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Publication date:
1993

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Yamamoto, H., Nielsen, S. P., & Nielsen, F. (1993). Predicted effects of countermeasures on radiation doses from contaminated food. (Denmark. Forskningscenter Risoe. Risoe-R; No. 665(EN)).

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Risø-R-665(EN)

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Abstract Quantitative assessments of the effects on radiation-dose reductions from nine typical countermeasures against accidental food contamination have been carried out with dynamic radioecological models. The foodstuffs are assumed to be contaminated with iodine-131, caesium-134 and caesium-137 after a release of radioactive materials from the Ringhals nuclear power station in Sweden resulting from a hypothetical core melt accident. The release of activity of these radionuclides is assumed at 0.07% of the core inventory of the unit 1 reactor (1600 TBq of I-131, 220 TBq of Cs-134 and 190 TBq of Cs-137). Radiation doses are estimated for the 55,000 affected inhabitants along the south-eastern coast of Sweden eating locally produced foodstuffs. The average effective dose equivalent to an individual in the critical group is predicted to be 2.9 mSv from food consumption contaminated with I-131. An accident occurring during winter is estimated to cause average individual doses of 0.32 mSv from Cs-134 and 0.47 mSv from Cs-137, and 9.4 mSv and 6.8 mSv from Cs-134 and Cs-137, respectively, for an accident occurring during summer. Doses from the intake of radioiodine may be reduced by up to a factor of 60 by rejecting contaminated food for 30 days. For the doses from radiocaesium, the largest effect is found from deep ploughing which may reduce the dose by up to a factor of 80.

ISBN 87-550-1875-0
ISSN 0106-2840

Grafisk Service, Risø, 1993

Contents

1 Introduction

The present work is a continuation of a previous study on radiation doses to critical groups from food contaminated after a hypothetical release of radioactive material from the Ringhals nuclear power station (Nielsen and Øhlenschlæger 1991). The present project comprises a quantitative assessment of the dose reductions from various countermeasures applied against a hypothetical radioactive contamination of foodstuffs. For this purpose, a set of computer models which simulate the radiological effects of the countermeasures has been developed. The assessment does not include other exposure pathways like inhalation of airborne radionuclides and external irradiation from radionuclides deposited on the ground. Such exposures may be considered in connection with countermeasures taken directly after an accidental release.

The report presents in Chapter 2 scenarios of the accident with the assumptions for the dose calculations. Chapter 3 identifies the countermeasures examined and describes the scenarios. Chapter 4 describes the models for the calculation of radiation doses from the accident and the doses resulting from the implementation of the countermeasures. In Chapter 5 the results are presented, including the radiological impacts (deposition densities) of the accidental release with maps of the contaminated area. Chapter 6 examines the effects of the countermeasures with calculation results and Chapter 7 gives the conclusions.

2 Accident Scenarios

The accident scenarios are based on a hypothetical core-melt accident in a unit of the Ringhals nuclear power station followed by a release of radioactive material to the surroundings. The release is assumed as the equivalent of 0.07% of the core inventory of iodine and caesium isotopes of the Ringhals nuclear power station unit 1 (corresponding to 0.06% of the inventory of the Forsmark reactor unit 3, Vattenfall 1982).

The calculations of average doses to individuals in the critical group living in the contaminated area and eating locally produced food are based on the following assumptions:

Release:	0.07% Ringhals release of 10 hours duration
Isotopes:	I-131 (1600 TBq), Cs-134 (220 TBq) and Cs-137 (190 TBq)
Meteorology:	Dry condition, Pasquill D, wind speed 5 m/s Rain, Pasquill D, wind speed 5 m/s, precipitation 0.5 mm/h
Seasons:	Winter and summer
Soil types:	High and low root uptake
Annual diet:	Milk (190 l/y), beef (15 kg/y), pork (40 kg/y), white bread (75 kg/y), vegetables (25 kg/y), potatoes (75 kg/y) and apples (50 kg/y)

The activity ratio between the two caesium isotopes in the predicted release (Cs-134/Cs-137 = 1.2) differs from the ratio found from the Chernobyl accident (Cs-134/Cs-137 = 0.55). The reason for this is believed to be differences in reactor type and fuel burn up.

It is assumed that grass is on the fields from 1 May to 31 October, beet- and potato-leaves and leafy vegetables emerge on 20 May. The harvest of cereals is assumed to occur on 28 August, leafy vegetables and apples on 27 September, and beets and potatoes on 27 October.

For the calculation of the doses from the animal produce, it is assumed that the cows are on pasture from 15 May to 15 October. During that period the cows are grazing and being outdoors day and night. They are taken to the stable in the morning and evening for milking and fed concentrates (not contaminated) in addition to cereals of local origin. The winter fodder for the cows is based on the following composition (daily consumption figures): 12 kg hay (harvested on 14 June), 3 kg concentrates (not contaminated), 10 kg barley (harvested on 28 August) and 2 kg fodder beets (harvested on 27 October). The fodder for the pigs is 1.4 kg cereals per day (harvested on 28 August).

For I-131, the radiation doses are calculated for a summer period only and without distinction between soil types. This is because of the lack of vegetation on the fields in winter, and the rapid decay of I-131 (halflife 8 days) would make the impact of an accident during winter trivial. The effects of the difference between the soil types on root uptake are not noticeable in this case, since the halflife is too short to make indirect contamination by root uptake significant.

For the caesium isotopes, calculations were made for the accident scenarios occurring in winter (20 January) and summer (19 July) to illustrate two seasonal extremes. In order to calculate dose commitments, it was necessary to extend the calculation periods (until 50 y), since the halflives of these isotopes are long and their transfers from soil to crops were prolonged.

The area affected by the contamination from the accident is chosen in the south-south-east direction from the Ringhals power plant and extending towards and beyond the city Varberg. This scenario was chosen in order to include typical agricultural areas for the southern part of Sweden. The range covered (50 km) is at the limit of the general use of the deposition model.

3 Countermeasure Scenarios

The countermeasures considered in this project are applied to reduce the internal radiation exposures to humans through consumption of foodstuffs contaminated with radioactive materials from the release. The countermeasures were identified considering the experiences after the Chernobyl accident in 1986. Some countermeasures are implemented directly in the agricultural activities and others in the food processing as well as the food trade. They are as follows:

a) ordinary ploughing and deep ploughing,
b) fertilization,
c) rejection of foodstuffs for shorter or longer time periods,
d) storage of food to allow for decay of radioiodine,
e) change of milk consumption (production of cheese and butter),
f) use of cereals and fruit for animal consumption,
g) reduction of meat contamination by feeding with clean fodder before slaughter,
h) dilution of contaminated cereals with uncontaminated cereals,
i) administration of Prussian blue to animals.

The countermeasures were implemented as described in the following scenarios. The scenarios were constructed without taking the socio-economic impacts due to the implementations of the countermeasures into consideration. The numerical values of the model parameters in the scenarios were based on experimental data from reports by the Commission of the European Communities (CEC 1991a, CEC 1991b) and the Swedish Radiation Protection Institute (Moberg ed. 1991).

a) Ordinary Ploughing and Deep Ploughing

This countermeasure reduces the amount of radiocaesium taken up through the roots of the crops by diluting the radioactivity in the root-zone with uncontaminated soil. A reduction of the amount of radioactivity to be transferred to animals from soil ingestion during grazing is also included. Two types of ploughing were studied - ordinary ploughing and deep ploughing. For the scenario, fields of grass, cereals, vegetables, potatoes and beets were assumed to be ploughed (no treatments were considered for apples).

Ordinary ploughing is similar to that carried out in ordinary agricultural practice. In the scenario, with the first ordinary ploughing after the deposition, the contaminated soil in the root zone was mixed with soil in deeper layers to which the contamination had not migrated. In this way, the radiocaesium concentration in the soil of the root zone was diluted. A value of 2 was adopted as a dilution factor (CEC 1991a). The first ordinary ploughing was assumed to be carried out on the day no. 300 (27 October) of the year of the accident.

Deep ploughing is a special treatment by which the contaminated soil in the root zone is assumed to be replaced almost entirely with uncontaminated deeper soil without any disturbance of fertility in the soil. Considering experimental data (Nilsson 1983, Roed 1990, Roed 1992), 5% of the total radioactivity which was contained in the upper soil layers (and in the grass on the pasture fields) before ploughing were assumed to remain in the surface soil and root zone after ploughing. In the scenario this countermeasure was implemented two days after the initial deposition. No harvest of these crops was assumed in the event year, since all crops in the fields would have been cut or destroyed before or at the ploughing. The cows were kept in the stables and fed with clean fodder after the destruction of the grass. Although the experimental data cited above support an average retention of about 5% of the total radioactivity in the root zone after deep ploughing, it must be noted that the data on deep ploughing are rather scarce compared to the data on ordinary ploughing. Additionally, deep ploughs are not generally available as ordinary ploughs are, for what reason this particular countermeasure could be difficult to implement for a large area.

b) Fertilization

Fertilization with potassium has proved to reduce radiocaesium uptake by crops (CEC 1991b; Rosén 1991). The effect depends on the nutritional conditions in the soil to which potassium is applied. For the scenario, cultivation in soil with low plant-available potassium is assumed. Potassium fertilization of 100-200 kg/ha was applied to the fields of grass, cereals, vegetables, potatoes and beets. The first application after the winter deposition was carried out on the days before the crops emerged in the year of the accident. For the summer scenario, the fertilization was carried out on the day after the deposition of radioactivity. Potassium is applied every year to maintain the effect.

