CHERNOBYL REACTOR ACCIDENT

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REPORT OF A CONSULTATION
6 MAY 1986

(PROVISIONAL)

WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE
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CHERNOBYL NUCLEAR ACCIDENT

Following the accident at a nuclear reactor in Chernobyl, USSR, the WHO Regional Office for Europe inaugurated procedures for the systematic collection and dissemination of information. Such were the complexities and uncertainties that it was decided to call a one day consultation of experts at short notice, who would review the situation and provide guidance as to the needs for immediate public health action and also advise on predicted longer term trends.

This meeting was held in Copenhagen on 6 May 1986 and the conclusions and recommendations of the expert group have already been distributed. The present report provides more detailed scientific background in relation to both the short-term recommendations and longer term considerations, together with a description of the course of events, so far as information is available, in the first 12 days after the accident occurred.

Note

This is a provisional document and does not constitute formal publication. The views expressed are those of the participants in the consultation and do not necessarily represent the decisions or the stated policy of the World Health Organization.

PART I - NARRATIVE*

INTRODUCTION

Following the nuclear accident in Chernobyl, USSR, the World Health Organization, both at the Regional Office for Europe in Copenhagen and at the Headquarters in Geneva, was approached by Member States for urgent advice on the existing situation, the prediction of consequences and advice on action to be taken at national level.

The Director General of WHO has entrusted the Regional Office for Europe with follow-up action and a team has been assembled for the period of the emergency.

Following an analysis of the situation, it was decided to urgently convene a group of experts. This group, composed of senior scientists with knowledge in the fields of meteorology, radiation protection, biological effects, reactor technology, emergency procedures, public health and psychology, met in Copenhagen on Tuesday, 6 May 1986, to analyse the development of events and their consequences.

THE CHERNOBYL REACTOR AND THE ACCIDENT

On 26 April 1986, very early in the morning, a reactor unit of 1 000 MW OF THE RBMK type in the Chernobyl Power Station ignited "following an explosion". Soviet authorities officially announced that the reactor fire had ended on May 5 and that the "reaction had stopped". No detailed information has been released on the events leading to the explosion and the subsequent fire.

The reactor unit involved is of the "channel" type, graphite moderated and light-water cooled, using low-enriched uranium. The water boils in the channels and a direct steam cycle to the turbine in used.

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Figure 1 presents schematically the main circuits of a nuclear power station with an RBMK reactor.

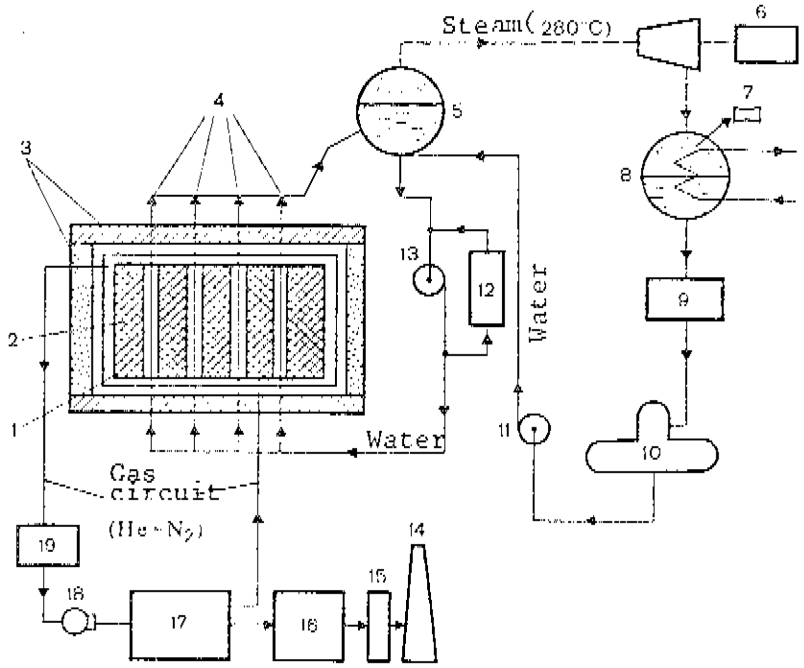

FIGURE 1

1 = Reactor

2 = Graphite pile

3 = Biological Shielding

4 = Fuel channels

5 = Drum separator (steam from water)

6 = Turbine generator

7 = Ejector (turbine)

8 = Condenser

9 = Cleaning of condensate radioactivity and impurities

10 = Deaerator

11 = Pump for auxiliary water supply

12 = Removal of impurities by ion exchange

13 = Main circulatory pump

14 = Ventilator stack

15 = Aerosol filter

16 = Gas holding tank (storage for radio-active decay)

17 = Adsorber for CO_2, CO, N_2, NH_3

18 = Compressor

19 = Aerosol & Iodide filters

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PART I NARRATIVE

In the absence of substantive information on the sequence of events leading to the explosion and fire, only conjectural scenarios can be postulated. One possible sequence would start with a rupture of the primary circuit at the level of one main steam collector, followed by turbine and main pump trips, vaporization of the coolant, possibly a zirconium-water reaction in the fuel cladding, with generation of hydrogen, and a partial meltdown of the fuel with release of radioactive materials. The postulated sequence would continue with overheating of the pressure tubes and the graphite, with further zirconium-water and other reactions, loss of reactor leak tightness, entrance of air and ignition of hydrogen and other flammable gases and then of graphite, with temperatures exceeding 2 000°C. At some point of the sequence, a gas explosion could have caused the damage to the reactor building reported by the Soviet media, while the large graphite mass continued burning until the fire was finally extinguished on May 5.

During the episode, substantial amounts of radioactive materials, basically fission products, were released into the atmosphere. Many fission product nuclides were released, but judging from results of measurements of samples obtained many hundred kilometres away, radionuclides of volatile elements prevailed in the release.

TRANSPORTATION AND DISPERSION OF THE RADIOACTIVE MATERIAL IN THE ATMOSPHERE

Due to the high temperature during the release, a substantial plume rise occurred, bringing released radioactive materials to high altitudes of from several hundred metres to over a kilometre.

The released materials would then be dispersed by diffusion and mainly by transportation by the prevailing winds at the different relevant heights.

Because of changes in the release rate, meteorological conditions, wind direction and speed, and other factors such as release duration, and changing of conditions along great distances, plume configuration and concentration at early times of dispersion provides little information on the resulting air concentrations many hundreds of kilometres from the accident site. Modelling techniques which are applicable for short distances must then be substituted, for longer distances, by assessments of the movement of air masses.

As summarized in an interim report from the Finnish Center for Radiation and Nuclear Safety, the weather in Europe on the morning of April 26th was dominated by a strong high pressure area over the Western parts of the Soviet Union and a low pressure area that reached from Iceland to North Western Europe. During the day a separate low pressure center was formed in Scandinavia. It moved quickly to the Norwegian sea and this move made room for a very warm air mass that streamed from the south to Finland. This warm air extended almost over the whole country before the morning hours of April 27th.

In the Chernobyl area (51° 17'N, 30° 15'E) the weather was at the starting time of the accident typical of a high pressure situation; winds were very weak and their direction varied strongly, a vast area of fog developed in the night. Higher in the atmosphere the wind field was more clear-cut than on the surface. Already at the height of 1.5 km (850 mb level) the wind speeds were 8 - 10 m/s and they were blowing from the south-east or south. A clear wind canal that reached over the outmost western parts of the Soviet Union directly to Finland is shown in Figure 2. It is a 850 mb level weather map for the situation at 03 Finnish time (00 GMT) on 26 April 1986. The stream velocities varied between 30 and 60 km/h, which means that the emission plumes moved easily in good 24 hours from the accident area to Finland.

