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Radiation Doses to the Norwegian Population

Summary of radiation doses from planned exposure and the environment

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Radiation doses. Radiation. Doses. Radiation exposure. Radioactivity. Environment. Food. Planned exposure. Medical radiation.

Abstract:
This report presents average radiation doses received by the Norwegian population from different sources of medical radiation, cosmic radiation, and from naturally occurring and artificial radioactivity in the environment and food. Examples of population groups with elevated exposure are also presented.

Referanse:
Komperød M, Friberg EG, Rudjord AL. Stråledoser til befolkningen. Oppsummering av stråledoser fra planlagt strålebruk og miljøet i Norge.
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Emneord:
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Resymé:
Rapporten presenterer gjennomsnittlige stråledoser til befolkningen i Norge fra ulike kilder innen medisinsk strålebruk, kosmisk stråling og fra naturlig og menneskeskapt radioaktivitet i miljøet og næringsmidler. Det er også gitt eksempler på befolkningsgrupper som får høyere doser enn gjennomsnittet.

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Radiation Doses to the Norwegian Population

Summary of radiation doses from planned exposure and the environment

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Statens strålevern

Norwegian Radiation
Protection Authority
Østerås, 2015

Content

1 Introduction

Radiation can be found everywhere in the environment. Naturally occurring radioactivity has always been present in the food we eat, the air we breathe, and in the ground beneath our feet– even in our bodies. Human activities are also causing radioactive contamination of the environment.

In addition to these sources, humans receive radiation through planned exposure in medical examinations, research and industry. Radiation from planned exposure contributes significantly to the national average dose, but the level of exposure varies greatly from person to person.

This report provides a summary of the estimated annual radiation doses received by the average Norwegian. We are presenting *effective* doses, which takes into account how damaging the radiation is to the body. More details concerning the calculations of estimated doses presented here, are provided in StrålevernRapport 2014:2 (1) and 2015:11 (2) (in Norwegian).

Workers in some occupations are more exposed to radiation than the average population. One example is medical personnel working with X-rays. Radiation doses to these occupationally exposed groups are not included in the calculation of doses to the general public; however, a few examples are provided in chapter 4.3.

Definitions of key concepts discussed in this report are provided on page 8.

1.1 What is radiation, and why is it harmful?

Radiation is the transport of energy in the form of particles or electromagnetic waves. There are two basic forms of radiation: ionising and non-ionising. Ionising radiation has enough energy to remove electrons from atoms and molecules in cells, creating ions. This can cause biological damage in the DNA or others parts of the cell. At low radiation doses, which is what we discuss in this report, the potential for adverse health effects is mainly an increased risk of developing cancer. Ionising radiation includes X-rays and radiation from radioactive elements.

Non-ionising radiation does not have enough energy to remove electrons from atoms and molecules. Examples of non-ionising radiation is UV light, visible light, and electric and magnetic fields. In this report, we are only discussing doses from ionising radiation.

1.2 How is the body exposed to radiation?

Radiation exposure can occur either by internal exposure via ingestion of radioactive substances through our diet or via inhalation into the lungs, or by external exposure to penetrating radiation from a source located outside of the body (Figure 1). Alpha and beta rays have a short range and can usually only cause damage if the radioactive elements make their way into the body through the digestive or respiratory system. Gamma rays and X-rays are highly penetrating. These rays have a long range in air and may deposit energy anywhere in the body, including inner organs.

