Living with an existing exposure situation due to accidental contamination: The need for long-term management and involvement – for how long?

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Abstract
The 1986 Chernobyl accident had consequences for livelihood and food production in areas as remote as Scandinavia, and created an existing exposure situation which still affects parts of the food production in Norway and Sweden. In response to the fallout Norwegian authorities chose a remediation strategy with the following key elements: (i) compensation to all farmers and other producers for economic losses due to the mitigating actions, (ii) limiting condemnation of food through the use of various remediation options like caesium binders, clean feeding and live monitoring of animals, (iii) sustaining the indigenous Sámi reindeer herding culture by adopting exceptionally high intervention levels for radiocaesium in reindeer meat, and (iv) limiting internal doses to vulnerable groups using dietary advices (and controlling this by using whole body monitoring).

Although the contamination challenges were largest in the first years after the fallout, the persistent but changing contamination levels have caused a long-term need for evaluations of parts of the remediation strategies – and for involvement of the local population. In this long-term management the establishment of local monitoring stations and the use of whole body monitoring of the most affected population groups proved very useful, not at least in helping the inhabitants understand and cope with the contamination situation.

Much of the experience summarised herein is based on the situation for a relatively particular population group, the Sámi reindeer herders. Yet it is believed that much of this experience is of more general nature and might be universally applicable to situations needing long-term management. Similarly for the last issue discussed in this paper, which is how strongly intervention limits for foods affect the duration of practical consequences in an existing exposure situation.

Key Words: Chernobyl, remediation, whole body monitoring, reindeer, stakeholder involvement

1. Introduction
The fallout from the April 1986 Chernobyl accident caused a long-lasting existing exposure situation in Norway. Although it took weeks to obtain an overview of the contaminated areas, it was already during summer 1986 realised that parts of the food production would be affected for decades. As late as in autumn 2011 maximum ^{137}Cs levels in reindeer meat still reached 5000 Bq/kg, well above intervention levels.

Radioactive fallout represents a particular contamination challenge. Even though the population can avoid contaminated foods and objects, we may be exposed to external radiation. Radioactive fallout is therefore an interdisciplinary issue calling for comprehensive monitoring and information efforts, including all elements of the environment around us. In the long-term of an existing exposure situation information needs may be less urgent, but there are nevertheless continuous needs for updated information and evaluations of appropriate actions.

In radiation protection terms 'existing exposure situations' are exposure situations that already exist when a decision on control has to be taken, including prolonged exposure situations after emergencies (ICRP 2007). Therefore, by definition, also the early chaotic and urgent situation in Norway after the Chernobyl accident was part of the existing exposure situation. This paper nevertheless focuses on the period after this early phase. It gives a brief introduction to the exposure situation in Norway, and summarises the remediation strategies and assessments around the chosen intervention levels for foods. Furthermore it presents some of the experiences from the use of dietary advices and monitoring of affected people, and from the establishment of local monitoring stations. The reflections on health concerns and public information needs in long-lasting exposure situations are mainly based on the author's nearly 20 years of experience from Chernobyl fallout management, particularly from work with one of the most radiocaesium-contaminated population groups world-wide; the Sámi reindeer herders of central Norway. The final discussion, on how long-lasting remedial actions in an existing exposure situation may be, is also related to reindeer husbandry.

2. The Chernobyl exposure situation in Norway

When the Chernobyl fallout reached Norway the authorities had no preparedness or plans for such situations, nor was there any countrywide monitoring system. The mapping of fallout was therefore based on sampling of snow, water and soil, and the first map of deposition levels became available in June. Figure 1 shows an interpolated map of ^{137}Cs levels from this initial mapping. The most affected areas were predominantly forest and mountain areas in southern and central Norway. The average deposition levels of radiocaesium (^{134}Cs and ^{137}Cs) in municipalities reached about 150 kBq/m^2 (Backe *et al* 1986) and external exposures were thus not considered a significant radiation protection issue.

