INTRODUCTION

The accident at Chernobyl, near Pripyat in Ukraine, was caused by an explosion in unit 4 of the nuclear power plant. Both the material released and its deposition distribution pattern were much less homogenous than anything released in weapons testing. The near field (up to a few kilometres from the reactor) was heavily contaminated, and part of this contamination was due to fuel particles.

The fire in the plant carried some of the materials to a height of about 1,000-1,500 metres where an air stream carried it first to the western part of the USSR and then on to Sweden and Norway. It was particularly the volatile elements, such as iodine and caesium, which reached the higher levels of the atmosphere and were then transported over great distances (hundreds of kilometres). During the ten days following the accident, when radioactive debris was being released to the atmosphere, the meteorological conditions changed and central and southern parts of Europe also received fallout. Part of this later release was also transported from Central Europe to Southern Norway in May. The fallout in parts of Norway and Sweden was some of the highest outside the former Soviet Union and average levels of $^{137}$Cs of up to 200 kBq/m$^2$ could be found on the ground surface. It mainly affected rural and mountainous areas with few inhabitants, but which were and are important for production of food. The highest contamination occurred where rain fell during the passage of the radioactive cloud.

FALLOUT AND BEHAVIOUR IN FARFIELD

The time of the year (April, May) when the fallout occurred, had influence on the consequences. In spring no animals were out grazing and almost no standing crops could receive direct surface contamination. However, uptake and the transfer in the semi-natural ecosystem became considerable important.

In semi-natural ecosystems, soils often have a low mineral content and very little clay and this usually means less findings of the radiocaesium. Even before the Chernobyl accident occurred, it was known that the root uptake of radiocaesium in a semi-natural ecosystem was higher than average in agricultural ecosystems [1].
Undisturbed soils generally have a top layer rich in organic matter and any caesium in this layer is more mobile and generally available for root uptake. However, in tilled agricultural soils, the radiocaesium tends to come into contact with clay particles which have the ability to absorb and irreversibly bind the caesium and greatly reduce its availability for root uptake. Undisturbed soils tend to support plant species which show a relatively high uptake of radiocaesium.

Earlier studies on fallout from nuclear tests had yielded data on the migration and uptake of important radioisotopes under the conditions of almost continuous fallout. Most of these studies concentrated on agricultural systems and with little focus being devoted to food production in semi-natural ecosystems except for the lichen-reindeer part of the food chain. Nevertheless, valuable data on root uptake and long-term behaviour of radiocaesium were obtained. Using these data, it was possible to reassess the results obtained in studies of nuclear weapons tests and to make realistic prognoses about the transfer of radiocaesium and its long-term behaviour after the Chernobyl accident for animals.

Earlier studies had suggested that fallout from Chernobyl would behave differently to fallout from weapons tests. Radioactive substance released under very special conditions could be present in other physico-chemical forms. [2]. A reduced soil-plant transfer of Chernobyl fallout radiocaesium compared to nuclear weapons tests fallout was observed [2] in farfield from the reactor accident. The weapons fallout was readily soluble in water but the Chernobyl fallout was found in a variety of different physico-chemical forms. Close to the Chernobyl site, Loschilov (1991) observed that physico-chemical form of radiocaesium played an important role in determining it's behaviour in the environment. The Chernobyl fallout radiocaesium deposited in Norway was to a minor extent found as fuel particles, mostly in the forms of colloids and simple cations [3] [4]

However, despite the fact that the Chernobyl caesium deposited in Norway was found in a variety of physico-chemical forms, it has been shown that radiocaesium from Chernobyl and radiocaesium from weapons fallout behaved very similarly with respect to distribution and migration in soil and uptake by plant and animals [5] [6]. This is true at least after the first initial phase after the fallout. The long term behaviour of radiocaesium in the environment is also very similar for the two fallouts [5] [6].

