COLLECTIVE DOSES IN SWEDEN AFTER THE CHERNOBYL ACCIDENT CALCULATION FOR INHALATION AND EXTERNAL IRRADIATION

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Introduction

The Chernobyl fallout over Sweden was essentially deposited between the 28 and 30 of April 1986. The radioactive material was dryly deposited with a rather even spatial distribution in most parts of the contry, but in the eastern and middle-northern part of Sweden the plume was washed out by rain during the 29 of April. This caused a quite high and uneven distribution. A second rainfall caused a lower increase along the southwest coast of Sweden on the 8 and 9 of May. A large number of cloud and ground radiation measurements were performed during the first two months after the accident. These measurements have been used to calculate the collective dose from inhalation and external radiation to the Swedish population. Here a short review of the measurements and calculational methods is given as well as an estimated sum of the collective effective dose equivalent.

Measurements of ground deposition

The cesium deposition has been mapped by aerial sodium-iodide spectrometric measurements by the Swedish Geological Co (Lindén and Mellander, 1986). Measurement heights were 60 or 150 m and the distances between flight lines were 2, 4, 10 and 50 km, depending on deposition density and variation. A deposition map for Cs-137 constructed from measurement data is given in fig 2. For the dose calculations, Cs-134 rather than Cs-137 is chosen as a reference nuclide in the aerial measurements, because it has a gamma energy which does not interfere too much with the gamma lines from natural nuclides or with the activity of old Cs-137 from nuclear fallout. The activity ratio of Cs-134 to Cs-137 was initially 0.6 : 1, so the Cs-137 deposition could be calculated from the measured Cs-134 values.

In situ high resolution gamma spectrometric measuremetswere performed 1 m above ground at about 50 locations by the National Defence Research Institute. These measurement were used to gain information on the nuclide composition in different regions and as a base for calibration of the aerial measurements. The individual activities and dose rates for the deposited nuclides Zr-95, Nb-95, Mo-99, Ru-103, Ru-106, Ag-110m, Sb-125, Te-129m, I-131, Te-132, I-133, Cs-134, Cs-136, Cs-137, Ba-140, Ce-141, Ce-144, Nd-147 and Np-239 were calculated. From these individual dose rate values, the ratio of total dose from all nuclides to the activity of Cs-134 was calculated for all measurement points. The ratio varies between 0.095 - 0.3 mSv per kBq/m^2 of Cs-134 for the first year, depending on geographical location and wet or dry deposition.

Measurements of air concentrations

The concentration of radionuclides in ground level air was measured at seven air filter stations by the National Defence Research Institute. These stations, Kiruna, Umeå, Östersund, Stockholm, Grindsjön (near Stockholm), Göteborg, and Ljungbyhed (near Malmö) are in continuous use for monitoring particulate air radionuclide concentration. Inhalation and external cloud doses for different regions were calculated from measured values. Gaseous components, such as gaseous iodine and noble gases could not be measured this way, since they penatrate the

air filter. For gaseous iodine, a correction factor of 5 has been applied in the dose calculation in order to include this component. This factor is based on measurements performed at one of the Swedish nuclear power stations. (Ingemansson, 1986). Noble gases and pure alfa- or beta emitters, such as Xe-133, Pu-239, and Sr-90 are not included.

Calculational metods

The effective dose equivalent from inhalation was calculated from the time integrated air concentrations using dose conversion factors from ICRP 30. These are valid for inhalation of 1 μm amad aerosol by adults. The collective dose for each of the 24 different counties of Sweden was calculated by selecting the dose equivalent for the nearest air filter station and multiplying by the population number.

Dose conversion factors for calculation of external cloud and ground effective dose were taken from Kocher, 1983. Kocher gives values which do not include daughters, but these have been added separately when the dose contribution from the daughter was larger than 1 %.

For calculation of collective dose from ground, the different deposition values from the aerial measurements of Cs-134 were used as main reference. For all counties, the number of people living within different deposition intervals were counted. The intervals used were 0-0.5, 0.5-1, 1-2, 2-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, 45-50, 50-55, and 55-60 kBq/m^2. Since the depth distribution in the soil is unknown, the deposition values are given as equivalent surface deposition density, which means that the numerical values correspond to the values which are obtained by using a calibration factor for an infinite plane surface area without any depth penetration. Since the cesium actually has penetrated into the ground, the real deposition values are higher. How much higher the values actually are, depend on soil type and the extent of agriculture cultivation. Analysis of depth distributions from a few samples taken in the wet deposition area indicate that the relaxation length for undisturbed soils is somewhat less than 1 cm. A value of 1 cm is used for all counties in the present work.