A detailed summary of the consequences of the Chernobyl fallout in Norway during 1986-1995 is given by Tveten *et al* (1998). The combination of season (early spring) and the food production systems in the most affected areas caused only limited consequences of the direct deposition onto vegetables and other crops in cultivated fields[1]. However, the unimproved – and relatively nutrient-poor – forest and mountain areas in central and southern Norway are extensively used for summer grazing of especially sheep and reindeer, and to a smaller extent cattle and goats. With the gradually improving knowledge of contamination levels, and based on 20 years of studies of nuclear weapon tests fallout in the lichen – reindeer – human food-chain in northern Norway (Westerlund *et al* 1987), it was therefore already in July 1986 realised that reindeer herding in the most contaminated areas would be affected for decades. Reassessment of time trends in radiocaesium concentrations in lamb during 1959-1971 later (Hove and Strand 1990) suggested that also other products from mountain and forest pastures would be affected for many years.

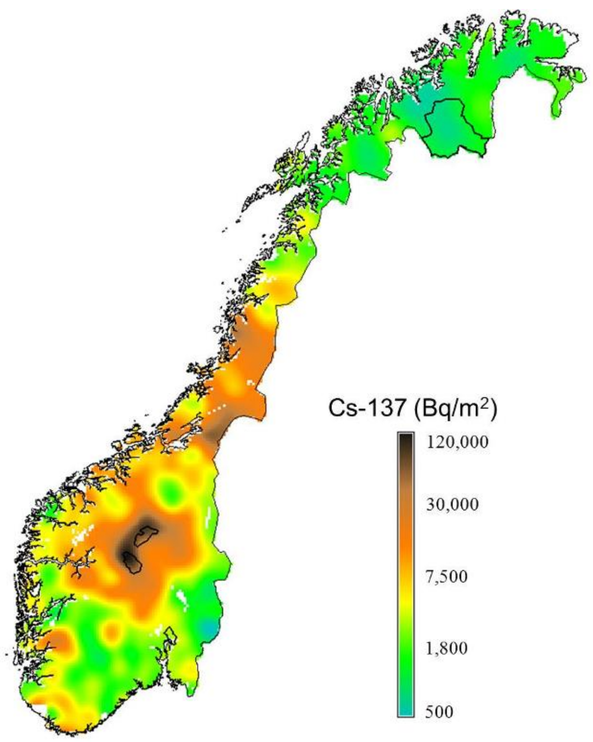

Figure 1 Map of Chernobyl ^{137}Cs deposition levels in Norway. Interpolated map based on municipality average values from Backe *et al* (1986).

3. Remediation strategies

Due to the lack of good overview of deposition patterns and contamination levels, control of food samples was used extensively during 1986 to check compliance with intervention levels. Trade bans were effectuated on some products (Tveten *et al* 1998), but restrictions were not placed on grazing in forest and mountain pastures. As elevated contamination levels in grazing animals were observed towards the autumn slaughtering season, trade of reindeer meat from central and southern Norway was

[1] Only about 3 % of Norway is cultivated agricultural area.

banned. Lamb were condemned if they contained >2000 Bq/kg, otherwise clean fed if above the intervention level (section 4).
On 31 July 1986 the government passed a resolution about compensation to all farmers and other producers for economic losses due to the mitigating actions including:

- Condemnation (compensation based on market value)
- Labour and various costs associated with application of countermeasures and remedial actions
- Indirect costs (e.g., lower income due to reduced meat quality after clean feeding of lamb)

Producing food for condemnation was – and is – unsustainable and highly unsatisfactory for the producers. In addition the cost/benefit analyses carried out in Norway to recommend effective remedial actions (actions recommended if cost per Bq or person-Sv avoided was lower than the monetary value of a person-Sv) showed that large scale condemnation, as in 1986, was far from cost-effective (Brynildsen *et al* 1996, Tveten *et al* 1998). As it was also evident that animal products would be contaminated during many years, the authorities in 1986-87 started testing various methods to maintain traditional food production whilst limiting the need for food rejection. Two of the main elements of the remediation strategy – and success stories in Norwegian Chernobyl remediation – have been the development of methods for:

- Measurement of radiocaesium in live animals pre slaughter (live monitoring), and
- Reduction in uptake of radiocaesium in grazing animals using caesium binders.

