# LONG TERM HEALTH EFFECTS IN SWEDEN FROM THE CHERNOBYL ACCIDENT

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## 1.    INTRODUCTION

The morning of 28 April 1986 was the beginning of an intensive period of radiation protection work in Sweden. During that morning the Chernobyl accident became known in the western world through the detection of radioactive contamination in Sweden and at the Forsmark nuclear power plant in particular [1]. The accident had occurred more than two days earlier and the existing weather had brought a first radioactive cloud to the Nordic countries.

Numerous measurements were performed during the months following the accident in order to clarify the distribution of the fallout and its nuclide composition as well as the potential health effects and the need for countermeasures. The measurements included aerial gamma measurements, *in situ* gamma spectrometry and measurements of both biological and non-biological samples. A large number of whole-body measurements were performed on various groups and on adults as well as on children.

The environmental consequences of the fallout have been studied in various research projects [2]. The effects on agriculture in Sweden was mainly limited to the first year after the accident. The long term effects are instead seen in products from the semi-natural ecosystems: in moose, roedeer, reindeer, mushrooms and fish from lakes in areas with a high deposition of radioactive caesium. High concentrations of $^{137}$Cs in reindeer meat in combination with an estimated effective ecological half-life of about 4 years [3], will cause problems for reindeer husbandry in the most contaminated parts for many years to come. Various countermeasures are still used to decrease the concentration of $^{137}$Cs in reindeer meat. In moose, roedeer and mushrooms, the ecological half-lives are very long and in some compartments seem to approach the physical half-life of $^{137}$Cs.

In the long time perspective, the two dominating exposure pathways in Sweden are external irradiation from the radioactive elements, mainly caesium, deposited on the ground and the internal irradiation through intake of contaminated foodstuffs. Two other pathways, inhalation and irradiation from the the radioactive cloud, were of minor importance. In this paper we summarize some of the work that has been performed in Sweden in order to estimate the dose consequences and we draw some conclusions about the health effects of the Chernobyl accident.

## 2.    EXTERNAL RADIATION

The doses due to external irradiation from the Chernobyl fallout have been estimated from nuclide specific radioactive measurements made by the Swedish Geological Company (SGAB), the Geological Survey of Sweden (SGU) and the Swedish Defence Research Establishment (FOA) [4,5,6 and references therein]. SGAB made a country-wide survey in 1986 using an air-borne NaI(Tl) gamma spectrometer and SGAB-SGU supplemented this survey with measurements over a part of the wet-deposition area along the Gulf of Bothnia in 1987 to 1992. The results have been given as deposition density of $^{134}$Cs and $^{137}$Cs (Fig. 1) assuming a surface distribution (the surface equivalent deposition density). The FOA measurements consisted of high resolution *in situ* gamma spectrometry and gamma spectrometric analysis of soil samples taken in connection with the *in situ* measurements.

It was found from the *in situ*-measurements that the Chernobyl debris contained detectable amounts of more than twenty gamma-emitting nuclides. Some of the short-lived nuclides such as $^{131}$I, $^{132}$Te and $^{140}$Ba were the main contributors to the gamma dose rate during the first months after the

