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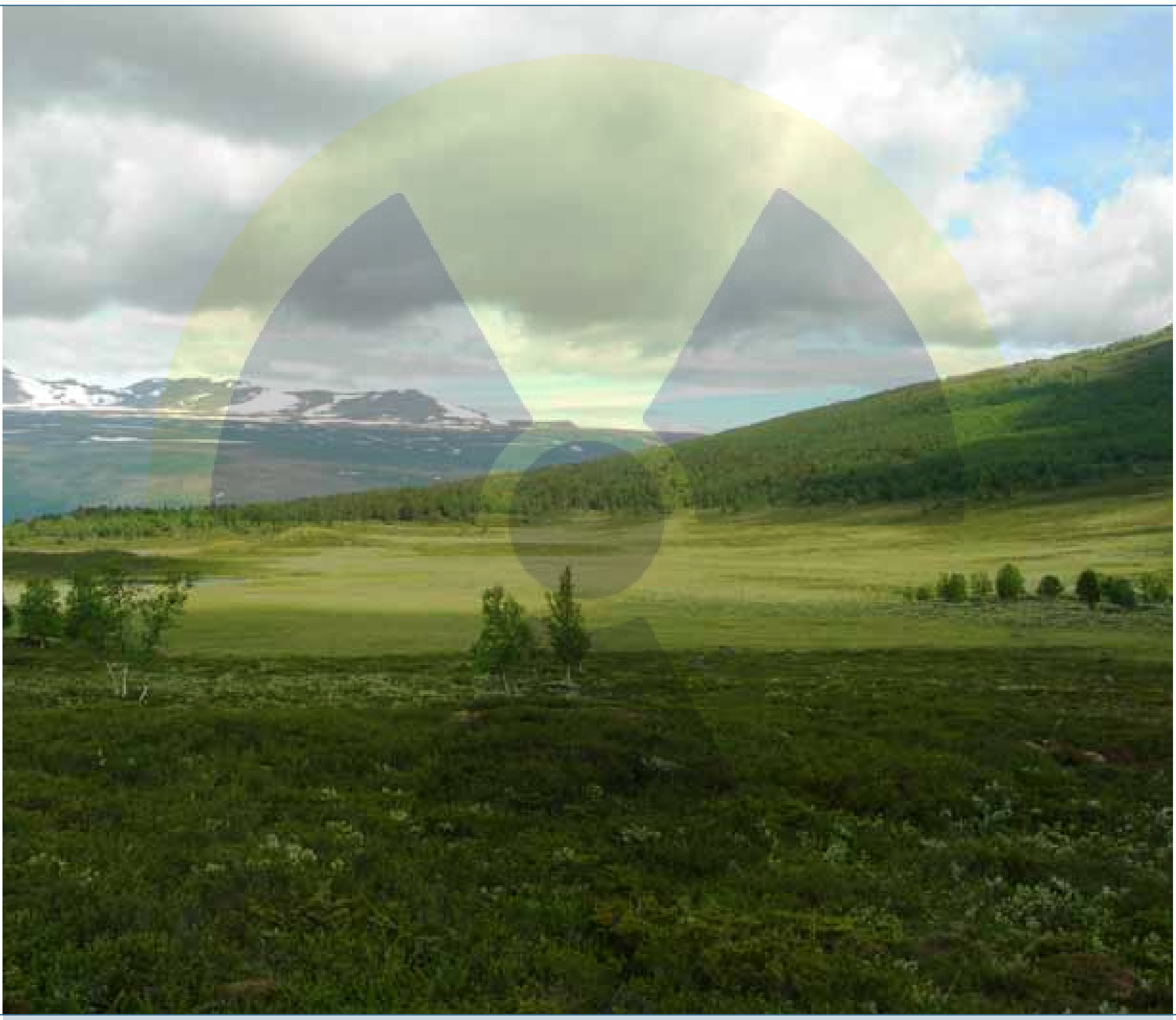

Consequences in Norway after a hypothetical accident at Sellafield

Predicted impacts on the environment

Statens strålevern
Norwegian Radiation Protection Authority

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Key words:
Impact assessment, radioactive fallout, Cs-137 in food chains, Sellafield

Abstract:
This report deals with the environmental consequences in Norway after a hypothetical accident at Sellafield. The investigation is limited to the terrestrial environment, and focus on animals grazing natural pastures, plus wild berries and fungi. Only ^{137}Cs is considered. The predicted consequences are severe – in particular for mutton and goat milk production.

Referanse:
Thørring H, Ytre-Eide MA, Liland A. Konsekvenser for Norge av en tenkt ulykke ved Sellafield-anlegget - Følger for det ytre miljø. StrålevernRapport 2010:13. Østerås: Statens strålevern, 2010.
Language: English

Emneord:
Konsekvensvurdering, radioaktivt nedfall, Cs-137 i næringskjeder, Sellafield

Resymé:
Rapporten redegjør for miljøkonsekvenser i Norge etter en tenkt ulykke ved Sellafield-anlegget. Utredningen er avgrenset til terrestrisk miljø, og vektlegger produkter fra dyr på naturbeite, samt ville bær og sopp. Det tas kun hensyn til ^{137}Cs. De estimerte konsekvensene er store – særlig for sauehold og geitemelksproduksjon.

Head of project: Ingar Amundsen

Approved:

Per Strand

Per Strand, director, Department for Emergency Preparedness and Environmental Radioactivity

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Consequences in Norway after a hypothetical accident at Sellafield

Predicted impacts on the environment

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Statens strålevern

Norwegian Radiation
Protection Authority
Østerås, 2010

Contents

Abstract

This report describes the possible environmental consequences for Norway due to a hypothetical accident at the Sellafield complex in the UK. The scenario considered involves an explosion and fire at the B215 facility resulting in a 1 % release of the total HAL[1] inventory of radioactive waste with a subsequent air transport and deposition in Norway. Air transport modelling is based on real meteorological data from October 2008 with wind direction towards Norway and heavy precipitation. This weather is considered to be quite representative as typical seasonal weather. Based on this weather scenario, the estimated fallout in Norway will be ~17 PBq of caesium-137 which is 7 times higher than the fallout from the Chernobyl accident.

The modelled radioactive contamination is linked with data on transfer to the food chain and statistics on production and hunting to assess the consequences for foodstuffs. The investigation has been limited to the terrestrial environment, focussing on wild berries, fungi, and animals grazing unimproved pastures (i.e. various types of game, reindeer, sheep and goats).

The predicted consequences are severe – especially in connection to sheep and goat production. Up to 80 % of the lambs in Norway could be exceeding the food intervention levels for radiocaesium the first years after the fallout, with 30-40 % likely to be above for many years. There will, consequently, be a need for extensive countermeasures in large areas for years or even decades involving several hundred thousand animals each year. Large consequences are also expected for reindeer husbandry – the first year in particular due to the time of fallout which is just prior to winter slaughter. The consequences will be most sever for reindeer herding in middle and southern parts of Norway, but problems may reach as far north as Finnmark where we find the majority of Norwegian reindeer production.

The consequences for game will mostly depend on the regional distribution of species. For instance, the density of moose is very low in the most contaminated western parts of Norway, whereas a considerable fraction of red deer is found in these areas. Consumption restrictions will probably be needed for moose, red deer and roe deer in many areas.

As part of the report “Nasjonalt risikobilde” (national threat assessment), the described Sellafield scenario is used to exemplify a nuclear threat scenario for Norway. It will look at wider consequences of such an accident, such as the impact on health, economy and society. The Norwegian Directorate for Civil Protection and Emergency Planning (DSB) is leading the work on the national threat assessment and the report is due in 2011.

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[1] HAL (Highly Active liquor) is highly radioactive liquid waste from reprocessing of spent nuclear fuel

Sammendrag

I denne rapporten har vi estimert miljøkonsekvensene i Norge av en hypotetisk ulykke ved Sellafield-anlegget i Storbritannia. Utgangspunktet for studien er et scenario der en eksplosjon og brann ved B215-enheten fører til at 1 % av det radioaktive avfallet i HAL-tankene[2] slippes ut og transporteres med luftstrømmene. Modellering av luftspredning tar utgangspunkt i et reelt vær fra oktober 2008, med vindretning direkte mot Norge og nedbør over store deler av landet. Dette været er vurdert til å være relativt typisk for årstiden. Med utgangspunkt i dette værscenariet er nedfallet av cesium-137 i Norge estimert til om lag 17 PBq – dvs. ca 7 ganger mer enn nedfallet fra Tsjernobyl-ulykken. Store deler av landet vil rammes av radioaktiv forurensning, og Vestlandet og Sørlandet blir sterkest berørt.

Den simulerte forurensningen kobles med data for overføring i næringskjeden og produksjons- og jaktstatistikk for utvalgte matvarer, slik at konsekvensene for matproduksjon kan estimeres. Studien er avgrenset til terrestrisk miljø, med vekt på ville bær, sopp og dyr på naturbeite: elg, hjort, rådyr, reinsdyr, sau og geit.

De estimerte konsekvensene er store – særlig i samband med sauehold og geitehold. Opptil 80 % av alt lammekjøtt kan komme til å overstige omsetningsgrensen for radioaktivt cesium i matvarer de første årene, mens 30–40 % trolig vil være over grenseverdien i lengre tid. Det vil følgelig bli nødvendig med omfattende mottiltak i mange år som inkluderer flere hundre tusen dyr i året, med de konsekvenser av praktisk og økonomisk art dette vil medføre. Reindriftsnæringa vil være spesielt utsatt det første året, fordi nedfallet kommer i slutten av oktober, som er rett før vinterslaktinga. Konsekvensene blir mest alvorlige for reindrift i Midt- og Sør-Norge, men problemene kan komme til å strekke seg helt nord til Finnmark der hoveddelen av norsk reinproduksjon ligger. Konsekvensene for hjortevilt vil være svært avhengig av geografisk forekomst av ulike arter. For eksempel er tettheten av elg svært lav på Vestlandet og Sørvestlandet, mens det er mye hjort i disse områdene. Restriksjoner for konsum av både hjort, elg og rådyr må påregnes i flere områder.

En bredere vurdering av konsekvenser for helse, samfunn og økonomi vil bli beskrevet i rapporten ”Nasjonalt risikobilde” der det beskrevne scenariet for Sellafield er valgt ut som atomscenario. Arbeidet med å utrede nasjonalt risikobilde ledes av Direktoratet for samfunnssikkerhet og beredskap, og rapporten er forventet publisert i 2011.

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[2] HAL (Highly Active Liquor) er høyaktivt flytende avfall fra reprosessering av brukt kjernebrensel

1 Background and focus of the report

The Norwegian Radiation Protection Authority (NRPA) has been given an assignment by the Norwegian Ministry of the Environment to perform an impact assessment of a hypothetical accident at the B215 facility for storing Highly Active Liquors (HAL) at Sellafield, UK. Currently, building B215 contains about 1000 m^3 HAL divided into 21 specially designed tanks – Highly Active Storage Tanks (HAST) [1, 2].

The scenario used involves an atmospheric release of between 0.1 – 10 % of the total assumed inventory contained in the B215 HASTs. The specific reason for the release and the course of events immediately prior to/during the release are not speculated upon. It is assumed that the release is due to a combination of an explosion and fire at the facility with a subsequent release of radionuclides to the atmosphere. The HASTs inventory includes many different fission products of which caesium-137 and strontium-90 would be of most concern. For simplicity, only the release of caesium-137 is considered in this impact assessment. Prevalent meteorological conditions coupled with Norway's geographical position make the country vulnerable in the event of an uncontrolled release due to an accident at Sellafield; especially a large atmospheric release is expected to give serious consequences in Norway. The Norwegian Meteorological Institute (met.no) has simulated the ^{137}Cs transport from Sellafield and resultant fallout in Norway using their SNAP model [3, 4]. The meteorological data used for simulations were collected from late October observations (2008), with wind direction towards Norway and heavy precipitation. This weather is considered by met.no as being quite representative of the typical seasonal weather. Model simulations were completed for ^{137}Cs releases present as both aerosols and as a component part incorporated in radioactive particles of different size classes. The results show that even large particles (radius up to 9 µm) reach Norway. More information about potential release, transport and fallout can be found in [5].