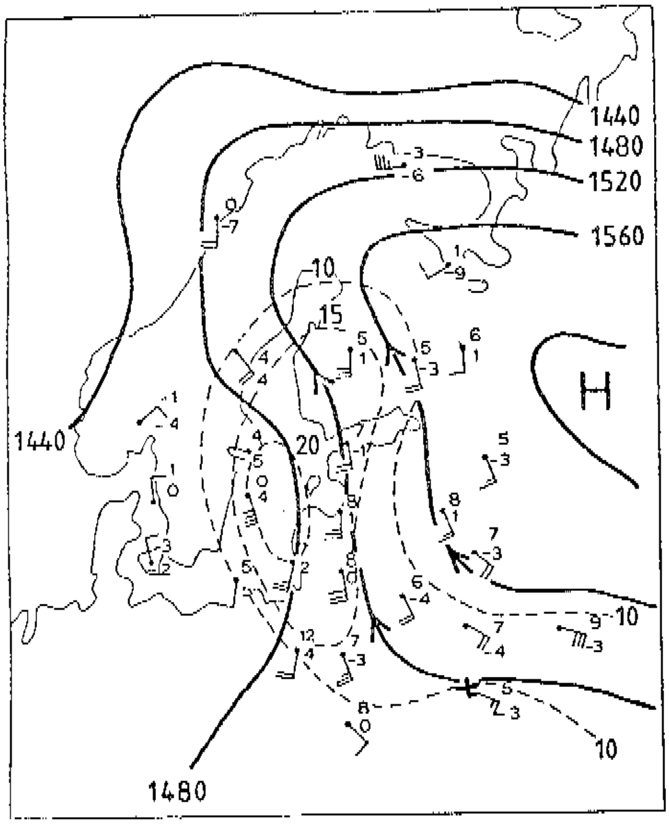


FIGURE 2
850 mb level height analysis in the situation on 26 April at 03 Finnish time (00GMT). The dashed line shows the analysis of wind speeds. The unit of speed is m/s.
(From the Finnish Meteorological Institute).

PLUME DIRECTION CALCULATIONS

The most illustrative picture of the distribution of the radioactive contamination over Europe is given in maps showing the calculated location of the radioactive plume at various times. These are shown in Figures 3 - 7, submitted by the Swedish Meteorological and Hydrological Institute. They have calculated the location of plumes originating at Chernobyl at various times and for each release time they have followed the plume, as it would have moved according to the meteorological information, for five days.

Since it is not known how the release of radioactive material varied with time during the period 26 April to 5 May, the plume locations only indicate the potential for radioactive contamination, but as will be shown in a later section of this report, the measurements of activity concentration in the air and on the ground give results which are fully consistent with the meteorological information.

Calculations have been made for two heights, 1 500 m and 750 m. During the first phase of the accident, most of the radioactive material was most likely brought up to high levels in the atmosphere and the level of 1 500 m may be the most relevant. The extension of the plume at that height has been shaded gray on the maps. Later, the activity was more likely at lower levels, and only the calculated result for 750 m is shown.

The depletion of the atmospheric content of radioactive material is caused by radioactive decay, by gravitational settling of the larger particles, by formation of aerosols close to ground level, and by rainfall. The rate at which radioactive aerosols are brought to the ground depends on the particle size, larger particles being deposited closer to the accident site by gravitational deposition. Rainfall is a most important depletion mechanism, as will be seen later when the results of activity measurements are discussed.

With some simplification, the plume directions may be grouped into the following five periods :

1. Area : Scandinania, Finland, Balticum
   Emission during : 26 April; arrived 27 - 30 April

2. Area : Eastern central Europe, Southern Germany, Italy, Yugoslavia
   Emission : 27 April; arrived 28 April - 2 May

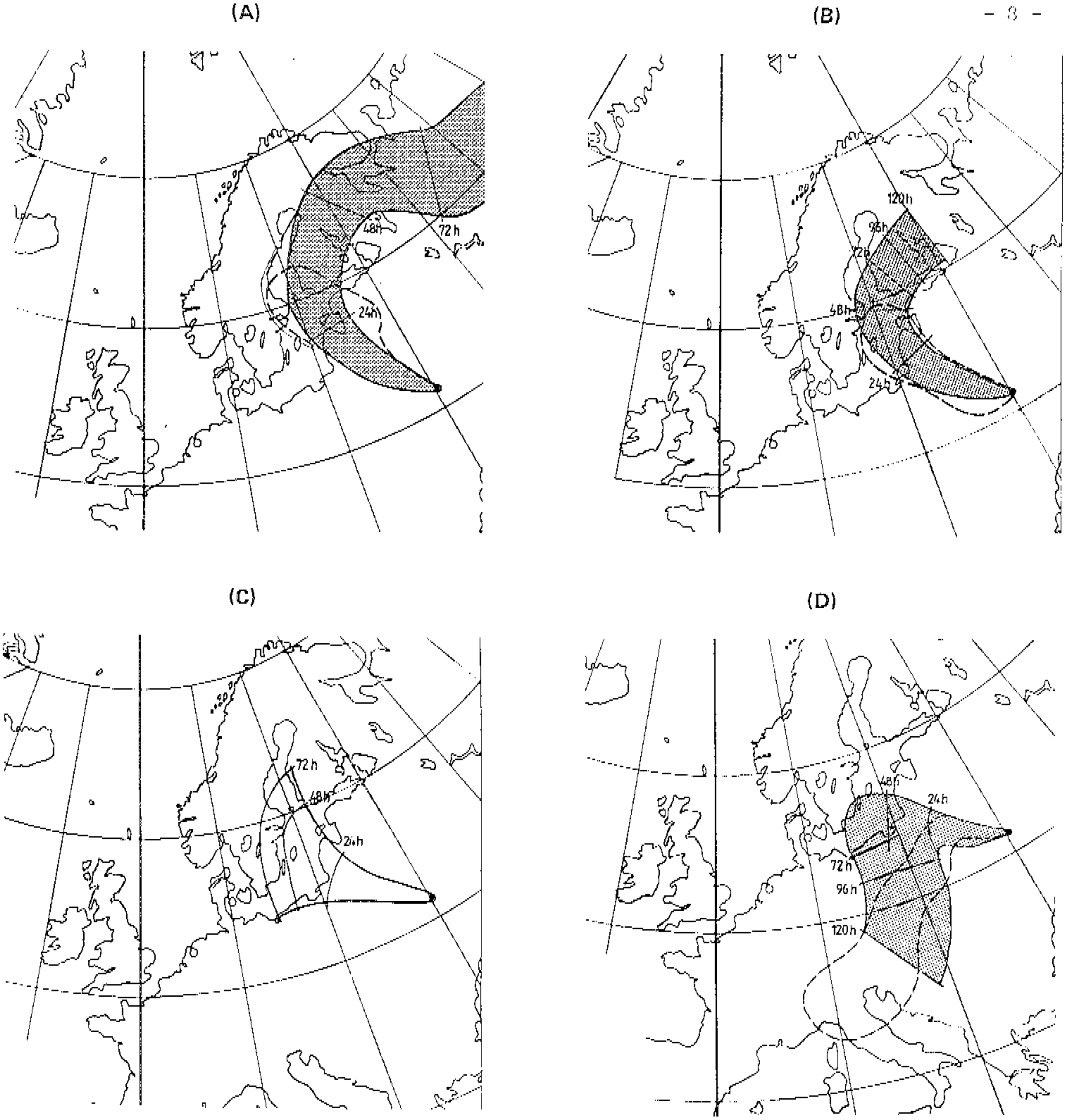
3. Area : Ukraine and eastwards
   Emission : 28 - 29 April; arrived 28 April - 2 May

4. Area : Balkan, Romania, Bulgaria
Emission : 29 - 30 April; arrived 1 - 4 May

5. Area : Black Sea, Turkey
Emission : 1 - 4 May, arrived 2 May and later.

It is not unlikely that most of the release occurred in the first two periods, so that the corresponding plumes (Figures 3 a-d and 4 a) are the most significant as regards movement of radioactive material.

