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Risk assessment of radioactivity in food

Opinion of the Scientific Committee of the Norwegian Scientific Committee for Food Safety

VKM, Alexander J, Brantsæter AL, Brunborg G, Fæste CK, Jaworska A, Komperød M, Lillegaard ITL, Rosseland CM, Skuterud L, Andersen LF, Elvevoll EO, Hjeltnes B, Hofshagen M, Krogdahl Å, Källqvist T, Opsahl-Sorteberg HG, Rafoss T, Skaar I, Skåre JU, Steffensen I-L, Vandvik V, Wasteson Y, Hemre G-I.

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Opinion of the Scientific Steering Committee of the Norwegian Scientific Committee for Food Safety
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Risk assessment of radioactivity in food

Authors of the opinion

The Norwegian Scientific Committee for Food Safety (Vitenskapskomiteen for mattrygghet, VKM) has appointed a working group consisting of both VKM members and external experts to answer the request from the Norwegian Food Safety Authority.

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Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

Table of Contents

Summary

Key words: VKM, risk assessment, Norwegian Scientific Committee for Food Safety, Norwegian Food Safety Authority, radioactive elements in food, caesium-137, Chernobyl disaster follow-up, Euratom Treaty regulation,

Since 1986, the management of radioactive contamination in food and feed in Norway has been driven mainly by the Chernobyl Disaster follow-up. Monitoring and countermeasures are still in place to reduce the exposure to the population. The Norwegian Food Safety Authority is in the process of revising the maximum levels (MLs) for radioactive substances in drinking water and food and establishing new ones where necessary (including for feed). These MLs are to be applicable in the management of the normal situation, immediately subsequent to any accidents, and possibly in the long-term follow-up period after accidents. As part of this process, the Norwegian Food Safety Authority requested the Norwegian Scientific Committee for Food Safety to assess the risk that radioactivity in food and feed poses to human health. More specifically, VKM was requested to address the following questions in the Terms of Reference (ToR):

- ToR1: What is the current health risk from radioactivity in food –food gathering and hunting included – to the whole population and specific groups in Norway?
- ToR2: What health risk would the current levels of caesium-137 measured in live reindeer and sheep pose to the whole population and specific groups, if no efforts were made to reduce them?
- ToR3: What would be the implication to the health risk if the ML for reindeer meat was reduced from 3000 to 1500 or 600 Bq/kg, respectively – for the whole population and for specific groups?
- ToR4: Would the procedure and the maximum levels laid down in the Euratom Treaty regulation on radioactive contamination of foodstuffs and feedstuffs following a nuclear accident be appropriate for managing similar scenarios in Norway?

All food products in the human diet contain radioactive elements. Although some of these elements are due to human activity, most radioactive elements present in our diet are of natural origin. Several factors affect the concentrations of the different radioactive elements in the various food products, including the abundance and chemistry of the radioactive elements and the biology and environment of the exposed plants and animals. Naturally occurring radioactive elements, especially polonium-210, are present in relatively high concentrations in seafood and game, including reindeer. Drinking water from groundwater supplies may contain high levels of radon-222.

Caesium-137 from the Chernobyl disaster in 1986 is still present at relatively high concentrations in some parts of the Norwegian environment, and there are large geographic variations in contamination levels. Norway has a strong tradition of using uncultivated mountain and forest pastures for animal husbandry, and animals grazing in uncultivated

pastures generally acquire higher concentrations of caesium-137 than animals feeding on cultivated grass and concentrated feed. After the fallout in 1986, lichens accumulated high levels of radioactive caesium, and these levels remained high for many years after the accident, resulting in particularly high concentrations in reindeer. Years with high mushroom abundance are also associated with elevated caesium-137 concentrations in both reindeer and sheep, contributing to the continued need for measures to reduce levels to below MLs in these animals.

Hazard Assessment
As part of the hazard assessment basic concepts of radioactivity, radiation, and exposure are described, such as radiation, decay of radioactive elements, types of radiation emitted, dose units, equivalent and effective doses of radiation, and dose rate. The hazard assessment is based on information from international organisations (International Commission on Radiological Protection, United Nations Scientific Committee on the Effects of Atomic Radiation, Committee of Biological Effects of Ionizing Radiation, World Health Organisation) regarding radiation effects and protection. Health effects of radiation are highly dependent on dose (mSv) and dose rate (dose received per unit of time, mSv/time). Low doses and low dose rates are of particular relevance in the estimates of possible health effects from intake of contaminated food. UNSCEAR defines low doses as those below 100 mSv. At doses above 100 mSv, there is strong epidemiological evidence of a causal relationship between exposure to radiation and a range of diseases, including cancer. At lower doses (<100 mSv), human data are inconsistent and the surmised effects are extrapolated from information from higher doses and from results from experimental studies.

The radiation doses from food in Norway are generally low. At such levels, cancer and heritable disease, i.e., stochastic and not deterministic effects, are considered to be the most important potential health effects. For estimating the health risks at very low doses, VKM used a linear non-threshold model (LNT), with an average unit risk of $5.5 \cdot 10^{-5}$ mSv^{-1} for cancer for the whole population. The estimated risk coefficient for heritable disease is $0.2 \cdot 10^{-5}$ mSv^{-1}(ICRP, 2007). Since this value is considerably lower and because the data are also more uncertain, heritable disease was not taken into account when characterizing the risk from radioactivity in food. There are considerable uncertainties in the risks calculated for low doses and dose rates based on LNT. In general, the model is considered to be conservative, implying that the actual human health risks are likely to be lower than those calculated.

Radioactivity in food and Consumption Groups
For **ToR 1**, the current levels of radioactive elements were established for the assessment of exposure based on dietary intake. Eight isotopes account for 99.5% of the effective radiation dose from food in Norway. In the assessment of risk from radioactivity in food at today's levels, VKM therefore considered these eight isotopes, i.e.: potassium-40, polonium-210, radon-222, radium-228, lead-210, caesium-137, carbon-14 and radium-226. Each of these isotopes has its specific characteristics regardi half-life, origin, and type of radiation emitted.

The mean concentrations of different radioactive elements vary by several orders of magnitude among the food items. Reindeer meat and wild mushrooms have the highest mean concentrations of caesium-137. The highest concentrations of polonium-210 are found in shellfish and reindeer meat.

VKM defined five specific groups among the general population with elevated exposure. For some of the specific groups, several different scenarios – represented by different combinations of consumption and occurrence data – were assessed. Elevated exposure to caesium-137 was assessed for three specific groups: consumers of contaminated reindeer meat, sheep meat and wild products (game, mushrooms and berries), respectively. VKM considered two specific groups for elevated exposure to naturally occurring radioactivity: polonium-210 in seafood and radon-222 in drinking water.

For **ToR2**, the effect of today's countermeasures to reduce caesium-137 concentrations in reindeer and sheep meat were assessed based on the same calculations as in ToR1, except that the caesium-137 concentration data were adjusted by also including measurements above the respective MLs. According to these calculations, due to a highly skewed distribution, the current countermeasures have little effect on the national mean caesium-137 level in reindeer and sheep meat, whose levels would increase by about 14 and 10 Bq/kg, respectively, if no countermeasures were performed. In meat from contaminated areas, the effect would be much more prominent. The greatest effect was seen in the levels in sheep meat from the most contaminated regions, which would increase by 3890 Bq/kg.

For **ToR3**, the effect of reducing the ML for radioactive caesium in reindeer meat to 1500 or 600 Bq/kg was assessed by adjusting the occurrence data set so that any measurements above the ML under consideration was reduced to that of ML. The calculations showed that reducing the ML to 1500 or 600 Bq/kg would reduce the national mean level of caesium-137 in reindeer meat by about 6 or 46 Bq/kg, respectively, in a typical year. In the most contaminated districts, the caesium-137 reduction would range from 41 to 1505 Bq/kg in the reindeer meat sold on the market.

For **ToR4**, the maximum permitted levels laid down in the Council regulation (Euratom) 2016/52 for emergency situations are presented. VKM considers it unlikely that iodine-131 contamination equal to the maximum permitted level could occur in Norway for the full 3-month period that the regulation would apply due to the rapid decay of iodine-131. Therefore, adjusted levels of iodine-131 were used in the assessment of potential exposure to the Norwegian population applying this regulation.

Exposure Assessment
The mean dose from all sources of ionising radiation to individuals in Norway has previously been estimated to be 5.1 mSv/year. On average, approximately 10% of this exposure comes from food. However, there may be large individual variations for some radioactive elements and food items. VKM calculated dietary exposure to radiation by multiplying consumption and occurrence data and the resulting intakes in Bq with ingestion dose coefficients developed by the ICRP to obtain the effective doses in Sv.

For **ToR1**, VKM estimated the mean exposure from anthropogenic and naturally occurring radioactive elements in the total diet to be 0.56 and 0.48 mSv/year for to 1-year-olds and adults, respectively. The largest contribution to this dose comes from the naturally occurring elements, polonium-210 and potassium-40. Although radioactive contamination in food contributes little to the mean consumer (0.0040 and 0.014 mSv for 1-year-olds and adults, respectively), it may still represent a radiation source of biological relevance for some individuals and in certain situations.

Of the scenarios for specific groups considered for ToR1, estimated effective doses ranged from 0.020 to 3.4 mSv/year. The highest estimated exposures were associated with a very high intake of reindeer meat from the most contaminated districts (3.4 mSv/year) and very high radon-222 levels in drinking water found in some wells drilled in bedrock (2.8 mSv/year).

For **ToR2,** VKM estimated the reduction in exposure associated with current countermeasures to be 0.0005 mSv/year or below for mean Norwegian adult consumers of reindeer and sheep meat. For the specific groups, the dose reduction ranged from 0.007 to 2.6 mSv/year for the scenarios considered. The largest effect was seen in consumers of sheep meat from the most contaminated regions.

For **ToR3**, VKM estimated the reduction in exposure associated with reducing the ML for radioactive caesium in reindeer meat from the current level (3000 Bq/kg) to 1500 or 600 Bq/kg for the mean adult consumer to be 0.00003 and 0.00022 mSv/year, respectively. For specific groups, the dose reduction resulting from reducing the ML to 1500 Bq/kg ranged from 0.0041 to 1.0 mSv/year for the scenarios considered in this assessment, and the corresponding dose reduction from decreasing the ML to 600 Bq/kg ranged from 0.031 to 2.4 mSv/year.

For **ToR4**, VKM considered that the assumptions of food contamination levels that form the basis for Council regulation 2016/52 (Euratom) for emergency situations to be appropriate for Norwegian conditions. Exposure of the whole population associated with applying the maximum permitted levels was calculated using modified levels of iodine-131. The estimated mean effective doses for 1-year-olds, 9-year-olds, and adults were 1.9, 1.0 and 0.98 mSv, respectively, for the 3-month period that the regulation should apply.

Risk Characterisation

The radiation doses associated with consumption of food are generally low and below the dose levels for which health effects have been observed in epidemiological studies. The relevant effects at very low and low dose levels are stochastic effects, i.e., increased risk of cancer and heritable effects. VKM estimated the incurred excess lifetime cancer risks associated with the radiation doses received per year (or 3 months) using an average lifetime risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1}. In line with WHO (WHO, 2011), in its assessment VKM considered an excess lifetime cancer risk caused by a life-long exposure below 10^{-5}, which corresponds to one extra case of cancer per 70 years for a population of 100,000, to be of little or no public health concern. This risk is equal to an average risk of about 10^{-7} per year. VKM used the terms listed in the table below for describing the risk levels associated with exposure to radioactivity in food.

Categories of cancer risk level	Nominal cancer risk/year	Cancer incidence rate(cases per 100 000/year)
Extremely low	$\leq 1 \cdot 10^{-7}$	≤0.01
Very low	$>1 \cdot 10^{-7}$-$1 \cdot 10^{-5}$	>0.01-1
Low	$>1 \cdot 10^{-5}$-$1 \cdot 10^{-4}$	>1-10
Moderate	$>1 \cdot 10^{-4}$-$1 \cdot 10^{-3}$	>10-100
High	$>1 \cdot 10^{-3}$-$1 \cdot 10^{-2}$	>100-1000

In **ToR 1** VKM assessed the cancer risk from exposure to natural and anthropogenic radioactive elements in food for 1-year-olds and adults of the whole population for both avearge and 95 percentile (P95) consumers. The risks for these groups were considered as low, and the contribution from anthropogenic sources (caesium-137) to the excess cancer risk was considered to be very low.

For high consumers of reindeer meat not taking any special measures against the Chernobyl contamination other than adhering to the MLs, the excess cancer risks from caesium-137 varied from very low to moderate for highly contaminated meat. For high consumers of sheep meat, the excess risks from caesium-137 varied from very low to low in those consuming highly contaminated meat. For high consumers of different wild products, the excess risks from caesium-137 were very low. For high consumers of fish and shellfish, the risks from polonium-210 were low and very low, respectively. The excess risk for consumers using drinking water containing radon-222 was low to moderate for water with high and very high levels, respectively.

In **ToR2,** VKM assessed the impact on the risk from excess radiation, provided no countermeasures were implemented for radioactivity in reindeer (ML for caesium-137 of 3000 Bq/kg) and sheep meat (600 Bq/kg).

Whole population

For mean consumers of reindeer meat with mean, high and very high levels of contamination, the excess risk would increase by about 5, 10, and 20% respectively. The risk categories would remain the same, extremely low and very low.

For the mean and P95 consumers of sheep meat with mean content of caesium-137 the excess cancer risk would increase by about 30%. However, the risk categories, extremely low and very low, respectively, would remain the same.

Specific Groups
For the high and very high consumers of reindeer meat with mean content of radioactive caesium the risk would increase by about 5% and remain in the same risk categories, very

low and low, respectively. For high and very high consumers of reindeer meat containing high and very high caesium-137 levels, the risk would increase by about 10 to 20% if no countermeasures were performed, but the risk categories would also remain unchanged at low and moderate, respectively.

For high consumers of sheep meat with mean and high radioactivity level the risk categories would remain very low and low, but the risk would increase by 30 and 100%, respectively. For consumers of very highly contaminated sheep meat, the risk would increase by about 7 times from low to moderate.

In **ToR3,** VKM assessed the impact of lowering the ML of caesium-137 in reindeer meat from the current level of 3000 to 1500 or 600 Bq/kg. Lowering the ML from 3000 Bq/kg to 600 Bq/kg would reduce the excess risk category from moderate to low for the very high consumers of reindeer meat from a highly or very highly contaminated area. For very high consumers of reindeer meat, containing high contamination levels, reducing the ML to 1500 Bq/kg, would change the risk category from moderate to low, however the actual risk reduction is quite low (~5%). For all other scenarios considered in the assessment, reducing the ML for reindeer meat to 1500 or 600 Bq/kg, would not affect the level of risk. The calculations assume that no effort are made to reduce the contamination in the reindeer meat consumed other than adhering to the ML.

In **ToR4,** VKM assessed the applicability of the procedure and the maximum permitted levels, as laid down in the Council Regulation 2016/52 (Euratom) on radioactive contamination of foods and feedstuffs in an emergency situation, to the Norwegian food consumption pattern. First, the share of products that might be contaminated was examined and found to be applicable to an emergency in Norway. Second, the exposure obtained using this share of contaminated foods, the maximum level permitted and Norwegian food consumption data were compared with exposure obtained in a similar exercise performed for the EU (Radiation Protection 105). The estimated level of protection was approximately similar to that in EU. This result was valid for 1-year-olds and adults.

The estimated total potential exposures from food following a nuclear accident ranged from 0.98 to 3.3 mSv/ 3 months, corresponding to an excess cancer risk of $5.3 \cdot 10^{-5}$ to $18 \cdot 10^{-5}$ when applying the maximum permitted levels. The associated risk category for both mean and P95 consumers is moderate for 1-year-olds and low for 9-year-olds and adults.

Council Regulation (Euratom) 2016/52 does not apply to drinking water, but leaves it to the discretion of the national competent authorities to decide whether the maximum permitted levels should apply to drinking water as well. VKM included drinking water in the above assessment, as this was also considered in the establishment of the maximum permitted levels.

VKM also assessed the applicability of the maximum permitted levels for radioactive caesium in animal feed as laid down in the Council Regulation (Euratom) 2016/52. The assessment suggested that under Norwegian conditions, the concentrations of radioactive caesium permitted in feed might result in meat contamination levels exceeding the maximum permitted levels.

Uncertainty Analysis
VKM conducted an uncertainty analysis during the assessment. For some of the scenarios, (i.e. high and very high consumers of sheep and reindeer meat and the scenarios for emergency situations) the exposure assumptions were worst-case. With regard to the associated radiation exposure and in the characterisation of cancer risk, these are based on several conservative assumptions, e.g., extrapolation using the LNT model. It is therefore likely that the actual risks are lower than those estimated. VKM also notes that the calculated risks are indications of the risk level at the population level and should not be used to calculate any incidences.

Sammendrag på norsk

Nøkkelord: VKM, risikovurdering, Vitenskapskomiteen for mattrygghet, Mattilsynet, radioaktive stoffer i mat

Key words: VKM, risk assessment, Norwegian Scientific Committee for Food Safety, Norwegian Food Safety Authority, radioactive elements in food

Håndteringen av radioaktiv forurensning i mat og fôr i Norge har siden 1986 i all hovedsak vært oppfølging av konsekvensene av Tsjernobylulykken. Fortsatt drives overvåkning og tiltak for å redusere befolkningens eksponering for radioaktivitet. Mattilsynet er i ferd med å revidere grenseverdier (ML) for radioaktive stoffer i mat, og ved behov sette nye grenser. Grenseverdiene skal brukes i håndtering av normalsituasjonen, direkte etter en hendelse, og ved langsiktig oppfølging etter en hendelse med radioaktiv forurensning. Mattilsynet har, som et ledd i utviklingen av regelverket, bedt Vitenskapskomiteen for mattrygghet (VKM) om å vurdere helserisikoen ved radioaktivitet i mat og fôr. VKM er bedt om å svare på følgene spørsmål (Terms of Reference, ToR):

- ToR 1: Hvilken helserisiko utgjør radioaktivitet i mat – inkludert mat som sankes og fangstes til eget bruk - for den generelle befolkningen og evt. utsatte grupper i dag?
- ToR 2: Hvilken helserisiko ville eksponering for cesium-137 utgjøre for ulike befolkningsgrupper dersom man ikke hadde gjort tiltak for å redusere mengden cesium-137, dvs. slik de framkommer i levendedyrmålingene for reinsdyr og sau?
- ToR 3: Hvilken endring i helserisikoen vil en reduksjon av grenseverdien fra 3000 Bq/kg til hhv. 1500 Bq/kg og 600 Bq/kg i norskprodusert reinsdyrkjøtt for hele befolkningen og spesielle grupper medføre?
- ToR 4: Hva blir helserisikoen for den norske befolkningen dersom «beredskapsgrenseverdiene» i Euratom-avtalen benyttes ved en hendelse, gitt de samme forutsetningene som i EUs ekspertvurdering?

All mat og drikke inneholder radioaktive stoffer. De fleste av disse stoffene forekommer naturlig, mens noen skyldes radioaktiv forurensing som følge av menneskelig aktivitet. Flere faktorer påvirker mengden av radioaktive stoffer i ulike matvarer, blant annet hvor mye det er av stoffet i naturen, og stoffets kjemiske egenskaper. Konsentrasjonen av radioaktivitet blir også påvirket av miljøet som omgir planten eller dyret som er eksponert. Sjømat og vilt, inkludert reinsdyr, har forholdsvis høye konsentrasjoner av naturlige radioaktive stoffer, spesielt polonium-210. Drikkevann fra grunnvannskilder kan inneholde høye nivåer av radon-222.

Cesium-137 fra Tsjernobyl-ulykken i 1986 finnes fremdeles i relativt høye konsentrasjoner i noen områder av Norge, men det er store geografiske variasjoner i forurensningsnivå. I

Norge er det tradisjon for å bruke utmark i skog og fjell til beite for husdyr. Dyr som beiter i utmark har generelt høyere konsentrasjoner av cesium-137 enn dyr som bare går på innmarksbeite og fores med kraftfôr. Lav akkumulerer høye nivåer av radioaktivt cesium, og nivåene i lav har vært høye siden Tsjernobyl-ulykken. Det har igjen ført til særlig høye konsentrasjoner i reinsdyr. Rike soppår er også forbundet med økte nivåer av cesium-137 både i reinsdyr og sau, noe som bidrar til at det fremdeles er behov for tiltak for å redusere nivåene til under grenseverdien.

Farevurdering

Som del av farevurderingen beskrives grunnleggende begreper om radioaktivitet, stråletyper, nedbryting av radioaktive stoffer, doseenheter, doseekvivalenter, doserater og effektive stråledoser. Farevurderingen av stråling er basert på informasjon fra internasjonale organisasjoner som arbeider med strålevern (International Commission on Radiological Protection, United Nations Scientific Committee on the Effects of Atomic Radiation, Committee of Biological Effects of Ionizing Radiation, Verdens helseorganisasjon). Helseeffekter av stråling er svært avhengig av dose (mSv) og doserate (dose per tidsenhet, mSv/tid). Lave doser og lave doserater er særlig relevant for å anslå mulige helseeffekter fra forurenset mat. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) definerer lave doser som doser under 100 mSv. Ved doser over 100 mSv er det sterke epidemiologiske holdepunkter for årsakssammenheng mellom eksponering for radioaktiv stråling og en rekke sykdommer, inkludert kreft. Ved doser som er under 100 mSv er funn i studier av mennesker inkonsistente, og mulige effekter er ekstrapolert fra høyere doser og fra eksperimentelle studier.

Eksponeringen for radioaktivitet i mat er generelt lav i Norge. Ved lave nivåer er kreft og arvelig sykdom, det vil si stokastiske og ikke-deterministiske effekter, regnet som de viktigste helseeffektene. VKM har brukt en lineær ikke-terskel modell (linear non-threshold - LNT) til å estimere helsekrisikoen ved svært lave doser. LNT-modellens gjennomsnittlige risiko per enhet stråledose er på $5{,}5 \cdot 10^{-5}$ mSv^{-1} for kreft i hele populasjonen. Den estimerte risikokoeffisienten for arvelige sykdommer er $0{,}2 \cdot 10^{-5}$ mSv^{-1} (ICRP, 2007). Siden denne verdien er mye lavere enn den for kreft, og fordi datagrunnlaget også er mer usikkert, er ikke arvelige sykdommer tatt hensyn til i risikokarakteriseringen av radioaktivitet i mat. Det er stor usikkerhet knyttet til risiko beregnet fra lave doser og doserater som baserer seg på LNT. Modellen regnes som konservativ, noe som tilsier at det er mer sannsynlig at helserisikoene er lavere enn de beregnede risikoene.

Radioaktivitet i mat og utsatte grupper

Åtte isotoper står for 99,5 prosent av den effektive stråledosen fra mat i Norge. VKM inkluderer derfor disse åtte isotopene i risikovurderingen av dagens nivå av radioaktivitet i mat: kalium-40, polonium-210, radium-228, bly-210, cesium-137, karbon-14 og radium-226. Hver av disse isotopene har sin spesielle karakteristikk når det gjelder halveringstid, opphav og hvilken stråling som sendes ut.

I arbeidet med Mattilsynets første spørsmål, **ToR 1**, ble eksponeringen beregnet ut fra dagens nivå av radioaktive stoffer i matvarer og fra matinntaket fra kostholdsundersøkelser. Gjennomsnittskonsentrasjonen av forskjellige radioaktive stoffer varierer med flere størrelsesordener mellom ulike typer matvarer. Reinsdyrkjøtt og vill sopp har de høyeste konsentrasjonene av cesium-137. Den høyeste konsentrasjonen av polonium-210 er funnet i skalldyr og i reinsdyrkjøtt.

VKM definerte fem grupper i befolkningen med økt eksponering fra radioaktiviet i mat. For noen av disse utsatte gruppene ble det laget flere scenarioer. Scenarioene vurderte ulike kombinasjoner av matinntak og nivå av radioaktivitet i maten. Økt eksponering for cesium-137 ble vurdert for tre utsatte grupper: konsumenter av forurenset reinsdyrkjøtt, av sauekjøtt, og av naturprodukter som vilt, sopp og bær. VKM har også sett på to utsatte grupper med økt eksponering fra naturlig radioaktivitet: polonium-210 i sjømat og radon-222 i drikkevann.

I **ToR 2** er det brukt de samme beregningene som i ToR 1 for å se på effekt av dagens håndteringstiltak for å redusere cesium-137-konsentrasjonene i reinsdyr og sau. I tillegg til å bruke resultatene fra ToR 1 er det brukt cesium-137-konsentrasjoner som er justert ved å inkludere målinger av levende dyr som ligger over grenseverdiene for reinsdyr og sau. Ifølge disse beregningene, har dagens tiltak liten effekt på landsgjennomsnittet av cesium-137-nivå i reinsdyrkjøtt og sauekjøtt. Uten noen tiltak ville gjennomsnittet av cesium-137 i reinsdyrkjøtt øke med 14 Bq/kg. For sauekjøtt ville økningen bli 10 Bq/kg. Dette skyldes i stor grad at konsentrasjonsdataene er skjevfordelte mellom forurensede og ikke forurensede områder. Økningen i konsentrasjonen i sauekjøtt fra forurensede områder ville vært mye større uten dagens tiltak. Den største endringen ved å fjerne tiltakene sees i sauekjøtt fra de mest forurensede regionene, der økningen ville ha vært 3890 Bq/kg.

I **ToR 3** ble effekten av å redusere grenseverdien i reinsdyrkjøtt fra 3000 Bq/kg til 1500 eller 600 Bq/kg vurdert ved å justere forekomstdataene slik at alle målinger over grenseverdien ble satt til den gitte grenseverdien. Beregningene viste at ved å redusere grenseverdien til 1500 eller 600 Bq/kg, ville landsgjennomsnittet av cesium-137 i reinsdyrkjøtt reduseres med henholdsvis 6 og 46 Bq/kg i et normalår. I de mest forurensede distriktene, ville endringer i grenseverdiene til 1500 og 600 bq/kg føre til reduksjoner på mellom 41 og 1505 Bq/kg i omsatt reinsdyrkjøtt.

I ToR 4 presenteres de tillatte maksimumsnivåer ved krisesituasjoner, foreslått av Council regulation (Euratom) 2016/52. VKM vurderte det som usannsynlig at forurensning av jod-131 i Norge vil være på nivå med maksmumsnivået for hele tremåndersperioden som reguleringen gjelder for, på grunn av den korte halveringstiden. Justerte nivåer av jod-131 ble derfor brukt for å vurdere hvilken eksponering som den norske befolkningen vil kunne utsettes for dersom Euratom-reguleringen benyttes.

Eksponering

Den gjennomsnittlige dosen av ioniserende stråling for norske individer har tidligere blitt estimert til 5,1 mSv/år. I gjennomsnitt kommer omtrent 10 prosent av denne eksponeringen fra mat. Mengden av radioaktivitet varierer imidlertid mellom de ulike radioaktive stoffene og mellom matvarer.. Den radioaktive eksponeringen fra mat er beregnet ved å multiplisere matkonsumet med forekomsttall av radioaktivitet i de enkelte matvarer og matvaregrupper. Eksponeringen i Bq ble deretter multiplisert med dosekoefisienten utarbeidet av International Commission on Radiological Protection (ICRP) for å få den effektive dosen i Sv.

I **ToR 1** har VKM estimert gjennomsnittlig eksponering for naturlige og menneskeskapte radioaktive stoffer i mat til å være 0,56 og 0,48 mSv/år for henholdsvis 1-åringer og voksne. Den største kilden er de naturlig forekommende stoffene polonium-210 og kalium-40. Selv om den gjennomsnittlige forbruker er lite utsatt for radioaktiv forurensing i mat (0,0040 og 0,014 mSv/år for 1-åringer og voksne), kan dette være en radioaktiv kilde som kan ha biologisk relevans for noen individer i enkelte situasjoner.

I **ToR 1** varierte estimert effektiv dose fra 0,020 til 3,4 mSv/år avhengig av hvilket scenario som ble vurdert. Den høyeste estimerte eksponeringen var forbundet med et svært høyt inntak av reinsdyrkjøtt fra de mest forurensede distriktene (3,4 mSv/år), og svært høyt radon-222-nivå i drikkevann fra private borebrønner i fjell (2,8 mSv/år).

I **ToR 2** beregnet VKM at reduksjonen i eksponering, gitt dagens tiltak og grenseverdier, utgjør 0,0005 mSv/år eller mindre for den gjennomsnittlige norske konsument av reinsdyr- og sauekjøtt. For utsatte grupper varierer reduksjonen fra 0,007 til 2,6 mSv/år. Den største estimerte reduksjonen ved dagens grenseverdi var blant konsumenter av sauekjøtt fra de mest forurensede regionene.

I **ToR 3** har VKM beregnet hvor mye eksponeringen vil reduseres ved å sette grenseverdien i reinsdyrkjøtt ned fra dagens nivå (3000 Bq/kg) til 1500 eller 600 Bq/kg. Reduksjonen ville for den gjennomsnittlige voksne konsumenten være på henholdsvis 0,00003 og 0,00022 mSv/år. For beregnede scenarioer hos utsatte grupper ville dosereduksjonen med en grenseverdi på 1500 Bq/kg være mellom 0,0041 og 1,0 mSv/år, mens dosereduksjonen ved en grenseverdi på 600 Bq/kg ville være mellom 0,031 og 2,4 mSv/år.

I **ToR 4** har VKM vurdert om grunnlaget for beredskapsgrenseverdiene i Euratom-avtalen (2016/2) er dekkende også for norske forhold. Eksponeringsberegningen tok utgangspunkt i beredskapsgrenseverdiene, men har brukt modifiserte nivåer av jod-131. Den estimerte gjennomsnittlige effektive dosen for 1-åringer, 9-åringer og voksne var henholdsvis 1,9, 1,0 og 0,98 mSv i den tremåneders perioden reguleringen skal gjelde.

Risikokarakterisering

Stråledosene som kommer fra mat er vanligvis lave og under dosenivåer som gir observerte helseeffekter i epidemiologiske studier. De relevante effektene av svært lave og lave dosenivåer er stokastiske effekter, dvs. at de fører til økt risiko for kreft og arvelige effekter. VKM estimerte tillegg i livstidskreftrisiko forbundet med strålingsdose per år (eller per 3 måneder) ved å bruke gjennomsnittlig livstids risikokoefisient på $5{,}5 \cdot 10^{-5}$ mSv^{-1}. VKM vurderte et tillegg i livstids kreftrisiko som følge av livslang eksponering på under 10^{-5} , som tilsvarer ett ekstra tilfelle av kreft på 70 år i en befolkning på 100.000, til å være av liten eller ingen betydning for folkehelsen. Denne risikoen vil være den samme som en gjennomsnittlig risiko på omtrent 10^{-7} per år. VKM bruker terminologien i tabellen under for å beskrive risikonivået forbundet med radioaktiv eksponering fra mat.

Kategorier av kreftrisiko	Nominal kreftrisiko/år	Kreftinsidensrate (tilfeller per 100 000/år)
Ekstremt lavt	$\leq 1 \cdot 10^{-7}$	≤0.01
Svært lavt	$>1 \cdot 10^{-7}$-$1 \cdot 10^{-5}$	>0.01-1
Lavt	$>1 \cdot 10^{-5}$-$1 \cdot 10^{-4}$	>1-10
Moderat	$>1 \cdot 10^{-4}$-$1 \cdot 10^{-3}$	>10-100
Høyt	$>1 \cdot 10^{-3}$-$1 \cdot 10^{-2}$	>100-1000

I **ToR 1** vurderte VKM kreftrisiko forbundet med eksponering for naturlige og menneskeskapte radioaktive stoffer i mat for 1-åringer og voksne både på gjennomsnittsnivå og for 95-persentilen (P95) av befolkningen. Risikoen i disse gruppene regnes som lav, og radioaktivitet fra menneskeskapte kilder (cesium-137) til tilleggsrisikoen er regnet som svært lav.

For storkonsumenter av reinsdyrkjøtt som ikke tar andre hensyn enn å følge grenseverdiene, varierte tilleggskreftrisikoen fra cesium-137 fra svært lav til moderat for kjøtt med svært høyt forurensningsnivå. For storkonsumenter av sauekjøtt, varierte tilleggskreftrisikoen fra cesium-137 fra svært lav til lav for kjøttet med svært høyt forurensningsnivå. For storkonsumenter av ulike produkter fra skog og mark, vil tilleggskreftrisikoene fra cesium-137 være svært lave. For storkonsumenter av fisk og av skalldyr vil risikoen fra polonium-210 være lav for fisk og svært lav for skalldyr. Tilleggsrisikoen for konsumenter som drikker vann med radon-222 vil være lav til moderat avhengig av om vannet inneholder høye eller svært høye nivåer av radon-222.

I **ToR 2** har VKM vurdert effekten av tilleggsrisiko fra stråling, gitt at ingen tiltak ble iverksatt for å redusere innholdet av radioaktivitet til grenseverdienene for cesium-137. Grenseverdiene er 3000 Bq/kg for reinsdyrkjøtt og 600 Bq/kg for sauekjøtt.

Hele befolkningen

Gjennomsnittskonsumentene av reinsdyrkjøtt fikk en økt tilleggsrisiko på omlag 5, 10 og 20 prosent hvis de spiste reinsdyrkjøtt med henholdsvis gjennomsnittlig, høyt eller svært høyt nivå av radioaktivitet. Risikokategoriene forble de samme, ekstremt lav og svært lav.

Både gjennomsnittskonsumenten og P95-konsumenten av sauekjøtt med et gjennomsnittlig innhold av cesium-137, fikk en økning av risikonivået på omkring 30 prosent hvis ingen tiltak ble iverksatt. Risikokategoriene forble de samme, ekstremt lav og svært lav.

Utsatte grupper

For konsumenter som spiste mye og svært mye reinsdyrkjøtt med gjennomsnittlig forurensningsnivå var økningen omtrent 5 prosent, og risikokategorien var den samme, henholdsvis svært lav og lav. For konsumenter som spiste mye eller svært mye reinsdyrkjøtt med høyt eller svært høyt cesium-137-nivå varrisikoøkningen på omtrent 10-20 prosent hvis ingen tiltak ble gjennomført. Også her var risikokategoriene de samme, henholdsvis lav og moderat.

Storkonsumenter av sauekjøtt med gjennomsnittlig og høyt innhold av cesium-137, hadde fortsatt et veldig lavt eller lavt risikonivå til tross for at risikoen økte med henholdvis 30 og 100 prosent uten tiltak. For konsumenter av sauekjøtt med svært høyt innhold av cesium-137, økte risikoen med omkring 7 ganger fra lavt til moderat nivå.

I **ToR 3** vurderte VKM virkningen av å senke grenseverdi av cesium-137 i reinsdyrkjøtt fra dagens nivå på 3000 Bq/kg til 600 Bq/kg. Reduksjon av grenseverdien til 600 Bq/kg for storkonsumenter av reinsdyrkjøtt fra områder som er høyt eller veldig høyt forurenset, ga en reduksjon i tilleggsrisiko for kreft fra moderat til lav. Reduksjon av grenseverdien til 1500 Bq/kg for storkonsumenter av reinsdyrkjøtt fra områder som er høyt forurenset, ga en reduksjon i tilleggsrisiko for kreft fra moderat til lav, til tross for at reduksjonen i prosent var relativt liten (~5 %). For alle andre scenarier som ble beregnet, førte ikke reduksjonen av grenseverdier til 1500 eller 600 Bq/kg til endring av risikokategori. Beregningene forutsetter at det ikke settes inn andre tiltak for å redusere innholdet av radioaktvitet i reinsdyrkjøtt enn å endre grenseverdien.