Live monitoring (Figure 2) gives the possibility to avoid slaughtering animals that would be condemned due to elevated contamination levels. Instead the slaughtering can be postponed and the animals clean fed to reduce contamination. Bentonite and zeolite were initially tried as caesium binders. More efficient and large scale application of caesium binders was obtained after developing methods of administering ammonium ferric hexacyanoferrate (AFCF), which gave larger reduction at much smaller quantities (Hove *et al* 1991). Norwegian methods and experiences on the use of AFCF were also made available to the contaminated areas of Russia, Ukraine and Belarus (IAEA 1997). More details on the Norwegian remediation strategies and their high cost-effectiveness during the first decade after the Chernobyl accident is given in Brynildsen *et al* (1996) and Tveten *et al* (1998).

The remedial actions and the methods of their implementation in Norway were developed with involvement of local authorities, farmer's and reindeer herder's unions, food industries etc. as it was recognised that the direct contact, from national scientists/experts to local people, was crucial for success of the strategies. However, developing techniques and methods to reduce contamination is just one challenge of a remediation strategy. Another is to use the information on contamination levels to develop robust regulations and compensation schemes. This challenge is increased by the dynamic behaviour of radioactive contamination (due to physical decay and environmental processes): Having initially obtained an overview of the contamination situation and developed and optimised strategies for management, the contamination levels will gradually decline – but at different rates in various media/products. Furthermore, since the effectiveness of remedial actions is dependent on the absolute contamination levels (activity concentrations) there is a need to reassess cost-efficiency as activity concentrations change. Therefore the strategies will have to be reassessed and updated, and regulators need to follow the monitoring and research that explains the time-trends to keep their regulations robust. Skuterud and Hansen (2008) gives an example of an outdated

Figure 2 Monitoring of radiocaesium in live reindeer. See Brynildsen and Strand (1994) for methods also for sheep and cattle.

regulation: Due to the 3-4 times increase in radiocaesium concentrations in reindeer meat as the animals change from summer to winter grazing a regulation was formulated to stimulate early slaughtering and ensure compensation due to lower animal slaughter weights in early autumn. However, after 15-20 years many herds had lower contamination levels during winter, the result being that herders were stimulated to slaughter when the animals were most contaminated.

The Chernobyl experiences in Norway also show that during a long-lasting exposure situation there may be societal changes that may affect remediation strategies. E.g., during the 25 years since the Chernobyl accident there has been a shift in the view of the responsibility of producers in delivering 'clean' food. While the strategies in Norway earlier have focussed on reducing farmer's responsibility, the authorities now consider giving the farmers larger responsibilities.

4. Intervention levels for foods

Intervention levels is a challenging topic as the public in general interpret these levels as directly related to toxicity and radiation protection, while in practice other concerns like customers' confidence in food production and trade are also important in the decision making process. Therefore countries may adopt different strategies to intervention levels, with Norway's strategy (described below) being an example differing significantly from Japan's recent decision on reducing the permissible level for radiocaesium in foods to 100 Bq/kg (MHLW, 2012).

At the time of the Chernobyl accident Norway had no intervention levels for radionuclides in foods. In May values of 1000 Bq/kg and 300 Bq/kg were chosen as temporary values for ^{131}I and ^{137}Cs respectively. During May and June the information on the extent of the fallout and the results of the food sampling provided a better basis for assessing the contribution by various foodstuffs to the public's radionuclide intake, and this was being used to assess more permanent intervention levels based on radiation protection principles. However, instead of determining new levels specific to the contamination situation in Norway, the levels adopted in June were the results of consultations among Nordic countries and were also in accordance with EC levels: 370 Bq/kg for radiocaesium (^{134}Cs + ^{137}Cs) in milk and baby-food and 600 Bq/kg for all other foodstuffs.

As the consequences for reindeer herding became evident during late summer and early autumn, with average radiocaesium concentrations in reindeer meat in some areas approaching 100 times the intervention level, and the experience from northern Norway indicating effective half-times for ^{137}Cs in reindeer of about 7 years, the reindeer herders felt their whole existence was endangered (Stephens 1987). Remedial actions were limited for the semi-domesticated free ranging animals in herds of hundreds and thousands (giving limited possibilities for fencing and clean feeding). Therefore, in November 1986 the government decided to increase the intervention level for radiocaesium in reindeer meat to 6000 Bq/kg in an attempt to try maintaining a meaningful business base for reindeer herders – and also protecting the associated Sámi culture and life-style. The decision followed a radiation protection assessment justifying the elevated level by the low average consumption of reindeer meat in the general population (~0.5 kg/year). The elevated level applied to traded reindeer meat, while high consumers like reindeer herders were recommended special actions (incl. dietary advices, section 5). From June 1987 the level of 6000 Bq/kg also applied for wild freshwater fish.