# Cesium - 137



## Cesium - 137 (kBq/m²)

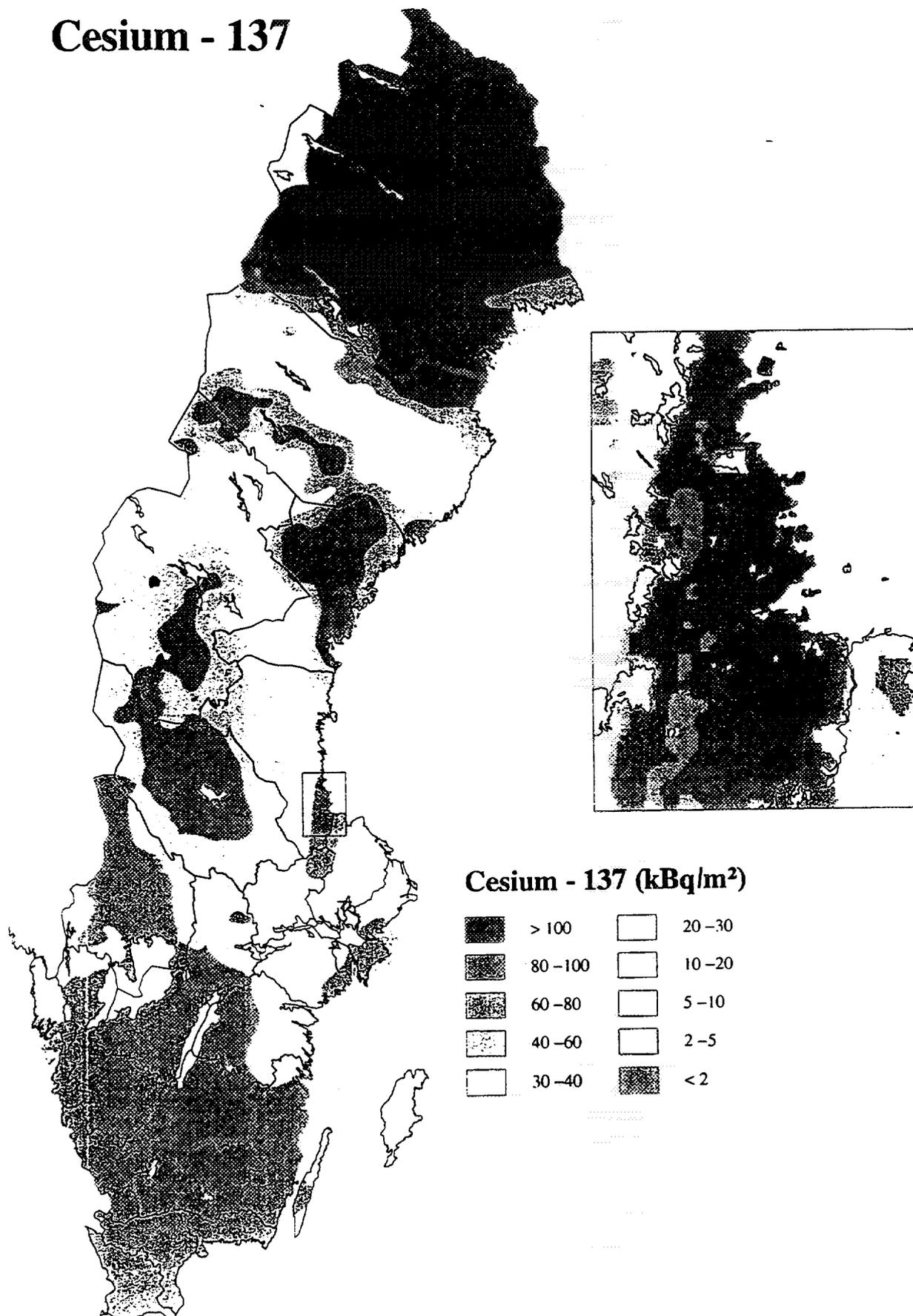| | | | |
|---|---|---|---|
| ■ | > 100 | □ | 20 – 30 |
| ▨ | 80 – 100 | □ | 10 – 20 |
| ▨ | 60 – 80 | □ | 5 – 10 |
| ▨ | 40 – 60 | □ | 2 – 5 |
| □ | 30 – 40 | ▨ | < 2 |

Fig. 1. Corrected $^{137}$Cs deposition in 1986 based on aerial measurements, *in situ* gamma spectrometry and other measurements. GIS techniques have been used in the compilation of the map. The high deposition area around the town of Gävle is shown in more detail.

event. However, the nuclide composition varied considerably between different parts of Sweden. Later $^{134}$Cs and $^{137}$Cs were the dominating contributors to the dose rate. After more than a year they were the only nuclides giving a significant gamma dose contribution.

