ENVIRONMENTAL GAMMA RADIATION MEASUREMENTS IN FINLAND AND THE INFLUENCE OF THE METEOROLOGICAL CONDITIONS AFTER THE CHERNOBYL ACCIDENT IN 1986

Supplement 10 to Annual Report STUK A55

Hannu Arvela, Leif Blomqvist, Heikki Lemmela, Anna Liisa Savolainen and Seppo Sarkkula
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Hannu Arvela, Leif Blomqvist, Heikki Lemmelä, Anna Liisa Savolainen* and Seppo Sarkkula*

* Finnish Meteorological Institute
P.O.Box 503, SF-00101 HELSINKI
FINLAND

Finnish Centre for Radiation and Nuclear Safety
P.O.Box 268, SF-00101 HELSINKI
FINLAND
ABSTRACT

Results from a survey of environmental gamma radiation levels in Finland after the Chernobyl accident 1986 were presented. The measurements were made by means of sensitive Geiger-counters and a gamma-spectrometer placed in cars. The results presented the level of external radiation caused by the cesium fallout on the first of October 1986. In the center of Southern Finland there are wide areas with exposure levels exceeding 0.04 μSv h\(^{-1}\), areas exceeding 0.2 μSv h\(^{-1}\) being very rare. The surface area weighted mean dose rate for the 461 municipalities in Finland was 0.037 μSv h\(^{-1}\) (range 0-0.23 μSv h\(^{-1}\) ). The corresponding estimated surface activity of \(^{137}\)Cs was 10.7 kBq m\(^{-2}\). The population weighted mean dose rate was 0.051 μSv h\(^{-1}\).

Results from measurements at eight dose rate monitoring stations were presented as daily dose rate recordings in 1985-1986, the rate of decrease of the excess dose rate demonstrating quite large variations in the period from May to August. This indicated that the composition of the short-lived nuclides in the fallout varied from place to place.

The influence of the meteorological conditions were reported with precipitation data from six days after the accident. There was a clear correlation between the results from precipitation and radiation measurements in different parts of Finland.
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1 INTRODUCTION

The results of the measurements performed by the stationary radiation monitoring stations of the Ministry of the Interior and of the Defence Forces after the Chernobyl accident gave preliminary information on the fallout situation in Finland. The Finnish Centre for Radiation and Nuclear Safety (STUK, SäteilyTurvaKeskus) initiated assessment of the environmental gamma radiation levels by means of sensitive Geiger-counters and a gamma-spectrometer placed in cars. The measurements were started on the 28th of April, the results from the first weeks following the accident having been reported earlier. Results from measurements at dose rate monitoring stations are presented in Chapter 3.

The short lived nuclides of the fallout and their varying contribution to the dose rate creates difficulties in the utilization of early exposure rate measurements for evaluations of the later dose rate levels which are caused mainly by cesium-nuclides. The STUK carried out a nationwide survey in Southern Finland from August to December, at which time the snow cover prevented accurate measurement. This report includes results from these autumn measurements. The earlier measurements aided in planning the routes of the survey.

The Finnish Meteorological Institute realized the meteorological study and analysis of precipitation presented in Chapter 4.
2 ENVIRONMENTAL GAMMA RADIATION SURVEY

2.1 INSTRUMENTS AND METHODS

The total exposure rate was measured using an effective Geiger-Müller tube and a high pressure ionization chamber (HPIC). The GM-tube, provided with a digital counter, was located above the car at a height of 2.5 m from the road surface. The HPIC was inside the car continuously recording the exposure rate with a chart writer.

The Ge-spectrometer with a multichannel analyzer connected to a tape recorder was also located inside the car, the detector being at a height of 1.5 m above the road surface. The relative efficiency of the pure Ge-detector was 30 %, the resolution being 2.0 keV at 1.33 MeV.

While driving each section the instruments were measuring at all times, the results thus representing average radiation levels of each section of the route. Compared with single measurements made at various points on each route the results give a much more representative survey on radiation levels.

Throughout this study the exposure level was recorded in units of $\mu$R h$^{-1}$ (microroentgens in an hour), the results being presented as dose rate in units of $\mu$Sv h$^{-1}$ (microsieverts in an hour). A conversion factor of $1 \mu$R h$^{-1} = 0.01 \mu$Sv h$^{-1}$ has been used.