I **ToR 4** vurderte VKM i hvilken grad Euratoms prosedyrer og grenseverdier for radioaktiv forurensning i mat og fôr i en krisesituasjon kan brukes i Norge med et norsk kostholdsmønster. VKM vurderte om andel matvarer som kunne bli forurenset ved en krise samsvarte med andelen som ble brukt Euratoms beregninger. Norske eksponeringsberegninger ble sammenlignet med et eksempel gjort i EU (Radiation Protection 105) for 1-åringer og voksne, der andel forurenset mat, grenseverdier og norske kostholdsundersøkelser ble brukt. Det estimerte nivået for beskyttelse mot radioaktiv forurensning tilsvarte nivået som ble beregnet for EU.

Det ble estimert at eksponering fra mat ved bruk av maksimumsgrensene kunne variere mellom 0,98 til 3,3 mSv/3 måneder, hvilket ga en tilleggskreftrisiko på henholdsvis $5{,}3 \cdot 10^{-5}$ og $18 \cdot 10^{-5}$. Dette tilsvarer risikokategoriene moderat for ett-åringer og lavt for 9-åringer og voksne.

Council Regulation (Euratom) 2016/52 omhander ikke spesifikt drikkevann, men sier at det er opp til nasjonale myndigheter å avgjøre om tillatte grenseverdier også skal omfatte drikkevann. VKM inkluderte drikkevann i denne vurderingen, siden drikkevann var vurdert i utarbeidelsen av av grenseverdiene.

VKM vurderte også hvilket utslag maksimumsgrensene i Euratom 2016/52 for radioaktivt cesium i fôr ville gi under norske forhold. Beregningene viste at hvis grenseverdiene brukes i en krisesituasjon, kan det føre til at konsentrasjonen av radioaktivt cesium i husdyr vil overskride grenseverdiene for kjøtt.

Usikkerhet

Under risikovurderingen ble det foretatt usikkerhetsanalyser. Beregningene baserer seg på flere konservative antagelser når det gjelder radioaktiv eksponering og karakterisering av kreftrisiko, for eksempel ekstrapolering ved bruk av LNT-modellen. Flere av scenarioene (konsumenter som spiser mye av saue- og reinsdyrkjøtt og beregningene i ToR 4 basert på beredeskapsverdiene) baserer seg på verstefallstenkning. Det er derfor sannsynlig at den faktiske risikoen er lavere enn estimert. VKM påpekte at den beregnede risikoen er indikasjoner på risikonivå på befolkningsnivå, og at risikotallene ikke skal brukes til å beregne forekomst av kreft.

Abbreviations and/or glossary

Abbreviations

BEIR	- Committee of Biological Effects of Ionizing Radiation (NRC,US)
BSS	- Basic Safety Standards
Bq	- becquerel
DDREF	- Dose and Dose Rate Effectiveness Factor
EEA	- European Economic Area
EU	- European Union
Gy	- gray
IAEA	- International Atomic Energy Agency
IARC	- International Agency for Research on Cancer
ICRP	- International Commission on Radiological Protection
J	- joule (energy unit)
kg	- kilogram (mass unit)
ML	- maximum level permitted for food placed on the market
mSv	- milliSievert (0.001 Sv)
NAS	- National Academy of Sciences
NFSA	- Norwegian Food Safety Authority
NRC	- (U.S.) National Research Council
NRPA	- Norwegian Radiation Protection Authority
P95	- 95 percentile
ROS	- Reactive Oxygen Species
SSK	- Strahlenschutzkommission (German Commission on radiological protection)
Sv	- sievert

ToR - Terms of Reference

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation

VKM – Norwegian Scientific Committee for Food Safety (Vitenskapskomiteen for mattrygghet)

WHO - World Health Organization

Definitions and Glossary

Absorbed dose means energy imparted by ionising radiation to an irradiated medium per unit mass, expressed in grays (Gy); 1 Gy = 1 J/kg.

Acute exposure is an exposure, usually consisting of one single dose, taking place within less than 24 h.

Becquerel (Bq) is the unit of radioactivity. It is defined as one transformation of an unstable element (isotope) to another unstable or stable isotope of an element, per second.

Carcinogenic denotes a treatment or a compound that may cause development of cancer when an animal or a human is exposed to it.

Chronic exposure is an exposure delivered over longer periods of time.

Deterministic effects denotes health effects in which the severity varies with dose. Typically, there is a threshold below which effects do not occur (e.g. acute radiation syndrome). Deterministic effects are also referred to as "tissue reactions" or non-stochastic effects.

Dose is a general term denoting the quantity of radiation energy absorbed in a target of a certain mass. Related terms: absorbed dose, effective dose, committed dose.

Dose rate is the dose delivered per unit time.

Equivalent dose is the absorbed dose (calculated in Sv or mSv) in a tissue or an organ, corrected for radiation type (alpha, beta, gamma radiation) by radiation weighting factors, reflecting the observed effectiveness of the different radiation qualities in causing health effects.

Exposure In radiation physics, exposure is a measure of the radiation intensity in air. In risk assessment, exposure denotes the dose of an agent relevant for a health effect (risk = exposure x hazard). (In toxicology: exposure is a dose time integral)

Half-life denotes the time needed for the original activity of a radioactive element to be reduced to one-half, as a result of all relevant processes. The *physical half-life* is the time required for the activity of a specified radioactive element to decrease, through a radioactive decay process, to one-half. The *biological half-life* is the time taken for the quantity of a radioactive material in a specified tissue, organ or region of the body to decrease to one-half, as a result of biological as well as physical processes.

Hazard is a biological, chemical, or physical agent that causes an adverse health effect.

Ingestion dose coefficients are factors used to convert the amount of incorporated radioactive elements (intake), to the dose in tissues or organs or the whole-body dose.

These factors (also called "dose conversion factors") depend on the radioactive element, the route of intake (e.g. inhalation, ingestion), the chemical compound, and the age of the person. Usually expressed as dose per unit intake, e.g. sieverts per becquerel (Sv/Bq).

Maximum level (ML) refers to the maximum permitted level of a radioactive element in food placed on the market. The ML should not be confused with the highest concentrations of an radioactive element measured in food, as these may exceed the permissible levels.

Linear Non-Threshold (LNT) model is a risk model that assumes that health effects are directly proportional to the radiation dose at all dose levels (i.e. linear dose-response), without any threshold value below which such effects are not to be expected.

P95 exposure is the estimated exposure at the 95-percentile.

Percentile is a common term for visualising the low, medium and high occurrence of a measurement. The whole distribution is split into one-hundred equal parts; the 95-percentile is the value (or score) below which 95% of the observations are found.

Radiation is transportation of energy in the form of moving particles (particle radiation) or electromagnetic radiation.

Radiation dose is a measure of the amount of radiation energy absorbed in a tissue.

Radioactive element denotes an unstable atom, in which the nucleus will spontaneously decay, resulting in the formation of another element or isotope; during this process ionising radiation is emitted in the form of alpha, beta, and/or gamma radiation.

Reference level is the level of residual dose or risk above which it is generally judged to be inappropriate to allow exposures to occur

Risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to (a) hazard(s) in food (as defined for food, by Codex Alimentarius).

Risk assessment is a scientifically based process consisting of the following steps: (i) hazard identification, (ii) hazard characterization, (iii) exposure assessment, and (iv) risk characterisation (Codex alimentarius)

Sievert (Sv) is the unit for quantitation of the biologically relevant dose of radiation. It is calculated and cannot be measured as a physical entity.

Stochastic effect is the adverse effect of ionising radiation due to transformation of a single cell, that may result in an increased risk of disease a long time after the exposure. Such effects are probabilistic, and include cancer and heritable effects. At low doses, radiation risks are primarily stochastic in nature, and in particular refer to cancer.

Background and Terms of Reference as provided by the Norwegian Food Safety Authority

Background

The management of radioactivity in food and feed in Norway has since 1986 been driven by the Chernobyl Disaster, and there is still a need for follow-up through countermeasures and measurements to reduce the exposure to the population. The Fukushima accident in 2011 serves as a reminder that accidents still happen and affect us, and that regulations, emergency response and monitoring systems must be updated and adapted to new situations. The Norwegian Food Safety Authority (NFSA), and the Norwegian Radiation Protection Authority (NRPA), have developed a comprehensive strategy for the control of radioactivity in feed and foodstuffs. The strategy describes the challenges connected with radioactive contamination, and is aimed at making the NFSA better prepared to deal with incidents.

Following the Chernobyl disaster, the EU has set maximum permitted levels for agricultural products from third countries through the Euratom Treaty. Euratom is not a part of the EEA agreement, and Norway is thus considered as a third country in this context. The levels apply for the sum of caesium-134 and caesium-137, and are 600 Bq/kg in food in general and 370 Bq/kg for food for infants and young children. In addition, Euratom has set maximum permitted levels for caesium and other elements in foodstuffs and feed that shall apply in the first phase after a nuclear accident. These are consistently higher than in the “Chernobyl Regulation”.

The provisions on radioactivity in food in Norway are made nationally and are in effect the same as the EU standards. The exceptions are wild caught freshwater fish, meat from semi-domesticated reindeer and game meat, which have maximum levels (MLs) of 3000 Bq/kg. Following ordinary risk considerations in today’s situation, only a few foodstuffs, most likely meat from reindeer and sheep, would be regulated. Other considerations, and in particular the need for harmonization with the EU standards, argue for a general ML for all foodstuffs. The NFSA’s assessment is currently that the latter option is the most appropriate, but some exceptions are still required.

As late as 2008 the NFSA and the NRPA assessed the MLs for foodstuffs in Norway, with a focus on a cost-benefit analysis of lowering the MLs for semi-domesticated reindeer and game meat (and wild freshwater fish), from 3000 Bq/kg to the general level of 600 Bq/kg. The conclusion was then that it is acceptable from a public health perspective to uphold the exception of 3000 Bq/kg for these food categories. The registered levels are still fluctuating within certain geographical areas, and a lowering of MLs would most likely be problematic for the industry, especially the reindeer based one. In spite of this, the goal is to eventually lower the MLs to the EU's recommended limits for third countries.

Since the levels of radioactivity in reindeer and sheep vary year-by-year, the authorities still administer a system of clean-feeding of animals with measured values of caesium-137 above the MLs, and thus share much of the responsibility for meat placed on the market being in compliance with the regulations.

Working on the emergency plans for radioactivity, the NFSA plan to establish a set of higher MLs that can be used during the first phase of an accident. The limits should reflect the EU's Euratom regulations as much as possible, i.e. they should also apply to feed and include also other nuclides. Even though this would include several already risk assessed levels, the NFSA concludes that the establishment of new MLs in national regulation should be based on a Scientific Committee for Food Safety risk assessment.

Data

- The Norwegian Agriculture Agency's and the NFSA's data from live animal testing (occurrence)
- The NFSA's monitoring program, slaughterhouse (occurrence)
- The NRPA's measurement data, (occurrence)
- Various dietary surveys, including Norkost
- The NRPA's measured levels in humans

Terms of reference

The Norwegian Food Safety Authority is in the process of revising the maximum levels (MLs) for radioactive substances in drinking water and food and establishing new ones where necessary (including for feed). Such MLs are applied in the management of the normal situation, incidents and in the long term follow up period after incidents. An assessment of the risk which radioactivity in food and feed poses to human health is important for the development of such regulations. Thus, the Food Safety Authority requests the Norwegian Scientific Committee for Food Safety to respond to the following questions:

1. What is the current health risk from radioactivity in food –food gathering and hunting included – to the whole population and specific groups in Norway? (ToR1)
2. What health risk would the current levels of caesium-137 measured in live reindeer and sheep pose to the whole population and specific groups, if no efforts were made to reduce them? (ToR2)
3. What would be the implication on the health risk if the ML for reindeer meat was reduced from 3000 to 1500 or 600 Bq/kg, respectively – for the whole population and for specific groups? (ToR3)
4. Would the procedure and the maximum levels laid down in the Euratom Treaty regulation on radioactive contamination of foodstuffs and feedstuffs following a nuclear accident be appropriate for managing similar scenarios in Norway? (ToR4)

1 Introduction

All humans are exposed to ionising radiation. The radiation is either natural in origin or is a consequence of human activities (anthropogenic). Natural radiation includes cosmic radiation and radiation from elements in the Earth's crust and in the diet, and exposure varies between regions and population groups. The exposure may be considerably higher in specific regions and for particular occupational groups (e.g., flight personnel). Ionising radiation from anthropogenic sources includes radiation from medical imaging techniques, nuclear installations, nuclear weapon tests, and nuclear accidents. This exposure is commonly lower than the exposure from natural radiation, but may change rapidly and significantly, e.g., in the situation of a nuclear accident.

A nuclear reactor accident may release considerable quantities of different radioactive elements. Many of them will disappear over a few days and weeks after the accident depending on their physical properties and weather conditions, whereas others with a long physical half-life, will remain in the environment for a considerable period of time. An example of the latter was the Chernobyl disaster in 1986, which caused considerable contamination in certain areas of Norway. Here, caesium-137 levels exceeding the maximum levels permitted in food placed on the market ("maximum level", hereafter abbreviated to ML) can still be found in some foods, including sheep and reindeer meat and wild mushrooms.

The most relevant sources of radioactivity in food today in Norway today are the naturally occurring radioactive elements and some anthropogenic radioactive elements originating from the Chernobyl nuclear accident.

Exposure to ionising radiation may cause a wide spectrum of health effects. At low doses associated with the consumption of contaminated food the most relevant health effect is assumed to be an increased risks of cancers.

In this risk assessment, VKM addresses possible health risks from the exposure to naturally occurring and anthropogenic radioactive elements in food (including beverages) in the Norwegian population and in population sub-groups with specific dietary habits.

The assessment also addresses the appropriateness of implementing the maximum permitted levels for radioactivity in food and feed laid down by Council Regulation (Euratom) 2016/52 , which is to be implemented during the first period after a nuclear accident, for Norwegian conditions. In doing so, the assessment estimates the implications for radiation exposure and associated health risks to the Norwegian population, given the current dietary food consumption in Norway.

Although this risk assessment focuses on intake of radioactivity through food, the reader should bear in mind that establishing MLs for radioactivity in foods is one of several actions available to protect the citizens from radiation exposure after nuclear accidents or emergencies. Tveten and colleagues (Tveten et al., 1998) give an overview of measures taken in Norway after the Chernobyl disaster. An example of special food relevance is the dietary advice that was prepared and is still applicable.

In Norway, the regulation and management of radioactive contamination in foods mainly involve mainly two authorities: the Norwegian Food Safety Authority (NFSA, in Norwegian: Mattilsynet), and the Norwegian Radiation Protection Authority (NRPA, in Norwegian: Statens strålevern).

1.1 Structure of the present assessment

All foods contain radioactive elements at different concentrations. In the present assessment, VKM has chosen to include the eight radioactive elements that have been estimated to account for 99.5% of the effective radiation dose from food in Norway: potassium-40, polonium-210, radon-222, radium-228, lead-210, caesium-137, carbon-14 and radium-226.

The levels at which these radioactive elements occur in food products differ greatly. Also, population sub-groups with specific food consumption patterns may have higher exposure to radioactive elements. In order to cover both food groups with different contamination level and specific population groups with a high consumption of contaminated food, VKM has developed a number of scenarios. An overview of the exposure groups is presented in 2.4.1. A more extensive explanation of the exposure groups and scenarios used to answer the request in the Terms of Reference (ToR) from the Norwegian Food Safety Authority is presented in Chapter 5.

The risk assessment has been structured following the same order as the ToR1-4 were presented in the request from the Norwegian Food Safety Authority. This applies to Chapters 5, 6, and 7.

2 Methodology and data

The data used in the assessment include intake of food from Norwegian dietary surveys in different age groups, occurrence of different radioactive elements in food products and food groups, and element-specific ingestion dose coefficients for calculating effective doses from radioactive elements in food. The health risks associated with different exposure scenarios were assessed using accumulated scientific data on health risks from exposure to ionising radiation and procedures from international bodies on radiation protection.

2.1 Literature

Various international organisations have made comprehensively reviewed scientific data and thoroughly assessed the health risks from radiation exposure. Based on these reviews, recommendations for radiological protection have been prepared (ICRP Publ 103, 2007). In the present risk assessment of radioactivity in food and feed for human health, the recommendations, publications, opinions and reports from the authorities/bodies described below were used. VKM has not performed any additional systematic literature review. In some cases original publications have been used (see list of references in Chapter 10).

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is the main international scientific body evaluating risks from ionising radiation. The Committee continually and systematically reviews the emerging literature and publishes reports of the status of the knowledge of radiation effects and sources.

National Academy of Sciences (NAS) U.S.A Committee on Biological Effects of Ionizing Radiation provides a series of reports concerning radiation health effects, called **Biological Effects of Ionizing Radiation (BEIR).**

The International Commission on Radiological Protection (ICRP) is an independent non-governmental organisation. ICRP provides its recommendations relating to radiation protection mainly on the background of the basic scientific knowledge gained and validated by UNSCEAR.

The International Atomic Energy Agency (IAEA) is the main UN organisation responsible for International Radiation Basic Safety Standards and collaborates with WHO, FAO and other UN organisations in developing guidances for food safety.

World Health Organization (WHO) periodically publishes reports on the health effects of radiation accidents, and collaborates with other UN agencies in publishing international standards and documents like Basic Safety Standards. The WHO agency, **International Agency for Research on Cancer** publishes periodical monographs that include radiogenic cancer risks.

Codex Alimentarius Comission (FAO/WHO) develops harmonised international food standards for international trading, including for radioactivity in food.

Euratom (European Atomic Energy Community) is the part of the EU that establishes safety and health regulations related to nuclear energy and ionising radiation. For example, Council Directive (Euratom) 2013/59 sets the basic safety standards (BSS) for the protection of human and animal health from ionising radiation. Council regulation (Euratom) 2016/52 lays down maximum permitted levels (ML) of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency. Euratom also regulates the import of agricultural products from third countries (including Norway, since Euratom is not part of the EEA) following the Chernobyl nuclear plant disaster.

2.2 **Dietary surveys**

The estimated consumption of foods and food groups presented in this assessment is based on data from Norwegian food consumption surveys for 1-year-old (Spedkost-07) and 9-year-old children (Ungkost 3) and adults (18-70 years) (Norkost 3). The daily intake of food and exposure to radioactive elements was computed by using food databases in the software system (KBS – "kostberegningssystem") developed at the Institute of Basic Medical Sciences, Department of Nutrition, at the University of Oslo (Rimestad et al., 2000). The intake of each relevant food and food category in the dietary surveys was estimated for individuals and then summarised for each group.

Short descriptions of the dietary surveys and the different methodologies used are given below:

1-year-old children: Spedkost 2007 is based on a semi-quantitative food frequency questionnaire. In addition to predefined household units, food portions were also estimated from photographs. The study was conducted in 2007, and a total of 1635 1-year-old children participated (Øverby et al., 2009).

9-year-old children: Ungkost 3 is based on a 4-day food intake registration with a web-based food diary. All food items in the diary were linked to photographs for portion estimation (Hansen et al., 2016) (Øverby and Andersen, 2002). The study was conducted in 2015 and 636 9-year-old children participated.

Adults: Norkost 3 is based on two 24-hour recalls by telephone questioning, performed at least one month apart. Food portions were presented in household measures or estimated from photographs. The study was conducted in 2010/2011, and 1787 adults (925 women and 862 men) aged 18-70 participated (Totland et al., 2012).

2.3 **Data on radioactivity in food**

Data on the concentration of a number of radioactive elements in different food items used for calculating radiation doses in this assessment were mainly been obtained from work conducted by the Norwegian Radiation Protection Authority (Strålevernet, rapport 2015:11 "Stråledoser fra miljøet" by Komperød et al. 2015). However, the caesium-137 concentration data were re-examined before being used for the dose estimations in this risk assessment, and new relevant data for polonium-210 have become available and were included. Slight revisions of the occurence data for both radioactive elements in connection with new findings were made as specificed in Appendix 1.

Typical concentrations of radioactive elements in various food categories that are mentioned in Strålevernrapport 2015:11 were derived from national monitoring data and Norwegian scientific literature when available. In cases where data from Norway or other Nordic countries were not available, international reference levels were used (UNSCEAR, 2000) (Brown et al., 2004). For most Norwegian food products and radioactive elements, the full distribution of radioactivity levels is not available. Therefore, only mean concentrations are used in the assessment of the current exposure in the whole population.

The assessment of groups consuming sheep and reindeer meat with high caesium-137 levels was based on measurements of live animals in contaminated areas, provided by the NFSA. The national mean concentration for reindeer meat was also adjusted slightly to represent the same time period as the data used in the assessment of ToR2 and ToR3.

However, for specific groups and for the whole population in ToR2 and ToR3 in the Terms of Reference, pertaining specfically to sheep and reindeer meat, high radioactivity levels are also assessed.

2.4 **Exposure groups considered in response to the Terms of Reference**

2.4.1 **Exposure groups assessed**

Food groups may have highly different levels of radioactive elements and specific groups with an elevated consumption of food with high levels may be more exposed due to their dietary habits. VKM has therefore developed a number of scenarios (overview in Table 2.4.1-1) in addition to assessing the different age groups in the whole population .

Several combinations of occurrence and consumption data for different food groups were used in order to calculate the total exposure to radiation from radioactive elements and to answer ToR1-4.

Table 2.4.1-1 Overview of the different groups representing the whole population and specific groups with elevated exposure used to assess health risk from radioactivity in food.

Exposure group	Food product	Consumption	Radioactivity levels		
			Mean	High	Very high
Whole population	All food[a]	Mean	ToR1		ToR4[b]
		P95	ToR1		
	Reindeer meat[c]	Mean	ToR2,ToR3	ToR2,ToR3	ToR2,ToR3
		P95[d]	-	-	-
	Sheep meat[c]	Mean	ToR2	ToR2	ToR2
		P95	ToR2	ToR2	ToR2
Specific groups with elevated exposure	Reindeer meat[c]	High	ToR1,ToR2,ToR3	ToR1,ToR2,ToR3	ToR1,ToR2,ToR3
		Very high	ToR1,ToR2,ToR3	ToR1,ToR2,ToR3	ToR1,ToR2,ToR3
	Sheep meat[c]	High	ToR1,ToR2	ToR2	ToR1,ToR2
	Wild products	High		ToR1	
	Drinking water[e]	Mean		ToR1	ToR1
	Fish[f]	High	ToR1		
	Shellfish[f]	High	ToR1		

[a]Calculated for all radioactive elements considered in this assessment (section 3.4.2).
[b]Using the maximum permitted levels laid down in Council regulation (Euratom) 2016/52.
[c]Radioactivity levels refer to caesium-137
[d]P95 consumption is not available for reindeer meat due to few consumers (<5%) and could therefore not be calculated..
[e]Radioactivity levels refer to radon-222.
[f]Radioactivity levels refer to polonium-210.

2.4.2 Age categories assessed

Health risks have been assessed for up to three separate age categories, as defined in Section 3.4.4. With regard to ToR1, exposure has been calculated for infants and adults, but not for children, because infants and adults represent the range of exposure, whereas children receive an intermediate level of exposure. With regard to ToR2 and ToR3, exposure is only calculated for adults because this age group is known to receive the highest exposure from intake of radioactive caesium. With regard to ToR4, exposure is calculated for 1-year-old infants, 9-year-old children, and adults (18-70 years). Children are included in this part of the assessment because they are particularly vulnerable to exposure from radioactive iodine in a situation with radioactive contamination due to their high consumption of milk. For specific groups with elevated exposure considered for ToR1-3, only adult consumers were assessed because this group has the largest consumption of the relevant food products.

2.5 Conversion from intake of radioactivity to dose

Intake of radioactive elements results in radiation exposure. However, since intake of various radioactive elements results in different radiation exposures, comparison of the intake of the different elements per se is not meaningful. Instead the intake is converted to radiation exposure (dose) by multiplication by ICRP's "ingestion dose coefficients" (Eckerman et al., 2012). These coefficients are specific for the various radioactive elements and for different age groups (for further details see Section 3.2.2.2).

For the intake of radon-222 in drinking water, the current norm is to calculate doses using the method and dose coefficients described by the U.S. National Research Council (NRC 1999).

Dose coefficients used in this assessment are presented in Section 3.4.4 (Table 3.4.4-1).

3 Hazard identification and characterisation

Ionising radiation and radioactivity may cause various health effects depending on several factors. First of all the amount of radiation received and from which elements the radiation originates are critical. For identification and characterisation of the hazards involved, this section first introduces some basic concepts of ionising radiation and its interactions with matter. Thereafter, a short description follows of biological damage and adverse health effects occurring at various exposure levels. Emphasis is on hazards associated with the relatively low doses and dose rates that predominate in exposure from radioactivity in food.

3.1 Basic concepts of radiation and radioactivity

3.1.1 Radiation from radioactive elements

Radiation denotes the transmission of energy in the form of particles or electromagnetic waves. Radiation is categorised as either ionising or non-ionising. Ionising radiation has sufficient energy to liberate electrons from atoms and molecules (i.e., ionise them) and such ionisations may cause damage in cells. Examples of ionising radiation are X-rays and radiation from decay of radioactive elements. Non-ionising radiation – which is not relevant for food intake - has less energy and includes visible light and UV light, thermal radiation (heat) and radio waves. At sufficiently high levels, also non-ionising radiation may also cause damage, but this occurs via different mechanisms (primarily heating).

3.1.1.1 *Decay of radioactive elements*

A radioactive element is an atom with an unstable combination of protons and neutrons in the nucleus. An unstable atom spontaneously undergoes conversion to another element (stable or unstable), and during this process protons or neutrons are emitted or transformed, and surplus energy is emitted as radiation. This process is known as radioactive decay. The resulting element (decay product) contains a new number of protons and/or neutrons in its nucleus, meaning that is has been transformed into another chemical element.

Some radioactive elements become stable after only a single decay, while others decay through many steps, transitioning through several different radioactive elements along the way, before reaching a stable state. Each radioactive element decays at a specific rate, and this rate is described as its physical half-life. The half-life is defined by the time needed for the original activity to be reduced by one half. The half-lives of the different radioactive elements formed during sequential decay range from fractions of a second to several billion years.

The becquerel (Bq) is the unit of radioactive decay. One Bq is defined as one decay per second.

3.1.1.2 *Types of radiation emitted by radioactive elements*

Radioactive elements may release energy in the form of alpha, beta, and/or gamma radiation. Alpha and beta radiation consist of particles, while gamma radiation is electromagnetic radiation (photons).

Alpha particles are essentially helium nuclei (two protons and two neutrons) in motion. Due to their high mass and strong absorption, alpha particles are capable of causing more severe damage in cells per hit than beta and gamma radiation. Alpha particles have a short range – only a few cm in air, and fractions of a millimeter in tissue - and the particles are unable to penetrate the outer skin layers. Thus, in principle, the radiation constituted by alpha particles will damage body tissues only when an alpha-emitting radioactive element is ingested or inhaled.

Beta particles consist of high-energy electrons or positrons, and beta radiation has a range of a few meters in air and about 1 cm in tissue. As with alpha radiation, beta radiation may cause damage if the radioactive element is ingested or inhaled, but causes less damage per hit than the larger and heavier alpha particles.

Gamma radiation is high-energy electromagnetic radiation (photons). This radiation has a long range, and may pass from an external source into tissue and deposit its energy anywhere in the body, including internal organs. Gamma radiation may cause damage both when the radioactive elements emitting such radiation are inside the body, and when located outside (e.g., on the ground).

At different dose levels, these types of radiation may cause different types and degrees of damage in cells.

3.2 Hazard identification

This section briefly describes the types of lesions induced by ionising radiation in cells and the associated hazards.

3.2.1 Types of radiation hazards

Ionising radiation is absorbed by biological material and interacts with intracellular molecules including DNA. In this way, radiation may kill or harm cells and tissues. The damage to tissues or organs depends on the type of radiation, its intensity and the total amount of radiation absorbed, and the specific sensitivity of the different tissues and organs.

Effects of radiation may be either deterministic or stochastic in nature. These two types are defined as follows (ICRP, 2007):

- **Deterministic (non-stochastic):** Injury in populations of cells, characterised by a threshold dose and a rise in the severity of the reaction as the dose is increased further.
- **Stochastic effects:** Malignant disease and heritable effects for which the probability of an effect occurring, but not its severity, is regarded as a function of dose without a threshold.

The radiation dose levels and dose rates associated with intake of contaminated food are generally relatively low, and deterministic radiation effects may occur only in extreme cases. Contaminated food might, however, induce stochastic effects. Consequently these are the principle focus in this description.

Stochastic effects are caused by the interactions of radiation with cells and their normal functions. Radiation may interact directly with DNA, causing molecular changes, or damage may arise via interactions with water in the cell, resulting in the production of reactive oxygen species (ROS). Types of damage include breaks in one or both strands of the DNA molecule and other chemical modifications of DNA or its bases. Most of the breaks in one DNA strand are efficiently and correctly repaired, but double-strand breaks and some DNA base lesions may be left un-repaired or incorrectly repaired, causing mutations. Cell mutation and subsequent cell division may start the process that ultimately result in cancer. If the mutated cell is a reproductive cell, it may lead to effects in the offspring. Foetal development is also sensitive to radiation and exposure may result in disease in the child.

In recent years, research has shown that ionising radiation at relatively low and moderate doses may interact with other types of molecules than DNA. This might have an impact on signal transduction processes within and between cells, as well as other cellular processes and expression of genes (UNSCEAR, 2012b). The relationship of these mechanisms to adverse health is unclear.

3.2.2 Radiation dose units

A well-defined terminology has been established to describe the effects of radiation. Radiation exposure results in a certain radiation dose, to a person, a tissue, or an organ, and this dose is given at a certain dose rate. Standardized physical units are used to describe this. The *absorbed dose* of radiation is expressed in gray (Gy), which denotes the amount of energy deposited by the radiation per amount of tissue. The definition is: 1 Gy= 1 J/kg. Other units have been established for the purpose of assessing damaging effect in the tissues, as explained below.

3.2.2.1 *Equivalent and effective dose of radiation*

The biological effect of ionising radiation depends not only on the quantity of radiation (absorbed dose in Gy), but also on the radiation quality, e.g. alpha, beta or gamma radiation, as well as properties of the tissue or organ. The biologically relevant dose is quantified in sievert (Sv or mSV), which cannot be measured as a physical entity. Conversion of Gy into Sv is specific for the type of radiation and the organ. The following terms are used (ICRP, 2007):

- **Equivalent dose** (calculated in Sv or mSv) is the absorbed dose in a tissue or organ, corrected for radiation type (alpha, beta, gamma radiation) by radiation weighting factors. In total this reflects the observed effectiveness of the different radiation qualities in causing health effects.
- **Effective dose** (calculated in Sv or mSv) is the tissue-weighted sum of all equivalent doses in all specified tissues and organs, of the whole body.

When assessing human health effects from radiation in general, the effective dose is used (although this is not always explicitly stated). One exception is for assessment of cancer in specific organs, when the absorbed dose is used as measure of dose.

3.2.2.2 *Effective doses from intake of radioactive elements*

Different radioactive elements emit different radiation types and energies, resulting in different radiation exposures. Therefore, exposure from various radioactive elements in foods cannot be assessed based solely on the intake of the elements (e.g., in becquerels per day). The becquerel intake has to be converted to radiation dose. For this purpose, the ICRP has derived sets of "ingestion dose coefficients". The ingestion dose coefficients are based on knowledge of uptake and distribution of the various radioactive elements in human tissues (see Section 3.4.3-3.4.4 for general information about some elements), on the decay and radiation qualities of the various elements, and on radiation and tissue weighting factors. Ingestion dose coefficients are given for tissues (as equivalent dose) or the whole body (as effective dose) (see Table 3.4.4-1). To account for differences in metabolism and sentitivity towards radiation in persons of various ages, separate values are given for the ingestion dose coefficients for different age groups.

The dose coefficients are designed primarily for radiation protection purposes when individual dose estimates are not available. Typically, they are used to estimate doses to the population (and not for assessment of doses at an individual level) based on contamination levels in monitored foodstuffs. In cases of significant contamination of individuals, it is more detailed analyses and assessment of doses based on individual measurements in tissue, excreta samples etc. are recommended.

3.2.2.3 *Dose rate*

The same dose of radiation can be *acute* (defined as delivered in less than 24 h) or *chronic* (delivered over longer periods of time). The concept *dose rate* expresses the dose per unit of time (for example mSv/h) and characterises the radiation intensity. The concept of dose rate is illustrated in Figure 3.2.2.3-1 below.

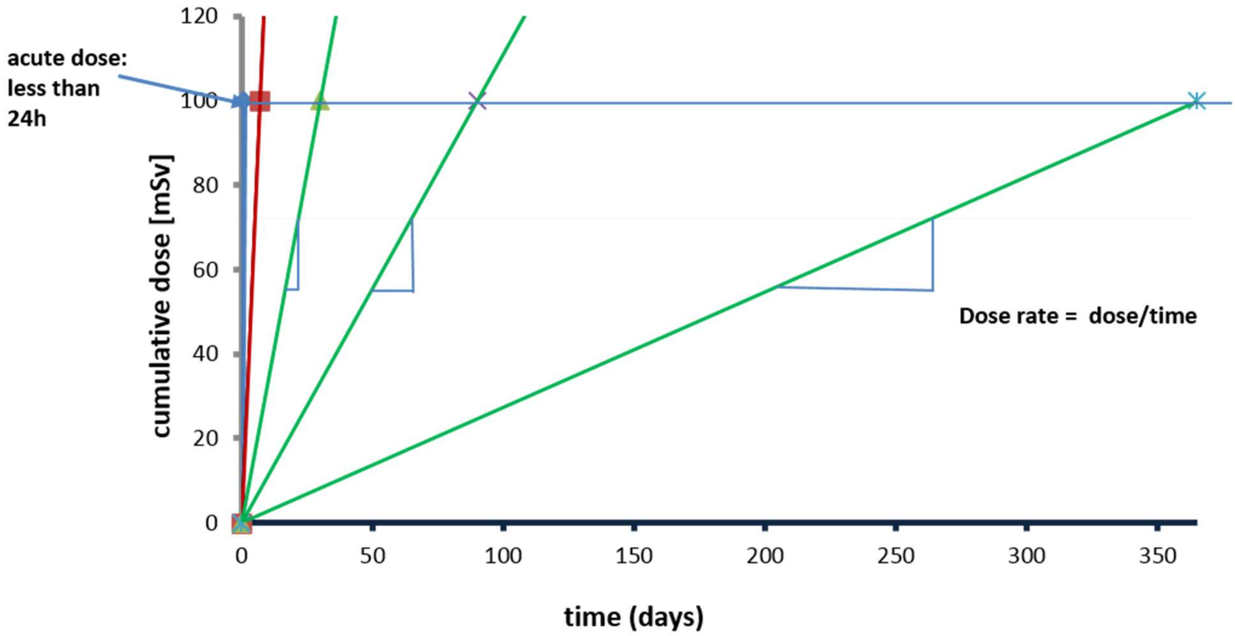

Figure 3.2.2.3-1 The same cumulative dose of radiation (i.e. sum of doses received during a time period) can be delivered as an acute dose (red line) or as a chronic dose (green lines).

3.3 Hazard characterisation

Much of our knowledge about the health effects of ionising radiation stems from the times of its early use, when radiation protection had not been well established. Experimental use of radioactive sources led to early observations of acute tissue (deterministic) effects and also radiation-induced cancer, for instance from a range of medical uses. The Life-Span Study of survivors of the Hiroshima and Nagasaki nuclear explosions in 1945 is a major source of information, as well as atmospheric Soviet and US nuclear weapons tests (in Semipalatinsk and Marshall Islands, respectively). Furthermore, workers in the nuclear industry in several countries constitute cohorts on radiation effects, as do other groups of employees exposed to radioactivity, e.g. radium dial painters, miners (radon). The Chernobyl accident is another case, and includes exposure to emergency and clean-up workers and inhabitants. Although some groups in Norway, particularly consumers of reindeer meat, received elevated exposure following the nuclear weapons tests and the Chernobyl fallout, no radiation health effects have been shown in the latter groups (see details in Appendix 2).