c) Rejection of Foodstuffs for Shorter or Longer Time Periods

This countermeasure reduces the amount of radioactive material transferred to humans at the last stage of the food chain. The scenarios were made separately for iodine and caesium. In case of radioiodine contamination, milk and vegetables are totally rejected. The rejection starts the day after the deposition and lasts for 30 days. In case of caesium contamination, milk, beef and apples are rejected in case of the winter deposition whereas milk, pork and bread are rejected in case of the summer deposition. These foodstuffs are the three dominant contributors to the total dose (from all foodstuffs) for the first year after the deposition when no countermeasures are applied. The rejections of milk, beef and pork are effective for one year after the accident. Apples and cereals for bread making are rejected at harvest of the year of the accident.

d) Storage of Food to Allow for Decay of Radioiodine

This countermeasure utilises the short halflife of I-131 in order to reduce the amount of radioactivity ingested by humans. In the scenario, all the milk and vegetables contaminated with I-131 are stored for certain periods prior to human consumption to allow for radioactive decay of the nuclide. Two different storage periods - a normal period and a maximum period in the general food trade - are examined. For milk, the normal storage period is assumed to be 3 days and the maximum period 7 days (CEC 1991a). For vegetables, the normal and the maximum periods are 5 days and 10 days, respectively (ibid.). The countermeasure starts the day after the deposition and lasts for 30 days.

e) Change of Milk Consumption (Production of Cheese and Milk)

Caesium as well as iodine has a tendency to concentrate in more aqueous products during milk processing, whilst high-protein or fat products, e.g. cheese and butter, are relatively depleted in these elements (CEC 1991a, CEC 1991b). In this countermeasure, the distribution of the elements among dairy products during the processing of the contaminated milk are utilised to reduce the amount of radioactivity to be ingested by the population. The milk production is assumed to be changed completely to that of cheese and butter, and uncontaminated milk becomes available for human milk consumption. The production and consumption of the cheese and the butter starts the day after the deposition and lasts 30 days for the iodine contamination and one year for caesium.

f) Use of Cereals and Fruit for Animal Consumption

This countermeasure reduces the amount of radiocaesium transferred to milk and beef. In the scenario, the cows are fed cereals and apples which are less contaminated than summer grass or winter silage. The altered fodder plan for the cows (daily consumption) comprises 10 kg barley, 3 kg apples and 3 kg concentrates (not contaminated). The countermeasure starts at the beginning of the pasture season after the winter deposition or on the day after the summer deposition and lasts until the beginning of the next pasture season. The cows are kept stabled during this period.

g) Reduction of Meat Contamination by Feeding with Clean Fodder

A change toward qualitatively better animal fodder just prior to slaughter is common practice in livestock farming (CEC 1991a). This countermeasure applies the practice to reduce the radiocaesium concentrations in beef and pork. In the scenario, the cows and the pigs are fed uncontaminated fodder in the last quarter of their lives: 150 days before each cow is slaughtered and 50 days before each pig is slaughtered, assuming that the lives of a typical cow and pig are 600 days and 200 days, respectively (ibid.). The countermeasure starts the day after the deposition and lasts 2 years after the accident. Simultaneously, consumptions of contaminated beef and pork are prohibited until uncontaminated meat becomes available.

h) Dilution of Cereals

This countermeasure reduces the radiocaesium concentration in cereals and cereal products. The contaminated cereals are assumed to be transported to a mill, mixed with cereals from uncontaminated regions and thereby diluted. As a result of this practice, cereals for the fodder for cows and pigs and for bread making are diluted corresponding to a factor of 5. The numerical value of the factor is adopted from experiences in Sweden. The countermeasure is treated as a permanent practice starting at the first harvest after the deposition.

It should be added, that the mixing of cereals is common practice in Swedish cereal mills, and that the dilution factor varies across the country depending on the quality of the harvested cereals. However, for the basic case we assume that no dilution occurs.

i) Administration of Prussian Blue

It is known that administration of Prussian blue (ammoniumhexacyanoferrate) to animals can reduce their caesium uptake (CEC 1991a). The countermeasure is applied to cows and pigs which produce milk, beef and pork, starting the day after the deposition and lasting one year after the accident.

4 Models

For the calculation of the radiation doses from contaminated foodstuffs without any countermeasures, we used dynamic radioecological models (hereafter referred to as the basic models). The main parts of the basic models are developed from Danish experience with radioactive fallout from nuclear weapons testing and from the Chernobyl accident (Øhlenschlæger 1991), and these models were used for the previous project. A revision of the previous model for radiocaesium was made in the present project. Models simulating the countermeasures were developed based on the countermeasure scenarios and implemented into the basic models. The models were implemented as Fortran codes which were made using a model development system for personal computers, TIME-ZERO (Kirchner 1989).

The dose factors for committed effective doses from ingested radionuclides were reviewed with the new ICRP Publication 56 (ICRP 1989) and those used in the previous report for caesium isotopes were revised:

I-131: 110 nSv Bq^{-1} for children
I-131: 13 nSv Bq^{-1} for adults
Cs-134: 19 nSv Bq^{-1} for adults
Cs-137: 13 nSv Bq^{-1} for adults

4.1 Basic Models

The revision of the basic models has comprised corrections of coding errors and modifications for improved simulations of the levels of radiocaesium from the Chernobyl accident observed in Denmark in the period of 1988-1991 after the levels peaked in 1986-87 (Aarkrog et al. 1991) as well as more realistic treatments of the different soil types. A sub-model simulating the metabolism of pigs was added to the basic models for the calculation of radiocaesium concentrations in pork. The main points of the revision are described below. Tables comparing the old and the revised parameter values including the unchanged parameter values are presented in the Appendix A.

Improved Simulation of the Radiocaesium Levels

For the simulation of caesium transfer between soil and crops, the following modifications were made: an introduction of rain splash effects of contamination from surface soil onto the external surfaces of the grass, an introduction of a timedependent fixation rate of caesium in the soil root zone changing its numerical value on the 1800th day after an initial deposition, revisions of the numerical values of densities of the crops on the fields, a revision of the numerical value of the ratio of caesium concentration in grass to that in fruit. The fixation of caesium in soil corresponds to an ecological halflife of 2 years for the first five years after the accident after which it is changed to 10 years (Aarkrog 1992).

The model for the cow metabolism was revised in terms of the numerical values of the parameters which represent transfer of radiocaesium between the model compartments (rate constants).

These revisions provided realistic simulations of the levels of radiocaesium from the Chernobyl accident observed in Denmark.

More Realistic Treatment of Soil Types

An assumption in the previous models that vegetation (grass) is present on the field all the year around regardless of the growing seasons resulted in an overestimation of the level of contamination for the winter scenario. This led to an underestimation of the relative contribution from the root uptake, which depends on the soil type.

The models were revised to simulate the growing season of the crops and to eliminate unrealistic contributions from the deposition on plant surfaces to the total contamination. In addition the numerical values of the concentration ratios of the plants were revised.

With this treatment, realistic effects of difference in soil types on radioactivity concentrations in crops were obtained compared to the results from the previous study.

Implementation of the Pig Model

A simple two-compartment pig model was developed similar to one used for the transfer of radiocaesium to lamb (Nielsen 1992). The model incorporates compartments for the gastro-intestinal tract and for the meat. The implementation of the metabolism includes an assumption of a biological halflife of 40 days for caesium (CEC 1991a).

Reliability of Model Predictions

The modelling of the transfer of radiocaesium from soil to vegetation and further to the animal produce has been changed and improved from the previous model version as described above. However, the selection of the model parameters have always been such that the model predictions have been tuned to agree with the actual levels of radiocaesium observed in Denmark after the Chernobyl accident. The model predictions of concentrations of radionuclides in foodstuffs will therefore generally agree within a factor of 3 compared with actual levels for a given contamination level.

4.2 Models for Countermeasures

For simulation of the countermeasures, the basic models were supplemented with additional mathematical sub-models or the parameter values were modified to represent the countermeasure scenarios described in Chapter 3. The implementation of the countermeasures is described below.

Ordinary Ploughing and Deep Ploughing

In order to simulate the reduction of root uptake by ordinary ploughing, the results of the radioactivity concentrations in the mixture of the surface soil, root-zone soil, deeper-layer soil and plants (in the case of grass field) were divided by 2 at the moment of the first ordinary ploughing. For deep ploughing, in order to represent the residual radioactivities in the soil layers after ploughing, the numerical values of the concentrations were multiplied by 0.05 at the moment of deep ploughing.

Fertilization

For simulation of the reduction of radioactivity transfer through roots by fertilization, the concentration ratios for root uptake were reduced by the following factors during the growing periods of the crops: 10 for grass and cereals, 1.5 for leafy vegetables and 1.0 (no effect) for root vegetables. The numerical values of the factors were based on experimental data after the Chernobyl accident (Rosén 1991) and were applied regardless of the soil types.

Rejection of Foodstuffs

The radioactivity concentrations in the rejected foodstuffs were set to zero during the rejection periods for simulation of the consumption mode of these foodstuffs by the population.

Storage of Food

The radioiodine concentration in the stored food at a moment of consumption was determined by including radioactive decay during the storage period.

Change of Milk Consumption (Production of Cheese and Butter)

In order to estimate the radioactivity concentrations in cheese and butter produced from the contaminated milk, ratios of radioactivity concentration of those products to the original milk were introduced. For Cs-134 and Cs-137, the ratios are 0.5 for cheese and 0.3 for butter, and for I-131 the ratios are 2 for cheese and 0.9 for butter on a fresh weight basis (CEC 1991a). The annual individual consumption of cheese and butter is assumed to be 12 kg and 7 kg, respectively (ibid.).