Other nuclides than cesium, have been taken into account, by using the in situ measurements of total effective dose to cesium deposition ratio for representative parts of all counties. The collective dose from ground within a county can then be calculated by the expression:

$$C = \sum_i f_{shield} \cdot f_{snow} \cdot g_{depth} \, N_i \cdot (D_{total}/A_{Cs\text{-}134}) \cdot (A_{i+1,Cs\text{-}134} + A_{i,Cs\text{-}134})/2$$

where N_i is the number of people living within a Cs-134 deposition interval,

$A_{i,Cs\text{-}134}$ is the lower limit of the interval,

D_{total}/A_{134} is the ratio of total dose to deposition of Cs-134,

f_{shield} is the time and population averaged shielding factor for dwellings

f_{snow} is the time averaged shielding factor for snow cover, and

g_{depth} is a correction factor for pentration into the ground.

The values for individual counties are added to obtain the collective dose for total Sweden. Separate calculations are made for the first year, where the depth penetration is assumed to be exponentially distributed whith a mean relaxation length of 1 cm and for the following years where the relaxation length is assumed to be 3 cm according to the proposal of UNSCEAR, 1982.

Table 1
Collective effective dose equivalent in Sweden
from inhalation, cloud and external ground irradiation

Calculated collective dose values are based on measurements of gamma emitting nuclides at six air filter stations, in situ high resolution gamma-spectrometric measurements and aerial sodium iodide spectrometry. The ground activity is assumed to follow an exponential depth distribution with a relaxation length of 1 cm during the first year (0-1 a) and 3 cm during the following 49 years (1-50 a). Time and population averaged shielding factors for buildings and snow cover are applied.

County	Population	Collective dose equivalent			
		Inhalation and cloud manSv	Ground 0-1 a manSv	Ground 1-50 a manSv	Total 0-50 a manSv
AB Stockholm	1562490.	25.	83.3	156.	264.
C Uppsala	250762.	4.01	86.8	520.	610.
D Södermanland	250515.	4.01	25.6	153.	183.
E Östergötland	392887.	6.29	16.8	95.1	118.
F Jönköping	300924.	4.81	8.59	33.6	47.
G Kronoberg	174265.	2.79	2.49	9.74	15.
H Kalmar	239380.	3.82	11.	43.4	58.2
I Gotland	56203.	0.899	7.51	20.	28.4
K Blekinge	151562.	2.42	1.96	8.96	13.3
L Kristianstad	280330.	2.02	4.78	16.6	23.4
M Malmöhus	747140.	5.39	10.8	47.5	63.7
N Halland	238347.	0.81	2.94	14.6	18.4
O Göteborg-Bohus	712078.	2.42	26.4	131.	160.
P Älvsborg	426325.	1.45	15.9	71.	88.4
R Skaraborg	270382.	0.919	3.72	16.6	21.2
S Värmland	280499.	0.954	17.	43.4	61.3
T Örebro	270961.	4.34	21.8	85.2	111.
U Västmanland	254691.	4.07	54.2	363.	422.
W Kopparberg	285113.	4.56	18.1	74.4	97.1
X Gävleborg	289217.	4.63	126.	747.	877.
Y Västernorrland	262072.	1.08	144.	958.	1100.
Z Jämtland	134731.	0.556	30.3	123.	154.
AC Västerbotten	245181.	0.463	51.3	337.	389.
BD Norrbotten	263684.	0.311	6.4	16.5	23.2
Total Sweden	8339739.	88.	777.7	4085.	4951.

Table 2

Collective effective dose equivalents from inhalation and external cloud and ground irradiation for different assumptions of the relaxation length of the exponential depth distribution during the first year (0-1 a). The relaxation length for the following years (1-50 a) is assumed to be 3 in all cases.

Relaxation length first year cm	0 - 1 a manSv	1 - 50 a manSv	0 - 50 a manSv
0	729.3	1967.	2696.
0.1	763.1	2371.	3134.
1	865.8	4085.	4951.
2	895.4	5231.	6126
3	965.7	6681.	7646.