3.3.1 Health effects

Health effects resulting from exposure to ionising radiation depend on the type of radiation, the dose and the dose rate. Table 3.3.1-1 describes levels of radiation exposure and associated health effects, for both deterministic and stochastic effects. The deterministic health effects are observed at high and very high acute doses.

Table 3.3.1-1 Health effects at different levels of radiation (Committee on Health Risks of Exposure to Radon, 1999; ICRP, 2007; Mettler and Upton, 2008; Pearce et al., 2012; Pierce and Preston, 2000; Salomaa et al., 2015; UNSCEAR, 2001; UNSCEAR, 2012a). There is international consensus on using absorbed dose in Gy for deterministic effects. For simplicity, VKM uses mSv and Sv in this text.

	Irradiation (Sv/mSV)	**Observed health effects / biological effects**
Very high doses	5-10 Sv	Lethal. Severe haematological, gastrointestinal, and neurological damage
High doses	3-5 Sv 1-2 Sv	Possibly lethal (50% of patients) if not treated. Manifested bone marrow damage, gastrointestinal damage Mild bone marrow damage, increased risk for cancer
Moderate doses	100 mSv - 1 Sv	Cancer, reduced sperm count/male sterility, cardiovascular damage / circulatory diseases, eye lens opacities, foetal damages
Low doses	Doses below 100 mSv	Some studies have shown increased risk for cancer at doses down to 30-50 mSv Biological effects, i.a. DNA damage.
Very low doses	Doses below 10 mSv	Biological effects: i.a. DNA damage

In recent years there have been observations, both in animal studies and from population studies, that radiation may also lead to other health effects such as coronary heart disease and neurological disease. However, the risk of these diseases is lower than that of cancer, and an increased cancer risk is still considered the predominant effect at low doses and dose rates.

Some experimental evidence from studies with cells exposed to low doses of ionising radiation suggests that certain biological endpoints (cell killing, genetic changes) may be the same or even reduced compared with non-irradiated cells. The implication that radiation at low doses might have beneficial effects is known as hormesis. There is, however, no convincing evidence that hormesis is relevant for human exposure and it is therefore disregarded in radiation protection (Committee to Assess the Health Risks from Exposure to Low Levels of Ionizing Radiation, 2006).

3.3.2 **Cancer and heritable effects**

Cancer and heritable effects are the most important health effects of ionising radiation at relatively low doses and dose rates. The International Agency for Research on Cancer (IARC) has categorized all types of ionising radiation as carcinogenic for humans, based on both animal studies and epidemiological research (IARC, 2012). There is no doubt that these health effects are indeed occurring (at least in mice, for heritable effects); but the magnitude of the risk at low doses and dose rates is debatable.

Cancer induced by radiation is indistinguishable from cancer from other causes. Therefore, to be recognised, an increased incidence of radiation-induced cancer in a population must be high enough to overcome statistical and other uncertainties (including confounders). Cancer is well documented in the range of doses defined as moderate, 100 mSv - 1 Sv. This documentation is based on epidemiological cancer studies of cohorts irradiated in association with the use and testing of nuclear weapons, and from radiation accidents, workers exposed to radiation, and groups subject to medical exposures (UNSCEAR, 2013b).

Potential cancer risk at very low doses, including those resulting from natural background radiation, is, in general, too low to be determined in observational (epidemiological) studies. However, experimental studies have shown that i.a. DNA damage can also be induced at very low doses.

Radiogenic cancers appear in exposed populations after varying periods of time. The latency period can range from 2 to 30 years, depending on the type of cancer. Leukaemia, thyroid and bone cancer appear within a few years of exposure to radiation, whereas most types of cancer are not expressed until at least 10 years after exposure.

Not all types of cancers are induced by radiation. Table 3.3.2-1 presents the tissues in which the most common radiogenic cancers occur, with several types of leukaemia, thyroid cancer and female breast cancer at the top.

Table 3.3.2-1 Relative occurrence of the most common types of radiogenic cancers (the table developed on the basis of ICRP 103 Annex A, (ICRP, 2007), (ICRP, 2015) (ICRP, 2015) and UNSCEAR 2013, Annex B (UNSCEAR, 2013b).

Tissue	**Adults**	**Children**
Lung	High	Low
Breast	High	High in adulthood
Bone marrow (leukemia etc.)	High	Very high
Stomach	Moderate	Moderate
Colon	Moderate	Moderate

Thyroid	Low	Very high
Skin	Low	High
Brain	Low	High

Heritable effects are diseases and effects that occur in the next generations due to mutations in female and male germ cells. They are classified according to disease class, mendelian (autosomal dominant and X-linked, chromosomal) and mulifractional (chronic multifractional and congenital abnormalities).

According to UNSCEAR and BEIR, there is no documented epidemiological evidence for heritable health effects in humans, but such effects have been shown in experimental animal studies.

In their calculations UNSCEAR has used the results from extensive experimental multigenerational studies on the incidence of the heritable effects in mice (UNSCEAR, 2001). The rates of incidence of genetic disease in mice have been related to the baseline frequency of the relevant classes of genetic diseases in humans. ICRP 103 (ICRP, 2007) calculated the risk for heritable effects based on UNSCEAR (UNSCEAR, 2001) as $0.2 \cdot 10^{-5}$ mSv^{-1}.

3.3.3 Differences in health risks due to age and gender

The risk for developing cancer after radiation exposure in the foetus is considered the same as for infants and young children (UNSCEAR, 2013a).

The risk of radiation carcinogenesis in generally decreases inversely with age of exposure. Children tend to be more prone to develop radiogenic cancer, by a factor of 2-3 compared with adults, but this sensitivity is dependent on cancer type (Table 3.3.2-1). For example, children, especially at young age, have a higher risk of leukemia and thyroid cancer than adults. On the other hand, for radiogenic lung cancer in children, there is evidence for lower lifetime risk (UNSCEAR, 2013a). The UNSCEAR commission recommends that giving one general estimate for the radiogenic cancer risk in childhood is avoided.

The increase in thyroid cancer incidence among children in the allout regions of Chernobyl in Belarus, Ukraine and Russia illustrates that children are at higher risk than adults of developing this type of cancer (UNSCEAR, 2012a). This is perhaps also the best example of health effects from radiation exposure via food, because the population received high doses of radioactive iodine (primarily iodine-131) from highly contaminated milk. The average thyroid dose to evacuees from the contaminated areas was estimated to about 500 mSv, with individual values ranging from less than 50 to more than 5000 mSv (UNSCEAR, 2012a).

The incidence of radiogenic cancer differs between men and women. In general, women are more likely to develop radiogenic cancer. For example, the female:male ratio of excess relative risk for developing solid radiogenic cancers is 1.68 (ICRP, 2007).

At higher doses, exposure of the unborn child to ionising radiation is of particular importance. Generally, there are higher risks of detrimental health effects for prenatal radiation exposure than in adults, but there is apparently a threshold of 100 mSv for such effects (UNSCEAR, 2010b). The preimplantation stage of the foetus is relatively sensitive to radiation, with embryonic death being one possible outcome. Exposure to moderate doses of radiation during organogenesis may also induce malformations and defects in the central nervous system.

3.3.4 **Estimates of health risk at very low doses**

For estimating radiation risks at low doses, the distinction must be made between the health effects that have been documented at specific dose levels, and effects that are undocumented, but are assumed to occur, although are difficult or impossible to demonstrate for humans. Some animal data, and also theoretical considerations, indicate that the risk of biological stochastic effects (cancer and hereditary effects) depends not only on the dose, but also on the dose rate. UNSCEAR (UNSCEAR, 2012b) defines low dose as below 100 mSv, and low dose rate as below 0.1 mSv/minute averaged over 1 hour.

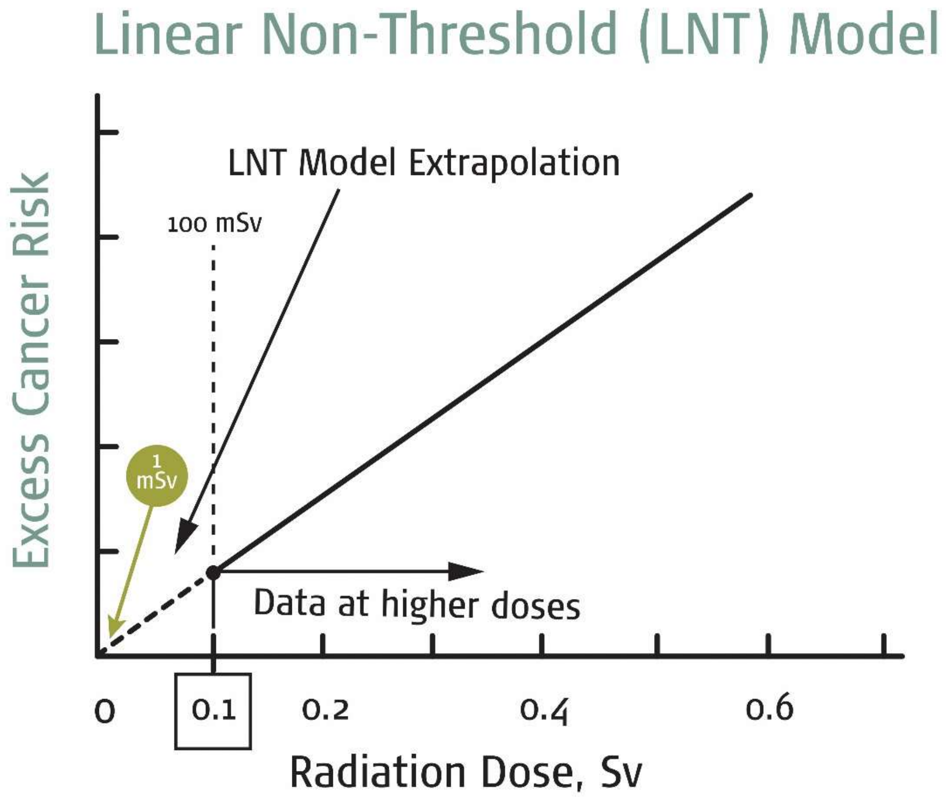

Figure 3.3.4-1 The linear non-threshold model.

Possible health effects from low doses of ionising radiation due to food intake are traditionally based on a linear hazard dose response, referred to as the linear non-threshold (LNT) model (ICRP, 2007) (Figure 3.3.4-1). This implies that an increased health risk due to radiation exposure is linearly related to the magnitude of the effective radiation dose. This is in accordance with the recommendations of the ICRP (ICRP, 2007), concluding from all available data, that the risk in a population per effective radiation dose, i.e., per Sv, is estimated to be 5.5% for cancer and 0.2% for heritable effects. These are average numbers for the whole population.

Life-time risk coefficients for excess cancer and heritable effects are presented in Table 3.3.4-1 below. These are numerical factors for estimating the risk of cancer and heritable effect from low level exposure of radioactive elements. These risk coefficients denote the average risk per unit exposure for persons exposed throughout their lifetime(cumulative dose), or the average risk per unit exposure (cumulative dose) for persons exposed for a brief period to the radionuclides. The ICRP 2007 recommendations (ICRP, 2007) derived specific risk models for leukaemia, thyroid, stomach, colon, liver, lung, female breast, ovary, oesophagus, bladder and all other solid cancers combined, and applied those models to cancer incidence data from six different Asian and Euro-American populations.

These risk models assumed gender-averaged and age-at-exposure-averaged populations to generate nominal cancer incidence risk coefficients in the context of radiological protection.

Table 3.3.4-1 Life-time risk coefficients averaged by gender and age at exposure for excess cancer and heritable effects (10^{-5} mSv^{-1}) based on incidence of cancer and calculated, based on animal studies, incidence of heritable effects (ICRP, 2007)

Exposed population	Cancer (10^{-5} mSv^{-1})	Heritable effects (10^{-5} mSv^{-1})
Whole	5.5	0.2
Adult	4.1	0.1

It should be noted that the concept of LNT has been developed to be applied primarily for radiation protection purposes in the context of risk management at the population level, and is not used to calculate risks at an individual level.

3.3.4.1 *Health risk at low dose rates*

Low doses and low doses rates are of particular relevance when estimating possible health effects from the intake of contamined food. The possibility of ionising radiation having lower effects at low doses and dose-rates led to the introduction of the Dose and Dose Rate Effectiveness Factor (DDREF). In the recommendations from 2007, the ICRP recommends that DDREF = 2 (ICRP, 2007), implying that the risk at low doses and dose rates is half that at higher levels. However, in their assessment of health consequences of the Fukushima accident, the WHO and IAEA applied a DDREF = 1. Moreover, the German Commission on Radiation Protection (SSK) recently revaluated the DDREF issue and found that accumulated experimental and epidemiological data available now do not justify using a DDREF that differs from 1.0 (SSK, 2014).

For the purpose of estimating health risks at very low doses, VKM used a risk coefficient for cancer (Table 3.3.4-1) of $5.5 \cdot 10^{-5}$ mSv^{-1}, as an average for the whole population, and extrapolated the risk according to the linear non-threshold model applying a DDREF = 1.

The estimated risk coefficient for heritable effects, which is mainly based on data from experimental animals and is more uncertain, is $0.2 \cdot 10^{-5}$ mSv^{-1}, which is much lower (< 4%) than for cancer risk. Risks of heritable effects were not included in the risk characterisation of the radiation doses in this risk assessment.

3.4 **Radioactive elements in food and associated hazard**

3.4.1 **Sources of radioactivity in Norway**

This section describes the main sources of radioactivity in food and in the environment in Norway today.

3.4.1.1 ***Naturally occurring radioactive elements***

Most natural radioactive elements originate in the Earth's crust. Potassium-40, uranium-238, and thorium-232 are primordial radioactive elements, which have been present since the Earth's formation. Uranium-238 and thorium-232 are the parental elements of long decay chains, causing the formation of many other radioactive isotopes before finally ending up as stable lead.

Other naturally occurring radioactive elements are created when stable elements in the atmosphere are bombarded with cosmic radiation. Such cosmogenic radioactive elements include carbon-14.

3.4.1.2 ***Anthropogenic radioactive elements***

Atmospheric nuclear weapon tests

The fallout from testing nuclear weapons in the atmosphere in the 1950s and 1960s is still the largest source of radioactive contamination on a global scale. The radioactive materials released in these tests were distributed relatively uniformly, mainly across the Northern hemisphere, including Norway. Elevated levels of iodine-131, strontium-90 and caesium-137 have been recorded in various food items. Iodine-131 has decayed and is not longer present, but detectable amounts of caesium-137 and strontium-90 from these weapons' tests are still present in the environment.

The Chernobyl disaster

On 26 April 1986, a reactor in the nuclear power plant in Chernobyl in the former Soviet Union (today's Ukraine) exploded, followed by the emission of enormous amounts of radioactive material. Large amounts of material was spread by winds to other European countries including Norway. The radioactive fallout varied enormously in different geographical regions, reflecting local precipitation patterns in the days following the accident. The most heavily affected areas in Norway were the mountainous areas in southern and central Norway (see Figure 3.4.1.2-1).

Most of the radioactive elements from the release, including iodine-131 decayed to negligible levels within weeks. Caesium-134, with a half-life of about 2 years, was a challenge in food production only during the first years. Caesium-137 with its half-life of 30 years, is still present in substantial quantities in soil and vegetation and in a number of food products from the affected areas. In order to comply with national and international regulations on food contamination, countermeasures are still conducted in several regions of Norway, particularly by producers of sheep and reindeer meat.

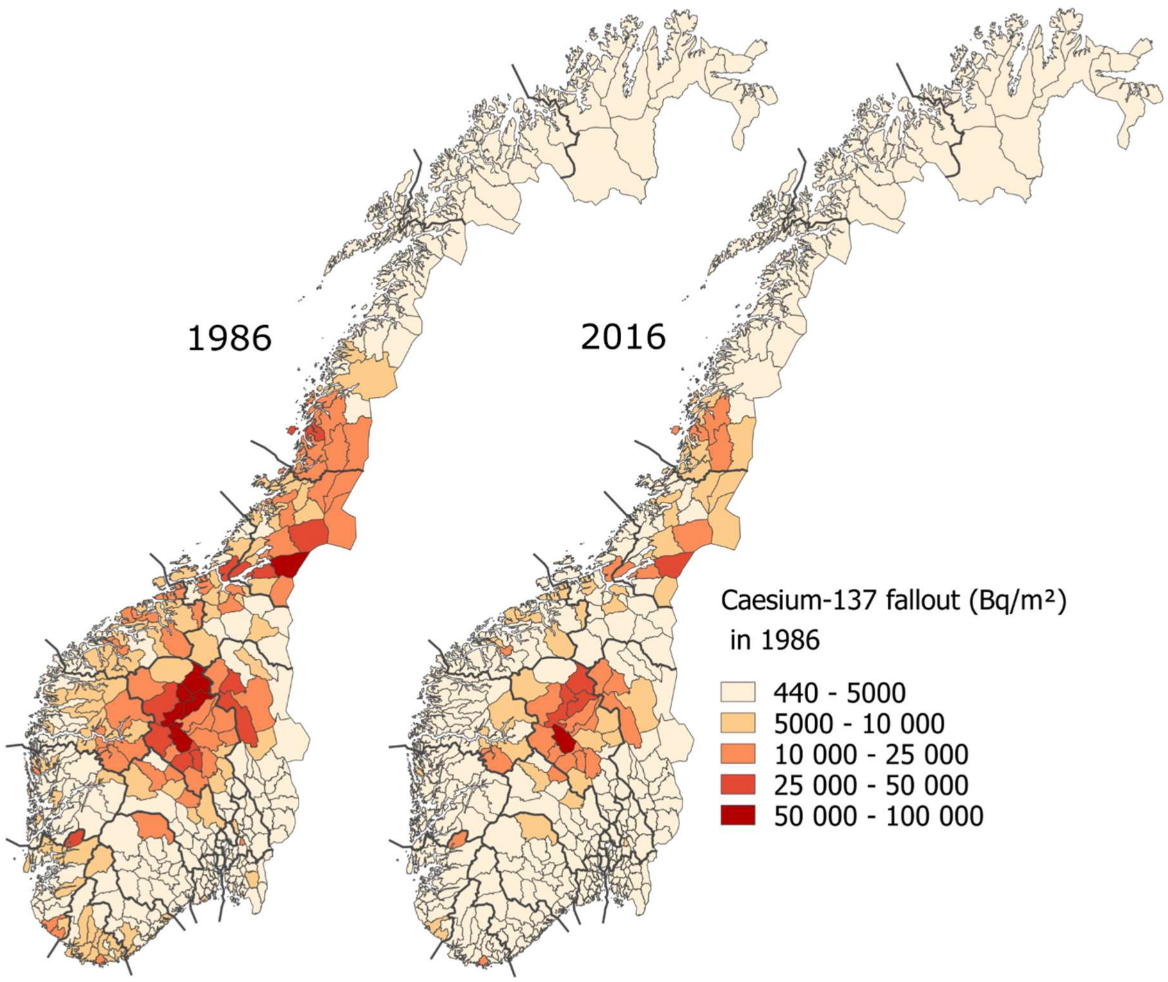

Figure 3.4.1.2-1 Mean concentrations of caesium-137 (Bq/m^2) fallout in soil in different municipalities after the Chernobyl disaster in 1986 (Backe et al., 1986), as well as the corresponding concentration in 2016 as corrected due to physical decay.

Other sources of radioactive contamination

Sea currents transport releases to Norway from nuclear industries in other European countries. The Sellafield reprocessing plant for spent nuclear fuel in the United Kingdom is the main source of relevance to Norway, releasing caesium-137, strontium-90, technetium-99, plutonium-239, and other radioactive elements to the Irish Sea. The contamination is observable along the Norwegian coast, but the levels of anthropogenic radioactive elements in the marine environment and in seafood are generally very low.

Very low levels of anthropogenic radioactive elements are also released from Norwegian hospitals, industries, and research facilities.

The accident in the Fukushima nuclear power plant in Japan, following the earthquake and tsunami on 11 March 2011, resulted in massive contamination of the surrounding area. Only trace levels from the release were detected in Norway.

In addition to actual releases from past and on-going events, Norway is in the vicinity of several potential sources of contamination. Examples are containers of radioactive waste dumped in the Kara and Barents Seas, as well as the sunken nuclear-powered Soviet submarines Komsomolets and K-129, both located in the Barents Sea.

3.4.2 **Radioactive elements addressed in the present assessment**

Eight isotopes have been estimated to account for 99.5% of the effective radiation dose from food in Norway (Komperød et al., 2015b): potassium-40, polonium-210, radon-222, radium-228, lead-210, caesium-137, carbon-14 and radium-226. VKM considered only these eight isotopes in the risk assessment for radioactivity in food at today’s levels. Their origins and relevant characteristics are listed in Table 3.4.2-1.

As described in Table 3.4.2-1, a specific fraction of naturally occurring potassium and carbon consists of the radioactive isotopes potassium-40 and carbon-14, respectively, and the associated dose contributions are considered to be consistent from person to person regardless of their diet. Therefore, VKM did not collect occurrence data or perform dose calculations for these isotopes. For potassium-40, UNSCEAR’s dose estimates were applied (UNSCEAR, 2010a). No estimate is available from UNSCEAR for carbon-14, and VKM therefore assumed that the average dose from carbon-14 in Norway is the same as that recently estimated for the Irish population (O'Connor et al., 2014).

Table 3.4.2-1 The main characteristics of the radioactive elements used in the risk assessment related to the current levels in food.

Radioactive element	Physical half-life	Origin	Main type(s) of radiation	Relevant characteristics and presence in food today
Naturally occurring radioactive elements				
Carbon-14	5730 years	Mainly cosmogenic (a small fraction anthropogenic)	Beta	Constitutes a specific fraction of all carbon. Carbon is present in all types of food, and the dose has been shown to be relatively consistent regardless of diet. Present in all parts of the body.
Lead-210	22 years	Uranium-238 in the Earth's crust	Beta Gamma	Radon gas in the atmosphere decays into lead-210, which binds to particles and is deposited on surfaces, including vegetation. Accumulates mainly in bone, but also in soft tissue such as liver and kidney. Highest concentrations found in seafood and food from uncultivated land (game/reindeer, wild mushrooms).
Polonium-210	138 days	Uranium-238 in the Earth's crust	Alpha	Decay product of lead-210. Accumulates in liver and kidneys, but also present in muscle. Found at highest concentrations in seafood, especially shellfish, as well as in food from uncultivated land (game/reindeer, wild mushrooms).
Potassium-40	1.3 billion years	The Earth's crust (primordial)	Beta	Makes up a specific fraction of all potassium. Potassium (incl. potassium-40) is homeostatically regulated in the body, and any excess will be excreted. Intake therefore does not affect ingested dose. Potassium is the most abundant element inside cells (as a free ion), particularly in physiologically active tissues (e.g., muscle).
Radium-226	1600 years	Uranium-238 in the Earth's crust	Alpha	The highest concentrations are generally found in seafood. It is absorbed and distributed in biological systems similarly to calcium. Accumulates in bone.

Radium-228	5.8 years	Thorium-232 in the Earth's crust	Beta	Like radium-226
Radon-222	3.8 days	Uranium-238 in the Earth's crust	Alpha	A noble gas that may emanate from rock/soil into the atmosphere or ground water. Decay product of radium-226. Of diet-related exposure, it is only relevant for drinking water, first and foremost from ground water supplies. Wells drilled in rock are particularly vulnerable, depending on geology and water chemistry. If water is stored or heated, the radon gas escapes from it.
Anthropogenic radioactive elements				
Caesium-137	30 years	In Norway, mainly Chernobyl disaster	Beta Gamma	Is absorbed and distributed in biological systems similarly to potassium, but because it is available in trace amounts compared to potassium, it is not affected by potassium regulation. In humans and animals, caesium is found at highest concentrations in physiologically active soft tissues. As with potassium, caesium is also transferred to milk. Highest concentrations are found in products from uncultivated land, incl. wild mushrooms, game, sheep, and reindeer.

3.4.3 Radioactive elements included in the Euratom Treaty regulation

Nuclear accidents have the potential to release a wide range of radioactive elements and substances that have the potential to contaminate food products. For instance, due to the explosion and open reactor fire at Chernobyl about 100 different radioactive elements were released. Such elements can pose a potential risk for food production if they are released in large enough quantities and have physical half-lives long enough for significant concentrations to be maintained from deposition in plants to harvest, distribution, and consumption. In the short term, many radioactive elements can contaminate vegetables by direct external deposition. In the long term, those elements that can easily be taken up by plants and animals pose the biggest challenge.

For the purpose of emergency situations, procedures and maximum permitted levels are laid down in the Council regulation (Euratom) 2016/52. The regulation is valid for a 3-month period after an accident involving radioactive material, and specifies maximum permitted levels for the sum of isotopes of various elements and mentions some isotopes explicitly (Table 5.4.1-2).

Of all the elements listed, most are short-lived, but some specific isotopes are of greater concern because of their long physical half-life. In this assessment, strontium-90, iodine-131, plutonium-239, and caesium-137 were used to assess ToR4. A description of these radioactive elements is provided in Table 3.4.3-1.

Table 3.4.3-1 Main characteristics used in the risk assessment related to the radioactive elements in Council regulation (Euratom) 2016/52 for emergency situations.

Radioactive element	Physical half-life	Main type of radiation	Relevant characteristics and likely presence in food after a nuclear disaster
Caesium-137	30 years	Beta Gamma	Is absorbed and distributed in biological systems similarly to potassium, but because it is available in trace amounts compared with potassium, it is not affected by potassium regulation. In humans and animals, caseium is found at highest concentrations in physiologically active soft tissues. As with potassium, caesium is also transferred to milk. The foods most likely to reach high concentrations are leafy vegetables, dairy products, freshwater fish and products from uncultivated land, including wild mushrooms, game, sheep and reindeer.
Iodine-131	8.0 days	Beta Gamma	Iodine is a volatile element relatively easily released during nuclear emergencies. It is an essential element (used in the production of thyroid hormones), and radioactive iodine in some chemical forms is readily taken up by humans and animals and concentrates in the thyroid gland. In lactating animals, iodine is excreted in milk, and contamination of milk is therefore the main risk besides contamination of fresh vegetables. Iodine-131 has a short physical half-life (8 days). The radiation dose will concentrate in the thyroid during the first weeks after a nuclear emergency.The foods most likely to reach high concentrations are milk and leafy vegetables.
Plutonium-239	24 110 years	Alpha	Plutonium is absorbed by the gut to a very limited extent, and the vast majority is excreted. The small fraction that is absorbed, accumulates in bone and liver. Animal products are therefore not expected to present a

			problem. The foods most likely to reach high concentrations are leafy vegetables.
Strontium-90	29 years	Beta	An alkaline earth metal, like calcium, and behaves similarly in the environment and in biological systems. It is less readily released during reactor accidents than iodine and caesium and is generally not transferred to food products as easily as caesium. In humans and animals, it accumulates in bones, and is also transferred into milk in lactating animals. The foods most likely to reach high concentrations are milk and leafy vegetables.

3.4.4 Dose coefficients for calculation of effective doses of radioactive elements in food

Exposure to radioactive elements in foods is assessed on the basis of the effective radiation dose of each element expressed in mSv, as explained in Section 3.2.2.2. Using this approach the effective dose from different radioactive element can be summed up. ICRP's ingestion dose coefficients (described in Table 3.4.4-1) were used to calculate effective radiation doses (expressed in mSv) from each radioactive element (ICRP 2012), except for radon-222 in drinking water, for which the method and dose coefficients described by the U.S. National Research Council were applied (National Research Council, 1999).

Effective doses in mSv were calculated separately for up to three separate age groups - infants, children and adults – as described in Section 2.4.2. The ICRP recommends using dietary data and dose coefficients corresponding to 1-year-olds, 10-year-olds and adults to represent the age groups 0–5 years, 6–15 years, and 16–70 years, respectively (ICRP 2006, 2012). Norwegian dietary data for the age groups 12 months, 9 years, and 18–70 years were used in this work.

Table 3.4.4-1 Effective dose coefficients (Sv/Bq) used in this work to estimate effective doses via ingestion (ICRP, 2012) (National Research Council, 1999).

Radioactive isotope	Infants (1 year old)	Children (10 years old)	Adults (18-70 years old)
Caesium-137	$1.2 \cdot 10^{-8}$	$1.0 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$
Iodine-131	$1.8 \cdot 10^{-7}$	$5.2 \cdot 10^{-8}$	$2.2 \cdot 10^{-8}$
Lead-210	$3.6 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$	$6.9 \cdot 10^{-7}$
Plutonium-239	$4.2 \cdot 10^{-7}$	$2.7 \cdot 10^{-7}$	$2.5 \cdot 10^{-7}$
Polonium-210	$8.8 \cdot 10^{-6}$	$2.6 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$
Radium-226	$9.6 \cdot 10^{-7}$	$8.0 \cdot 10^{-7}$	$2.8 \cdot 10^{-7}$
Radium-228	$5.7 \cdot 10^{-6}$	$3.9 \cdot 10^{-6}$	$6.9 \cdot 10^{-7}$
Radon-222	$2.3 \cdot 10^{-8}$	$5.9 \cdot 10^{-9}$	$3.5 \cdot 10^{-9}$
Strontium-90	$7.3 \cdot 10^{-8}$	$6.0 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$

The estimated dose coefficients for the various radioactive isotopes are based on a given fractional uptake from the gastrointestinal tract (a factor f1 with value between 0 and 1). If it is known that isotopes will be ingested in chemical forms with other uptake efficiencies, the coefficients can be scaled accordingly. Furthermore, the dose coefficients give the integrated dose until the age of 70 years. The coefficients will substantially overestimate the annual dose received, especially for radioactive isotopes with long residence time in the human body, because the integrated lifetime dose is allocated to the year of intake.

Carbon-14 and potassium-40 constitute an almost constant contribution to the radiation dose from food, indepent of the food consumed. For potassium-40, VKM used the age-weighted average dose, 0.17 mSv/year, as calculated by (UNSCEAR, 2010a). The contribution from carbon-14, 0.01 mSv/year, was as calculated by Irish authorities (O'Connor et al., 2014). (See also the Norwegian Radiation Protection Authority (Komperød et al., 2015b).

3.5 Summary of hazard identification and characterisation

In this Section, basic concepts of radioactivity, radiation and exposure are described.

The hazard assessment is based on information from international organisations of radiation effects and radiation protection (ICRP, UNSCEAR, BEIR, WHO). Health effects of radiation depend strongly on dose and dose rate. Low doses and low doses rates are of particular relevance when estimating possible health effects from intake of contaminated food. UNSCEAR defines low doses as those below 100 mSv, and low dose rates as those below 0.1 mSv/minute, averaged over 1 hour. At doses above 100 mSv, there is strong epidemiological evidence of a causal relationship between exposure to radiation and a range of diseases including cancer. At lower doses, human data are inconsistent and effects are extrapolated from higher doses and from experimental studies.

The radiation doses from food in Norway are generally low. At such levels, cancer and heritable disease – i.e., stochastic and not deterministic effects - are considered to be the most important potential health effects.

At the dose levels relevant for exposure from radioactive elements in food, human data are inconsistent, and effects are extrapolated from higher doses and from experimental studies.

For estimating the health risks at very low doses, VKM used a linear no-threshold model (LNT), with an average risk of $5.5 \cdot 10^{-5}$ mSv^{-1} for cancer for the whole population. The estimated risk coefficient for heritable disease is $0.2 \cdot 10^{-5}$ mSv^{-1}. As this is considerably lower, and also because the data are more uncertain, heritable disease was not taken into account when characterising the risk from radioactivity in food.

There are considerable uncertainties in the risks calculated for low doses and dose rates based on LNT. In general, the model is considered to be conservative implying that the actual human health risks are likely to be lower than calculated.

Eight isotopes account for 99.5% of the effective radiation dose from food in Norway. In the assessment of risk from radioactivity in food at today’s levels, VKM considered the following eight isotopes: potassium-40, polonium-210, radon-222, radium-228, lead-210, caesium-137, carbon-14, and radium-226. Each of these has its own specific characteristics, i.e. half-life, origin, and type of radiation emitted.

4 Current levels of radioactivity in food

All food products in the human diet contain radioactivity. Several factors affect the concentration of the different radioactive elements in the various food products.
The most important factors are:

- The amounts of the elements in the environment (contamination or natural variation).
- The chemical properties of the elements, that affect uptake (e.g., whether they ressemble nutrients).
- The chemistry and nutrient abundance of soil and water, which also affect, uptake by organisms.
- The species-specific diet and biological differences in uptake of the various plants and animals.

Once taken up by an organism, the rate at which a specific radioactive element is removed from that organism varies between species. The biological half-life describes the rate at which a specific radioactive element present in an organism is removed via excretion. This rate may vary due to differences in metabolism.

The rate at which radioactive contamination declines in an organism also depends on the rate at which the specific contaminant is removed from the ecosystem and food chain (the ecological half-life). For example, after the Chernobyl accident, caesium-137 concentrations in lake ecosystems declined more quickly than in terrestrial environments, generally resulting in a sharper drop in caesium-137 concentrations in freshwater fish than in terrestrial animals.

4.1 General overview of concentrations of radioactive elements in different foods

Naturally occurring potassium-40 is present in most food products and normally gives the largest radiation dose from food to most of the population. Differences in doses are small because the physiological concentrations of potassium are tightly regulated in the body. Polonium-210 is the second most important contributor to the radiation dose from food to the average population. Seafood, especially shellfish, contains relatively high levels of polonium-210 and other naturally occurring radioactive elements, thus contributing to the highest radiation dose of all food groups; however, there are large variations between different fish and shellfish species. Regarding anthropogenic radioactive elements, only small amounts of caesium-137 are retained by marine organisms due to the high potassium concentrations in seawater. In contrast, freshwater fish were highly contaminated in many districts in the years immediately after the Chernobyl disaster, but levels are now greatly reduced (Strålevernrapport 2014:9, Gjelsvik et al. 2014).

Animals grazing in natural, uncultivated mountain and forest pastures generally acquire higher concentrations of both caesium-137 and some naturally occuring radioactive elements, such as polonium-210 and lead-210, than animals feeding on cultivated grass and concentrated feed. There are large geographic variations in caesium-137 contamination of land, reflecting precipitation patterns in the days directly following the Chernobyl accident (Figure 3.4.1.2-1).

The presence of radon-222 in drinking water is very unevenly distributed, being based on the type of supply and geographical variations, leading to great differences in exposure among the population. Based on information in the reports from the waterworks register (Myrstad et al., 2015) 80% of the Norwegian population receive their drinking water from surface water supplies. Surface water generally contains very low levels of radon, while those supplied by groundwater are more exposed. For an estimated 5-10% of the population supplied by private wells drilled in bedrock, radon-222 levels in their drinking water may be very high (Komperød et al. 2015). The sub-population exposed to elevated radon-222 levels in drinking water is considered in scenarios in the current risk assessment.

Estimated mean concentrations of radioactive elements in key food products relevant for this risk assessment are provided in Table 5.1.1-1. Detailed occurrence data are presented in Appendix 1.

4.2 **Caesium-137 in reindeer and sheep**

In the areas most heavily contaminated by the Chernobyl fallout, the NFSA still regularly inspects sheep and reindeer prior to slaughter for their content of radioactive caesium. In order to answer ToR1-3, a similar approach will be used for describing the radioactivity levels and consumption of reindeer and sheep meat.

4.2.1 **Contamination and transfer of radioactive caesium**

During the early phase after the Chernobyl fallout, direct deposition of radioactive elements on plant surfaces was an important contamination pathway. During the spring and summer of 1986, surface contamination on plants gradually reduced, and uptake through roots became the main pathway of contamination in plants. In fertilised and cultivated fields, radioactive caesium was never considered a significant problem due to low uptake. Ploughing mixes any contamination in a thicker soil layer, partly diluting it and removing it from the root zone. Use of fertilizer introduces large quantities of potassium that compete with radioactive caesium for uptake into plants.