Use of Cereals and Fruit for Animal Consumption

A sub-model representing the fodder plan for the cows was modified to simulate the altered fodder plan. The value for the cow's intake rate of radioactivity from contaminated surface soil during grazing was set to zero for the application period of this countermeasure.

Feeding with Clean Fodder Before Slaughter

During animal feeding with clean fodder, the radiocaesium concentrations in beef or pork are assumed to decrease with effective halflives based on a combination of the radioactive halflife and the biological halflife. To check the effective halflives implemented for cows and pigs in the models, the basic model was run using a constant daily intake of radioactivity. The halflifes for Cs-134 were found from the simulations to be 32 days in beef and 38 days in pork, and for Cs-137 to be 34 days in beef and 40 days in pork. These values compare reasonably well with the default values from CEC (1991a) which for Cs-137 are 40 days for beef and 35 days for pork. For the implementation of the present countermeasure the radiocaesium concentrations in the meat at a moment of consumption were estimated by calculating the decrease during the periods of using clean fodder before slaughter (150 days for cows and 50 days for pigs).

Dilution of Cereals

The calculation of radiocaesium concentrations in the cereals and cereal products which were diluted with uncontaminated crops was implemented by multiplying the concentrations by a dilution factor of 0.2.

Administration of Prussian Blue

For simulation of the reduction of radiocaesium uptake by domestic animals given Prussian blue, the radioactivity concentrations in the foodstuffs were reduced by the following factors at human consumption: 5.5 for milk, 4.0 for beef and 9.1 for pork. The numerical values of the factors were adopted from experimental data (CEC 1991a).

5 Dose Calculations

The radiation doses to the population without application of the countermeasures were estimated using the basic models. In order to obtain average individual doses from the deposition, the calculations were made in three steps:

1) A deposition pattern for each radionuclide was calculated over the contaminated area and weighted with the population distribution in the area to obtain population-weighted concentrations (person Bq m^{-2}). The population density was based on statistics for the Halland county (Nyholm 1992).
2) Doses (first-year doses and dose commitments) from unit depositions of radioactivity were calculated for each radionuclide (Sv per Bq m^{-2}).
3) The results from 1) and 2) were combined to calculate collective doses (person Sv) divided by the total population to obtain average individual doses (Sv) from the deposition.

5.1 Deposition Map over the Contaminated Area

The deposition patterns over the contaminated area was estimated using the Risø PLUCON dispersion model (Thykier-Nielsen 1980). For I-131 there was only a marginal difference (20%) between the results for the dry and the wet deposition for which reason the average deposition was selected. The relatively small difference between wet and dry deposition is due to the highly reactive elemental iodine which is assumed at 10% of the total iodine release. The chemical form of the remaining iodine fraction is assumed to be organic. The deposition map for I-131 is shown in Figure 1. Figures 2 and 3 show the maps for Cs-134 for the dry and the wet condition, respectively, and Figures 4 and 5 for the dry and the wet deposition of Cs-137. From the calculation, the population-weighted radioactivity concentrations were estimated for the affected area. The population distribution was used at the finest resolution (1 × 1 km^2) and a coarser presentation of the data is shown in Figure 6. The following list gives the population-weighted concentrations:

I-131: 51 person GBq m^{-2} averaged for the two conditions,
Cs-134: 1.6 person GBq m^{-2} for the dry condition,
3.7 person GBq m^{-2} for the wet condition,
Cs-137: 1.4 person GBq m^{-2} for the dry condition,
3.1 person GBq m^{-2} for the wet condition.

A total of 55,000 persons are found to be affected by the contamination shown in the Figures 1 - 5 by summing the population distribution within the sector 140°-160° from Figure 6. The variability of the contamination over this area is illustrated in the figures and in Table 1 which gives the average, maximum and minimum deposition values for the isotopes and conditions considered. If we interpret the variability of the contamination in terms of dose variability by assuming truly local food production, we find that the maximum doses rise a factor of about 14 over the average doses, and that the minimum doses lie a factor of about 3 lower than the average doses.

5.2 Doses from Unit Deposition

The doses were calculated from the deposition of 1 Bq m^{-2} of each radionuclide and expressed as total doses (summation of the doses from all foodstuffs). The results of these calculations are given in Appendix B.

5.2.1 Doses from I-131

The doses from consumption of milk and vegetables contaminated after the unit deposition of I-131 are unchanged from the previous study and shown in Table B1. The doses for children are due to milk consumption only while those for adults are from the consumption of both milk and vegetables. A fraction of 37% of the adult dose is due to the consumption of vegetables and 63% to that of milk.

5.2.2 Doses from Cs-134 and Cs-137

The doses from unit depositions of the caesium isotopes are shown for Cs-134 in Table B2 and

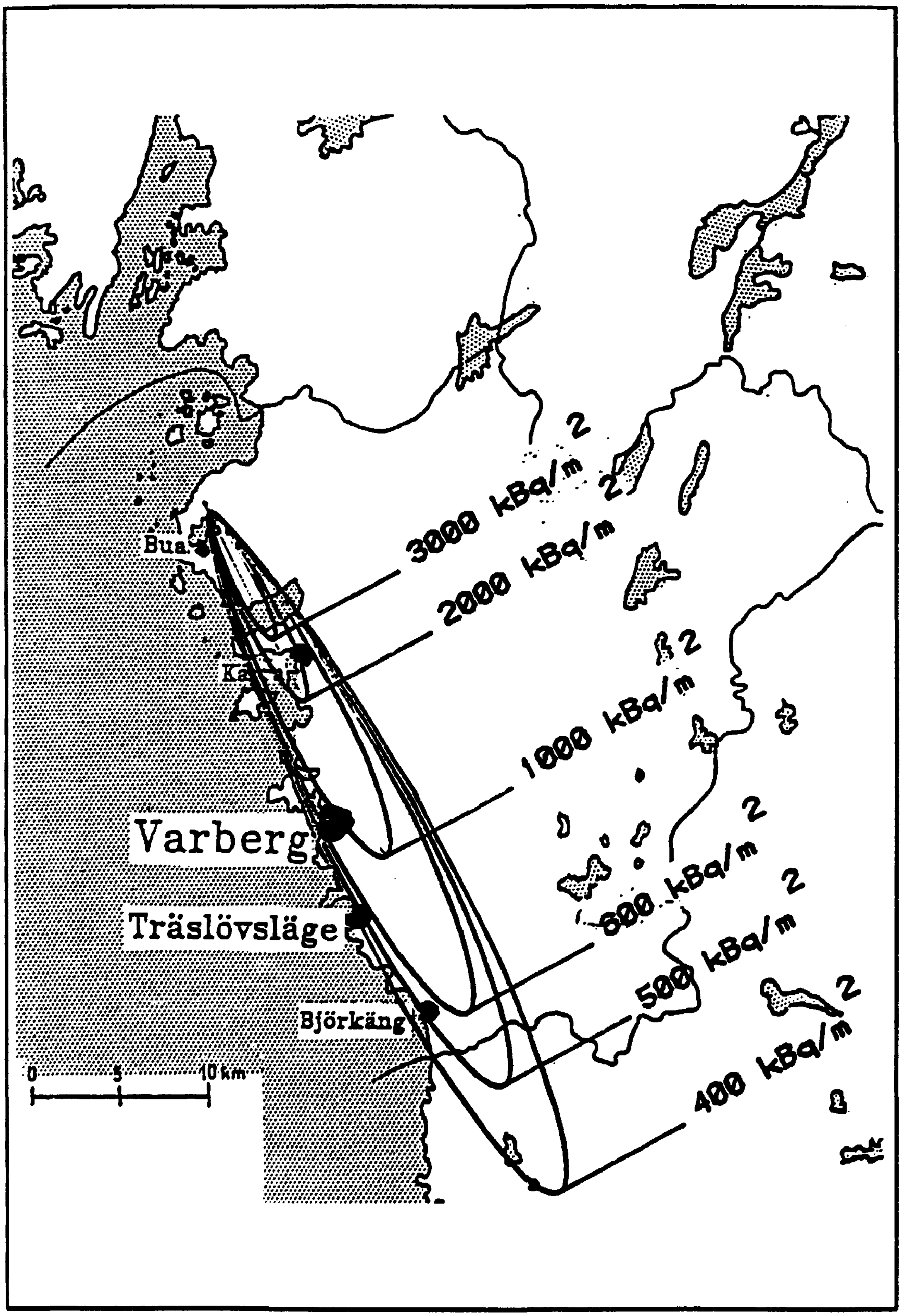

Figure 1. Deposition of inorganic I-131 calculated by the PLUCON model for a release of 1600 TBq of I-131 from the Ringhals power station for an average of dry and wet conditions.