Although it was not explicitly stated at the time the intervention level was raised to 6000 Bq/kg, it was the intention to reduce the level as contamination levels declined and it was justified, i.e., found cost-efficient on a radiation protection basis. In 1994 the level was reduced to 3000 Bq/kg, while later assessments (in 2001 and 2009) have concluded that reductions to 1500 Bq/kg have not been cost-efficient. Justification on a radiation protection basis has been the most important criteria in these assessments, but other aspects also need to be taken into account. These include e.g. consumer needs and practical consequences for producers. For the producers a lowering of levels will impose more application of remedial actions, and these consequences may be perceived as reintroducing the fallout.

5. Dietary advices, monitoring of affected people and local monitoring stations

By implementing an elevated intervention level for products consumed in small quantities by the general public, the Norwegian authorities chose two approaches to the protection of the population: The intervention levels for traded foods where selected to protect the general consumers. As these elevated levels would not give a satisfactory level of protection for groups with high consumption of the particularly contaminated products (i.e., ensure ingestion doses below 5 mSv the first year after the accident, and below 1 mSv in subsequent years), these groups required separate actions. In addition to reindeer herders this included groups like hunters and fishers with high consumption of game and wild freshwater fish.

An important action was the production and distribution of a leaflet with dietary advices for consumers (Norwegian Directorate of Health 1987). This leaflet contained information about appropriate consumption rates of foods containing various levels of radiocaesium, and gave advices on methods of cooking and preparation to reduce contamination levels. The reindeer herders were in addition:

- Provided clean reindeer meat from less contaminated areas (not very successful because the herders prefer their own production)
- Offered compensation for labour and expenses associated with clean feeding of animals for own consumption
- Offered compensation for purchase of alternative foodstuffs (to replace reindeer meat)
- Monitored to survey their internal radiocaesium doses

Figure 3 Whole body monitoring of reindeer herder (left) in NRPA's mobile lab (with chair geometry). 15-20 min measurement give opportunity to communicate on diets, risks etc. one-to-one. We all perceive risks differently, and have different information needs.

Whole body monitoring (Figure 3) was initially used as a method to survey internal doses, and after the Chernobyl fallout it also gave the authorities information on the successfulness of the remediation strategies. However, combined with appropriate information on diet and radiocaesium levels in foods (e.g. assisted by software tools like CORPORE (Levy *et al* 2008)), the repeated monitoring is also a useful tool for the population to check their personal efforts to reduce radiocaesium intake. As such is it may help them cope with the contamination situation (Tønnessen *et al* 1996). The suite of measures in sum reduced the ingestion doses to reindeer herders 80-90 % the first year and totally about 73 % during the period 1986-2009 (Skuterud and Thørring 2012). In addition to monitoring reindeer herders, some selected hunters/gatherers and general rural population groups were monitored in Norway the first years after Chernobyl (Strand *et al* 1992).

To improve the monitoring capacity in general, and to enable more information gathering at the local level in particular, Norwegian authorities during summer 1986 initiated the creation of local monitoring stations in food control laboratories across the country. At these stations the local population could have their food controlled free-of-charge. The chosen strategy of elevated intervention levels combined with dietary advices would not have been feasible without these stations.

Similar useful experiences from using whole body monitoring and local food control labs were obtained in the long-term exposure situation in Belarus (Lochard 2007, Bataille *et al* 2008).

6. Health concerns and public information needs

It is well known that uncertainty may breed fear – particularly in connection with exposure to radioactive contamination (e.g., Gardner 2008). The main concerns of an affected population is likely to be those about health effects, but the need for information does not only relate to health risks – it relates to all aspect of the contamination and exposure situation – for inhabitants, consumers and producers. The public often discusses radioactive contamination and radiation with the "mysterious" properties "can't hear, see or smell" – discussions which easily induce unnecessary fear in addition to potentially leading to undesirable (i.e., more risky) behaviour. Inhabitants in a contaminated area will inevitably start making their own interpretation of the information they receive, and of the contamination situation around them. Therefore the inhabitants – and not at least the authorities – will benefit from information on radiation, properties of the contamination and expected behaviour in the environment and in humans. It is too easy to underestimate the range of information the public is able to utilise. Another challenge is the public's confidence in the information providers: Even in non-nuclear Norway it may take years for representatives of authorities to reach a level of confidence in the local population where the information is accepted as unbiased.