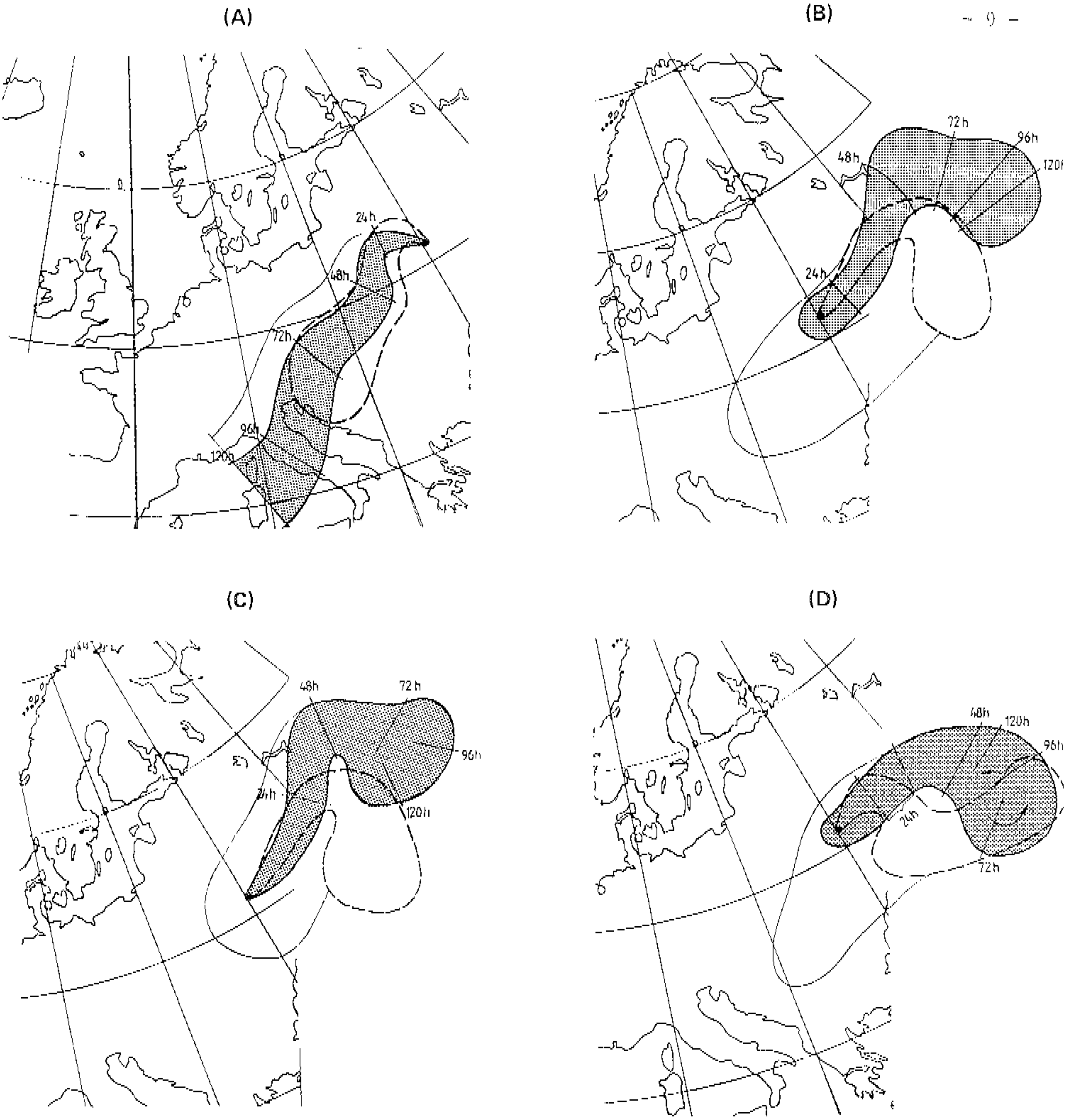
The plume calculations end at 120 hours (5 days) because of the uncertainties of calculations for longer movement periods. The later movement and dispersion of radioactive material already in the atmosphere is more difficult to assess. However, for each plume shown on the maps, there is also remaining activity from earlier plumes. Figure 7 indicates general wind directions on the evening of 5 May, the day when the releases had ceased according to USSR reports. It illustrates how older material may have moved towards the northwest. This explains why countries such as the Benelux, United Kingdom and Denmark have had some contamination although they have been outside the immediate plumes.



Figures 3 a, b, c and d illustrate the movement in the atmosphere of any radioactive material that might have been released from the Chernobyl reactor during the first days after the accident. The approximate location of plumes originating at Chernobyl at various times have been calculated from the meteorological information by the Swedish Meteorological and Hydrological Institute. The four diagrams represent the following assumed emission times at Chernobyl:

(a) Saturday, 26 April, 00.00 hours GMT
(b) Saturday, 26 April, 12.00 hours GMT
(c) Saturday, 26 April: transition stage 12 - 24 GMT
(d) Sunday, 27 April, 00.00 hours GMT

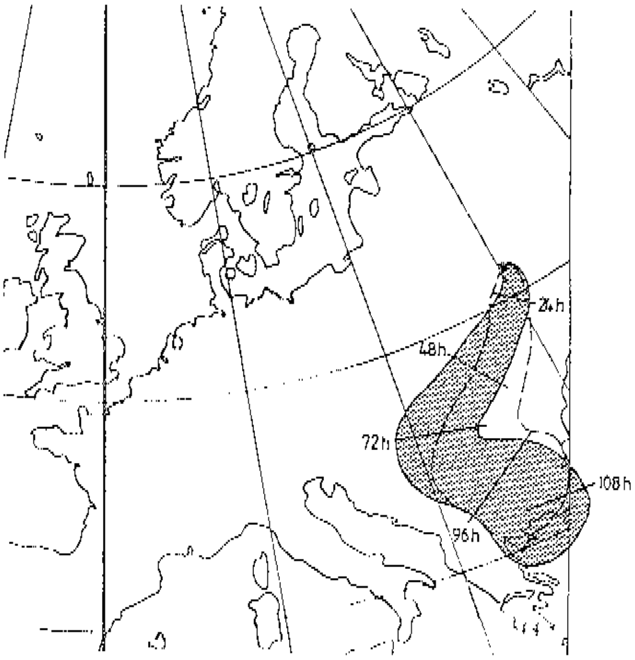
Full lines indicate the level 1500 m, dashed lines 750 m. The transport time is indicated for the level 1500 m. The thin line in Figure 3 a indicates an uncertainty area due to weak and variable winds.



Figures 4 a, b, c and d illustrate the movement in the atmosphere of any radioactive material that might have been released from the Chernobyl reactor during the period Sunday, 27 April to Tuesday, 29 April. The notations are the same as in Figure 3, with the transport times given for the level 1500 m. The four diagrams represent the following emission times at Chernobyl:

(a) Sunday, 27 April, 12.00 hours GMT
(b) Monday, 28 April, 00.00 hours GMT
(c) Monday, 28 April, 12.00 hours GMT
(d) Tuesday, 29 April, 00.00 hours GMT

(A)



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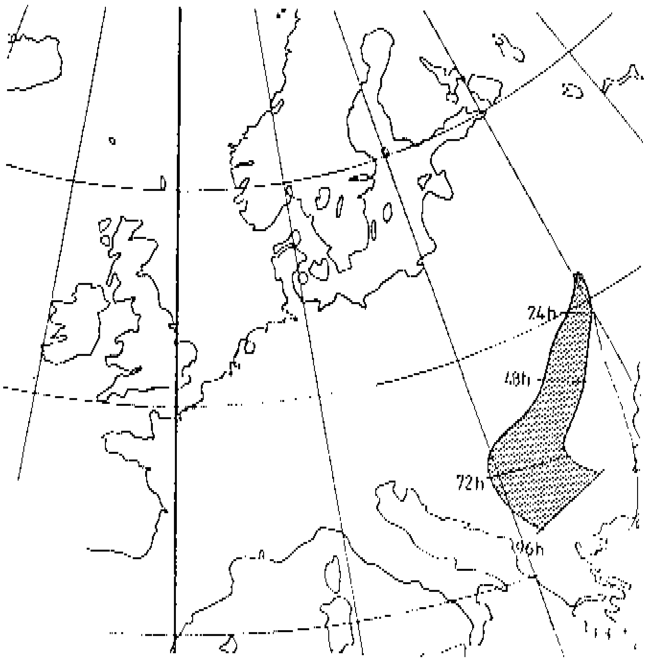