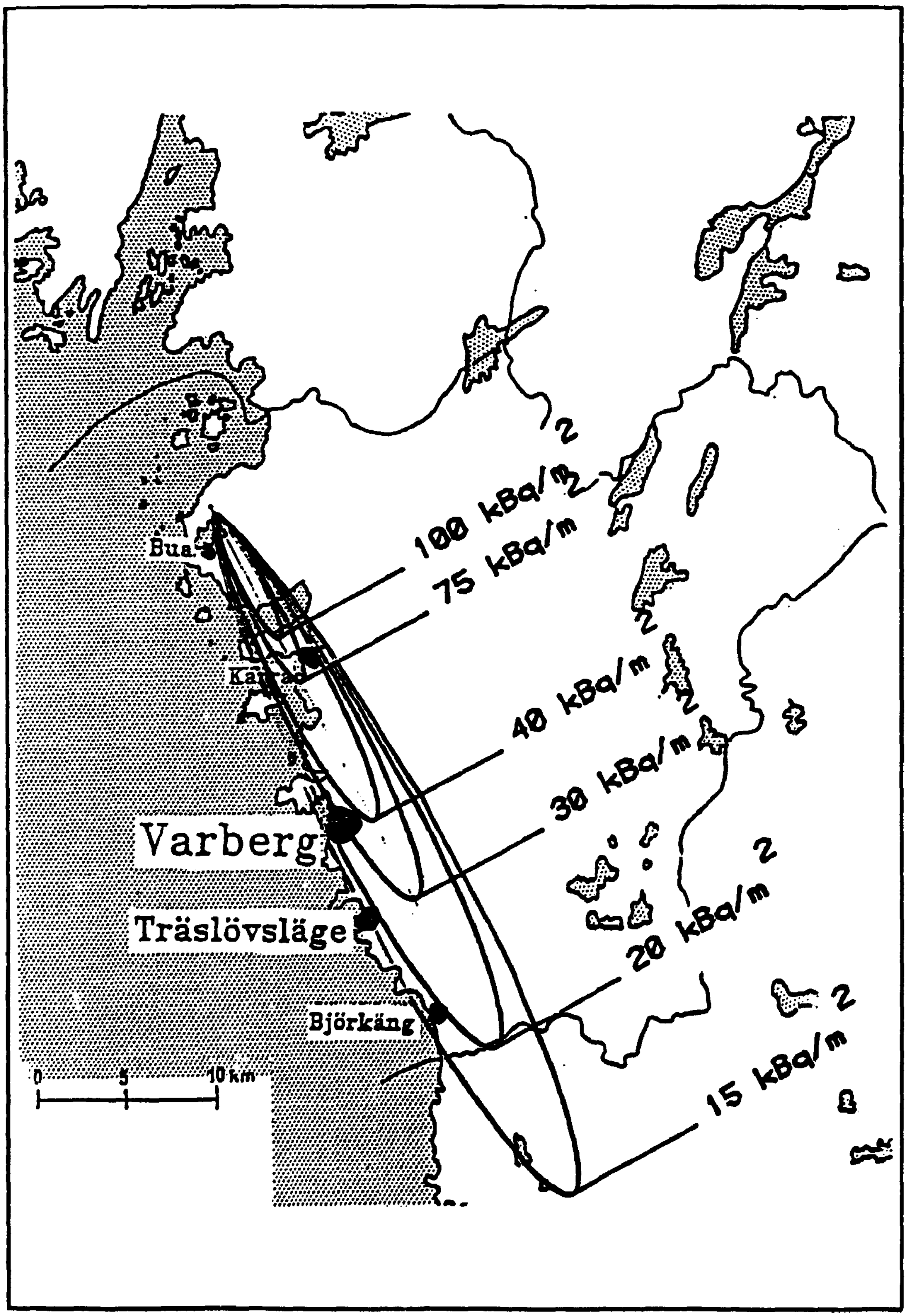

Figure 2. Deposition of Cs-134 calculated by the PLUCON model for a release of 220 TBq of Cs-134 from the Ringhals power station for dry conditions.

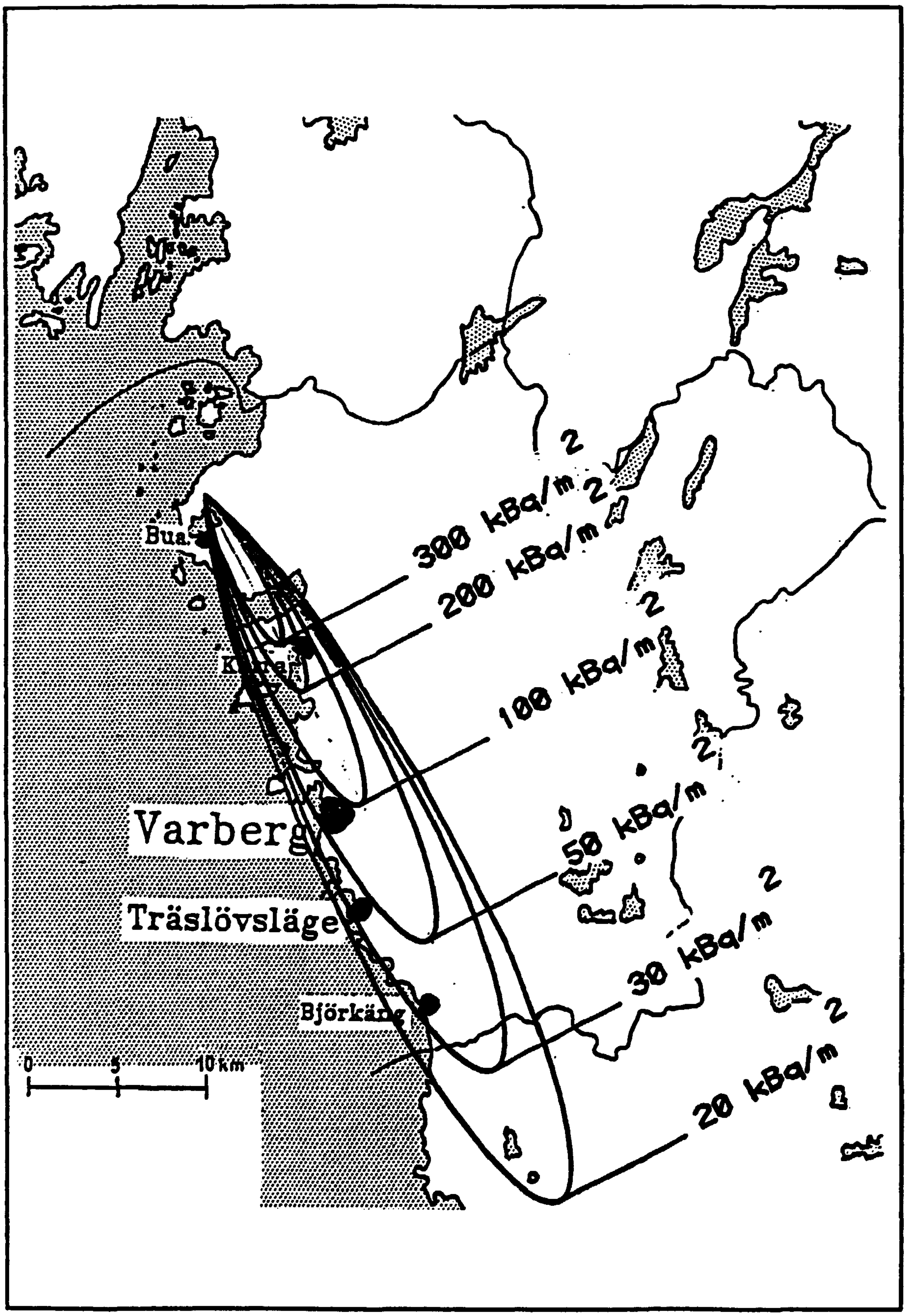

Figure 3. Deposition of Cs-134 calculated by the PLUCON model for a release of 220 TBq of Cs-134 from the Ringhals power station for wet conditions.