The results of the *in situ* measurements and the soil sample analyses were used to calculate correction factors for penetration in soil to be applied to the aerial measurements of $^{134}$Cs and $^{137}$Cs. For the locations where such measurements were made in 1986 - 1989 the average ratio between the deposition density determined by soil sample analysis and by *in situ* measurements increased regularly from 1.6 to 2.4. This increase corresponds quite well to the change with time of the equivalent surface deposition density values observed in the wet deposition area. The ratios have been used as correction factors for estimating the actual deposition density and the equivalent dose rates from the surface equivalent deposition density. The correction factors for calculating equivalent dose rates from the aerial measurements were quite small, they increased from about 1.15 to 1.25 in the same time period.

The *in situ* measurements were also used to calculate the one-year, two-year and fifty-year doses *per* unit deposition density of $^{134}$Cs. The estimates of the dose equivalent rate were made based on results showing an initial depth distribution length of one centimeter and a regular increase to three centimetres after three years. For the following years the depth distribution was assumed to be unchanged according to the results of aerial measurements. It was found that the one-year effective dose equivalent estimates varied with low values in the range 80 to 100 μSv per kBq/m² in the wet-deposition area where the caesium isotopes dominate the one-year dose. High values of 200 to 300 μSv per kBq/m² in the Stockholm-Gotland and southeast coast areas reflect the fact that shortlived nuclides dominate the first-year dose in this dry deposition area.

A population weighted $^{134}$Cs deposition density, i e the number of person-Bq *per* unit area was calculated by combining the population number with the average deposition density in the area. Depending on the area of the administrative units and variability, the averaging was performed over parishes, communes or counties. For the counties along the Gulf of Bothnia, where the deposition density varied strongly and the population is quite unevenly distributed, a demographic data base from Statistic Sweden (SCB) was used. As a rule the averaging in these counties was made over 5 kilometer squares although sometimes it was found necessary to use one kilometer squares.

The shielding effects of dwellings and the time people actually are staying indoors are important modifying factors when estimating the dose received by the population. The average shielding effects in different regions, taking into account house type distribution, occupancy factors and the effect of snow cover were calculated.

## 2.1. Results from measurements and dose calculations

By combining the population-weighted $^{134}$Cs deposition density with the appropriate dose factors and other modifying factors the collective doses for the counties and Sweden as a whole were calculated. It was found that the collective doses over one year, two years, and fifty-years for Sweden were, respectively, about 600, 1000 and 5000 manSv. The counties receiving the highest collective doses were, as expected, in the wet-deposition area. About two thirds of the fifty year collective dose was estimated to be received by the population living in the wet deposition area. It was further estimated that 70 percent of the population received one-year doses less than 0.04 mSv and 95 percent doses less than 0.3 mSv. The highest doses were received on coast areas along the Gulf of Bothnia (Fig. 1). In this region it was estimated that some 250000 persons received one-year doses above 0.5 mSv and about 40000 doses above 1 mSv. The highest one-year doses, about 2 mSv, were received by less than 1000 persons.

## 2.3. Uncertainties in the dose estimates - on-going studies

The dose and deposition density estimates are primarily based on nuclide-specific measurements of surface equivalent deposition densities. Comparisons between the aerial measurements and the high

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resolution measurements indicated that results from the two systems agreed by twenty percent or better in high-deposition areas. Repeated aerial measurements along the same flight paths show that the reproducibility is within a few percent for averages over one kilometer or more. The total error in equivalent surface deposition density of the caesium isotopes is estimated to be better than ten percent for such averages. In areas with low deposition densities the aerial measurements give lower estimates than the *in situ* measurements by a factor 2-3. In such areas the *in situ* measurements were used for calibrating the aerial measurements. In general these aerial measurements will, hovever, have a far larger uncertainty than the *in situ* measurements in the wet-deposition area.