In the following we have selected one of the source terms described in [5], namely the release of 1 % of the total HAL with assumed particle size of 2.2 µm. The total released activity of caesium-137 from that scenario is 94 PBq[3], which is roughly the same as the amount released in connection with the Chernobyl accident (85 PBq). 17 PBq of the released caesium-137 activity is deposited in Norway, and the predicted regional deposition density is shown in Figure 1. For comparison, the total deposition in Norway from the Chernobyl accident was 2.3 PBq [6].

Sellafield. (Photo: Sellafield Ltd.)

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[3] 1 PBq equals 1 000 000 000 000 000 Bq

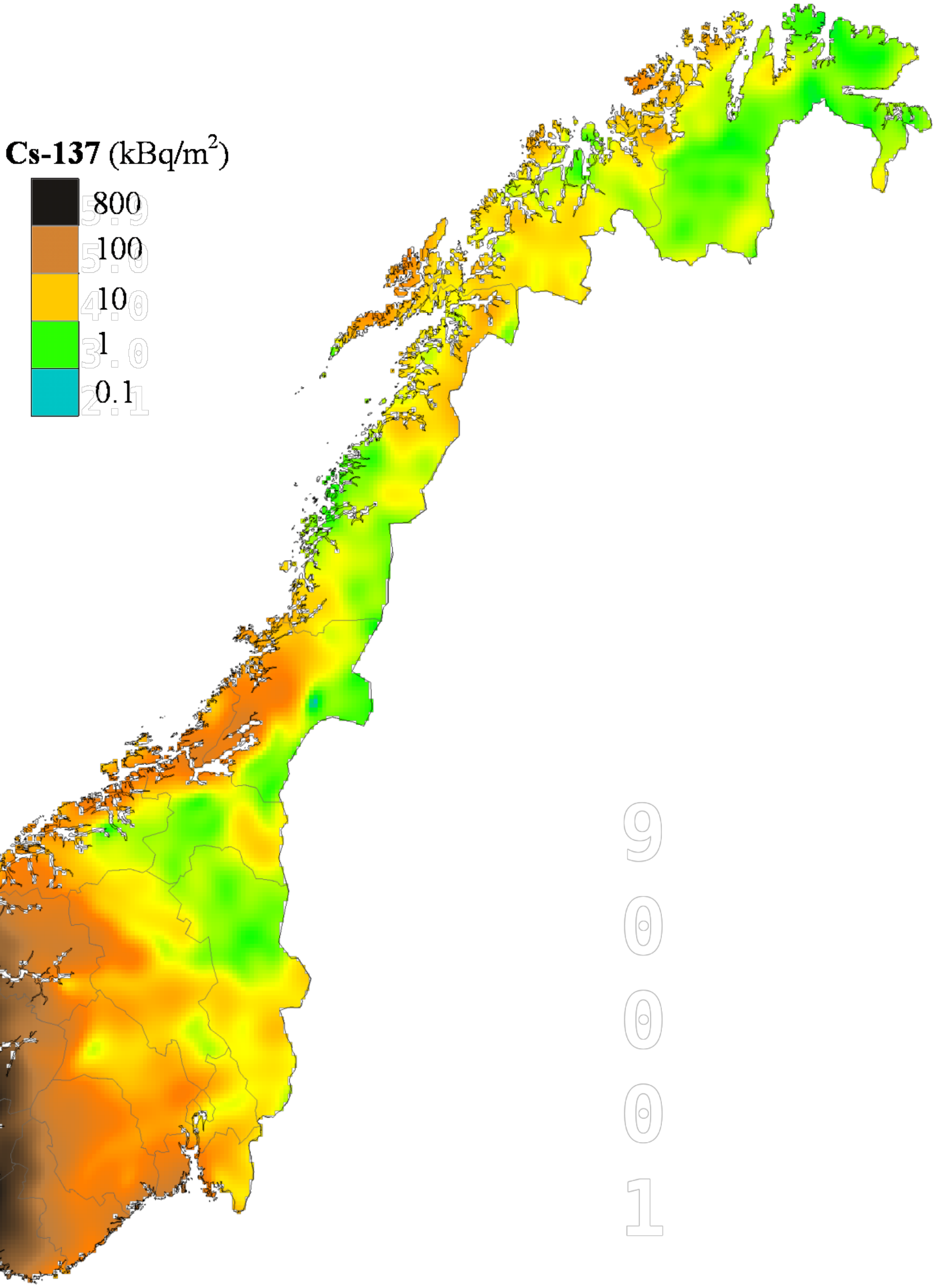

Figure 1: Deposition map for a predicted 1 % release of the highly active liquor waste inventory due to an explosion and fire in B215 at Sellafield, UK.

Radioactive fallout of this magnitude over Norway will give a wide range of consequences in the early phase that would need to be dealt with, e.g. health advice to people in high fallout areas, possible cleaning of urban areas, food and drinking water temporary restrictions and large measurement campaigns to establish clean and contaminated zones. Since the agricultural season is over in late October, no direct consequences are foreseen for normal agricultural produce on farmed land. However, the time coincides partly with the hunting season for certain game species and a temporary hunting restriction might be imposed. It will also coincide with the slaughter period for semi-domesticated reindeer in many areas.

The present report will look at the environmental[4] consequences of the hypothetical fallout in Norway, focussing on the long term perspective and the terrestrial environment (i.e. freshwater and marine ecosystems have been excluded). Based on experience from the Chernobyl accident, attention will be paid to animals grazing unimproved pasture and woodland, since the transfer of radioactive caesium is higher in such environments compared to cultivated areas when considering long-term consequences of radioactive fallout (see e.g. [7]). In Norway, sheep and goats – and to lesser extent milking cows[5] – graze natural pastures during summer. Our focus will be on these types of animals, plus reindeer and various type of game (i.e. moose, red deer and roe deer). Wild berries and fungi will also be included due to their importance in connection with human consumption and the particularly high uptake in certain species of fungi.

A wider consideration of consequences is performed under the work of the Directorate for Civil Protection and Emergency Planning (DSB) who have been assigned the task of producing a national threat assessment report where the Sellafield scenario described here will exemplify a nuclear threat scenario. The threat assessment report will be published in 2011.

2 Introduction

Caesium (Cs) is an alkali metal, resembling the biologically essential element potassium (K) in many respects. The element is therefore easily taken up by all living species as an analogue to potassium. The radioactive isotope caesium-137 considered in this impact assessment is rather long-lived with a physical half-life of 30.17 years.

2.1 Uptake of caesium-137 in vegetation

In the early phase (i.e. weeks, months) after an accident radioactive substances directly deposited on vegetation surfaces may dominate plant contamination. However, most of this contamination is removed quite rapidly by factors such as wind, rain and litter fall [8]. Lichens make one important exception here and can retain deposited radioactive caesium for years due to slow growth and long persistence of lichen tissues [9]. In the mid to long term phase (i.e. years to decades) most of the deposited caesium will have reached the soil, and uptake is largely governed by the physical and chemical properties of the soil (e.g. organic matter content, pH, type and percentage of clay minerals, competing ions such as K), and vegetation specific features such as root depth and ability to accumulate caesium. The initial physical and chemical form of the fallout (i.e. free ion, particles) will also be of importance.

Various species of lichens. (Photo: NRPA)

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[4] Here interpreted as vegetation, animals and animal products important in connection with human food production. Doses to biota will not be considered in this report

[5] Dairy milk is mainly produced on farms with intensive use of high quality roughage and concentrates, less than 5 % is from uncultivated pastures [34].

In general, highly organic soil with low levels of caesium-fixing clays (e.g. illite), low potassium levels and high concentration of ammonium will tend to have higher transfer to plants than mineral soils rich in clay with high potassium levels. Many natural ecosystems in Norway have soils of such type, whereas mineral soils with appreciable quantities of clay minerals and moderate to low content of organic matter predominate in the majority of agricultural areas.

There may be considerable differences in uptake between various plant species growing in the same area – up to one or even two orders of magnitude (see [10, 11]), and if we include fungi the range will be further enlarged. In general the uptake in vegetation from a specific area increases in the following order:

Trees➔Herbs and grasses➔Fungi[6]

Examples of important caesium-accumulating species are common heather (*Caluna vulgaris*) among plants and "the Gypsy" (*Cortinarius caperatus*) among mushrooms.

Cortinarius caperatus. (Photo: NRPA)

Variations in the physical and chemical properties of the soil may lead to marked regional differences in uptake in the same species of plants. Such differences can also be influenced by time since fallout (see also section 2.3). Recent studies from various Norwegian bilberry birch forest sites have showed that transfer to the same 5 plant species[7] more than 20 years after the Chernobyl accident were in average 7-8 times higher in southernmost Norway compared with the mountainous areas of Vågå in southern central Norway [12]. Regional trends have also been found by Skuterud et al., with considerably higher transfer to plants in central Norway compared with sites in Vågå [13].

2.2 Uptake and excretion of caesium in animals

Due to the chemical similarity to the essential element potassium, radioactive caesium is largely transferred from feed to animal soft tissues (especially muscles) and is also easily distributed to milk. Since caesium is not strongly bound in specific body parts it is removed from the body quite rapidly. There are, however, differences between animals in how long time caesium stays in the body, important factors in this respect being size, metabolism, and gender. It is therefore common to specify biological half-times[8] for various types of animals (see e.g. [11]). Examples being:

- Lamb: 14 days
- Goat milk: 3-4 days
- Reindeer: 10-25 days
- Cattle: 29 days

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[6] Lichens have been excluded here since these species do not take up caesium from the soil, merely through fallout

[7] Birch (*Betula pubescens*), juniper (*Junipherus communis*), bilberry (*Vaccinium myrtillus*), cowberry (*Vaccinium vitis idaea*), and wavy hair grass (*Deschampsia flexuosa*)

[8] The time it takes for half the amount of a particular element (e.g. caesium) to be excreted from an organism

2.3 Factors influencing radioactive caesium levels in free grazing animals

There are many factors influencing radioactive caesium levels in free grazing animals: Obviously, the regional deposition density, together with the uptake in feed plants from a particular grazing area, is of major significance. Then comes the time passed since fallout: Does the plant available fraction of radioactive caesium decrease rapidly with time, or does it remain fairly constant? A considerable fraction of natural surface soils in Norway are highly organic, with limited number of available caesium fixating clay sites. Since caesium does not have a very strong affinity towards humus, a large fraction of the nuclides may consequently be in mobile form in such soils, being available to plants decades after fallout[9]. However, high mobility might cause the caesium to be more rapidly leached out of the root zone (and finally out of the soil profile); on the other hand this effect may again be counteracted by plant uptake – as long as it is high enough.

Free grazing animals can have large home ranges in forest and mountain areas, and thus local variations in deposition, soil to plant transfer, and types of vegetation found at the various sites may have a large impact on the intake of radioactive caesium. Moreover, different animal species grazing in the same areas might – due to their feed preferences – have largely different concentration in their body[10]. For instance, measurements from Norway after the Chernobyl accident showed levels of radiocaesium in moose meat considerably lower than in sheep grazing in the same areas [11]. In addition, there are individual feed preferences within the same species grazing in the same area.