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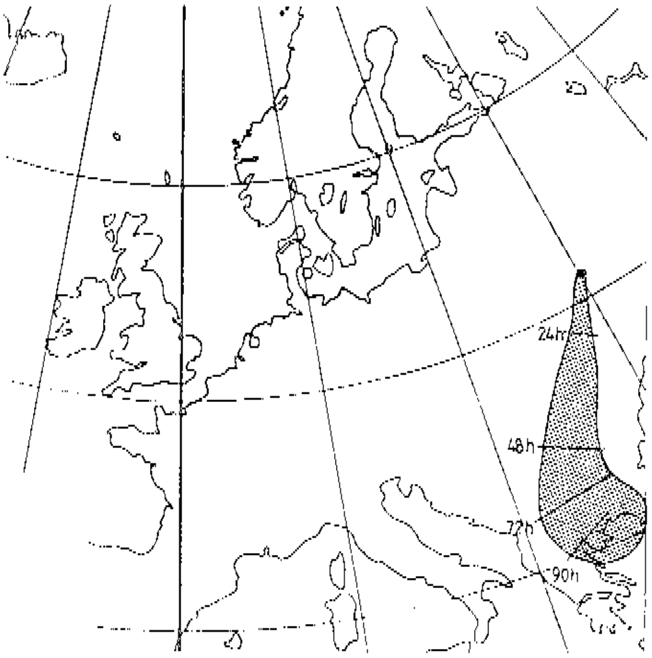

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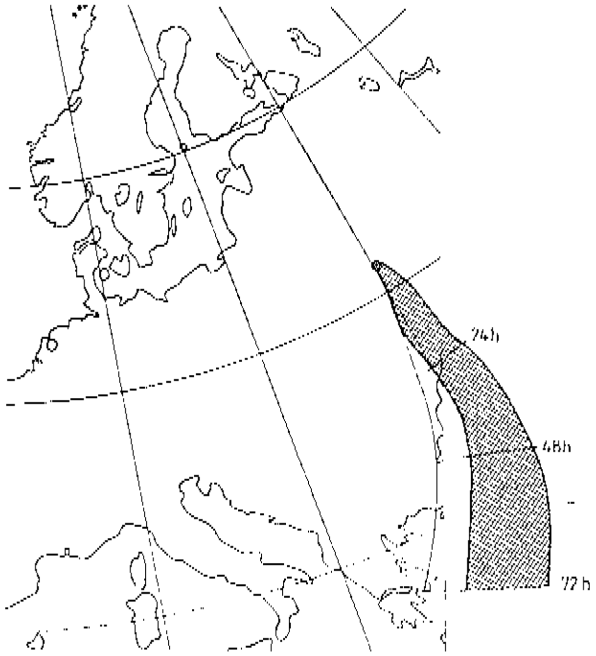
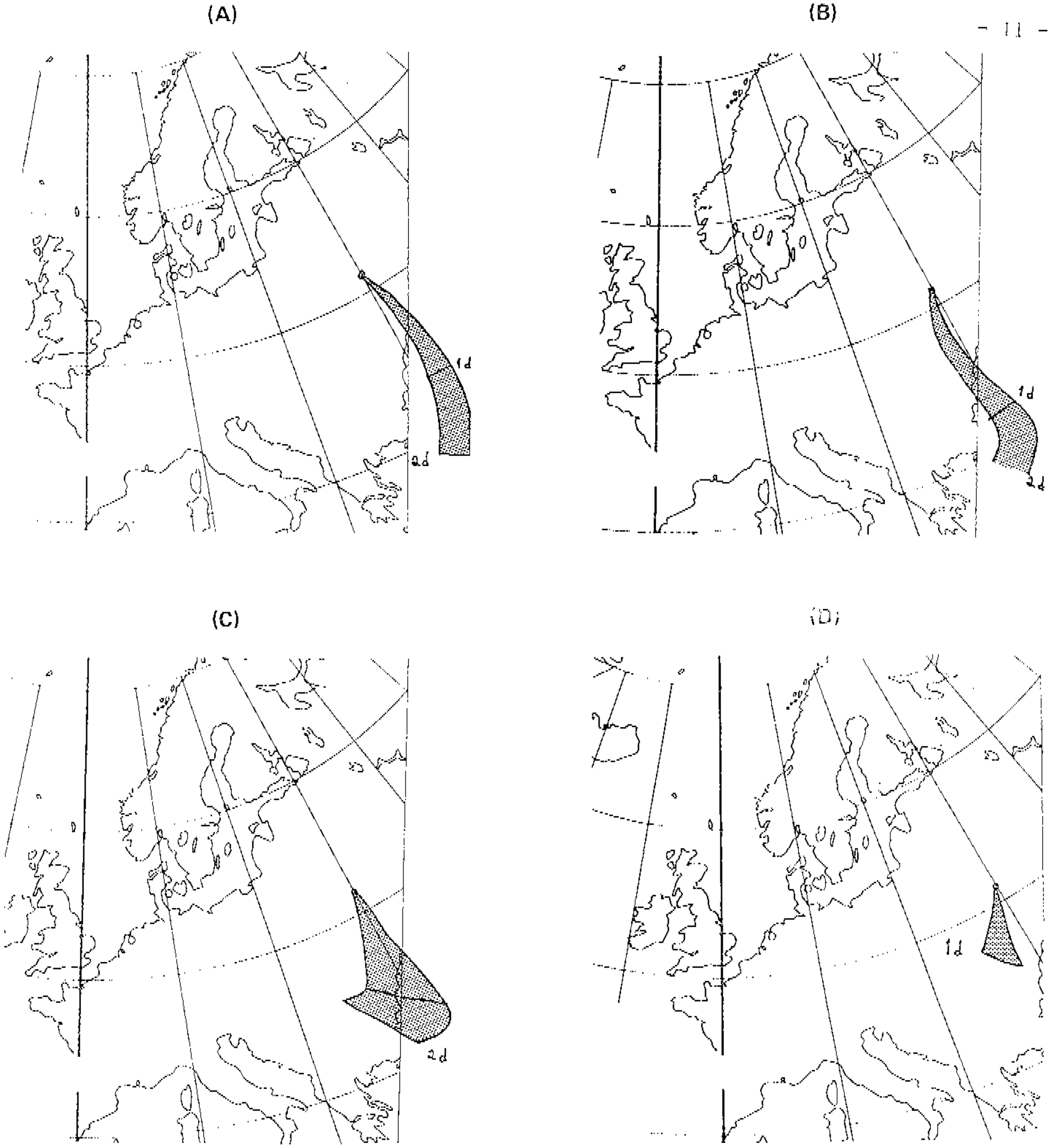


Figures 5 a, b, c and d illustrate the movement in the atmosphere of any radioactive material that might have been released from the Chernobyl reactor during the period Tuesday 29 April to Thursday, 1 May. In b, c and d, the curves relate to the height of 750 m, because it is no longer likely that much of any released material would reach higher levels. The four diagrams represent the following emission times at Chernobyl:

(a) Tuesday, 29 April, 12.00 hours GMT
(b) Wednesday, 30 April, 00.00 hours GMT
(c) Wednesday, 30 April, 12.00 hours GMT
(d) Thursday, 1 May, 00.00 hours GMT