The conversion from equivalent surface deposition density to open-air effective dose equivalent rate, which is determined by the dose conversion factors of the relevant nuclides and the nuclide composition as determined by the *in situ* measurement, does not introduce any appreciable errors. The conversion from area-averaged to population-averaged deposition density and shielding correction is quite straightforward and does not introduce any appreciable errors. The correction for depth distribution may introduce a systematic error of perhaps ten percent. The conversion from effective dose equivalent rate to first-year and two-year dose equivalent is straight-forward. The fifty-year dose estimate depends on assumptions regarding the future behaviour of $^{137}$Cs. The assumption used is that the depth distribution will not change after the first three years. This should give an over-estimate of the fifty-year dose. The results from the aerial measurements indicate that the movement of the $^{137}$Cs in the soil profile is quite small after a few years so there is no indications that this over-estimate should be important.

In urban areas, where many dwellings are surrounded by "hard surfaces", the dose-rate both indoors and outdoors may be significantly affected by weathering [7], including effects as wash-off, resuspension, road sweeping and migration. Quantification of this effect will be the aim of a recently launched urban radioecology study at the Swedish Radiation Protection Institute (SSI). A new system developed at SSI will be used for detailed measurements in an urban area affected by a significant fallout after the Chernobyl accident. The system [8] consists of a small mobile gammaspectrometer with automatic positioning using DGPS (Differential Global Positioning System). The system can be used carried as a backpack or in cars or helicopters. Preliminary measurements of primary $^{137}$Cs photon fluence have been made. A comparison between reference areas, grass areas within the city boundary, and the average along streets and pavements indicates that the average street value is 10-30 % of the average reference value. The effect on individual and collective dose will be investigated in the study.

At present, a subjective estimate is that the county averaged first- and second-year doses have an overall uncertainty of less than 20 percent in the wet-deposition areas and somewhat more, perhaps 30 percent in other parts of Sweden.

## 3. INTERNAL RADIATION

The estimate of the committed internal dose to the Swedish population from the fallout in Sweden after the Chernobyl accident is based on whole-body measurements and supported by results from measurements of food-stuffs and of human tissues. Since the radiation dose to humans in Sweden is so low that no somatic detriments are expected and the preliminary estimation of the collective dose to the population is so low that no significant changes of the overall risk for detrimental effects late in life can be expected, many studies have been focused on understanding the behaviour of caesium in our environment and the resulting body burden of caesium in man.

The radionuclides giving the main part of the internal radiation dose are $^{134}$Cs and $^{137}$Cs. During the first weeks after the release, internal contamination of $^{131}$I and "hot particles" was observed but the resulting doses were small compared to the doses from radioactive caesium [9],[10]. The inhalation dose was estimated to be in the range 1-20 $\mu$Sv including the dose from "hot" particles as well as from $^{131}$I. The few measurements made on $^{131}$I in human thyroid showed maximum concentrations of 1 kBq [11]. The total 50-year collective dose from inhalation has been estimated to 150 manSv [9].

## 3.1. Some performed studies

Since 1959 a reference group of about 36 persons employed at SSI have regularly been whole-body measured. During the years 1986 and 1987 frequent measurements were performed of this group to study both the short and long time changes of radioactive caesium in the body. Additional staff members at SSI and their children were measured to establish possible differences in dose between adults and children belonging to the same family. The reference group at SSI is presently measured twice every year. Two groups from the high deposition area of Gävle are regularly monitored at the SSI with the aim to follow the changes in body burden over a longer period of time. Farmers with food-stuffs based on domestic production form one of the groups while the other group (non-farmers) living in the same area buy their food-stuffs in shops.

People from forest provinces and Laplanders in mountain areas with a relatively high fallout were studied as they could be expected to have a high intake of caesium [12]. This study was performed by the Radiation Physics Department at the University of Umeå.