There may also be seasonal variations in feed preferences: The obvious example here is reindeer that eat mainly (highly contaminated) lichens during winter, but changes to (less contaminated) green plants in summer. Another – more broadly important example – is the availability of fungal fruit bodies in the grazing area. As described above, many species of fungi can have a very high uptake of radioactive caesium compared with most green plants. Since most fungal fruit bodies appear in autumn many animals show marked seasonal variations in uptake of radioactive caesium – with higher transfer in autumn than in other parts of the year. There are considerable differences in mushroom abundance between years, so a marked year to year variability is also to be expected.

The time it takes for the activity concentration in plants, animals or similar to be reduced to the half, either due to factors such as immobilisation in soil, transport out of the ecosystem, or radioactive decay, is given by the effective ecological half-time t1/2(eff.ecol.):

$$t_{1/2}(\text{eff. ecol.}) = \frac{t_{1/2}(\text{phys.}) \times t_{1/2}(\text{ecol.})}{t_{1/2}(\text{phys.}) + t_{1/2}(\text{ecol.})}$$

Where,

$t_{1/2}$(phys.): physical half-life of radionuclide

$t_{1/2}$(ecol.): ecological half-time of element

The ecological half-time is ecosystem specific, and varies with the type of natural product considered. Generally, contamination levels of radioactive caesium in many plants, mushrooms and free grazing animals in Norway show a long duration (see Table 1).

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[9] For the previously mentioned sites in Southernmost Norway about 30-40 % of the ^{137}Cs was in a mobile form more than 20 years after fallout, whereas the same for the Vågå sites were 1–8 %.

[10] For example cattle and sheep eat mainly grass, whereas goats prefer leaves, bark and shoots from trees and bushes

Table 1: Effective ecological half-times for caesium-137 in vegetation, animals and foodstuffs in Norway [17]

Animal/food stuff	Time period	Season	Ecological half-time (years)	Remarks
Lamb	1989-2004		11.1±3.1	In Valdres, Oppland County
Cow milk	1989-2004		4.0±0.6 to 12.1±1.8	Region dependent
Goat milk	1989-2004		6.7±0.5 to 11±1.1	Region dependent
Reindeer	1986-1995	Autumn	4.5±0.4	
Reindeer	1995-2007	Autumn	No decline	Same as physical half-life
Reindeer	1986-1995	Winter	4.0±0.1	
Reindeer	1995-2007	Winter	6.6±1.5	

2.4 Contamination management: Intervention levels and countermeasures

Intervention levels state when dose limiting countermeasures have to be activated. The current limits for radioactive caesium in foodstuffs for sale in Norway are:

• Reindeer and game meat:	3000 Bq/kg
• Freshwater fish:	3000 Bq/kg
• Milk and infant food:	370 Bq/kg
• Basic foodstuffs:	600 Bq/kg

An additional limit of 50 Bq/l has been specified by the industry for milk used in brown (whey) cheese production.

Large contaminated areas within a country, and predictions of a decade or more of necessary management, would represent a huge challenge to any country. There is a range of possible countermeasures that could be implemented after a nuclear or radiological accident leading to fallout. A good summary is given in the EURANOS handbooks for contamination management that can be downloaded from:

http://www.euranos.fzk.de

For our purpose three broad groups of countermeasures may be specified:

- Food bans and dietary advice
- Additives given to animals to reduce gut uptake of radioactive caesium (e.g. Prussian blue supplement through concentrates, boli, or salt licks)
- Animal management (e.g. clean feeding, changing slaughter time)

Many of these countermeasures have been successfully used post-Chernobyl in Norway.

Prussian blue boli for sheep. (Photo: NRPA)

3 Modelling approach

In order to evaluate consequences of deposited radioactive caesium (and other radioactive substances) in natural systems a Geographical Information System based model called "STRATOS" has been developed. This easily upgradeable model incorporates information regarding deposition, transfer to vegetation and animals, intervention levels and geographical distribution of animals (see Appendix 1 for a model overview).

3.1 Transfer to vegetation and animals

Detailed information on soil parameters are usually not known for natural ecosystems, and especially information regarding clay content (and type) is not generally available for natural soils in Norway. Moreover, the large diversity of plants species and varying abundance of mushrooms in the grazing area makes it difficult to specify animal diet. Therefore, so called aggregated transfer factors (T_{ag}) are used to model transfer of radioactive caesium to various animals.

The aggregated transfer factor is defined as the ratio between the activity concentration (C) in a given animal or plant (Bq/kg fresh weight) and the total deposition density (D) in the grazing area (Bq/m^2). Concentration of caesium-137 in animals or vegetation can thus be derived from deposition data using the following equation:

$$C = D \times T_{ag}$$

In some ecosystems the T_{ag} value varies with time due to e.g. fixation in soil, whereas in others the time since deposition does not have a large impact on levels in vegetation and animals (disregarding physical half-life).

To cope with regional and temporal variability we use three T_{ag}s representing a most likely (expected) value combined with reasonable minimums and maximums based on existing data from post-Chernobyl studies in Norway and other (Nordic) areas, together with more generic data from the IAEA [14, 15, 16]. No attempt is currently made to derive region specific T_{ag}s or to directly include effective ecological half-lives in the model, since the available data in most cases are too scarce. A summary of the transfer data currently used in the model is shown in Table 2; background details regarding derivation of T_{ag}s for each product are given in appendix 2.

In years were mushrooms are particularly abundant in the natural pasture the transfer might be 2-4 times higher than the "expected".

Table 2: Summary information regarding transfer factors (m^2/kg) used in modelling for various food stuffs. All products in fresh weight.

Product	Harvest period	Transfer factor			Details
		Expected	min	max	
Wild berries	Jul-Sep	0.007	0.0003	0.04	Appendix 2.1
Mushrooms	Jul-Oct	0.02	0.0005	0.2	Appendix 2.2
Moose	Sep-Nov	0.02	0.005	0.2	Appendix 2.3
Red deer	Sep-Nov	0.02	0.005	0.2	Appendix 2.4
Roe deer	Oct-Des	0.05	0.005	0.2	Appendix 2.5
Reindeer	Late Oct-Mar	0.25	0.05	1.5	Appendix 2.6
Reindeer	Sep-early Oct	0.15	0.05	0.5	Appendix 2.6
Lamb	Oct-Des	0.04	0.01	0.2	Appendix 2.7
Goat milk	Jun-Sep	0.007	0.001	0.02	Appendix 2.8

3.2 Contamination maps

The STRATOS model is used to generate geographical information. For our purpose exact activity concentrations in products, as such, are not of direct interest. More important is whether a natural product in a specific region is likely to be considered "clean" or not. That is, being below or above the specified intervention level as defined in section 2.4. Consequently, the information in the contamination maps only deals with areas above or below the intervention level for a given T_{ag}. Colour coding is used to specify the affected areas as defined by the three T_{ag}s used per product: Clean areas (i.e. below the intervention level) using max transfer will be shown in green, whereas khaki areas are above the intervention level using max transfer. Furthermore, orange areas are above the intervention level using the expected transfer, while red colour denotes areas above the intervention level assuming the minimum transfer (i.e. sure to be above the intervention level no matter what).

An example of geographical representation is shown in Figure 2. It is important to note that as a logical consequence of the definition of the areas (by using different T_{ag}s), the khaki areas will include both the orange and red areas, whereas the orange areas will include the red areas.

How to actually interpret the coloured areas specified by the transfer factors will differ between products (see blue boxes in appendices 2.1-2.8). Yet, some general comments can be made. The max transfer factor can typically be representative of the first period after an accident or for particularly vulnerable areas[11]. If products do not exceed the intervention level using such a high transfer value, it is likely that the area will be "clean" (i.e. no need for countermeasures). Therefore the max T_{ag} may also be viewed as a screening value for areas where countermeasures may be necessary in some period after the hypothetical accident and areas where this it not very likely to be the case. The expected transfer factor is the most likely transfer based on the existing amount of data from a mid to long term perspective (years to decades), taking into consideration the hunting season for wild animals, slaughter time for domestic or semi-domesticated animals, and grazing period for milk production. The min transfer might be interpreted as being representative of areas of very low sensitivity to radioactive caesium and/or for the situation decades after an accident. Consequently, the red areas are very likely to exceed the intervention level in any case after the hypothetical accident.

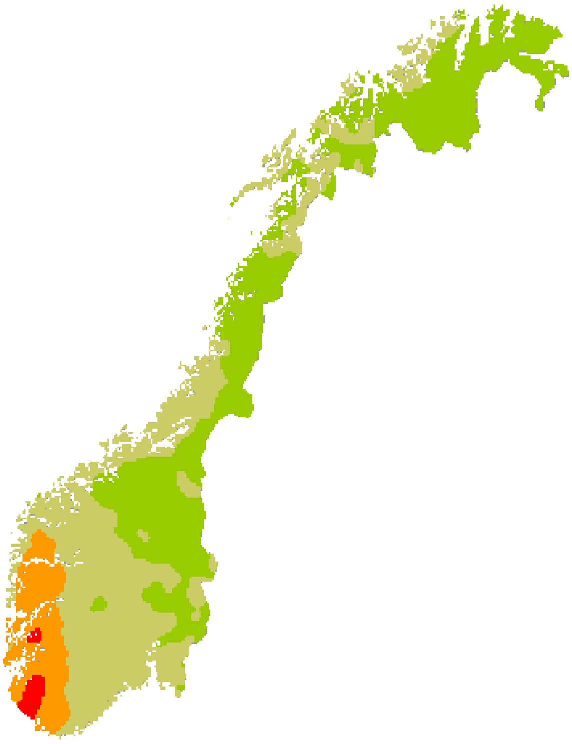

Figure 2: Example: Areas above intervention levels for expected transfer (orange), minimum transfer (red) and maximum transfer (khaki). Green areas are likely to be clean in all phases after the hypothetical accident.

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[11] For vegetation groups such as mushrooms it may also represent a high accumulating species

3.3 Regional distribution of animals

One important matter yet to be considered is the geographical distribution of an animal of interest. Are they found in the areas with the highest deposition or is most of the production/ distribution outside the contaminated areas? For this purpose it is necessary to consider GIS data regarding regional distribution of domestic and wild animals. An example for moose is shown in Figure 3, whereas details regarding geographical distribution of various species of animals are given in appendix 2.3-2.8.

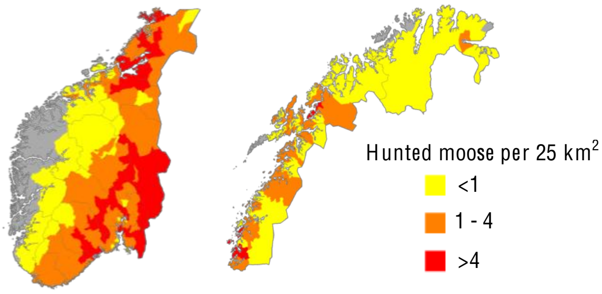


Figure 3: Distribution of hunted moose. Grey denotes areas with no animals present or no hunting taking place.

The number of animals in each 5 x 5 km pixel have been generated from slaughter or hunting statistics from a specified area (which might be a grazing area, a municipality or something similar, depending on the available geographical information). We have made an assumption, that the relevant animals are uniformly distributed within this specified area (A), which indeed is not true – but as long as the area is small enough this will be a satisfactory approximation for our purpose. Details regarding basic data used for various animals are given in Table 3.

3.4 Estimation of affected animals

The number of affected animal in a particular region (N_i) or in Norway as a whole (N), can be generated using the following equation:

$$N = \sum_i N_i = \sum_i^n \left(\frac{I_i}{A_i}\right) n_i$$

Where,
I_i: number of 5 x 5 km pixels above the intervention level in area i
A_i: total number of 5 x 5 km pixels in area i
n_i: total number of animals in area i

A simplified example showing how the calculation is done is given in Appendix 1.