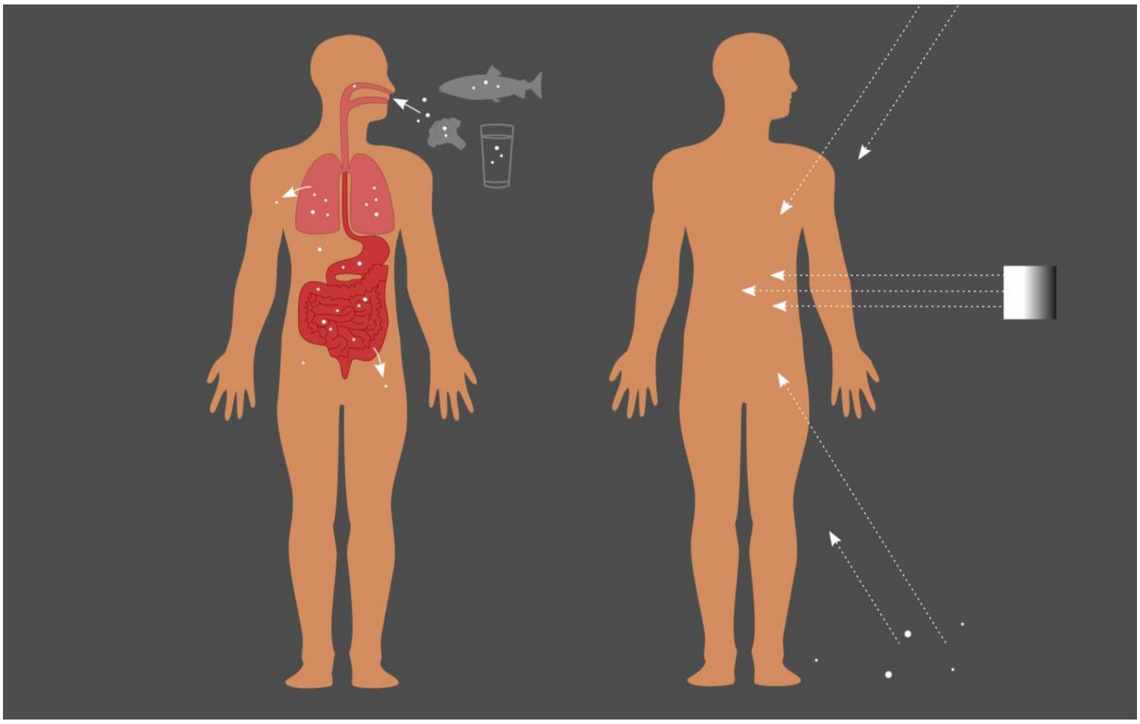


Figure 1. The different pathways for exposure to ionising radiation. When you eat or drink, radioactive elements can cause radiation doses directly in the digestive system. Some elements may also be absorbed in the gut and transported to other parts of the body. Likewise, inhalation of radioactive substances in the air can cause doses directly to the lungs, or become absorbed and cause doses to other organs. External exposure takes place when the source of radiation is located outside of the body, as is the case with X-ray instruments, radioactive materials in the ground, or cosmic radiation. Gamma rays and X-rays can also pass through the body without causing any damage at all. (Illustration: Mari Komperød).

1.3 Where does the radiation come from?

1.3.1 Radiation originating from human activities (artificial sources)

Ionising radiation is used in the medical field in the treatment of diseases and for diagnostic purposes, such as conventional X-rays and CT imaging. Exposure to medical radiation is increasing, mainly because technological advances allows for new types of diagnostic examinations and treatments.

The Norwegian environment is contaminated by artificial radioactive materials from sources such as the nuclear industry, nuclear weapons testing and releases of radioactive materials from hospitals and research facilities. The release of long-lived radioactive substances cause long-term problems. For example, radioactive contamination from the Chernobyl accident in 1986 is still present in the soil in Norway, and continues to be absorbed by plants and mushrooms and transferred up the food chain. Norwegian seas and coastal areas are also continuously receiving radioactive contamination from foreign sources, such as Sellafield in Great Britain.

The expression *radioactive contamination* covers both the release of artificial radioactive material to the environment, and instances where human activities lead to a build-up of naturally occurring radioactive substances in the environment. The latter is the case for example in the oil industry, where sea water containing enhanced levels of naturally occurring radioactivity in the reservoirs (so-called “produced water”) is pumped up along with the oil.

1.3.2 Radiation originating from natural sources

Most of the radiation in the environment occurs completely naturally. Most of these substances originate in rock in the ground, but many of them are transported to other parts of the environment, for example radon gas in the air or potassium-40 present in our food.

The earth is continuously bombarded with cosmic radiation from space. The atmosphere blocks most of this radiation, but a small fraction reaches the earth's surface. In addition, certain stable elements in the atmosphere are transformed into radioactive elements due to the impact of cosmic radiation. These so-called cosmogenic radioactive elements make up a very small contribution of the natural radioactivity in our environment.

Definitions of key concepts related to radiation

Radiation is transportation of energy in the form of particles (particle radiation) or waves (electromagnetic radiation). Ionising radiation is radiation with enough energy to remove electrons from atoms and molecules (including DNA molecules) in cells that are hit, thereby causing biological damage in the body. Ionising radiation includes X-rays and radiation from radioactive substances. (Non-ionising radiation includes UV light, visible light, infrared radiation, and electric and magnetic fields.)

Radiation dose is a measure of how much radiation energy that is absorbed in a tissue. In this report, we are discussing *effective* doses, which is a quantity that describes how damaging the radiation is to the body by taking into account the type of radiation (alpha, beta, or gamma/X-ray) and which organs or tissues that are being irradiated. The unit for effective dose is the sievert (Sv).

Radioactive elements are atoms with an unstable nuclei. An unstable nucleus will spontaneously decay into another element or isotope, and emit ionising radiation in the form alpha, beta, and/or gamma radiation in the process. Some radioactive elements are naturally occurring, and have always been present in the environment. Others are artificial; that is, produced as a result of human activity.

The activity of radioactive elements if measured in **bequerel (Bq)**. 1 Bq is defined as one nucleus decay per second. As a result of the decay, the atom is now transformed into a new isotope of the same element, or a different element which may have vastly different properties.

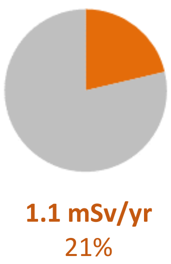
X-rays are an artificial source of radiation and are generated when voltage is added to an X-ray tube. The energy of the X-ray beam can be altered by changing the voltage, and thus creating the radiation quality that fits the purpose. X-rays with low energy are often used to make images for diagnostic purposes. X-rays with high energy are used in radiation therapy to kill cancer cells.

2 Planned radiation exposure

Radiation is used for various purposes in the fields of medicine, research, industry, and nuclear facilities. Planned exposure mainly results in doses to patients and to workers in a few particularly exposed occupations. In situations where planned exposure leads to radioactive contamination, and therefore causes exposure of the general population, these contributions are included in doses from the environment in chapter 3.