Figures 6 a, b, c and d illustrate the movement in the atmosphere of any radioactive material that might have been released from the Chernobyl reactor during the period Friday, 2 May to Monday, 5 May. The curves relate to a level of 750 m. The four diagrams represent the following emission times at Chernobyl:

(a) Friday, 2 May, 00.00 hours GMT
(b) Saturday, 3 May, 00.00 hours GMT
(c) Sunday, 4 May, 00.00 hours GMT
(d) Monday, 5 May, 00.00 hours GMT

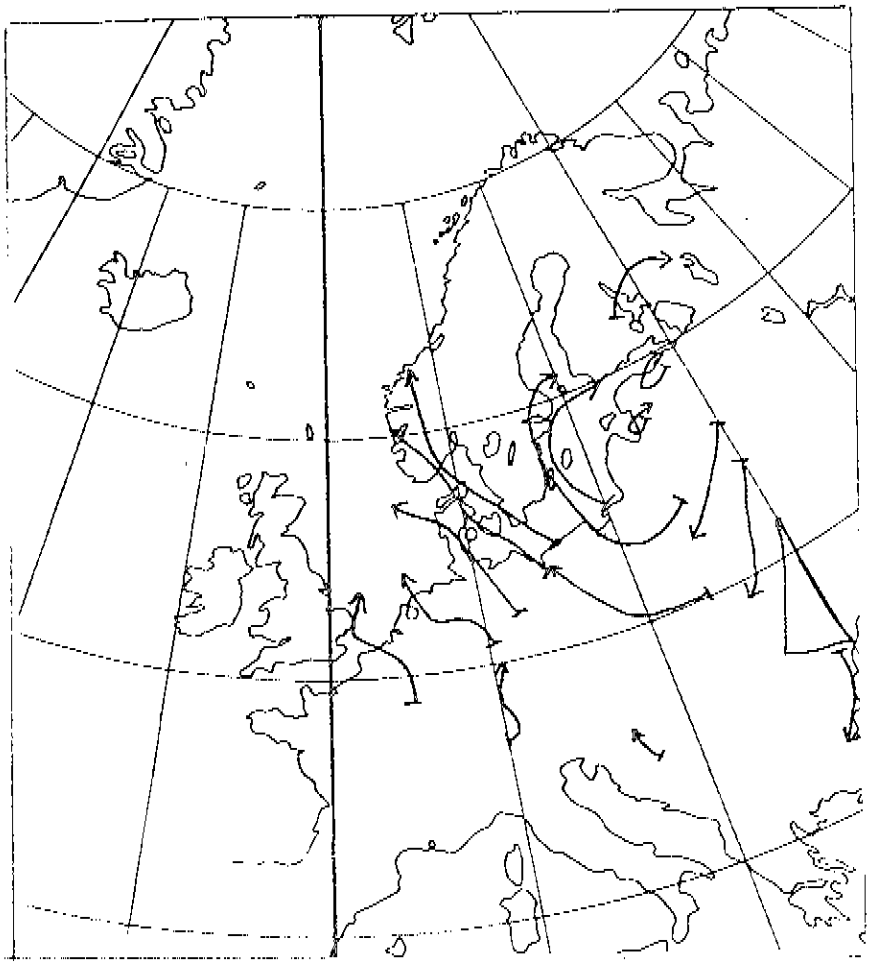


Figure 7: Indication of movements of air masses in Europe on 5 May at 18.00 hours GMT. Some radioactive material from early releases moves towards northeast.

CONSEQUENCES INSIDE THE USSR

According to the USSR Investigation Commission, two workers died immediately from the accident, but not from radiation injuries. One died from severe heat burns, the other when part of the reactor building collapsed from the accident. About 200 workers were brought to hospital and it is reported that 18 of these have been exposed to such high radiation doses that their condition is severe. Evacuation of the Chernobyl area was said to have commenced on Sunday, 27 April at 14:00 hours (the accident was reported to have occurred at 01.23 hours on Saturday, 26 April). According to other USSR reports, some 40 000 persons were then evacuated and several days later a further 40 000 were moved out of the area. There is not yet enough information to make it possible to assess the short-term radiological consequences of the radiation in the close to the accident or elsewhere in the Ukraine.

In accident scenarios that have been used in various countries for the purpose of emergency planning, the dominating long-term consequence is due to the deposition of cesium-137 (half-life about 30 years) over large agricultural areas, causing contamination of various farm products, but also causing external exposure from the ground. Experience from studies of the world-wide radioactive fallout from the atmospheric nuclear weapons testing gives useful information on critical pathways and transfer factors through the various food chains.

RADIOLOGICAL CONSEQUENCES OUTSIDE THE USSR

Exposure routes

The exposure of man due to the atmospheric contamination by radioa stances is caused by a number of routes, the most impor

- External exposure from the radioactive cloud;
- Internal exposure from radioactive substances taken into the body by inhalation during the passage of the cloud;
- External exposure from radioactive substances deposited on the ground;
- Internal exposure from radioactive substances taken into the body by ingestion of contaminated food (and in rare cases water).

Except for noble gases, which only expose by gamma and beta radiation from the cloud and contribute little to the total dose, the deposition pathways dominate the exposure. The main nuclides that have been found in the air and deposited on the ground after the accident are :

Zr-95	half-life	65	days
Nb-95		35	days
Mo-99		2.8	
Tc-99m		0.38	
Ru-103		40	
Te-132		3.3	
I-132		0.1	
I-131		8.05	
I-133		0.88	
Cs-134		767	
Cs-136		13	
Cs-137		11 000	
Ba-140		12.8	
La-140		1.7	
Ce-141		32.5	
Ce-144		285	
Np-239		2.4	

Most of these are isotopes of relatively volatile elements. In fresh fallout from nuclear weapons tests Zr-95/Nb-95, which are not considered volatile, were more important in contributing to the total external gamma dose than in the case of the present accident where the relative abundance of these nuclides is not so high. In the fresh material, Te-134/I-132 and Ba-140/La-140 were important contributors to the dose, in addition to iodine-131. The long-lived Cs-137 was present in relatively high proportions with activities between 1 and 10 per cent of those for iodine-131 during the first few days.

For short-term internal exposure, the iodine isotopes are the most important, dominated by iodine-131. The exposure route is through milk but also by inhalation. Iodine is taken up by the thyroid and infants consuming fresh milk receive the highest radiation doses, mainly because the iodine is retained in a smaller size thyroid than in adults, thus giving a higher concentration and a higher radiation dose. It should be noted that the radiation dose is the energy absorbed per unit mass of irradiated tissue.

Biological effects

Outside the USSR, radiation levels from the accident, as reported, are too small to cause any acute radiation effects. The remaining possible biological effects are therefore late effects, namely cancers, genetic and teratogenic effects. Iodine in the thyroid increases the probability of thyroid nodules and cancer in this organ. The current assumption is that there is no threshold dose below which the late effects cannot occur and that, therefore, any small dose will cause a proportionally small probability of incurring some effect. For cancer this will not happen until after a latency period of tens of years. Teratogenic effects will be evident after birth and genetic effects may appear in one or more generations of offspring to the exposed individuals. The normal frequency of the various late effects is the result of a variety of causative influences of which radiation is only one. The additional probability of being affected by some late effect caused by an incremental radiation dose is therefore not easily derived from comparisons with the natural background radiation.

The Chernobyl accident has caused an uneven deposition of radioactive material in the countries reached by the radioactive plumes, with local high values substantially exceeding the average for the country. The question arises whether epidemiological studies could be expected to show increased frequences of late effects. On the basis of the assumption that, for cancer and genetic effects which appear at random with a probability that is proportional to the effective dose equivalent (a quantity used in radiation protection to make different exposure situations intercomparable), the expected number of persons affected would be proportional to the product of the number of people exposed and their average effective dose equivalent. The effective dose equivalent is measured in sievert (Sv) or millisievert (mSv). The risk factor is of the order of 10^{-5} per mSv for deaths by cancer.