Table 3: Summary of regional data

Animal type	Type of regional data	Period	Area (A)	More info
Moose	Hunting statistics	2006-09	Municipality	See Appendix 2.3
Red deer	Hunting statistics	2006-09	Municipality	See Appendix 2.4
Roe deer	Hunting statistics	2009	Municipality	See Appendix 2.5
Semi-domesticated reindeer	Slaughter numbers	2007-10	Herding district	See Appendix 2.6
Wild reindeer	Hunting statistics	2008	Grazing area	See Appendix 2.6
Lamb	Distributions	2008	Grazing area	See Appendix 2.7
Goats	Milk production	2009	Municipality	See Appendix 2.8

4 Results and discussion

Based upon the maximum transfer factors, all natural products from areas with a deposition <2 kBq/m^2 should be below the intervention level. Above this overall screening deposition the most sensitive animals/products are reindeer, goat cheese, high accumulating mushrooms and lamb, whereas wild berries, game and goat milk are less sensitive. For the latter no countermeasures should be necessary in any period after the hypothetical accident as long as the deposition is below 15-20 kBq/m^2. Still, one cannot completely rule out the possibility of need for countermeasures in areas below the screening level e.g. in years with high abundance of mushrooms.

4.1 Caesium-137 in vegetation

Cowberries (Vaccinum vitis-idaea) (photo: NRPA)

4.1.1 Wild berries

As evident from Figure 4, berries from most parts of Norway are within the green zone after the hypothetical deposition, and are therefore not likely to be subject to gathering restrictions. There are, however, areas where berries are at risk of being above the intervention level – especially in the western and south-western part of the country. Based on transfer data given in appendix 2.1, bilberries and cloudberries are likely to have higher concentration of radioactive caesium than cowberries and raspberries. No areas were above the intervention level of 600 Bq/kg using the minimum transfer factor, thus no red areas are shown in Figure 4a.

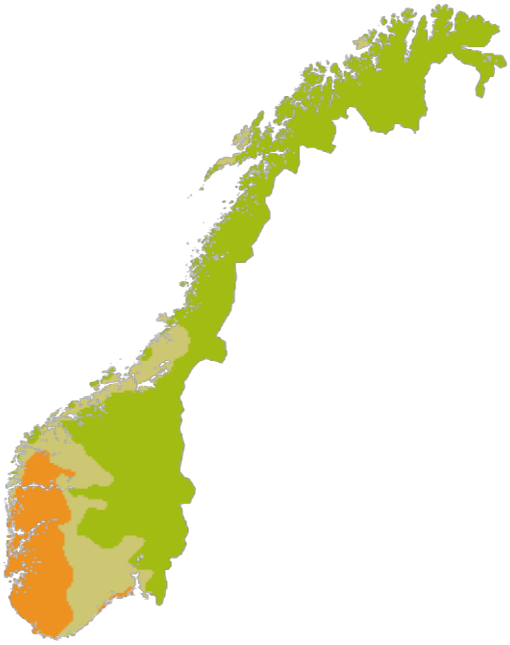


Figure 4: Predictions for wild berries. Areas above intervention levels for expected (orange) and max (khaki) transfer. Green areas are likely to be clean in all phases after the hypothetical accident.

4.1.2 Mushrooms

As dealt with in appendix 2.2, the coloured areas in Figure 5 can be attributed to type of mushroom. Consequently, high accumulator fungi such as *Cortinarius caperatus* probably will be above the intervention level for most parts of Norway (as represented by the orange and khaki area in Figure 5), whereas more popular species such as *Cantharellus cibarius* and *Boletus edulis* are likely to be above in Southern and Western parts of the country (i.e. orange areas). Low accumulators (e.g. *Coprinus comatus*) should be below intervention level of 600 Bq/kg – even in the most contaminated areas. Consequently, there are no red areas in Figure 5.

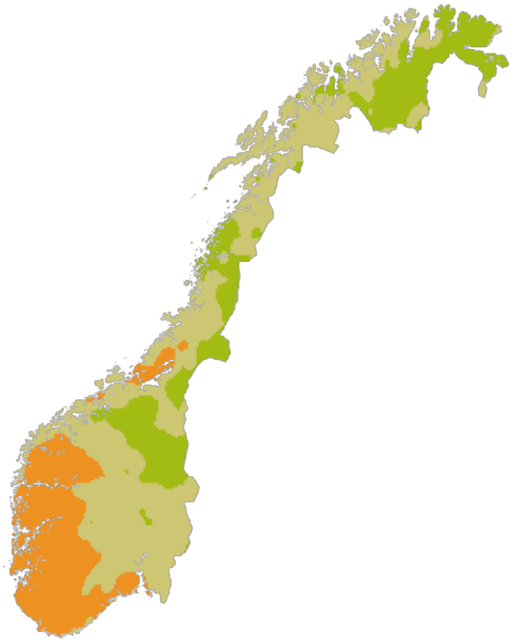


Figure 5: Predictions for mushrooms. Areas above intervention levels for expected (orange) and max (khaki) transfer. Green areas are likely to be clean in all phases after the hypothetical accident.

4.2 Caesium-137 in animals and animal products

Contamination maps for game, reindeer and domestic animals are shown in Figures 6-8. Based on these data and regional distribution data given in appendices 2.3-2.7 the number of affected animals (per year) has been calculated for minimum, expected and maximum transfer. Results are shown in Table 4.

From Table 4, the predicted overall trend is that the most affected animals/products – given our deposition scenario – are lamb and products from goats, whereas moose and semi-domesticated reindeer will be less affected (as long as the long term perspective is considered for reindeer). Among game, red deer and wild reindeer are most affected. In the following, results for each category of animals will be discussed in more detail.

Table 4: Animals affected per year

Type	Number of animals affected Expected (min-max)	Total animals	% of total Expected (min-max)
Lamb*	380 000 (250 000-720 000)	890 000	43 (28-81)
Goats (whey cheese production)	22 000 (9 500-33 000)	35 000	62 (27-92)
Red deer	11 000 (430-26 000)	33 000	32 (1-78)
Goats (milk production)	9 300 (1 900-15 000)	35 000	26 (5-42)
Wild reindeer	1 100 (660-2 000)	5 200	21 (13-38)
Roe deer	6 100 (700-13 000)	30 000	20 (2-43)
Semi-domesticated reindeer**	4 100 (140-43 000)	73 000	6 (<1-58)
Moose	1 200 (<100-11 000)	36 000	3 (<1-30)

*Numbers refer to registered lamb (ca 80 % of the total). Real slaughter numbers will be higher (see App. 2.7)

**Based on current practice in all herding districts concerning autumn or winter slaughter

4.2.1 Game

Given the hypothetical deposition scenario there will be likely restrictions on hunting in the western and south-western parts of Norway. In limited areas in Rogaland and Hordaland counties the levels in game are estimated to be above the intervention level of 3000 Bq/kg assuming minimum transfer (red areas in Figure 6).

The density of moose, however, is very low in the most contaminated (red and orange) areas, and the major fraction of moose is – as evident from the distribution map in Appendix 2.3 – hunted in the clean (green) areas. In contrast, red deer is mainly found in the Western part of Norway, which explains the much higher number of affected red deer compared with moose as given in Table 4. Roe deer are not present in parts of the most contaminated areas, but are nevertheless quite common in the South-West, and the number of affected animals is consequently higher than for moose.

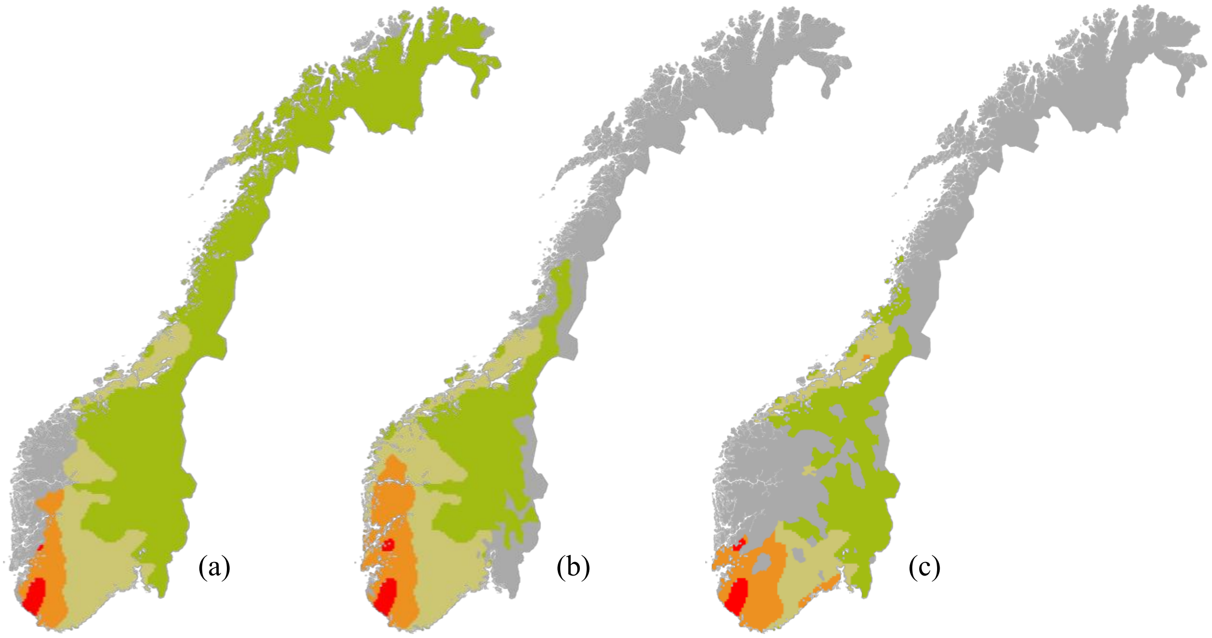


Figure 6: Predictions for game: (a) Moose, (b) Red deer, (c) Roe deer. Areas above intervention levels for expected (orange), min (red) and max (khaki) transfer. Green areas are likely to be clean in all phases after the hypothetical accident. No hunting data for grey regions – either due to no animals present or lack of hunting data for the period considered.

4.2.2 Reindeer

Since the hypothetical fallout occurs in late October, winter slaughtered reindeer from most herding districts in Norway are likely to be above the intervention level of 3000 Bq/kg the first year after the accident (cf. khaki areas in Figure 7a). In subsequent years it will be possible to limit the consequences by employing autumn slaughter as a countermeasure. This countermeasure has shown good effect when managing the Chernobyl consequences in Norway. As evident from Figures 7a and 7b, long-term consequences for semi-domesticated reindeer production will presumably be limited to herding districts in the western part of Trøndelag and Oppland counties, plus smaller areas in Northernmost Norway.

Due to the more south-westerly distribution of wild reindeer, a larger percentage of these animals are likely to be affected by the fallout than is the case for the semi-domesticated variant, even though the total number of affected animals will be lower (as shown in Table 4). The large red areas shown in Figure 7c indicate that for a considerable fraction of the animals (i.e. 13 %) the consequences will be long-lasting, with likely use of hunting restrictions. Since hunting is performed in September the effect of lichens on animal activity level is not that pronounced, but higher vulnerability is expected in years with high abundance of mushrooms in the grazing areas. This is of course also the case for autumn slaughtered semi-domesticated reindeer.