In this report, medical imaging is the only form of planned exposure that is included in the average dose to the general public. The reason is that diagnostic examinations concern the population in general. This is not the case for radiation therapy, in which radiation is administered as part of the treatment of disease. The additional dose received by exposed workers is not included in calculations of average doses to the population because the radiation exposure is related to an occupation, and not the general public. Occupational exposure is briefly mentioned in chapter 4.3.

2.1 Doses to patients from medical imaging



Medical diagnostic imaging make up the largest contribution to the average dose from artificial sources. Patients' exposure to medical radiation is different from other radiation exposures because it is applied to the patient's own advantage, and in a controlled setting.

The radiation dose that the patient receives at each examination varies greatly according to the type of imaging used and which organs are being exposed, but also depending on the type of equipment and local procedures. CT imaging and interventional radiology generally cause higher radiation doses than conventional X-rays.

The average total radiation dose from diagnostic imaging is estimated to 1.1 mSv/year (1, 4) (Figure 2). The annual contributions from the various types of imaging are as follows:

- 0.88 mSv from CT
- 0.11 mSv from angiography
- 0.05 mSv from nuclear medicine
- 0.03 mSv from conventional X-rays
- 0.02 mSv from dental X-rays

Doses from medical imaging are unevenly distributed in the population: Most individuals receive no or very low doses from medical examinations each year (e.g. a dental X-ray), while a few patients receive many mSv during the course of a year. Therefore, very few actually receive a dose that corresponds to the estimated average.

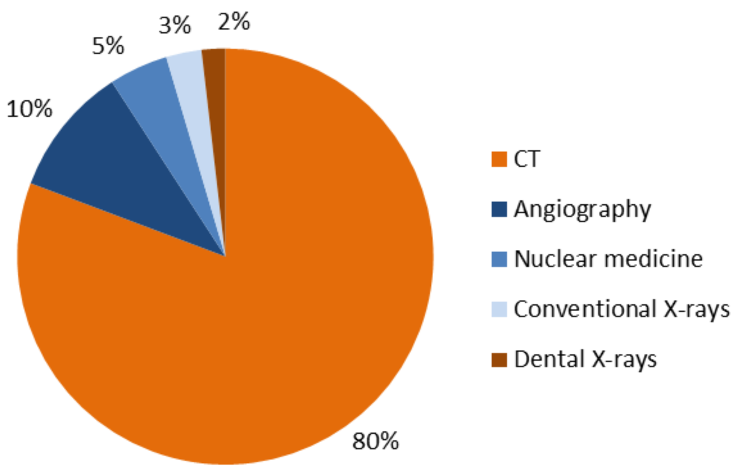


Figure 2. The diagram shows the estimated annual radiation doses (mSv/year) from various types of medical diagnostic imaging in Norway. The total average dose from all types of examinations is estimated to 1.1 mSv/year.

CT makes up 80 % of the radiation dose caused by medical examinations, and the number of CT examinations is increasing. Referrals to diagnostic imaging must be medically justified. As long as the examinations are medically justified, the benefit of receiving medical radiation will outweigh the potential health risks associated with the radiation dose in almost all cases[1].

[1] More details on the dose estimates are available in StrålevernRapport 2010:12 (5) and StrålevernInfo 2012:2 (6) (both in Norwegian).

3 Radiation from the environment

In this chapter, we present radiation doses from both naturally occurring and artificial sources in the surrounding environment. We are all exposed to these sources every day through inhalation, ingestion and external radiation. The underlying calculations for the radiation doses presented in this chapter are provided in detail in StrålevernRapport 2015:11 (in Norwegian).

3.1 Radioactive substances in the air

The majority of the radioactive elements we find in the air originate either from gas emanating from the ground or building material, or from resuspended soil particles. Radioactive substances in the air mainly cause doses to the lungs, although some elements may also be absorbed through the lung tissue and transported to other organs. Of the various elements that we are exposed to via inhalation, radon causes by far the largest dose. In the case of both radon and thoron, it is in fact their progeny (decay products) that cause most of the radiation dose.

3.1.1 Radon in air

2.5 mSv/yr
48%

Radon (radon-222) is a gas that continuously forms in rock and soil. Normally, the radon concentration outdoors is low. Indoors, however, radon may concentrate to high levels and cause significant radiation doses. Radon gas usually enters the building from the ground through cracks and unsealed openings in the building.

When the buildings are heated during the winter, a negative pressure is created inside the building. This forces ground air and radon gas into the building unless the building is completely sealed towards the ground below (Figure 3). If radon is present in the household water, which may especially be a problem inn wells drilled in rock, the radon gas is released to the indoor air when water is tapped. This may add a significant contribution to the radon levels in the indoor air[2].

Areas of the country containing rocks with a high level of uranium (e.g. alum shale, granite and pegmatite), as well as areas where the ground is highly permeable, have a higher risk of elevated radon concentrations. A survey from 2000-2001 showed an average radon concentration of 88 Bq/m^3 in indoor air in Norway, which according to our estimations results in an average dose of 2.5 mSv/year. This is somewhat higher than the previous estimate of 2.2 mSv. The slight increase is due to the fact that the previous estimate used the worldwide average of 80% indoor occupancy, whereas the new calculation factors in 90% indoor occupancy, which according to statistics is the average in Norway (7).