Norway has a strong tradition of using uncultivated mountain and forest pastures for animal husbandry. Dairy cows, cattle, sheep, and goats may graze these pastures during the summer months, whereas reindeer graze these areas all year round. Today, the highest concentrations of caesium-137 are mainly found in reindeer and sheep. In contrast, dairy animals are handled daily, and potential milk contamination can be easily reduced by supplementation with caesium binders, such that milk is not an important source of radioactive caesium to Norwegian consumers.

Forest and mountain pastures in Norway are generally nutrient-poor, which is associated with a high uptake of caesium by plants. Another challenge is the presence of potentially large amounts of wild mushrooms. Several mushroom species take up significantly more caesium-137 than other plants. All ruminants eat mushrooms, and as early as 1988 it became evident that in those years with an abundance of mushrooms, the levels of radioactive caesium in grazing animals increased significantly.

Lichen makes up a large portion of the reindeer diet. Lichens have no roots and absorb and retain nutrients and contamination directly from air and precipitation. Furthermore, lichens are evergreen, long-lived, and grow slowly. Therefore, lichens accumulated very high levels of radioactive caesium after the fallout in 1986, and the levels remained considerably elevated for many years after the accident.

4.2.2 Measures to reduce caesium-137 levels in reindeer and sheep

The Chernobyl fallout in Norway resulted in mean levels of 40–50,000 Bq/kg in reindeer meat from several herds in central and southern Norway during the winter of 1986/87, with maximum concentrations observed as high as 150,000 Bq/kg. Consequently, all reindeer meat produced that year south of the Rana fjord was considered unfit for human consumption. About 2300 tonnes of sheep meat was also condemned in autumn 1986. Various actions and measures to alleviate the consequences and to allow food production in the contaminated areas were implemented (Tveten et al., 1998).

The ML for radioactive caesium was initially set at 370 Bq/kg for milk and infant food, and 600 Bq/kg for all other foods, including reindeer meat. In November 1986, the ML in reindeer meat was increased from the general level for basic foodstuffs (600 Bq/kg) to 6000 Bq/kg, because of the dramatic consequences that the Chernobyl fallout had for reindeer husbandry. From a radiation protection perspective, the increase was justified because of the low consumption rate of reindeer meat by the average Norwegian adult consumer (i.e., 400-500 g/year). In 1994, the ML was lowered to 3000 Bq/kg.

Some of the measures implemented to reduce and control caesium-137 in food are still active today:

- Caesium-137 contamination levels are monitored in live animals before slaughter (to avoid slaughtering animals with contamination above the ML of 3000 Bg/kg, which would result in condemnation of the meat).

- Contaminated animals are given feed containing low caesium levels before slaughter (clean-feeding) in order to reduce their contamination levels below the ML.
- Grazing animals are given a caesium-binding compound (Prussian blue) to reduce the uptake of ingested caesium-137 from the gastrointestinal tract.

Before slaughtering reindeer and sheep from contaminated areas, the caesium-137 levels in a number of randomly selected animals from each herd are measured:

- In reindeer herds, the number of animals to be used for control measurements equals the square root of the intended number of animals to be slaughtered. If none of the reindeer in the control sample are found to be contaminated above the ML of 3000 Bq/kg, then the herd is approved for slaughter. If any animal in the sample is found to be contaminated above the ML, then caesium-137 levels in all animals are measured, and only those with contamination levels below the ML are slaughtered. Unapproved animals are either released (slaughter postponed) or subject to clean-feeding before slaughtering.
- In sheep flocks, caesium-137 levels in between 5-15 animals are usually measured, depending on the size of the herd. If the median caesium-137 concentration in the sample exceeds the ML of 600 Bq/kg, the flock is subjected to clean-feeding before slaughtering.

4.2.3 **Current levels of caesium-137 in reindeer and sheep**

In Norway, the Chernobyl accident mainly affected reindeer husbandry south of Saltfjellet (Figure 4.2.3-1). Today, the highest caesium-137 concentrations are observed in the reindeer herding districts in the south of Nordland, inner Nord-Trøndelag, and in Gudbrandsdalen/Valdres. Current levels of caesium-137 in reindeer meat are generally below the ML of 3000 Bq/kg, but higher concentrations may occur in some districts because of local deposition “hot spots”. An abundance of mushrooms will increase the levels of caesium-137 in reindeer and sheep. In 2014, an abundance of mushrooms resulted in caesium-137 levels in reindeer up to 8,200 Bq/kg. The national mean level used in the intake estimate of caesium-137 in meat from semi-domesticated reindeer was much lower (208 Bq/kg), reflecting that 70% of reindeer meat production in Norway occurs in Finnmark where the contamination levels generally are low (Figure 4.2.3-2).

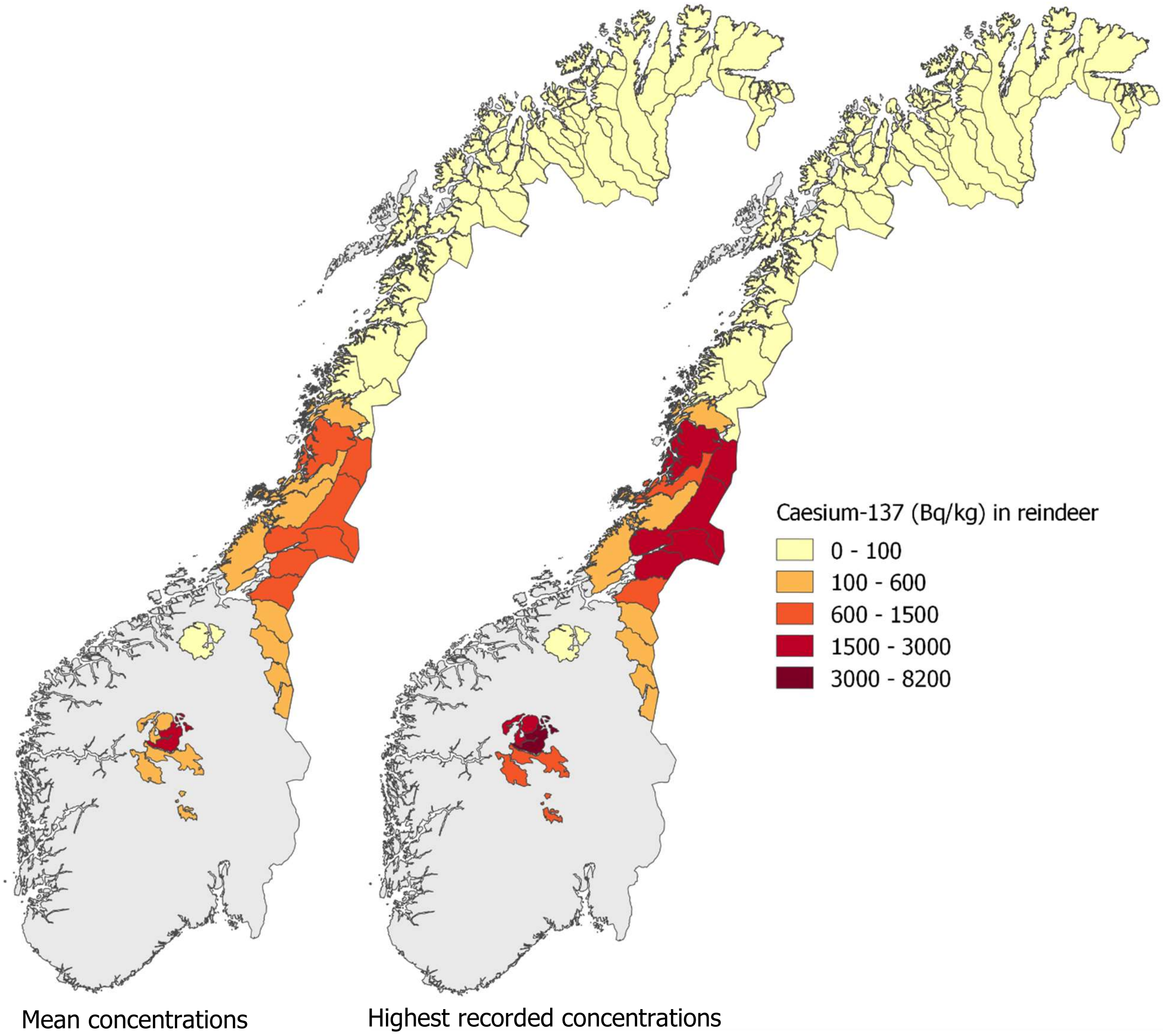

Figure 4.2.3-1 Caesium-137 concentrations in semi-domesticated live reindeer from different reindeer-herding districts (data from the NFSA). The maps show the mean (left) and the highest recorded (right) concentrations during the period 2013–2014. For districts in which no measurements are available for 2013–2014 (i.e. districts with low levels of contamination), expert judgment has been used to estimate current mean levels based on past levels. In these districts, there is no basis for determining "highest recorded level" and mean levels are therefore displayed in both maps.

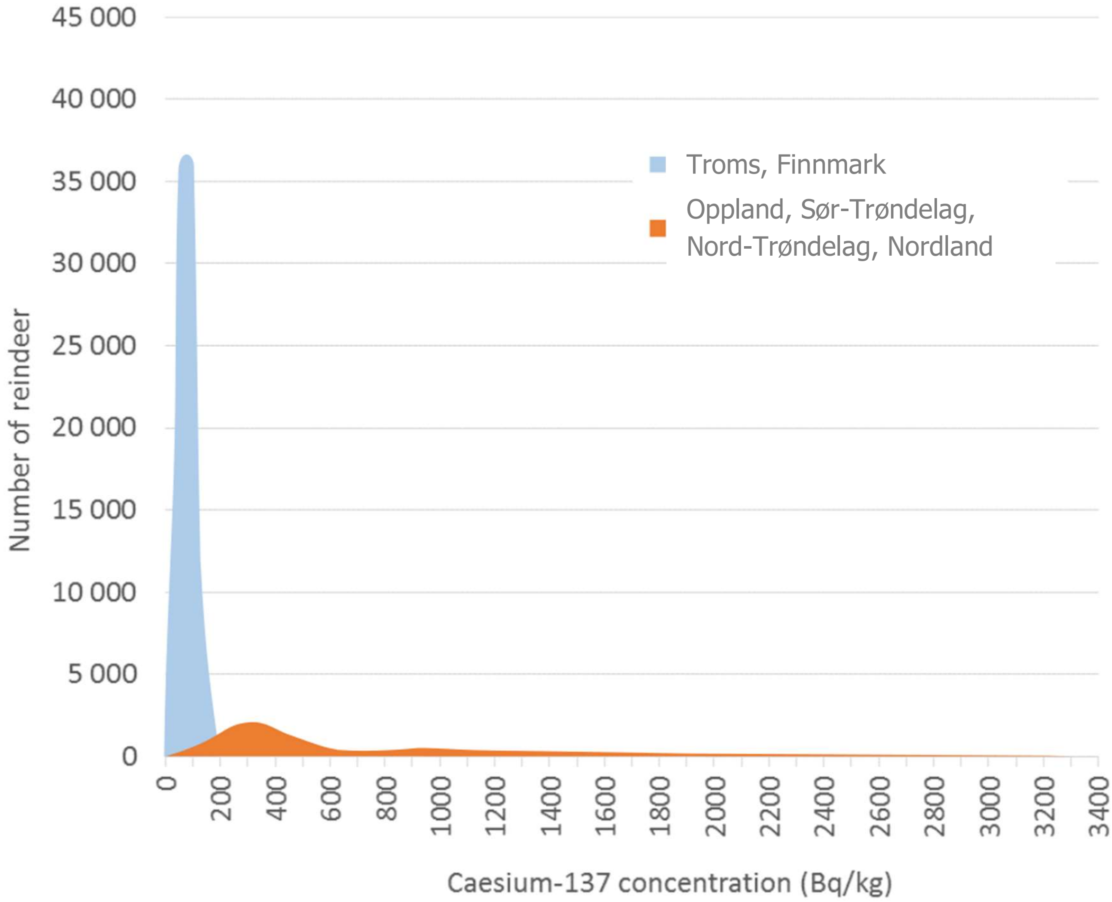

Figure 4.2.3-2 Distribution of caesium-137 contamination levels in reindeer in the two northern-most counties, Finnmark and Troms (which contain little contamination and produce most of the reindeer meat) and the counties Nordland, Sør-Trøndelag, Nord-Trøndelag and Oppland (which produce less reindeer meat, but received much more contamination after the Chernobyl accident). Based on data provided in Table A4-1 (Appendix 4).

Free-range grazing is the most common type of sheep husbandry in Norway and practiced in all regions, including those areas affected by the Chernobyl fallout. High caesium-137 concentrations in sheep have been observed in many areas in years with high mushroom abundance. However, in years with low amounts of mushrooms, concentrations in sheep above the maximum level of 600 Bq/kg are also regularly found in the most contaminated areas in Hedmark, Oppland, Nord-Trøndelag, and Nordland. Consequently, the need for live monitoring and clean-feeding varies from year to year (Figure 4.2.3-3). Autumn 2014 was rich in mushrooms in many areas in southern Norway, resulting in caesium-137 levels in sheep as high as 4,500 Bq/kg. However, as with reindeer meat production, sheep are mainly farmed in areas with relatively low caesium-137 fallout, resulting in an estimated national mean level of 30 Bq/kg in sheep meat. This value is used in the exposure calculations in this assessment.

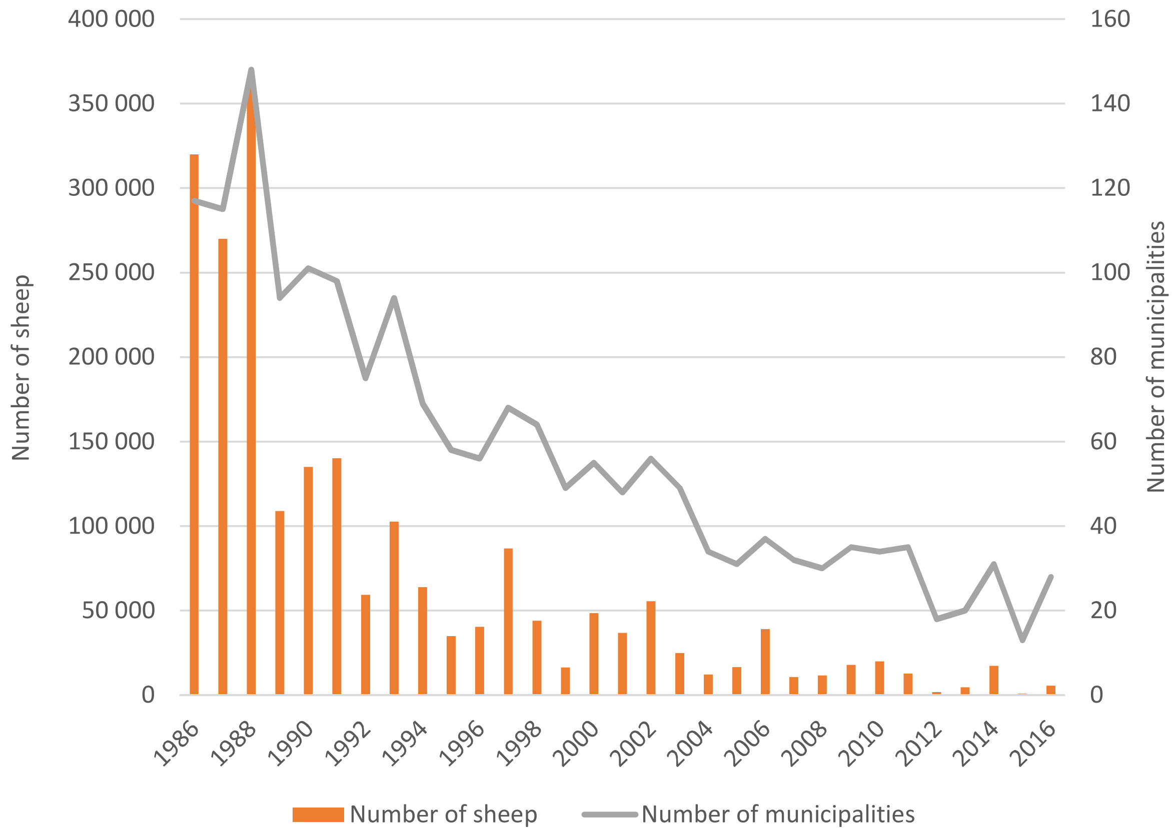

Figure 4.2.3-3 Number of sheep subject to "clean-feeding" before slaughtering, and number of municipalities in which this countermeasure was applied from 1986–2016. Data provided by the Norwegian Agriculture Agency based on applications for financial compensation submitted by sheep farmers.

4.3 Summary of current levels of radioactivity in food

All food in the human diets contain radioactive elements. Some of these elements are produced by human activity, but most radioactive elements in our diet are natural in origin.

Several factors affect the concentrations of the different radioactive elements in the various food products, including the abudance and chemistry of the different elements and the biology and environment of organisms used for food.

Naturally occurring radioactive elements, especially polonium-210, occur in relatively high concentrations in seafood and game, including reindeer. Drinking water from wells drilled in bedrock may contain high levels of radon-222.

Caesium-137, from the Chernobyl disaster in 1986, is still present at relatively high concentrations in some parts of the environment, and there are large geographic variations in contamination levels. Norway has a strong tradition of using uncultivated mountain and forest pastures in animal husbandry, and animals grazing in uncultivated pastures generally acquire higher concentrations of caesium-137 than animals feeding on cultivated grass and concentrated feed. Lichens accumulated high levels of radioactive caesium after the fallout in 1986, and the levels remained high for many years after the accident, resulting in particularly elevated concentrations in reindeer. Those years with a high mushroom abundance are associated with elevated caesium-137 concentrations in both reindeer and sheep, contributing to the continued need for countermeasures in order to reduce levels below the ML in these animals.

5 Consumption and occurrence for different exposure groups

This chapter presents the consumption and occurrence data that VKM have compiled in response to the terms of reference (ToR). The dietary intake of several age groups has been estimated in the whole population for ToR1-4 (see Section 2.4.2). Different consumption and occurrence scenarios have also been developed for specific groups with elevated exposure, in response to ToR1-3. These specific groups have elevated exposure due to higher consumption of certain food products and/or due to elevated concentrations of radioactive elements in their diet. An overview of all assessments made for the whole population and for the specific groups for each question in the ToR is summarised in Section 2.4.1.

5.1 Consumption and occurrence data of radioactivity in the total diet at the current situation (ToR)

ToR1 asks for an assessment of the health risk for the whole population and specific groups, given the current levels of radioactivity in food. In this part of the assessment, the whole diet and both anthropogenic and naturally occurring radioactive elements are considered.

5.1.1 Whole population

For the assessment of health risk to the whole population in the current situation, VKM has considered occurrence of eight radioactive elements (see Section 3.4.2). Of these eight elements, caesium-137 is the only one of anthropogenic origin. In addition, the following seven naturally occurring radioactive elements are included in the assessment: potassium-40, polonium-210, radon-222, radium-228, lead-210, carbon-14 and radium-226. However, the doses from potassium-40 and carbon-14 are assumed to be constant regardless of diet and were not calculated on the basis of consumption and occurrence data, as was done for caesium-137, polonium-210, radon-222, radium-228, lead-210, and radium-226. The dietary exposure for the whole population is based on estimated mean concentrations of each of these six radioactive elements in each food product. The concentration data for each radioactive element and food product considered for this part of the assessment are provided in Appendix 1. An overview of a few selected food products, illustrating the variation in the levels of radioactive elements in selected key foods used in this assessment is also provided in Table 5.1.1-1.

Table 5.1.1-1 Estimated current mean concentrations of radioactive elements (Bq/kg) in key food products (ToR1). Concentrations are based on Norwegian measurements and literature data from other countries as provided in Komperød and coworkers (2015), with slight modifications as described in Appendix 1. Full details are provided in Appendix 1.

	Level of radioactivity Bq/kg					
	Caesium-137	**Polonium-210**	**Lead-210**	**Radium-226**	**Radium-228**	**Radon-222**
Reindeer	208	9.3	0.5	0.015	0.01	0
Sheep	30	2	0.08	0.015	0.01	0
Pork	1	0.06	0.08	0.015	0.01	0
Wild mushrooms	120	4	0.4	0.03	0.02	0
Root vegetables	1	0.04	0.03	0.03	0.02	0
Milk	0.05	0.015	0.015	0.005	0.005	0
Fatty saltwater fish	0.14	2.6	0.2	0.2	1.8	0
Shellfish	0.09	11	0.2	0.7	1.8	0
Freshwater fish	30	0.43	0.056	0.1	0	0
Drinking water	0.001	0.005	0.01	0.0005	0.0005	38[a]

[a]Estimated mean concentration. Surface drinking water sources (which supply 80% of the Norwegian population) are expected to contain less than 1 Bq/L. However, groundwater-based drinking water may contain significant concentrations, especially wells drilled in bedrock. These wells have a large effect on the mean concentration for the whole population.

The mean concentration of different radioactive elements varies by several orders of magnitude in the various food items. For example, the estimated caesium-137 concentration ranges from 0.001 Bq/kg in drinking water to 208 Bq/kg in reindeer meat. Reindeer meat and wild mushrooms are the food items with highest mean concentrations of caesium-137. The highest concentrations of polonium-210 are found in shellfish and reindeer meat, with an estimated means of 11 and 9.3 Bq/kg, respectively. A general description of the current radioactivity levels in food is presented in Chapter 4.

Radium-226, lead-210, polonium-210, and radon-222 (found in water) are all part of the same decay chain and hence their concentrations tend to correlate. For example, reindeer meat, wild mushrooms, and seafood, which have relatively high concentrations of both polonium-210, also have relatively high concentrations of lead-210. However, data for each specific food product is not always available to reveal such patterns.

It is worth noting, as decribed in Section 3.2.2.2, that the activities (Bq) of the different radioactive elements are not directly comparable in terms of their associated exposure. For example, the ingestion of 1 Bq polonium-210 results in a higher exposure than 1 Bq caesium-137. This is due to the different physical and chemical properties as described in Section 3.2.2.2, which are also reflected in different ingestion dose coefficients (Section 3.4.4-1).

Infants and adults are considered for ToR1 (see Section 2.4.1). Mean consumption rates for these age categories are used. An overview of the mean consumption divided into major food groups is provided in Table 5.1.1-2.

Table 5.1.1-2 Consumption (g/day) of different food groups by 1-year-olds (Spedkost-07) and adults (Norkost 3).

Food group	1-year-olds g/day		Adults g/day	
	Mean	P95	Mean	P95
Bread	65	154	171	374
Cereal products	5	16	67	244
Cakes	4	16	35	144
Potatoes	25	67	66	200
Vegetables	32	94	147	339
Fruit and berries	101	293	285	702
Meat, blood, offals	23	56	143	336
Fish and shellfish	12	40	67	238
Egg	2	7	25	95
Milk and dairy products	148	534	333	916
Cheese	10	32	39	105
Butter, margarine, oil	9	28	31	79
Sugar	1	4	18	67
Beverages	254	600	2137	3783
Baby food[a]	627	1374	-	-
Miscellaneous	17	48	110	324

[a]Baby food includes both food and infant formula.

The consumption data show that the main food group of 1-year-olds is baby food, with an intake of 627 g/day and 1374 g/day for mean and P95 values, respectively. Aside from baby food, the main food groups for both 1-year-olds and adults are milk/dairy products, beverages (including drinking water), fruits/berries, and bread. Adults consume approximately twice as much meat, fish/shellfish, and vegetables, relative to their total food, consumption as 1-year-olds.

Comparing the relationship between P95 and mean consumption, the patterns are fairly similar for 1-year-olds and adults. P95 1-year-old consumers of milk/dairy products and fish/shellfish consume 3–4 times as much of these foods than average; and this is the same for P95 adult consumers of fish/shellfish. P95 1-year-old and adult consumers both eat 2–3 times as much meat as the mean consumers in their age categories.

5.1.2 **Specific groups**

ToR1-3 also request that the health risk to specific groups are assessed. The VKM has defined five specific groups with elevated exposure, as described below, in Sections 5.1.2.1-5.1.2.5. The combinations of consumption and occurrence data for these specific groups are defined on the basis of expert judgment, as no accurate data for such groups are available.

Elevated exposure to caesium-137 was assessed for three specific groups. Two specific groups were considered for the elevated exposure to naturally occurring radioactivity – polonium-210 and radon-222.

For some of these five specific groups, several different combinations of consumption and occurrence levels were considered. For example, two different consumption levels and three different occurrence levels were assessed for a specific group with elevated exposure due to caesium-137 in reindeer meat (Section 5.1.2.1). In this assessment, each combination of consumption and occurrence assessed for the specific group is termed a scenario. For example, in the case of the specific group with elevated exposure to caesium-137 in reindeer meat, a total of six scenarios were assessed.

Only adults have been assessed for the specific groups, as they are considered to be the age group with highest exposure for the selected scenarios. The food consumption data and occurrence data used in the different specific group scenarios in response to ToR1 are provided in Tables 5.1.2-1 and 5.1.2-2.

Table 5.1.2-1 Levels of radioactive elements (Bq/kg) in food items used in the different scenarios (ToR1).

Specific group	Food item	Level of radioactivity (Bq/kg)		
		Mean	High	Very high
		Caesium-137		
Reindeer meat	Reindeer meat	208	1191[b]	2105[c]
Sheep meat	Sheep meat	30[a]	--	600[d]
Wild products	Game meat		110[e]	-
	Mushrooms		1100[e]	-
	Berries		100[e]	-
		Radon-222		
Drinking water	Drinking water	-	400[f]	2200[g]
		Polonium-210		
Seafood	Fish filet	2.6[h]		
	Shellfish	11[i]		

[a]National mean concentrations used in the current exposure estimation; [b]Mean of the mean concentrations in each of the most contaminated districts; [c] Mean of the single highest recorded concentration in each of the most contaminated districts, taking into account the ML of 3000 Bq/kg; [d]ML for sheep meat; [e] Median concentration in the county with the highest recorded levels in such products; [f]Mean concentration in drinking water from private wells drilled in bedrock; [g]P95 concentration in drinking water from private wells drilled in bedrock; [h]Mean concentration in fatty fish; [i]Mean concentration weighted according to consumption rate of each species.

Further descriptions of the occurrence and consumption data used in the assessment of elevated exposure to specific groups are presented in Sections 5.1.2.1 to 5.1.2.5.

It should be noted that although exposure is only assessed for one radioactive element per specific group in this assessment, consumption of these food items may in reality lead to increased exposure to several radioactive elements. For example, reindeer meat and wild mushrooms, used in this report as scenarios for high exposure to caesium-137, are also known to contain more polonium-210 than most foods. As briefly noted in Section 5.1.1, the naturally occurring radioactive elements that are part of the same decay chain also tend to have concentrations that correlate with each other. Therefore, seafood, which is used as a scenario for high exposure to polonium-210, also contains above-average levels of lead-210. Drinking water with high radon-222 levels is also likely to contain higher concentrations of polonium-210. However, VKM has chosen to consider only the radioactive elements that represent the largest contribution to the effective dose, in order to assess better illustrate the impact of these elements on health risk.

Table 5.1.2-2 Consumption (g/day) of food items used in specific groups (ToR1).

	Food item	Consumption level	Consumption (g/day)
Reindeer meat	Reindeer meat	High[1]	143
		Very high[2]	336
Sheep meat	Sheep meat	High[1]	143
Wild products	Game meat	High[3]	46
	Mushrooms	High[4]	28
	Berries	High[5]	75
Drinking water	Drinking water	Mean[6]	982
Seafood	Fish filet	P95[7]	201
	Shellfish	P95[8]	35

[1]Mean consumption of all meat from Norkost 3; [2]P95 consumption of all meat from Norkost 3; [3]P95 consumption of game meat from Norkost 3; [4]P95 consumption of all types of mushrooms from Norkost 3; [5]P95 of jam consumption from Norkost 3; [6]Mean drinking water consumption from Norkost 3; [7]P95 consumption of fish filet from Norkost 3; [8]P95 consumption of shellfish from Norkost 3.

5.1.2.1 *Specific population group 1: consumers of reindeer meat*

Food consumption data and caesium-137 concentrations measured in reindeer were used for the calculation of six exposure scenarios, including two levels of consumption and three concentrations of caesium-137 in reindeer meat (Table 5.1.2.1-1).

Table 5.1.2.1-1 Overview of the six specific group scenarios used to assess elevated exposure to caesium-137 in reindeer meat (ToR1).

Specific group	Food item	Consumption level	Level of radioactivity (caesium-137)		
			Mean	High	Very high
Reindeer meat	Reindeer meat	High	X	X	X
		Very high	X	X	X

The intake by the high consumption group is based on the mean total meat consumption measured in Norkost 3, assuming all meat is reindeer meat. This is similar to the mean consumption of reindeer meat by reindeer herders found in dietary surveys (Skuterud and Thorring, 2012). A very high consumer scenario was also introduced for reindeer meat because dietary surveys of reindeer herders also show that some persons consume more reindeer meat than those defined as high consumers (Skuterud and Thorring, 2012; Skuterud and Thorring, 2015). For the very high consumer group, the P95 for consumption of total meat in Norkost 3 has been used, with all meat considered to be reindeer meat (Table 5.1.2-2).

Two different contamination levels, 1191 Bq/kg and 2105 Bq/kg, were used to represent high and very high caesium-137 levels in the scenarios (Table 5.1.2-1). These values were calculated based on the mean and highest measurements of caesium-137 in reindeer in the five districts with the highest concentrations. The data were adjusted for the ML of 3000 Bq/kg, meaning that reindeer with contamination levels above this level were not included in the calculations. Data from 2013 and 2014 were selected because 2014 represents a year with an abundance of mushrooms, whereas mushroom occurrence was low in 2013. Averaging data from the five most contaminated districts in two different years ensures that the scenarios are realistically high, but do not produce an overly conservative assessment.

Consumers who have a high or very high intake of reindeer meat are more likely to be involved with reindeer herding than other consumers. There are, however, also scenarios included that are based on the assumption of high consumers who frequently buy reindeer meat in ordinary stores. For this scenario, we used the national mean concentration of caesium-137 in reindeer meat (208 Bq/kg).

It is unlikely that consumers obtain their annual supply of reindeer meat only from animals with the highest contamination levels, but rather from a number of different animals over the course of a year. A person with very high consumption living in one of the most contaminated districts is therefore expected, on average, to consume meat containing the high caesium-137 level, which represents the mean level in the area. Thus, the combination of very high consumption and a very high caesium-137 level in reindeer meat represents an over-estimation.

As previously noted, the high consumption rates correspond to reindeer meat intake by reindeer herders. These scenarios could therefore represent groups of reindeer herders. However, due to the high contamination levels in reindeer meat and the important role reindeer meat have in Sámi reindeer herders' diet, after the Chernobyl accident special actions were taken and dietary advice prepared to reduce radiation doses. For instance, in their own households, reindeer herders have been recommended using meat that is less contaminated than the permissible level of 3000 Bq/kg, and special measures are available when their animals are contaminated above 600 Bq/kg (the permissible level for basic foods). Furthermore, since the Chernobyl accident, the Sámi reindeer herders have routinely been offered the opportunity to check their personal contamination levels. The results of this monitoring suggests that the various actions taken reduced doses to the herders by more than 70% (Skuterud and Thørring, 2012).

The number of persons registrered as being directly related to reindeer herding in the five districts and used to define the high and very high caesium-137 levels amounts to about 120 (Landbruksdirektoratet, 2016). In addition, relatives and friends of these people are alos likely to have a high intake of reindeer meat. The scenarios for high and very high consumers of reindeer meat presented in this risk assessment are only relevant for these persons if they take none of the recommended measures against radioactive contamination (please see above).

5.1.2.2 ***Specific population group 2: consumers of sheep meat***

Two scenarios (Table 5.1.2.2-1) were developed for the specific group with elevated exposure to caesium-137 in sheep meat for ToR1. One consumption level and two caesium-137 concentration levels were assessed.

Table 5.1.2.2-1 Overview of the two specific group scenarios used to assess elevated exposure to caesium-137 in sheep meat (ToR1)

Specific group	Food item	Consumption level	Level of radioactivity (caesium-137)		
			Mean	High	Very high
Sheep meat	Sheep meat	High	X	(X)[a]	X

[a]Same as very high

The calculations are based on the assumption that high consumers of sheep meat have this as their only source of meat. The intake data for this group are based on the mean total meat consumption measured in Norkost 3, with all meatassumed to be sheep meat. There are no data supporting the scenario that some people consume this much sheep meat each year, and this is therefore most likely an overestimation.

Consumers who have a high intake of sheep meat are more likely to be closely associated with the farming community and may represent individual farm owners and their families, and other persons living on, or close to, a farm. One of the scenarios is, however, based on the assumption of a high consumer who frequently buy sheep meat from ordinary stores. For this hypothetical case, the national mean concentration of caesium-137 in sheep meat, 30 Bq/kg, has been used.

The two farms with the highest caesium-137 concentrations in sheep from each of the counties Nordland, Nord-Trøndelag, Sør-Trøndelag, Oppland, and Hedmark were used to establish high levels of contamination for the scenario calculations. However, the median caesium-137 levels in measurements of live sheep meat exceeded the ML of 600 Bq/kg in all farms considered in 2013-2014. Because only sheep meat below 600 Bq/kg would be allowed to enter the market, both the high and very high caesium-137 levels would be reduced to 600 Bq/kg before consumption (Table 5.1.2-1). In order to avoid assessing the health risk from two identical concentration levels, 600 Bq/kg was only applied as "very high" level in the assessment of ToR1.

5.1.2.3 *Specific population group 3: consumers of wild products*

The intake of caesium-137 from the consumption of game meat, wild mushrooms and wild berries by hunters and gatherers was calculated in individual scenarios based on high consumption rates estimated from Norkost 3. For the occurrence data, the median caesium-137 concentrations in the county with the highest recorded caesium-137 levels in such products was used. An overview is provided in Table 5.1.2.3-1.

Table 5.1.2.3-1 Overview of the three specific group scenarios used to assess elevated exposure to caesium-137 from the wild products (ToR1).

Specific group	Food item	Consumption level	Level of radioactivity (caesium-137)		
			Mean	High	Very high
Wild products	Game meat	High		X	
	Wild mushrooms	High		X	
	Wild berries	High		X	

Considering that this specific group represents 5% of the population of the most contaminated areas of Norway, this scenario is estimated to be of relevance for may be between 10,000 and 50,000 people.

5.1.2.4 *Specific population group 4: consumers of drinking water containing radon-222*

Drinking water from private wells drilled in bedrock contains relatively high levels of radon-222 (see Section 4.1). Two different scenarios for the levels of radon-222 in drinking water have been calculated based on the data for mean consumption of tap water for adults reported in Norkost 3 (Table 5.1.2.4-1). The occurrence levels assessed were the mean and P95 concentrations of radon-222 in drinking water from private wells drilled in bedrock (see Table 5.1.2-1).

Table 5.1.2.4-1 Overview of the two specific group scenarios used to assess elevated exposure from radon-222 in drinking water (ToR1).

Specific group	Food item	Consumption level	Level of radioactivity (radon-222)		
			Mean	High	Very high
Drinking water	Drinking water	Mean		X	X

Accurate data on the number of people in Norway using private wells in bedrock are not available, but best estimates show that 10% of the population is served by drinking water from private wells, and that 80-90% of the these are drilled in bedrock (Komperød et al. 2015 and unpublished data from NFSA). This corresponds to 300,000-400,000 people for the mean radon level for private wells in bedrock, with a subgroup of 5%, or 15,000-20,000 for the P95 radon level.

5.1.2.5 *Specific population group 5: consumers of seafood*

Intake of polonium-210 from the consumption of saltwater fish and shellfish was estimated in two scenarios for high consumers of these food products (Table 5.1.2.5-1). The consumption is based on the P95 consumption data of these products in Norkost 3, and the occurrence data used are the mean national concentrations of polonium-210 in fish and shellfish (Table 5.1.2-1).