In order to better assess the collective dose to the Swedish population from radioactive caesium in food, a random sample of 218 individuals from the whole country was whole-body counted one year after the Chernobyl accident. Half the group returned one year later, in 1988, for a second measurement. To ensure a statistically correct sample with few drop-outs from the measurements, a stratified selection in two steps was performed [13]. During the autumn 1994 a third random sample of 200 persons from the Swedish population was whole-body counted. The selection of these persons was done in the same way as the previous random samples. At the same time, in 1994, a foodbasket study was performed to assess the average intake of $^{137}$Cs by the Swedish population. The standardised foodbasket was collected from two grocers in 10 localities, of which the majority came from areas with the highest fallout. Each food basket contained 104 different provisions covering 90 % of the consumption, and was subdivided in common foodstuffs and locally produced foodstuffs [14].

To obtain a better knowledge of the intake of radioactive caesium of people consuming products from the forest, whole-body measurements were performed on hunters and their families living in three different areas of northern Sweden. This study was made by FOA in Umeå in 1994 [15]. During the years 1988 to 1993 the concentration of $^{137}$Cs in the population of northern Sweden was also measured on muscle samples from medico-legal autopsis [16].

## 3.2. Results from measurements and dose calculations

Figure 2 shows the bodyburden of $^{137}$Cs expressed as Bq/(kg body weight) in a number of groups measured between 1959 and 1995 [13,17,18]. As can be seen, the variation of the body burden can be as large as two orders of magnitude between different groups. It can further be seen that the weighted average bodyburden for individuals in Sweden (three data points representing the three random samples) follow closely the data for the SSI reference group.

From the foodbasket study [14] the population weighted average intake in 1994 is estimated to be 270±50 Bq/year. From this intake and metabolic data for different population groups [13] the calculated bodyburden would be 1.3 Bq/kg for the average citizen. The measured average bodyburden of the random sample at same time was found to be 2.0 Bq/kg. The difference between estimated and measured bodyburden can be explained by the 10 % of the foodstuffs not included in the food basket. These foods is home produced or forest products such as moose, roedeer, fish, mushrooms and wild berries.