2.2 CALIBRATION

2.2.1 GM-tube

The following factors affecting the calibration have been considered.
- Point source calibration, $^{137}$Cs, and calculated response to both natural and fallout radiation$^{3,4}$
- Comparison between the GM-counter and the HPIC
- Attenuation factor of the car

2.2.2 Ge-spectrometer and surface activity

The source activity of the soil surface and the corresponding dose rate for the nuclides identified can be estimated using point source calibration and theoretical conversion factors. The accuracy of the estimate depends on the knowledge of the source depth distribution in soil. A reasonable approximation is to assume an exponential distribution according to the relation

\[ S = S(0) e^{-\frac{z}{\lambda}} \]

where \( S \) is the activity concentration at depth \( z \), \( \lambda \) is the reciprocal of the relaxation length and \( \gamma \) the density of soil.

We improved our prior estimates for the distribution parameter of cesium by making comparisons with soil samples obtained at a short distance from the road. At these calibration sites measurements were made in an immobile car, the direct spectroscopic estimate on the surface activity (Bq m\(^{-2}\)) being compared with the surface activity calculated from the soil sample measurement. The final calibration factor for source activity of 290 kBq m\(^{-2}\)/\( \mu \)Sv h\(^{-1}\) corresponds to an effective source depth distribution of \( \frac{\lambda}{\gamma} = 0.4 \text{ cm}^2 \text{ g}^{-1} \).

The following factors cause uncertainty in these evaluations:
- the conversion factor is sensitive to the source depth distribution
- different wash out of the fallout on the road area and in the surrounding area
- the effect of ground roughness, which effectively buries the source deeper in the ground

The final experimental calibration factor for source activity to some extent accounts for these uncertainties.

2.2.3 Final dose rate calibration

For measurements made with solely the GM-counter the dose rate
caused by the Chernobyl fallout was calculated by subtracting the natural background radiation level from the dose rate measured. This was made on the basis of a nationwide study on natural background radiation during the years 1975-1980. The measurements were performed with a high-pressure ionization chamber installed in a car, each measurement representing the mean value for a particular area.

By cumulating the accuracies of both the measurements with only the GM-counter and the background subtractions the accuracy of the calculated increases of radiation levels was 0.03-0.05 μSv h⁻¹ for levels of 0-0.3 μSv h⁻¹, respectively.

Measurements with both the GM-counter and the spectrometer gave much more accurate results on the dose rate increase of the sections of the routes measured. The minimum detectable surface activity of $^{137}$Cs was better than 100 Bq m⁻², the respective dose rate due to cesium nuclides being only 0.0005 μSv h⁻¹.

The final dose rates, for sections of routes measured, using the spectrometer, were based on measurements of $^{134}$Cs and an experimental relationship between the $^{134}$Cs photopeak count rates and the dose rate increases calculated from the GM-counter results. By using $^{134}$Cs results the influence of the variations of the previous cesium surface activity originating from nuclear tests was avoided. This disturbing influence was marked in areas with low Chernobyl fallout levels.

2.2.4 Effect of road

Measurements carried out at the calibration sites on fields near the road with the GM-tube were compared with the results measured above the car. On average the car measurements represent fairly well the levels detected off the road. The washout of fallout from the road surface was partly compensated by stronger radiation on the shoulder.
2.3 RESULTS AND DISCUSSION

2.3.1 Dose rate levels

A total of 16,000 kilometres were measured by car. The results comprised 400 GM-measurements with spectroscopy and 450 with only the GM-measurements. The survey was carried out to the south of 65° N as the fallout level in the north of Finland can be detected only with sensitive spectrometric measurements. The results present the level of external radiation caused by the Chernobyl fallout on the first of October 1986 which is the mid-point of the study period. The levels given are mean values for the sections of the routes. The recorded radiation level is presented in map form giving the dose rate in units of μSv h\(^{-1}\), Figure 1.

The increase of dose rate ranges from 0.003 to 0.35 μSv h\(^{-1}\). In the center of Southern Finland there are wide areas with exposure levels exceeding 0.04 μSv h\(^{-1}\), areas exceeding 0.2 μSv h\(^{-1}\) being very rare. The surface area weighted mean value for the 461 municipalities in Finland was 0.037 μSv h\(^{-1}\) (range 0-0.23 μSv h\(^{-1}\)). The corresponding estimated surface activity of \(^{137}\)Cs was 10.7 kBq m\(^{-2}\), the activity of \(^{134}\)Cs was 52 percent of the \(^{137}\)Cs activity. The population weighted mean value was 0.051 μSv h\(^{-1}\).