Table 5.1.2.5-1 Overview of the two specific group scenarios used to assess elevated exposure to polonium-210 in fish and shellfish (ToR1).

Specific group	Food item	Consumption level	Level of radioactivity (polonium-210)		
			Mean	High	Very high
Seafood	Fish filet	High	X		
	Shellfish	High	X		

5.2 Consumption and occurrence of caesium-137 in reindeer and sheep if no efforts were made to reduce levels (ToR2)

ToR2 asks for an assessment of the health risks associated with caesium-137 in reindeer and sheep in the whole population and specific groups should no efforts be made to reduce the levels in meat, i.e., no countermeasures performed to reduce concentrations exceeding the ML. Today, countermeasures are conducted in certain areas in order to reduce the caesium-137 concentration in reindeer and sheep meat below the ML of 600 and 3000 Bq/kg, respectively.

In order to make this assessment, the same calculations were performed as for ToR1 for reindeer and sheep meat (see Section 5.1), except that the caesium-137 concentration data were adjusted such that live animals above the respective ML were also included in the calculations. Animals with measurements above the ML were excluded in the calculations in ToR1, because these animals would not enter the market, and countermeasures would be performed to reduce the levels before slaughter. The resulting occurrence data used to answer ToR2 are provided in Table 5.2-1.

According to these calculations, the national mean level of caesium-137 in reindeer meat, provided that no countermeasures were performed, would increase from 208 to 222 Bq/kg. The levels in the most contaminated districts (high and very high level) would increase from 1191 to 1297 Bq/kg and from 2105 to 2538 Bq/kg, respectively. The national mean caesium-137 concentration in sheep meat would increase from 30 to 40 Bq/kg, and the most contaminated animals (very high level) would increase from 600 to 4490 Bq/kg. Thus, the largest effect, relative to current levels, was for sheep meat.

Consumption data are the same as those for the whole population in Table 5.1.1-2. and for the relevant specific group scenarios in Table 5.1.2-2.

Table 5.2-1 Estimated levels of caesium-137 (Bq/kg) in Norwegian reindeer and sheep if no efforts were made to reduce them (ToR2). The levels are derived by including measurements of animals with caesium-137 concentrations above the respective MLs.

Food item	Caesium-137 (Bq/kg)		
	Mean	**High**	**Very high**
Reindeer meat	222[a]	1297[b]	2538[c]
Sheep meat	40[a]	1171[b]	4490[c]

[a]Mean national concentrations, including animals with caesium-137 concentrations above the respective MLs; [b]Mean of the mean concentrations in the most contaminated districts, including animals with caesium-137 concentrations above the respective MLs; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, including animals with caesium-137 concentrations above the respective MLs.

The mean consumption rates of reindeer and sheep meat in Norkost 3, as well as the P95 consumption rate for sheep meat, are presented in Table 5.2-2. Under 5% of the participants in Norkost 3 reported having eaten reindeer meat and P95 data were therefore not provided. The high and very high consumption rates used for the specific groups are the same as those described in Section 5.1.2.

Table 5.2-2 Consumption (g/day) of reindeer and sheep meat (ToR2).

Food item	Consumption level	Consumption (g/day)
Reindeer meat	Mean[a]	1
	High[b]	143
	Very high[c]	336
Sheep meat	Mean[d]	10
	P95[e]	81
	High[b]	143

[a]Mean consumption of reindeer meat from Norkost 3; [b]Mean consumption of all meat from Norkost3; [c]P95 consumption of all meat from Norkost 3; [d]Mean consumption of sheep meat from Norkost 3; [e]P95 consumption of sheep meat from Norkost 3.

5.3 Caesium-137 in reindeer meat on the market if the ML was reduced (ToR3)

ToR3 addresses health risks in the whole population and in specific groups from consumption of reindeer meat contaminated with caesium-137 at reduced MLs, i.e. 1500 or 600 Bq/kg. Values for consumption of reindeer meat are derived from the same data as described in Section 5.1.

In order to estimate caesium-137 occurrence if the ML for reindeer was reduced from 3000 Bq/kg to 1500 Bq/kg or 600 Bq/kg, VKM assumed that enforcement of the ML in reindeer meat remains the same as it is today, and that no meat above the ML enters the market. This assessment does not take into consideration any countermeasures that may reduce the level in the whole herd. That is, VKM assumes that any individual animals with caesium-137 levels exceeding the ML would be reduced to the ML (not lower) before slaughter.

Food consumption data and caesium-137 concentrations measured in live reindeer were used for calculations in 18 exposure scenarios, including two levels of consumption and nine concentrations of caesium-137 in reindeer meat (Tables 5.3-1 and 5.3-2).

The estimates show that reducing the ML to 1500 Bq/kg would result in no significant change in the national mean level of caesium-137 in reindeer meat, as the current mean levels are already below 1500 Bq/kg in most reindeer herding districts. Reducing the ML to 600 Bq/kg is estimated to decrease the mean national level of caesium-137 in reindeer meat by 46 Bq/kg in a typical year.

The reduction has a larger impact on the scenarios for high and very high contamination levels. For reindeer with high or very high contamination levels of caesium-137, lowering the ML to 1500 Bq/kg would reduce the level in the meat sold on the market by 41 or 697 Bq/kg, respectively. For the same reindeer, decreasing the ML to 600 Bq/kg would reduce the levels of of caesium-137 in the meat sold on the market by 601 or 1505 Bq/kg.

It should be noted that these estimates represent a year with medium caesium-137 concentrations in reindeer meat. In years with a high mushrooms abundance and thus elevated caesium-137 levels in reindeer from the contaminated districts, lowering the MLs would have a larger effect, while in other years it would have a smaller effect.

Table 5.3-1 Levels of caesium-137 (Bq/kg) in Norwegian reindeer measured across Norway, and in contaminated areas, excluding animals with caesium-137 concentrations above the respective ML.

Specific group	Level of caesium-137 (Bq/kg)								
	ML 3000 (current)			ML 1500			ML 600		
	National	Contaminated area		National	Contaminated area		National	Contaminated area	
	Mean[a]	High[b]	Very high[c]	Mean[a]	High[b]	Very high[c]	Mean[a]	High[b]	Very high[c]
Reindeer meat	208	1191	2105	202	1150	1480	162	590	600

[a]National mean concentrations, adjusted by respective ML; [b]Mean of the mean concentrations in each of the most contaminated districts, adjusted by respective ML; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, adjusted by respective ML.

Table 5.3-2 Consumption (g/day) of reindeer meat (ToR3).

Food item	Consumption level	Consumption (g/day)
Reindeer meat	Mean[a]	1
	High[b]	143
	Very high[c]	336

[a]Mean consumption of reindeer meat from Norkost 3; [b]Mean consumption of all meat from Norkost 3; [c]P95 consumption of all meat from Norkost 3.

5.4 Concentrations of radioactive elements applying maximum permitted levels provided in the Council regulation (Euratom) 2016/52 for emergency situations (ToR4)

This Section presents the basis for the concentration data used to answer ToR4. This ToR iexamine whether the procedure and the maximum permitted levels, as laid down in Council regulation (Euratom) 2016/52 on radioactive contamination of foodstuffs and feedstuffs following a nuclear accident, are appropriate for managing similar scenarios in Norway.

5.4.1 Food

The consumption data from the Norwegian food consumption surveys for 1-year-olds, 9-year-olds, and adults (18-70 years) were grouped in categories corresponding to the various permitted levels in Council regulation (Euratom) 2016/52 . Consumption of the aggregated food groups by different age classes are shown in Table 5.4.1-1. Due to their relatively high consumption of fresh milk, which makes them vulnerable to exposure from iodine-131, 9-year-olds were included in the exposure estimate for an emergency situation.

Table 5.4.1-1 Consumption of foods (g/day) grouped in categories according to the Council regulation (Euratom) 2016/52, in 1-year-olds (Spedbarnskost-07), 9-year-olds (Ungkost 3) and adults (Norkost 3).

	1-year-olds		**9-year-olds**		**Adults**	
	Mean	P95	Mean	P95	Mean	P95
Infant food[a]	321	771	-[b]	-[b]	-[b]	-[b]
Dairy products[c]	163	551	364	708	372	967
Liquid food[d]	352	838	575	1089	2137	3783
Other food[e]	511	958	768	1183	1165	1888

[a]Infant food includes baby food and infant formula, but not breastmilk; [b]Infant food was not consumed by this age group; [c]Diary products includes milk, cheese and other diary products; [d]Liquid food includes drinking water, coffee, tea and other beverages; [e]Other foods includes all other foods not covered in the former three food categories.

The maximum permitted levels in the Council regulation (Euratom) 2016/52 are presented in Table 5.4.1-2. The regulation is intended to apply for a 3-month period.

Table 5.4.1-2 Maximum permitted levels of radioactivity in food (Council Regulation (Euratom) 2016/52).

Radioactive elements	Food (Bq/kg)			
	Infant food	**Dairy products**	**Liquid food**	**Other food (except minor food)**
Sum of isotopes strontium, notably Sr-90	75	125	125	750
Sum of isotopes of iodine, notably I-131	150	500	500	2000
Sum of alpha-radiation emitting isotopes of plutonium and transplutonium elements, notably Pu-239	1	20	20	80
Sum of all other elements of half-life greater than 10 days, notably Cs-134 and Cs-137	400	1000	1000	1250

It should be noted that Council regulation (Euratom) 2016/52 does not apply to drinking water, but states that consumption of tap water was taken into account when developing the maximum permitted levels, and leaves it to the discretion of the national competent authorities to decide whether the maximum permitted level for liquid foods should also be applied to drinking water (see more details in Section 6.4.1).

With the exception of for iodine-131, the levels in Table 5.4.1-2 were used to assess potential radiation doses to consumers in Norway in the event of accident. As demonstrated below, it is unlikely that iodine-131 contamination levels in Norway will be as high as the maximum permitted level for the full 3-month period that the regulation would, potentially, apply. This is due to the relatively short physical half-life of iodine-131, and the geographical distance to large nuclear reactors. Therefore, VKM performed an assessment using more realistic maximum levels of iodine-131 in foods, as supported by information from the Fukushima accident.

Adjustment of iodine-131 levels used in this assessment

The highest iodine-131 concentrations reported from Fukushima reached 5300 Bq/L in milk and 54,000 Bq/kg in spinach within a few days after the accident (Ministry of Health, 2011). Due to the physical half-life and removal of contamination from vegetable surfaces by precipitation and wind the contamination levels in agricultural products declined relatively rapidly. Concentrations in milk declined to levels below about 500 Bq/L within two weeks after the accident, and no milk samples contained more than 10 Bq/L about a month after the accident. In vegetables, contamination levels above 2000 Bq/kg were observed during the first month, but no observations above 10 Bq/kg were reported later than two months after the accident. In their assessment of the Fukushima accident consequences, UNSCEAR assumed that concentrations of iodine-131 were close to zero four months after the accident (UNSCEAR, 2013b).

Based on the information above, a conservative assessment of the potential iodine-131 intake during the 3 months following a nuclear accident can be made as follows: assuming that 4 months after the fallout, the iodine-131 concentration is about 1 Bq/kg (cf. the UNSCEAR assumption above), the physical half-life indicates an initial level of 32,000 Bq/kg. This is in the range of the initial levels observed in vegetables after the Fukushima accident, and thus enables the following estimates to be made (see Figure 5.4.1-1):

- For the broad category of "other food", the maximum permitted level of 2000 Bq/kg (Table 5.4.1-2) may be considered relevant for about 30 days after an emergency. After that the concentrations in food are lower due to physical decay, and can be described by exponential decline with the physical half-life of 8 days, reaching 13 Bq/kg at 3 months after the fallout. This results in a mean concentration of iodine-131 of about 950 Bq/kg in these food products during the the first 3 months after an emergency.

- In "dairy produce" and "liquid food", the maximum permitted level of 500 Bq/kg may be relevant for about 50 days, before declining exponentially to 13 Bq/kg by 3 months after a fallout. Thus, the mean concentration during the initial 3 months following an accident is about 340 Bq/kg.

- For "infant food", the maximum permitted level of 150 Bq/kg may be considered relevant for about 60 days, with exponential decline thereafter, resulting in a mean concentration of 120 Bq/kg.

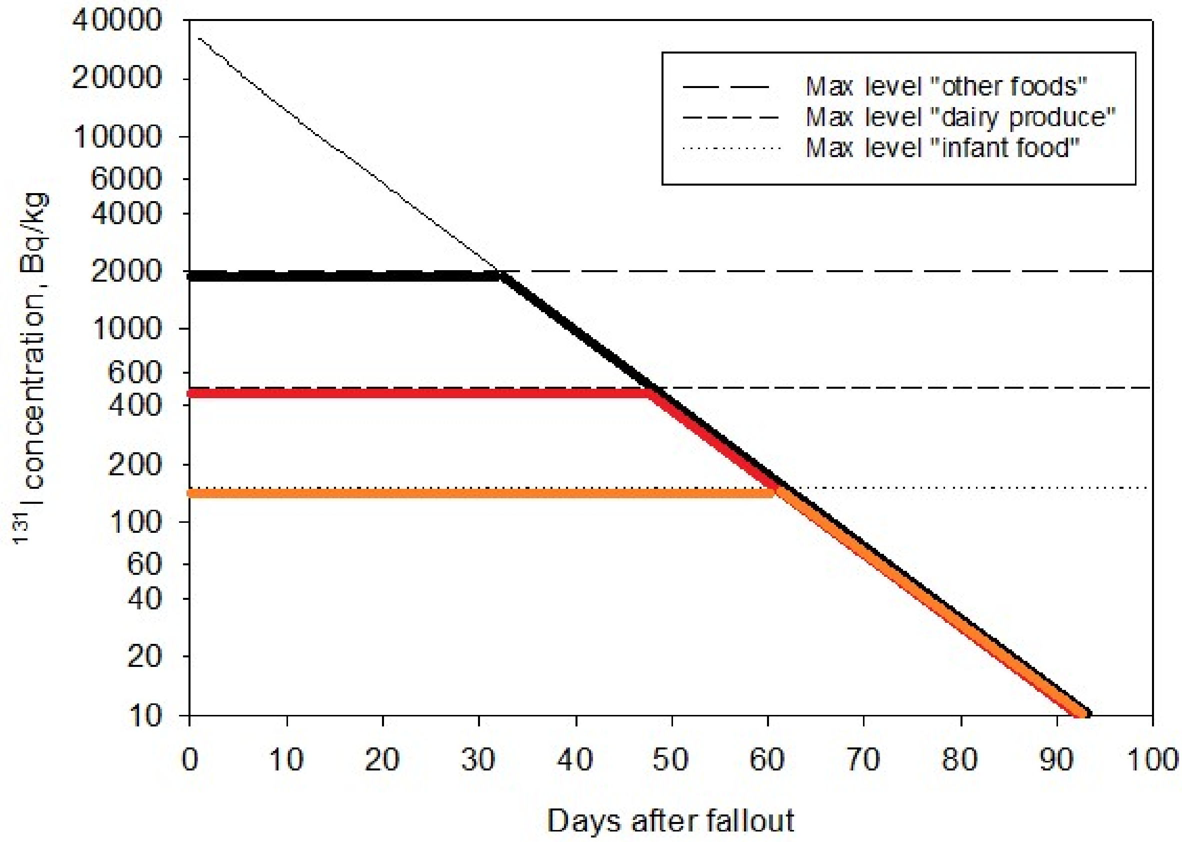

Figure 5.4.1-1 Exponential reduction of iodine-131 concentrations in food after a nuclear accident, from an initial level of 32,000 Bq/kg to 1 Bq/kg after 4 months (due to the physical half-life of 8.02 days). Horizontal lines give the Euratom Treaty maximum permitted levels in "other foods" (long dash), "dairy produce" and "liquid food" (medium dash), and "infant food" (dotted line), and the coloured lines show the potential concentrations in traded foods in their respective categories during the first 3 months after the accident.

As previously mentioned, weather conditions such as precipitation are likely to result in a more rapid decline in contamination levels in vegetation than given by the physical half-life. Thus, the estimates above can be considered conservative. As an example, Figure 5.4.1-2 presents some data on contamination in grass after the Fukushima accident, showing that the levels of iodine-131 declined twice as rapidly as would be calculated from the physical half-life alone.

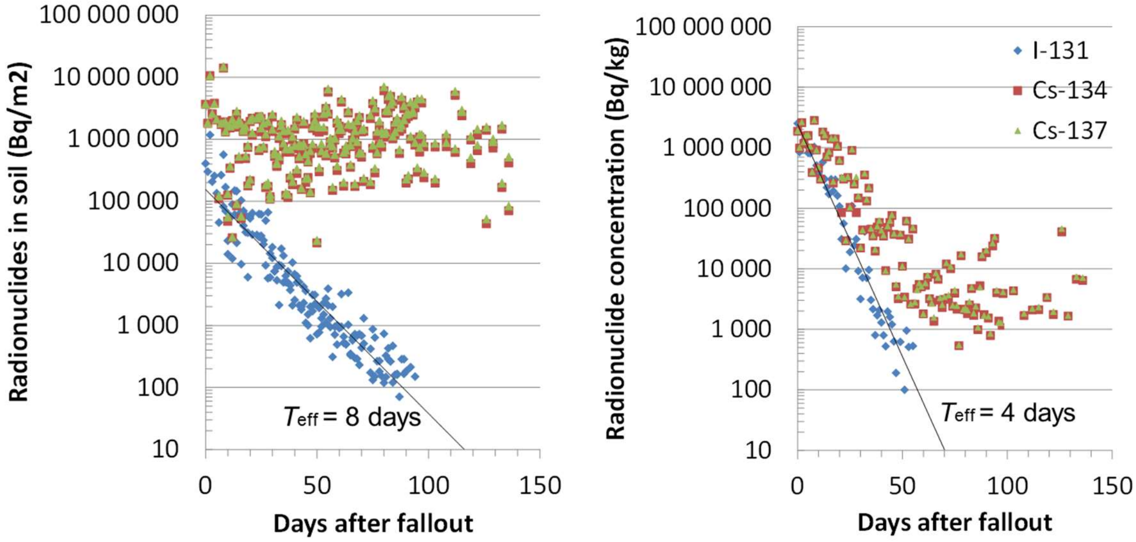

Figure 5.4.1-2 Contamination levels of iodine-131, caesium-134 and caesium-137 measured in soil (left) and grass (right) at ~50 km north-west of the Fukushima nuclear power plant after the accident (Ministry of Education, 2011), illustrating that concentrations in vegetation decrease more rapidly than physical decay due to "weathering" (T_{eff} is effective half-life; the black lines correspond to exponential fits to the iodine-131 data).

Table 5.4.1-3 summarizes the values used as levels in food in the 3-month period after a radiological emergency to calculate exposure in Section 6.4, taking into account the above considerations above on iodine-131 levels.

Table 5.4.1-3 Potential levels of radioactive elements in food in the first 3 months after a radiological emergency, based on the maximum permitted levels of radioactive contamination in food and by using modified levels for iodine-131.

Radioactive element	**Food (Bq/kg)**			
	Infant food	**Dairy products**	**Liquid food**	**Other food (except minor food)**
Sum of isotopes strontium, notably Sr-90	75	125	125	750
Sum of isotopes of iodine, notably I-131, modified	120	340	340	950
Sum of alpha emitting isotopes of plutonium and transplutonium elements, notably Pu-239	1	20	20	80
Sum of all other elements of half-life greater than 10 days, notably Cs-134 and Cs-137	400	1000	1000	1250

5.4.2 **Feed**

The Council regulation (Euratom) 2016/52 gives maximum permitted levels for radioactive caesium in feed, but no other radioactive element; see Table 5.4.2-1.

Table 5.4.2-1 Maximum permitted levels for the sum of caesium-134 and caesium-137 in feed as ready for consumption (Council Regulation (Euratom) 2016/52).

Feed for	Bq/kg
Pigs	1250
Poultry, lamb, calves	2500
Other	5000

In assessing whether these maximum permitted levels would be appropriate for managing a situation after nuclear fallout in Norway, VKM used these concentration levels to estimate concentrations in food products from the animals. However, as grass would probably be the most contaminated feed in a fallout situation, due to the direct contamination of edible parts, this assessment focuses on the milk and meat of animals with grass as their main feed source. Thus, pigs and poultry were not considered as they are fed less contaminated concentrates or mixed feed (cf. corresponding considerations regarding pork and poultry in the worst-case scenario in Section 6.4.1).

Concentrations of radioactive elements in animal products can be estimated using empirically studied relationships between concentrations of radioactive elements in animal products and their feed. Two approaches are commonly used, denoted respectively by the transfer coefficient (F) and the concentration ratio (CR) (IAEA, 2010). The transfer coefficient is the equilibrium ratio between the concentration of a radioactive element in a product divided by the animal's daily dietary intake of that element (and therefore has the units d/L or d/kg). The concentration ratio is the equilibrium ratio of the element in a product (fresh weight) divided by the radionuclide concentration in the feed (dry matter). Estimates of contamination levels in products using transfer coefficients require knowledge of animals' feed intake. Appropriate values for feed intake were obtained from a European project review (Nielsen and Andersson, 2008) (Thørring et al., 2016).

Table 5.4.2-2 summarises the maximum permitted levels for feed, the daily feed (grass) intake, the various transfer parameters and the estimated concentrations of radioactive caesium in food products resulting from feeding animals contaminated feed (see approach in Section 5.4.2). The estimated concentrations are based on average transfer parameter values, although reported parameter values show a large range (see information in the references provided).

Table 5.4.2-2 Maximum permitted level for radioactive caesium in feed, daily grass intake by animals, transfer coefficients and concentration ratios for the various products, and the resulting estimated concentrations of radioactive caesium in animal products (F: estimated using transfer coefficients; CR: Estimated using concentration ratio).

Animal (product)	**Maximum permitted level** (Bq/kg)	**Grass intake**[1] (kg/d)	**Transfer coefficient, F**[2,3] (d/kg or d/L)	**Concentration ratio, CR**[2,3]	**Estimated concentrations, Bq/L or Bq/kg**	
					F	**CR**
Cow (milk)	5000	50	0.0049	0.11	1200	2800
Goat (milk)	5000	6	0.11	0.22	3300	5500
Cattle (beef)	5000	28	0.022	0.23	3100	5800
Lamb (lamb)	2500	5	0.19	0.64	2400	8000

[1]From Thørring et al. (2016); [2]Values for beef and lamb from IAEA (2010), and cows and goat's milk from updates in (Howard et al., 2016; Howard et al., 2017); [3]Values are, respectively, geometric and arithmetic means for transfer coefficients and concentration ratios, reflecting how values are summarised in the references.

The estimated concentrations in Table 5.4.2-2 indicate that contaminated feed may result in concentrations in food products that are higher than the maximum permitted levels given in Table 5.4.1-2. This suggests that the maximum permitted levels in feed are too high.

VKM is not aware of the basis for Euratom's maximum permitted levels in feed. Presumably, the maximum permitted levels have been derived from similar, but reversed calculations, as in Table 5.4.2-2 with some additional considerations of amounts and potential contamination levels of various feedstuffs fed to farm animals in the EU. Thus, a larger proportion of grass in the diet of Norwegian animals (Thørring et al., 2016) may explain the relatively high concentration estimates in Table 5.4.2-2. Furthermore, products like goat's milk and lamb may be of low significance in EU generally, and therefore may not have been included in deriving the maximum permitted levels for feed.

5.5 Summary of consumption and occurrence in different exposure groups

For ToR1, the current levels of six radioactive elements in various food items are established for the assessment of exposure based on dietary intake: caesium-137, polonium-210, radon-222, radium-228, lead-210, and radium-226. The mean concentrations of the different radioactive elements varies by several orders of magnitude in the food items. Reindeer meat and wild mushrooms have the highest mean concentrations of caesium-137. The highest concentrations of polonium-210 are found in shellfish and reindeer meat.

Five specific consumer groups with elevated exposure risks were defined by VKM. For some of the specific groups, several different scenarios – represented by different combinations of consumption and occurrence data – are assessed. Elevated exposure to caesium-137 was assessed for three specific groups: consumers of contaminated reindeer meat, sheep meat, and wild products (game, mushrooms and berries). Two specific groups were considered for elevated exposure to naturally occurring radioactivity: polonium-210 in seafood and radon-222 in drinking water.

For ToR2, the effect of today's countermeasures to reduce caesium-137 concentrations in reindeer and sheep meat were assessed, based on the same calculations as in ToR1, except that the caesium-137 concentration data were adjusted, by also including measurements from live animals above the respective MLs. According to these calculations, the current countermeasures have little effect on the the national mean caesium-137 level in reindeer meat and sheep meat, the levels of which would increase by 14 and 10 Bq/kg, respectively, if countermeasures were not performed. In meat from contaminated areas, the effect would be much more prominent. The greatest effect was seen in the levels of caesium-137 in sheep meat from the most contaminated regions, which would increase by 3890 Bq/kg.

For ToR3, the effect of reducing the ML for radioactive caesium in reindeer meat to 1500 or 600 Bq/kg was assessed by adjusting the occurrence data set so that any live measurements above the considered ML were reduced to the ML. The calculations show that by decreasing the ML to 1500 or 600 Bq/kg the national mean level of caesium-137 in reindeer meat would reduce by 6 or 46 Bq/kg, respectively, in a typical year. In the most contaminated districts, the associated caesium-137 reduction would range from 41 to 1505 Bq/kg in the reindeer meat sold on the market.

For ToR4, the maximum permitted levels laid down in the Council regulation (Euratom) 2016/52 for emergency situations are presented. It seems highly unlikely that iodine-131 contamination equalling the maximum permitted level could occur in Norway for the full 3-month period that the regulation would apply. Therefore, adjusted levels of iodine-131 were used in the assessment of potential exposure to the Norwegian population applying this regulation. The concentrations that might occur in domesticated animals should the maximum permitted levels for radioactive caesium in animal feed be implemented were also assessed. The calculations suggest that implementing the maximum permitted levels for feed under Norwegian conditions may result in concentrations exceeding the maximum permitted levels occurring in meat.

6 Dietary radiation exposure

The average dose of ionising radiation to individuals in Norway from all sources is estimated to be 5.1 mSv/year (Figure 6-1, based on (Komperød et al., 2015a) and new radioactivity data used in this assessment). The highest contribution to the overall radiation exposure to the population in Norway is associated with inhalation of naturally occurring radon-222 in indoor air. Medical imaging is estimated to provide the highest dose contribution from anthropogenic sources (Komperød et al. 2015).

On average, approximately 10% of the total radiation dose received by the Norwegian population comes from food. Of this food-related dose, about 2% originates from anthropogenic radioactive elements and the remaining 98% from naturally occurring radioactive elements. However, there may be large individual differences in the dose from radioactivity in food depending on a person's specific diet and the food's geographical origin. Although radioactive contamination in food contributes little to the average individual dose compared with other sources of radiation, it may still represent a significant source for some individuals and in certain situations.

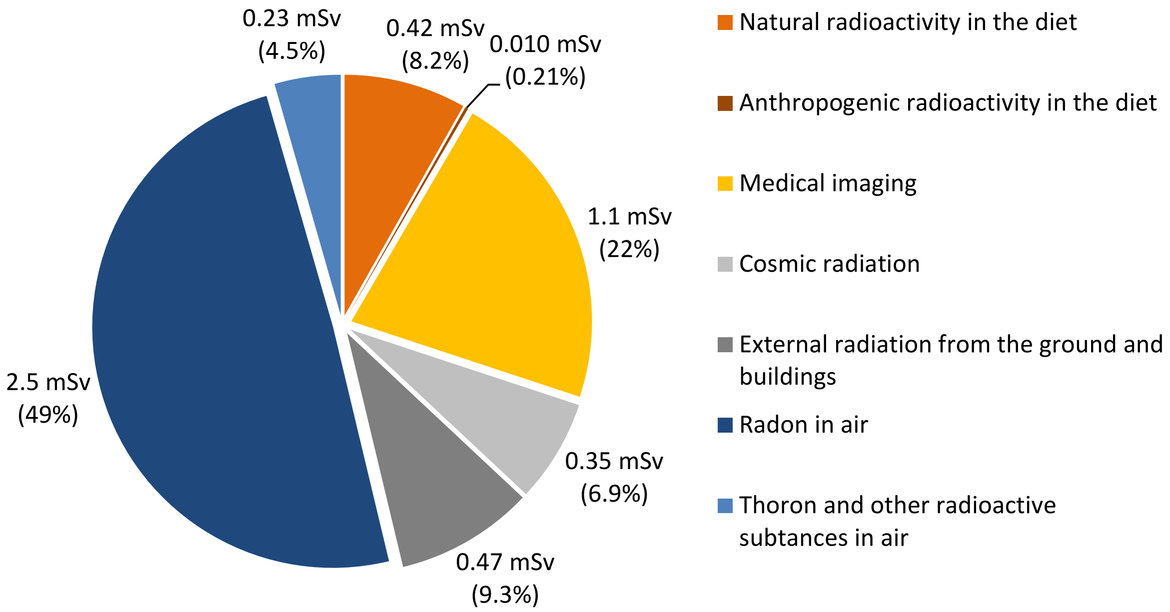

Figure 6-1 Estimated mean effective dose (mSv/year) from all different sources of radiation to members of the public in Norway, in total amounting to 5.1 mSv/year (based on (Komperød et al., 2015a) and new radioactivity data used in this assessment).

The total average dose estimated for the Norwegian population is higher than the worldwide average radiation dose of approximately 3.0 mSv/year, estimated by UNSCEAR (UNSCEAR, 2010a). This is mainly due to the relatively high exposure to radon, which is related to geological and climate conditions and to building practice, as well as higher doses associated with medical examinations. The latter reflects the high standard of health care in industrialised countries like Norway.

Calculating exposure from radioactivity in food

All four questions in the ToR require dietary exposure calculations.

Dietary exposure to radioactivity (effective doses) per year was calculated using the following equation for each radioactive element:

- Consumption of each food (kg/day) x 365 days x radioactivity in food (Bq/kg) x dose coefficient (mSv/Bq) = dietary exposure (mSv/year) for a given radioactive element.

The dose coefficients used to calculate the effective dose based on consumption and occurrence data are the international standard values derived by the ICRP (Section 3.4.4).

For total dietary exposure, all radioactive elements are summarised (mSv) during a defined time period (1 year or 3 months).

The equation above gives the total exposure to radioactivity from food during 1 year (mSv/year).

6.1 Exposure to radioactivity from the total diet in the current situation (ToR1)

In answer to ToR1, exposure from the natural and anthropogenic radioactive elements present in the total diet are calculated for the whole population and specific groups. The calculations are made based on the consumption and occurrence data described in 5.1.

6.1.1 Whole population

Exposure of the whole population to radioactivity in the diet has been calculated for 1-year-olds and adults, because these groups are considered to represent the range of exposure.

Exposure to carbon-14 and potassium-40 is assumed to be constant (Section 3.4.2), and a constant effective dose is used in the exposure assessment.

The remaining six radioactive elements, for which exposure is calculated based on diet, are caesium-137, polonium-210, radon-222, radium-228, lead-210, and radium-226. Calculation of the mean and P95 exposure from these six elements is based on food consumption data from national surveys, as provided in Section 5.1.1, and occurrence data provided in Appendix 1 (key food items summarised in Table 5.1.1-1).

The mean exposure to all eight natural and anthropogenic radioactive elements included in the assessment of current exposure is estimated at 0.56 and 0.48 mSv/year for 1-year-olds and adults, respectively. The largest contribution to these doses comes from the naturally occurring elements polonium-210 and potassium-40. The P95 exposure to all eight radioactive elements is 1.0 and 0.81 mSv/year for 1-year-olds and adults, respectively (Table 6.1.1-1).

Table 6.1.1-1 Mean and P95 effective dose (mSv/year) to 1-year-olds and adults using the current levels of all eight radioactive elements in food considered for the whole population (ToR1).

Radioactive elements	**1-year-olds mSv/year**		**Adults mSv/year**	
	Mean	P95	Mean	P95
Naturally occurring radioactive elements				
Polonium-210	0.17	0.37	0.12	0.36
Radium-228	0.083	0.20	0.039	0.11
Radon-222	0.075	0.19	0.080	0.19
Lead-210	0.041	0.068	0.023	0.036
Radium-226	0.0082	0.014	0.0062	0.011
Carbon-14[a]	0.01	0.01	0.01	0.01
Potassium-40[a]	0.17	0.17	0.19	0.19
Anthropogenic element				
Cesium-137	0.0040	0.0072	0.014	0.043
Sum of naturally occurring and anthropogenic radioactive elements				
Total	**0.56**	**1.0**[b]	**0.48**	**0.81**[b]

[a]Assuming a constant contribution from carbon-14 and potassium-40; [b]Total P95 is calculated from the person specific total of all eight radioactive elements (not from the sum of P95 from each element).

Detailed overview of the exposure from the different food groups and each of the six radioactive elements for which exposure is calculated based on diet, are shown in Tables 6.1.1-2 and 6.1.1-3 for 1-year-olds and adults respectively. The mean total dose for 1-year-olds is 0.38 mSv/year, and the mean total dose for adults is 0.28 mSv/year (i.e., as in Table 6.1.1-1 without the contributions from carbon-14 and potassium-40).

Table 6.1.1-2 Mean effective dose (mSv/year) to 1-year-olds from the current levels of the six radioactive elements calculated based on diet (caesium-137, radium-226, lead-210, polonium-210, radium-228, radon-222) in different food groups (ToR1).

	Mean effective dose (mSv/year) 1-year-olds						
	^{137}Cs	^{226}Ra	^{210}Pb	^{210}Po	^{228}Ra	^{222}Rn	Sum of elements
Bread	0.000029	0.0018	0.0043	0.013	0.0081	0	**0.027**
Other cereal products	0.000063	0.00025	0.00066	0.0022	0.0010	0	**0.0043**
Vegetables and potatoes	0.00025	0.00060	0.0022	0.0074	0.0023	0	**0.013**
Fruit and berries	0.00039	0.0011	0.0039	0.013	0.0042	0	**0.022**
Meat, blood, offal	0.00053	0.00011	0.0025	0.0045	0.00042	0	**0.0080**
Fish and shellfish	0.000007	0.00088	0.0033	0.034	0.046	0	**0.085**
Egg	0.000007	0	0.000131	0.00032	0	0	**0.00046**
Milk and dairy products	0.00032	0.00025	0.0029	0.0071	0.0015	0	**0.012**
Cheese	0.00067	0.000035	0.00026	0.00064	0.00021	0	**0.0018**
Beverages	0.000002	0.00011	0.0033	0.0042	0.00062	0.075	**0.083**
Baby food	0.0015	0.0031	0.017	0.085	0.018	0	**0.12**
Miscellaneous	0.000017	0	0.000525	0.0016	0.00021	0	**0.0024**
Total	**0.0040**	**0.0082**	**0.041**	**0.17**	**0.083**	**0.075**	**0.38**

Food groups contribute with different proportions to the effective dose from food (Table 6.1.1-2 and Table 6.1.1-3). For 1-year-olds, baby food contributes with the largest proportion to the effective dose from the six radioactive elements calculated based on diet, followed by fish and shellfish and beverages. For adults, beverages followed by fish and shellfish provide the largest contribution to the effective dose from the six radioactive elements.

Table 6.1.1-3 Mean effective dose (mSv/year) to adults from the current levels of the six radioactive elements calculcated based on diet (caesium-137, radium-226, lead-210, polonium-210, radium-228, and radon-222) in different food groups.