Based on whole-body measurements in 1994, 90 % of the population is estimated to have a bodyburden of less than 5 Bq/kg and 99% of the population less than 10 Bq/kg body weight. Only a limited number of persons are expected to have a body burden exceeding 100 Bq/kg. The average bodyburden of the random sample, 2 Bq/kg, corresponds to a dose rate of 5 µSv/year. The dose from the measured body burden of $^{134}$Cs and $^{137}$Cs is calculated using a model described by Legget [19], which takes into account the body size.
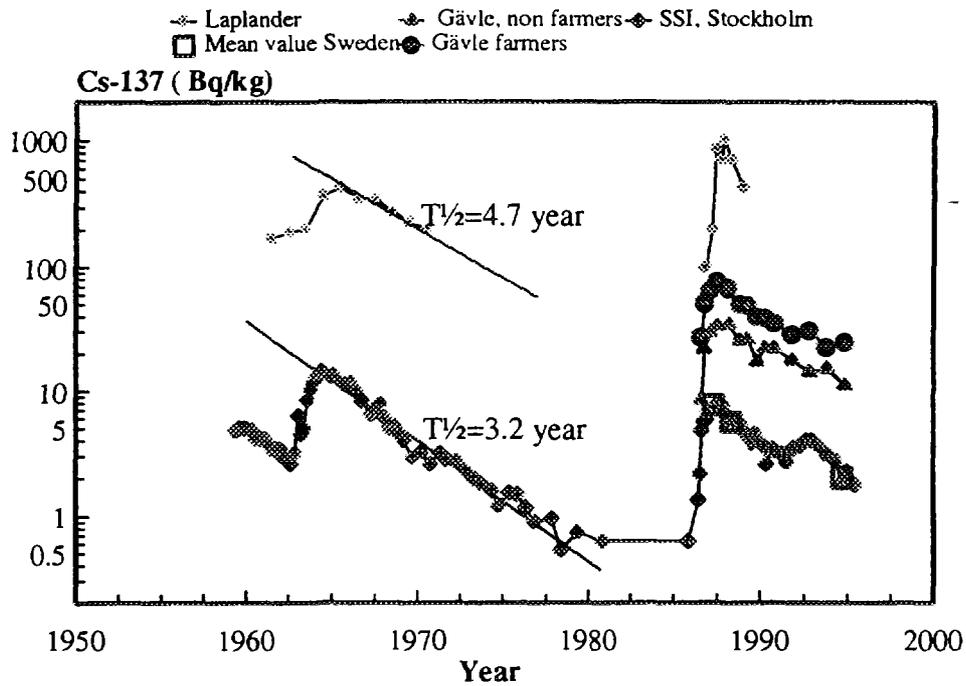
Fig. 2. Measured body burden of $^{137}$Cs (Bq/kg body weight) in a number of groups in Sweden between 1959 and 1995. During the period 1965 to 1975, the yearly intake of $^{137}$Cs decreased with a half time of 3 - 5 years. The squares show the measured average body burden of the whole population.
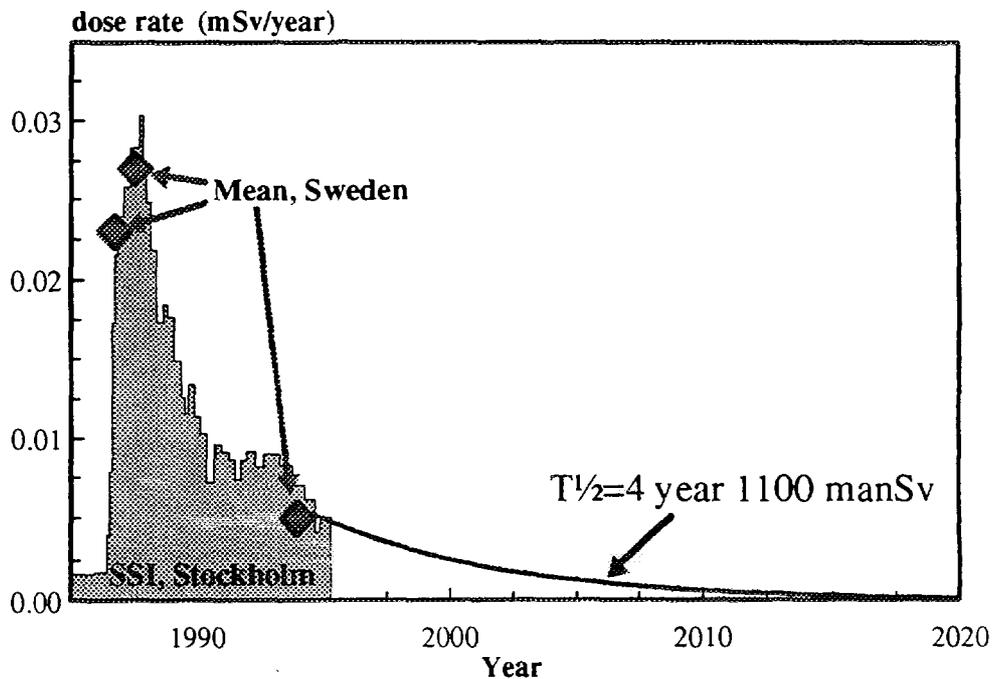


Fig. 3. The committed collective dose estimate of 1100 manSv from caesium in food is based on the measured average body burden of the population, the variation of the body burden in the SSI group and a decrease in intake corresponding to a half time of 4 years.