The level for the northern parts of Finland was estimated at 0.005 μSv h\(^{-1}\), based on the northernmost measurements from this study, in combination with the meteorological situation and deposition, soil sample and lichen measurements.\(^7^,\(^8\)

The natural background level in Finland varies from 0.08 to 0.21 μSv h\(^{-1}\), the average value being 0.11 . The increase caused by the Chernobyl fallout is thus comparable with the variations in the natural background radiation level.

The average distance between the mid-points of the sections of the routes in areas exceeding 0.04 μSv h\(^{-1}\) was 20-30 km. In the
northern and eastern areas below 0.04 μSv h⁻¹ this was up to 50 km, these areas also being the least populated. The non-measured areas may contain small local extremes and average radiation levels differing slightly from the levels presented on the map. The map, however, presents the main features of the distribution of the Chernobyl radiation level in Southern Finland. Comparison with the precipitation results presented in Chapter 4 and with the other research materials of the STUK also confirms this conclusion.

2.3.2 Other nuclides

In addition to ¹³⁴Cs and ¹³⁷Cs the nuclides observed in measurements made during autumn 86 were ⁹⁵Zr, ⁹⁵Nb, ¹⁰³Ru, ¹⁰⁶Ru and ¹¹⁰Ag. Their contribution to the dose rate was on the first October generally less than 0.002 μSv h⁻¹, being however about ten times higher in a few areas. The results given represent the dose rate caused by cesium as the calibration was based on ¹³⁴Cs and ¹³⁷Cs measurements. Also results from the first months include short lived radionuclides mainly ¹³¹I and ¹³₂I. 
3 MEASUREMENTS AT DOSE RATE MONITORING STATIONS

3.1 The network

The dose rate monitoring network in Finland comprises about 390 stations, operated by the Ministry of the Interior, the Defence Forces and the Frontier Guard. The network is intended for civil defence purposes, hence the radiation detectors are Geiger-Müller tubes with rather poor sensitivity. Notwithstanding, it is possible to measure dose rates at the natural background level. At the time of the Chernobyl accident there were three categories of operational stations, as follows:

- 20 stations were equipped with auxiliary electronic pulse counting units designed and manufactured by the STUK. At these stations the pulse count from the GM tube is recorded on the basis of an hourly summation; normally the measurement at 3 p.m. is recorded each day. The minimum detectable change is determined by the counting statistics - a 10% change in the dose level gives a statistically significant response.

- 27 stations record continuously, equipped with analog plotters using monthly charts. At these stations the time constant of the monitoring instrument is rather long, enhancing the signal-to-noise ratio. The detection threshold corresponds to roughly a doubling of the background dose rate.

- The rest of the stations normally measure only once a week. At background levels no reading is obtainable on the analog scale, but pulses can be counted either aurally from the loudspeaker or visually from an indicator light on the monitoring instrument. In this manner roughly a doubling of the background level is detectable. However, the method works only in a limited pulse rate range, and the accuracy is, of course, rather poor.
The first two categories are herein referred to as continuously measuring stations.

In the days following 27 April, 1986, the entire monitoring network was placed on alert, which meant that continuously measuring stations reported their recordings every three hours, and the remainder of the stations three times a day. All results were collected each morning by the Ministry of the Interior and relayed to the STUK. Each morning The Rescue Department of the Ministry of the Interior compiled rough maps of the radiation situation based on these results. The maps were usually released in the early afternoon of the same day; examples of such maps may be found in the STUK interim reports of May 1985 1,2.

The location of the 20 stations equipped with digital pulse registers are shown on the map in Figure 2. These stations proved very useful in estimating the radiation exposure occurring in Finland after Chernobyl and especially in following its behaviour over time.

3.2 Results and discussion

Graphs showing the results of the daily dose rate recordings at eight pulse register equipped stations in 1985 - 1986 are shown in Figures 3a-3h. These were selected among those with the most complete records, with a view to geographical balance, given in Figure 2 with names underlined.

The net difference between the curves for 1985 and 1986 in the graphs gives the contribution of the Chernobyl fallout. In the winter error is created by differences in the thickness of the snow cover, affecting the natural background.

The rate of decrease of the external dose rate was determined from the graphs for five stations: Uusikaupunki, Pieksämäki, Heinola, Seinäjoki and Kerava. The dose rates for Ylivieska and Kuusamo in the northern part of Finland (Figures 3g and 3h) could not be employed since they received a small amount
of fallout. The graph for Forssa (Figure 3e) was excluded due to lack of results from 1985. The results are shown in Table 1. Dates used in the determination were:

- May 11th, 1986 (15th day after the accident, also used in dose estimates of the USSR report to the post-accident review meeting of the IAEA 9.)