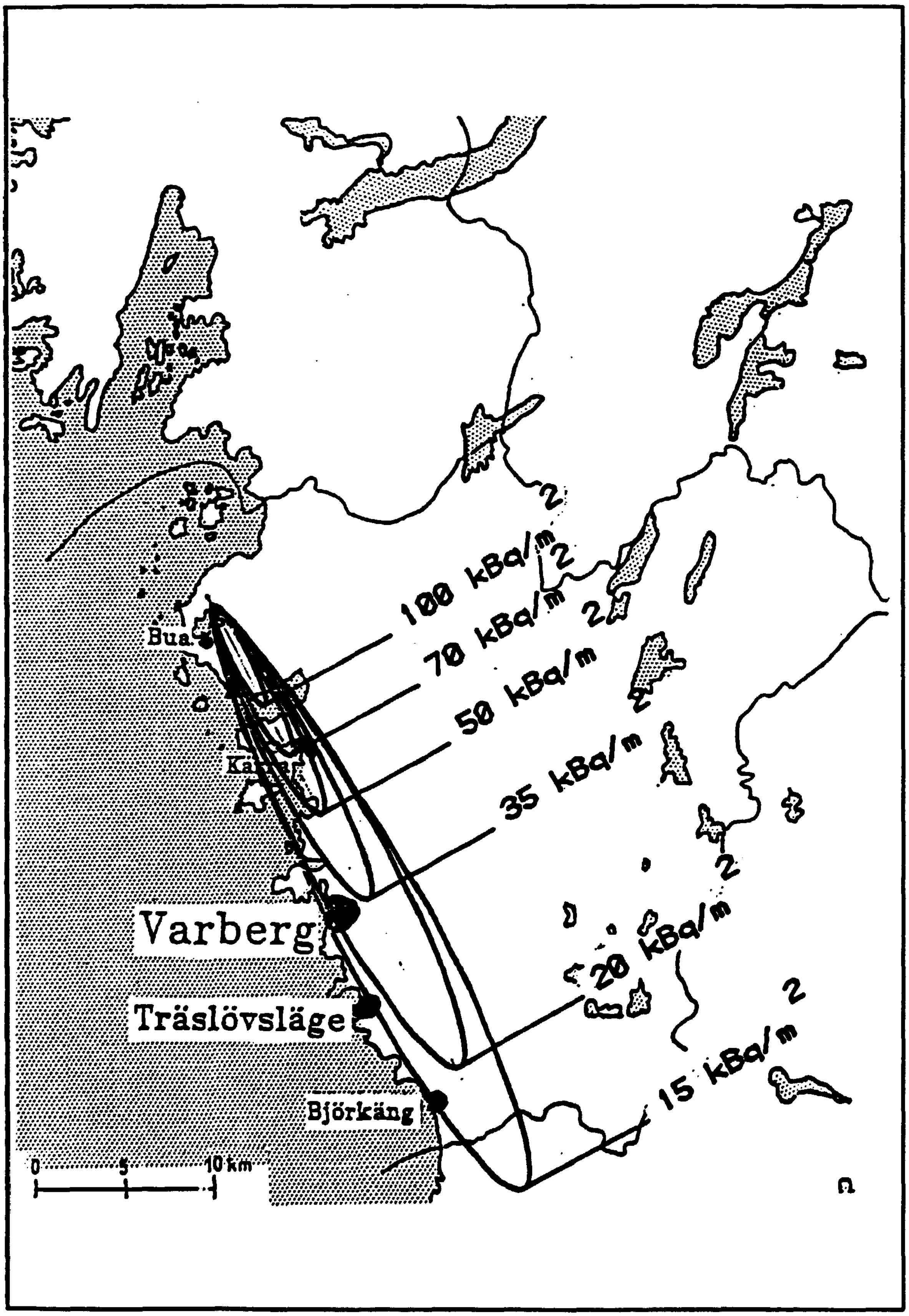

Figure 4. Deposition of Cs-137 calculated by the PLUCON model for a release of 190 TBq of Cs-137 from the Ringhals power station for dry conditions.

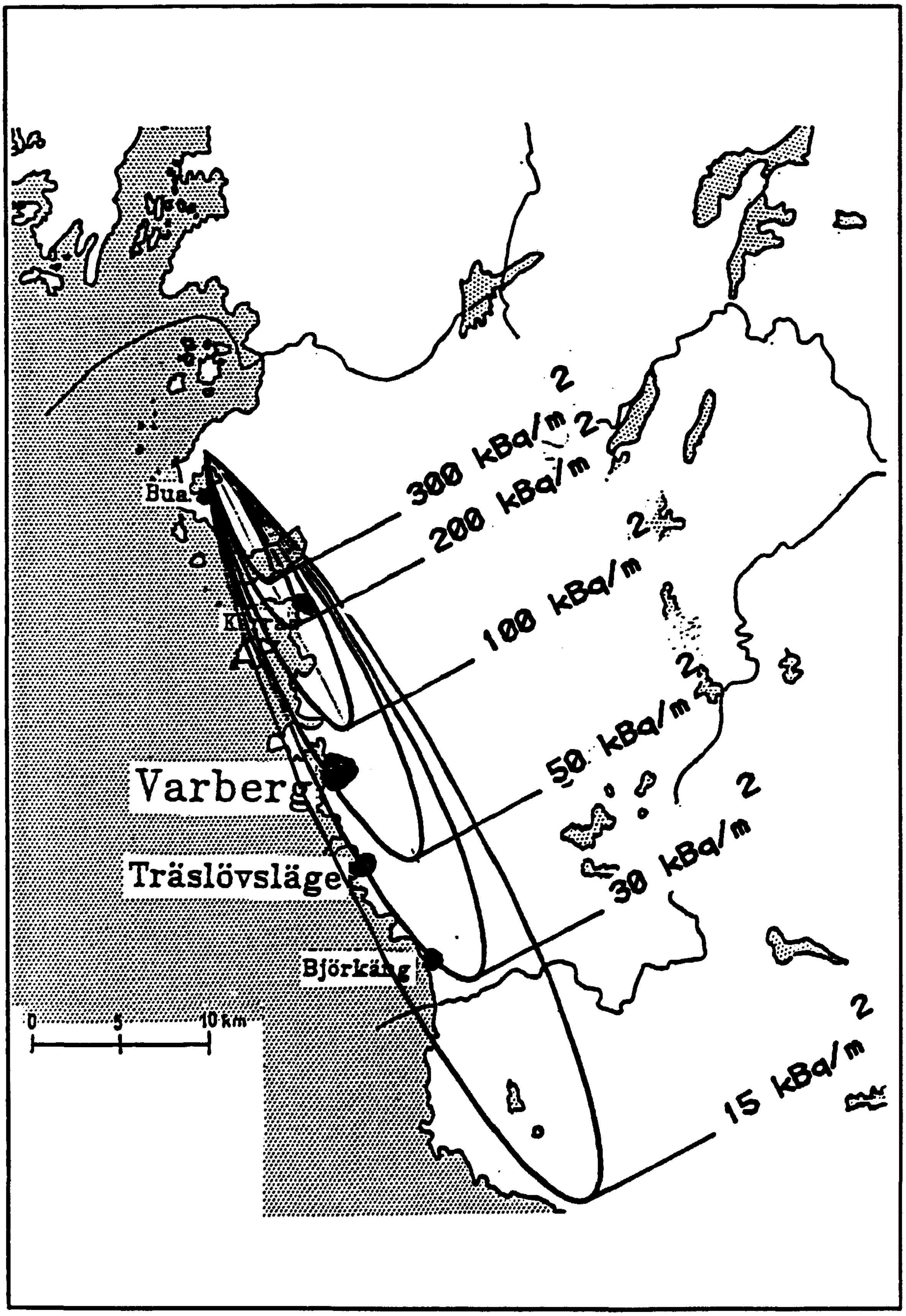

Figure 5. Deposition of Cs-137 calculated by the PLUCON model for a release of 190 TBq of Cs-137 from the Ringhals power station for wet conditions.

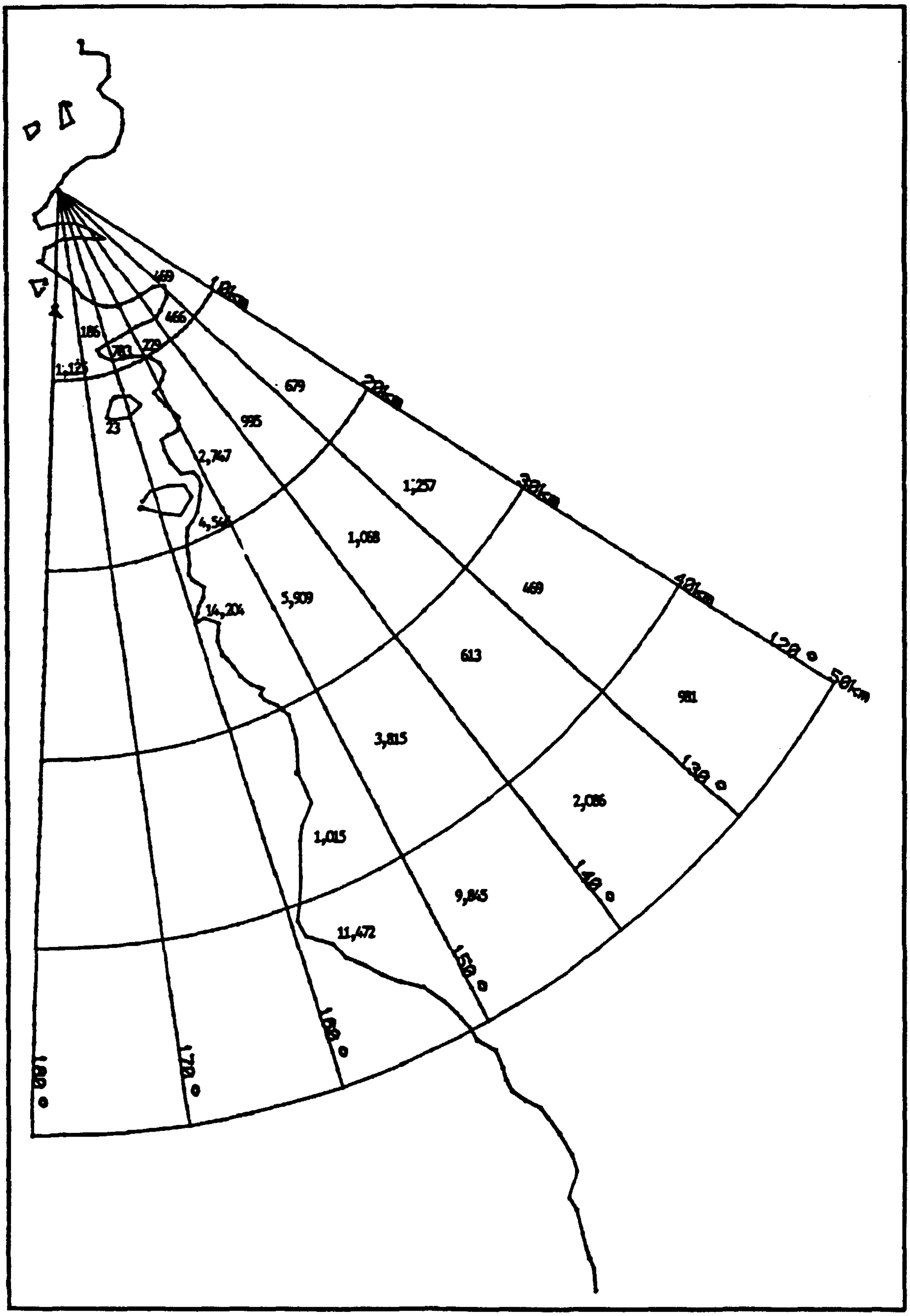

Figure 6. Population distribution used for the calculation of average individual doses from ingestion of contaminated foodstuffs (Nyholm 1992).

for Cs-137 in Table B3. The doses are given as first-year doses (doses received during the first 365 days after the accident) and dose commitments for the winter and summer deposition as well as for two soil types. The doses were estimated for adults. The dose commitments for radiocaesium were calculated from the estimated dose rates for sufficiently long time periods to ensure a negligible truncation (< 1%). For the winter deposition each simulation time was 50 y and for the summer deposition each simulation time was 30 y. The reason for this difference is that for the winter scenarios the root uptake is an important transfer mechanism where the rate of fixation of caesium to the soil (10 y halflife) is the limiting process. For the summer scenario it is the direct contamination of the crops that dominates and the root uptake is negligible.