[2] The radiation dose received when drinking water containing radon is included in the calculation of doses from ingestion in chapter 3.2. However, the dose from radon that is released from water to the air, and then inhaled, is included in the estimated dose from air presented in this chapter.

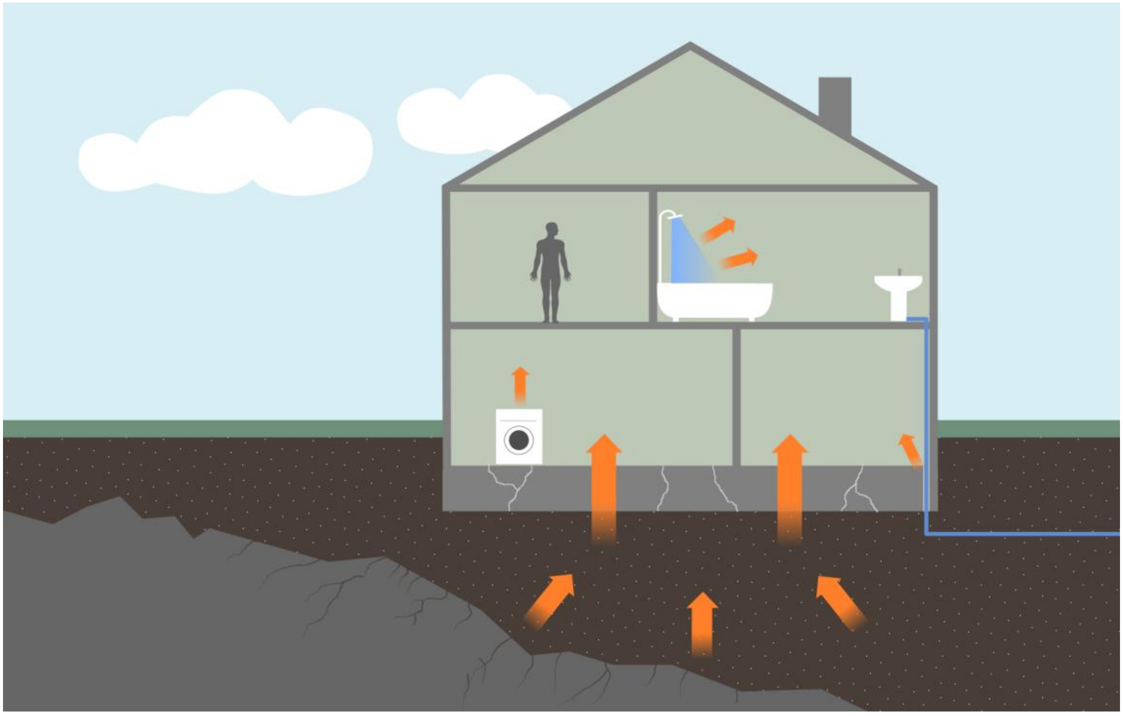


Figure 3. Radon enters the building from the ground below through cracks and unsealed openings in the building and foundation. If the household water contains radon, radon gas is released to the indoor air when water is tapped, for example during use of the shower or washing machine. (Illustration: Mari Komperød)

3.1.2 Thoron in air

0.22 mSv/yr
4.3%

Thoron (radon-220) is a radon isotope that has many of the same properties as radon-222, but it usually does not receive as much attention. In most cases, thoron doses are far lower than the doses from radon; however, thoron doses are not insignificant. The majority of the thoron present in the indoor air originates from indoor building surfaces containing rock. A limited research study in Norway has found an average thoron concentration that corresponds to a radiation dose of 0.22 mSv/year, ranging from 0.02 to 0.35 mSv/year (8).

3.1.3 Other radioactive substances in the air

0.006 mSv/yr
0.12%

Radioactive elements other than radon and thoron are also found in the air, although usually in low concentrations. The worldwide average radiation dose from naturally occurring radioactive substances other than radon and thoron in air has been estimated to 0.006 mSv/year, of which the largest contribution comes from lead-210, followed by polonium-210 (9). The dose received by inhalation of artificial radioactive elements is negligible and assumed to be 0 mSv/year for the purpose of our calculations.

The total dose caused by inhalation other radioactive elements other than radon and thoron is therefore estimated to 0.006 mSv/year.

3.2 Radioactive substances in food and drinking water

Radioactive elements in the diet emits radiation to the digestive system. Some radioactive substances are actively absorbed and transported to other tissues in the body, such as muscles or the skeleton, while others are quickly excreted.

Using conversion coefficients of the International Commission of Radiation Protection (ICRP) (10), the radiation dose to the average Norwegian from food and drinking water was estimated to 0.52 mSv/year from naturally occurring sources and 0.01 mSv/year from artificial sources. This brings us to a total of 0.53 mSv/year from the Norwegian diet[3].

Potassium-40 is present in most foods; however, the potassium concentration is carefully regulated by the body. Therefore, potassium-40 causes a fairly contant radiation dose of approximately 0.17 mSv/year, regardless of the amount of potassium-40 in your diet.

Fish and shellfish cause by far the highest radiation dose of all the food groups in the average Norwegian diet (Figure 4). This is because seafood, and especially shellfish, contain more polonium-210 and radium than other food products. Radon in groundwater supplies is the main contributor to the average radiation dose from drinking water.