- August 1st, 1986 representing the start of the mobile surveys, presented in this report.

- November 15th, 1986 chosen near the end of the survey period when snowfall has not yet affected the dose rate.

The ratio of the dose rate on August 1st to the dose rate on May 11th was on average 0.34, varying from 0.19 to 0.49. This variance indicated that the composition of the short-lived nuclides in the fallout varied from place to place. The November 15th to August 1st ratio, on average 0.76, had less variance, the decrease in that period corresponding to an effective half life of 9 months.
4 INFLUENCE OF THE METEOROLOGICAL CONDITIONS

4.1 Meteorological situation and dispersion

In the accident on 26 April at 01.23 LT (Local Time) there occurred two explosions. Burning material and sparks shot into the atmosphere above the reactor, and a fire started. According to observers the gases rose to a height of about 600-1000 m. It is possible, however, that radioactive gases rose even higher than the observations of the visible smoke from the fire itself indicate. The height of the plume surveyed by airplanes on 27 April exceeded 1200 m in the northwesterly direction at about 30 km from the reactor site. During the following days its height did not exceed 200-400 m.

This meteorological study was based on international and national weather observational materials from various levels in the atmosphere. During the night of the occurrence of the Chernobyl accident, 26 April, the weather situation over Europe was dominated by a strong high pressure centered over the northwestern part of the Soviet Union and a low situated over Central Europe. On the night of Saturday, 26 April, there existed an inversion layer up to about 400 m in the Chernobyl area with light winds prevailing in those layers of the atmosphere near the ground.

Further along the route taken by the plume the wind speeds were greater (12-17 m/s) in a layer between 50-700 m than in this inversion layer near the ground. The lowest part of the emission plume was transported in this layer from the Chernobyl area over Northeastern Poland and Southern Sweden towards Denmark (Fig. 4).

The long range transport of the radioactive plume of distances exceeding 1000 km, which includes Finland, can be estimated to have taken place at an upper level in the mixing layer of about 2000 m. Measurements made from aircraft over Finland show that
radioactive materials were found even at the level of about 3000 m.

The upper part of the radioactively contaminated plume moved with the airstream (according to air parcel trajectory calculations for the 925 hPa and 850 hPa standard pressure levels, i.e. at about 750 m and 1500 m respectively) to the northwest, turning later towards the Uppsala region of Sweden and Western Finland. Over Finland the plume continued north, later turning east. The airmass near the surface was quite uncontaminated. The radioactive plume spread over Southern and Central Finland between Sunday, 27 April and Tuesday, 29 April. On 30 April and finally on 1 May a cold northerly airstream strengthened and spread into the whole of Finland. After this time the atmosphere over Finland was gradually purified.

The contaminated upper level airmass, associated with a frontal zone extending from Lapland to Central Finland and further southwestwards, reached the ground due to vertical mixing and scavenging by rainfall. The deposition rates increased locally and radioactivity was commonly found at the ground. The first observation of the increased radioactivity was noted in Kajaani (64°17'N, 27°41'E) on 27 April at 20.40 LT. By later analysis of the records of aerosol monitoring stations it was found that the fallout arrived at Nurmijärvi (60°31'N, 24°39'E) on 27 April 15.20 LT, at Mariehamn (60°07'N, 19°54'E) at 19.50 LT, and at Helsinki (60°10'N, 24°57'E) on 28 April at 03.00 LT.

Radioactive materials gradually accumulated on the ground by transport through dry and wet deposition, the rate of which depends on the physical and chemical properties of the gases and particles and on the atmospheric conditions. Most often the local rise in radiation levels depends on particles washed down by rain or snow (wet deposition), precipitation passing through the plume collecting particles and soluble gases. Vapours may also be scavenged by precipitation. The depletion in the
cloud varies widely with atmospheric stability, wind speed and surface conditions. However, conditions are rarely homogenous over large distances and so depletion may vary widely. Heavy rain cleans the air better than slight rain or snowfall. The height of the rainclouds and the duration of the rain significantly affect the effectiveness of the cleaning process. However, all rain after the Chernobyl accident was not contaminated; only those rains which developed in the contaminated air masses.

4.2 Precipitation analyses

The analyses of occurrence of precipitation over Southern and Central Finland are presented daily from 27 April to 2 May in Figures 5-10, amounts in mm over 24 hour period from 08.00 LT. The analyses were carried out utilizing 360 precipitation stations, independently of the measurements of radioactivity. On 27 April showers were very slight; on 28 April there occurred some pronounced shower areas over different parts of the western coast, Southwestern and Central Finland.

