National reports:

SWEDEN

Monitoring the fallout

by Mikael Jensen and John-Christer Lindhé

In Sweden fallout from the Soviet reactor in Chernobyl was first detected on 28 April when personnel from the morning shift at the Forsmark power station measured increasing amounts of radioactivity on personnel passing the station's portal monitor. A check of surface contamination on the ground by the station also showed increased values.

The reactor site was partly evacuated, but it soon became clear that increased levels of radioactivity could be measured all over the Swedish eastern coast. Early measurements by the Swedish National Defense Research Institute (FOA) showed that the source of the release was not an atmospheric nuclear bomb but rather a nuclear reactor accident. Backward air parcel trajectories are automatically calculated by the Swedish Institute of Meteorology and Hydrology and transmitted daily to FOA. That morning they indicated that the source was to be found in the direction of Lithuania, White Russia, and the Ukraine. Suspicion first fell on the large nuclear power plant at Ignalino in Lithuania, which is much closer to Sweden than Chernobyl.

In Sweden radiation measurements (in microroentgen per hour at ground level) during the period 1-8 May 1986 showed the highest levels near the city of Gävle (400 microroentgen per hour and higher measured as the mean value over large areas). Locally, values exceeded 1000 microroentgen per hour in smaller areas. This area experienced rainfall on Monday 28 April and Tuesday morning 29 April.

Countermeasures taken

The Swedish National Institute of Radiation Protection (SSI) initially issued recommendations against drinking rain-water collected from open surfaces and a few other minor restrictions. However, it soon became clear that the sole restriction deemed necessary at the time was keeping cows indoors in regions with grass contents of caesium higher than 1 kilobecquerel per square metre, which corresponds roughly to a total ground concentration of 3 kilobecquerel per square metre. Measurements on milk from the test farms where cows grazed in areas with high concentrations of caesium showed that this was a very conservative estimate giving a more than ample margin to meet the limit of 300 becquerel per litre of

Messrs Jensen and Lindhé are with the Swedish National Institute of Radiation Protection (SSI) in Stockholm.

Surface deposition at four Swedish sites (kilobecquerel per square metre)

Radionuclide	Stockholm	Hallstähammar	Tärnsjö	Hudiksvall
Zirconium-95	1.5	0.7	1.0	0.2
Niobium-95	1.4	0.8	1.4	0.2
Molybdenum-99	0.8	1.3	4.4	1.2
Ruthenium-103	1.0	2.1	7.7	2.2
Iodine-131	6.7	50	170	27
Tellurium-132	1.6	22	210	13
Caesium-134	0.2	6.5	24	6.5
Caesium-137	0.3	8.2	32	5.7
Barium-140	2.0	10	36	9.0
Lanthanum-140	1.8	7.8	23	6.6
Neptunium-239	5.0	2.0	—	2.0
Dose rate (microsievert per hour)	0.1	1	5	0.8

Notes: The table shows preliminary results from some relatively high intensity regions.
In Stockholm readings were taken at a lawn outside the laboratory (dry deposition); in Hallstähammar, in an open space at the edge of a forest; in Tärnsjö, in plowed soil of a high rainfall region; and in Hudiksvall, at a wet air strip.

About this article...

This report is a first attempt to present an overall view of recommendations by the Swedish National Institute of Radiation Protection (SSI) and of the measurements made by many Swedish authorities and organizations after the Chernobyl accident.

Two resources turned out to be essential for the early mapping of the fallout and the detailed analysis of its composition: the network of sampling stations for ground-level air run by the Swedish National Defense Research Institute (FOA), and the high analysis capability maintained by its Nuclear Detection Laboratory. This laboratory also carried out high altitude sampling with help from the Air Force. Its In Situ Gamma Group also was transported around the country by Navy Helicopters for reliable and detailed deposition measurements in the early phase.

Other especially useful resources were the SSI's monitoring stations throughout Sweden to measure deposition on the ground, and the big scintillation detector system flown across the country by the Swedish Geological Company (SGAB). Together, these produced a very good overall picture of the radiation pattern.