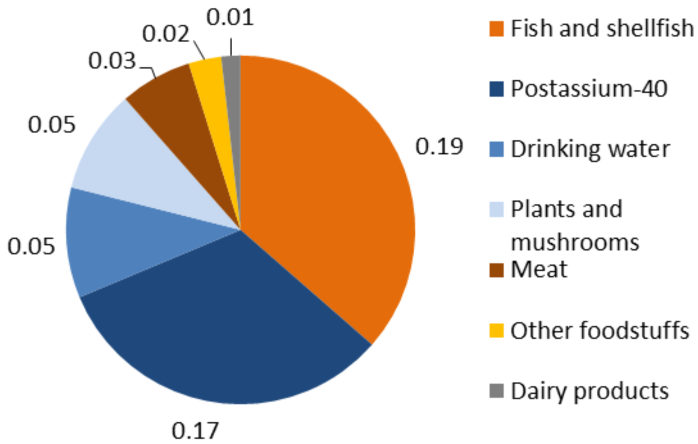


Figure 4. The diagram shows the estimated average dose (mSv/year) from natural and artificial radioactive elements in different food groups. The doses from potassium-40 and carbon-14 are displayed separately because they are present in nearly all foods and the doses are relatively constant regardless of the diet.

The long-lived radioactive element caesium-137 is the main contributor to the dose from radioactive contamination today. The majority of the caesium-137 that can be found in food products from the terrestrial environment in Norway, stems from the Chernobyl accident in 1986. In general, the concentration of radioactive contamination in seafood is much lower than in foods derived from the terrestrial environment and freshwater systems.

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[3] Doses from the Norwegian diet are conservatively estimated. This is because ICRPs dose conversion coefficients themselves are somewhat conservatively estimated, and because the radioactivity levels in food will decrease to a certain extent during storage and preparation (cooking). We have nevertheless chosen this approach as this is the norm in radiation protection and because we do not wish to risk underestimating the doses from foodstuffs.

3.3 External radiation from the environment

Everyone is exposed to external ionising radiation from the surrounding environment every day. The most significant sources are cosmic radiation from space and radioactive elements in the ground and in buildings.

3.3.1 Cosmic radiation

0.35 mSv/yr
6.8%

The earth is continuously bombarded with rays and particles from space. The dose from cosmic radiation increases with increasing altitude and latitude. Taking into account the amount of time spent indoors, we can estimate an average dose of 0.31 mSv/year received by the Norwegian population at ground level, ranging from 0.30 to 0.45 mSv/year depending on where you live (Figure 5).

Because radiation exposure is much higher at very high altitudes, many people also receive an extra radiation dose from air travel each year. The average dose from comic radiation received during air travel is estimated to 0.04 mSv/year; however, the actual dose will vary greatly depending on how frequent and how far you fly. In summary, the total average dose to the Norwegian population from cosmic radiation is estimated to 0.35 mSv/year.

3.3.2 Radiation from the ground and building materials

0.47 mSv/yr
9.1%

Radioactive elements emitting gamma radiation is present almost everywhere in the environment. The floors and walls of our buildings shield us from much of the radiation from the outdoor environment. However, building materials derived from rock, such as concrete and brick, also contain naturally occurring radioactive elements that emit radiation.

The actual dose rates indoors and outdoors are very similar; however, since Norwegians are indoors 90% of the time on average (11), the indoor dose rate plays a much larger role in determining the average dose to the public. The external radiation dose received indoors is estimated to 0.43 mSv/year, while the external radiation dose received outdoors is estimated to 0.04 mSv/year. In total, the calculated average dose from external radiation received from the ground and building materials is 0.47 mSv/year.

Deposition of caesium-137 on the ground caused a relatively high dose from external radiation in the most contaminated areas immediately following the Chernobyl accident. Today, however, radioactive contamination only amounts to a small fraction of the external radiation dose from the environment. Naturally occurring radioactive substances is responsible for most of the radiation dose we receive from the ground and elsewhere in nature when we are outdoors. The radiation dose received outdoors is highly dependent on the type of rock present in the ground (Figure 5).