More extensive and contiguous rains occurred from 29 April to 1 May. During that period the rain front was moving from the western coastline through Central Finland towards Southeastern Finland, where considerable rainfall was observed. As the rain fell as showers large local differences occurred in the rainfall and in the radioactive fallout, respectively.

Figure 11 gives the cumulative amount of precipitation (in mm) during the period when the radioactively contaminated plume was in the atmosphere over Finland, from 27 April 08.00 to 2 May 08.00 LT, including Northern Finland (400 stations altogether).

There is a clear correlation between the results from precipitation and radiation measurements in different parts of Finland.
ACKNOWLEDGEMENTS

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Table 1. Dose rate ratios in 1986 illustrating the decrease of the excess external dose rate at selected measuring stations.

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<th>Excess dose rate on May 11 $\mu$Sv h$^{-1}$</th>
<th>Aug. 1 May 11</th>
<th>Nov. 15 Aug. 1</th>
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<tr>
<td>Uusikaupunki</td>
<td>0.76</td>
<td>0.19</td>
</tr>
<tr>
<td>Pieksämäki</td>
<td>0.43</td>
<td>0.37</td>
</tr>
<tr>
<td>Heinola</td>
<td>0.31</td>
<td>0.36</td>
</tr>
<tr>
<td>Seinäjoki</td>
<td>0.27</td>
<td>0.30</td>
</tr>
<tr>
<td>Kerava</td>
<td>0.08</td>
<td>0.49</td>
</tr>
<tr>
<td>Five station average</td>
<td>0.34</td>
<td>0.76</td>
</tr>
</tbody>
</table>
Figure 1  External dose rate (µSv/h, microsieverts in an hour) and estimated $^{137}$Cs surface activity concentration (kBq/m$^2$, kilobecquerels per square meter) caused by the Chernobyl fallout in Finland, on October 1, 1986.
Figure 2.

External dose rate monitoring stations equipped with digital pulse counters. The results from the stations underlined are shown in Figures 3 a - g of this report.
Figure 3 a. External dose rate at Uusikaupunki (21°24'E, 60°48'N). NOTE: The y-axis scale differs from Figures 3 b - g.
Figure 3 b. External dose rate at Pieksamäki (27°09'E, 61°18'N).
Figure 3 c. External dose rate at Heinola (26°02' E, 61°12' N).
Figure 3 d. External dose rate at Seinäjoki (22°50'E, 62°48'N).
Figure 3 e. External dose rate at Forssa (23°37'E, 60°49'N). NOTE: The background level shown is extrapolated from the data for 10 days preceding the arrival of the Chernobyl fallout, since data from 1985 was unavailable.
Figure 3 f. External dose rate at Kerava (25°05'E, 60°26'N).
Figure 3 g. External dose rate at Ylivieska (24°29'E, 64°04'N).
Figure 3 h. External dose rate at Kuusamo (29°09'E, 65°57'N).
Figure 4
Schematic diagram of the transport of radioactive releases from the Chernobyl accident at the early stages April 26, 1986 at 00-06 LT.
Figure 5
Amount of precipitation (mm) in Southern and Central Finland over 24 hour period from 27 April 1986 08.00 LT.
Figure 6
Amount of precipitation (mm) in Southern and Central Finland over 24 hour period from 28 April 1986 08.00 LT.
Figure 7
Amount of precipitation (mm) in Southern and Central Finland over 24 hour period from 29 April 1986 08.00 LT.
Figure 8
Amount of precipitation (mm) in Southern and Central Finland over 24 hour period from 30 April 1986 08.00 LT.
Figure 9
Amount of precipitation (mm) in Southern and Central Finland over 24 hour period from 1 May 1986 08.00 LT.
Figure 10
Amount of precipitation (mm) in Southern and Central Finland over 24 hour period from 2 May 1986 08.00 LT.
Figure 11
Cumulative amount of precipitation (mm) in Finland
from 27 April 08.00 to 2 May 08.00 LT.
Institute of Radiation Physics (SFL) 1958 - 1975
Institute of Radiation Protection (STL) 1975 - 1984
Finnish Centre for Radiation and Nuclear Safety (STUK) since 1st March 1984

Report code prefix letters (representing the acronym of the Finnish name of the institution) have been changed with the names of the institution.

Report numbers continue in the original progressive series.

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SFL-A3 Paakkola, O. Radiostrontium in milk, grass and some other biological samples in Finland. Helsinki, 1966.


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