Furthermore, measurements were carried out by several external bodies, including laboratories at Swedish nuclear power stations and universities.

Time has not permitted SSI to closely examine all data, nor can we guarantee that the organizations responsible for different measurements reported to SSI have had proper time to evaluate and doublecheck their data. Detailed results and descriptions of measurement conditions will have to follow later.

caesium in milk and foodstuffs. It was also found that the content of caesium fell as new grass grew up. Gradually, restrictions were removed and on 25 June cows could again graze freely all over Sweden. Many activities remain to be followed up. Also, meat from wildlife and reindeer (predominantly slaughtered in the autumn) may exceed the limit.

It was found that routine occupational health procedures often met the radiation protection requirements. One example is the normal protective measures taken against dust during changes of large industrial air filters.

Radiation monitoring: The air

FOA continuously measures radionuclides in air at ground stations using forced ventilation through glass-fiber filters, and by aircraft equipped with air filters.*

Following Chernobyl, ground-level filters were changed much more frequently than normal, in periods of every 3 hours. Each day FOA and the Air Force analysed the radionuclide concentration at some altitude between 100 and 800 metres on a route chosen from expected cloud trajectories.

Iodine-131 and other radionuclides were present in the air at ground level. The iodine collected on the filter corresponds to a maximum concentration of about 10 becquerel per cubic metre for the Stockholm area.**

Parts of the filters have been autoradiographed to identify hot particles. Gamma spectroscopy studies of such identified particles show an expected enhancement of refractive elements, such as cerium, ruthenium, zirconium, and others. Single hot particles identified on the ground by simply using a gamma sensing instrument have turned out to emit radiation from almost purely ruthenium and molybdenum radionuclides.

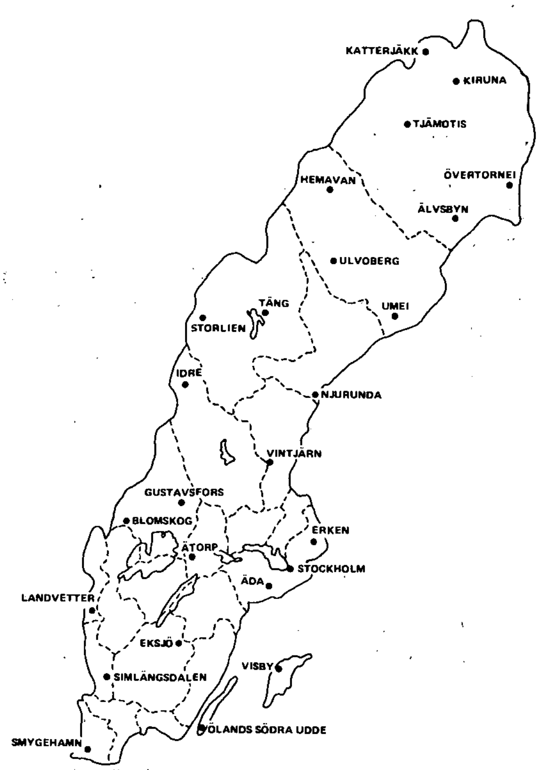
Aircraft surveys

Measurements also were made by the Swedish Geological Company in aircraft flown 150 metres above the ground. These measurements have been used to give a general first picture that was later followed by grass sampling and measurements by mobile patrols (gamma spectrometry). (Such surveys also are considered valuable in emergency planning in the event of Swedish reactor accidents. They are expected to be launched in the intermediate period within a few days after an accident). The aircraft carry equipment for gamma spectrometry that can be used to describe the distribution of individual gamma-emitting nuclides.

Site measurements

In situ measurements (employing a high-resolution germanium detector looking down from one metre above ground) were carried out by FOA continuously at the Laboratory in Stockholm and with their mobile system at a number of places between Malmö and Rudiksvall (See accompanying table).