	Mean effective dose (mSv/year) Adults						
	^{137}Cs	^{226}Ra	^{210}Pb	^{210}Po	^{228}Ra	^{222}Rn	Sum of elements
Bread	0.00081	0.0014	0.0021	0.0045	0.0026	0	**0.011**
Other cereal products	0.00052	0.00082	0.0013	0.0027	0.0015	0	**0.0069**
Vegetables and potatoes	0.0031	0.00068	0.0021	0.011	0.0011	0	**0.018**
Fruit and berries	0.0011	0.00087	0.0021	0.0052	0.0015	0	**0.011**
Meat, blood, offals	0.0059	0.00022	0.0031	0.026	0.00035	0	**0.035**
Fish and shellfish	0.00011	0.0016	0.0033	0.056	0.030	0	**0.091**
Egg	0.00012	0.000041	0.00050	0.00066	0.000076	0	**0.0014**
Milk and diary products	0.00078	0.00017	0.0013	0.0022	0.00043	0	**0.0048**
Cheese	0.00095	0.000020	0.00015	0.00026	0.000050	0	**0.0014**
Beverages	0.00023	0.00026	0.0056	0.0054	0.00050	0.080	**0.092**
Miscellaneous	0.00034	0.00019	0.00096	0.0057	0.00088	0	**0.0081**
Total	**0.014**	**0.0062**	**0.023**	**0.12**	**0.039**	**0.080**	**0.28**

ToR2 and ToR3 in this assessment are concerned exclusively with exposure to caesium-137. For this reason, the sources of this radioactive element are described in greater detail. As shown in Figure 6.1.1-1, meat and meat products is the food group contributing most to exposure to caesium-137, followed by vegetables.

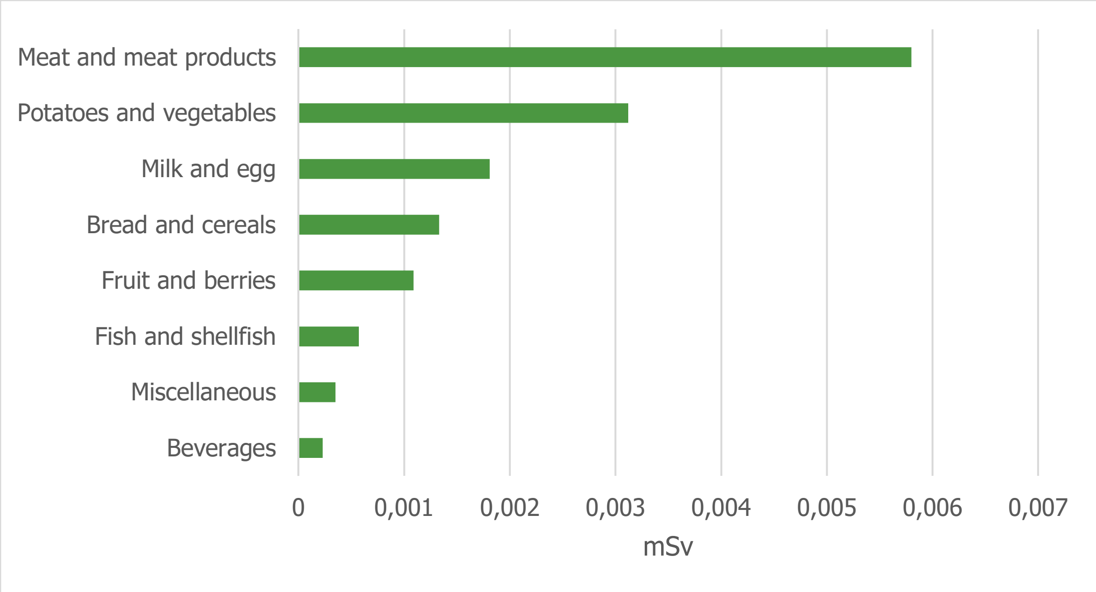

Figure 6.1.1-1 Contribution by different food groups to the mean doses from caesium-137 to adults.

6.1.2 Specific groups

For ToR1 concerned with specific groups with elevated exposure to the current levels of radioactivity in food, only adult consumers were assessed as their consumption of the relevant food products is greatest consumption. Calculation of exposure of the specific population groups is based on the consumption and occurrence data described in Section 5.1.2.

The estimated exposure of specific groups to the current radioactivity levels in food are presented in Table 6.1.2-1. Of the scenarios considered, the highest doses were associated with elevated exposure to caesium-137 in reindeer meat and radon-222 in drinking water. Effective doses were estimated up to 3.4 mSv/year for scenarios with reindeer meat (very high consumers of very highly contaminated meat) and up to 2.8 mSv for drinking water (mean consumption for highly contaminated water). These doses are in addition to the exposures associated with other radioactive elements and food items. It should be noted that although exposure has been assessed for only one radioactive element per specific group in this assessment, consumption of these food items may, in reality, result in increased exposure to several radioactive elements. For example, high and very high consumers of reindeer meat will receive an estimated dose of 0.58 and 1.4 mSv/year, respectively, of polonium-210 in reindeer meat (data not shown in tables).

Individuals with high consumption of seafood will receive a slightly higher dose of polonium-210 than the average Norwegian. However, it must also be taken into consideration that, in real life, a person with such high consumption of seafood will probably have a lower intake of radioactive elements from other foods. High consumption of game meat and wild mushrooms and berries from areas contaminated by the Chernobyl disaster results in 0.21 mSv/year combined. Although this is not the scenario that results in the highest exposure, it represents a significant increase over the mean dietary exposure to the mean adult (0.48mSv/year).

Table 6.1.2-1 Effective dose (mSv/year) for specific groups using the current levels of the radioactive elements (ToR1).

Specific group	Food item	Consumption level	Effective dose (mSv/year) Level of radioactivity		
			Mean	High	Very high
			Caesium-137		
Reindeer meat	Reindeer meat	High[1]	0.14[a]	0.81[b]	1.4[c]
		Very high[2]	0.33[a]	1.9[b]	3.4[c]
Sheep meat	Sheep meat	High[1]	0.020[a]		0.41[d]
Wild products	Game meat	High[3]		0.024[e]	
	Wild mushrooms	High[4]		0.15[e]	
	Wild berries	High[5]		0.036[e]	
			Radon-222		
Drinking water	Drinking water	Mean[6]	-	0.50[f]	2.8[g]
			Polonium-210		
Seafood	Fish filets	High[7]	0.23[h]		
	Shellfish	High[8]	0.17[i]		

[1]Mean consumption of all meat from Norkost 3; [2]P95 consumption of all meat from Norkost 3; [3]P95 consumption of game meat from Norkost 3; [4]P95 consumption of all types of mushrooms from Norkost 3; [5]P95 of jam consumption from Norkost 3; [6]Mean drinking water consumption from Norkost 3; [7]P95 consumption of fish filet from Norkost 3; [8]P95 consumption of shellfish from Norkost 3. [a]National mean level as used in current exposure estimation (5.1.1); [b]Mean of the mean concentrations in each of the most contaminated districts; [c]Mean of the single highest recorded concentration in each of the most contaminated districts, taking into account the ML of 3000 Bq/kg; [d]ML for sheep meat; [e]Median concentration in the county with the highest recorded levels in such products; [f]Mean concentration in drinking water from private wells drilled in bedrock; [g]P95 concentration in drinking water from private wells drilled in bedrock; [h]Mean concentration in fatty fish; [i]Mean concentration weighted according to consumption rate of each species.

6.2 Exposure to the current levels of caesium-137 in reindeer and sheep if no efforts were made to reduce them (ToR2)

For ToR2, all levels of caesium-137 contamination were assessed for both the whole population (mean and P95 consumption) and for the specific groups. For ToR2 calculations, VKM assumed that countermeasures reduce the caesium-137 only to the ML. Countermeasures that may reduce caesium-137 levels below the ML in the food consumed have not been considered.

The estimated exposure for all groups and caesium-137 levels should no countermeasures be in place to the reduce the levels in reindeer and sheep meat are presented in Table 6.2-1.

The reduction in exposure to caesium-137 in reindeer and sheep meat that results from current countermeasures, as compared with the exposure if no countermeasures to reduce the levels were implemented, is presented in Table 6.2-2.

The countermeasures have little effect on the exposure of the average consumer. The largest effect is seen in consumers of sheep meat from the most contaminated regions. Persons with a mean and P95 consumption of sheep meat from one of these areas would receive another 0.18 and 1.5 mSv/year, respectively, if no efforts were made to reduce the levels. High consumers of the same sheep meat would receive an additional 2.6 mSv/year. However, this consumption of sheep meat is likely to be an overestimation (see Section 5.1.2.2).

Persons with a high or very high consumption of reindeer meat from the most contaminated areas would receive another 0.3 or 0.6 mSv/year, respectively. However, it should be noted that persons with high consumption of reindeer meat from these districts are advised to choose reindeer meat with caesium-137 concentrations below the ML. Following this advise would be likely to reduce exposure, but this could not, however, be taken into account in this assessment.

All levels of caesium-137 contamination were used for calculating the exposure for both the whole population (mean and the 95th percentile consumption) and for the specific groups. It was assumed that implementations of countermeasures reduce the caesium-137 only to the ML. Countermeasures that may further reduce exposure to the caesium-137 in the food consumed, such as adhering to dietary advice, were not considered. The estimated exposures for all groups and caesium-137 levels should no countermeasures be in place to the reduce thecaesium-137 levels in reindeer and sheep meat are presented in Table 6.2-1. The resulting dose reduction associated with performing countermeasures using today's MLs are presented in Table 6.2-2.

Table 6.2-1 Effective dose (mSv/year) from caesium-137 in reindeer and sheep meat if no efforts were made to reduce the levels (ToR2).

Food item	Exposure group	Consumption level	Effective dose (mSv/year)		
			Caesium-137 level		
			Mean[a]	High[b]	Very high[c]
Reindeer meat	Whole population	Mean[1]	0.0010	0.0062	0.012
		P95[2]	-	-	-
	Specific groups	High[3]	0.15	0.88	1.7
		Very high[4]	0.35	2.1	4.0
Sheep meat	Whole population	Mean[1]	0.0019	0.056	0.21
		P95[2]	0.015	0.45	1.7
	Specific groups	High[3]	0.027	0.79	3.0

[1]Mean consumption of the respective food item in Norkost 3; [2]P95 consumption of the respective food item in Norkost 3 – under 5% of participants reported eating reindeer meat in Norkost 3 and therefore

P95 could not be calculated; [3]Mean consumption of all meat from Norkost 3; [4]P95 consumption of all meat from Norkost 3.
[a]Mean national concentrations, including animals with caesium-137 concentrations above the respective MLs; [b]Mean of the mean concentrations in the most contaminated districts, including animals with caesium-137 concentrations above the respective MLs; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, including animals with caesium-137 concentrations above the respective MLs.

Table 6.2-2 Reduction in effective dose (mSv/year) from caesium-137 in reindeer and sheep meat resulting from current countermeasures, as compared with exposure if no countermeasures to reduce the levels (ToR2). This was calculated by subtracting the current exposure (Table 6.1.2-1 for specific groups) from the exposure provided no countermeasures (Table 6.2-1).

Food item	Exposure group	Consumption level	Effective dose increase (mSv/year) provided no countermeasures		
			Caesium-137 level		
			Mean[a]	High[b]	Very high[c]
Reindeer meat	Whole population	Mean[1]	<0.0005	0.0005	0.002
		P95[2]	-	-	-
	Specific groups	High[3]	0.01	0.07	0.3
		Very high[4]	0.020	0.2	0.6
Sheep meat	Whole population	Mean[1]	0.0005	0.027	0.18
		P95[2]	0.0038	0.22	1.5
	Specific groups	High[3]	0.007	-	2.6

[1]Mean consumption of the respective food item in Norkost 3; [2] P95 consumption of the respective food item in Norkost 3 - under 5% of participants reported eating reindeer meat in Norkost 3 and therefore P95 could not be calculated; [3]Mean consumption of all meat from Norkost 3; [4]P95 consumption of all meat from Norkost 3.
[a]Mean national concentrations, including animals with caesium-137 concentrations above the respective maximum levels; [b]Mean of the mean concentrations in the most contaminated districts, including animals with caesium-137 concentrations above the respective maximum levels – could not be calculated for sheep meat as this caesium-137 level was not calculated for ToR1; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, including animals with caesium-137 concentrations above the respective maximum levels.

6.3 Exposure to caesium-137 in reindeer if the ML was reduced (ToR3)

ToR3 requests assessment of the health risks associated with caesium-137 in reindeer meat for the whole population and specific groups if the ML was reduced from 3000 Bq/kg to 1500 or 600 Bq/kg. Exposure has been calculated using the same approach as in ToR1, except that animals with levels above 1500 and 600 Bq/kg have been reduced to these levels in the calculations.

The consumption and occurrence data used are presented in Section 5.3. Exposure is only calculated for adults because this is the age group with the highest consumption of reindeer meat, as well as the largest ingestion dose coefficients for caesium-137. For the assessment of ToR2, all levels of caesium-137 contamination were assessed for both the whole population (mean and the P95 consumption) and for the specific groups. The estimated exposure for all groups are shown in Table 6.3.2-1, whereas the estimated dose reductions associated with lowering the ML from 3000 Bq/kg to 1500 or 600 Bq/kg are presented in Table 6.3.2-2.

6.3.1 **Whole population**

For the average Norwegian with a mean consumption of reindeer meat containing mean caesium-137 levels, the dose reduction associated with reducing the ML from 3,000 Bq/kg to 1,500 or 600 Bq/kg is estimated to be 0.00003 and 0.00022 mSv/year, respectively. Thus, for the vast majority of the population, decreasing the ML would have very little impact on exposure to caesium-137 due to the low mean consumption of reindeer meat. Most reindeer meat produced in Norway would not be affected by reducing the ML because caesium-137 concentrations are already well below 600 Bq/kg.

6.3.2 **Specific groups**

For those with a very high consumption of reindeer meat from the most contaminated areas, reducing the ML to 1500 Bq/kg was estimated to reduce their exposure to caesium-137 by 1 mSv/year. Reducing the ML to 600 Bq/kg would reduce exposure by 2.4 mSv/year for the same group. Exposure would be reduced by 1 mSv/year also for two other scenarios considered for an ML of 600 Bq/kg. It should be noted that persons with high consumption of reindeer meat from these districts are currently advised to select reindeer meat containing caesium-137 concentrations below the ML; the implications of this intervention have not been considered in this assessment.

Table 6.3.2-1 Effective dose (mSv/year) from caesium-137 in reindeer meat with the current and reduced maximum permitted levels (ToR3). More details are provided in Appendix 4.

Exposure group	Consumption level (reindeer meat)	Effective dose (mSv/year) at different MLs for caesium-137								
		ML 3000 (current)			ML 1500			ML 600		
		Mean [a]	High [b]	Very high [c]	Mean [a]	High [b]	Very high [c]	Mean[a]	High[b]	Very high[c]
Whole population	Mean[1]	0.00099	0.0057	0.010	0.00096	0.0055	0.0070	0.00077	0.0028	0.0028
Specific groups	High[2]	0.14	0.81	1.4	0.14	0.78	1.0	0.11	0.40	0.41
	Very high[3]	0.33	1.9	3.4	0.32	1.8	2.4	0.26	0.94	0.96

[1]Mean consumption of reindeer meat in Norkost 3 (under 5% participants reported eating reindeer meat in Norkost 3 and therefore P95 is not included); [2]Mean consumption of all meat from Norkost 3; [3]P95 consumption of all meat from Norkost 3.
[a]National mean concentrations, adjusted by the respective maximum level; [b]Mean of the mean concentrations in each of the most contaminated districts, adjusted by the respective maximum level; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, adjusted by the respective maximum level.

Table 6.3.2-2 Reduction in effective dose (mSv/year) if MLs for reindeer meat were reduced to 1500 or 600 Bq/kg (ToR3). The dose reduction shown is calculated by substracting the estimated doses at the 1500 and 600 Bq/kg MLs from the corresponding doses at the current ML (3000 Bq/kg).

Exposure group	Consumption level (reindeer meat)	Effective dose reduction (mSv/year) at reduced MLs for caesium-137					
		ML 1500			ML 600		
		Mean [a]	High[b]	Very high[c]	Mean[a]	High[b]	Very high[c]
Whole population	Mean[1]	0.00003	0.0002	0.003	0.00022	0.0029	0.0072
Specific groups	High[2]	0.0041	0.028	0.42	0.031	0.41	1.0
	Very high[3]	0.0095	0.065	1.0	0.074	0.96	2.4

[1]Mean consumption of reindeer meat in Norkost 3 (under 5% participants reported eating reindeer meat in Norkost 3 and therefore P95 is not included); [2]Mean consumption of all meat from Norkost 3; [3]P95 consumption of all meat from Norkost 3.
[a]National mean concentrations, adjusted by the respective maximum level; [b]Mean of the mean concentrations in each of the most contaminated districts, adjusted by the respective maximum level; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, adjusted by the respective maximum level.

6.4 **Exposure applying maximum permitted levels provided in Council regulation (Euratom) 2016/52 for emergency situations (ToR4)**

The maximum permitted levels laid down in Council Regulation (Euratom) 2016/52 are based on a reference level of 1 mSv per year for the increment in individual effective dose by ingestion, and on the basis of the general assumption that 10% of food consumed is contaminated. The regulation states that different assumptions apply to infants under 1 year, but without specifying these assumptions further. The regulation does not apply to drinking water, but states that each Member State is "free to choose to refer to the maximum levels for liquid food set out in this Regulation in order to manage the use of water intended for human consumption". In Radiation protection 105 (EC 1998), which reviewed and described the basis for the establishment of the maximum permitted levels set out in the regulation, it was assumed that 1% of liquid food and 50% of infant food was contaminated – in addition to the general 10% assumption on all other foods.

VKM has assessed whether the procedure and maximum permitted levels laid down in Council Regulation (Euratom) 2016/52 are appropriate for managing similar scenarios in Norway in two parts:

1. Whether the share of food assumed to become contaminated, which formed the basis for setting the maximum permitted levels, is appropriate for Norwegian conditions (Section 6.4.1).
2. What would be the exposure associated with consuming food at the maximum permitted levels using Norwegian consumption data (Section 6.4.2), and whether this offers the same level of protection as estimated for the EU (Section 7.4).

6.4.1 **Food contamination level assumptions in Council Regulation 2016/52 - applicability in Norway**

In order to investigate whether it is appropriate to assume that 10% of the food consumed in Norway may be contaminated, a hypothetical worst-case scenario was applied. In the worst-case scenario, the most important regions for food production in Norway (Østlandet, Rogaland, and Trøndelag), were assumed to be severely affected by radioactive fallout. This area is much larger than that affected by the Chernobyl fallout in 1986.

In these areas, the concentrations of radioactivity in all of the contaminated food groups were assumed to reach the maximum permitted levels described in Council regulation (Euratom) 2016/52, with the exception of iodine-131 (Table 5.4.1-3). For this isotope, rapid decay due to its short physical half-life of 8 days was taken into account, as described in Section 5.4.1. All cow's milk, sheep meat, beef, wheat, potatoes, vegetables, fruit, and berries produced during the year were assumed to be contaminated. In contrast, pork and poultry were assumed to contain no contamination because they mainly eat processed concentrated feed, not fresh plants. Seafood was also assumed not to be contaminated due to the low transfer of caesium-137 to organisms in the marine environment. Norway's current level of self-sufficiency was also taken into account (i.e., the percentage of consumption that comes from Norway's own production vs. imported food) (FAO, 2011). Further details on the calculations are provided in Appendix 3.

The resulting share of different food products that may be contaminated in this worst-case scenario is presented in Table 6.4.1-1.

Table 6.4.1-1 The percentage of food consumed in Norway that may be contaminated, given the worst-case scenario assessed. Calculation involved the share of Norway's total production that occurs in the contaminated area by the share of self-sufficiency. It is assumed that imported food is uncontaminated. Further details on the calculations are provided in Appendix 3.

Food group	Norway's total production in the considered area (%)	Self-sufficiency (%)	Share of food consumed in Norway that is contaminated (%)
Cereal products	98	54	**53**
Vegetables	94	37	**35**
Fruit and berries	53	3.0	**2**
Beef	67	87	**58**
Sheep	56	96	**54**
Milk and yoghurt	64	100	**64**

The proportion of contaminated food in in relation to the total food consumed in Norway in this hypothetical worst-case scenario was estimated by multiplying the mean consumption data for adults (Norkost 3, see Section 2.2), the proportion of self-sufficiency, and the proportion of domestic food production affected for each food category (Table 6.4.1-1), (excluding drinking water and water-based beverages). The resulting mean consumption of contaminated food was divided by the total annual consumption, resulting in a total of 25% of the total consumption of food being contaminated based on these calculations. This is significantly higher than the 10% that forms the basis for the Council regulation; however, in order to provide a conservative assessment, the hypothetical scenario used is unrealistically overstated in many of its assumptions. The affected region must receive precipitation during the days when the contaminated air masses reach the different parts of the country, and even under such circumstances, it would be unlikely that all of the food products included in this assessment would become contaminated to the maximum permitted level. In order for all the foods products considered to be contaminated, then the radioactive fallout would have to occur during the harvesting season for all affected products at the same time, i.e., this would mean that all products produced throughout the year were harvested/produced at the same time in the whole country. This is obviously not realistic. For example, a full year's production of cow's milk cannot take place directly after a radioactive fallout. Cow's milk constitutes about half of the total food production contaminated in the above scenario, meaning that if we consider an even production of milk over the course of the year, only a small share would be affected during the period directly after a fallout. VKM has not made a detailed account of such factors, but considers that the resulting share of contaminated food would be reduced by 50% or more.

On the basis on these considerations, VKM concludes that the assumption that 10% of general food consumed may be contaminated in this situation is also appropriate for Norway.

Council regulation (Euratom) 2016/52 applies to food, minor food and feed which could be placed on the market, and not to water intended for human consumption (for which Directive 2013/51/Euratom applies). However, dose calculations in Radiation Protection 105 were carried out assuming drinking water to be 1% contaminated to maximum permitted level. The report states that in order for the assumption of 10% contamination for other foodsto be valid, it would be necessary to assume that drinking water supplies are contaminated to a large extent. Due to substantial contribution of protected ground water in the EU water supply, and the interconnection between reservoirs that allow for switching to uncontaminated water, Radiation Protection 105 concluded that a contaminated drinking water fraction of 1% is a conservative assumption. Should widespread contamination of surface water supplies occur, the report states that it is the matter of the competent authority to assess consequences and possible actions. Quoting Radiation Protection 105 (p.10-11): "This would be an intervention situation with a primary concern for health rather than a matter of placing on the market with economic implications, to which the Council Regulation applies. This is the reason why […] the Regulation states that 'Values are calculated taking into account consumption of tap-water and the same values should be applied to drinking water supplies at the discretion of competent authorities in Member States'."

Surface water makes up 80% of the water supply in Norway, and in many larger population centres, interconnected supplies will allow switching off contaminated water. Furthermore, the contamination levels observed in drinking water in Norway after the Chernobyl accident in 1986 were only fractions of that in meat, milk and plant-based foods. (E.g., the highest average deposition of radioactive caesium from Chernobyl in a municipality in Norway was about 160,000 Bq/m^2, which corresponds to a concentration of 16 Bq/L if deposited onto a 10 m deep water-body. This conservative calculation results is 1.6% of the Council regulation's maximum permissible level for liquid food.) Thus, VKM concludes that the general assumptions in Radiation Protection 105 and Council regulation (Euratom) 2016/52 for drinking water seem appropriate also for Norway. Significantly higher drinking water contamination is possible only related to more extreme contamination events, which would require separate management (as mentioned in Radiation Protection 105, see above).

The reasoning behind the assumption that 50% of infant food is contaminated is not provided in Radiation Protection 105. In the opinion of VKM, this is an unrealistic assumption, especially as infant food is often processed rather than fresh. This means that there is a significant delay between harvesting and consumption, during which period countermeasures can be implemented. However, to provide a highly conservative evaluation, such that infants are awarded an additional level of protection, unrealistically high assumptions may be made in the establishment of maximum permitted levels and dose calculations. VKM therefore considers the highly conservative assumption of 50% contamination level, although unrealistic, to be appropriate for use in the management of radioactive fallout.

6.4.2 Exposure from food using maximum permitted levels in Council regulation (Euratom)

The expsoure associated with applying Council regulation (Euratom) 2016/52 in emergency situations was assessed using Norwegian consumption data (Table 5.4.1-1) and the maximum permitted levels provided in the regulation, with modified levels of iodine-131 (Table 5.4.1-3). In our assessment, 10% of the food was assumed to be contaminated, as this assumption forms the basis for the maximum permitted levels. As demonstrated in Section 6.4.1, this is also an appropriate assumption for Norwegian conditions. Because the regulation is meant to be in effect for a 3-month period after the emergency, effective doses were calculated for a 3-month period (Table 6.4.2-1 to 6.4.2-3). The estimated effective doses are the doses resulting from 3 months' consumption of contaminated foods, not the dose received during these 3 months, since a large fraction of the dose from ingested strontium-90, caesium-137 and plutonium-239 would be received during a longer time period due to their longer half-lifes.

Table 6.4.2-1 Effective dose (mSv/3 months) for 1-year-olds when applying the maximum permitted levels laid down by Council regulation (Euratom) 2016/52, but using adjusted iodine-131 values (ToR4). It is assumed that 1% of liquid food, 50% of infant food and 10% of other food are contaminated.

Effective dose (mSv/3 months) 1-year-olds										
	Strontium-90		Iodine-131		Caesium-137		Plutonium-239		**Total**	
	mean	P95	mean	P95	mean	P95	mean	P95	**mean**	**P95**
Infant food	0.079	0.19	0.31	0.75	0.069	0.17	0.0061	0.015	**0.47**	**1.1**
Dairy products	0.013	0.045	0.090	0.30	0.018	0.060	0.012	0.042	**0.13**	**0.45**
Liquid food	0.0029	0.0069	0.019	0.046	0.0038	0.0090	0.0027	0.0063	**0.029**	**0.068**
Other food	0.25	0.47	0.79	1.5	0.069	0.13	0.15	0.29	**1.3**	**2.4**
Total[a]	**0.35**	**0.61**	**1.2**	**2.1**	**0.16**	**0.29**	**0.18**	**0.32**	**1.9**	**3.3**

[a]Total P95 is calculated from the person specific total effective dose of the four food groups (not from the sum of P95s from each food group).

Table 6.4.2-2 Effective doses (mSv/3 months) for children when applying the maximum permitted levels laid down by Council regulation (Euratom) 2016/52, but using adjusted iodine-131 values

(ToR4). Dietary data from the Norwegian dietary surveys in 9-year-olds (n=636) are used. It is assumed that 1% of liquid food and 10% of other food are contaminated.

Effective dose (mSv/3 months) 9-year-olds										
	Strontium-90		Iodine-131		Caesium-137		Plutonium-239		Total	
	mean	P95	mean	P95	mean	P95	mean	P95	**mean**	**P95**
Infant food	-	-	-	-	-	-	-	-	**-**	**-**
Dairy products	0.025	0.048	0.058	0.11	0.033	0.064	0.018	0.034	**0.13**	**0.26**
Liquid food	0.0039	0.0074	0.0092	0.017	0.0052	0.0098	0.0028	0.0053	**0.021**	**0.040**
Other food	0.31	0.48	0.34	0.53	0.086	0.13	0.15	0.23	**0.89**	**1.4**
Total[a]	**0.34**	**0.51**	**0.41**	**0.60**	**0.12**	**0.18**	**0.17**	**0.25**	**1.0**	**1.5**

[a]Total P95 is calculated from the person specific total effective dose of the four food groups (not from the sum of P95s from each food group).

Table 6.4.2-3 Effective doses (mSv/3 months) for adults when applying the maximum permitted levels laid down by Council regulation (Euratom) 2016/52, but using adjusted iodine-131 values (ToR4). It is assumed that 1% of liquid food and 10% of other food are contaminated.

Effective dose (mSv/3 months) Adults										
	Strontium-90		Iodine-131		Caesium-137		Plutonium-239		Total	
	mean	P95	mean	P95	mean	P95	mean	P95	**mean**	**P95**
Infant food	-	-	-	-	-	-	-	-	**-**	**-**
Dairy products	0.012	0.031	0.025	0.065	0.044	0.11	0.017	0.044	**0.098**	**0.25**
Liquid food	0.0067	0.012	0.014	0.026	0.025	0.044	0.0096	0.017	**0.056**	**0.099**
Other food	0.22	0.36	0.22	0.36	0.17	0.28	0.21	0.34	**0.82**	**1.3**
Total[a]	**0.24**	**0.37**	**0.26**	**0.40**	**0.24**	**0.37**	**0.24**	**0.37**	**0.98**	**1.5**

[a]Total P95 is calculated from the person specific total effective dose of the four food groups (not from the sum of P95s from each food group).

6.5 **Summary of dietary radiation exposure**

The mean dose from all sources of ionising radiation to individuals in Norway is estimated to be 5.1 mSv/year. On average, approximately 10% of this exposure comes from food. However, there may be large individual differences for some radioactive elements and food items.

Dietary exposure to radiation is calculated by multiplying the consumption and occurrence data provided in Chapter 5 by the ingestion dose coefficients developed by the ICRP.

For ToR1, the mean exposure from anthropogenic and naturally occurring radioactive elements in the total diet is estimated to be 0.56 and 0.48 mSv/year for to 1-year-olds and adults, respectively. The largest contribution to this dose comes from the naturally occurring elements polonium-210 and potassium-40. Although radioactive contamination in food contributes little to the mean consumer (0.0040 and 0.014 mSv for 1-year-olds and adults, respectively), it may still represent a significant radiation source for some individuals and in certain situations.

Of the scenarios for specific groups considered for ToR1, estimated effective doses range from 0.020 to 3.4 mSv/year. The highest estimated exposures were associated with a very high intake of reindeer meat from the most contaminated districts (3.4 mSv/year) and very high radon-222 levels in drinking water found in some wells drilled in boreholes (2.8 mSv/year).

For ToR2, the reduction in exposure associated with current countermeasures was estimated at 0.0005 mSv/year or less for the mean adult consumers of reindeer and sheep meat. For the specific groups, the dose reduction ranged from 0.007 to 2.6 mSv/year for the scenarios considered. The largest effect is seen in consumers of sheep meat from the most contaminated regions.

For ToR3, the reduction in exposure associated with reducing the ML for radioactive caesium in reindeer meat from the current level (3000 Bq/kg) to 1500 or 600 Bq/kg for the mean adult consumer was estimated to be 0.00003 and 0.00022 mSv/year, respectively. For specific groups, the dose reduction due to decreasing the ML to 1500 Bq/kg ranged from 0.0041 to 1.0 mSv/year for the scenarios considered, whereas the corresponding dose reduction of decreasing the ML to 600 Bq/kg ranged from 0.031 to 2.4 mSv/year.

For ToR4, the assumptions of food contamination levels that form the basis for Council regulation 2016/52 (Euratom) for emergency situations, were considered appropriate for Norwegian conditions. Exposure of the whole population associated with applying the maximum permitted levels was calculated using modified levels of iodine-131. The estimated mean effective doses for 1-year-olds, 9-year-olds and adults were 1.9, 1.0, and 0.98 mSv, respectively, for the 3-month period that the regulation would apply.

7 Risk characterisation

The radiation doses associated with consumption of food are generally in the low dose range and below the levels at which health effects have been observed in epidemiological studies. As described in Section 3.3. of Hazard Characterisation, the relevant effects at very low and low dose levels are stochastic effects, i.e., leading to an increased risk of cancer and heritable effects. For conversion of exposure to radiation from radioactive elements into risks associated with adverse effects, specific risk coefficients (see Section 3.3.4) have been established. An average lifetime risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1} (see Table 3.3.4-1) was assumed applicable for cancer incidence in the whole population. In comparison, the estimated risk coefficient for heritable effects, $0.2 \cdot 10^{-5}$ mSv^{-1}, is much lower (<4%). The heritable risk coefficient is mainly based on data from experimental animals and is more uncertain. Risks of heritable effects were not included in the risk characterisation of the radiation doses. Hence, excess risks associated with the exposure to very low doses of radiation from food are linearly extrapolated and based exclusively on the risk coefficient for cancer. The risk coefficient applies to excess radiation exposure above that from natural background radiation.

It should be noted that the risks estimated for low dose exposure in the following risk characterisation are based on several conservative assumptions and, thus, the actual risks may be lower. The calculated risks are indications of risk levels at the population level and should not be used to calculate any incidence of events.

VKM has estimated the incurred excess lifetime cancer risks associated with the radiation dose received via food per year. An excess lifetime cancer risk caused by a life long exposure to a carcinogen that is genotoxic below 10^{-5}, which is equivalent to one extra case of cancer in a population of 100,000 during 70 years of exposure, is commonly considered to be of little or no public health concern; this risk level has been used when deriving guideline values for drinking water (WHO, 2011). An excess lifetime risk of 10^{-5} incurred during 70 years would translate into an average risk of about 10^{-7} per year. In this assessment, VKM has used the terms listed in Table 7-1, for describing the risk levels associatied with exposure to radioactivity in food.

The categories of risk levels in Table 7-1 are quantified as indicated in subsequent tables, whereas qualitative descriptors are used in the text.

Table 7-1 Summary of risk categories.

Categories of cancer risk level	Nominal cancer risk/year	Cancer incidence rate (extra cases per 100,000/year)
Extremely low	$\leq 1 \cdot 10^{-7}$	≤0.01
Very low	$>1 \cdot 10^{-7}$-$1 \cdot 10^{-5}$	>0.01-1
Low	$>1 \cdot 10^{-5}$-$1 \cdot 10^{-4}$	>1-10
Moderate	$>1 \cdot 10^{-4}$-$1 \cdot 10^{-3}$	>10-100
High	$>1 \cdot 10^{-3}$-$1 \cdot 10^{-2}$	>100-1000

7.1 Health risk from radioactivity in the total diet in the current situation (ToR1)

The radiation doses to the general population from food are mainly from naturally occurring radioactive substances (see Chapter 6). This implies that any risk associated with the radiation dose received each year is more or less constant, and will accumulate throughout life. For specific population subgroups with elevated exposure to naturally occurring radioactive substances due to particular dietary habits, the resulting yearly dose rates will also remain roughly constant, but at a higher level. In contrast, for population groups receiving excess radiation doses from anthropogenic radioactive elements, i.e., caesium-137 – deposited in 1986, the radiation dose will decrease in the coming years due to physical decay and ecological processes. However, because the decay rate for caesium-137 is about 30 years, it is assumed that the excess risk associated with the radiation dose in the scenarios, as calculated in this risk assessment, should remain practically constant for the next 10 to 15 years.

Exposure to radioactivity from naturally occurring radioactive elements in food is considered part of the natural background radiation (see Chapter 1), and, by definition, the risk coefficient does not apply to this exposure. However, this does not mean that background radiation is without risk. The average natural radiation exposure received from food in Norway is about 6% of the total natural background radiation (see Chapter 6). It is noted that natural background radiation may vary considerably.

ToR1 from NFSA requests an assessment of the magnitude of risk for the whole population associated with exposure to radioactivity, including naturally occurring radioactive elements, via the diet (baseline). For this purpose, VKM applied the ICRP risk coefficient for cancer (see above, $5.5 \cdot 10^{-5}$ mSv^{-1}) developed for excess exposure. Using this approach enabled comparison of the excess risks associated with special dietary habits, as described in the different scenarios for specific groups, with that from food to the whole population.

Our approach of calculating population risks due to very low doses is supported by a study of Wakeford and co-workers (Little et al., 2009; Wakeford et al., 2009) who estimated the risk of radiation-induced childhood leukaemia from background radiation at annual doses in the range of 0.5 – 2.5 mSv/year, based on models established by BEIR (Committee to Assess the Health Risks from Exposure to Low Levels of Ionizing Radiation, 2006) and UNSCEAR (UNSCEAR, 2006); the authors found that there were only small deviations from the linear LNT model (Figure 3.3.4-1). Hence, extrapolation of the cumulative dose to values close to zero (Figure 3.3.4-1) would be appropriate, allowing estimation of a baseline risk for additional radioactive exposure from general food consumption.