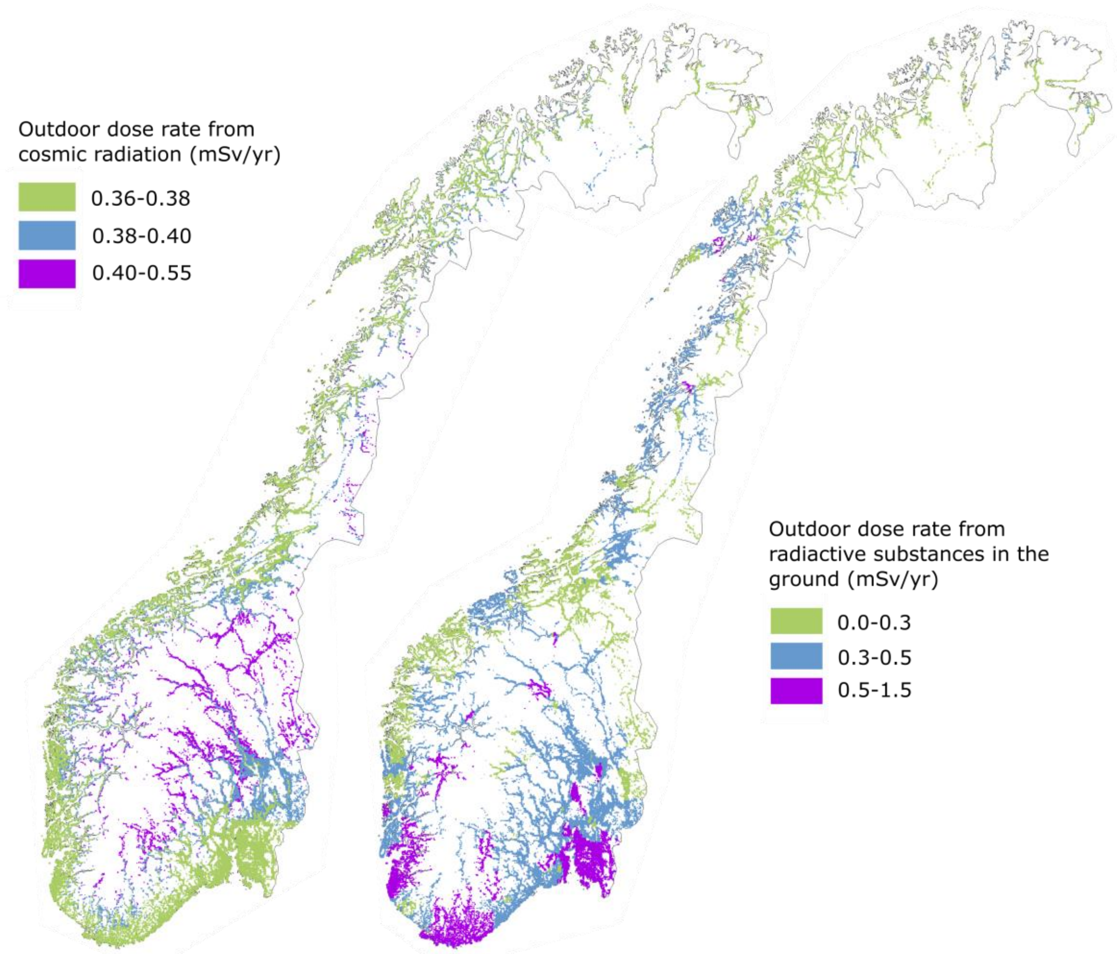

Figure 5. Average dose rates (mSv/year) outdoors from cosmic radiation (left) and radioactive substances in the ground (right) in Norway. The maps only shows dose rates in populated areas. Dose rates are higher than the estimated radiation dose to the public, because the dose also takes into account the shielding of building materials during indoor occupancy.

4 Summary of radiation doses received by the Norwegian Population

4.1 Average radiation dose

The total average dose from ionising radiation to the Norwegian population is estimated to 5.2 mSv/year. The single highest dose contribution is caused by inhalation of radon in indoor air. Medical imaging provides by far the largest dose contribution from artificial sources.

Radioactive contamination contributes little to the average dose compared to other sources of radiation; however, radioactive contamination may still cause a significant contribution to a few highly exposed groups (see chapter 4.3). Figure 6 provides an overview of the average doses received by the Norwegian public from different exposures.

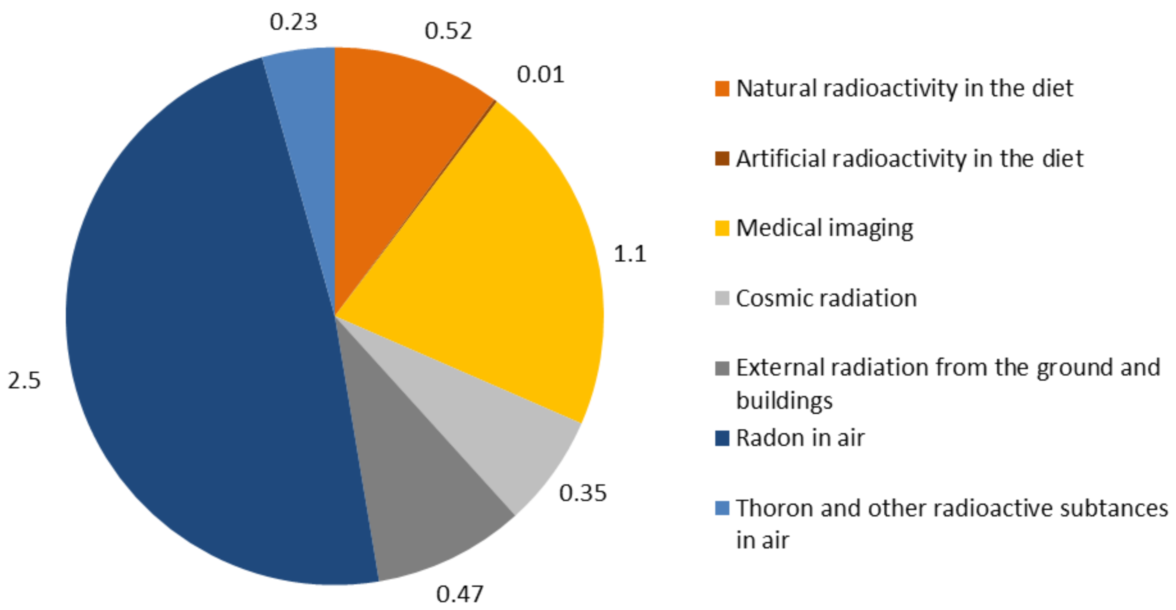

Figure 6. Summary of the average radiation dose (mSv/year) received by the Norwegian population from various sources.