Radiocaesium was the most important radionuclide for dose to man from both types of fallout, and consumption of contaminated food is an important source of dose [7][8][9][10]. Result from experimental fields showed no significant difference in the soil-to-plant transfer of the two types of fallout.

It was shown by Oughton (1989) that both types of fallout were in equilibrium with the stable caesium in the soil and despite the fact that deposition of the fallout occurred 20 years apart.
the transfer factors were almost identical. These measurements were made on a highly organic soil containing very little clay.

The effective ecological half life can be long (up to 30 years) for many of the plants and food stuffs produced in the semi-natural ecosystem [5]. The long ecological half life may be due to several factors. Assessments made in the wake of the Chernobyl accident showed that the ecological half-life of ruminants grazing semi-natural ecosystems had not been properly addressed [5]. It was not generally known that effective ecological half-life could be that long, especially if fungi were present for the grazing animals (I,II).

In semi-natural ecosystems, root uptake is the rate-determining step and therefore also governs the intake by grazing animals. The main exception to this is the lichen-reindeer pathway where surface contamination of the lichens is largely responsible for the activity levels of radiocaesium in reindeer in winter when lichens are the main source of food for reindeer. In winter, the ecological half-life for weapons fallout and Chernobyl fallout in reindeer showed no significant difference: the half-life being 3 - 4 years in both cases (table). This again demonstrate the similarity in behaviour of radiocaesium from nuclear weapons and from Chernobyl.

COUNTERMEASURES

In order to minimise the harmful effects of radiation arising from fallout it may be beneficial to implement countermeasures and thus reduce the dose to man. Clearly it is essential to administer such countermeasures so as to derive the maximum benefit.

This means evaluating the effectiveness of the countermeasures in terms of practicability, monetary cost, social cost etc. etc. Other important considerations are when to apply the countermeasures and for what length of time the countermeasures should be called for. To do this it is essential to understand and predict the long-term behaviour of the more important radioisotopes.

There is generally a good agreement on the basic radiological protection philosophy regarding the introduction of countermeasures following an accident [11]. It is agreed that countermeasures should be justified and optimised and should result in a net benefit to man, i.e. they must do more good than harm.

Agricultural countermeasures studies were first conducted some 40 years ago largely as a safeguard against possible contamination of land through fallout from nuclear weapons. The countermeasures study was aimed mainly at combating contamination of crops, fodder and animals by Sr, Cs and I.
Generally, the implementation and effectiveness of countermeasures will depend on many different factors. Some of the most important are time of year when fallout occurred (seasonality), site-specific factors, type of agriculture products, the physico-chemical form of the fallout etc. However, just as important, are also economic, psychologic and social consequences to be considered.

Fallout on the ground and urban constructions such as buildings and roads can be an important source of external radiation to man. A considerable reduction in potential dose can be achieved through carefully planned decontamination procedures or, in the extreme, by evacuation or relocation. Such countermeasures were not used in Norway following the Chernobyl accident but they were judged to be unnecessary and used in the former USSR. Countermeasures for external radiation will not be discussed further in this document but some appropriate studies on this subject have been reported [12] [13].

In the event of a nuclear release, countermeasures against inhalation of radioactive materials may be called for. Such countermeasures would of necessity be short term. Appropriate countermeasures would be remaining indoors, wearing gas mask and taking of potassium iodate tablets to reduce uptake of radioiodine by the thyroid gland. In Norway, after the Chernobyl accident, no countermeasures were used to reduce the dose from inhalation.

A variety of techniques are available for minimising man's intake of radioactivity from contaminated food. Any proposed countermeasure should take into account factors such as effectiveness, practicability, cost and social consequences. Many normal agricultural practices are effective in minimising uptake for newly contaminated land. Often agricultural countermeasures are connected to:

1) Reducing uptake from soil to plants by use of fertilisers, ploughing or changing the land use.
2) Reducing the transfer from plants to animals by the use of food additives.
3) Increasing the rate of excretion from the animal.
4) Processing of contaminated crops to yield a less contaminated product.

