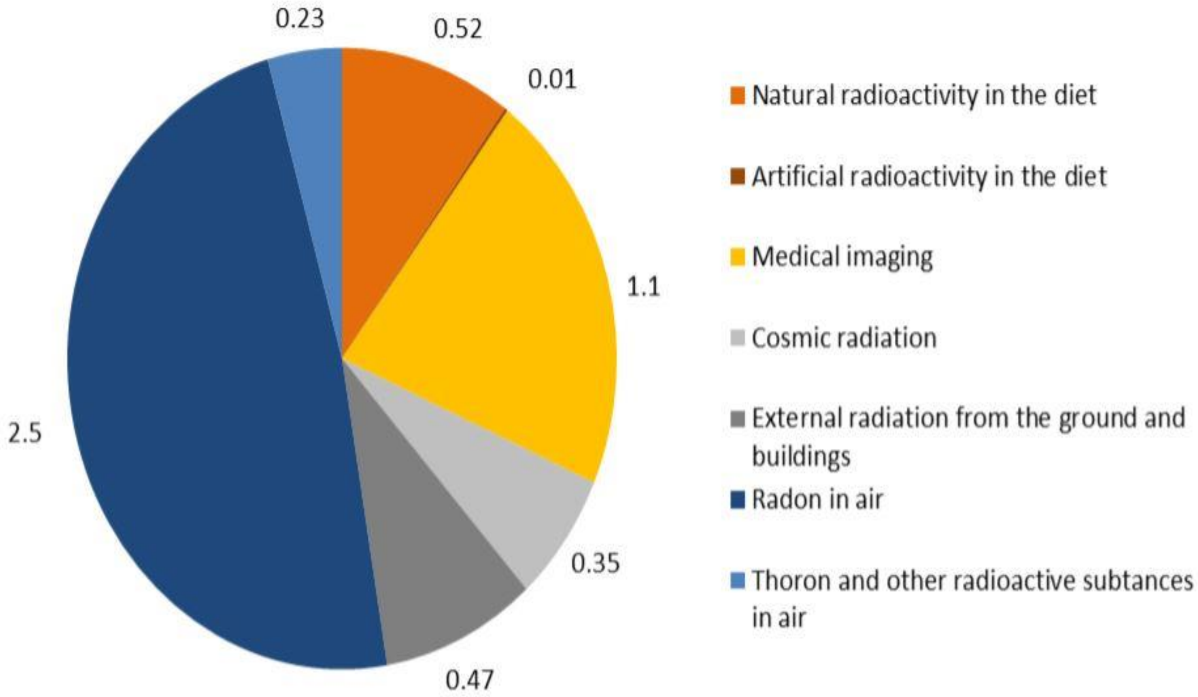

Figure 4. Radiation dose from different radiation sources provides an annual dose of 5.2 mSv/year to the Norwegian population, of which almost 50% comes from radon (Komperød et al. 2015).

1.1.7. Equilibrium factor and dose calculation

In an indoor environment, radon progenies can attach to the dust, aerosol particle, walls, or any material found inside a house. On the contrary, outdoors, they are usually attached to the building surfaces deposited on the ground or washed out of the air during heavy rain (DSA 2021**)**. Many other environmental factors can influence the radionuclide activity ratios in the outdoor environment, including the exhalation rates and atmospheric stability conditions. As a result, there is no radioactive equilibrium between radon concentration and progenies (Porstendorfer et al. 1978; Porstendorfer 1994).

Environmental factors such as ventilation rate, type of ventilation, exhalation, and surface deposition of radon progeny can significantly influence concentration ratios between radon and its progeny in the indoor environment by removing the progenies in the air resulting in their disequilibrium with radon. (Chen and Harley 2018) (Fig. 5). The dose to the lungs is from the progenies, not radon gas. Therefore, dose models do not use measured radon gas concentration as input instead of equilibrium factor since it gives information about the degree of disequilibrium between radon gas and progenies (Chen and Harley 2018).

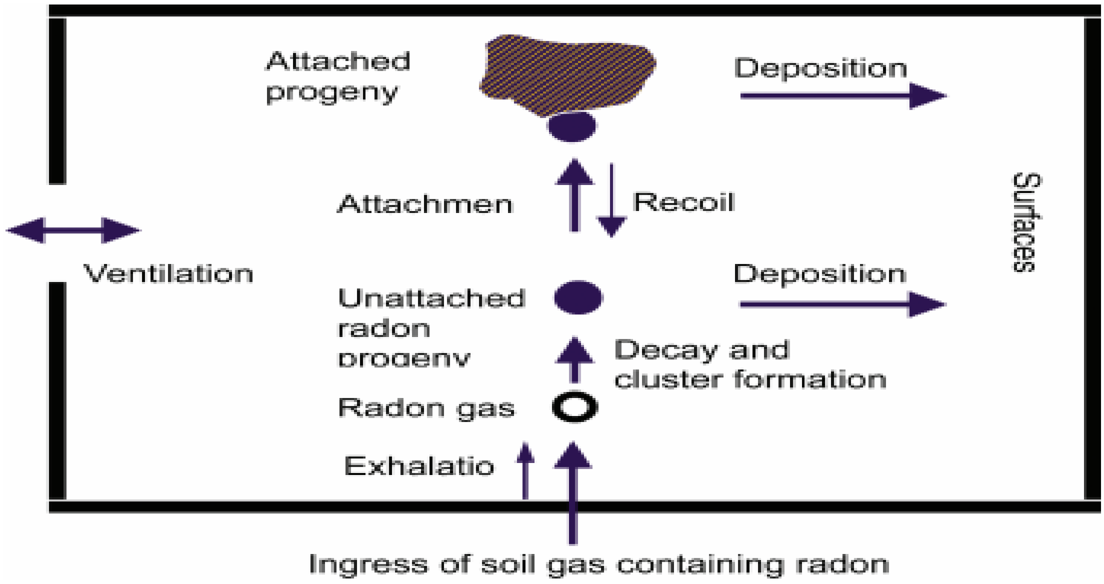

Figure 5. Representation input and output of radon and progenies in the indoor environment (NA/NRC 1991; Porstendorfer, J. 1994).

Since radon progenies measurements are expensive because of the need for electrically operated equipment (ICRU 2012), a national or worldwide equilibrium factor value is used to estimate the progeny activity concentration in the air when they cannot be measured, and equilibrium factor is important for both exposure and dose assessments (Chen and Harley 2018). The equilibrium factor value in the indoor and outdoor environment is significantly influenced by the unattached fraction. Both attached and unattached fractions are also important parameters for what dose a person receives. For instance, in a room with high aerosol particles from cigarette smoke, the equilibrium factor is higher because the amount of attached fraction is also high.

Most progenies are attached to the aerosol particle suspending in the air because of their large size compared to the free fraction. They hardly deposit on a surface leading to a high equilibrium factor (Porstendorfer, 1994). Therefore, the equilibrium factor is higher in the outdoor environment because the progenies are mostly suspended in the air since there are not many surfaces to attach to (ICRU 2012). UNSCEAR (2000, 2008) suggests using an international equilibrium factor of 0.4 for indoor air 0.6 for outdoor air. However, values may change over time and place due to changing conditions and location (ICRU 2012), as shown in table 2. Therefore, values may be subject to change when new researchers are made to reduce the uncertainty in the dose calculations.

Table 2. equilibrium factors mean values from different studies and places. (Harley et al. (, 2012).

Measurements	F
Reineking and Porstendorfer (1990) 79 measurements in 10 rooms	0.30+0.1 (0.15, 0.49)
Hattori and Ishida (1994) 4500 measurements, 2 nuclear power plants (high ventilation)	0.30+0.1 (0.1, 0.6)
Hopkeet al. (1995) 143 samples in 2 houses with a smoker	0.48+0.11 (0.25, 0.80)
Hopkeet al. (1995) 422 samples in 5 non-smoking houses	0.38+0.17 (0.11, 0.97)
Clouvas et al. (2003) 4-h measurements for 29 weeks in a lab	0.62+0.09 (0.46, 0.82)
Clouvas et al. (2003)4-h measurements in 25 apartments	0.47+0.09 (0.2, 0.7)
Chen and Marro (2011) Grab samples in 12 576 houses	0.54+0.15 (0.20, 0.82)
Harleyet al. (2012) 3-month measurements in 2 labs and 6 houses	0.75+0.12 (0.59, 0.95

Many studies about the relation of radon exposure dose to respiratory track from radon and its progenies pointed out they are influenced by

- Radon concentration,
- Equilibrium factor
- Unattached fraction or fraction of the unattached daughters,
- Type of breathing such as nose breathing or mouth breathing
- Rate and depth of respiration,
- Geometrical parameters of different parts of the respiratory system (fig.6)
- Body response to the alpha dose from radon and progenies (Stranden, Berteig et al. 1979).

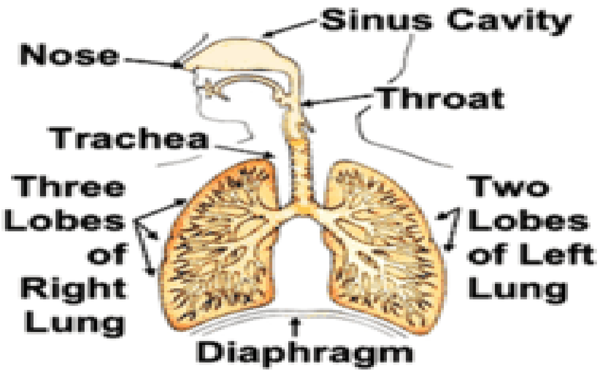

Figure 6. Human respiratory system (Ionescu (2013).

The equilibrium between radon and its short-lived progeny is used to calculate the dose in the lungs or respiratory tract in general. The equilibrium factor for short-lived radon progenies can be calculated using the following equation from Stranden et al. 1979 (equation 1) or SARAD n.d. (equation 2).

$$F = \frac{EEC}{C_{Rn}} \qquad (1)$$

Where:

EEC- Equilibrium equivalent activity concentration

C_{Rn}- Radon concentration

Or

$$F = \frac{EEC_{Rn} + unattached\ EEC + cluster\ EEC}{C_{Rn} slow} \qquad (2)$$

Where:

F - equilibrium factor

EEC_{Rn}- Equilibrium equivalent activity concentration of radon

$unattached\ EEC$ - Equilibrium equivalent activity concentration of unattached fraction

$cluster\ EEC$ – Equilibrium equivalent activity of concentration of cluster

$C_{Rn} slow$- Radon concentration measured in slow mode

The equilibrium factor depends on radon concentration in indoor air and other factors such as the equivalent activity concentration of radon, the amount of unattended fraction, and cluster in the room's environment.