The mobile spectroscopy system also made measurements in the plume above the Baltic Sea during the evening of 28 April. Later that night, this cloud was washed out by rain and produced high deposition areas south of Gävle.*



Sweden's radiation monitoring stations

At the end of the 1950s, Sweden established a system of some 25 stations to continuously monitor gamma radiation from the ground due to fallout from atmospheric testing of nuclear weapons. As the weapon fallout has diminished, these stations have served to follow variations in natural background radiation. Now in 1986, they have proved to be very useful as one means of following levels of gamma radiation over the country after a severe nuclear accident. The stations are under the auspices of the Swedish National Institute of Radiation Protection (SSI).

These stations use an ionization chamber placed 2.5 metres above the ground. They register gamma radiation from the ground, as well as the constant contribution from cosmic radiation. The detector cannot distinguish between gamma radiation from the ground and from the air. In the case of low air activity after the passage of the plume from Chernobyl, the detector reading reflected mainly the ground deposition.

Information from these stations has been a valuable indicator of the general trend all over the country. Information from at least some stations was available each morning, which enabled authorities to report the trend during the previous night.

Grass measurements

The significance of measuring grass samples stemmed from the decision recommending that cattle be kept in stables until readings showed acceptable levels. This level was set at 10 kilobecquerel per square metre of iodine-131 (corresponding to an expected milk concentration of about 2 kilobecquerel per litre). Grass samples were taken and evaluated by laboratories of Swedish nuclear power plants, the universities of Lund and Uppsala, and Studsvik Energiteknik AB.

---

* For a description, see "The Swedish Air Monitoring Network for Particulate Radioactivity", in *IEEE Transactions on Nuclear Science*, Vol. NS-29, No. 1, (February 1982) Extract.

** To calculate doses from such measurements, a proper factor must be applied to account for iodine passing through the filter. A comparison with other measurements indicates that a value for this factor is perhaps 3, not higher than 5. (This would correspond to a maximum air concentration in the Stockholm area of $3 \times 10 = 30$ becquerel per cubic metre for iodine-131.)

* The cloud, and its resulting wet deposition, had a different nuclide composition compared to the dry deposition. Most important was the fivefold increase in the tellurium-132/iodine-131 ratio in the wet deposition. As the half-life of tellurium is rather short (3.25 days), this means that fallout fields of high density and wet deposition will initially decay somewhat faster than the fields of lower density and dry deposition.

Water and foodstuffs

Monitoring measures related to water and food generally focuses on the relatively short-lived iodine-131 and long-lived caesium-137 and strontium-90.

SSI has been monitoring radioactivity content in dairy milk since 1962. After Chernobyl, the sampling programme was extended to cover 11 main regions with daily samples from 29 April on. A few days later (2 May) the programme was extended to cover daily 42 dairies in Sweden that produce milk for consumption. This extensive monitoring will be reduced when the situation has stabilized, but the content of long-lived activity in milk will be followed up for a longer period. Iodine-131 concentration in dairy milk in Sweden during the period 28 April to 7 May was found to be around 20 becquerel per litre with the highest value about 200 becquerel per litre from one district.

Besides this nationwide programme, detailed monitoring of milk was performed in a region (Gotland) where high values of gamma radiation had been reported.

Most milk-producing cows were stalled at the end of April, but a limited sampling programme was launched on 2 May nationwide covering farms where cows were not stalled. On the same day, the emergency monitoring staffs at big dairies were alerted.

Measurements also were made of mothers' milk. In the Stockholm region, samples taken between 27 April and 4 May showed expected low concentrations of iodine-131 (8 to 25 becquerel per litre).

The content of iodine-131 in the thyroid of the staff at SSI and other people in Stockholm was estimated from measurements at the Institute. The content was found to vary from a few up to 100-200 becquerel. Measurements later were done at hospitals around Sweden showing similar low values.