Results

The collective effective dose equivalents in different counties and total Sweden for the first year and for the first fifty years after Chernobyl are given in table 1. For inhalation and cloud, the collective dose is around 100 manSv. For external radiation from ground the collective dose is estimated to be around 800 manSv for the first year, and 5000 manSv for the first fifty years. From foodstuffs, the collective dose is reported to be around 1000 manSv for fifty years (Holmberg et al, 1987). This adds up to a total of approximately 6000 manSv from all radiation sources. Using a risk figure of 0.02 fatal cancers per sievert, the Chernobyl fallout will cause roughly 100 - 200 cases of fatal cancers in Sweden over a fifty year period.

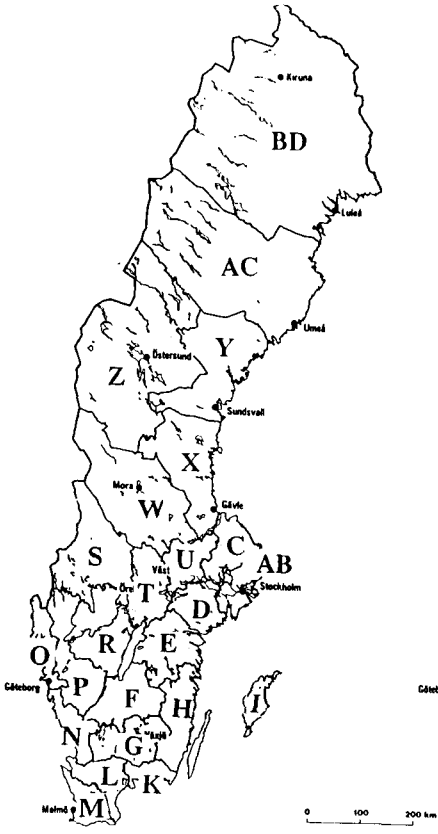

Fig 1. Map showing the different counties of Sweden.

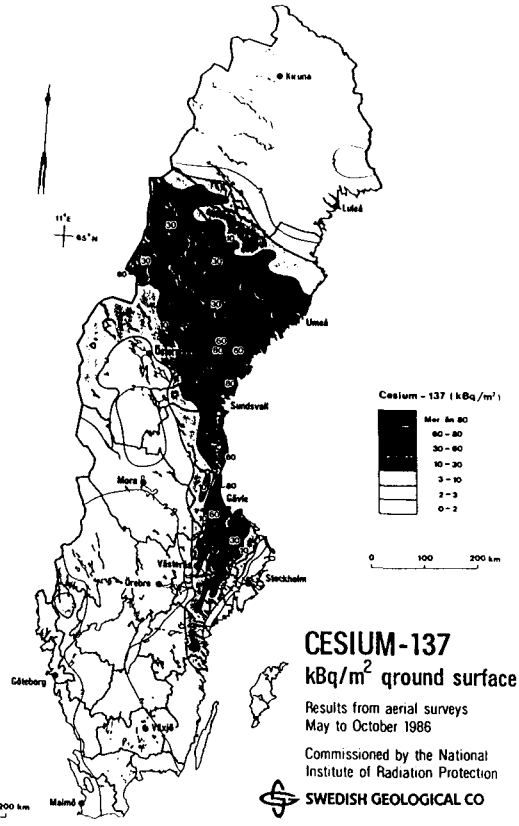

Fig 2. Cs-137 equivalent surface deposition based on aerial measurements.

References

Holmberg M., Edvarson K., Finck R. Radiation Doses in Sweden from the Chernobyl Fallout. National Institute of Radiation Protection. Submitted for publication, 1987.

ICRP. Pergamon Press, 1978.

Ingemansson T. Forsmark Nuclear Power Station. Personal communication, 1986.

Kocher D.C. Health Physics 45, pp 665-686, 1983.

Lindén A. and Mellander H. Swedish Geological Co. Report TFrap 8606, 1986.

Lönsjö H. Distribution of Radiocesium from the Chernobyl Accident in Cultivated Soil within C-, U-, X, and Y-county. Radioecology Department, Sveriges Lantbruksuniversitet. (In Swedish) 1987.

UNSCEAR. United Nations Publications, 1982.