The effective dose can be calculated using the following equation from DSA 2015:

$$E = A * L * K * O * T \qquad (3)$$

Where:

E = effective dose (mSv/year)

A - activity concentration of radon (88 Bq/m^3)

K - Dose conversion factor (9 · 10-6 mSv per (Bq · t · m^{-3}))

L - The equilibrium factor between radon and radon daughters (0.4)

O – Part of indoor residence time (0.9)

T - Number of hours per year (24 hours ×365 days)

The mean radon dose of 2.5 mSv / year to the Norwegian population comes from these values.

1.1.8. The fraction of unattached progenies or unattached fraction

An unattached and attached fractions of progenies are formed after radon decay. The unattached fraction, fp, also known as free fraction, is a fraction of the potential alpha energy concentration of the short-lived progeny that is not attached to the ambient aerosol particles. The attached fraction is the part of radon progenies that is attached to the ambient aerosol particles. The unattached fraction is formed shortly after the decay of radon gas when the freshly formed radionuclides react instantly with water vapor or H^2SO^4 and grow from 0.5 nm to clusters of about 1.2 nm diameter (Andreae, 2013; Kulmala et al., 2013; UNSCEAR, 2008). the particles grow to about 2 nm or 5 nm when reacting with other substances like ammonia, organic amines forming clusters (Andreae, 2013; Kulmala et al. 2013; Porstendorfer, 2001).

The unattached fraction varies from 0.03 and 0.08 for normally ventilated dwellings with indoor aerosol particles. In indoor workplaces such as schools and offices range from 0.03 to 0.15, and a few studies found values greater than 0.20 (Hattori and Ishida, 1994; Hattori et al.1995; Porstendorfer 2001; Tokonami et al.19 96; Vaupotic 2008; Yu et al., 1998). The Unattached fraction is higher than 0.10 for poorly ventilated (ICRU 2012)

The following equation from DSA (n.d.) can be used in the calculation of the unattached fraction:

$$fp = \frac{unattached\ EEC + cluster\ EEC}{EEC_{Rn} + unattached\ EEC + cluster\ EEC} \qquad (4)$$

Where:

fp - unattached fraction

$unattached\ EEC$ - Equilibrium equivalent activity concentration of unattached fraction

$cluster\ EEC$ – Equilibrium equivalent activity of concentration of cluster

EEC_{Rn}- Equilibrium equivalent activity concentration of radon

The amount of the free fraction depends on degree of the attachment to the aerosol particle and the number concentration of particles of the ambient aerosol (Porstendorfer (2001). But it can change with changing conditions (El-Hussein, 1996) (Raabe (1969).

$$X = \beta * Z \qquad (5)$$

Where:

X - Attachment rate (s-)

β- Attachment coefficient (m^3s)

Z- Aerosol number concentration (m^{-3})

2- Methods

A new in-situ instrument from SARAD, EQF 3220, was used in Bærum, Oslo, Ski, and Ås from October 2020 to April 2021 in-situ measurements. Oslo is the capital city of Norway, and Bærum, Ski, and Ås located Viken region about 30 minutes from Oslo (Fig.7). Most of the dwellings were selected because they were close to the DSA and NMBU. Most owners are DSA or NMBU employees or students willing to make their homes available for measurements. Since most Norwegians live in this area, many people are at risk of radon-induced lung cancer as high radon levels are expected in their homes (Kollerud et al. 2014).

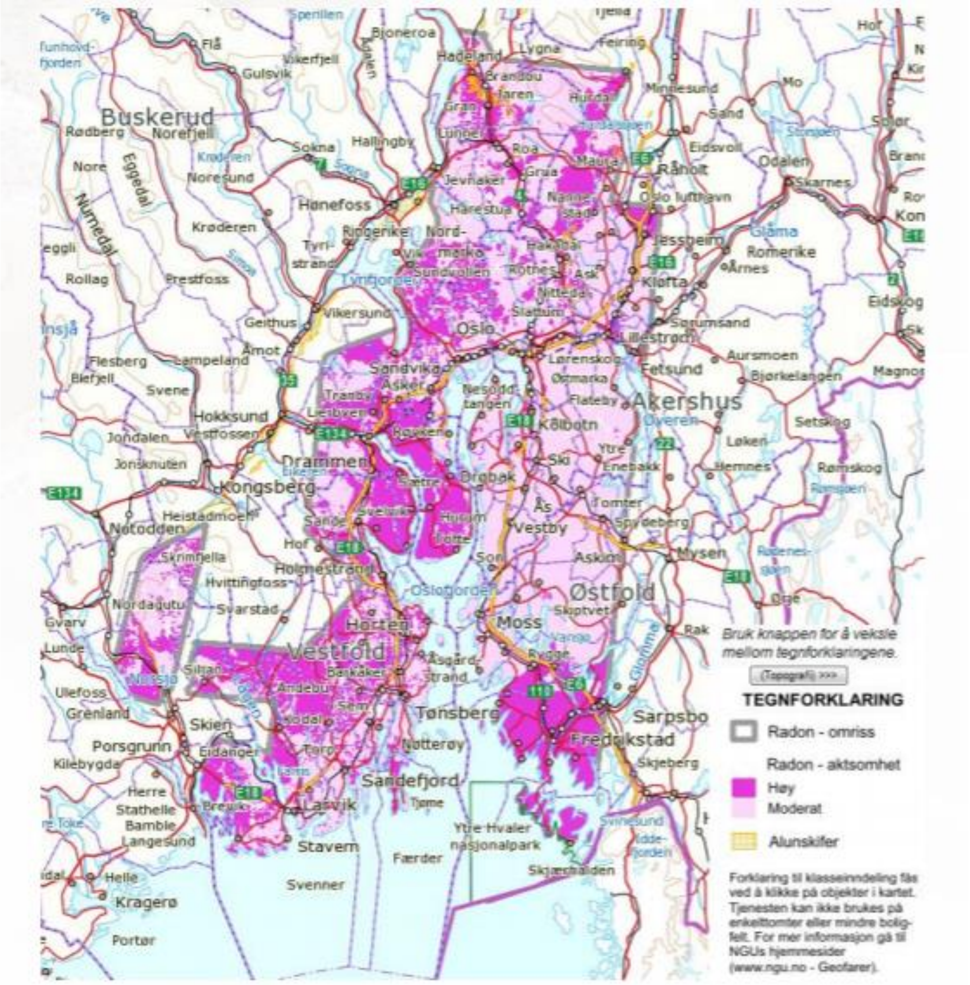

Figure. 7. Radon map of Bærum, Oslo Ski and Ås (Smethurst et al. 2008).

Fourteen dwellings were recruited, and a new instrument was used to measure radon and progeny concentrations in each of them. As a brand-new instrument, many measures were carried out as a test before the actual measurements were made. The measurement started with the instrument that belongs to DSA which will be referred to as DSA-instrument. Months later, NMBU acquired a new device like the one from DSA, which was also used along in measurements. This second instrument will be referred to as NMBU- instrument.

The measurements started in October 2020 and ended in April 2021. Only the DSA-instrument was used in the first months, and later both instruments were used in parallel in the same room to compare the results. After a while, it was possible to separate and use them individually in different buildings. First, shorter time cycles of 1h were used and later increased. The cycle was changed to 3h, 6h 12h to 24h. However, the 24h cycle was used in most homes. Initially, the results were collected from a filter of the detector that gave wrong results. Finally, the correct results were taken from the radon detector. The radon concentration and values of radon concentrations and equilibrium factor were compared across the houses.

2.1. Principal of operation of EQF 3220

Figure 8. The new SARAD instrument is used for indoor radon concentration (SARAD n.d).

The instrument has a spectroscopic working monitor that can be used in slow or fast calculation mode when measuring radon activity concentration (Fig.8). While in the slow mode, both ^{214}Po and ^{218}Po can be measured. It takes about 3 hours to read the first cycle of ^{214}Po and ^{218}Po. ^{218}Po has a half-life of 3 minutes, and it takes approximately five half-lives until equilibrium which are 15 minutes to complete a cycle. While fast mode has the advantage of giving immediate results and time saving, its sensitivity is very low, which offers high statistical error. On the other hand, the slow mode has a higher sensitivity and low statistical error (SARAD 2016). Therefore, the slow mode registration results are the only ones used to determine radon concentration and equilibrium factor.

The instrument has an airflow rate of 1.5l/minute, and it is composed of 3 detectors. The sampling head is designed for continuous monitoring of the radon progeny. A stainless-steel mesh at the top separates the unattached fraction products (1st detector), while a membrane filter collects the attached fraction products (2nd detector). The filter and screen prevent progenies inlet into the chamber (3rd detector). Two semiconductors in the sampling head detect the nuclides of each fraction product. Ions are collected on the sensor by electrical field forces, and the nuclides are separated by alpha-spectroscopy. The equilibrium state between the collection and decay process is reached after about five half-life times of each nuclide. The radon gas is continuous into a chamber in the instrument. (SARAD 2016).

Short after the decay process of radon, the electron found in the ^{218}Po are scattered away from the shell. Afterward, there is the formation of a positivity charge of ^{218}Po that remains positively charged. Po particles, with a half-life of 3.05 minutes. They are later collected on the surface of the semiconductor detector by electrical field forces. Only about 50% of the total emitted the sensor will register ^{218}Po. The equilibrium between decay rate and ^{218}Po happens after 15 minutes. The 15 minutes are the least time required for radon and progeny detection in the fast mode, equivalent to about five half-lives of ^{218}Po. The higher the concentration of radon, the more ^{218}Po will be emitted and collected on the surface of the detector. When the equilibrium between radon and ^{218}Po is achieved, the decay chain is followed by the other short-lived progenies. The short-lived progenies are ^{214}Pb,^{214}Bi, and ^{214}Po with a half-life of 27 minutes, 20 minutes, and 60 microseconds respectively (SARAD 2016).