Limiting consumption of contaminated food, abandoning land and moving people from contaminated areas are obvious methods for reducing potential radiation dose. Ploughing and the addition of fertilisers are normal agricultural practices which can also be effective in reducing dose. Where meat producing animals are contaminated through grazing contaminated pastures, contamination in meat can be greatly reduced by using clean pastures of forage for just a few weeks before slaughtering (special feeding).
The implementation of countermeasures will have implications in terms of cost to society. Such cost has to be compared with the corresponding reduction in health risk. The Chernobyl accident presented an opportunity to evaluate the cost-benefit of various countermeasures. The effect of different countermeasures may be estimated from experiments and experience after implementation in Norway following the Chernobyl accident. The cost of the countermeasures were estimated from available accounts and budgets in connection with implementation and compensation regulations. Information of the scale of the contribution and the effect of the countermeasures make it possible to estimate the averted dose. The findings compiled will be the basic for performing an simple cost benefit analyses.

COUNTERMEASURES AND COST-BENEFIT ANALYSIS

However, no plans for countermeasures existed at the time of the accident, so they had to be improvised. Due to research and developments some countermeasures, e.g. interdiction were replaced by more convenient and cost-effective methods.

Six types of countermeasures were used in Norway to reduce radiation doses following the Chernobyl accident. They were interdiction of food, special feeding, fertilisation of natural pasture, the use of caesium binders, changing diet and changing slaughtering time of reindeer. Countermeasures considered, but not implemented, were the relocation of animals to uncontaminated areas and restriction of some agricultural production in contaminated areas. Table shows the result of cost benefit analyses performed on countermeasures implemented in Norway after the Chernobyl accident.

Table

Cost of countermeasures in terms of manSv saved.

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>NOK/manSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interdiction sheep</td>
<td>1000 000</td>
</tr>
<tr>
<td>Interdiction reindeer</td>
<td>340 000</td>
</tr>
<tr>
<td>Special feeding</td>
<td>250 000</td>
</tr>
<tr>
<td>Change of slaughter time</td>
<td>94 000</td>
</tr>
<tr>
<td>Prussian blue boli</td>
<td>4 000</td>
</tr>
<tr>
<td>Prussian blue concentrate</td>
<td>1 000</td>
</tr>
<tr>
<td>Dietary Advices</td>
<td>40</td>
</tr>
</tbody>
</table>
From a radiation protection point of view it was correct to implement countermeasures in Norway after the Chernobyl accident. The countermeasures implemented reduced the doses, and therefore are expected to reduce the health risk [14]. In retrospect, the countermeasures taken have been proved to be cost-effective. However, in optimizing countermeasures it is necessary to consider more than cost in monetary terms and averted dose.

JUSTIFICATION OF IMPLEMENTING COUNTERMEASURES

Almost all countermeasures used in Norway were justified. The cost of their implementation was less than the possible cost inflicted on the society had the potential dose not been reduced (III, table 6, [14]).

The value of countermeasures can be calculated as the monetary cost of averting radiation dose (in units of manSv). It is assumed in this extent that the relationship between dose and effect is linear. The society's willingness to save a statistical life can be expressed by an a-value. This willingness is compared with other risks faced by society. Currently, in the Nordic countries a value of 100,000 $ per manSv is recommended [15]. Countermeasures with a cost of averted dose below this value are justifiable, and this was the fact for almost every countermeasure used after the Chernobyl accident (III, Table 6). However, the result showed that effect and cost-effectiveness of the implemented countermeasures varied considerable (III, table 6). This together with social and political considerations had to be taken into account in establishing the strategy for mitigating the consequences of the Chernobyl accident.