The estimated total dose presented here is slightly higher than the previous estimate of 4.6 mSv/year. The increase is mainly due to the inclusion of thoron in the calculation and the use of a higher and more accurate indoor occupancy rate when calculating the dose from radon. A more detailed calculation of doses from the diet also reveals a slightly higher dose from natural radioactivity than previously estimated.

By comparison, UNSCEAR estimates a worldwide average radiation dose of approximately 3.0 mSv/year (12). The higher dose estimate for the Norwegian population is mainly due to higher doses from radon related geological conditions and building practice, as well as higher doses from medical examinations, reflecting the high standard of health care systems in industrialised countries compared to developing countries [4].

4.2 Development of radiation doses over time

The average radiation dose may vary with time. Our estimations show that doses from some sources are increasing, while others are decreasing.

4.2.1 Medical use of radiation

Medical use of radiation is rapidly increasing. This is related to technological developments in medical equipment, along with an increasing number of professions and departments performing radiological procedures. The radiation dose per examination has generally diminished, mainly due to technological advances and stricter requirements in radiation protection optimisation. There has also been major changes in the usage pattern for the various radiological modalities, and the use of CT has doubled from 2002 to 2008. PET and PET/CT scans have also become more common in the field of nuclear medicine, and the dose contribution from PET is expected to increase (5).

Norway performs slightly fewer radiological examinations per person than the European average, but is at the same time among the countries performing the most examinations using CT in Europe. As a result of the many CT scans, Norway is also among the countries with the highest radiation doses from radiological examinations in Europe (13, 14).

4.2.2 Naturally occurring radioactivity

Naturally occurring radioactivity will always be present in the environment. However, your radiation exposure is influenced by factors such as where you live, your building construction, dietary habits and drinking water quality. Radon in indoor air and drinking water can effectively be reduced with simple and affordable countermeasures. Such countermeasures reduce the radiation doses to individuals, and over time, this may potentially noticeably reduce the average doses received by the population. Meanwhile, more frequent and longer flights is leading to slightly increasing doses from cosmic radiation to the general public.

4.2.3 Radioactive contamination

Terrestrial radioactive contamination in Norway is almost exclusively a result of past incidents, and the levels are slowly decreasing as the radioactive substances are washed out and decay. Continuous releases to the sea from Norwegian and foreign sources has also contributed to the contamination of Norwegian waters. These releases have been reduced since the early 2000s, and the levels in the marine environment are slowly decreasing as a result.

Countermeasures still have to be carried out each year to reduce the concentration of caesium-137 from the Chernobyl accident in sheep and semi-domesticated reindeer. Individuals may reduce their radiation doses by limiting their intake foods high in caesium-137. This is mainly relevant to reindeer herders and others who eat large amounts of reindeer, game and other wild foods from the most contaminated areas.

[4] The world average dose estimates is 1.26 mSv/year for radon inhalation and 0.6 mSv/year for medical examinations (11).

4.3 Population groups with elevated exposure

Some groups within the population receive higher doses of radiation than the average Norwegian. This increased exposure may be related to what they eat, where they live, or their occupation. We have estimated radiation doses of fictitious individuals representing six groups with elevated radiation exposure:

- A person with a high consumption of wild foods (game and wild mushroom and berries) from a highly contaminated area
- A person with a high seafood consumption
- Average aircrew
- A person with a high consumption of reindeer from a contaminated area (reindeer herder)
- A person with high levels of natural radioactivity in the drinking water
- A patient receiving one abdominal CT scan per year as a part of a follow-up examination[5]
- A person living in a building with high levels of radon (based on 1000 Bq/m^3)