For these reasons, the slow mode takes about 3 hours since the goal is to measure the alfa-emitters ^{218}Po and ^{214}Po. The beta emitters ^{214}Pb and ^{214}Bi are emitted on the way and delay the process. Each ^{218}Po causes one detachable decay by the ^{214}Po. However, they can be separated by alpha spectrometry since both emit different energies and generate alpha spectrum for each data recorded and its use for all father calculations of the results.

2.2. Statistical Error

In general, a constant value is used as radon concentration. Still, many radon atoms are sent to the detector surface during the radioactive decay, and they vary a lot over the time of sampling. As a result, radon decay is a statistical process and statistical error. The observed derivation should be used to find what is considered as the actual value or outcome of the number of decays, N. To reduce statistical error, the instruments were tested using measurements of 1,3,6,12 and 24 hours in a cycle. The higher the radon concentration, the more counts (N), and less uncertainty as shown in equation 6 (SARAD 2016). The 24h cycle gave less Statistical uncertainty since it was possible to get many numbers of counts and some of the dwellings had very low radon concentration making the 24h the best choice. The longer the cycle, the more counts, and less uncertainty. Finally, it was observed that the 24h cycle in both instruments did not show a statistically significant difference when used in parallel.

$$E\,(\%) = 100\,\% * K * \sqrt{\frac{N}{N}} \qquad (6)$$

Where:

E - Statistical error

K – Sigma number
N - number of detected counts

$$C_{Rn} = \frac{N}{T * S} \qquad (7)$$

Where:
C_{Rn}- radon concentration
N - number of detected counts
T - integration interval
S - sensitivity of the instrument

There are two factors to consider for each serious radon measurement: calculated radon value and error band for a specific confidence interval. There are three commonly used confidence intervals, the 1, 2, and 3 Sigma (σ), which represent the likelihood of 68.3%, 95.45%, and 99.73%, respectively (Table 2). Sigma 1 is the confidence interval that will be used to determine radon and progeny statistical error in this research's calculations.

Table 3. The three commonly used confidence intervals, the 1, 2, and 3 Sigma (σ)represent the likelihood of 68.3%, 95.45%, and 99.73%, respectively.

Confidence Interval	Required Mean Value for N at the Detection Limit
63,2 % (σ1)	1
σ2- 95 % (σ2)	3
σ3- 99,75 %(σ3)	6

Only 12 out of the 14 dwellings will be used to calculate radon concentration and equilibrium factor since these places were measured using the 24h cycle, which is more accurate with low error (sigma 1).

The study analysed the data using a statistical package called Stata. The study first got the descriptive data statistics where mean, minimum, and maximum values were obtained. The study also carried out different t-tests, correlated the variables, and ran an Ordinary Least Square (OLS) regression.

3- Results and discussion

3.1. Measurements using DSA and NMBU instruments in parallel

Table 4 shows the results of measurements of 5 dwellings using the DSA and NMBU instruments with cycles 1h, 3h, 6h, 12h, and 24 hours during the testing and first phase of the research. The values of Rn fast and slow, equilibriums factor, and the unattached fraction of the two instruments are presented. The DSA- instrument registered radon concentration a mean of 151 Bq/m^{3,} and the NMBU-instrument has 152 Bq/m^3. For DSA, the minimum radon concentration is 24 Bq/m^3 and 487 Bq/m^3 maximum, while NMBU has a minimum of 24 Bq/m^3 and a maximum of 489 Bq/m^3.

Table 4. Results of the five dwellings in Bærum, Oslo, Ski, and Ås using DSA and NMBU instruments in parallel- the first phase of the study.

Variable	Home	Mean	Min	Max
Rn fast DSA (Bq/m^3)	5	158	23	528
Rn fast NMBU (Bq/m^3)	5	166	23	547
Rn fast error DSA %	5	21.2	10.3	37.5
Rn fast error NMBU %	5	17.9	10.3	31.8
Rn slow DSA (Bq/m^3)	5	151	24	487
Rn slow NMBU (Bq/m^3)	5	152	24	489
Rn slow error DSA%	5	15.2	7.0	31.7
Rn slow error NMBU%	5	11.4	6.8	15.3
Equilibrium factor DSA	5	0.26	0.11	0.47
Equilibrium factor NMBU	5	0.24	0.11	0.38
Unatt. fraction DSA	5	0.48	0.30	0.64
Unatt. fraction NMBU	5	0.48	0.28	0.59

The box plot shows that the radon concentration from DSA-instrument and radon concentration from NMBU-instrument have equal mean values (Fig.9). This is also confirmed from the t-test paired results. At a 5% significance level, the paired t-test failed to reject the null hypothesis, which says that the means are the same with the p-value of 0.99 (Appendix, table 13).

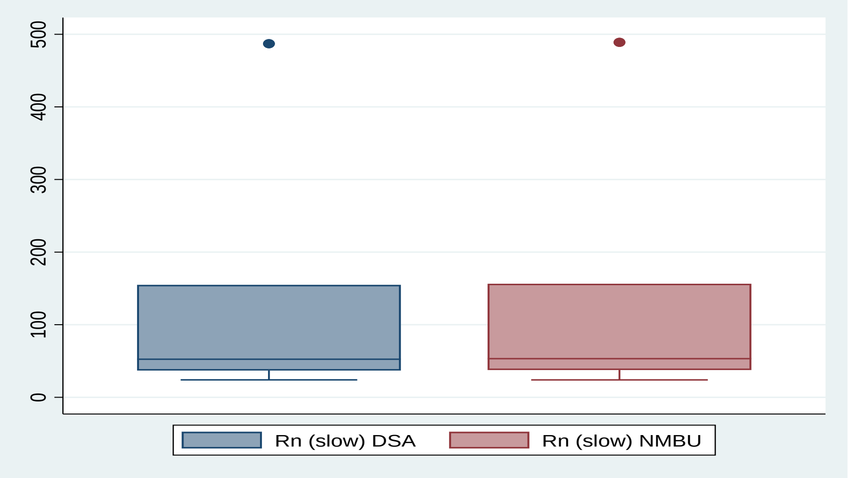

Figure 9. Box plot for comparison of radon concentration measured from DSA and NMBU instruments placed in parallel using 1h, 3h, 6h, 12h, and 24h-cycles in the five dwellings in Bærum, Oslo, Ski, and Ås.

The above figure shows that the two variables of equilibrium factor of DSA-instrument and NMBU-instrument are not statistically different (Fig.10). This is also confirmed from the t-test paired results. At a 5% significance level, the paired t-test failed to reject the null hypothesis, which says that the means are the same with the p-value of 0.85 (Appendix, table 14). Overall, the variation from both instruments is not statistically significant. After the testing phase, it was possible to use the devices separately in future sampling.

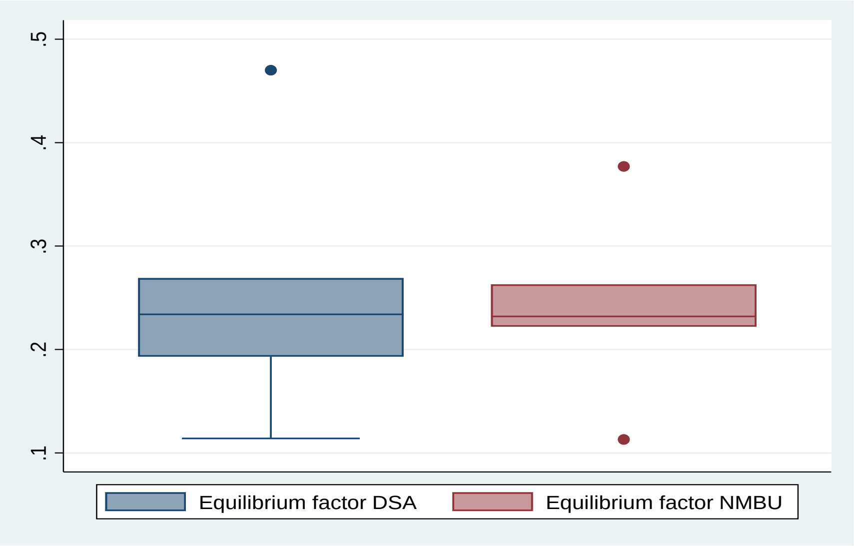

Figure 10. Box plot for comparison of equilibrium factor measured from DSA and NMBU instruments placed in parallel using 1h, 3h, 6h, 12h, and 24h-cycles the five dwellings in Bærum, Oslo, Ski, and Ås.

3.2. Radon concentration in Oslo, Ski, and Ås

The study measured indoor radon concentration in 24-cycle in 12 houses- 2 in Oslo, 1 in Ski, and 9 in Ås. Ås contained the highest radon concentration value of 569 Bq/m^3 and the lowest of 24 Bq/m^{3,} also found in Ski. Dwellings in Oslo, Ski, and Ås have radon mean values of 53 Bq/m^3, 24 Bq/m^{3,} and 178 Bq/m^{3,} respectively (Table 5).

Table 5. Results of radon concentration measurements mean, minimum and maximum values in Oslo, Ski, and Ås.

	Obs.	Mean	Min	Max
Oslo				
B. pressure (mbar)	2	1004	997	1011
Temperature (^{0}C)	2	20	14	26
Humidity (%rH)	2	45.9	14.7	77.1
Rn fast (Bq/m^3)	2	54	44	64
Rn slow (Bq/m^3)	2	53	43	62
EEC Rn (Bq/m^3)	2	6.21	2.8	9.63
Unatt. EEC (Bq/m^3)	2	4.51	3.42	5.6
Clust. EEC (Bq/m^3)	2	0.19	0.09	0.3
Ski				
B. pressure (mbar)	1	990	990	990
Temperature (^{0}C)	1	29	29	29
Humidity (%rH)	1	11.7	11.7	11.8
Rn fast (Bq/m^3)	1	23	23	23
Rn slow (Bq/m^3)	1	24	24	24
EEC Rn (Bq/m^3)	1	3.51	3.51	3.51
Unatt. EEC (Bq/m^3)	1	1.39	1.39	1.39
Clust. EEC (Bq/m^3)	1	0.08	0.08	0.08
Ås				
B. pressure (mbar)	9	995	980	1018
Temperature (^{0}C)	9	23	15	27
Humidity. (%rH)	9	9.57	0	42
Rn fast (Bq/m^3)	9	176	25	570
Rn slow (Bq/m^3)	9	178	24	569
EEC Rn (Bq/m^3)	9	22.3	4.6	111
Unatt. EEC (Bq/m^3)	9	21.6	1.97	69
Clust. EEC (Bq/m^3)	9	5.11	0	16

The regional mean value is 145 Bq/m^3, about six times more than Ski and four times the one of Oslo (Table 6). In most cases, concentrations close to the lowest and mean value was measured in the room with good ventilation and first floor. The highest values are from rooms with poor ventilation and mostly at basements since radon comes from the ground and seeps first to the lowest floor like in the research of Stranden et al. in the years 1977-1978 (Stranden et al.1979). In general, dwellings on the floor that are in direct contact with the ground tend to have higher radon concentration levels than those on higher floors (DSA 2004).