7.1.1 **Whole population**

1-year-olds

The effective dose from the sum of natural and anthropogenic radioactive elements in food for mean and P95 exposure of 1-year-olds was calculated as, respectively, 0.56 and 1.0 mSv/yea (Table 6.1.1-1), based on the occurrence (Appendix 1) and consumption (Table 5.1.1-2) data presented. By application of the average lifetime risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1} (Table 3.3.4-1) this exposure translates into an additional cancer risk from the total diet (baseline) of $3.1 \cdot 10^{-5}$ and $5.5 \cdot 10^{-5}$ (mean and P95) per year (Table 7.1-1).

The contribution from anthropogenic element, caesium-137, to the exposure is 0.0040 and 0.0072 mSv/year for mean and P95 exposure of 1-year-olds. This translates into an excess cancer risk of $2.2 \cdot 10^{-7}$ and $4.0 \cdot 10^{-7}$ per year, respectively.

VKM considers the risk for 1-year-olds from exposure to natural and anthropgenic radioactive elements in food, for both mean and P95 consumers, as low. The contribution to this risk from anthropogenic sources is considered as very low (see Table 7-1).

Adults

The effective dose from the sum of natural and anthropogenic radioactive elements in the diet for mean and P95 adult consumers was calculated as, respectively, 0.48 and 0.81 mSv/year, (Table 6.1.1-1), based on the occurrence (Appendix 1) and consumption data (Table 5.1.1-2) presented. By application of the average life-time risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1} (Table 3.3.4-1). This translates into an additional risk from the total diet (baseline) of $2.6 \cdot 10^{-5}$ and $4.5 \cdot 10^{-5}$ (mean and P95) per year (Table 7.1-1).

The major radioactive elements contributing are naturally occurring polonium-210 and potassium-40.

Table 7.1-1 Cancer risk of radiation from total diet (baseline) expressed as 10^{-5} per year for 1-year-olds and adults from all eight radioactive elements considered.

	1-year- olds		**Adults**	
	Mean	P95	Mean	P95
Total cancer risk from food	3.1	5.5	2.6	4.5

The contribution from anthropogenic element, caesium-137, to the exposure is 0.014 and 0.043 mSv/year for adult mean and P95 consumers, respectively, translating into an excess risk of $7.7 \cdot 10^{-7}$ and $2.4 \cdot 10^{-6}$ (mean and P95, respectively) per year.

VKM considers the risk from exposure to natural and anthropgenic radioactive elements in food in adults in the whole population for both mean and P95 consumers as low. The contribution from anthropogenic sources is considered as very low.

7.1.2 Specific groups

Only adults were considered in the scenarios for specific groups. The following groups were considered (see 5.1.2):

- High and very high consumers of reindeer meat from contaminated areas
- High consumers of sheep meat from contaminated area
- High consumers of wild products (game meat, mushrooms, berries) from contaminated area
- Consumers of drinking water with high concentration of radon-222
- High consumers of seafood (fish and shellfish)

The excess health risk for these specific population groups was estimated by using the respective occurence (Table 5.1.2-1) and consumption (Table 5.1.2-2) data to calculate the associated effective doses (Table 6.1.2-1) and application of the average lifetime risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1} (Table 3.3.4-1). The resulting excess risks per year are shown in Table 7.1.2-1.

The specific population groups incurring the highest excess risk from particular food products are high and very high consumers of reindeer and high consumers of sheep meat containing high and very high amounts of caesium-137. Excess risk from radon-222 mostly affect consumers of drinking water from private wells in bedrock with a high content of radon-222.

Consumption of hunted or gathered wild products adds only a very low excess risk to the baseline risk (Table 7.1.2-1).

In various scenarios of high consumers of reindeer meat, the excess risks from caesium-137 vary from very low to moderate in those consuming highly contaminated meat.

For high consumers of sheep meat the excess risks from caesium-137 vary from very low to low in those consuming highly contaminated meat.

For high consumers of different wild products VKM considers the excess risks from caesium-137 as very low.

For consumers using drinking water contaminated with radon-222, VKM considers the excess risk as low to moderate for water with high to very high contamination, respectively.

For high consumers of fish and shellfish, the risk from polonium-210 is low and very low, respectively.

Table 7.1.2-1 Excess cancer risk for specific groups with elevated exposure from their diet, expressed as 10^{-5} per year (ToR1). Exposure (mSv/year) is also provided.

Specific group	Food item	Consumption level	Level of radioactivity					
			Mean		High		Very high	
			Exposure (mSv/y)	**Risk** (10^{-5} y^{-1})	**Exposure** (mSv/y)	**Risk** (10^{-5} y^{-1})	**Exposure** (mSv/y)	**Risk** (10^{-5} y^{-1})
			Caesium-137					
Reindeer meat	Reindeer meat	High[1]	0.14[a]	0.77	0.81[b]	4.5	1.4[c]	7.7
		Very high[2]	0.33[a]	1.8	1.9[b]	10	3.4[c]	19
Sheep meat	Sheep meat	High[1]	0.020[a]	0.11			0.41[d]	2.3
Wild products	Game meat	High[3]			0.024[e]	0.13		
	Wild mushrooms	High[4]			0.15[e]	0.83		
	Wild berries	High[5]			0.036[e]	0.20		
			Radon-222					
Drinking water	Drinking water	Mean[6]	-		0.50[f]	2.8	2.8[g]	15
			Polonium-210					
Seafood	Fish filet	High[7]	0.23[h]	1.3				
	Shellfish	High[8]	0.17[i]	0.94				

[1]Mean consumption of all meat from Norkost 3; [2]P95 consumption of all meat from Norkost 3; [3]P95 consumption of game meat from Norkost 3; [4]P95 consumption of all types of mushroom from Norkost 3; [5]P95 of jam consumption from Norkost 3; [6]Mean drinking water consumption from Norkost 3; [7]P95 consumption of fish fillets from Norkost 3; [8]P95 consumption of shellfish from Norkost 3. [a] National mean level as used in current exposure estimate (Section 5.1.1); [b]Mean of the mean concentrations in each of the most contaminated districts; [c]Mean of the single highest recorded concentration in each of the most contaminated districts, taking into account the maximum level of 3000 Bq/kg; [d]Maximum level for sheep meat; [e]Median concentration in the county with the highest recorded levels in such products; [f]Mean concentration in drinking water from private wells drilled in bedrock; [g]P95 concentration in drinking water from private wells drilled in bedrock; [h]Mean concentration in fatty fish; [i]Mean concentration weighted according to consumption rate of each species.

7.1.3 **Summary**

Whole population

VKM considers the cancer risk from exposure to natural and anthropgenic radioactive elements in food in 1-year-olds and adults of the whole population, for both mean and P95 consumers, as low.

The contribution from anthropogenic sources (caesium-137) to the excess cancer risk is considered as very low.

Specific groups

In various scenarios of high consumers of reindeer meat the excess cancer risks from caesium-137 vary from very low to moderate for those consuming highly contaminated meat and not taking any special measures against the Chernobyl contamination other than adhering to the MLs.

For high consumers of sheep meat, the excess risks from caesium-137 vary from very low to low, for those consuming highly contaminated meat.

For high consumers of different wild products the excess risks from caesium-137 are very low.

For consumers using drinking water containing with radon-222, the excess risk is low to moderate for water with high to very high levels, respectively.

For high consumers of fish and shellfish, the risks from polonium-210 are low and very low, respectively.

7.2 Excess health risk associated with exposure to the current levels of caesium-137 in reindeer and sheep if no efforts were made to reduce them (ToR2)

ToR2 requests an assessment of the health risks to the whole population and specific groups associated with caesium-137 in reindeer and sheep, should no efforts be made to reduce the levels in meat, i.e., no countermeasures are performed to reduce concentrations in animals with levels exceeding the ML.

For the risk to the general population associated with exposure to radioactivity in reindeer and sheep meat, provided there were no countermeasures, VKM estimated the excess risk without adjusting for countermeasures currently performed to reduce concentrations exceeding the ML in reindeer meat (3000 Bq/kg) and sheep meat (600 Bg/kg) (see Table 5.2-1).

In order to address the health risk in specific groups, four scenarios were considered. These were adults with high and very high consumption of reindeer meat and adults with high consumption of sheep meat from areas with high or very high contamination with caesium-137 (see Section 5.2). Exposure and risk associated with mean and P95 consumption of meat with high and very high caesium-137 concentrations were not assessed for ToR1. These levels have been calculated in order to compare the estimated concentrations with and without countermeasures in ToR2; however, they are not presented in the report. For the specific groups in ToR1, exposure and risk were not calculated for the high level of caesium-137 in sheep meat, as this would be the same as for very high level when using the ML of 600 Bq/kg. For comparison reasons in ToR2, highly contaminated sheep meat is estimated to be the same as very highly contaminated sheep meat applying todays countermeasures.

7.2.1 **Whole population**

The excess health risk from one year of exposure to caesium-137 in reindeer and sheep meat was estimated for the whole population using mean consumption (Table 5.2-2) data of reindeer meat, and mean and P95 for sheep, and three scenarios of caesium-137 occurrence on the assumption that no countermeasures were implemented (Table 5.2-1). The associated cancer risks were calculated using the calculated radiation doses (Table 6.2-1) and the average lifetime cancer risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1} (Table 3.3.4-1). The resulting excess risks per year are shown in Table 7.2.2-1.

For the mean consumer of reindeer meat (with mean level of radioactivity), the excess cancer risk increased by about 5%, but remained extremely low provided no countermeasures.

Similarly, for mean consumers of reindeer meat with high and very high levels of caesium-137, the risk increased by about 10 and 20%, respectively, but still remained in the same risk category, i.e very low.

For the mean and P95 consumers of sheep meat with no countermeasures, containing mean caesium-137 levels, the excess cancer risk increased by about 30%, but remained in the same risk categories, i.e., extremely low and very low, respectively.

For the mean and P95 consumers of sheep meat consuming highly contaminated sheep meat, the risk would be very low and low, respectively. For consumers of very highly contaminated sheep meat the risk would increase about 7 times. For the mean consumers, the risk would increase from very low to low, and for P95 consumers the risk would remain in the same risk category, i.e., low.

7.2.2 **Specific groups**

The excess health risk for the specific groups was estimated by using their respective consumption data (Table 5.2-2) and occurrence data (Table 5.2-1) to calculate the associated effective doses (Table 6.2-1) and applying the average lifetime cancer risk coefficient of $5.5 \cdot 10^{-5}$ mSv-1 (Table 3.3.4-1). The resulting excess cancer risks per year are shown in Table 7.2.2-1.

High and very high consumption of reindeer meat from contaminated areas

For high and very high consumers of reindeer meat with mean content of caesium-137 (provided no countermeasures and the national mean content of caesium-137 increasing from 208 to 222 Bq/kg, see also Sections 5.1 and 5.2), the risk would increase by about 5%. This implies, however, that the risks remain in the same categories, i.e., very low and low, respectively. For high and very high consumers of reindeer meat containing high and very high caesium-137 levels, the risk would increase by about 10 to 20% if no countermeares were performed, but the risk category would also remain unchanged at low and moderate, respectively.

High consumption of sheep meat from contaminated area

For the high consumers of sheep meat with mean content of caesium-137 (without any countermeasures, the national mean content of caesium-137 will increase from 30 to 40 Bq/kg see also Sections 5.1 and 5.2), the risk will increase by about 30%, but remain in the same risk category, i.e., very low. Consumption of highly contaminated meat would result in the excess cancer risks being categorised as low, whereas consumption of very highly contaminated meat (without any countermeasures the content of caesium-137 in contaminated district will increase from 600 to 4490 Bq/kg, see also Sections 5.1 and 5.2.) would increase the risk by about 7 times, from the category low risk to moderate risk.

Table 7.2.2-1 Excess cancer risk per year from caesium-137 in reindeer and sheep meat for the whole population and specific groups if no efforts were made to reduce caesium-137 levels, expressed as 10^{-5} per year (ToR2). Effective dose (mSv/year) is also provided.

Food item	Exposure groups	Consumption level	Caesium-137 level					
			Mean[a]		High[b]		Very high[c]	
			Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose mSv/year	Risk (10^{-5} y^{-1})
Reindeer meat	Whole population	Mean[1]	0.0010	0.0055	0.0062	0.034	0.012	0.066
		P95[2]	-	-	-	-	-	-
	Specific groups	High[3]	0.15	0.83	0.88	4.8	1.7	9.4
		Very high[4]	0.35	1.9	2.1	12	4.0	22
Sheep meat	Whole population	Mean[1]	0.0019	0.010	0.056	0.31	0.21	1.2
		P95[2]	0.015	0.083	0.45	2.5	1.7	9.4
	Specific groups	High[3]	0.027	0.15	0.79	4.3	3.0	17

[1]Mean consumption of the respective food item in Norkost 3; [2] P95 consumption of the respective food item in Norkost 3 - under 5% of participants reported eating reindeer meat in Norkost 3; [3]Mean consumption of all meat from Norkost 3; [4]P95 consumption of all meat from Norkost 3.

[a]Mean national concentrations, including animals with caesium-137 concentrations above the respective maximum levels; [b]Mean of the mean concentrations in the most contaminated districts, including animals with caesium-137 concentrations above the respective maximum levels; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, including animals with caesium-137 concentrations above the respective maximum levels.

7.2.3 Summary

Whole population

Provided no countermeasures:

For the mean consumer of reindeer meat with mean, highly contaminated and very highly contaminated meat, the excess risk would increase by about 5, 10, and 20%. The risk categories would remain the same, extremely low and very low.

For the mean and P95 consumers of sheep meat with mean content of caesium-137 the excess cancer risk would increase by about 30%. However, the risk categories, extremely low and very low, respectively, would remain the same. When consuming highly contaminated sheep meat the risk would be very low and low, and for consumers of very highly contaminated sheep meat, the risk would increase risk about 7 times. For the mean consumers, the risk would increase from very low to low, and for P95 consumers the risk would remain in the same risk category, i.e., low.

Specific groups

The impact of not applying today's ML of caesium-137 (3000 Bq/kg and 600 Bq/kg for reindeer and sheep meat, respectively) was calculated for several contamination scenarios: mean, high and very high contamination of caesium-137 and for different intake scenarios; reindeer meat: high and very high intake and sheep meat: high intake.

For high and very high consumers of reindeer meat with mean contamination, the risk would increase by about 5% and remain in the same risk categories, very low and low, respectively. For high and very high consumers of reindeer meat with high and very high contamination, the risk would increase by about 10 to 20% if no countermeares were implemented, but the risk category would remain unchanged at low and moderate, respectively.

For high consumers of sheep meat with mean contamination, the risk would increase by about 30%, but remain in the same risk category, very low. High consumption of highly contaminated meat would result in risks categorised as low. Consumption of highly and very highly contaminated meat would result in the risk being categorised as low and, for the latter, increasing by about 7 times from the category low risk to moderate.

7.3 Excess health risk associated with exposure to caesium-137 in reindeer if ML were reduced (ToR3)

ToR3 requests an assessment of the health risk associated with reducing the current ML of 3000 Bq/kg for radioactive caesium in reindeer meat to 1500 or 600 Bq/kg. These calculations assume that the contamination level is reduced to the ML, but that no additional effort are made to reduce the contamination in the reindeer meat consumed.

7.3.1 Whole population

The excess exposure to caesium in reindeer meat for the mean member of the whole population was calculated with the assumption that the ML of caesium-137 in reindeer meat was reduced from 3000 to 1500 or 600 Bq/kg. This would result in the doses being reduced by 0.00003 and 0.00022 mSv/year (or about 3 and 20%), respectively (Table 6.3.2-2). Thus, a reduction in caesium-137 ML has very little impact on the mean content of caesium-137 in reindeer meat on the market and therefore also on the radiation dose for the average member of the population.

The calculated risk associated with caesium-137 in reindeer meat at different MLs is presented in Table 7.3-1. VKM considers that, in all cases, the excess cancer risk associated with the calculated radiation dose from reindeer meat with a mean caesium-137 content using reduced MLs would be extremely low, as was estimated for ToR1 using the current ML.

The impact on the cancer risk for an mean consumer, consuming reindeer from contaminated areas, would also be slight, as the risk in all cases would be considered as very low.

This low impact on the risks to the mean consumer is due to the low mean consumption of reindeer meat and the fact that most of the reindeer meat is produced in areas with low contamination levels and would not be affected by reduced MLs.

7.3.2 Specific groups

The impact of reduced ML of caesium-137 in reindeer meat was calculated for several scenarios: high and very high consumption and mean, high and very high contamination level. It should be noted that persons with a high consumption of reindeer meat from these districts are currently advised to choose reindeer meat containing caesium-137 concentrations below the ML, but this is considered in this assessment.

For the high consumers of reindeer meat with mean contamination, the risk is very low and would not change by lowering the ML to 1500 or 600 Bq/kg. Also for those consuming meat with high or very high caesium-137 the risk category would remain as low risk.

For very high consumers of reindeer meat containing high contamination levels, reducing the ML to 1500 Bq/kg, would change the risk category from moderate to low, however the actual risk reduction is quite low (~5%). For the very high consumers of meat from very highly contaminated area, lowering the ML for caesium-137 in reindeer meat from the current level of 3000 to 1500 Bq/kg would not affect the risk category from moderate. Reducing the ML to 600 Bq/kg would change the risk category for very high consumers of reindeer meat with high and very high levels of contamination from moderate to low.

7.3.3 Summary

Lowering the ML of caesium-137 in reindeer meat with the current level of 3000 Bq/kg to 600 Bq/kg would reduce the excess risk category from moderate to low for the very high consumers of reindeer meat from a highly or very highly contaminated area. For very high consumers of reindeer meat, containing high contamination levels, reducing the ML to 1500 Bq/kg, would change the risk category from moderate to low, however the actual risk reduction is quite low (~5%). For all other scenarios considered in the assessment, reducing the ML for reindeer meat to 1500 or 600 Bq/kg, would not affect the level of risk. The calculations assume that no effort are made to reduce the contamination in the reindeer meat consumed other than adhering to the ML.

Table 7.3-1 Excess cancer risk per year (10^{-5} ·year^{-1}) from caesium-137 in reindeer meat, with current and reduced MLs (ToR3). Exposure (mSv/year) is also provided.

	Consump-tion level	**Effective dose (mSv/year) and associated risks (10^{-5} y^{-1}) at different MLs for caesium-137**																	
		ML 3000 Bq/kg (current)						**ML 1500 Bq/kg**						**ML 600 Bq/kg**					
		Mean[a]		High[b]		Very high[c]		Mean[a]		High[b]		Very high[c]		Mean[a]		High[b]		Very high[c]	
		Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk 10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk 10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})	Dose (mSv/y)	Risk (10^{-5} y^{-1})
Whole pop-ulation	Mean[1]	0.00099	0.0054	0.0057	0.031	0.010	0.055	0.00096	0.0053	0.0055	0.03	0.0070	0.039	0.00077	0.0042	0.0028	0.015	0.0028	0.015
Specific groups	High[2]	0.14	0.77	0.81	4.5	1.4	7.7	0.14	0.77	0.78	4.3	1.0	5.5	0.11	0.61	0.40	2.2	0.41	2.3
	Very high[3]	0.33	1.8	1.9	10	3.4	19	0.32	1.8	1.8	9.9	2.4	13	0.26	1.4	0.94	5.2	0.96	5.3

[1]Mean consumption of reindeer meat in Norkost 3 (under 5% reported eating reindeer meat in Norkost 3 and therefore P95 is not included); [2]Mean consumption of all meat from Norkost 3; [3]P95 consumption of all meat from Norkost 3.
[a]National mean concentrations, adjusted by the respective maximum level; [b]Mean of the mean concentrations in each of the most contaminated districts, adjusted by the respective maximum level; [c]Mean of the highest recorded concentrations in each of the most contaminated districts, adjusted by the respective maximum level.

7.4 **Excess health risk associated with exposure applying maximum permitted levels provided in the Euratom Regulation for emergency situations (ToR4)**

For the purpose of emergency situations, procedures and maximum permitted levels were developed by Euratom, as laid down in the Council Regulation 2016/52. The regulation is valid for a 3-month period after an accident involving radioactive material and specifies maximum permitted levels for the sum of isotopes of various elements and mentions some isotopes explicitly (Table 5.4.1-2). An assessment of the appropriateness of the maximum permitted levels for the EU in general was published in "Radiation protection 105, EU Food Restriction Criteria for Application after an Accident" (EC Directorate-General Environment Nuclear Safety, 1998), but in this publication only potential radiation doses were estimated and an assessment of the associated risks were not included.

The procedure and the maximum permitted levels laid down in Council Regulation 2016/52 (Euratom) on radioactive contamination of foods and feedstuffs following a nuclear accident or other radiological emergency were considered with respect to whether they were appropriate for managing similar scenarios in Norway. First, the share of food that may be contaminated, which forms the basis for the maximum permitted levels, was examined using a hypothetical worst-case scenario. The outcome of this was that the share of food assumed in the procedure of the Council Regulation 2016/52 was likely to be applicable to an emergency situation in Norway (see Section 6.4.1). Second, the exposure associated with the maximum permitted levels for strontium-90, iodine-131, caesium-137 and plutonium-239 was calculated using Norwegian food consumption data for 1-year-olds, 9-year-olds and adults. In calculating the exposure, it was assumed that 1% of liquid foods, 50% of infant foods and 10% of other foods were contaminated at the maximum permitted level, as described in Section 6.4. In this section, the estimated doses are compared with those obtained in Radiation protection 105. It should be noted that in the latter report, iodine values were not adjusted according to physical decay, whereas this was done by VKM when applying the maximum permitted levels to the Norwegian situation. VKM considered adjustment for iodine as more realistic (see also Section 5.4). The assessment of food contamination levels and hypothetical exposures are described in Section 6.4.

Also, the cancer risks associated with the exposures calculated in 6.4 is presented and categorized using the risk categories in Table 7-1. Table 7-1 refers to risks per year, but were used for assessing the effective doses resulting from 3 months' consumption of contaminated food since a large fraction of the dose will be delivered after the 3 months' period the council regulation applies (section 6.4.2).

7.4.1 **1-year-olds**

The total potential exposure to all 4 radioactive elements (strontium-90, iodine-131, caesium-131, and plutonium-239) for 1-year-olds over 3 months was 1.9 and 3.3 mSv (mean and P95) (see Table 6.4.2-1).

The associated added life time risk incurred in the 3 months after a nuclear accident (using a life time risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1}) is $1.0 \cdot 10^{-4}$ and $1.8 \cdot 10^{-4}$ (mean and P95, respectively). The excess cancer risk is moderate.

Table 7.4.1-1 Comparison of the mean effective doses (mSv/3 months) for 1-year-olds from food for the different radioactive elements as estimated in Radiation Protection 105 and in the current assessment (ToR4).

Effective dose (mSv/3 months) 1-year-olds					
	^{90}Sr	**^{131}I**	**^{137}Cs**	**^{239}Pu**	**Total**
EU *	0.21	1.11	0.13	0.08	**1.5**
Norway	0.35	1.2	0.16	0.18	**1.9**

*The mean effective doses from Radiation Protection 105 (mSv/year) were divided by 4 to estimate the doses for 3 months.

The doses calculated as being incurred during the 3 month period, using the maximum permitted levels and Norwegian food consumption data are somewhat higher, but in the same range, as those estimated for the EU (Table 7.4.1-1). Thus, applying the same maximum permitted levels as those for the EU will result in approximately the same level of protection.

7.4.2 **9-years olds**

The resulting potential exposure from all 4 radioactive elements (strontium-90, iodine-131, caesium-131, and plutonium-239) for 9-year-olds during the 3 month-period is 1.0 and 1.5 mSv (mean and P95, respectively).

The associated health risk incurred in the 3 month-period after a nuclear accident (using a risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1}) is $5.3 \cdot 10^{-5}$ and $8.3 \cdot 10^{-5}$ (mean and P95, respectively). Thus, the excess cancer risk is low.

As no dose for this age group was calculated by the Radiation Protection 105, no comparison could be conducted.

7.4.3 **Adults**

The resulting potential exposure from all 4 radioactive elements (strontium-90, iodine-131, caesium-131 and plutonium-239) for adults during the 3 month-period is 0.98 and 1.5 mSv (mean and P95, respectively) (Table 7.4.3-1) and (Table 6.4.2-3).

The associated health risk incurred in the 3 month-period after a nuclear accident (using a risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1}) is $5.4 \cdot 10^{-5}$ and $8.3 \cdot 10^{-5}$ (mean and P95, respectively).Thus, the excess cancer risk is low.

Table 7.4.3-1 Comparison of the mean effective doses (mSv/3 months) for adults from food for the different radioactive elements as estimated in Radiation Protection 105 and in the current assessment (ToR4).

Effective dose (mSv/3 months) Adults					
	^{90}Sr	^{131}I	^{137}Cs	^{239}Pu	Total
EU Lower level	0.16	0.33	0.15	0.15	**0.79**
EU high level	0.37	0.8	0.34	0.38	**1.9**
Norway mean	0.24	0.26	0.24	0.24	**0.98**
Norway P95	0.37	0.4	0.37	0.37	**1.5**

*The mean effective doses from Radiation Protection 105 (mSv/year) were divided by 4 resulting in estimation for 3 months.

The doses estimated using Norwegian food consumption data are somewhat higher, but in the same order of magnitude, as those estimated in the EU. Thus, a similar level of protection is obtained when applying the EU maximum permitted levels to the Norwegian food consumption pattern.

7.4.4 **Summary**

By applying the procedure and the maximum permitted levels, as laid down in the Council Regulation 2016/52 (Euratom) on radioactive contamination of foods and feedstuffs, to the Norwegian food consumption pattern in an emergency situation provides an approximately similar level of protection to that in EU. This is valid for 1-year-olds, 9-years-olds, and adults.

The estimated total potential exposures from food ranged from 0.98 to 3.3 mSv, and the associated excess cancer risks low to moderate ($5.3 \cdot 10^{-5}$ and $18 \cdot 10^{-5}$) for mean and P95 consumers, respectively, when applying the regulation's maximum permitted levels and the same share of contaminated food during the 3 month-period immediately after a nuclear accident for the three age groups.

8 Uncertainties

8.1 Uncertainties related to hazard assessment of radioactivity in food

8.1.1 Uncertainties related to calculation of effective doses using ingestion dose coefficients

When converting the ingested dose of each radioactive element into effective doses VKM used the ICRP effective dose coefficients established for the corresponding radioactive element. These are based on physiological and dosimetric modelling, which is in itself associated with significant uncertainties (e.g. Etherington et al. 2006). ICRP coefficients have been developed in order to compare calculated intake with limits and recommendations, and lean towards conservative assumptions such that doses are not underestimated. Examples include assumptions of absorption of elements in the gastro-intestinal tract, and the rates at which the elements are excreted from the body. Especially for small children/infants there is limited data available for validation of models for several radioactive elements (e.g., polonium-210). Given children's higher radiosensitivity, the parameter estimates are correspondingly conservative. These conservative assumptions become apparent, for example, when results from measurements of caesium-137 in people from the Sami reindeer-herding population are compared with calculated doses (Skuterud et al., 2002).

8.1.2 Uncertainties related to life time risk coeffcients and their use to estimate risk at very low doses

VKM used llifetime risk coefficients established by IRCP (2007) for estimations of risks associated with radiation exposure. Current ICRP lifetime risk coefficients are based on epidemiological investigations with some incorporation of data from animal and in vitro studies. The epidemiological data are mainly from acute external exposure of the Japanese population. Uncertainties in these risk coefficients may be due to sampling errors in epidemiological data underlying risk models, as well as lack of precision and accuracy in dose assessment in these studies. Further, there are additional factors contributing to the uncertainty. Among these are differences in uniformity of radiation exposure, latency period for different types of cancer, differences due to age and gender, as well as differences in sensitivity in different tissues and organs regarding to development detrimental radiation effects (including the possible presence of threshold levels for the induction of some cancers). However, the numerical values used in calculating general risk coefficients are usually conservative, and the lifetime risk coefficient used in this report probably tend to overestimate the risk.

In addition to the uncertainties associated with extrapolation of data on cancer risk from acute external ratioation to chronic radiation from ingested radiactive elements in food is the uncertainty related to the extrapolation of the risk coefficient to the lowest doses.

The application of the risk coefficient to fractions of the natural background radiation (e.g., various natural radioactive elements in foods) is also uncertain as the dose coefficient is derived from groups receiving radiation doses in addition to the natural radiation (no one receives zero radiation dose).

The relationship between radiation exposure and lifetime cancer risk is complex and varies depending on several factors. These include the radiation dose and the dose rate, but also the age at time of exposure, gender and cancer site. These factors can influence the uncertainty in projecting radiation risks, in particular when assessing risks at low doses. t is also likely that lifestyle factors and other exposures can modify the risk of radiogenic cancer. One well-known example is the synergistic effect of smoking on the risk of lung cancer from radon daughter isotopes. Such factors are likely to contribute to the uncertainty. In particular, in extrapolating risks from moderate to very low doses and dose-rates, data for humans are lacking. The documented evidence of health effects at doses below 100 mSv is limited to a few epidemiological studies of good quality. Such studies often lack the sufficient statistical power. The use of the linear non-threshold (LNT) model for assessing risks at very low doses and dose rates, and applying a dose reduction factor (DDREF) of 1 would be expected to result in an overestimate of the risk rather than an underestimate. Thus, the model used to quantify radiogenic cancers is considered conservative.

8.2 Uncertainties related to exposure assessment

8.2.1 Naturally occurring radioactive elements in food

With regard to naturally occurring radioactive elements in food, data from other countries for many food categories had to be used due to lack of Norwegian occurrence data. If available, data from other Nordic or Northern European countries were used. However, in many cases, international reference values were used. It is unclear how accurately these data represent the mean levels in Norwegian food products.

In order to estimate the national mean level of radon-222 in drinking water, information about the number of people served by different types of drinking water supplies is necessary. For private supplies, no complete overview is available – and even for public supplies, different sources state different numbers for how many are served by surface water supplies. The estimates used in this work are best estimates based on available data about waterwork supplies (Komperød et al., 2015b), but are conservative estimates compared to other sources.

8.2.2 Occurrence of caesium-137 in food

Monitoring data from the NRPA and the NSFA on caesium-137, in particular since the 1986 Chernobyl accident, were used in this assessment. These data mainly reflect the most contaminated areas and foods. In situations where caesium-137 levels may be significant, such as in sheep and reindeer from contaminated areas, extensive amounts of Norwegian data are available. In contrast, for foods with lower contamination levels, such as grains and vegetables, no recent Norwegian data are available, and estimations, at times conservative estimations, were made based on European data. Thus, the national mean contaminations of caesium-137 may be overestimated for some foods. However, given the low concentrations in the many foods and food groups, this is not expected to have an impact on the estimated health risk.

8.2.3 Radioactivity reduction in food prior to dietary intake

VKM has not taken into account the physical decay of radioactive elements from the time of harvesting until consumption. For short-lived radioactive elements, notably polonium-210 with a physical half-life of 138 days, the activity concentration will be significantly reduced for some food products, due the physical decay of the radioactive element that occurs prior to consumption. Furthermore, some radioactivity may also be lost during food preparation and cooking. For example, boiling is known to reduce the concentration of caesium-137 in food due to release from the food to the boiling water (IAEA, 2010) which is usually discarded. Similarly, some of the radon-222 in drinking water from the tap will be lost through evaporation prior to consumption. Radon-222 data is based on water collected directly from the tap and sealed. Radon-222 is in this assessment only assumed to be present in drinking water from the tap, not in other water-based beverages.

The lack of correction for physical decay and reductions due to food preparation means that the concentrations of radioactive elements used in the calculations in the present risk assessment are likely to be somewhat higher than those actually consumed.

8.2.4 Uncertainties related to dietary estimations

The methods used for consumption recording in one-year-olds (food frequency questionnaire; FFQ), 9-year-olds (four-day food records), and adults (24-hour recalls), are not similar, and date from these three surveys cannot be directly compared. However, all three surveys were nation-wide and participants were invited by arbitrary selection from the population.

There is much information available on the diet of the general population in Norway. However, national dietary surveys are not designed to cover the consumption of rarely eaten foods. In the present opinion there are several of the food items with high concentrations of caesium-137 that are eaten by a low percentile of the population, or with a low frequency. To get good data on the consumption pattern of these foods like reindeer meat and wild products, specific dietary surveys have to be conducted. For specific populations, with higher consumption of reindeer and sheep meat, there is a lack of information available. For reindeer herders there are some data on high consumption and traditional use of reindeer meat, but there are not the same data for farmers of sheep meat. In order to make scenarios that also includes those that eat most of reindeer and sheap meat, potentially overly conservative estimates have been made.

8.2.5 Uncertainties related to the assessment of procedures and maximum levels in Norwegian foods after a future accident

The assessment of the relevance of procedures and percentage contamination in Council Regulation 2016/52 (Euratom) was based partly on a simple accident scenario resulting in significant contamination of the 10 most important food producing counties in Norway. I.e., the accident must be on the scale of the Chernobyl accident, while the wind and precipitation during the first days after the accident must result in larger fallout in eastern, south-western and central Norway. For comparison, only parts of eastern and central Norway received large fallout from the Chernobyl fallout. Furthermore, the scenario assumes that the accident must occur during summer, immediately prior to harvesting, and that all products (the whole annual production) are harvested/produced at the same time. This is obviously overly simplified and extremely conservative, and is done only to estimate an upper value of the potentially contaminated fraction of Norwegian food production. It is unrealistic to estimate consequences of all possible future nuclear accidents, therefore Council Regulation 2016/52 (Euratom) also emphasizes that regulations will have to be adapted to the specific situation within three months of an accident.

In the Radiation Protection 105 maximum permitted levels are divided into five groups. In this assessment four of the groups are used. The group "minor foods" was not used since it includes foods which neither in amount nor frequency will affect the exposure estimate. It is unclear which foods the Radioation Protection 105 allocates into the four main maximum permitted level groups. It is specially unclear if the Radiation Protection 105 allocates infant formula to the food category "Baby food", "Dairy products" or "Liquid food stuffs including drinking water". However, this is only relevant for the comparison of Norwegian exposure and exposure estimated in Radiation Protection 105 in response to ToR4.

8.3 Summary of uncertainties in the risk assessment

The risk characterisation is the result of the integration of the hazard assessment and exposure assessment. The overall uncertainty is a combination of the uncertainties in these to element. An evaluation of the overall effect of identified uncertainties is presented in Table 8.3-1, highlighting the main sources of uncertainty and indicating the direction of the uncertainties, i.e. whether the respective source of uncertainty might have led to an over- (+) or underestimation (-) of the resulting risk (EFSA, 2006).

Table 8.3-1 Qualitative evaluation of influences of uncertainties on the risk assessment of radioactivity in food.

Source of uncertainty	Direction
Hazard assessment	
ICRP ingestion dose coefficients	+
ICRP life-time risk coefficients	+
Linear non-threshold extrapolation from high doses to very low doses	+
DDREF=1	+
Applying risk coefficient to fractions of natural background radiation	+
Exposure assessment	
Consumption data	
Different dietary assessment methods	+/-
High scenarios for sheep	+
Very high scenarios of reindeer	+
Consumed fraction of diet contaminated (ToR4)	+
Foodgroups consumed in ToR4 scenario may differ from those used in RP 105	+/-
Occurrence data	
National mean concentrations estimated from few or non-representative samples, from older data, or from other countries	+/-
Annual variation (level dependent on mushroom abundance)	+/-
Small number of samples for some foods	+/-
No activity reduction due to storage or cooking prior to dietary intake	+
No reduction due to evaporation of radon from drinking water from tap	+
Calculation of the effect of reducing the ML for caesium-137 in reindeer meat does not take into account the likely event that if concentrations exceeding the ML are observed in the herd, countermeasures may be performed that reduce the mean level in the whole herd.	+
Precision of analytical methods	+/-
Sampling methods and representativity	+/-
Feed	
Variability in plants' interception and uptake of radioactive caesium	+/-
Uncertainty in the estimated transfer to animal products (ToR4)	+/-

+: uncertainty likely to cause over-estimation.
- : uncertainty likely to cause under-estimation.