Doubling the natural background for one year would mean an extra radiation dose of 1 mSv and would be expected to lead to some 100 cancer deaths appearing over a period of several decades in a population of 10 million people. Even if a much more pessimistic risk factor were used, the expected increase in the annual cancer rate would be difficult to detect. If infants consume milk at the iodine-131 action level of 2000 Bq/l used in a number of countries, their effective dose equivalent accumulated over the contamination period would be a few mSv. Considering the documented uneven distribution of iodine deposition, the number of infants exposed near the action level in any one country would only be expected to be a few hundred or at most a thousand. The expected number of lethal cancer would then be less than one, i.e. it is more likely than not that there will be no such case, in the most exposed sub-group, although some case of thyroid cancer or nodules cannot be ruled out.

Within the first week after the accident a number of measurements have been made on activity concentrations in milk and exposure rates outdoors. The results of these measurements are only indirectly related to the health consequences. The probability of cancer and genetic effects is assumed to be proportional to the total radiation dose committed by the event, i.e. would be proportional to the time integral of the concentrations and exposure rates. This is illustrated schematically in Figure 8.

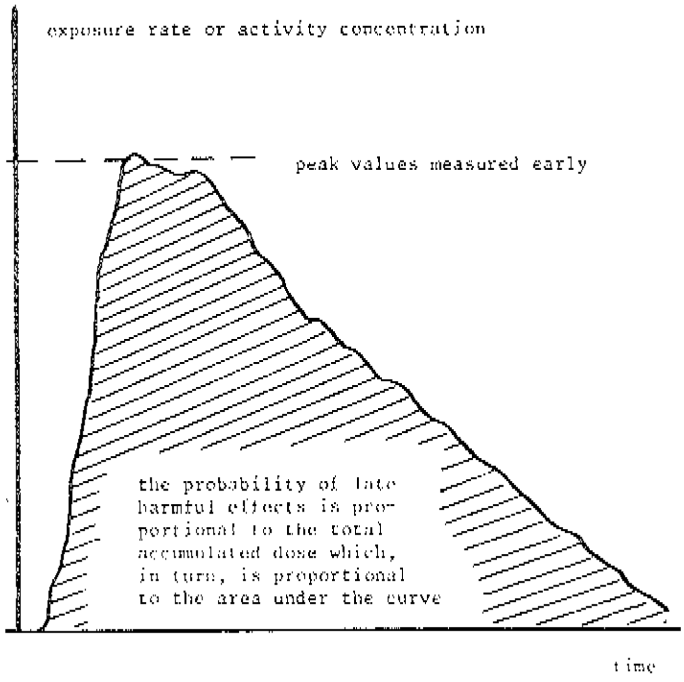


FIGURE 8 : Illustration of the relation between rates or concentrations and the total accumulated dose.

In order to assess the integrated quantity, which is assumed to be proportional to the probability of harmful effects, it is necessary to know the shape of the curve showing the variation with time. For exposure from the ground, this can be deduced from knowledge of the composition of gamma-emitting radionuclides and their half-lives. The early deposition in Finland and Sweden had a large share of short-lived radionuclides : Mo-99, Tc-99m, I-133 and Np-239 have half-lives shorter than three days, and only Sr-90, Cs-134, Cs-137 and Ce-144 of the more important radionuclides have half-lives longer than three months. Only a fraction of the initial dose-rate can therefore be expected to remain over a long time.

In a corresponding way, it is necessary to find the relation between the expected integrated intake of iodine-131 and the peak concentration of the nuclide in milk. This relation is only partially determined by the half-life of iodine and depends on local conditions.

The third type of late effects, the teratogenic effects, cannot be related to the total accumulated dose, since the period of exposure is of importance.

For irradiation in utero, there is no evidence of teratogenic effects during the first few weeks of gestation for fetal doses less than 100 millisievert (mSv). However, recent evidence suggests the random induction of severe mental retardation, with a probability of 0.04 per cent per millisievert of fetal dose, in the period of about 8-15 weeks after conception, and with no indication of a threshold dose. The risk seems to be clearly smaller after 15 weeks and may then have a threshold. Prior to 8 weeks no such risk has been detected.

The above considerations are particularly relevant for external gamma exposures from deposited radionuclides. Taking into account the decay of the deposited radionuclides, the time spent indoors and the shielding afforded by houses, and the relationship between outdoor exposures in air and fetal dose, it appears that the continuous presence of pregnant women in an area of ground deposition, during the 8-15 week post conception period would not significantly increase the normal risk of mental retardation, if the peak exposure rates in air do not exceed a few hundred microroentgen per hour. Therefore, in areas where exposure rates are smaller than this value, no special precautions are needed.

THE FIRST OBSERVATIONS

The first observation of the fallout is reported to have been made at the radiation monitoring station of Kajaani in Finland, where external exposure rates between 70 and 100 μR/h were measured on the evening of 27 April, 1986. This is consistent with a release at Chernobyl in the night between Friday and Saturday, 25-26 April (cf. Figure 3 a). A heavy shower of rain had caused the fallout.

It was thought that the radiation might have been caused by one of the radon peaks that had been detected in previous years when snow melted in the spring. However, on Monday, 28 April, the Rescue Department of the Ministry of the Interior asked for results from its own monitoring stations. It was found that some stations had results that were 1.2 - 2.5 times the normal values.

In Sweden, the contamination was first observed at the Forsmark nuclear power station on the Baltic coast about 100 km north of Stockholm. An activity deposition was detected in the morning, within the site of the station. No reason for the contamination was found within the power station and the Swedish Radiation Protection Institute was alerted.

It was soon found that the gamma spectrum of the air activity, which could be also be measured at a number of other places along the Swedish east coast, indicated relative amounts of cesium-134 and cesium-137 that made it unlikely that the activity came from a nuclear explosion. The conclusion was that there must be some abnormal release from a reactor southeast of Sweden and Finland. Meteorological trajectories were drawn back towards the Black Sea, but the first guess was that the source was a large nuclear power plant in Latvia. However, at 21.00 hours on Monday, 28 April, the USSR news media acknowledged that an accident had occurred at the Chernobyl nuclear power plant.

Between 12 GMT on Saturday, 26 April and 00 GMT on Sunday, 27 April, the direction of the air masses from Chernobyl shifted (cf. Figure 3c) and radioactive material released from the accident site on Sunday, 27 April moved, first west and then south, over the German Democratic Republic, Poland, Czechoslovakia, Hungary, Austria, the southern part of the Federal Republic of Germany, Switzerland and northern Italy (Figures 3 d and 4 a).

In southern Germany, a heavy rainfall caused a localized activity deposition in the Munich area in the afternoon of Wednesday, 30 April. This is consistent with a release on Sunday, 27 April (cf. Figure 4 a), i.e. more than one day after the accident. Within a few hours the exposure rate increased from the normal 8 μR/h to about 110 μR/h. The activity deposition was dominated by Te-132/I-132 and I-131, but Cs-137 was present in an activity that was about 1/4 of the activity of iodine-131. This means a cesium-137 deposition of about 40 kBq/m^2 which is quite remarkable, considering that the total accumulated deposition of cesium-137 from the atmospheric nuclear weapons testing was about 5 kBq/m^2 in the 40-50° latitude band (according to the 1982 UNSCEAR report).

The two events : the Scandinavia-Finland contamination and the Central-East Europe contamination dominate the European exposure situation after the accident. Any radioactive material released from Chernobyl after Sunday, 30 April, has moved eastwards or south, involving Ukraine, Balkan, Romania, Bulgaria, Turkey and the Black Sea region. Contamination found in other countries has essentially been secondary, by movements of air masses with radioactive material more than five days old, counted from the time of the release.