Table 6. Total results of radon concentration measurements in the study area -the second phase of the study.

Variable	Obs.	Mean	Min	Max
B. pressure (mbar)	12	996	980	1018
Temperature (^{0}C)	12	23	14	29
Humidity (%rH)	12	15.8	0	77.1
Rn fast (Bq/m^3)	12	143	23	570
Rn slow (Bq/m^3)	12	145	24	569
EEC Rn (Bq/m^3)	12	18.0	2.8	111
Unatt. EEC (Bq/m^3)	12	17.1	1.39	69
Clust. EEC (Bq/m^3)	12	3.88	0	16

According to the data from WHO in 2009, Norway has a radon concentration average of 88 Bq/m^3. However, the data from the Norwegian radiation and nuclear safety authority 2001 (table 7) shows a significantly higher value of 102 Bq/m^3 in the Oslo region. The highest mean, 2830 Bq/m^3, was found in a rural area of Norway in the Kinsarvik municipality. Røyken and Stange had 154 Bq/m^3 and 350 Bq/m, respectively. The Norwegian geology can explain high radon levels in Norway has a lot of alum shale and uranium-enrich bedrock (DSA 2014).

Table 7: Average values of indoor radon concentration in Oslo, Røyken, Stange, and Kinsarvik municipalities before the implementation of mitigation measures (DSA 2001).

Municipality\residential area	The proportion of homes > 200 Bq/m^3	Average radon conc. (Bq/m^3)	The 5 highest measurements in each area, ranked (Bq/m3)				
			nr. 1	nr. 2	nr. 3	nr.4	nr.5
Oslo	13	102	1000	750	690	640	610
Røyken municipality	17	154	1 500	1500	1500	1400	1100
Stange municipality	45	350	5 300	4900	4800	4500	3400
Kinsarvik (rural)	100	2 830	16600	13 000	8350	8200	7900

Radon mean in Europe is around 69 Bq/m^3 and the world average is 39 Bq/m^3(WHO 2009). These values are very low compared to the Scandinavian or Norwegian mean of 88 Bq/m^3 (WHO 2009) and the 145 Bq/m^3 of this study. For instance, in Thessaloniki, Greece, 26 houses had a mean of 34 Bq/m^3 (Clouvas et al. 2006). According to Scandinavian surveys, the Danish radon mean value is 53 Bq/m^3 (SIS 2001), Finland 96 Bq/m^3 (STUK 2006-2007), Sweden 108 Bq/m^3 (Swedjemark 1993). Iceland is assumed to have the lowest value due to basalt's different types of rock (DSA, 2014). These Scandinavian values are also lower compared to the 145 Bq/m^3. Worldwide, the values are quite different from the one of this study. For instance, in Ottawa, Canada, the mean was 51 Bq/m^3 in 6 dwellings (Harley et al. 2012) and 20 Bq/m^3 in 18 cities (Chen et al. 2011). India and China had 63 Bq/m^3, 1265 dwellings in Asia, and 26 Bq/m^3 in 14593 homes respectively (Chen and Harley 2018). In Africa, El-Mina in Egypt had a mean of 123 Bq/m^3 (Mohamed 2005). The value found in Egypt is higher than what was expected in a country with a warm climate and there is little data on radon concentration in Africa. Overall, radon mean values around the globe are a lot lower than the one found in this study. However, the radon values from the survey from 1984-2003 are a lot higher than the new mean of 145 Bq/m^3 found in this study. The result of this study cannot be conclusive, given insufficient data due to the limitations of the study itself and covid-19 restrictions.

The changes in radon mean over the years could be explained by the fact that measured houses are different and therefore exposed to a different type of bedrock with less uranium content and changes in lifestyle as people are more aware of radon-induced lung cancer. A plausible justification for this change would be because people are more aware of radon-induced cancer. Thanks to the approach made by the national radiation and nuclear safety authority (DSA) and the media in general. For instance, many campaigns on radon were made from 1998-2003. videos about radon were shown in commercial breaks of Norwegian television in 2001-2002 to encourage people to take radon measurements in their homes (DSA 2004).

The study's low radon concentrations could also be explained by the new regulation described in Section 6, fifth paragraph of the Radiation Protection Regulations and TEK 17. The regulation emphasizes that buildings should have improved ventilation systems and use construction material that prevents the input and accumulation of radon, to get indoor air above 100 Bq/m$^{3)}$ considering the economic and social aspects. (DSA, 2014; 2017) (Hassfjell et al. 2017). Information about radon makes the population aware of the dangers of radon to their health, and indoor radon reduction is taken more seriously both in new and old dwellings.

Although the radon average of the study is less than 200 Bq/m^3, it deserves special attention because, from 100 Bq/m^3 onwards, actions to reduce radon should be taken. Furthermore, it does not mean that Ski and Oslo that have values below the regional one are out of danger. Most cancer cases are in low radon homes since most of the population lives in this environment. Bochicchio et al. 2017, suggest a focus not only in the considered prone areas but also in those with low radon concentration since there is a high number of cancer cases in areas considered safe. In addition, most lung cancer cases are found in places or homes with radon levels below 100 Bq/m^3. As a result, about 63 percent of the lung cancer deaths caused by radon-induced cancer are people exposed to less than 200 Bq/m^3 (DSA 2009).

The recommendation radon limit in Norway is 200 Bq/m^3 (DSA 2000). However, in dwellings with concentrations above 100 Bq/m^3, radon mitigation measures should be implemented to reduce radon in indoor air. Mitigation actions aim to achieve indoor radon concentrations as low as reasonably achievable -ALARA principle (DSA 2018). The residential mitigation measures can help to reduce about 100 lung cancer cases in Norway each year, with a significant impact in smokers and former smokers than in non-smokers (Hassfjell 2017). If Nordic countries have indoor radon concentrations below 100 Bq/m^3 about 360 could be saved in a year since people living in homes with radon levels below 200 Bq/m^3 represent 63% of lung cancers deaths in the area (DSA 2014). However, areas with indoor radon concentrations below 100 Bq/m^3 still give a risk for lung cancer. Therefore, people should avoid exposure to high levels of radon if possible (IARC-WHO 2015).

If smokers reduce or quit smoking, lung cancer cases could be reduced by a factor of 25 without underestimating the risk for non-smokers (DSA 2018). If people implement daily simple mitigation measures like opening windows to improve ventilation rate that balances indoor and outdoor radon concentrations, indoor radon exposure could be reduced. These simple daily measures could be more beneficial to people that for some reason, cannot have a sophisticated ventilation system, seal the cracks, or reduce or quit smoking. And about 100 lung cancers can be reduced in Norway each year even with unchanged smoking habits. If smokers change their stop smoking, the number of lung cancer incidents associated with radon will decrease, even if the mitigation measures are not implemented (Hassfjell et al. 2017). The combination of both reductions of smoking and indoor radon concentration would significantly reduce lung cancer incidents in the Norwegian population.

3.3. Equilibrium factor

The equilibrium factor of the 12 dwellings varied from 0.1 to 0.35. The lowest and highest equilibrium factor values are both from Oslo. Oslo, Ski, and Ås have equilibrium factors mean values of 0.23, 0.21, and 0.26, respectively. Ski has the lowest mean value, whereas Ås has the highest. The regional and overall mean value is 0.25. The regional mean does not differ a lot from the one of Oslo, Ski, and Ås. When the equilibrium factor is significantly higher than the lowest measured value and substantially lower than the highest measured value can lead to over or underestimating the equilibrium equivalent activity concentration and the dose given to the lungs (Chen and Harley 2018).

The unattached fraction varies from 0.29 to 0.85. The lowest equilibrium factor value is from Ski, whereas the highest is from Ås. Oslo, Ski has unattached fraction mean values of 0.48, 0.3, and 0.53 respectively. Ski has the lowest mean value, whereas Ås has the highest. The regional and overall mean value is 0.5 (Table 8).

Table 8. Results of equilibrium factor and unattached fraction in Oslo, Ski, and Ås.

Variable	Place	Obs.	Mean	Min	Max
F	Oslo	2	0.23	0.10	0.35
	Ski	1	0.21	0.21	0.21
	Ås	9	0.26	0.16	0.34
	Regional	12	0.25	0.10	0.35
fp	Oslo	2	0.48	0.38	0.57
	Ski	1	0.30	0.29	0.29
	Ås	9	0.53	0.30	0.85
	Regional	12	0.50	0.29	0.85

3.4. Comparison of new equilibrium factor to previous Norwegian value by Stranden

The equilibrium factor is also statistically different from 0.5 from Stranedn at a 5% level of significance. The t-test shows 95% confidence that the equilibrium factor of this study is less than the previous national equilibrium factor value of 0.5 (Table 9).

Table 9. The Results of the equilibrium factor t-test in comparison to the Norwegian previous measured value of 0.5.

```
. ttest F=0.5

One-sample t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
       F |      12    .2496667    .0216943    .0751512    .2019179    .2974154
------------------------------------------------------------------------------
    mean = mean(F)                                                t = -11.5391
Ho: mean = 0.5                                   degrees of freedom =       11

   Ha: mean < 0.5               Ha: mean != 0.5               Ha: mean > 0.5
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

3.5. Comparison of new equilibrium factor to worldwide suggested by UNSCEAR

The results above show that the values reject the null hypothesis that F = 0.4 with a p-value of zero at a 5% significance level. The new calculated equilibrium factor is statistically different from 0.4 suggested by UNSCEAR (Table 10).

Table 10. The Results of the equilibrium factor t-test in comparison to the UNSCEAR value of 0.4.