The relative contributions to the total doses from consumption of each foodstuff category are shown in Table B4 and Table B5 for Cs-134 and in Table B6 and Table B7 for Cs-137.

The dose from pork consumption shows a higher contribution to the total dose for the summer deposition than for the winter case. This is due to the higher contamination levels of cereals in case of an accident during summer and the fact that cereals are used for the pigs' fodder.

5.3 Doses from the Total Deposition

Average individual doses were calculated in the way described above. The calculations were made for mineral soil which is characteristic for the soil types of the area considered (Eriksson 1992).

5.3.1 Doses from I-131

Table 2 shows the results of the individual average doses of the affected population. The doses are estimated as effective dose equivalent commitments. The fraction of the children (under the age of one year) was assumed as 1.4% of the total population based on the Swedish statistics data (Statistical Yearbook 1993).

5.3.2 Doses from Cs-134 and Cs-137

Table 3 shows the results of the individual average doses to the affected population from the deposition for the dry conditions and in Table 4 for the rainy conditions. The doses are estimated as first-year doses (effective dose equivalents committed from the first-year's food consumption) and effective dose equivalent commitments to adults.

5.3.3 Collective Doses

Collective doses were calculated for the population affected (55,000 individuals) and the results are shown in the Tables 5, 6 and 7.

6 Effects of the Countermeasures

The countermeasures were simulated with the models described in Chapter 4 and radiation doses to the critical group from the implementation of these countermeasures were calculated assuming an initial deposition of each radionuclide of 1 Bq per m^{-2}. The effect of each countermeasure is expressed as the ratio of the radiation dose with the countermeasure applied (reduced doses) to that without any countermeasures (the basic dose, see Chapter 5.). The effects were estimated for nuclide-specific doses. The effects on the first-year doses and the dose commitments were examined in connection with the seasons and the soil types.

6.1 Effects on Iodine Contamination

The dose reductions found from the calculations are shown in Table 8. There was no significant difference between the effects on the doses to adults and those to children.

The largest reduction of the radiation dose, a factor of 60, was realised by the rejection of milk and vegetables for 30 days after the deposition, reflecting extensive decay of radioiodine during this period. The storage of milk and vegetables in fresh form for their maximum possible periods could save half of the doses due to the physical halflife of I-131. Powdered milk or frozen vegetables, for example, could be stored for longer periods and thus provide a further dose reduction. The change of milk consumption by production of cheese and butter could halve the doses even under the assumption of immediate consumption after their production. Cheese and butter have an advantage of permitting storage for a long period. A possibility to store these products for a longer period could therefore be considered to allow for further decay of I-131.

6.2 Effects on Caesium Contamination

The dose ratios found from the calculations are shown in Tables 9 and 10 for Cs-134 and in Tables 11 and 12 for Cs-137. The trends of the effects for Cs-134 are similar to those for Cs-137. The influence on the dose ratios from the two seasons (winter and summer) is significant whereas that from the two soil types is less pronounced. This is attributed to a dominant contribution to the contamination of crops from the direct deposition onto the plant surfaces compared to that from the root uptake.

The largest reduction of the doses is found from deep ploughing using the assumptions made. This particular countermeasure yields a reduction of up to two orders of magnitude. This results from a large reduction of the caesium transport in every pathway to food contamination. The destruction of the highly contaminated first year's harvests at the ploughing also contributes to the effect. The other countermeasures against root uptake of radioactive materials by crops - ordinary ploughing and fertilization - produce little or no effects except for winter deposition on organic soil. This is due to a relatively small contribution from root uptake to the total contamination except for organic soil. The assumptions of the time of initiation for the countermeasures also influence the results. For example, the assumed ordinary ploughing at the end of October causes no effects on the first-year's harvest.

We have also studied the effect on doses from Cs-137 of an ordinary ploughing carried out shortly after the deposition occurs accompanied by the destruction of all crops on the fields. The effect of ploughing carried out after a summer deposition and the rejection of all contaminated food except fruit was estimated to reduce the first-year dose from the mineral soil contaminated with Cs-137 by a factor of 80, and a factor of 30 for the dose commitment. The reduction for the first year is similar to that from deep ploughing and attributed primarily to the interruption of the consumption of the contaminated foodstuffs. For the case of winter deposition, we have examined an ordinary ploughing at the time of resowing in the end of winter, accompanied by destruction of the crops sown in the previous year. The dose reduction was found to be a factor of 3 for the first-year dose and mainly due to a reduced amount of radiocaesium transferred from the diluted surface soil to grass by rain splash, and for the dose commitment a reduction factor of 2 was found.

Rejection of selected foodstuffs for one year after the deposition has a relatively large effect on the first-year doses. The effect on the first-year doses depend on the remaining components of the diet (Table B4 or B6) and this is why the effect is smaller in summer than in winter. The effect on the dose commitments was related to the dose saved in the first year since the rejection was assumed to last only one year after the event. A contribution of the dose saved in the first year to the dose commitment is insignificant in the winter deposition. The effect in this case is therefore smaller on the dose commitment than on the first-year doses.

Use of cereals and fruit for animal consumption is found to be effective mainly on the first-year doses after the winter deposition. In the summer case, higher levels of contamination of cereals by the initial direct deposition on the crops weaken the effect. The higher cereal contamination, on the contrary, strengthen the effect of dilution of cereals with uncontaminated crops in the summer deposition, since this countermeasure affects caesium concentration in bread - a major dose contributor for the summer scenario.

Change of milk consumption could save about 70% of the first-year dose in case of the winter deposition. In the first year after the deposition, the individual intake of radiocaesium from ingestion of cheese and butter corresponds to 4% of the intake from the original milk. However, the reduction of the intake does not lead to a similar reduction of the total dose since the contribution of milk consumption to the total dose is 70% at the most.

The effects of using clean fodder for the animals before slaughter are independent of the seasons and not very significant. Residual radiocaesium in the meat after feeding clean fodder are estimated as 5% and 40% of untreated beef and pork, respectively. Nevertheless, the decrease of radioactivity in the meat does not significantly reduce the total doses due to the limited contribution from the meat to the total doses.

The trend of the effects for the two seasons found from administration of Prussian blue is analogous to that found from change of milk consumption: Relatively large dose reductions are obtained only for the first-year doses from the winter deposition. The first-year doses can be reduced by up to a factor of 5, and the dose commitment by up to a factor of 2.

6.3 Illustrative Example

As an illustrative example we may consider the effect of a set of countermeasures on the average doses from the three isotopes after a release of activity during summer in dry conditions. We assume that selected contaminated foodstuffs (milk, beef, pork and vegetables) are rejected for one year after the accident.

The basic case without countermeasures gives to the total population an average individual dose commitment of 2.9 mSv from I-131, 4.1 mSv from Cs-134 and 3.1 mSv from Cs-137 or a total dose commitment of 10.1 mSv.

For the effects of the countermeasures we have found a reduction factor for I-131 of 0.017 (Table 8), a factor of 0.22 (Table 9) for Cs-134 and a factor of 0.24 (Table 11) for Cs-137. We thus find an average individual dose commitment of $0.017 \times 2.9 + 0.22 \times 4.1 + 0.24 \times 3.1 = 1.7$ mSv corresponding to an overall reduction factor of $1.7 / 10.1 = 0.17$.

7 Conclusions

Quantitative assessments of the effects on radiation dose reductions from various countermeasures assumed against accidental food contamination have been carried out with dynamic radioecological models developed for this purpose.

The foodstuffs were assumed to be contaminated after a release of radioactive materials from the Ringhals nuclear power station after a hypothetical core melt accident. The release was assumed to amount to 0.07% of the core inventory of iodine-131 (1600 TBq), caesium-134 (220 TBq) and caesium-137 (190 TBq) for the Ringhals nuclear power station unit 1.

The size of the contaminated area was estimated using the Risø PLUCON dispersion model and assuming a north-north-west wind direction towards Varberg. The deposition of radioiodine from a release of 1600 TBq inorganic I-131 was predicted to reach a distance of about 40 km along the coast of the area at levels higher than 400 kBq m^{-2}. The same distance was estimated for the dry deposition of radiocaesium at levels higher than 15 kBq m^{-2} from releases of 220 TBq of Cs-134 and 190 TBq of Cs-137. The deposition levels were higher for the rainy condition.

The radiation doses were calculated with dynamic radioecological models using typical Swed-

The doses were expressed as average dose commitments to individuals of the critical group eating locally produced food. The dose commitment from I-131 was estimated to be 2.9 mSv covering the range of 15 mSv to children under 1 year and 2.7 mSv to adults. The dose commitments from dry deposition of Cs-134 and Cs-137 were predicted to be 0.14 mSv and 0.21 mSv, respectively, for an accident during the winter season and 4.1 mSv and 3.1 mSv, respectively, for an accident during the summer. The dose commitments from wet deposition of Cs-134 and Cs-137 were predicted to be 0.32 mSv and 0.47 mSv, respectively, for a winter accident and 9.4 mSv and 6.8 mSv, respectively, for an accident during the summer.