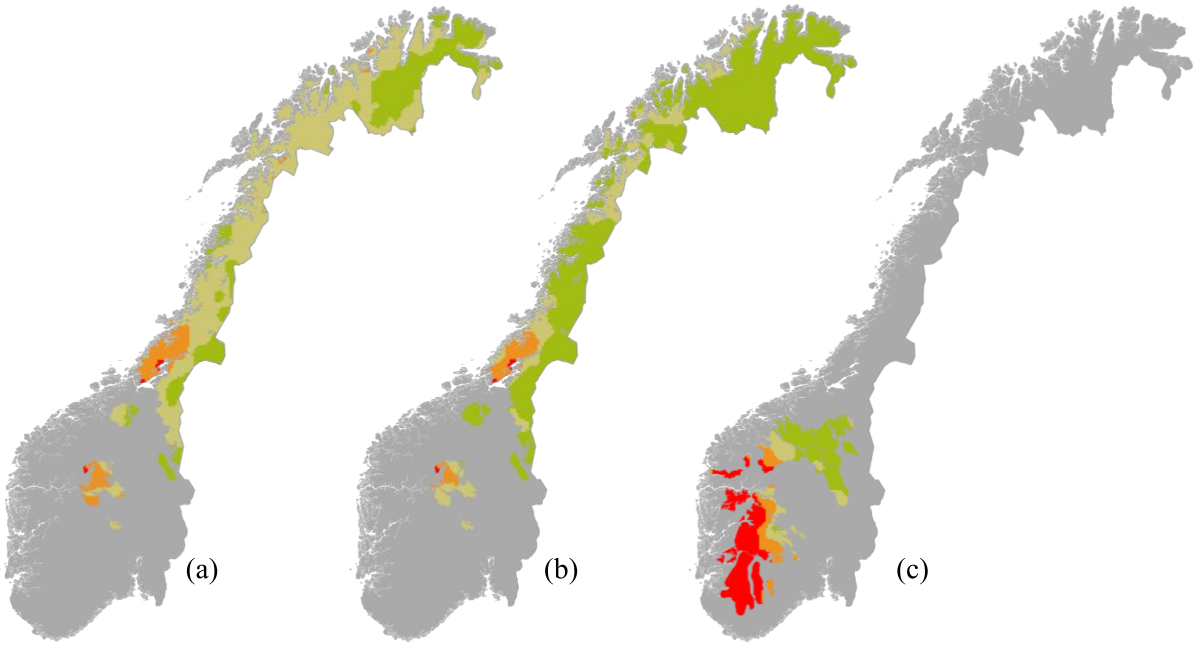


Figure 7: Predictions for reindeer: (a) Semi-domesticated, winter; (b) Semi-domesticated, autumn; (c) Wild, autumn. Areas above intervention levels for expected (orange), min (red) and max (khaki) transfer. Green areas are likely to be clean in all phases after the hypothetical accident. No slaughter/hunting data for grey regions.

4.2.3 Domestic animals

As stated above, our modelling results predict that the most serious consequences of the hypothetical fallout will be in connection with domestic production. Even using the minimum transfer a considerable fraction of lamb in Norway will be above the intervention level of 600 Bq/kg (i.e. 28 %) as shown in Figure 8a. There will, consequently, be a need for extensive countermeasures in large areas for years or even decades to come (see chapter 4.3). For production of the traditional Norwegian brown whey cheese the consequences might even be worse (at least from a percentage perspective) – with likely need for countermeasures as far north as Troms County (see Figure 8c). Goat milk, however, might be clean in most areas from Oppland to Troms County (Figure 8b).

Milk from free grazing cows is not directly considered in this impact assessment. It may, however, be assumed that cow milk from the red or orange areas for goat milk are likely to be above the intervention level of 370 Bq/l. This is a conservative assumption since transfer to cow milk is generally 3-5 times lower than to goat milk from the same grazing area. As stated earlier, 95 % of all cows in Norway graze on home fields, which are considerable less vulnerable to radioactive caesium contamination (due to common practices such as ploughing and fertilising).

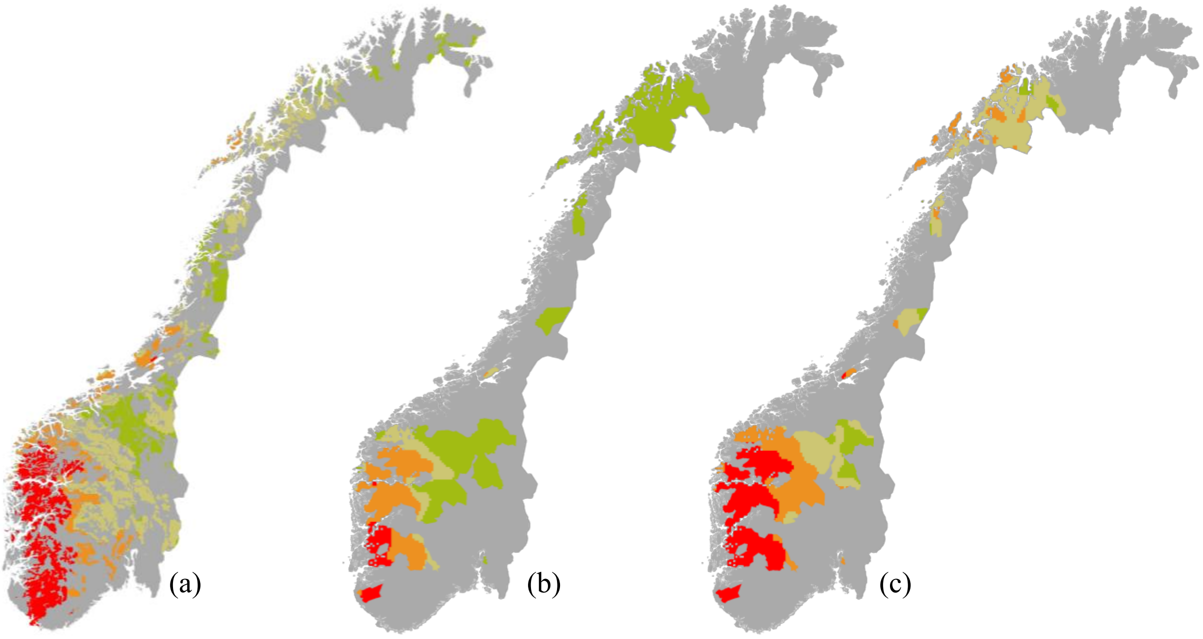
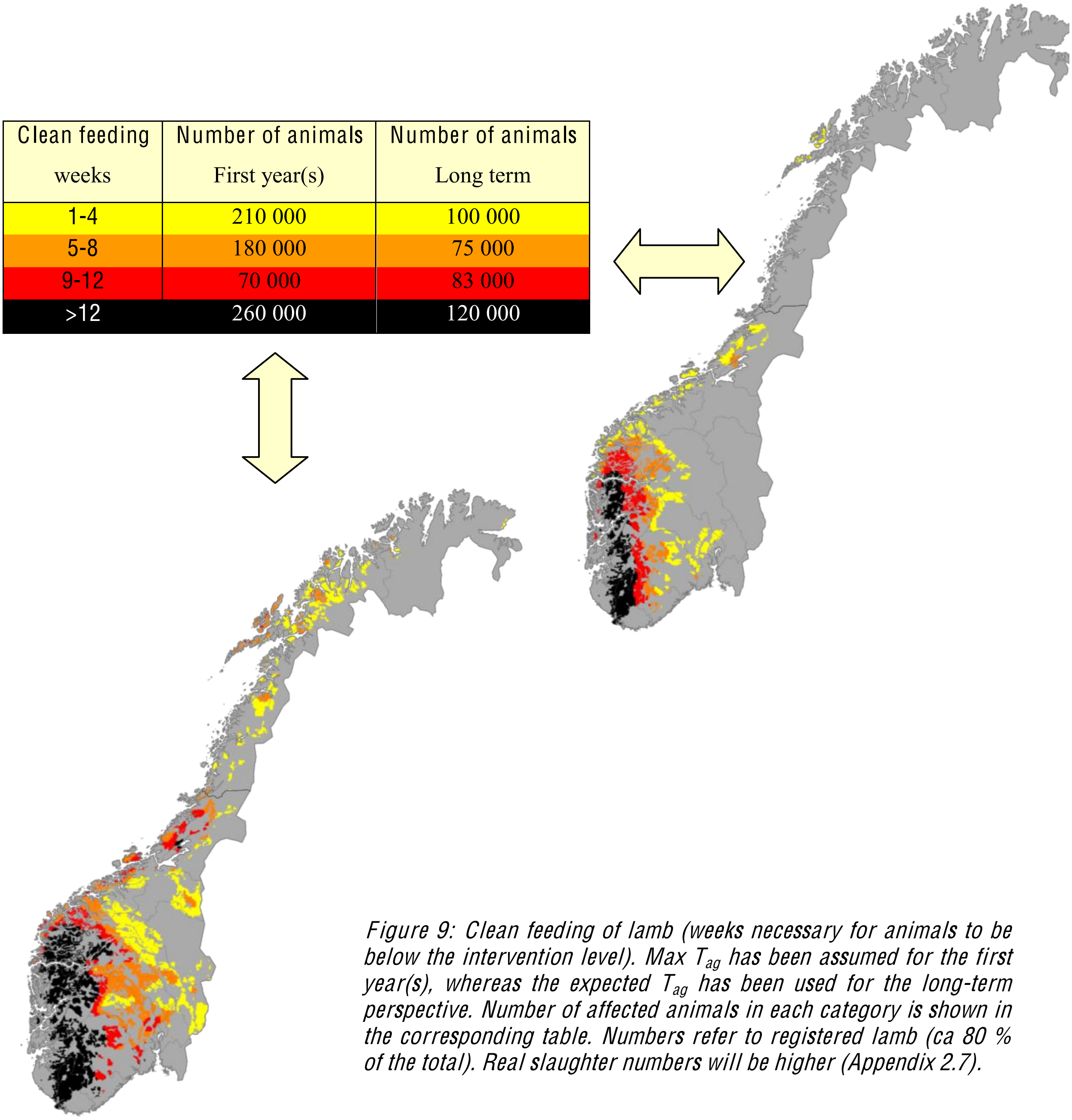


Figure 8: Predictions for (a) lamb meat, (b) goat milk and (c) whey cheese from goat. Areas above intervention levels for expected (orange), min (red) and max (khaki) transfer. Green areas are likely to be clean in all phases after the hypothetical accident. No sheep or goats in grey regions.

4.3 Clean feeding of sheep – a case study

As a result of the extensive consequences predicted for sheep production, it has been decided to investigate the potential need for countermeasures after the hypothetical fallout. Clean feeding of lamb/sheep is still, more than 20 years after the Chernobyl accident, a highly relevant countermeasure, and approximately 50 000 animals were treated for up to several weeks in 2009. The corresponding numbers for the early years after the accident in 1986 were around 300 000 per year (see miljostatus.no).

Figure 9 shows the number of weeks of clean feed necessary for lamb to be below the intervention level in different regions after the hypothetical fallout from Sellafield. A conservative biological half-time of 3 weeks – also used in Norway for management of the Chernobyl consequences – was assumed for the study. The max transfer (0.2) was assumed to represent the first year(s), whereas the expected transfer (0.04) was applied for long-term predictions (see appendix 2.7). The corresponding numbers of affected animals in each of 4 clean feeding categories after predicted contamination level are also shown.



Clean feeding weeks	Number of animals First year(s)	Number of animals Long term
1-4	210 000	100 000
5-8	180 000	75 000
9-12	70 000	83 000
>12	260 000	120 000

Figure 9: Clean feeding of lamb (weeks necessary for animals to be below the intervention level). Max T_{ag} has been assumed for the first year(s), whereas the expected T_{ag} has been used for the long-term perspective. Number of affected animals in each category is shown in the corresponding table. Numbers refer to registered lamb (ca 80 % of the total). Real slaughter numbers will be higher (Appendix 2.7).

From a farmer and animal welfare point of view, long clean feeding times are problematic. There is not enough room in the barns to accommodate so many animals during the winter. Clean feeding times over 8 weeks will be particularly problematic. In this case a combination of countermeasures must be foreseen. For instance the use of boli with Prussian blue distributed to the lambs before the grazing period starts to reduce the uptake of ^{137}Cs in the meat, followed by clean feeding after gathering in September. This was done in several areas of Norway after the Chernobyl accident [17].