```
. ttest F=0.4

One-sample t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
       F |      12    .2496667    .0216943    .0751512    .2019179    .2974154
------------------------------------------------------------------------------
    mean = mean(F)                                                t =  -6.9296
Ho: mean = 0.4                                   degrees of freedom =       11

   Ha: mean < 0.4               Ha: mean != 0.4               Ha: mean > 0.4
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

The hypothesis was proven wrong since the equilibrium factor of 0.25 is almost a half of both worldwide of 0.4 suggested by UNSCEAR 2008 and the previous value of 0.5 reported by Stranden et al. 1979.

Stranden et al. 1979 carried out radon concentration inside measurements in 120 dwellings in the area around Oslo from 1977-1978. They used a sampling time of 20 minutes by sampling air in 9l in evacuated containers. These samples were analysed in a 12.6l ionization chamber. The technique was used for radon measurements in Norwegian mines in the past. However, for equilibrium factor determination, only 25 dwellings were used. The measurements were performed in houses located around Oslo (Stranden, Berteig et al. 1979). This method is different from the one used in this study and could be one of the reasons for the significant difference in equilibrium factors values between both studies.

When the equilibrium factor is compared to values from other countries globally, it is much smaller. For instance, in China, Cheng et al. (2002) had an equilibrium factor mean of 0.47 in more than 8,528 measurements made in 26 provinces between 1984 to 1990 using repeated short-term measures with continuous monitors. Another example is a review of Cheng et al. 2002 and Pan 2003 that had equilibrium factor mean value of 0.48 in more than 5,638 measurements made in 17 provinces from 1983 to 1998. However, recent Chinese publications from 1999 to 2015 found equilibrium values that varied from 0.24 to 0.60 with an overall average of 0.47. The value is consistent with the old one even though the authors used improved methods for more accuracy, such as intercomparisons, certified calibration, long-term with continuous monitoring. The equilibrium factor average of 0.5 would be more representative in Chine for most dwelling types in different places and environmental conditions. Overall, in areas warm and humid countries, equilibrium factor of 0.35 would be suitable for risk assessment and dose to the lungs (Chen and Harley 2018).

The equilibrium factor varied from 0.1 to 0.5 with an overall average of 0.37 in India in 1,265 houses, and most of them were long-term measurements (Chen and Harley 2018). An equilibrium factor from 0.31 to 0.35 was found in Egypt in 45 dwellings using short-term measures (Ei-Hussein 2005; Mohamed 2005). The value fits the area since most African countries are warm with low radon concentrations. Low radon concentrations in a country with a warm climate are also examples of how the worldwide average overestimates the equilibrium factor and the dose to the lungs. For this study, the radon mean of 145 Bq/m^3, the equilibrium factor mean of 0.25, a dose conversion factor of $9 \cdot 10^{-6}$ mSv per $(Bq \cdot t \cdot m^{-3})$) part of indoor residence time of 0.9, the number of hours per year of 8.760, would give mean radon dose of 2.6 mSv /year to Norwegian population (equation 3).

In Europe, the country with the highest mean value is Greece, with an equilibrium factor of 0.49 (Clouvas et al. 2006), Italy had 0.48 (Bochicchio et al. 1996), and Lithuania had 0.47(Jasaitis and Girgzdys 2011). In Scandinavian, Sweden had an equilibrium factor of 0.44 (Swedjemark 1983). The value of this study is a lot different from the one found in these countries. However, a very close value was expected given the geological similarities of the Scandinavian countries.

An equilibrium factor average like the one of this study was found in Kumaun Himalaya in India in 100 dwellings (Ramola 2011), China in Hong Kong in 62 dwellings (Yu et al. 1998: 1999), and Iowa in, the U.S. in 98 dwellings (Sun et al. 2009). These areas have a warmer climate with a low amount of uranium. Therefore, a lower equilibrium factor average of around 0.2 is expected, unlike Norway, a freezing country with uranium-rich bedrock.

There is no record of equilibrium factor lower than the one of this study, even in independent studies. For instance, Harley et al. 2012 found an equilibrium factor of 0.75 in 3 months measurements of 2 laboratories and 6 houses. Clouvas et al. 2003 found an equilibrium factor of 0.62 in a laboratory using 4 hours measurements for 29 weeks (Table 2).

While countries like China have almost the same equilibrium factor over the years, in Norway, the value of this study is about a half of Stranden et al. 1979. These changes could be justified by the fact that people no longer smoke cigarettes indoors, making the fraction of unattended progenies greater and the equilibrium factor smaller. The main reason is that this study has a minimal number of homes and measurements. For the equilibrium factor, Stranden et al. 1979 measured 25 dwellings. For radon concentration, the Norwegian survey from 1984-2003 measured thousands of homes which is a lot compared to the only 12 homes of this study. The previous Norwegian measurements have been corrected for season variations (DSA 2009), while in this study, the sampling period carried on from October 2021 to April 2021 with correction of the results.

The differences are sometimes in method rather than the values found in measurements. For instance, Stranden et al. 1979 used high sampling airflow for equilibrium factor determination. The airflow rate used by Stranden et al. 1979 was 1.2 l/min, while the one used in this study was 1.5l/min. Most of the published determinations of the equilibrium factor were based on long-term samples (ICRU 2012). For instance, Danish and Finnish surveys were carried out measuring radon in a whole year, while the study used a few months with less than five days of continuous measurements. In the past, some values were based on measurements in rooms left unventilated for 8 hours before sampling (Stranden et at. 1979) with no use of certified calibration (Chen and Harley 2018).

3.6. Correlation between equilibrium factor and radon concentration

A positive correlation between the equilibrium factor and radon concentration was observed. (Fig.11). Dwellings with low levels of radon concentration have a low equilibrium factor. For instance, Ski has the lowest radon concentration mean of 24 Bq/m^{3,} and the lowest equilibrium factor mean of 0.21. Both Ski radon concentration and equilibrium factor mean values were the lowest among all measured areas. Ås has the equilibrium factor mean value of 0.26 because of the high radon concentration mean of 178 Bq/m^3 found in this area. The same radon concentration and equilibrium factor relationship were observed by Stranden et al. 1979. He explained this by the probability of radon concentration being high in ventilation in homes resulting in a high equilibrium factor (Stranden, Berteig et al. 1979). Since the equilibrium factor varies concerning radon concentration, it is essential to consider this when calculating the radiation dose to the lungs. One of the ways to reduce equilibrium factor and radiation dose to the lung is to reduce indoor radon concentration.

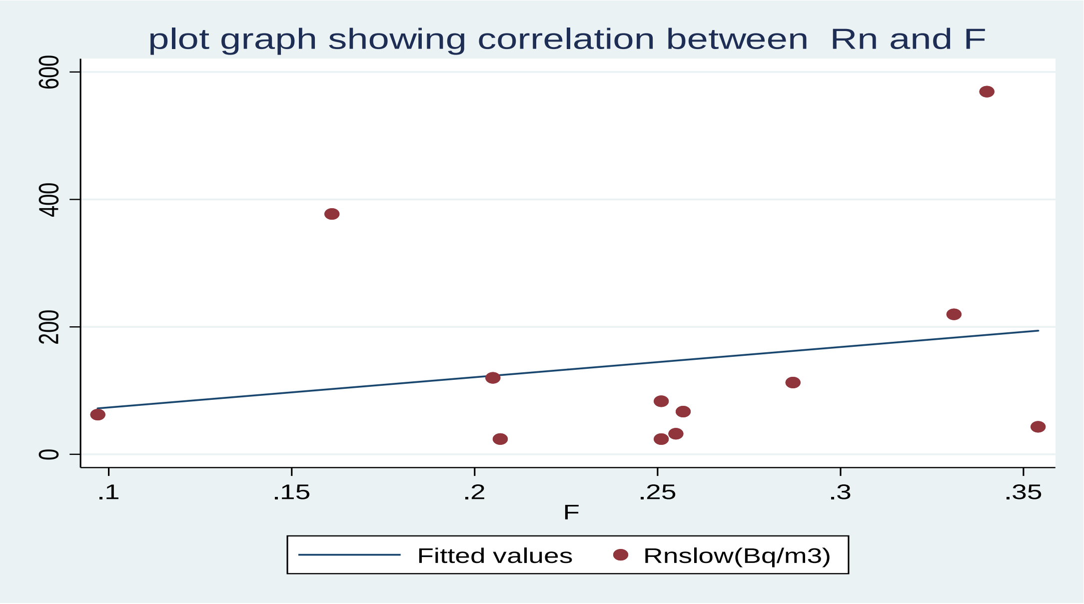

Figure 11. The plot graph shows the positive correlation between the equilibrium factor and radon concentration in indoor air.

3.7. Correlation between equilibrium factor and unattended fraction

There is a negative correlation between unattached fraction and equilibrium factor (Fig.12), and the same relationship was found in other studies (Fig.13). Dwellings with low levels of unattached have a high equilibrium factor. For instance, dwelling number 8 has a high unattached fraction of 0.85 and a low equilibrium factor of 0.16 while, dwelling number 2 has a high equilibrium factor of 0.35 because of its low unattached fraction of 0.38 (Appendix, table 15).

Equilibrium factor and unattached fraction relationship depend on the ratio of the deposition rates of the attached and unattached radon progeny, the surface to volume ratio, the deposition velocity, ventilation rate, and the radon entry rate (ICRU 2012). It can be significantly influenced by aerosol concentration fluctuations (El-Hussein, 1996). Overall, an increase of unattached result a decrease of the equilibrium factor.