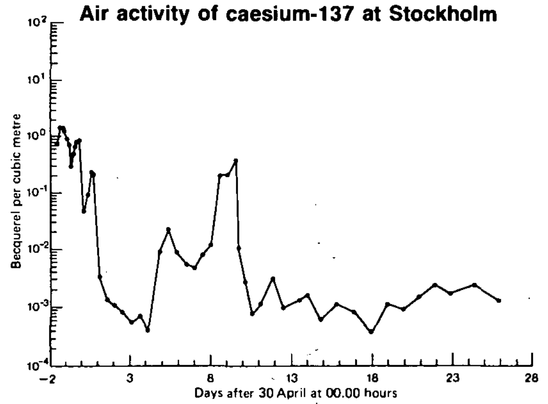
Vessels and vehicles

Some measurements were done by SSI and other institutions on vessels from abroad. On a few vessels passing the southern part of the Baltic Sea during the first days after the accident, radioactive contamination detected was at levels up to 1000 kilobecquerel per square metre. After deck washing, contamination went down considerably.

Measurements also were made of air filters and other automative and aircraft parts where high concentration would be expected. Dose rates in no case were alarming.

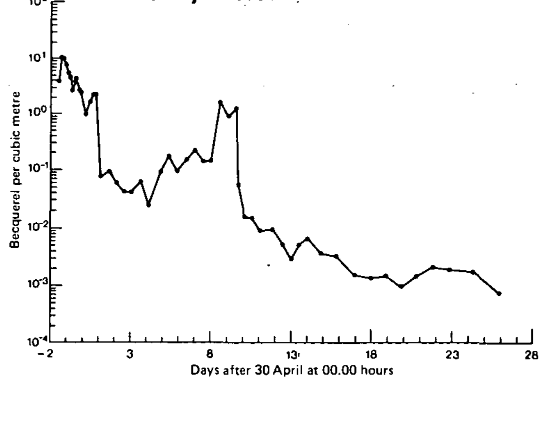
Surveys on marine helicopters that had flown through the radioactive plume on 28 April were carried out by FOA. No values near the action level of 20 microsievert (2 millirem per hour) at a distance of one metre were found.

Air activity of caesium-137 at Stockholm



These graphs show the variation from filter measurements (uncorrected for filter efficiency) in the first two weeks after the radioactive plume arrived over Sweden.

Air activity of iodine-131 at Stockholm



Swedish authorities involved

The Swedish National Institute of Radiation Protection (SSI) is the co-ordinating authority in cases of widespread radioactive fallout in peacetime. Before Chernobyl, SSI had co-ordinated preparedness measures in two cases of re-entry into the earth's atmosphere of nuclear-powered satellites.

The type of co-operation with other authorities depends on the magnitude of hazards involved. If a very serious one is at hand, Sweden's 25 county councils will be given far-reaching responsibilities for co-ordinating protective measures at their regional level. This was not considered necessary after Chernobyl but was kept in reserve. The county councils were kept informed of developments regularly.

Apart from SSI, a large number of central authorities were involved:

- FOA — The Swedish National Defense Research Institute (planning measures and evaluation of results, measurements)
- SKI — The Nuclear Power Inspectorate (situation at the reactor)
- SMHI — Swedish Insitute of Meteorology and Hydrology (weather forecasts)
- LBS — Swedish Board of Agriculture (farming measures)
- SLV — Swedish National Food Administration (food regulations)
- SOS — National Board of Health and Welfare (iodine tablets, information to medical personnel, information to community health authorities)
- RPS — National Swedish Police Board
- Authorities responsible for transports by road, rail ,sea, and air
- Swedish Defense authorities for army, fleet, and air forces.

In addition, a large number of research institutions and commercial companies were involved in monitoring.

Information was supplied to many Swedish embassies abroad. Contacts were kept with international organizations such as the IAEA, World Health Organization, Organisation for Economic Co-operation and Development, Nuclear Energy Agency, and International Commission on Radiological Protection. Bilateral contacts were kept with authorities in about 20 countries.