4.4 Final comments

We have in this impact assessment focused solely on a hypothetical fallout from Sellafield. However, there are still problems with Chernobyl fallout in many regions in Norway. This will of course contribute to the total challenge. As described in StrålevernRapport 2009:7 [5], there will also be other radioactive substances present in the fallout that will contribute to the total radiological impact. Strontium-90 will be an important contributor in this respect particularly for milk and cheese production since strontium resembles calcium and thus will follow calcium in the animal system and cheese production. The total strontium-90 content in the HAL-tanks is presently 4.61 PBq (compared to 6.28 for caesium-137). The total consequences of an explosion and fire in the HAL-tanks will thus be larger than what is presented in this report.

As part of the report “Nasjonalt risikobilde” (national threat assessment), the described Sellafield scenario is used to exemplify a nuclear threat scenario for Norway. It will look at wider consequences of such an accident, such as the impact on health, economy and society. The Norwegian Directorate for Civil Protection and Emergency Planning (DSB) is leading the work on the national threat assessment and the report is due in 2011.

5 Conclusions

The environmental consequences for Norway following a hypothetical accident at Sellafield – with a release of 1 % of the total assumed inventory contained in the B215 HASTs – will according to our model predictions be severe, particularly in connection to sheep and goat production.

Up to 80 % of all lambs could be exceeding the food intervention level for radiocaesium the first few years after the fallout, with 30-40 % likely to be above for years or even decades. There will, consequently, be a need for extensive countermeasures in large areas for many years involving several hundred thousand animals each year. Large consequences are also expected for reindeer husbandry – the first year in particular due to the time of fallout in October (i.e. just prior to winter slaughter). The consequences for game will mostly depend on the regional distribution of different species. For instance, the density of moose is very low in the most contaminated western parts of Norway, whereas a considerable fraction of red deer is found in these areas. Consequently, about 10 times as many red deer as moose are expected to be above the intervention level.

The deposited amount of ^{137}Cs in this scenario, e.g. based on wind direction towards Norway and heavy precipitation, is about 7 times larger than the fallout from the Chernobyl accident over Norway. So far, the direct costs for mitigating actions in agriculture and reindeer husbandry due to the Chernobyl accident in Norway have exceeded 665 million NOK. The annual costs for countermeasures are still around 15 million NOK per year and we foresee the need for countermeasures for another decade. In addition, there are other costs not included in the above estimates (monitoring, voluntary work, psychosocial effects, loss in production etc.), so the total cost to society from the specified hypothetical accident at Sellafield will be huge. Moreover, a real accident would also give fallout of ^{90}Sr which would add significantly to the consequences described in this report.

This project has highlighted the importance of continuing work to reduce the risks involved with storage of HAL at Sellafield. British authorities have indicated they regard this type of accident as potentially serious and that the situation is under continuous evaluation to further reduce the risks of accidents at Sellafield.

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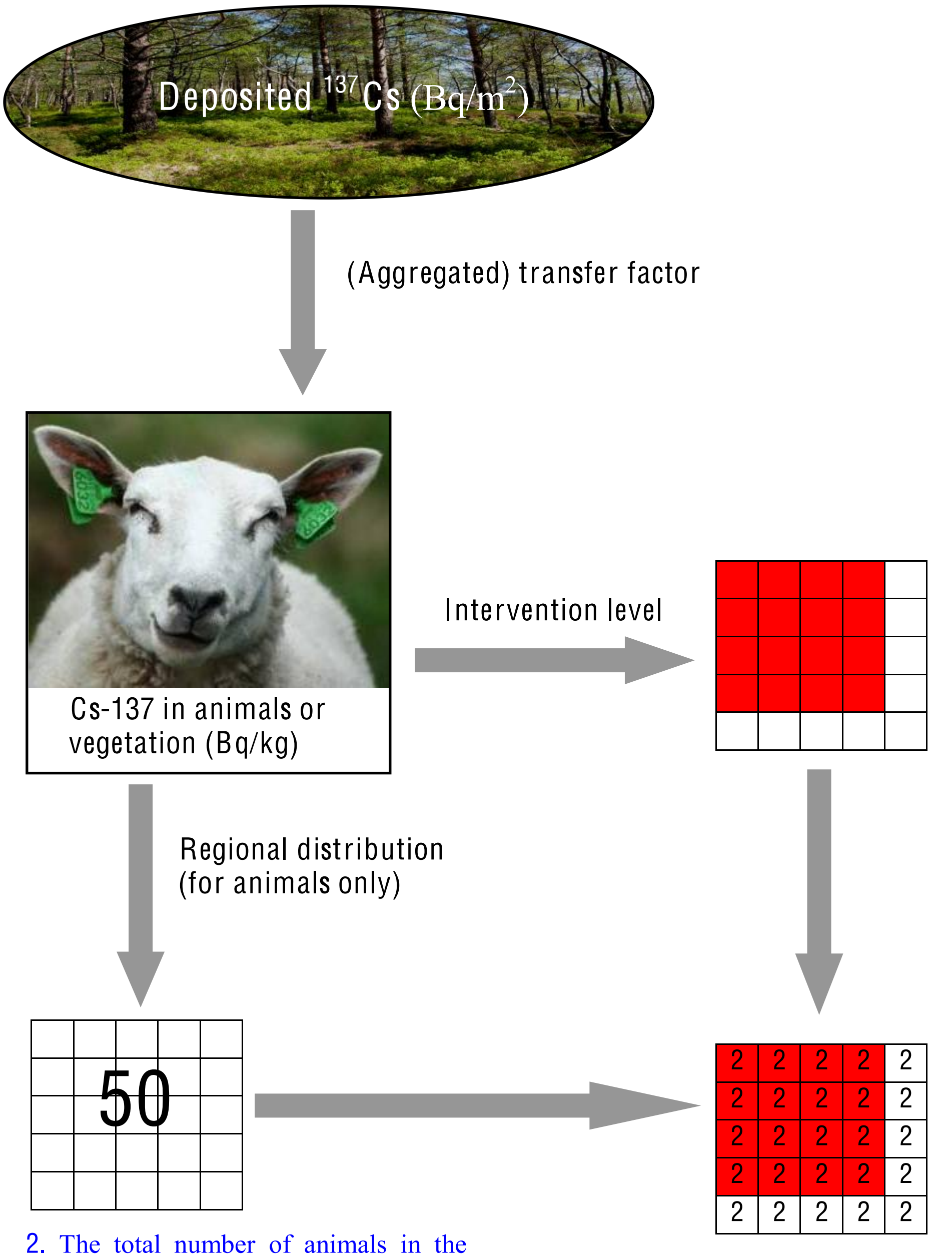
Appendix 1 – Overview of the STRATOS model

STRATOS incorporates information regarding: (a) transfer to vegetation and animals, (b) intervention levels and (c) geographical distribution of animals. The starting point is the deposition data for 5 x 5 km pixels for a specified area (e.g. a municipality, a county or a whole country). An example using a very small area comprising of only 25 pixels is shown to illustrate the philosophy behind the model.



1. In this arbitrary selected area, 16 out of 25 pixels are above the intervention level (shown in red)

2. The total number of animals in the arbitrary selected area of 25 pixels is 50. The area might be a grazing area, a municipality or something else

3. Combining the information regarding pixels above the intervention level (marked in red) with the number of animals found in this area (assuming that the animals are evenly distributed) gives a total number of 32 (i.e 64 % of the animals in the area are above the intervention level)

Appendix 2 – Supplementary information

2.1: Wild berries
2.2: Fungi
2.3: Moose
2.4: Red deer
2.5: Roe deer
2.6: Reindeer
2.7: Lamb
2.8: Goats

2.1: Wild berries

Cloudberry (Rubus chamaemorus) (Photo: NRPA)

Caesium dry weight transfer factors (m^2/kg) for the most popular wild berries among gatherers in Norway are shown in the subsequent table. All data are from [15, 16].

Latin name	Norwegian name	English name	Mean	Range
Vaccinium myrtillus	Blåbær	Bilberry	0.054	0.002-0.33
Vaccinum vitis- idaea	Tyttebær	Cowberry	0.030	0.004-0.12
Rubus chamaemorus	Multer	Cloudberry	0.100	0.008-0.14
Rubus idaeus	Bringebær	Raspberry	0.032	0.005-0.10

Conversion factors from dry weight to fresh weight for various types of berries are also given in [16]. For the types of berries included here the range is 0.13-0.17.

Based on the data above, the following fresh weight T_{ag}s were generated for berries:

Selected tags for the model run:
Min: 0.0003 (low range from the table above)
Expected: 0.007 (Mean for the four types of berries above)
Max: 0.04 (Top range from the table above. Vulnerable areas)

2.2: Mushrooms

Most edible mushrooms are mycorrhizal, living in symbiosis with the roots of trees and bushes. Visible fungal fruit bodies are usually found from mid July to end of September [11].

Cortinarius caperatus (Photo: NRPA)

Caesium transfer factors (m^2/kg) to mushrooms are highly variable (ranging 3-4 orders of magnitude). Data for important edible mushrooms in Norway (according to http://www.soppognyttevekster.no/default.aspx?id=1257) are presented in the table below. The data are given as dry weight and are taken from [16].

Latin name	Norwegian name	English name	Geometric mean	Range
Coprinus comatus	Matblekksopp	Wig	0.005	0.0004-0.015
Lactarius deliciosus	Furumatriske	Saffron milkcap	0.2	0.0008-0.5
Russula integra	Mandelkremle	Brittlegill (unspecified)	0.5*	0.03-4.2
Cantharellus cibarius	Kantarell	Chantarelle	0.2	0.015-0.7
Craterellus tubaeformis	Traktkantarell	Trumpet chantarelle	0.9	0.6-1.5
Boletus edulis	Steinsopp	Penny bun / Cep	0.09	0.0004-1.4
Hydnum rufescens	Rødgul piggsopp	Terracotta hedgehog	0.4**	
*Cortinarius caperatus****	Rimsopp	The gypsy	2.3	0.4-8.0

**Russula* species ***Hydnum* species ***Earlier *Rozites caperatus*

To convert from dry to fresh weight a factor of 0.10 was used as recommended by [15]. In the future the generic data above are supposed to be replaced with monitoring data from Norway.

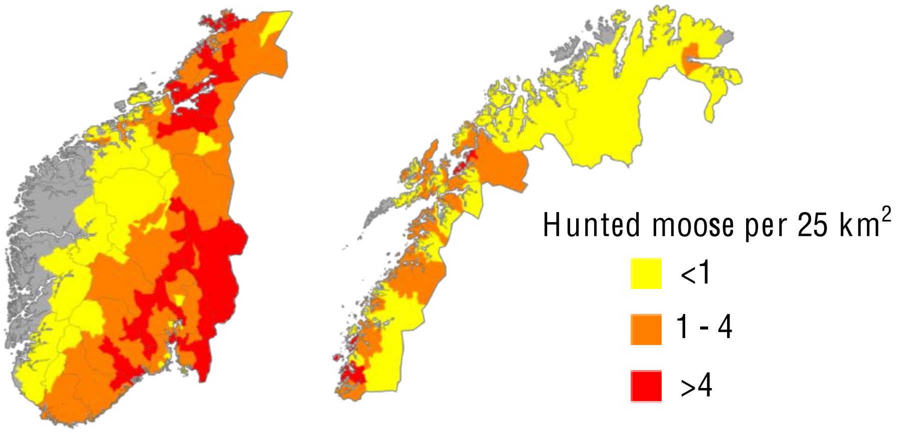
Selected T_{ag} for the model run:
Min: 0.0005 (low accumulators e.g. *Coprinus comatus*)
Expected: 0.02 (average e.g. *Cantharellus cibarius*)
Max: 0.2 (High accumulators e.g. *Cortinarius caperatus*)

2.3: Moose

Moose (*Alces alces*) is hunted in large numbers in Norway and contributes appreciably to the human diet. The Norwegian moose stock has been relatively stable since the early 90s, and in the period 1995-2009 about 35 000 moose was shot annually. Normal hunting period of moose in Norway is – with regional variations – from September to end of October. For details see http://www.lovdata.no/for/sf/md/md-20070201-0112.html.