The countermeasures applied in Norway were mainly in line with those described in the literature [16] but some new were also developed (IV). Crick (1992) showed the importance of cost-benefit analysis in decision-making regarding the implementation of countermeasures in the contaminated agricultural environment. In the wake of the Chernobyl accident, cost-benefit analyses on the use of caesium-binders in Norway came out favourably (more cost-effective) compared with some countermeasures taken in the former USSR [17]. The estimated optimum level estimated for the use of caesium binders for dairy cattle was found to be 40 and 8,000 Bq/kg in the former USSR (Crick 1992). This is in the same range in which the countermeasures were applied in Norway (III).

OPTIMIZING

The cost-effectiveness of different countermeasures varied considerable (III, table 6) but it was necessary to use countermeasures in combination even if some countermeasures were more cost-effective than others. In an optimizing process the aim is to use the most cost-effective of the justifiable countermeasures. This may indicate that one should focus on using
the most cost-effective of the available countermeasures (e.g. the dietary advices) before the use of the less cost-effective ones (e.g. special-feeding). However, the cost per unit averted dose for the different countermeasures is not showing the total cost. The total negative consequences of the Chernobyl accident and use of countermeasures are also dependent on the economic losses from reduced sales of agricultural products due to fear of radiation (III).

Immediately after the accident the situation is not clear and there was insufficient knowledge about the fallout pattern. In Norway, as in several other European countries, the Health Authorities introduced intervention levels for radiocaesium contamination of food. There were little room for optimizing the situation. Later a clearer radiological protection philosophy was introduced. Clearly some countermeasures will have advantages in being practicable and leading to the greatest reduction in dose at minimum cost. This would be the input for a simple cost-benefit analysis but social and psychological factors must also be included in an overall strategy (III), [14]. Overall, the objective of a countermeasure programme is to reduce the dose to the population while minimizing economic and psychosocial consequences.

After the Chernobyl accident, the countermeasures applied were carefully monitored and a more or less optimum situation was achieved (III). In retrospect, it was shown that most of the countermeasures employed were justified (III). For people to be confident that the food they are purchasing carries no or very small health risk is an important point when considering the social cost to society. To have basic food products below the intervention levels is, together with information about health risk, probably one of the major factors in establishing trust among consumers. It is also important that basic food bought in shops should not require the consumers to take any special precautions. Thus it is necessary to compare more than just costs and averted dose.

A decrease in the sale of some agricultural products represented a potential economic loss considerably higher than the cost of implemented countermeasures (III). Not all the countermeasures would have the desired effect of satisfying the consumers. The intervention levels were especially important in this respect. This gave some limited use of dietary advices and the need for countermeasures working in the agricultural production system e.g special feeding and caesium binders. Dietary advices were given to critical groups (VI, VII, VIII) and permitted higher national intervention levels for certain foodstuffs.

The use of only dietary advices alone instead of also special feeding would perhaps have given the same averted dose at a lower cost. However the special feeding program led to activity levels in food below the invention levels (III) and no active involvement by the consumers was called for (III, IV). The combination of the different countermeasures took this into consideration and probably gave the maximum reduction of the total negative consequences.
A decrease in consumption of some of the most affected foods (e.g. lamb) occurred. The decrease in consumption of lamb was about 5 to 10% in the first years (III). This represented a loss of about NOK 50 to 100 mill. On the other hand, if no countermeasures except interdiction had been taken and the intervention was maintained, the cost would have been about 100 to 400 mill NOK each year (III). Without countermeasures, lost sales of lamb could have been considerable and for several NOK 100 mill.

From the discussion above one may conclude that measures taken to protect the population from radiation dosed and health consequences of the Chernobyl accident where relative extensive and resource demanding III, [14]. Their main intent was to reduce the physical health effects by reducing radiation dose. The dose was reduced and the relationship between cost and reduced dose was acceptable and below the value recommended (III). They may also have had beneficial effect on physiological and social health of many people, although firm evidence does not exist. The countermeasures implemented also had a beneficial effect on costs to the agricultural community since international derived intervention level were implemented. Without the implementation of countermeasures the agricultural community would probably have suffered much greater losses through a fall in sales of the more sensitive foods (e.g lamb and reindeer meat).

REFERENCES