Despite some limitations in assessing occurrence of radioactive elements in food, dietary consumption and the uncertainties related to calculation of total exposure, in particular in the assumptions used in some exposure scenarios, VKM considers the exposure estimates presented in this opinion are within realistic and possible ranges for each exposure scenario.

Taking into account the conservative assumptions made both in the hazard assessment deciding to use linear extrapolation of the ICRP life-time risk coefficient for cancer and worst case assumptions particular in some of the high exposure scenarios VKM considers the overall uncertainty in the outcomes of the cancer risks caused by radioactivity in food in Norway to most likely result in an overestimation of the actual risks.

9 Conclusions (with answers to the terms of reference)

9.1 Introduction

All food items in the human diet contain radioactive elements. Some of these elements contaminate food as a result of human activity, e.g., nuclear accidents and weapons tests, but most radioactive elements occurring in our diet are of natural origin. Several factors affect the concentration of the different radioactive elements in the various food products, including abundance and chemistry of the radioactive elements and the biology and environment of the contaminated organisms. Naturally occurring radioactive elements, especially polonium-210, are present in relatively high concentrations in seafood and game. Drinking water from wells drilled in bedrock may contain high levels of radon-222. Caesium-137, resulting from the Chernobyl accident in 1986, is still present in relatively high concentrations in the some parts of the environment, and there are large geographic variations in contamination levels. Norway has a strong tradition of using uncultivated mountain and forest pastures for animal husbandry, and animals grazing in uncultivated pastures, mainly reindeer and sheep, generally acquire higher concentrations of caesium-137 than animals feeding on cultivated grass and concentrated feed. Countermeasures in sheep and reindeer are still conducted in order to reduce the caesium-137 concentrations below ML in these animals, and levels vary from year to year.

9.2 Hazard identification and characterisation

- VKM considered only the following eight radioactive elements in the risk assessment for radioactivity in food at today's levels: potassium-40, polonium-210, lead-210, radium-226, radium-228 and radon-222, caesium-137 and carbon-14. These radioactive elements were included in the assessment, as they have been estimated to account for 99.5% of the effective dose from food in Norway.

- The hazard assessment is based on information from international organisations concerned with radiation effects and radiation protection (e.g., ICRP, UNSCEAR, BEIR, WHO).

- The radiation doses from food in Norway are generally low and cancer and heritable diseases are considered the most important health effects.

- At doses that are relevant for exposure to radioactive elements in food, human data are scarce and inconsistent. The effects are extrapolated from data from higher doses and from the results of experimental studies.

- Effective doses for exposure to infants, children and adults are calculated using dose coefficients provided by ICRP.
- For estimating the health risks at very low doses, the VKM used a linear non-threshold model (LNT), with a risk of $5.5 \cdot 10^{-5}$ mSv^{-1} for cancer for the whole population. The estimated risk coefficient for heritable diseases is $0.2 \cdot 10^{-5}$ mSv^{-1}, which is considerably lower and more uncertain than that for cancer and was therefore not taken into account when characterising the risk from radioactivity in food.

9.3 **Exposure Assessment**

- The mean dose from all sources of ionising radiation to individuals in Norway is about 5.1 mSv/year. On average, approximately 10% of this exposure comes from food. However, there may be large individual differences for some radioactive elements and food items.
- Dietary exposure to radiation was calculated by multiplying the consumption and occurrence data provided in Chapter 5 by the ingestion dose coefficients developed by the ICRP.
- For the whole population, the mean exposure from anthropogenic and naturally occurring radioactive elements in the total diet was estimated the be 0.56 and 0.48 mSv/year for to 1-year-olds and adults, respectively. The largest contribution to these doses comes from the naturally occurring elements polonium-210 and potassium-40. Although radioactive contamination in food contributes little to the mean consumer exposure (0.0040 and 0.014, for 1-year-olds and adults, respectively), it may still represent a significant radiation source for some individuals and in certain situations.
- Of the scenarios considered for specific groups considered for, estimated effective doses range from 0.020 to 3.4 mSv/year. The highest estimated exposures were associated with a very high intake of reindeer meat from the most contaminated districts (3.4 mSv/year) and very high radon-222 levels in drinking water as found in some wells drilled in bedrock (2.8 mSv/year).
- The reduction in exposure to caesium-137 associated with current countermeasures was estimated to be 0.0005 mSv/year or below for the mean adult consumers of reindeer and sheep meat. For the specific groups, the dose reduction ranged from 0.007 to 2.6 mSv/year for the scenarios considered. The largest effect is seen in consumers of sheep meat from the most contaminated regions.
- The reduction in exposure to caesium-137 associated with lowering the ML for reindeer meat from the current level (3000 Bq/kg) to 1500 or 600 Bq/kg was estimated to 0.00003 and 0.00022 mSv/year, respectively, for mean adult consumers. For specific groups, the dose reduction due to lowering the ML to 1500 Bq/kg ranged from 0.0041 to 1.0 mSv/year for the scenarios considered in this assessment, and the corresponding dose reduction from lowering the ML to 600 Bq/kg ranged from 0.031 to 2.4 mSv/year.

- In assessing the applicability of the Council regulation 2016/52 (Euratom) for emergency situations to the Norwegian situation, VKM considered that the assumption of food contamination levels that form the basis for this regulation was appropriate for Norwegian conditions. Exposure of the whole population was calculated using the assumption that 1% of liquid foods, 50% of baby foods, and 10% of other food consumed was contaminated at the maximum permitted levels specified by the regulation, but using modified levels of iodine-131. The estimated mean effective doses for 1-year-olds, 9-year-olds, and adults were 1.9, 1.0, and 0.97 mSv, respectively, for the 3-month period that the regulation would apply.
- It was estimated that feed containing the maximum permitted levels for animal feed laid down in Council regulation 2016/52 (Euratom) may, under Norwegian conditions, result in contamination levels in some animals that exceed the maximum permitted levels in meat.

9.4 **Risk Characterisation and answers to the terms of reference**

- The radiation doses associated with consumption of food are generally low and below the dose levels for which health effects have been observed in epidemiological studies. The relevant effects at very low and low dose levels are stochastic effects, i.e., leading to an increased risk of cancer and heritable effects.
- VKM has estimated the incurred excess lifetime cancer risks associated with the radiation doses received per year (or 3 months) using an average lifetime risk coefficient of $5.5 \cdot 10^{-5}$ mSv^{-1}.
- VKM considered an excess lifetime cancer risk caused by a lifelong exposure below 10^{-5} (i.e., 1 extra case of cancer per 100,000 population during 70 years of exposure), corresponding to an average risk of about 10^{-7} per year, to be of little or no public health concern. VKM used the terms listed in Table 9.4-1 to describe the risk levels associated with exposure to radioactivity in food.

Table 9.4-1 Summary of risk categories (same as Table 7-1).

Categories of cancer risk level	Nominal cancer risk/year	Cancer incidence rate (cases per 100 000/year)
Extremely low	$\leq 1 \cdot 10^{-7}$	≤0.01
Very low	$>1 \cdot 10^{-7}$-$1 \cdot 10^{-5}$	>0.01-1
Low	$>1 \cdot 10^{-5}$-$1 \cdot 10^{-4}$	>1-10
Moderate	$>1 \cdot 10^{-4}$-$1 \cdot 10^{-3}$	>10-100
High	$>1 \cdot 10^{-3}$-$1 \cdot 10^{-2}$	>100-1000

9.4.1 **ToR 1**

What is the current health risk from radioactivity in food –food gathering and hunting included – to the whole population and specific groups in Norway?

Answer

Whole population

- VKM considers the cancer risk from exposure to natural and anthropogenic radioactive elements in food in 1-year-olds and adults of the whole population, for both mean and P95 consumers, as low (Table 9.4.1-1).
- The contribution from anthropogenic sources (caesium-137) to the excess cancer risk is considered very low.

Specific groups

- For reindeer meat, the excess cancer risks from caesium-137 vary from very low to moderate for high consumers of highly contaminated meat, not taking any measures against the Chernobyl contamination other than adhering to the ML of 3000 Bq/kg.
- For sheep meat, the excess risks from caesium-137 vary from very low to low for high consumers of highly contaminated meat.
- For high consumers of different wild products VKM considers the excess risks from caesium-137 as very low.
- For consumers using drinking water contaminated with radon-222, the excess risk is low to moderate for water with high to very high contamination, respectively.
- For high consumers of fish and shellfish, the risk from polonium-210 is low and very low, respectively.

Table 9.4.1-1 Summary of cancer risk levels for the whole population and specific groups in the current situation (ToR1).

Exposure group	Age group	Radioactive element	Food product	Consumption	Risk level		
					Radioactivity levels		
					Mean	High	Very high
Whole population	1-year-olds	All	All food	Mean	Low	-	-
				P95	Low	-	-
	Adults	All	All food	Mean	Low	-	-
				P95	Low	-	-
Specific groups	Adults	Caesium-137	Reindeer meat	High	Very low	Low	Low
				Very high	Low	Modera te	Moderate
			Sheep meat	High	Very low	-	Low
			Game meat	High	-	Very low	-
			Wild mushrooms	High		Very low	
			Wild berries	High		Very low	
	Adults	Radon-222	Drinking water	Mean		Low	Moderate
	Adults	Polonium-210	Fish filet	High	Low	-	-
			Shellfish	High	Very low		

9.4.2 **ToR 2**

What health risk would the current levels of caesium-137 measured in live reindeer and sheep pose to the whole population and specific groups, if no efforts were made to reduce them?

Answer

The impact of not applying today's ML for caesium-137 (3000 Bq/kg and 600 Bq/kg for reindeer and sheep meat, respectively) were calculated, using the mean content of caesium-137 in reindeer and sheep meat, without any adjustment for the effect of countermeasures.

Provided no countermeasures:

<u>Whole population</u>

- For mean consumers of reindeer meat containing mean caesium-137 levels, the excess risk increased by about 5% and remained extremely low. For mean consumers of highly and very highly contaminated reindeer meat, the risk increased by about 10 and 20%, respectively, but remained in the same risk category, very low, provided that no countermeasures were performed (Table 9.4.2-1).

- For mean and P95 consumers of sheep meat containing mean caesium-137 levels, the excess cancer risk increased by about 30% and remained in the same risk categories, extremely low and very low, respectively. For the mean and p95 consumers of highly contaminated sheep meat, the risk would remain in the same risk categories, very low and low, respectively, if no efforts were made to reduce the caesium-137 concentrations. For mean and P95 consumers of very highly contaminated sheep meat, the risk would increase risk by about 7 times. For the mean consumers, the risk would increase from very low to low, and for P95 consumers the risk would remain in the same risk category, i.e., low.

<u>Specific groups</u>

- The effect of not performing countermeasures for sheep and reindeer were calculated for three different contamination scenarios: mean, high, and very high caesium-137 levels, and different consumption scenarios: high and very high consumption for reindeer meat and high consumption for sheep meat.
- For the high and very high consumers of reindeer meat with mean caesium-137 content, the risk would increase by about 5% and remain in the same risk categories, i.e. very low and low, respectively, without any countermeasures. For high and very high consumers of reindeer meat containing high and very high caesium-137 levels, the risk would increase by about 10 to 20% if no countermeasures were performed, and the risk category would remain unchanged at low and moderate, respectively.
- For high consumers of sheep meat with mean caesium-137 content, the risk would increase by about 30%, but remain in the same risk category of very low. High consumption of highly and very highly contaminated meat would result in the risks being categorised as low and moderate, the latter increasing by about 7 times from the low risk category if no countermeasures were performed.

Table 9.4.2-1 Summary of cancer risk levels associated with caesium-137 in reindeer and sheep meat for adults of the whole population and specific groups if no countermeasures were performed (i.e. no MLs) (ToR2). The scenarios for which the risk level would change compared with the current situation are shown in bold type. Percentage increase of risk associated with caesium-137 in reindeer and sheep meat (not overall risk from diet) is also provided.

Exposure group	**Food product**	**Consumption**	**Risk level**		
			Radioactivity levels		
			Mean	High	Very high
Whole population	Reindeer meat	Mean	Extremely low ~+5%	Very low ~+10%	Very low ~+20%
	Sheep meat	Mean	Extremely low ~+30%	Very low ~+100%	Very low → **Low** ~+600%
		P95	Very low ~+30%	Low ~+100%	Low ~+600%
Specific groups	Reindeer meat	High	Very low ~+5%	Low ~+10%	Low ~+20%
		Very high	Low ~+5%	Moderate ~+10%	Moderate ~+20%
	Sheep meat	High	Very low ~+30%	Low ~+100%	Low → **Moderate** ~+600%

9.4.3 **ToR 3**

What would be the implication on the health risk if the ML for reindeer meat was reduced from 3000 to 1500 or 600 Bq/kg, respectively – for the whole population and for specific groups?

<u>Whole population and specific groups</u>

- Lowering the ML for caesium-137 in reindeer meat from the current level of 3000 to 600 Bq/kg would reduce the risk category from moderate to low for the very high consumers of meat from a highly or very highly contaminated area (Table 9.4.3-1). For very high consumers of reindeer meat, containing high contamination levels, reducing the ML to 1500 Bq/kg, would change the risk category from moderate to low; however, the actual risk reduction is quite low (~5%). For all other scenarios considered in the assessment, reducing the ML for reindeer meat to 1500 or 600 Bq/kg, would not affect the level of risk. These estimates assume that these consumers do not take any further measures to reduce their exposure to the caesium-137 levels in reindeer meat further once they are below the ML.

Table 9.4.3-1 Summary of cancer risk levels associated with caesium-137 in reindeer meat for adults of the whole population and specific groups should the MLs be reduced from the current level of 3000 Bq/kg to 1500 or 600 Bq/kg (ToR3). The scenarios for which the risk level would change compared with the current situation are shown in bold type. Percentage decrease of risk associated with caesium-137 in reindeer meat (not overall risk from diet) is also provided.

Exposure group	**Consumption**	**Risk level**					
		ML 1500 Bq/kg			ML 600 Bq/kg		
		Radioactivity levels			Radioactivity levels		
		Mean	High	Very high	Mean	High	Very high
Whole population	Mean	Extremely low ~-5%	Very low ~-5%	Very low ~-30%	Extremely low ~-20%	Very low ~-50%	Very low ~-70%
Specific groups	High	Very low ~-5%	Low ~-5%	Low ~-30%	Very low ~-20%	Low ~-50%	Low ~-70%
	Very high	Low ~-5%	Moderate → **Low** ~-5%	Moderate ~-30%	Low ~-20%	Moderate → **Low** ~-50%	Moderate → **Low** ~-70%

9.4.4 **ToR 4**

Would the procedure and the maximum levels laid down in the Euratom Treaty regulation on radioactive contamination of foodstuffs and feedstuffs following a nuclear accident be appropriate for managing similar scenarios in Norway?

- The share of food that may be contaminated, and which forms the basis for the maximum permitted levels, was examined using a hypothetical worst-case scenario. VKM considers that the share of contaminated food assumed in the procedure of the Council Regulation 2016/52 is also applicable to an emergency situation in Norway.
- A level of protection approximately similar to that in EU is obtained by applying the procedure and the maximum permitted levels for food laid down in the Council regulation (Euratom) 2016/52 on radioactive contamination following a nuclear accident to the Norwegian food consumption pattern. This is valid for 1-year-olds, 9-years-olds and adults.
- The estimated total potential exposures from contaminated food ranged from about 0.98 to 3.3 mSv and the associated excess cancer risks from low to moderate (5.3 and $18 \cdot 10^{-5}$) when applying the maximum permitted levels, with modified levels of iodine-131 during the 3-month period following a nuclear accident for the three age groups (Table 9.4.4-1). The total risk level to the population during this period would be in addition to that estimated for the current situation (ToR1).
- The assessment of the maximum permitted levels of radioactive caesium in feed in Council regulation (Euratom) 2016/52 indicates that these levels may result in contamination levels in food products that are 3-6 times above the maximum permitted levels of the same regulation. Thus, VKM notes that the maximum permitted levels for feed appear inappropiate for Norway provided adherence to maximum permitted levels in food.

Table 9.4.4-1 Risk levels associated with applying the maximum permitted levels of Council Regulation 2016/52 (Euratom) for 3 months for contamination with strontium-90, iodine-131, caesium-137, and plutonium-239, using modified levels of iodine-131 and in accordance with the procedure described in Section 6.4. This risk is in addition to that estimated for the current situation in ToR1.

Exposure group	Radioactive elements	Food product	Age group	Consumption	Risk level
Whole population	Strontium-90, iodine-131, caesium-137, plutonium-239	All foods	1-year-olds	Mean	Moderate
				P95	Moderate
			9-year-olds	Mean	Low
				P95	Low
			Adults	Mean	Low
				P95	Low

10 Data gaps

In this chapter, insufficient knowledge and/or data related to the topic covered in the risk assessment is described. All data gaps described was uncovered during the risk assessment process.

10.1 **Data on occurrence of radioactivity in Norwegian food**

Monitoring data from the NRPA and the NSFA on caesium-137, in particular since the 1986 Chernobyl accident, were used in this assessment. These data mainly reflect the most contaminated areas and food products. In situations where caesium-137 levels may be significant, such as in sheep and reindeer from contaminated areas, considerable amounts of Norwegian data are available. In contrast, for food products with lower contamination levels, such as grains and vegetables, no recent Norwegian data are available, and estimations, at times conservative estimations, were made based on European data. Thus, the national mean contaminations of caesium-137 may be overestimated for some products.

With regard to naturally occurring radioactive elements in food, data from other countries for many food categories had to be used due to lack of Norwegian occurrence data. If available, data from other Nordic or Northern European countries were used. However, in many cases, international reference values were used. It is unclear how accurately these data represent the mean levels in Norwegian food products.

- There is a need for Norwegian occurrence data on food products with low contamination levels.
- More measurements of natural radioactivity in foodstuffs that are representative for the Norwegian diet, especially for seafood, would improve the reliability of the dose estimates.

Information about the number of people served by different types of drinking water supplies, including sourse and treatment, is necessary in order to estimate national mean levels of radon-222. No such overview is available for private supplies.

10.2 **Norwegian occurrence data on “ready to eat” food**

For short-lived radioactive elements, notably polonium-210 with a physical half-life of 138 days, the activity concentration will be significantly reduced for some food products, due the physical decay of the radioactive element that occurs prior to consumption. Furthermore, some radioactivity may also be lost during food preparation and cooking. For example, boiling is known to reduce the concentration of caesium-137 in food due to release from the food to the boiling water (IAEA, 2010) which is usually discarded.

A Total Diet Study (TDS) denotes an internationally recognised method to establish the mean concentration of different substances, such as different radioactive elements, in prepared food. In a TDS, samples of food at retail outlets throughout Norway are collected, prepared, and the “ready to eat” food is analysed. Combined with nationwide dietary surveys, the data would provide an improved scientific basis for estimating the average population’s dietary exposure to e.g. radioactive substances.

10.3 Consumption data

Generally, there is much information available on the diet of the general population in Norway, including mean consumption of reindeer and sheep meat. However, for specific populations, with higher consumption of reindeer and sheep meat, there is a lack of information available.

- There is a need for dietary data on population sub-groups with specific food consumption patterns.

10.4 Validity for dose coefficients for radioactive elements in small children

When converting the ingested dose of each radioactive element into effective doses VKM used the ICRP effective dose coefficients established for the corresponding radioactive element. These are based on physiological and dosimetric modelling and have been developed in order to compare calculated intake with limits and recommendations. The effective dose coeffcicients lean towards conservative assumptions to ensure that doses are not underestimated. Examples include assumptions of absorption of elements in the gastro-intestinal tract, and the rates at which the elements are excreted from the body. Especially for small children/infants there is limited data available for validation of models for several radioactive elements.

- More data on absorption, distribution, metabolism and excretion of the different radioactive elements at different ages and development stages would reduce the need for conservative estimates.

10.5 Factors that modify health risk from radioactive elements

The relationship between radiation exposure and lifetime cancer risk is complex and varies depending on several factors. These include the radiation dose and the dose rate, but also the age at time of exposure, gender and cancer site. These factors can influence the uncertainty in projecting radiation risks, in particular when assessing risks at low doses. It is also likely that lifestyle factors and other exposures can modify the risk of radiogenic cancer. One well-known example is the synergistic effect of smoking on the risk of lung cancer from radon daughter isotopes.

- Research on effects following combined exposure to radioactive elements and different life style factors that might have an impact on the resulting life time health risk.

11 References

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Appendix 1

Activity concentration data

The occurrence data used to assess the current health risk to the whole population are based on the data provided by Komperød (Komperød et al., 2015b). However, the following modifications were made to the data:

- The caesium-137 concentration in juice was reduced from 1 Bq/kg to 0.5 Bq/kg, assuming lower levels in juice than in fruit and berries, according to the IAEA processing factors (IAEA, 2010).
- In Komperød (Komperød et al., 2015b), the mean level of polonium-210 in shellfish (48 Bq/kg) was based on Norwegian monitoring data, which mainly consisted of molluscs (blue mussels). However, new data suggest that polonium-210 concentration in northern shrimp (*Pandalus borealis*), which makes up the majority of Norwegian shellfish consumption, are an order of magnitude lower. The resulting polonium-210 values applied for various types of shellfish are:
    - Shrimp: 5 Bq/kg (Skjerdal and Haanes, personal communication)
    - Crab and crayfish: 15 Bq/kg (Hosseini et al., 2010)
    - Blue mussels: 48 Bq/kg (NRPA monitoring data)
    - Scallops: 56 Bq/kg (NRPA monitoring data)

Table A1-1 Activity concentration data used in the exposure calculation, Bq/kg.

Food group	Cs-137 Bq/kg	Ra-226 Bq/kg	Pb-210 Bq/kg	Po-210 Bq/kg	Ra-228 Bq/kg
Bread, cereals, cakes	1	0.08	0.05	0.06	0.06
Potatoes, vegetables	1	0.03	0.03	0.04	0.02
Leafy vegetables	1	0.05	0.08	0.1	0.04
Mushroom, wild	120	0.03	0.4	4	0.02
Fruit, berries	1	0.03	0.03	0.04	0.02
Juice	0.5	0.03	0.03	0.04	0.02
Beef	5	0.015	0.08	0.06	0.01
Pork, chicken	1	0.015	0.08	0.06	0.01
Sheep	30	0.015	0.08	2	0.01
Reindeer	208	0.015	0.5	9.3	0.01
Meat products	6.3	0.015	0.08	0.06	0.01
Fish, fatty	0.14	0.2	0.2	2.6	1.8
Fish, lean	0.13	0.2	0.2	0.24	1.8
Freshwater fish	30	0.1	0.056	0.43	0
Unspecified marine fish	0.14	0.2	0.2	1.4	1.8
Shrimp	0.09	0.7	0.2	5	1.8
Crab and crayfish	0.09	0.7	0.2	15	1.8
Blue mussels	0.09	0.7	0.2	48	1.8
Scallops	0.09	0.7	0.2	56	1.8
Milk, milk products	0.5	0.005	0.015	0.015	0.005
Cream, soure cream	0.31	0.005	0.015	0.015	0.005
Cheese	0.29	0.005	0.015	0.015	0.005
Brown cheese	30	0.005	0.015	0.015	0.005
Egg	1	0.015	0.08	0.06	0.01
Sugar, salt	0	0	0	0	0
Tap water[1]	0.001	0.0005	0.01	0.005	0.0005
Water, drinks based on water	0.001	0.0005	0.01	0.005	0.0005
Wine	1	0.03	0.03	0.04	0.02
Miscellaneous	0.64	0.016	0.023	0.13	0.034
Baby porridge	0.23	0.011	0.016	0.014	0.008
Jars of babyfood w/meat	1.2	0.018	0.031	0.070	0.012
Jars of babyfood w/fish	0.77	0.037	0.038	0.56	0.15
Jars of babyfood w/vegetables	0.6	0.019	0.026	0.039	0.013
Infant formula	0.50	0.005	0.015	0.015	0.005

[1]Tap water is the only food item that contain radon-222, the estimated radon-222 consentration is 38 Bq/kg.

Appendix 2

Information on exposure of reindeer herders to radioactivity since the 1960s

Elevated levels of radioactive caesium from the atmospheric nuclear weapons testing were detected in reindeer meat in 1961 (Liden, 1961), and prompted studies on contamination in reindeer meat consumers in most circumpolar countries. Studies of reindeer herders in Norway commenced in Kautokeino in 1965, and were still ongoing when the Chernobyl disaster happened. The year 1965 was also when the highest concentrations in humans were recorded, corresponding to an annual dose of about 1.6 mSv (Westerlund et al., 1987). The cumulative dose to reindeer herders in Kautokeino during the period 1950 – 2010 was estimated at 18 mSv (Skuterud and Thorring, 2015). The levels of Chernobyl fallout in central and southern Norway were much higher than the nuclear weapons tests fallout in the 1950-1960s. Maximum levels of radioactive caesium in reindeer herders in central Norway were detected in 1988, corresponding to an average annual dose of 2.1 mSv. However, maximum individual levels corresponded to 14-15 mSv/year, which would also have been the mean level had no countermeasures and dietary advice been applied (Skuterud and Thorring, 2012).

Studies on possible health consequences among the North Sámi population due to nuclear weapons testing have been conducted, but similar studies have not been performed among the fewer South Sámi after the Chernobyl disaster. In northern Norway cohort studies of cancer incidence and mortality from 1970 to the late 1990s gave no indication of increased risks (Haldorsen and Tynes, 2005; Tynes and Haldorsen, 2007). For all types of cancer combined, the study found 20−25% lower incidence among the Sámi than among the local reference population and among the general Norwegian population. No increases in incidences of cancers often related to radiation, like leukemia, thyroid, bone, and breast cancers, were found. These findings are in agreement with results from similar studies in Sweden and Finland (Hassler et al., 2008; Kurttio et al., 2010). The Finnish study (Kurttio et al., 2010) found some indication of an increased risk of cancer associated with estimated cumulative radiation doses received during childhood (before 15 years of age), but the authors concluded that the finding should be interpreted with caution due to uncertainties in dose estimates.

The health studies conclude that the traditional Sámi reindeer herding lifestyle seems to contain elements that reduce the risk of cancer and cardiovascular diseases, e.g., physical activity and a diet rich in antioxidants (from berries) and unsaturated fatty acids (from fish).

Appendix 3

Worst-case scenario developed for the assessment of potential food contamination levels in Norway (ToR4)

The maximum permitted levels in Council Regulation (Euratom) 2016/52 on radioactive contamination of food and feed in an emergency were developed based on a reference level of 1 mSv/year in incremental effective doses to individuals from ingestion, based on the general assumption that 10% of the food consumed is contaminated. In dose assessments in Radiation protection 105 (EC Directorate-General Environment Nuclear Safety, 1998), the level of contaminated drinking water is also assumed to be 1% and in infant food to 50%. In ToR4, the VKM was asked to evaluate whether the procedure and maximum permitted levels laid down in the Euratom regulation would be appropriate for managing similar situations in Norway.

In order to perform such an evaluation, for the 10% contamination level assumed for most food products, a worst-case scenario for radioactive contamination of food in Norway was developed. Because there are very many relevant factors in such a calculation, simplifications were necessary. However, the overall estimates are conservative such that the potential consequences associated with a future emergency are not underestimated.

Contaminated region

The regions with the highest agricultural production were all assumed to be contaminated. These make up 10 of Norway's 19 counties:

- Østlandet (Østfold, Akershus, Oslo, Hedmark, Oppland, Buskerud, Vestfold)
- Trøndelag (Nord-Trøndelag, Sør-Trøndelag)
- Rogaland

Statistics on the food production in each county were collected from Statistics Norway (Statistics Norway, 2016)

Description of worst-case scenario

Contaminated food products

In the counties considered, the following products, which make up a considerable portion of the average diet, were assumed to contain radioactivity concentrations equal to the maximum permitted levels of strontium-90, iodine-131, plutonium-239, and caesium-137 as specified in 2016/52/Euratom:

- Cow's milk
- Sheep meat
- Beef
- Wheat (100% of wheat and 0% of other grains were assumed used for human consumption. This is an overestimate for wheat and an underestimate for other grains, but considered an overall fair approximation).
- Potatoes
- Vegetables (grown outdoors)
- Fruits and berries

These products are considered to be vulnerable to contamination from radioactive fallout because they are produced in open fields. However, the assumption that all of these products would be contaminated at the maximum permitted level in the affected regions must be considered an overestimate. For instance, this scenario requires that the accident and fallout occur immediately before harvest, and that all products are harvested/produced at the same time. Furthermore, for animal products, it assumes that the whole annual production takes place during a few days after fallout. Pork and poultry were not assumed to be contaminated because they mainly live inside and are fed concentrates. Seafood was also assumed not to be contaminated due to dilution and low uptake of these radioactive elements in the marine environment.

Wild foods, such as game, reindeer, and freshwater fish, would be likely to be heavily affected, but were not included due to their minor contribution to the total national diet. Other minor foods, as well as food products that are normally stored or imported, were also assumed to be uncontaminated.

Table A3-1 Annual production of agricultural products in the counties assumed to be contaminated in this worst-case scenario (Statistics Norway), as well as proportion of domestic contaminated food and level of self-sufficiency (share of domestic production vs. national consumption; (FAO, 2011)) of the contaminated products.

	Cow's milk (tonnes)	Sheep meat (tonnes)	Beef (tonnes)	Wheat (1000 tonnes)	Potatoes (1000 tonnes)	Vegetables grown outdoors (tonnes)	Fruit and berries (tonnes)
Total domestic production	*1 370 670*	*25 556*	*79 671*	*389.5*	*307.7*	*125 549*	*27 775*
Østfold	30 738	139	1738	130.9	14.5	10 014	1279
Akershus and Oslo	25 122	225	1744	84.9	16.4	4113	1283
Hedmark	81 642	1368	5392	47.3	135.4	10 778	1660
Oppland	165 810	3181	11 554	15.3	22.2	16 040	1313
Buskerud	27 396	1324	2127	37.1	8.6	21 952	4736
Vestfold	14 700	121	1205	61.6	39.5	26 969	2454
Rogaland	243 636	5428	13 288	-	14.9	15 406	860
Sør-Trøndelag	135 762	1577	6822	1.6	2.1	743	305
Nord-Trøndelag	157 128	945	9149	1.9	29.2	11 527	846
Production in contaminated areas (in tonnes):	**881 934**	**14 308**	**53 019**	**380.6**	**282.8**	**117 543**	**14 736**
Proportion of domestic production that is contaminated	*0.64*	*0.56*	*0.67*	*0.98*	*0.92*	*0.94*	*0.53*
Self-sufficiency*	*1*	*0.96*	*0.87*	*0.33*	*0.93*	*0.37*	*0.03*

*(FAO, 2011)

Level of self-sufficiency

The proportion of domestic food production that would be contaminated in the given scenario was calculated based on the production statistics for each county for each food category (Statistics Norway).

Statistics from the United Nation's Food and Agriculture Organization (FAO, 2011) were used to assess how much of the domestic food production is consumed within Norway. FAO's food balance sheets from 2011 were used and Norway's self-sufficiency was estimated by assessing the ratio between domestic production and total domestic supply.

A summary of the estimated percentage of contaminated food, self-sufficiency and the resulting share of food consumed that would be contaminated in this scenario is presented in Table 6.4.1-1.

Proportion of consumed food consumption that is contaminated

The proportion of consumed food affected by the hypothetical worst-case scenario described was estimated by multiplying together the mean consumption data for adults (Norkost 3, see Section 2.2), the proportion of self-sufficiency, and the proportion of domestic food production affected for each food category, with the exception of drinking water and water-based beverages.

The resulting mean consumption of contaminated food was divided by the total annual consumption, resulting in a total of 25% of the total consumption of food being contaminated based on these calculations. As described in more detail in Section 6.4, when taking into account other factors, including that a whole year's food production cannot be contaminated at the same time, the assumption of 10% contamination level is considered appropriate for Norwegian conditions.

Appendix 4

Effect on caesium-137 concentration in reindeer meat if MLs were reduced

Data set

Up-to-date information on contamination levels are available only from the most contaminated districts. If information was lacking, current levels were estimated based on historical data combined with expert judgement of assumed time trends. Monitoring data from different districts show a standard deviation of roughly 30%.

Calculation of mean levels in herds if MLs were reduced

The current practice in management of radioactive contamination of reindeer is that no animals with higher concentration than the ML are allowed onto the market (see Section 4.1.1.2). For animals containing more than the ML, slaughter is delayed or clean-feeding is implemented until levels are below the ML. Therefore, the mean level in the meat from any single herd would always be expected to be lower than the ML, because no animals would contain more than the limit, and some animals would contain less.

A normal distribution curve for each district was generated based on mean caesium-137 concentrations for each district and 30% standard deviation using the 'rnorm' function in the R programming language. In the resulting distributions, the concentration of animals exceeding the MLs were replaced by concentrations equal to the ML (1500 and 600 Bq/kg), and new national mean concentrations were calculated. An average of five runs was used for the evaluation.

The calculated mean concentrations in each reindeer herd if MLs were reduced to 1500 or 600 Bq/kg are presented in Table A4-1.

Table A4-1 Current mean caesium-137 concentrations (Bq/kg) today and estimated effects of reduced MLs. The total national mean concentration (weighted by the number of animals slaughtered in each district) is also provided.

County	Reindeer herding district	No. of animals slaughtered[b]	3000 (current)	1500	600
Oppland	ØA LOM TAMREINLAG	1361	400	400	398
Oppland	ØB VÅGÅ TAMREINLAG	1598	1681	1459	599
Oppland	ØC FRAM REINLAG	1926	300	301	300
Oppland	ØE FILEFJELL REINLAG	1858	400	400	401
Sør-Trøndelag	UW 3 - ELGÅ	1169	450	450	440
Sør-Trøndelag	UX 2 - RIAST/HYLLING	2547	300	299	299
Sør-Trøndelag	UY 4 - FEMUND (vinterdistrikt)	110	350	353	345
Sør-Trøndelag	UZ 1 - ESSAND	2182	300	301	299
Sør-Trøndelag	ØG TROLLHEIMEN	797	100	100	100
Nord-Trøndelag	VA 7 - GASKEN-LAANTE	182	700	698	557
Nord-Trøndelag	VF 8 - SKÆHKERE	865	880	869	580
Nord-Trøndelag	VG 9 - LÅARTE	621	1240	1176	591
Nord-Trøndelag	VJ 10 - ØSTRE-NAMDAL	1656	1008	994	588
Nord-Trøndelag	VM 11 - ÅARJEL-NJAARKE	162	500	482	562
Nord-Trøndelag	VR 6 - FOVSEN-NJAARKE	475	200	201	200
Nordland	WA 18 - VOENGELH-NJAARKE	391	400	397	399
Nordland	WB 20 - JILLEN-NJAARKE	137	750	758	567
Nordland	WD 19 - BYRKIJE	274	1328	1232	592
Nordland	WF 21 - RØSSÅGA/TOVEN	204	400	394	402
Nordland	WK 23 - HESTMANNEN/STRANDTINDENE	172	100	100	99
Nordland	WL 22 - ILDGRUBEN	299	100	99	100
Nordland	WN 24 - SALTFJELLET	701	100	100	100
Nordland	WP 25 - BALVATN	248	100	99	100
Nordland	WR 26 - DUOKTA	109	100	100	101
Nordland	WS 27 - STAJGGO/HÁBMER	165	100	100	99
Nordland	WX 28 - FROSTISEN[a]	21	100	102	97
Troms	*All districts*	1774	90	90	90
Finnmark	*All districts*	51161	80	80	80
Total		**73163**	**208**	**202**	**162**

[a]In some cases, the mean concentrations estimated for the reduced ML are slightly higher than today's level. This is due to the random assignment of values to a normal distribution as described above;[b]Mean for years 2007-2010.