INTERPRETATION OF MEASUREMENT DATA

Extensive data on measurement results have been reported to the WHO from twenty-two countries. WHO also asked a number of laboratories and public health authorities specifically to provide data that can be used for the assessment of health consequences. Of special value is the information on the deposition of various radionuclides and particularly of iodine-131 and cesium-137. Such data are the basis for a general assessment of the situation.

Useful in this respect is also data on the external exposure rate, provided that they are supplemented by some information on the nuclide composition of the deposition.

Of immediate value for the public health authorities have been data on milk contamination. A distinction must be made between blended dairy milk which would not show the high concentrations that may be found in milk from single farms, both because peak concentrations are reduced by blending milk of different origins but also because the time between production and consumption is longer, so that the most shortlived radionuclides in fresh fallout have decayed to a certain degree.

The reason why milk is an important food-chain link, not only for iodine-131 but also for a number of other radionuclides is that grazing cattle very efficiently collect activity deposited on grass over large areas. This is also the case of goats and sheep whose milk usually shows substantially higher activity concentrations than cows milk. The relation between the deposition and the concentration in milk depends on the "area consumed" by the grazing animals.

Local rainfall has caused great variations in the activity deposition, with local spots sometimes showing 50 times average values even within regions exposed to the same plume. Some countries show great variations just because they have only peripherically been reached by a plume. The data therefore does not yet permit assessments of reliable average values. However, it must be remembered that the extreme values usually relate to limited areas and small fractions of the total population.

The complexity of the problem is illustrated by the fact that milk levels when cows are grazing, may either be elevated after rainfall, or else reduced by rainfall, because rain will wash out activity from the air that is inhaled by cattle and thus reduce their intake of radioactive substances, provided that the water they consumed did not become more contaminated due to the rain.

Measurements on activity concentration in ground level air have served two purposes. Some measurements, such as those of total beta activity in air, give some indication of the location of the plume and the time of maximum contamination when there is no precipitation. However, the results are difficult to interpret when, for example rainfall depletes the air contamination. Other measurements of air activity have given information on the nuclide composition of the radioactive material.

Some countries have so far reported that no or only insignificant contamination has been found, e.g. Iceland, France, Portugal and Spain - countries where no significant contamination would be expected on the basis of the meteorological information.

A provisional summary of some of the reported data is shown in Table 1, giving data on the external exposure rate, the deposition of iodine-131 and the concentration of iodine-131 in milk. This information is for different times within the first ten days after the accident. Because some material has decayed during that period, the data are not directly intercomparable but still gives a consistent picture of the contamination situation, fully in agreement with the meteorological information shown in Figures 3 - 7.

Table 1 should nevertheless be read with caution. In preparing this report there has not been sufficient time to fully evaluate all information that has been received and it is likely that some relevant information is lacking in the table and that some numbers may be not completely accurate. It is not yet possible to assess average values from the skewed distributions and the reader is warned not to draw too firm conclusions from the extreme values which are somewhat uncertain and usually represent a very localized situation.

There is no good correlation between extreme values for the various quantities reported just because the extremes may not refer to the same location or time. The peak external exposure rate gives perhaps the best indication of the distribution of the contamination, partly because it has been easy to measure. These values are also shown in Figure 9, on a map which also indicates the relevant plumes from the reactor. It should be remembered that the peak values will not persist once the shortlived radionuclides have decayed. High exposure rates from fresh fallout are therefore less significant than high rates at a later time when, for example, cesium-137 is a large contributor to the exposure rate.

TABLE 1 - Review of reported data (Note: Due to the short-time available for writing this report, the table may not be complete and should be read with caution)

Country	External exposure rate above background (μR/h)	Deposition of iodine-131 (kBq/m²)	Iodine-131 concentration in milk (Bq/1	
			Dairy milk (blended)	Peak values, usually for raw farm milk
Austria	2 - 230			1 500*
Czechoslovakia	20 - 200		- 500	1 000*
Denmark	1 - 2	3	0 -	30
Fed.Rep.Germany	- 250			1 200*
Finland	0 - 370	0.6 - 120	20 - 40	
Hungary	24 - 43	80 - 150	50 - 200	2 300*
Iceland	0		0	
Israel	1 - 2		0 - 7	
Luxembourg	7			
Malta		1		
The Netherlands	1 - 12	0.5 - 3		175
Norway	6 - 22	20 - 80	15 - 57	
Poland	10 - 440	0.1 - 200	0 - 600	1 700*
Portugal	0	0	0	
Sweden	2 - 300	0.3 - 170	2 - 55	2 900*
Switzerland	5 - 130	1.6 - 7	7 - 110	440
United Kingdom	1 - 50	0.7 - 3	2 - 15	190
Yugoslavia	- 150		50 - 150	

* The peak values are local and only to small groups of people

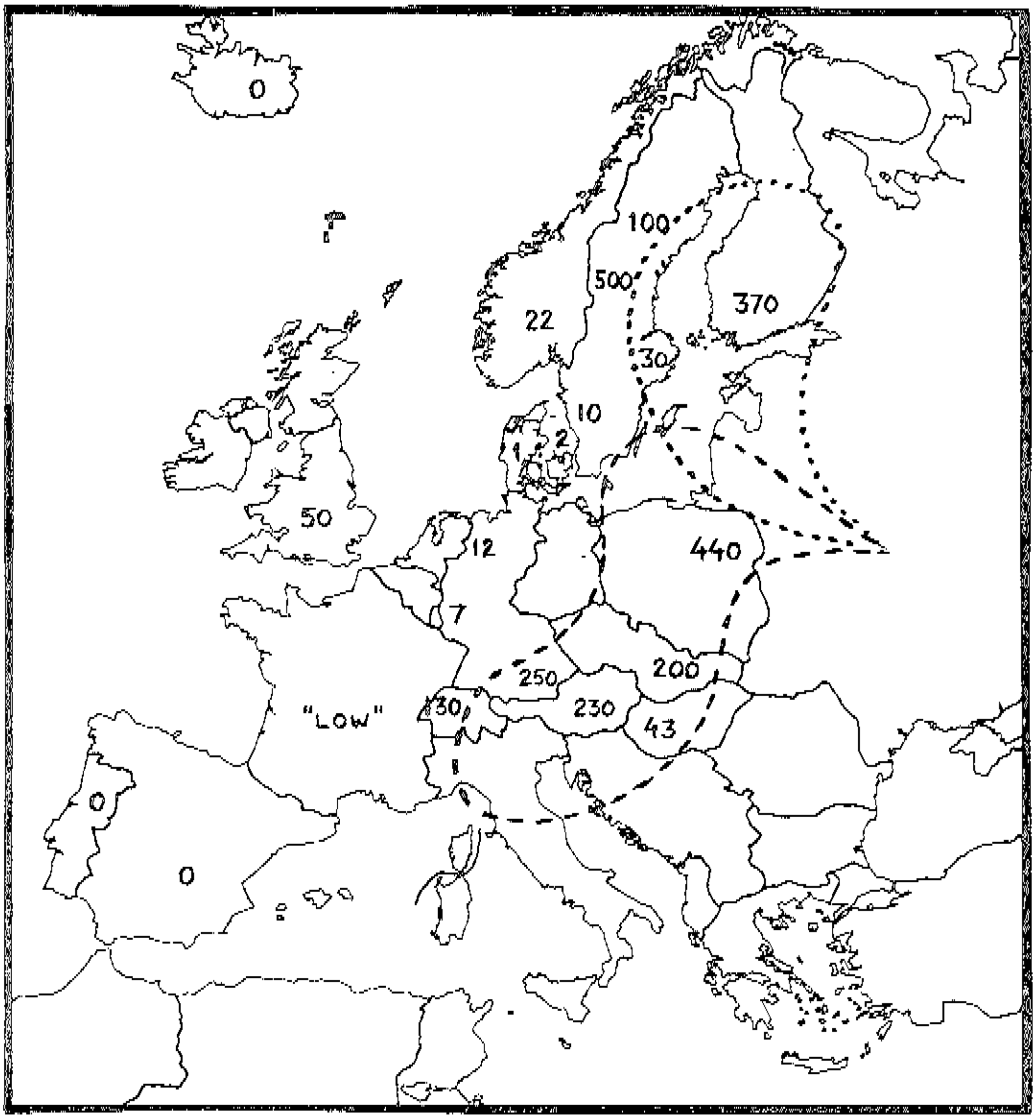


Figure 9: Geographical distribution of the peak values reported on the external exposure rate (µR/h).