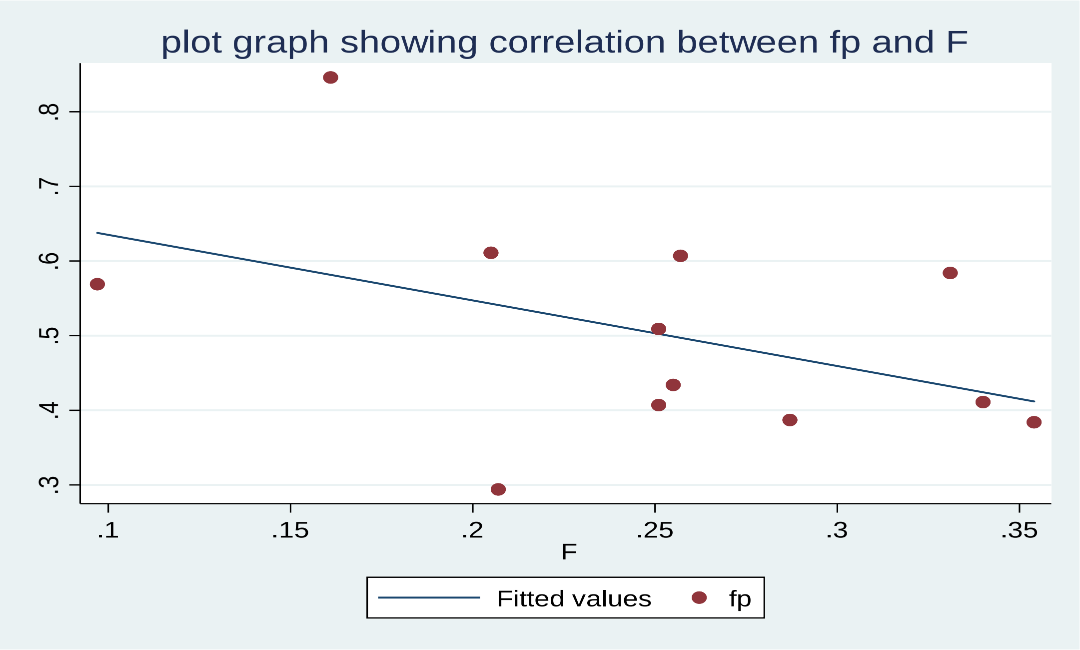

Figure 12. The plot graph shows the negative correlation between the equilibrium factor and unattached fraction in indoor air.

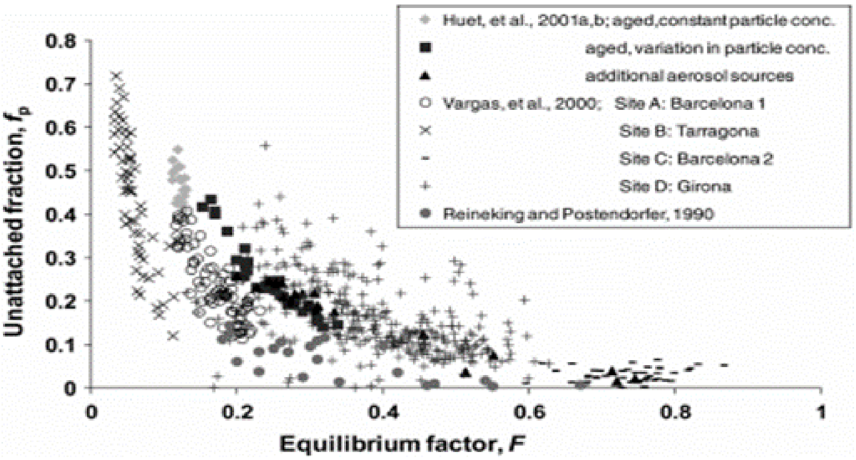

Figure 13. A graph from previous studies showing the negative correlation between equilibrium factor and unattached fraction in indoor air (Marsh et al. 2002; Huet et al. 2001; Reineking and Porstendorfer 1990; Vargas et al. 2000).

The unattached fraction mean found in this research is 0.5, but unattached fraction values in the range of 0.03 to 0.08 are for standard indoor air quality (Porstendorfer 2001). However, the value is greater than 0.10 for rooms with poor ventilation without an external aerosol source like a cigarette. Unattached fraction above 0.2 have been found by many authors in poor ventilated rooms with air cleaner (El-Hussein 2005; Hattori and Ishida, 1994; Hattori et al. 1995; Huet et al. 2001; Porstendorfer 2001; Tokonami et al. 1996; Vaupotic 2008; Yu et al. 1998) The unattached fraction is also more significant in a room with clean air since there are fewer aerosol particles to bound to (ICRU 2012).

The unattached fraction average is far beyond what is expected in a typical indoor environment of 0.03-0.08. There is no doubt that the rooms have very few aerosols since most particles are free (unattached) as there are not many particles in the air to get attached. High unattended fraction confirms that none of the homeowners where the sampling took place smoke indoors, although cigarettes are not the only aerosol source. These rooms have little dust as well as a result, and many radon progeny particles remain free. Combustion of food in the kitchen releases aerosols (ICRU 2012). However, the aerosols from this source are very few, and none of the measurements were made in the kitchen.

In rooms with poor ventilation, there is little radon and its progenies output. Therefore, their fractions tend to attach to the aerosol particles and stay in the air. A lot of attached fractions are formed, resulting in a higher equilibrium factor. Clean environments tend to have low attached fractions and high unattached fractions due to lack of aerosol. Most particles fall to the ground resulting in a low equilibrium factor (Porstendorfer 1994). Despite the unattached fraction being usually smaller when compared with the attached fraction, it has a significant effect on the bronchial dose because of its greater deposition efficiency in the bronchial region, giving a higher dose (ICRU 2012). Therefore, unattached fraction deserves special attention in dose calculation and risk assessment.

3.8. Variation of equilibrium factor over the time by the influence of ventilation rate, pressure, and humidity

The equilibrium factor changes over the years and in a short period of time. The positive correlation between radon concentration and equilibrium factors and negative correlation between the unattached and equilibrium factor has been observed. However, many other factors can influence the equilibrium factor. The study observed variation of equilibrium among the measured homes. The variations are mainly influenced by ventilation rate, humidity, atmosphere pressure. The figure bellow shows a variation of equilibrium factor in a room located in Ås for 4 days sampling period using 24 hours cycle (fig. 14).

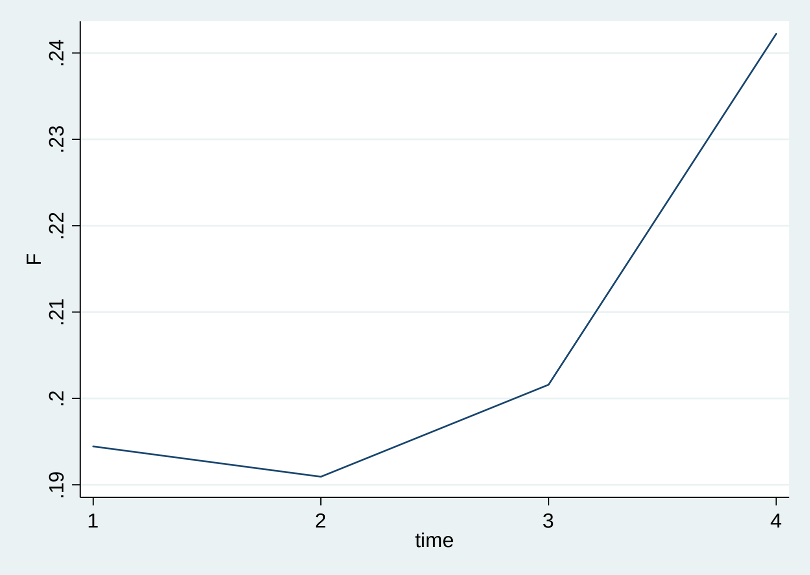

Figure 14. Variation of equilibrium factor in 4 days in one of the measure rooms in Ås**.**

Ventilation rate, pressure, and humidity are some environmental factors that can affect the equilibrium factor. There are three types of ventilation, natural, balanced, and mechanical. All houses have natural ventilation, so the study did not consider the different types of ventilation for comparison among the homes. But the type of ventilation used or ventilation rate in a home is an essential factor when measuring the indoor radon as it significantly influences radon influx (Stranden et al. 1979).

Ventilation rate deserves special attention since it can affect radon concentration (Krisiuk et al. 1971; Pohl-Ruhling J. and Pohl E., 1969 Wilkening et al. 1974; Jonassen 1975), mainly during cold winters when people keep the door and windows closed to conserve heat in dwellings (Stranden, Berteig et al. 1979). According to Chen and Harley 2018, ventilation rate is the factor that most influences the equilibrium factor variation. An increase in atmospheric pressure will decrease the radon concentration because of ventilation or exchange between indoor and outdoor air (Pohl-Rilling J. and Pohl E., 1969). Stranden et al. 1979 observed that a daily drop of the atmospheric pressure of 1.3 mbar resulted in an increase in the concentration of about 5% to 7%, while Jonassen (1975) the same decrease in atmospheric will increases almost 8% of the mean value of the radon concentration in a poorly ventilated room.

Eighty seven percent (87%) of the changes in the equilibrium factor are explained by variations in the explanatory variables. The study observed that EEC Radon, radon slow, and radon fast are statistically significant at a 10% significance level. When radon's equilibrium equivalent activity concentration (EEC Rn) increases by one unit of Bq/m^3, the equilibrium factor increases by 0.01. When radon slow (Rn slow) increases by one Bq/m^3, the equilibrium factor increases by 0.02. Radon fast (Rn fast) gives high statistical uncertainties and therefore is not used for the equilibrium factor variation. (Table 11)

Table 11. Regression showing the influence of pressure, humidity, radon concentration, and other variables in equilibrium factors in the indoor environment.

VARIABLES	(1) Coef.
B. pressure (mbar)	-0.00
	(0.00)
Humidity (%rH)	0.00
	(0.00)
Rn fast (Bq/m^3)	-0.02*
	(0.01)
Rn slow (Bq/m^3)	0.02*
	(0.01)
EEC Rn (Bq/m^3)	0.01**
	(0.00)
Unatt. EEC (Bq/m^3)	-0.01
	(0.02)
Clust. EEC (Bq/m^3)	0.02
	(0.02)
Constant	0.24
	(1.57)
Observations	12
R-squared	0.87

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

4- Conclusion

The results demonstrated that radon concentration in Oslo, Ski, and Ås varied from 24 Bq/m^3 to 569 Bq/m^3. Ås contained both the highest and the lowest, which was also found in Ski. However, the overall mean is 145 Bq/m^3. Radon concentrations mean values in Europe are around 69 Bq/m^{3,} and the world average is 39 Bq/m^3. These values are very low when compared to the value found in this study. However, the mean is lower when compared to the finding from the Norwegian radiation and nuclear safety authority and private companies in 1984 -2003. The results also demonstrated that the equilibrium factor varied from 0.1 to 0.35. Both the lowest and highest values are from Oslo. The regional and overall mean value is 0.25. The hypothesis was proven wrong since the equilibrium factor of 0.21 is almost half of both worldwide of 0.4 suggested by UNSCEAR 2008 and the previous measure value of 0.5 reported by Stranden et al. 1979.