Nine typical countermeasures have been implemented into the radioecological models. The effects of these countermeasures have been estimated in terms of reduced doses to individuals in the critical group. Against I-131 contamination, the countermeasures utilising the short halflife of the nuclide appear quite effective. Especially, rejecting contaminated food for 30 days can reduce the dose by a factor of 60. Against radiocaesium contamination, the largest effect is found from deep ploughing which may reduce the dose comthe given assumptions. However, the dose-reduction effect of this particular countermeasure is less well documented than those of the other countermeasures. Rejection of contaminated food for one year has a relatively high effect on the first-year dose, but this high effect does not extend to the dose commitment where we find reductions up to a factor of about 4. On the other hand, the first-year dose is a substantial fraction of the dose commitment. The other countermeasures reduce doses by a factor of two at most.

The results of the present assessment are as good as the data on which the models and their parameters are based. The models for the transfer of radioactivity through the foodchains are tuned to experimental data from Denmark after the Chernobyl accident giving predictions that agree with observations within a factor of 3. No formal parameter uncertainty analysis has been carried out, but the different accident scenarios are chosen to reflect the influence of meteorology, seasons and soil types. The predicted results thus illustrate the range of values expected from variations of these important conditions: dry and wet deposition, deposition in winter and summer, and high and low root uptake from soil to plant. The reduction factors represent average conditions and only little information is available on the variability of the reduction factors adopted from the references.

The set of models developed in this project will serve as a useful tool for emergency planning. Future work will include establishment of scenarios of countermeasures based on cost-benefit considerations.

Acknowledgements

The authors wish to thank Kjell Nyholm, the Swedish Radiation Protection Institute, who provided us with the population distribution data from the Halland county. This work was done under contract PT-92.0080 with Vattenfall AB and contract SSI P 682.92 with the Swedish Radiation Protection Institute.

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Tables

Table 1. Deposition of radionuclides over the area considered showing average, maximum and minimum values (MBq m^{-2}). The deposition is calculated with the PLUCON dispersion model (Thykier-Nielsen 1980).

Nuclide	Condition	Average deposition (MBq m^{-2})	Maximum deposition (MBq m^{-2})	Minimum deposition (MBq m^{-2})
I-131	Average	0.9	11	0.4
Cs-134	Dry	0.03	0.5	0.015
Cs-134	Wet	0.07	1	0.02
Cs-137	Dry	0.03	0.4	0.015
Cs-137	Wet	0.06	0.8	0.015

Table 2. Average individual effective dose equivalent from the total deposition of I-131.

Dose to children (mSv)	Dose to adults (mSv)	Dose to total population (mSv)
15	2.7	2.9

Table 3. Average individual effective dose equivalent from dry deposition of radiocaesium on mineral soil.

Isotope	Season	First-year dose (mSv)	Dose commitment (mSv)
Cs-134	winter	0.070	0.14
Cs-134	summer	3.5	4.1
Cs-137	winter	0.053	0.21
Cs-137	summer	2.4	3.1

Table 4. Average individual effective dose equivalent from wet deposition of radiocaesium on mineral soil.

Isotope	Season	First-year dose (mSv)	Dose commitment (mSv)
Cs-134	winter	0.16	0.32
Cs-134	summer	8.1	9.4
Cs-137	winter	0.12	0.47
Cs-137	summer	5.2	6.8

Table 5. Collective effective dose equivalent from the total deposition of I-131.

Dose to children (man Sv)	Dose to adults (man Sv)	Dose to total population (man Sv)
11	150	160

Table 6. Collective effective dose equivalent from dry deposition of radiocaesium on mineral soil.

Isotope	Season	First-year dose (man Sv)	Dose commitment (man Sv)
Cs-134	winter	3.8	7.7
Cs-134	summer	190	220
Cs-137	winter	2.9	12
Cs-137	summer	130	170

Table 7. Collective effective dose equivalent from wet deposition of radiocaesium on mineral soil.

Isotope	Season	First-year dose (man Sv)	Dose commitment (man Sv)
Cs-134	winter	8.9	18
Cs-134	summer	440	520
Cs-137	winter	6.5	26
Cs-137	summer	290	370

Table 8. Effects of the countermeasures against dose commitments due to deposition of I-131 expressed as dose reduction ratios.

Countermeasure	Ratio = Reduced dose / Basic dose Children	Adults
Rejection of foodstuffs	0.017	0.017
Storage		
milk ; 3 days veg. ; 5 days	0.75	0.72
milk ; 7 days veg. ; 10 days	0.53	0.48
Change of milk consumption	--	0.48

Table 9. Effects of the countermeasures against first-year doses and dose commitments to adults due to deposition of Cs-134 on mineral soil expressed as dose reduction ratios.

Countermeasure	Ratio = Reduced dose / Basic dose			
	Winter		Summer	
	First-year	Commitment	First-year	Commitment
Ploughing				
ordinary	1.0	0.90	1.0	1.0
deep	0.011	0.044	0.011	0.012
Fertilization	1.0	0.92	1.0	1.0
Rejection of foodstuffs	0.017	0.50	0.17	0.22
Change of milk consumption	0.32	0.65	0.61	0.69
Cereals & fruit for feed	0.034	0.33	0.59	0.68
Feeding with clean fodder	0.75	0.79	0.70	0.74
Dilution of cereals	1.0	0.92	0.54	0.51
Prussian blue	0.22	0.60	0.36	0.48

Table 10. Effects of the countermeasures against first-year doses and dose commitments to adults due to deposition of Cs-134 on organic soil expressed as dose reduction ratios.

Countermeasure	Ratio = Reduced dose / Basic dose			
	Winter		Summer	
	First-year	Commitment	First-year	Commitment
Ploughing				
ordinary	1.0	0.63	1.0	0.94
deep	0.010	0.079	0.011	0.020
Fertilization	0.86	0.45	1.0	0.94
Rejection of foodstuffs	0.069	0.84	0.17	0.29
Change of milk consumption	0.34	0.89	0.61	0.69
Cereals & fruit for feed	0.11	0.79	0.60	0.69
Feeding with clean fodder	0.72	0.89	0.70	0.75
Dilution of cereals	0.93	0.68	0.54	0.50
Prussian blue	0.23	0.89	0.37	0.51

Table 11. Effects of the countermeasures against first-year doses and dose commitments to adults due to deposition of Cs-137 on mineral soil expressed as dose reduction ratios.

Countermeasure	Ratio = Reduced dose / Basic dose			
	Winter		Summer	
	First-year	Commitment	First-year	Commitment
Ploughing				
ordinary	1.0	0.78	1.0	1.0
deep	0.011	0.076	0.012	0.015
Fertilization	0.95	0.84	1.0	1.0
Rejection of foodstuffs	0.017	0.75	0.16	0.24
Change of milk consumption	0.31	0.83	0.63	0.72
Cereals & fruit for feed	0.035	0.65	0.63	0.72
Feeding with flean fodder	0.71	0.88	0.71	0.74
Dilution of cereals	0.95	0.87	0.52	0.48
Prussian blue	0.21	0.80	0.38	0.52

Table 12. Effects of the countermeasures against first-year doses and dose commitments to adults due to deposition of Cs-137 on organic soil expressed as dose reduction ratios.

Countermeasure	Ratio = Reduced dose / Basic dose			
	Winter		Summer	
	First-year	Commitment	First-year	Commitment
Ploughing				
ordinary	1.0	0.59	1.0	0.88
deep	0.011	0.096	0.012	0.036
Fertilization	0.88	0.39	1.0	0.81
Rejection of foodstuffs	0.075	0.94	0.16	0.44
Change of milk consumption	0.36	0.96	0.63	0.81
Cereals & fruit for feed	0.12	0.94	0.65	0.81
Feeding with clean fodder	0.75	0.94	0.71	0.81
Dilution of cereals	0.96	0.65	0.52	0.51
Prussian blue	0.25	0.96	0.38	0.63

Appendix A

Parameter Values for the Caesium Model

Description and Unit	Previous Value	Present Value
Dose factor [nSv Bq^{-1}] for adults		
Cs-134:	20	19
Cs-137:	14	13
Date of ploughing and sowing [Day No.]	135 (15 May)	300 (27 October)
Resuspension factor [m^{-1}]	1.72E-6	< 2000 days: 1.4E-5*((time-event) **(-1.26)) otherwise: 1.0E-9
Splashing rate [d^{-1}]	not used	3.0E-5
Deposition velocity, dry deposition [m d^{-1}]	86.4	172.8
Washout coefficient	1.0E+6	1.0E+6
Transfer factor (TF) from upper soil to root zone [d^{-1}]	1.98E-2	6.3E-4
Root zone depth [m]	0.25	0.25
TF, fixation of Cs in root zone [d^{-1}]	3.2E-3	<1800 days: 1E-3 >1800 days: 2E-4
Weathering constant [d^{-1}]	0.08	0.08
Fraction of surficial deposit absorped into plant	0.05	0.05
Density of plants		
Grass:	0.1	0.14
Beet leaves:	3.5	2.0
Beetroot (Potatoes):	6.5	3.0
Vegetables:	2.0	2.0
[kg m^{-2}]		
Concentration ratio of Cs for mineral soil		
Grass:	0.032	0.03
Beets:	0.04	0.3
Beet leaves:	0.2	1.2
Vegetables:	0.5	0.5
Cereals:	0.02	0.1
[Bq kg^{-1} plant per Bq kg^{-1} soil-dry weight]		
Concentration ratio of Cs for organic soil		
Grass:	0.3	0.3
Beets:	0.04	0.6
Beet leaves:	0.2	1.2
Vegetables:	0.5	1.0
Cereals:	0.2	1.0
[Bq kg^{-1} plant per Bq kg^{-1} soil-dry weight]		
Radioactivity ratio fruit to	0.05	First year: 0.01