Regional distribution

Regional distributions based on municipality hunting statistics; annual average for 2006-2009 is shown below:



Source data: Statistics Norway http://statbank.ssb.no

Transfer data

Moose with access to farmland can have lower contamination levels than those grazing solely in outfields and calves have shown consistently higher mean radiocaesium activity concentrations than adults (possibly due to metabolic differences) [18, 19]. Moose diet changes during the year, and slight seasonal variations in caesium-137 concentrations in meat have therefore been observed, with highest levels found in the autumn. The predominant fodder plants ingested the months before hunting season are firewood, birch and bilberry. Moose seems to consume only small amounts of fungal fruit bodies (1-2 % of rumen content), but even this limited amount may give a significant contribution to daily intake of caesium-137 [19].

Most Nordic studies on transfer of radioactive caesium to moose have been conducted in Sweden and Finland. These data have been summarised in [18] ranging from 0.006-0.087 with a best estimate of 0.02. Recently a study was performed based on moose liver samples from three regions in Norway [20]. In that study up to ten times higher transfer were observed for southernmost Norway – possibly due to a generally high transfer to plants in this area. After correction of the original data from dry weight to fresh weight using a factor of 0.25, the mean value (min-max) becomes 0.025 (0.014-0.24). Furthermore, recent concentrations of caesium-137 in moose meat from different hunting districts in six Norwegian counties have been reported by Gaare et al [21]. By using these data and (decay corrected) municipality deposition data from [22] we have estimated a mean T_{ag} of 0.023 for the country as a whole.

The physical half-life seems to determine the effective half-time for radiocaesium in moose meat [16, 19].

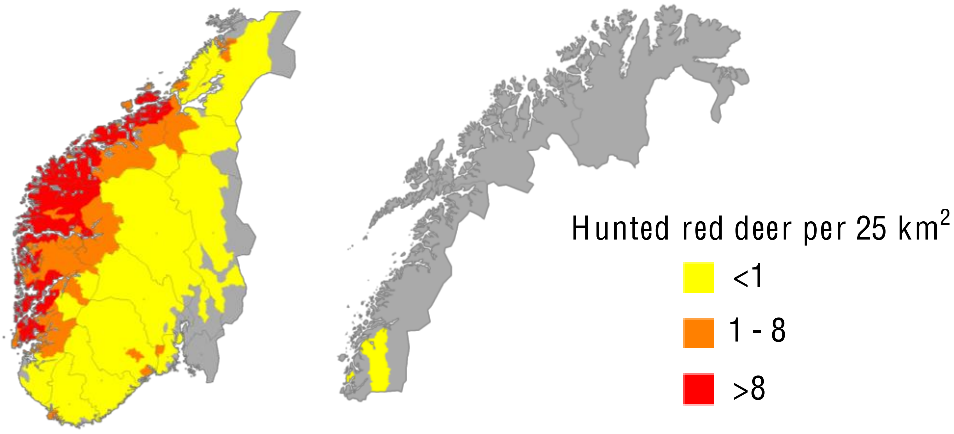
Selected T_{ag}s for the model run:
Min: 0.005 (Low transfer for Nordic conditions)
Expected: 0.02 (Best estimate from the investigations described above)
Max: 0.2 (Very high transfer, only relevant for vulnerable areas e.g. the southernmost part of Norway)

2.4: Red deer

Red deer (*Cervus elaphus*) is on the rise in Norway, and in recent years there has been a considerable stock increase, which has markedly influenced hunting statistics: In 1990 about 10 000 red deer were hunted annually, whereas the corresponding number for 2009 was 37 700 (which is even higher than the number of moose hunted that year). The normal hunting period is from 10 September to 15 November (see http://www.lovdata.no/for/sf/md/md-20070201-0112.html). According to [19], feeding habits for red deer are rather similar to those of roe deer.

Regional distribution

Regional distributions based on municipality hunting statistics; annual average for 2006-2009 is shown below:



Source data: Statistics Norway http://statbank.ssb.no

Transfer data

Considerably less data is available for red deer than for moose or roe deer. Due to low human consumption, the uptake of radioactive caesium was scarcely studied in connection with the Chernobyl accident in the Nordic regions. There is, however, a few data from central Europe (Germany, Austria and the Czech Republic) reported by the IAEA [15, 16] ranging from 0.01-0.05 and an expected T_{ag} of 0.03 has been proposed in [14]. Furthermore, data from Scotland suggest a transfer of 0.02-0.04 [19]. A Norwegian study has recently been published, reporting caesium-137 concentrations in red deer meat from different hunting districts in four counties [21]. By combining this data with (decay corrected) deposition data from [22], we calculated a mean aggregated transfer factor for Norway of 0.017, which corresponds well with the data above.

Selected T_{ag}s for the model run:
Min: 0.005 (same as for moose)
Expected: 0.02 (average based on Gaare et al., 2010)
Max: 0.20 (same as for moose)

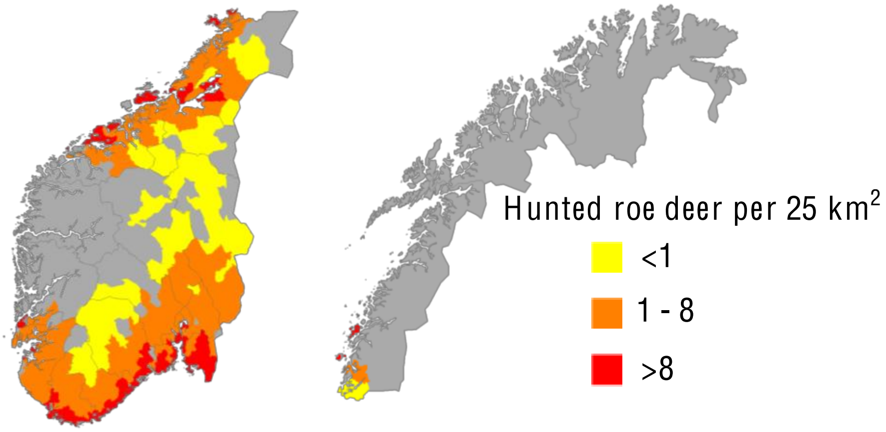
Note that the range is uncertain due to the limited amount of available transfer data for red deer.

2.5: Roe deer

Roe deer (*Capreolus capreolus*) is the smallest cervide found in Norway. As with moose there is seasonal variation in diet, but roe deer feed more actively and have a more variable diet. During summer herbs are the predominant feed, while in autumn roe deer increase their intake of dwarf shrubs such as bilberry, cowberry and heather. When available, fungal fruit bodies comprise a very important part of diet and a mean rumen content of 20 % has been reported for roe deer in central Sweden, reaching 80 % for particular animals. For more details regarding roe deer seasonal diet see [19]. Roe deer hunting time in Norway is generally from 25 September to 23 December, but starting in early August for adult roebucks (see http://www.lovdata.no/for/sf/md/md-20070201-0112.html).

Regional distribution

Regional distributions based on municipality hunting statistics; numbers for 2009 are shown below. Total annual hunting numbers are about 25-30 000 animals:



Source data: Statistics Norway http://statbank.ssb.no

Transfer data

Transfer of radioactive caesium to roe deer is highly variable, but animals grazing solely in forests generally have higher transfer than those with access to farmland. There are also marked seasonal differences, with highest transfer in the autumn – mainly due to high intake of mushrooms. According to [23] there are small variations in transfer outside the mushroom season.

In the recently published IAEA report [16] roe deer T_{ag}s ranges from 0.005-0.05. Most data, however, are from central Europe and refers to the period January to June, which is outside hunting season for Norway. From central Sweden it has been reported that autumn T_{ag}s for the period 1988-92 were 0.14 in average, with a peak transfer of 0.23 in 1988. For other parts of the year T_{ag}s were reported to be: 0.043 (December-January), 0.029 (in spring), and an annual mean T_{ag} of 0.05 has been suggested [19]. From the same area for the period 1989-94, [23] reports T_{ag}s of 0.024-0.036 during January to June, with 2.4-4.9 times higher transfer in August-September. According to [11] measurements in Norway are similar to those in Sweden.

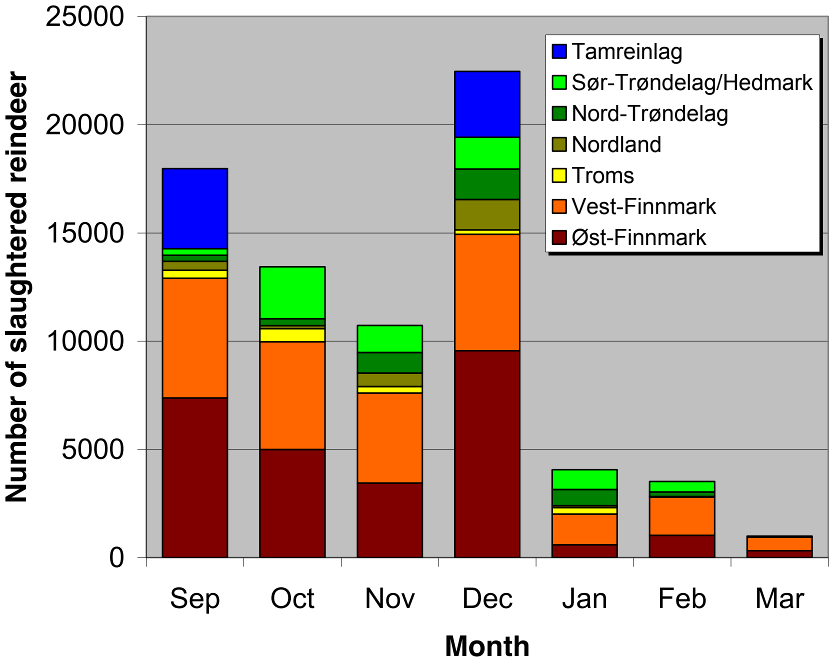
Very variable data for effective half-times of radiocaesium in roe deer is reported in [16]. Data from central Sweden suggest that it is similar to the physical half-life [19, 23]

Selected T_{ag}s for the model run:
Min: 0.005 (Low transfer for Nordic and central European conditions, January to June)
Expected: 0.05 (Best estimate for the hunting period. Some influence from fungi)
Max: 0.20 (Early hunting period, high abundance of mushrooms in the grazing area)

2.6: Reindeer

Reindeer (*Rangifer tarandus tarandus*) in Norway are either wild or semi-domesticated. The latter is an important food source, especially for the Sami population. Since the atmospheric nuclear weapon tests mostly in the 1950-60's it has been known that reindeer meat is sensitive to fallout of radiocaesium, since reindeer use lichens as a major food source. During winter lichens may constitute 70-80% of the feed intake, whereas in summer green plants dominates – but even during summer lichens constitutes 10-20% of the intake [24]. For more details regarding seasonal feed preferences of reindeer see [25].