The study had a limited number of measurements. Even though the given statistics are significant, they are not representative enough to conclude that the equilibrium factor has changed in Norway or is lower than the recommended value from UNSCEAR. Stranden et al. 1979 carried out equilibrium factor measurements only in Oslo in only 25 homes, and little or nothing is known about the rest of the country. The findings of this study may imply that recommended values of equilibrium factor for dose calculation can be used since simultaneous measurements of radon concentration and progenies are expensive. However, for better risk assessment, a measured equilibrium factor would give a more accurate value to avoid overestimating the radiation dose delivered to the lungs. More long-term measurements are needed to establish a national equilibrium factor value. More radon measurements are also required in many homes, and different municipalities in Norway, like the radon survey carried out by Norwegian Radiation Protection Authorities and private companies in 1984 -2003. More information is need about the influence of climate, type of ventilation, type of building, and other aspects that affect the equilibrium factor.

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Appendix

Appendix I. Results of measurements of the 1st phase of the study.

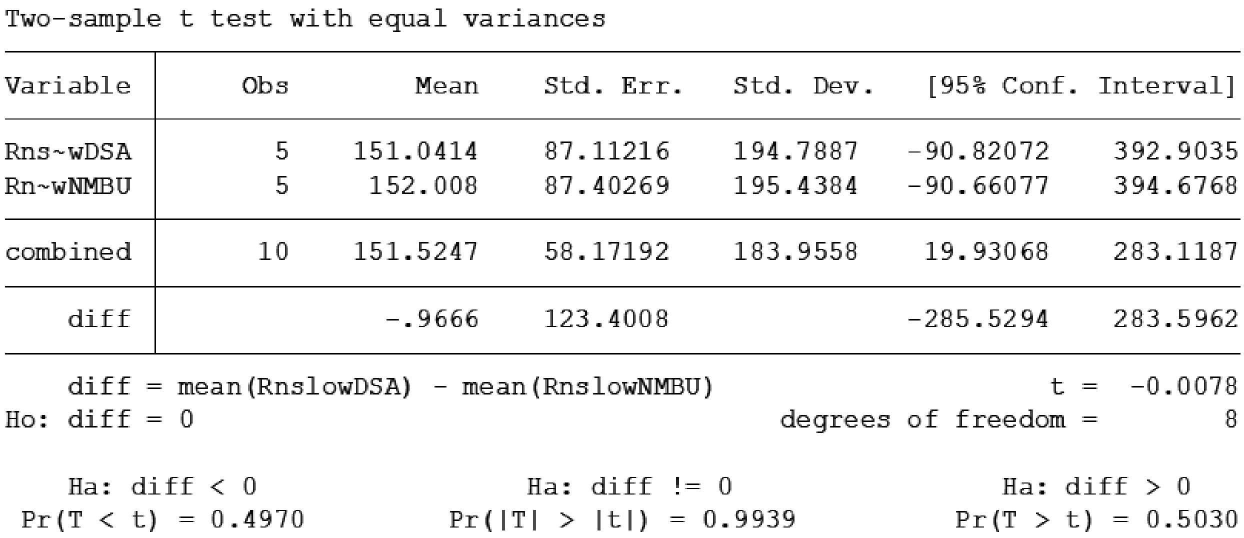
Table 12. Results of parallel DSA and NMBU instruments in 1h, 3h, 6h, 12h, and 24h-cycles of each of the 5 dwellings in Bærum, Oslo, Ski, and Ås in the first phase of the study.

Dwelling-1	N	Mean	Min	Max
Rn fast DSA (Bq/m^3)	23	155	90	225
Rn fast NMBU (Bq/m^3)	23	163	103	273
Rn fast error DSA %	23	19.4	15.4	25.8
Rn fast error NMBU %	23	18.1	13.5	22.4
Rn slow DSA (Bq/m^3)	23	155	78	227
Rn slow NMBU (Bq/m^3)	23	156	71	244
Rn slow error DSA %	23	13.4	10.7	19
Rn slow error NMBU %	23	12.7	9.85	18.6
Equilibrium factor DSA	23	0.27	0.17	0.36
Equilibrium factor NMBU	23	0.23	0.1	0.35
Unatt. fraction DSA	23	0.64	0.36	0.88
Unatt. fraction NMBU	23	0.56	0.25	0.85
Dwelling-2				
Rn fast DSA (Bq/m^3)	4	528	1.69	1058
Rn fast NMBU (Bq/m^3)	4	547	4.68	1150
Rn fast error DSA %	4	37.5	4.08	108
Rn fast error NMBU %	4	31.8	3.77	81.8
Rn slow DSA (Bq/m^3)	4	487	0.83	1078
Rn slow NMBU (Bq/m^3)	4	489	6.76	1120
Rn slow error DSA %	4	31.7	2.83	108
Rn slow error NMBU %	4	15.3	2.64	38.6
Equilibrium factor DSA	4	0.47	0.01	0.63
Equilibrium factor NMBU	4	0.38	0.05	0.65
Unatt. fraction DSA	4	0.37	0.13	0.53
Unatt. fraction NMBU	4	0.59	0.45	0.85
Dwelling-3				
Rn fast DSA (Bq/m^3)	6	50	20	74
Rn fast NMBU (Bq/m^3)	6	54	18	76
Rn fast error DSA %	6	11.9	5.92	17
Rn fast error NMBU %	6	11.3	5.51	18.8
Rn slow DSA (Bq/m^3)	6	52	24	78
Rn slow NMBU (Bq/m^3)	6	53	19	76
Rn slow error DSA %	6	7.56	3.89	10.6
Rn slow error NMBU %	6	7.35	3.68	11.3
Equilibrium factor DSA	6	0.11	0.07	0.2
Equilibrium factor NMBU	6	0.11	0.06	0.2
Unatt. fraction DSA	6	0.63	0.53	0.73
Unatt. fraction NMBU	6	0.57	0.37	0.79
Dwelling-4				
Rn fast DSA (Bq/m^3)	2	23	18	28
Rn fast NMBU (Bq/m^3)	2	23	22	25
Rn fast error DSA %	2	10.9	9.31	12.37
Rn fast error NMBU %	2	10.3	9.64	10.9
Rn slow DSA (Bq/m^3)	2	24	21	27
Rn slow NMBU (Bq/m^3)	2	24	23	25
Rn slow error DSA %	2	7.1	6.51	7.66
Rn slow error NMBU %	2	6.75	6.58	6.91
Equilibrium factor DSA	2	0.19	0.19	0.19
Equilibrium factor NMBU	2	0.22	0.2	0.24
Unatt. fraction DSA	2	0.3	0.29	0.31
Unatt. fraction NMBU	2	0.28	0.27	0.3

Dwelling-5

Rn fast DSA (Bq/m^3)	8	35	5.4	112
Rn fast NMBU (Bq/m^3)	8	42	6.2	124
Rn fast error DSA %	8	26.5	4.6	44.4
Rn fast error NMBU %	8	18	-1	35
Rn slow DSA (Bq/m^3)	8	37	4.9	119
Rn slow NMBU (Bq/m^3)	8	38	4.6	125
Rn slow error DSA %	8	16.1	3.09	28.2
Rn slow error NMBU %	8	15	2.9	30.2
Equilibrium factor DSA	8	0.23	0.18	0.33
Equilibrium factor NMBU	8	0.27	0.15	0.47
Unatt. fraction DSA	8	0.44	0.21	0.67
Unatt. fraction NMBU	8	0.38	0.23	0.6

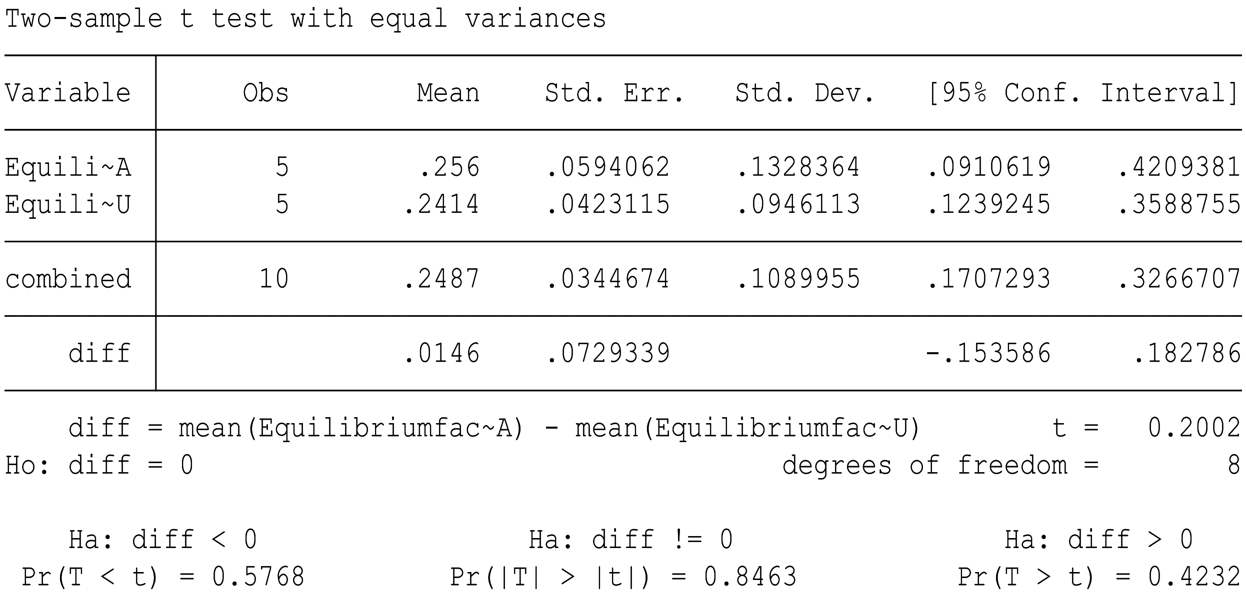
Table 13. The Results of the DSA- radon concentration paired t-test compared to NMBU-radon concentration with instruments in parallel.



```
Two-sample t test with equal variances
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
Rns~wDSA |       5    151.0414    87.11216    194.7887   -90.82072    392.9035
Rn~wNMBU |       5     152.008    87.40269    195.4384   -90.66077    394.6768
---------+--------------------------------------------------------------------
combined |      10    151.5247    58.17192    183.9558    19.93068    283.1187
---------+--------------------------------------------------------------------
    diff |               -.9666    123.4008               -285.5294    283.5962
------------------------------------------------------------------------------
    diff = mean(RnslowDSA) - mean(RnslowNMBU)                     t =  -0.0078
Ho: diff = 0                                     degrees of freedom =        8

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.4970         Pr(|T| > |t|) = 0.9939          Pr(T > t) = 0.5030
```