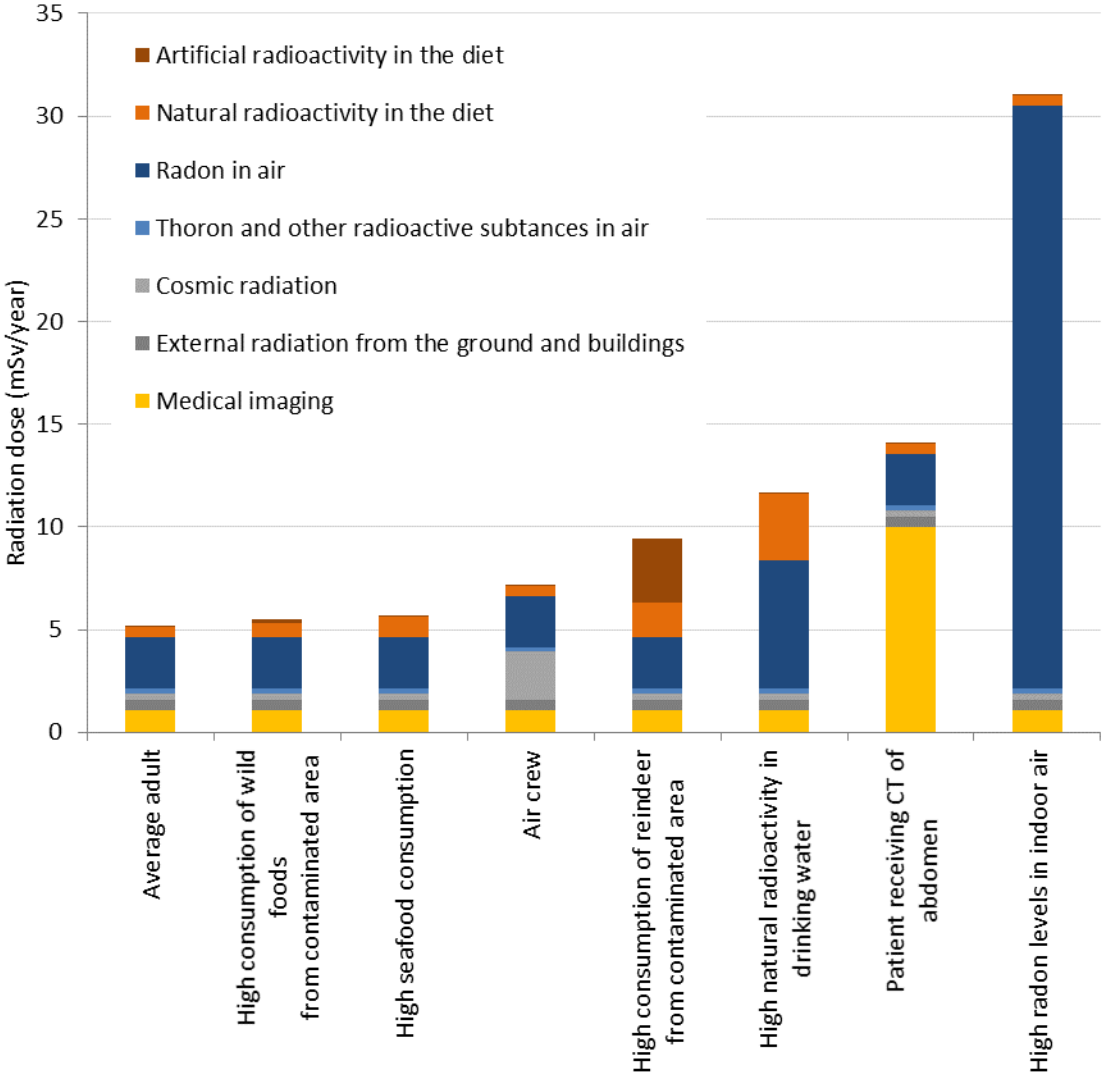

Figure 7. Comparison of radiation doses received by an average Norwegian and persons representing the various examples of elevated exposure. (The assumptions and estimations are described in the Strålevernrapport 2015:11 (in Norwegian)). This comparison is only meant to illustrate the point that different population groups receive different doses depending on e.g. diet, residence or occupation.

[5] The estimated dose from one CT scan to the abdomen is 10 mSv.

These are only examples of how different factors affect the radiation dose, and there will be many individuals within each of these groups receiving both higher and lower doses. There are also individuals that are exposed to elevated levels due to other factors than the ones we have selected to present.

Naturally occurring radioactivity in the ground cause significantly elevated doses for persons living in buildings with high radon levels in the indoor air or that have a high level of natural radioactivity in their drinking water (of which radon causes the highest dose contribution). Reindeer herders living in the most contaminated areas are also exposed to a significant dose contribution from radioactive contamination.[6]

The figure clearly shows that radiation exposure related to medical imaging greatly impacts the radiation dose of the individuals undergoing these examinations. People who receive one or more CT scans per year as part of a disease follow-up, for example, will have a high level of exposure compared to the national average.

Occupational exposure

Workers in some occupations also receive significantly higher doses than the average Norwegian. This may be due to increased levels of natural radioactivity in their workplace, such as increased exposure to cosmic radiation for aircrew (figure 7) or increased exposure to radon for people working in rock caverns.

For other occupations, the exposure is related to the planned use of radiation (chapter 2). People working with medical radiation are generally the most exposed occupation group. This is particularly the case for personnel performing interventional procedures, such as interventional radiologists and cardiologists. In addition to the risk associated with the radiation dose received by the whole body, high radiation doses to the eye lens may also cause cataract.

The radiation dose to all occupationally exposed workers in Norway must be monitored, and the annual dose must not exceed 20 mSv from the radiation source related to their occupation.[7]

[6] The radiation doses from ingestion are estimated using ICRPs dose conversion factors and are somewhat conservatively estimated. The calculated dose to a person with a high consumption of reindeer from a contaminated area is 3 mSv/year, while whole body measurements of caesium-137 in the bodies of reindeer herders suggest that the actual doses from their ingestion of reindeer meat is probably lower than our estimation shows. Based on the direct whole body measurements of reindeer herders, there are likely still individuals receiving doses of more than 1 mSv/year from the radioactive fallout from the Chernobyl accident.

[7] More information about occupationally exposed workers is available in StrålevernRapport 2011:11 (3) (in Norwegian).

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