Parameters for metabolism of cows

RC: Rate constant, unit [d^{-1}]

Description and Unit	Previous Value	Present Value
Breathing rate [$m^3 d^{-1}$]	38.8	130
RC: soil consumption	0.03	0.03
RC: from lungs to stomach	2.46	10
RC: from lungs to circulating fluids	1.54	10
RC: from stomach to intestines	1.39	0.07
RC: excretion from intestines	3.3	5.0
RC: from intestines to circulating fluids	6.7	14.8
RC: excretion from circulating fluids	2.0	0.827
RC: from circulating fluids to soft tissues - long retention time	0.138	0.253
RC: from soft tissues to circulating fluids - long retention time	0.05	0.0265
RC: from circulating fluids to soft tissues - short retention time	1.732	0.565
RC: from soft tissues to circulating fluids - short retention time	0.462	0.297
RC: from circulating fluids to udder	0.8	0.15
RC: from udder to milk production	4.0	4.0

Parameters for metabolism of pigs

RC: Rate constant, unit [d^{-1}]

Description and Unit	Previous Value	Present Value
RC: from GI-tract to meat	not used	1.08
RC: excretion from GI-tract	not used	1.0
RC: excretion from meat	not used	0.0173

Parameter Values for the Iodine Model

The parameter values are unchanged from the previous report (Nielsen and Øhlenschlæger 1991).

RC: Rate constant, unit [d^{-1}]

Description and Unit	Default Value
Dose factor [Sv Bq^{-1}]	Children (1 year old): 1.1E-7 Adults: 1.3E-8
Interception factor [-]	3.0E-1
RC: from soil layer no.1 to soil layer no.2	6.65E-4
RC: from soil layer no.2 to soil layer no.3	1.72E-4
RC: from soil layer no.1 to external plant no.1	6.48E-6
RC: from external plant no.1 to soil layer no.1	4.95E-2
RC: from soil layer no.1 to external plant no.2	2.67E-4
RC: from external plant no.2 to soil layer no.1	1.00E-0
RC: from soil layer no.1 to internal plant no.1	6.67E-4
RC: from internal plant no.1 to soil layer no.1	1.00E-0
RC: from soil layer no.2 to internal plant no.2	1.67E-4
RC: from internal plant no.2 to soil layer no.2	1.00E-0
Transfer factor of iodine: daily intake to milk [Bq l^{-1} milk per Bq d^{-1}]	1.0E-3

Appendix B

The tables in this appendix give the results of the calculations for the basic model without the application of countermeasures for unit depositions of activity (1 Bq m^{-2}). The Tables B1 to B3 give the individual dose equivalents and the Tables B4 to B7 give the relative contributions from different foodstuffs to the total dose from ingestion for the various scenarios.

Table B1. Effective dose equivalent from deposition of I-131 (1 Bq m^{-2}).

Dose to children (nSv)	Dose to adults (nSv)
16	2.9

Table B2. Effective dose equivalent from deposition of Cs-134 (1 Bq m^{-2}).

Season	Soil type	First-year dose (nSv)	Dose commitment (nSv)
winter	mineral	2.4	4.8
winter	organic	2.9	19
summer	mineral	120	140
summer	organic	120	160

Table B3. Effective dose equivalent from deposition of Cs-137 (1 Bq m^{-2}).

Season	Soil type	First-year dose (nSv)	Dose commitment (nSv)
winter	mineral	2.1	8.3
winter	organic	2.4	54
summer	mineral	93	120
summer	organic	93	160

Table B4. Relative contributions from different foodstuffs to the effective dose from ingestion (first-year doses and dose commitments) in the case of Cs-134 deposition on mineral soil.

Season	Dose type	Milk (%)	Beef (%)	Pork (%)	White bread (%)	Vegetables (%)	Potatoes (%)	Apples (%)
winter	1.yr.	72	26	0.7	0.4	0.1	0.4	1.0
winter	Comm.	57	22	3.3	4.0	0.6	9.9	3.1

Table B5. Relative contributions from different foodstuffs to the effective dose from ingestion (first-year doses and dose commitments) in the case of Cs-134 deposition on organic soil.

Season	Dose type	Milk (%)	Beef (%)	Pork (%)	White bread (%)	Vegetables (%)	Potatoes (%)	Apples (%)
winter	1.yr.	68	24	2.9	1.9	0.2	1.0	1.0
winter	Comm.	37	14	14	16	0.6	13	5.0
summer	1.yr.	40	15	21	22	0.2	0.02	1.1
summer	Comm.	34	13	22	27	0.3	1.7	1.6

Table B6. Relative contributions from different foodstuffs to the effective dose from ingestion (first-year doses and dose commitments) in the case of Cs-137 deposition on mineral soil.

Season	Dose type	Milk (%)	Beef (%)	Pork (%)	White bread (%)	Vegetables (%)	Potatoes (%)	Apples (%)
winter	1.yr.	71	26	0.7	0.5	0.1	0.5	1.1
winter	Comm.	44	18	5.7	7.0	1.2	20	5.0
summer	1.yr.	38	15	22	24	0.2	0.003	1.1
summer	Comm.	31	13	24	29	0.3	1.2	1.3

Table B7. Relative contributions from different foodstuffs to the effective dose from ingestion (first-year doses and dose commitments) in the case of Cs-137 deposition on organic soil.

Season	Dose type	Milk (%)	Beef (%)	Pork (%)	White bread (%)	Vegetables (%)	Potatoes (%)	Apples (%)
winter	1.yr.	67	24	3.1	2.1	0.2	2.0	1.1
winter	Comm.	30	12	16	19	0.7	15	6.0
summer	1.yr.	38	15	22	24	0.2	0.02	1.1
summer	Comm.	31	12	22	27	0.3	4.7	2.6

Bibliographic Data Sheet **Risø-R-665(EN)**

Title and author(s)

Predicted Effects of Countermeasures on Radiation Doses from Contaminated Food

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ISBN	ISSN
87-550-1875-0	0106-2840

Dept. or group	Date
Environmental Science and Technology Department	February 1993

Groups own reg. number(s)	Project/contract no(s)

Pages	Tables	Illustrations	References
31	12	6	19

Abstract (Max. 2000 characters)

Quantitative assessments of the effects on radiation-dose reductions from nine typical countermeasures against accidental food contamination have been carried out with dynamic radioecological models. The foodstuffs are assumed to be contaminated with iodine-131, caesium-134 and caesium-137 after a release of radioactive materials from the Ringhals nuclear power station in Sweden resulting from a hypothetical core melt accident. The release of activity of these radionuclides is assumed at 0.07% of the core inventory of the unit 1 reactor (1600 TBq of I-131, 220 TBq of Cs-134 and 190 TBq of Cs-137). Radiation doses are estimated for the 55,000 affected inhabitants along the south-eastern coast of Sweden eating locally produced foodstuffs. The average effective dose equivalent to an individual in the critical group is predicted to be 2.9 mSv from food consumption contaminated with I-131. An accident occurring during winter is estimated to cause average individual doses of 0.32 mSv from Cs-134 and 0.47 mSv from Cs-137, and 9.4 mSv and 6.8 mSv from Cs-134 and Cs-137, respectively, for an accident occurring during summer. Doses from the intake of radioiodine may be reduced by up to a factor of 60 by rejecting contaminated food for 30 days. For the doses from radiocaesium, the largest effect is found from deep ploughing which may reduce the dose by up to a factor of 80.

Descriptors INIS/EDB

CESIUM 134; CESIUM 137; CONTAMINATION; FISSION PRODUCT RELEASE; FOOD; IODINE 131; MATHEMATICAL MODELS; RADIATION DOSES; REMEDIAL ACTION

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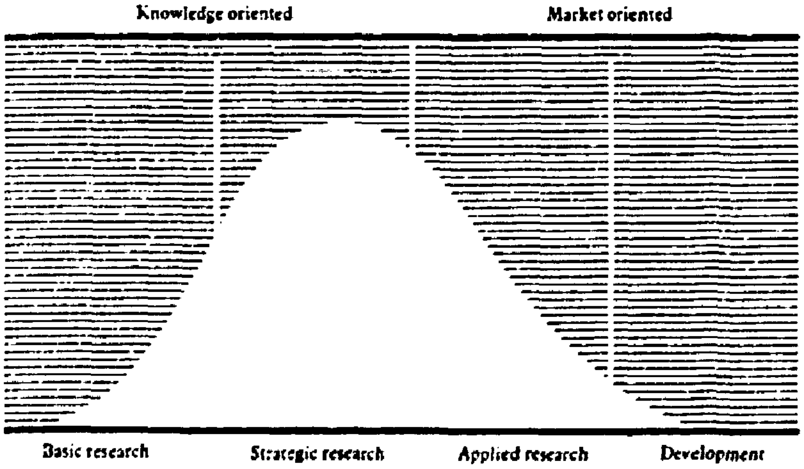

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ISBN 87-550-1875-0
ISSN 0106-2840

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