Table 14. The Results of the DSA- equilibrium paired t-test compared to NMBU- equilibrium factor with instruments in parallel.



```
Two-sample t test with equal variances
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
Equili~A |       5        .256    .0594062    .1328364    .0910619    .4209381
Equili~U |       5       .2414    .0423115    .0946113    .1239245    .3588755
---------+--------------------------------------------------------------------
combined |      10       .2487    .0344674    .1089955    .1707293    .3266707
---------+--------------------------------------------------------------------
    diff |               .0146    .0729339               -.153586     .182786
------------------------------------------------------------------------------
    diff = mean(Equilibriumfac~A) - mean(Equilibriumfac~U)        t =   0.2002
Ho: diff = 0                                     degrees of freedom =        8

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.5768         Pr(|T| > |t|) = 0.8463          Pr(T > t) = 0.4232
```

Appendix. II. Results of the measurements of the 2nd Phase of the Study

Table 15- Results of radon concentration measurements 24h-cycles in each of the 12 dwellings in Oslo, Ski, and Ås in the study's second phase.

Dwelling-1

	N	Mean	Min	Max
B. pressure (mbar))	14	997	977	1010
Temperature (^{0}C)	14	26	20	29
Humidity (%rH)	14	14.7	0	30
Rn fast (Bq/m^3)	14	64	20	83
Rn slow (Bq/m^3)	14	62	44	78
EEC Rn (Bq/m^3)	14	2.8	0.3	8.53
Unatt. EEC (Bq/m^3)	14	3.4	0.13	8.02
Clust. EEC (Bq/m^3)	14	0.09	0	1.2
F	14	0.1	0.01	0.2
Fp	14	0.57	0.31	0.74
Dwelling-2				
B. pressure (mbar)	2	1011	1009	1014
Temperature (^{0}C)	2	14	12	16
Humidity (%rH)	2	77.1	75.2	79.02
Rn fast (Bq/m^3)	2	44	33	56
Rn slow (Bq/m^3)	2	43	33	53
EEC Rn (Bq/m^3)	2	9.63	6.62	12.62
Unatt. EEC (Bq/m^3)	2	5.6	3.82	7.38
Clust. EEC (Bq/m^3)	2	0.3	0	0.6
F	2	0.35	0.33	0.38
Fp	2	0.38	0.37	0.4
Dwelling-3				
B. pressure (mbar)	4	990	988	992
Temperature (^{0}C)	4	29	28	31
Humidity (%rH)	4	11.72	0	24.8
Rn fast (Bq/m^3)	4	23	18	28
Rn slow (Bq/m^3)	4	24	21	27
EEC Rn (Bq/m^3)	4	3.51	2.86	4.2
Unatt. EEC (Bq/m^3)	4	1.39	1.19	1.62
Clust. EEC (Bq/m^3)	4	0.08	0	0.3
F	4	0.21	0.19	0.24
Fp	4	0.3	0.28	0.31
Dwelling-4				
B. pressure (mbar))	3	980	974	988
Temperature (^{0}C)	3	21	20	23
Humidity (%rH)	3	0	0	0
Rn fast (Bq/m^3)	3	30	23	39
Rn slow (Bq/m^3)	3	32	27	39
EEC Rn (Bq/m^3)	3	4.62	2.87	6.82
Unatt. EEC (Bq/m^3)	3	3.42	2.26	4.26
Clust. EEC (Bq/m^3)	3	0	0	0
F	3	0.26	0.18	0.35
Fp	3	0.43	0.35	0.6

Dwelling-5				
B. pressure (mbar)	2	1018	1017	1018
Temperature (^{0}C)	2	24	24	24
Humidity (%rH)	2	0	0	0
Rn fast (Bq/m^3)	2	66.	61	71
Rn slow (Bq/m^3)	2	67	63	71
EEC Rn (Bq/m^3)	2	6.8	5.8	7.79
Unatt. EEC (Bq/m^3)	2	7.55	6.16	8.93
Clust. EEC (Bq/m^3)	2	2.97	2.79	3.14
F	2	0.26	0.24	0.28
Fp	2	0.61	0.61	0.61
Dwelling-6				
B. pressure (mbar)	3	991	988	992
Temperature (^{0}C)	3	26	25	26
Humidity (%rH)	3	0	0	0
Rn fast (Bq/m^3)	3	110	87	152
Rn slow (Bq/m^3)	3	113	88	159
EEC Rn (Bq/m^3)	3	19.6	15.1	26.1
Unatt. EEC (Bq/m^3)	3	10.5	7	16.4
Clust. EEC (Bq/m^3)	3	2.36	1.7	3.6
F	3	0.29	0.27	0.3
Fp	3	0.39	0.33	0.43
Dwelling-7				
B. pressure (mbar)	2	1001	999	1003
Temperature (^{0}C)	2	26	26	27
Humidity (%rH)	2	0	0	0
Rn fast (Bq/m^3)	2	82	67	94
Rn slow (Bq/m^3)	2	83	73	94
EEC Rn (Bq/m^3)	2	10	8.77	11.2
Unatt. EEC (Bq/m^3)	2	7.7	7.03	8.39
Clust. EEC (Bq/m^3)	2	2.62	2.1	3.14
F	2	0.25	0.19	0.31
Fp	2	0.51	0.51	0.51
Dwelling-8				
B. pressure (mbar)	3	982	975	990
Temperature (^{0}C)	3	15	14	15
Humidity (%rH)	3	0	0	0
Rn fast (Bq/m^3)	3	363	334	413
Rn slow (Bq/m^3)	3	377	351	428
EEC Rn (Bq/m^3)	3	9.54	5.87	11.82
Unatt. EEC (Bq/m^3)	3	41.8	38.7	46.6
Clust. EEC (Bq/m^3)	3	9.51	6.1	11.8
F	3	0.16	0.14	0.18
Fp	3	0.85	0.81	0.88
Dwelling-9				
B. pressure (mbar)	5	1008	1004	1012
Temperature (^{0}C)	5	24	23	25
Humidity (%rH)	5	6.26	0	31
Rn fast (Bq/m^3)	5	218	9	358
Rn slow (Bq/m^3)	5	220	9	369
EEC Rn (Bq/m^3)	5	24.4	1.25	40
Unatt. EEC (Bq/m^3)	5	40	0.73	69
Clust. EEC (Bq/m^3)	5	16	0	30
F	5	0.33	0.22	0.38
Fp	5	0.58	0.37	0.78

Dwelling-10				
B. pressure (mbar)	4	998	992	1004
Temperature (^{0}C)	4	27	26	28
Humidity (%rH)	4	12.4	0	25.4
Rn fast (Bq/m^3)	4	115	107	124
Rn slow (Bq/m^3)	4	120	115	125
EEC Rn (Bq/m^3)	4	9.46	8.15	10.7
Unatt. EEC (Bq/m^3)	4	12.7	9.65	15
Clust. EEC (Bq/m^3)	4	2.37	1.85	2.84
F	4	0.20	0.19	0.23
Fp	4	0.61	0.53	0.67
Dwelling-11				
B. pressure (mbar)	3	981	972	995
Temperature (^{0}C)	3	25	25	26
Humidity (%rH)	3	25.6	23.8	29.1
Rn fast (Bq/m^3)	3	25	6.7	37
Rn slow (Bq/m^3)	3	24	6.1	35
EEC Rn (Bq/m^3)	3	4.6	0.5	9.8
Unatt. EEC (Bq/m^3)	3	2	0.7	2.62
Clust. EEC (Bq/m^3)	3	0	0	0
F	3	0.25	0.2	0.36
Fp	3	0.41	0.21	0.59
Dwelling-12				
B. pressure (mbar)	3	999	995	1000
Temperature (^{0}C)	3	20	20	21
Humidity (%rH)	3	41.9	40.5	43.3
Rn fast (Bq/m^3)	3	569	478	745
Rn slow (Bq/m^3)	3	569	474	751
EEC Rn (Bq/m^3)	3	111	96.6	123
Unatt. EEC (Bq/m^3)	3	69	54.3	93.7
Clust. EEC (Bq/m^3)	3	10.2	8.68	12.4
F	3	0.34	0.31	0.38
Fp	3	0.41	0.38	0.46

Table 16. Variance covariance showing the relationship between the explanatory variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) B. pressure (mbar)	1.000									
(2) Temperature (^{0}C)	-0.052	1.000								
(3) Humidity (%rH)	0.284	-0.483	1.000							
(4) Rn fast (Bq/m^3)	-0.010	-0.412	0.115	1.000						
(5) Rn slow (Bq/m^3)	-0.018	-0.417	0.103	1.000	1.000					
(6) EEC Rn (Bq/m^3)	0.115	-0.201	0.320	0.850	0.839	1.000				
(7) Unatt. EEC (Bq/m^3)	0.065	-0.404	0.111	0.979	0.978	0.834	1.000			
(8) Clust. EEC (Bq/m^3)	0.218	-0.277	-0.115	0.746	0.749	0.524	0.853	1.000		
(9) F	0.384	-0.288	0.473	0.222	0.212	0.483	0.320	0.327	1.000	
(10) fp	0.067	-0.318	-0.401	0.313	0.329	-0.163	0.311	0.451	-0.443	1.000

Appendix III. Information about year of construction and type of ventilation of all the measured dwellings

Table 17. Information about the year of construction and type of ventilation of all the 14 dwellings measured in Bærum, Oslo, Ski, and Ås.

Dwelling number	Year of construction	Type of ventilation
1	1983	Natural
2	1952	mechanical
3	1986	Natural
4	1975	Natural
5	1983	Natural
6	1968	Natural
7	1973	Natural
8	1968	Natural
9	1971	Natural
10	2001	Natural
11	1968	Natural
12	1952	Natural
13	2010	mechanical
14	1986	Natural

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