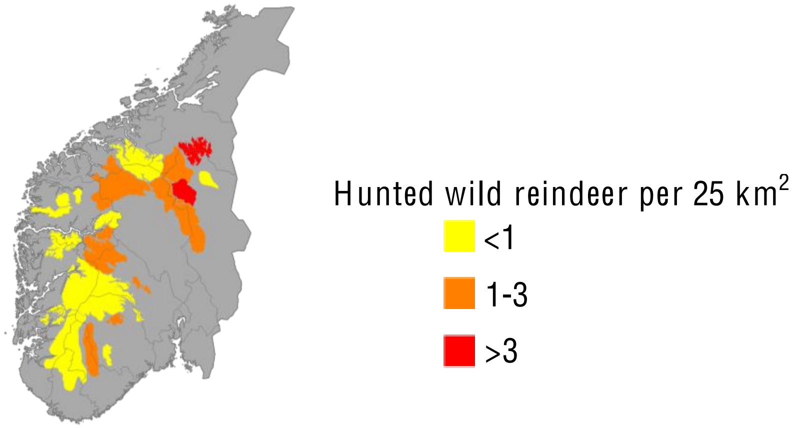
More than 70 000 semi-domesticated reindeer are slaughtered annually in Norway, the major fraction in Finnmark County in the northernmost part of the country (70 %). Normally, reindeer are slaughtered from September to March; slaughter times for different regions are given below:



Wild reindeer are hunted from 20 August to 30 September, and about 5000 wild reindeer are hunted annually.

Regional data

Slaughter data for 71 herding districts provided by the Norwegian reindeer husbandry administration for the period 2007-2010 has been used to derive regional distribution of semi-domesticated reindeer in Norway, while hunting statistics from Statistics Norway for the year 2008 have been used to generate the wild reindeer map (as shown below). No relevant distribution map is currently available for semi-domesticated reindeer.



Hunting numbers for different municipalities are from Statistics Norway http://statbank.ssb.no. Supplementary information regarding animal distribution is taken from the Norwegian Directorate for Nature Management http://www.dirnat.no.

Transfer data

Due to the variable importance of lichens in reindeer diet during the year, radiocaesium activity concentration in reindeer meat increases from late August/early September to November. During winter (November - early May) it is fairly constant, although there is a slow decrease due to reduced food intake. Then there is a faster decrease as the reindeer change to summer grazing (from May to end June), where the animals reach a stable low plateau which lasts to late August. The start of the increase in radiocaesium activity concentrations will depend on the time when mushrooms appear in the grazing area. Detailed seasonal T_{ag}s are available from various regions in Sweden: For the first year after the Chernobyl accident the T_{ag}s were typically: 0.1-0.2 (September), 0.3-0.4 (October), 0.5-0.8 (November-December), 0.9-1.2 (January-February) (see [26]). Using data from different herding districts in two regions of Central Norway (Sør- and Nord-Trøndelag counties) and combining these with (decay corrected) Chernobyl deposition data from [22], we calculated average aggregated transfer factors for the winter grazing period 1986-87 of 1.1 and 1.5, respectively. The autumn T_{ag} for the same periods was also estimated, ranging from 0.3-0.6. Previously a T_{ag} of 1.8 has been proposed based on winter values of reindeer in Kautokeino from 1960s onwards [27].

Effective ecological half-lives of caesium-137 in reindeer are shown in Table 1, ranging from about 4-5 years for the first 10 years after the Chernobyl accident (slightly dependant on season). For the next decade, however, the effective ecological half-time increases to 6.6 years for the winter period, while approaching the physical half-life for autumn. This difference is mainly due to longer effective ecological half-lives for green plants, comprising the animal feed during the summer season, than for lichens, constituting the most important winter feed.

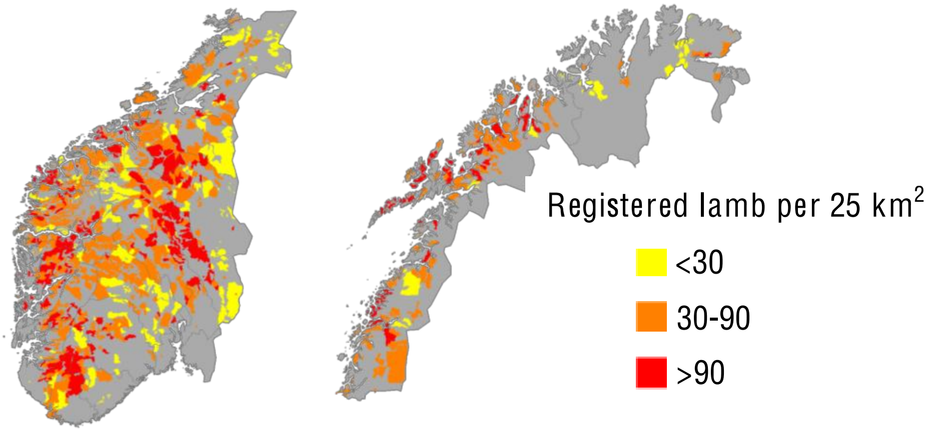
Due to the season dependent transfer it was decided to separate between autumn and winter when selecting T_{ag}s for the model runs:

Selected T_{ag}s for the model run:
Winter:
Min: 0.05 (Several decades after fallout)
Expected: 0.25 (Transfer after a decade, assuming an effective half-time of 4 years)
Max: 1.5 (First year)

Autumn:
Min: 0.05 (Several decades after fallout, areas with low transfer to feed plants)
Expected: 0.15 (Transfer after a decade, assuming an effective half-time of 5 years)
Max: 0.50 (First year, high abundance of mushrooms - or sensitive areas in subsequent years)

2.7: Lamb

Most sheep in Norway graze in mountainous areas or in other outfields such as forests. Lambs are born during March to May and are released on mountain pastures with their mothers in May-June. All sheep are gathered in September and most of the lambs are slaughtered in October-November [28]. Annual slaughter numbers for the period 2006-2008 were 1 000 000 lamb (http://www.animalia.no) and 1 200 000 sheep (http://statbank.ssb.no). Regional distribution of lamb based on grazing area[12] statistics are mapped below. Unfortunately, only registered lamb are included, which corresponds to approximately 80 % of the total number of lamb in Norway.



Distribution data are from The Norwegian Forest and Landscape Institute http://kilden.skoglandskap.no

Due to the fraction of unregistered lamb (20 %), the numbers of affected animals in the main report (Table 4) is lower than the actual slaughter numbers. However, assuming the same regional distribution and applying correction factors based on total slaughter numbers, it possible to make quick estimates.

Transfer data

Hove and Strand [7] calculated ^{137}Cs T_{ag} values for lamb on unimproved pastures for the nuclear atmospheric test fallout ranging from 0.013 to 0.093 for the period 1966-1972, and 0.07-0.10 from 1986 to 1988. Chernobyl ^{137}Cs fallout was also considered in the study, ranging from 0.024-0.136; the highest value was obtained in 1988 when mushrooms were abundant. The importance of fruit bodies compared to vegetation as sources of radiocaesium to sheep has been assessed by [29].

A later study by Hove et al. [30] gave a range of 0.034-0.043 for the period 1990-93 (mean value was 0.039). The latter value was used by the IAEA [15] as being representative of the late period after deposition. For the early period T_{ag}s of 0.14, 0.63 and 0.16 were recommended for the three northernmost Norwegian counties Nordland, Troms and Finnmark, respectively.

In connection with an assement of the long-term consequences of an accident at the Kola nuclear power plant [31] an initial T_{ag} of 0.15 was used (combined with an effective ecological half-time of 7.6 years).

Selected T_{ag}s for the model run:
Min: 0.01 (grazing areas with low transfer)
Expected: 0.04 (Best estimate for the long term perspective – years to decades)
Max: 0.20 (First year after the deposition, high abundance of mushrooms in the grazing area)

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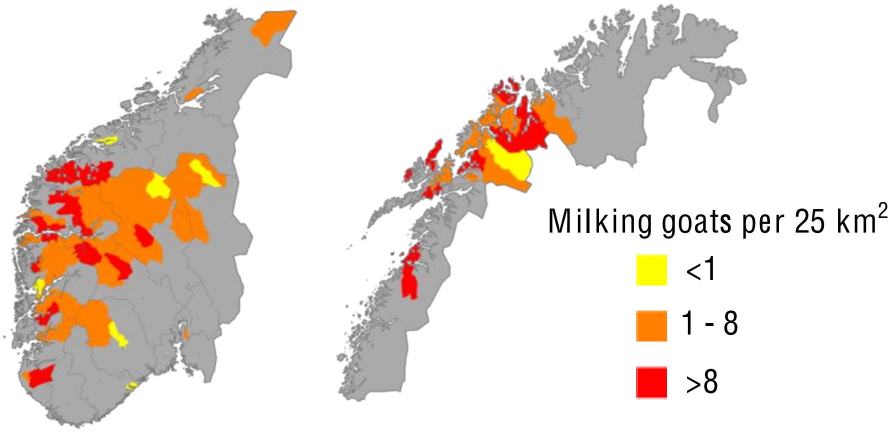
[12] Beitelag (in Norwegian)

2.8: Goats

Norway has the largest number of goats of the Nordic countries (32 000), and large volumes of goat milk are used in whey cheese production. Normal management practice is to make goats kid in February to April, so they are in peak or high lactation during the summer grazing period. Summer grazing period usually extends from mid May to late September, and mainly natural pastures or mountain pastures are used. The goats receive daily supplements with small amounts of concentrates [28]. Regional distribution of goats is shown in the following map:



The animal distribution map (number of animals) is made from municipality milk production statistics (Tine, 2009) assuming that one average goat produces 570 litres of milk annually (Source: The Norwegian Association of Sheep and Goat Farmers, 2010: http://www.nsg.no). This assumption leads to 35 000 milking goats in the whole country, which is fairly similar to the number from 2006 given above.

Transfer data

Some transfer data concerning goat milk grazing in out fields were found in the review by Skuterud et al. [18], ranging from 0.001 to 0.014 (omitting goats grazing on meadow pasture). T_{ag} recommendations from the IAEA [14] were 0.004 (0.002-0.01). For the present report the available information was considered too limited. Therefore results from a Norwegian monitoring program going on from 1988 to present were used – mainly to derive a best estimate T_{ag} for the whole country. The monitoring program included caesium-137 measurements in goat milk from various farms in up to 6 counties in Norway – done on a weekly basis from approximately early June to late September for up to 22 years. By combining these data with (decay corrected) Chernobyl deposition data from [22], we calculated an average aggregated transfer factor of 0.007 for the whole summer grazing period. To check whether there were any differences between different time-periods, we also divided in two groups: 1988-2000 and 2001-2010. However, the results were quite similar: 0.007 (0.002-0.014) for 1988-2000 and 0.007 (0.002-0.012) for the period 2001-2010. Ranges given in brackets are the 10th and 90th percentile, respectively – just to give an impression of variability. Generally, the caesium-137 level in animals is highest when the mushrooms show up in the grazing area: T_{ag}s may increase 2-4 fold when mushrooms are abundant in the grazing area [7, 32].

To demonstrate the effect of differences in pasture type on the radiocaesium levels in goat milk, Garmo and Hansen [33] grazed goats on meadow as well as on willow pastures. The aggregated transfer factors for meadow were about a fifth of that from willow (i.e. 0.0002). The higher value on willow pasture was due to both higher transfer of radiocaesium from soil to plants, and the presence of plant species with a higher uptake of radiocaesium.

Selected T_{ag}s for the model run:
Min: 0.001 (Early summer grazing period, low plant uptake etc.)
Expected: 0.007 (Best estimate based on summer monitoring 1988-2010)
Max: 0.02 (Late in the grazing period, lot of mushrooms in the grazing area)

Statens strålevern
Norwegian Radiation Protection Authority

StrålevernRapport 2010:1
Virksomhetsplan 2010

StrålevernRapport 2009:2
A novel dosimetric protocol for high energy photon radiotherapy beams in Norway using radiochromic film (electronic version only)

StrålevernRapport 2010:3
Om kvalitetskontroll av linac

StrålevernRapport 2010:4
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StrålevernRapport 2010:5
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