Knowledge of radiation doses – external as well as internal (e.g., obtained from whole body measurements) – is a premise for assessing risks. Nevertheless, the dose information may not be enough to provide answers to the populations concerns. The monitoring of the reindeer herders in Norway is a typical example: Many years of study have given a good understanding of the doses they have received (Skuterud and Thørring 2012). But as the doses are low compared to levels known to give health effects, the results apparently does not give satisfactory answers to their primary questions like "What level of risk am I exposed to?" or " Did I develop cancer because of the Chernobyl fallout?". If the risks are so low, why do we carry out whole body monitoring? And if the risks are so low for the high-consuming reindeer herders, why do they have to use remedial actions before they can trade their products to the general public?

Assessing health consequences at the individual level is one challenge – consequences at population level another. It is challenging to conduct health surveys of relatively small population groups living in contaminated areas with a design expected to give clear scientific output. There has therefore been some hesitation about conducting health surveys among the Chernobyl affected Sámi reindeer herders in central Norway because they are a separate ethnic group, they have a special diet and life-style, they are few in numbers (about 500 – 1000 individuals) and there is little (if any) relevant health statistics pre-Chernobyl. But these reasons are no good explanations for the affected persons, and in the long term there is an increased need for health surveys. Having said that, studies of cancer incidence and mortality in the general Sámi population in the Nordic countries show that the risk of developing and dying from cancer is low among the Sámi, both in comparison with general populations and regionally matched reference populations of non-Sámi (Hassler *et al* 2008).

The above risk related questions are just examples of queries illustrating some information needs in the population. A range of other questions relates to more concrete and practical aspects of their specific contamination situation (in their surroundings, in their foods etc.), and about options for reducing contamination and exposure. Availability of monitoring equipment is required, both for analysing food and environmental samples and for monitoring of external exposure. With active involvement and some radioecological explanations the inhabitants will gain knowledge which will help them understand the situation, the variability and time-trends. This will empower them to make their own choices, thus helping them cope with the situation and promote positive outcome expectancies (Tønnessen *et al* 1996). A lasting existing exposure situation is a resource demanding (in terms of man-power) long-term information challenge as the contamination situations and remediation options are site specific, the questions are specific for many of the inhabitants, and the needs will change along with the continuously changing contamination and exposure situations.

In addition to the general public information needs, food producers require particular attention. This includes involving them as stakeholders with particular practical knowledge and skills in developing, choosing and implementing appropriate remedial actions. Again, the needs may vary from producer to producer, and the involvement and information adapted to each case. In the long term the needs will change according to the continuous evaluation and optimisation along with changing contamination levels. Furthermore, through the years the producers will develop experience and local knowledge that will make them valuable stakeholders in management and regulation. The sharing of experiences and "good practice" on the use of AFCF-containing salt-licks among reindeer herders in Norway is one example.

Finally, in a long-lasting existing exposure situation it should not be forgotten that there will also be continuous information needs related to new-comers and new producers, e.g., new generations of farmers.

7. For how long does the existing exposure situation last?

The duration of an existing exposure situation is determined by different factors like initial contamination levels and physical half-lives of the radionuclides released. The long-term need for remedial actions is in addition influenced by how authorities choose to manage the exposure situation, e.g. through choices of acceptable doses to the public, intervention levels and application of the ALARA principle. The current contamination situation in Norwegian reindeer can be used to illustrate the issue:

In some grazing areas there has been no significant decline in ^{137}Cs concentrations in reindeer during the last ~10 years, with average concentrations persisting about 2000-3000 Bq/kg (Figure 4). Even with the current intervention level of 3000 Bq/kg that means that control of reindeer and remedial actions will be necessary before slaughter of the most contaminated herds for many years to come. According to the 2001 and 2009 assessments of cost-efficiency, the management strategy is still justified from an economic point of view.