The prediction of the cumulated committed dose to the Swedish population is based on the observation that the change of bodyburden for an average person during the first nine years has followed the pattern shown by the SSI reference group (Fig. 2). With the assumption that the yearly intake of caesium will decrease with a "half-time" of 4 years (Fig. 3), which is slightly longer than the value, 3.7 years, estimated from the measurements of muscle samples[16] and from the experience after the atmospheric bomb tests during the sixties (Fig. 2), the cumulated committed 50 year dose to the whole Swedish population is estimated to 1100 manSv. Under these assumptions the uncertainty is estimated to ± 200 manSv.

### 3.3. Dose estimates based on whole-body measurements as compared to concentrations in food

Many measurements have been done of ^{137}Cs concentrations in foodstuffs. In particular, these measurements show that the concentration of caesium in game meat (moose and roedeer) have decreased very little or not at all [20]. Based on this fact, the calculated amount of activity transferred to man from game and freshwater fish was estimated to have an essential influence of the cumulative collective dose. The food consumption data and available data from activity measurements were used to estimate the dose to the Nordic population [21]. The reported internal committed collective dose to the Swedish population was 9000 manSv which is almost nine times higher than the prediction of 1100 manSv calculated above from whole-body measurements. According to earlier experience, use of food consumption data and data on activity concentrations in food could be expected to give a slight overestimation as the use of activity data in foodstuffs often have been found to predict a too high body burden [13].

The results from our whole-body measurements of the random sample of the Swedish population, the study on the sub-population hunters and their families [15], the study on the muscle samples [16], and the results from the food-basket study [14] lead to our conclusion: It is important to use representative food samples for the estimation of intake for a population. In principle, we believe that the best estimate is obtained with well planned whole-body measurements.

## 4. HEALTH EFFECTS IN SWEDEN

The fallout from the Chernobyl accident caused no acute health effects in Sweden. It is unlikely that any late effects (cancer) will be possible to detect.

The total 50-year collective dose to the Swedish population due to the radioactive fallout from the Chernobyl accident is estimated to be 6000±1000 manSv, mainly caused by external irradation from radionuclides deposited on the ground and internal irradion from ingested foodstuffs. With the presently accepted risk factors (ICRP 60) this would lead to about 300 cases of fatal cancer. Even though these cases will appear predominantly in the high deposition areas of Sweden, the increase will be very low (<0.3% over 50 years) also in the county of Västernorrland which received the highest deposition. For the whole of Sweden the relative increase will be ten times lower.

During the first years after the accident, a number of actions were taken by the Swedish authorities to limit the effects of the fallout. Of particular importance in respect to dose were the restrictions on food: both limits for sale in the shops and diet recommendations to certain groups of people. The restrictions on milk during the first weeks also reduced the dose consequences. It is difficult to estimate the additional collective dose to the Swedish population without restrictions.

There has been a discussion whether the radioactive fallout in Sweden could lead to an observable increased incidence of childhood leukemia. An estimate based on radiation doses and risk factors from the ICRP shows that this is very unprobable. In an epidemiological study covering the years 1986-1991 [22] it was concluded that there has been no significant increase in the incidence of acute childhood leukeaemia in areas of Sweden contaminated after the Chernobyl accident.

Even though the Chernobyl accident has not caused, and is not likely to cause, any observable somatic health effects in Sweden it has lead to substantial worry and concern especially in areas with a high deposition of radioactive caesium. These effects were particularly evident the first years after the accident. However, in September 1994, around 200000 people in these regions (5 counties) still state that they have some, mostly minor, changes in their diet due to the accident. This can be compared to 350000 in February 1987 (Statistic Sweden, SCB). The figures for the whole of Sweden is about twice as high. It is particularly forest products like meat from moose and roedeer, wild berries and mushrooms that are of concern as well as lake fish. Nine years after the accident, these products can still contain more than 1500 Bq/kg of $^{137}$Cs, which is the limit for sale. A more general conclusion is that many people experience that the Chernobyl fallout to some extent has affected their quality of life.

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