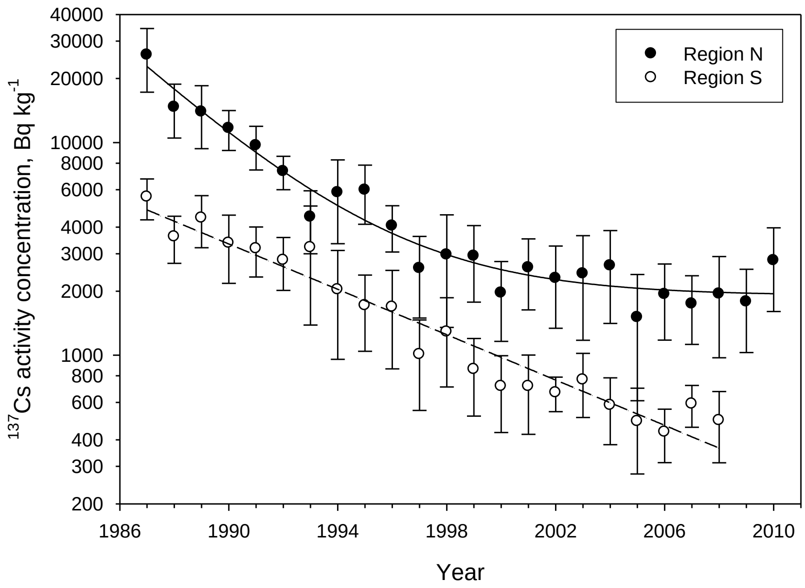

Figure 4 Average (±SD) ^{137}Cs concentrations in reindeer during winter in two regions of Norway, N (Nordland and Nord-Trøndelag counties) and S (Sør-Trøndelag and Hedmark counties). The long-term trend in Region N was best approximated by an exponential model the activity concentration declined towards a constant level of 1900 ± 730 Bq/kg (from Skuterud and Thørring 2012).

Current ^{137}Cs concentrations in reindeer meat are above 600 Bq/kg (the intervention level for basics foodstuffs) in about 11 herding districts, and above the intervention level of 3000 Bq/kg in 4-5 herding districts (Norwegian Reindeer Husbandry Administration 2011). The total meat production in the 11 districts is about 330 tons. The total ^{137}Cs activity in this traded meat corresponds to a collective dose of about 3.1 person-Sv more than if the intervention level had been 600 Bq/kg. With a nominal probability coefficients for cancer of 0.055 Sv^{-1} (ICRP, 2007) this suggests about one cancer case per 6 years of reindeer meat production (if no remedial actions are taken).

Although the contamination of Norwegian reindeer meat is not a public health challenge (and this fact might affect the herders' motivation for application of remedial actions), the authorities consider reducing the intervention levels – much because of the more political challenge of maintaining a intervention level higher than any other country. That might prolong the need for remedial actions another 30-40 years (based on the current understanding of time-trends).

Interestingly, UK is currently considering lifting restrictions on sheep originating in the two areas where full controls remain (North Wales and Cumbria; FSA 2011). Their consideration is based on an assessment showing that the risk to consumers from radioactivity in sheep resulting from the Chernobyl nuclear accident is now very low. The assessment refer to the reinforced view by the ICRP that protection from radioactivity should consider the actual risk to individuals (measured as the effective dose) rather than purely relying on a fixed limit of contamination, and demonstrates that the controls are no longer proportionate to the very low risk.

8. Conclusion

A quarter of a century with Chernobyl management in Norway shows that an existing exposure situation due to accidental contamination may require decades of management, commitment and involvement. Although the challenges were largest in the first years after the fallout, there is a constant need for evaluations of time-trends and experiences and for improvements – optimisation – both in cost-efficiency and practical consequences for the affected population.

Although the main challenges were due to vulnerable food production systems and a self-supporting indigenous population group, the information needs related to the exposure situation in Norway also covered external exposures etc. Radioactive fallout affects the whole environment in which we live, and can as such not be reduced to just a question of food safety and radionuclide intake. Our experience shows that authorities dealing with long-lasting existing exposure need to take the total contamination situation into consideration when planning for remediation and rehabilitation. The aim of the management should be to make the situation for the inhabitants as understandable and predictable as possible. In this situation it is also important to carefully assess the role of food intervention levels in determining the number of years remedial actions will be necessary.

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