Note: The two dominating plume situations are only schematically indicated, the exact border lines of the initial plumes are diffuse and affected by, e.g. rainfall and variable winds. The local depositions, causing the peak exposure rates from the ground, are highly dependent on rainfall.

COUNTERMEASURES

The radioactive contamination over Europe from the reactor accident has caused considerable concern and national authorities have given advice depending on local situations. In many cases WHO has been asked about appropriate countermeasures.

In order to understand the need and justification for countermeasures, the biological risk picture must be interpreted. The radiation doses at the contamination levels that have been reported outside the USSR cannot produce acute radiation effects. Situations that have called for rapid intervention to avoid or reduce the risk of acute radiation harm are only related to the immediate accident area, which for catastrophic reactor accidents is usually considered to involve the nearest 30-50 kms. Depending on the type of accident and the weather conditions, rapid intervention may be needed at somewhat larger distances down wind. The recognized problem which such rapid intervention (from advice to stay indoors to immediate evacuation) is that it has to be pre-planned and, after an accident, initiated so early that results of radiation measurements are either non-existant or scant and contradictory. In other words, such actions have to be initiated on the basis of technical information about the potential for large releases, rather than on reliable radiation data confirming such releases.

In the present case, this situation did not exist outside the USSR. The relevant effects are therefore exclusively effects which are considered to be of a stochastic nature and for which no threshold dose is assumed, such as cancer and genetic effects. In a cautious approach, mental retardation after fetal exposure is also assessed on the basis of the non-threshold assumption. For the stochastic effects, the probability of inducing the effect in a given individual is taken to be proportional to the accumulated radiation dose from the accident. Since, under this assumption, any radiation dose, however small, would cause a corresponding probability of effect, although small if the dose is small, measures to avoid or reduce a dose would only be justified if the measures themselves do not cause a risk higher than the risk avoided. The basic principle is to take measures to reduce all doses as far as it is reasonably achievable, by countermeasures which are expected to achieve a positive net benefit to the exposed individuals.

This means that some very simple precautions could be advisable even if the avoided dose is very small. Such precautions are, for example, avoiding rainwater for drinking if there are alternatives (rainwater may have substantially higher concentrations of radionuclides than water from other sources) and washing or temporarily avoiding fresh surface vegetables on which radioactive dust may have fallen (although invisibly).

Other measures, which may themselves cause problems, would only be justified if larger doses are involved Such measures include precautions with regard to the use of milk for infants. The actual countermeasures may vary from sending all raw milk to dairies for blending with milk that is less contaminated, discarding fresh milk, using the contaminated milk for cheese or dried milk production (thereby allowing for the decay of iodine-131 and other shortlived radionuclides) to taking milk-producing cattle temporarily from grazing. The choice of action would depend upon what is practicable in a given situation and might differ with local situations as well as with the time of the year. In a number of countries "action levels" have been given by the authorities, i.e. contamination levels above which actions may be considered. It is important to recognize that, with the principle of "as low as reasonably achievable" action levels should always be supplemented by specification of the type of action for which the levels are appropriate. For the above-mentioned actions to reduce the thyroid dose in infants by avoiding milk contamination various action levels have been given by national authorities. They may sometimes appear to differ, but the differences may then only reflect different ways of applying the limits. For example, in some countries 2000 Bq/l is used as an action level for iodine-131 in milk (this level will cause an effective dose equivalent to about 0.4 mSv per liter of milk ingested by a child). In other countries a lower value of 500 Bq/l is used, but is then applied to blended dairy milk which does not show as high concentrations as milk from single farms. The higher action level prevents a risk to the most exposed infants, the lower level is intended to prevent a lower risk to become the average risk in a larger population.

Action levels are sometimes compared with other recommended limits, e.g. with the internationally recommended dose limits for members of the population and may then be found to be higher. This is because the normal dose limits are requirements when normal operations involving radiation exposure are planned and they apply to doses which may occur year after year. The action levels relate to unique situations (it is not likely that those who receive the highest doses after one accident would be excessively exposed also if some other accident happens).

It can be seen from Table 1 that the reported data indicate that the iodine-131 contamination of dairy milk in a few countries approached some national action levels and that a few data have been reported where action levels for not consuming farm milk directly have in fact been exceeded. This explains various actions that have been taken both with regard to grazing cattle and the direct use of some milk. In general, however, these high levels are exceptions and the average values are clearly below any action levels. If there is no more release of iodine-131, it would be expected that the highest values will rapidly decrease so that no new or additional actions are needed. However, iodine-131 is not the only radionuclide in milk, although it dominates. If there are several radionuclides present, the action level for any particular radionuclide should be lower than if that nuclide were present along.

A number of actions have clearly not been warranted by the balance of dose avoided and severeness of the action itself. It has not been justified to advise against the use of any other drinking water than rainwater, because groundwater and surface water from large reservoirs are not easily contaminated. It has not been considered advisable to avoid breast feeding of infants or to limit the time spent outdoors.

The use of iodine tablets is a very special counter measure. The iodine will block the thyroid for uptake of radioactive iodine, if the tables are taken in before the inhalation or ingestion of radioactive iodine. Since ingestion of radioiodine can be controlled by controlling the use of contaminated milk, only inhalation is the relevant case. In many emergency plans there is a preparedness for the distribution of iodine tablets to people in the nearest area around the reactor, in case there is a risk of inhalation of radioiodine from the direct plume. As already mentioned, countermeasures of this type must be initiated so early that direct information of the degree of air contamination is not available. This was the basis for the use of iodine tablets in some parts of Poland at a stage when the information about the accident was very scant. However, afterwards it is clear that such measures were not needed outside the USSR. When results of measurements became available, a number of national authorities explicitly advised against the use of iodine tablets, because the dose avoided by their use does not seem to justify the risks, although small, of widespread use of the tablets.

Many questions have been raised about restrictions on travel to countries exposed to the radioactive plumes as well as within the USSR. Many questions have also been asked food consumption and import.

Table 1 and Figure 9 provide the basis for answers to these questions. As regards travel, the possible routes of exposure mentioned on page 14 would have to be considered. Of these the first two no longer exist unless there is a new development of the accident. What remains is external exposure from the ground and internal exposure from contaminated food.

It is clear from Table 1 and Figure 9 that the external exposure now given no cause for concern outside the USSR. Within the USSR it is likely to be of concern within the nearest area (30 - 50 kms) and perhaps at somewhat longer distances in the plume directions.

Internal exposure from contaminated food would be caused by contaminated milk and fresh surface vegetables from areas covered by the plumes. The reported contamination levels do not warrant concern within these areas outside the USSR, with the possible exception of precautions in the use of fresh farm milk. Dairy milk shows essentially low levels. The simple advice to wash fresh vegetables is a common sense measure. The situation outside the USSR therefore does not seem to justify any travel restrictions. However, no data have yet been received from Romania and Bulgaria which would have been exposed to any radioactive material released from Chernobyl after Tuesday, 29 April.

Regarding any health risk from food exported from the USSR and from the European countries exposed to the radioactive plumes, it is again milk and fresh surface vegetables that would be the critical food-stuffs. It follows from the information received, that blended dairy milk does not have contamination above action levels and that the contamination caused by iodine-131 is a temporary problem. Other food-stuffs would not be of immediate concern, with the possible exception of thyroids from grazing cattle. In the long-term, cesium-137 may be found in meat and grain and it is advisable to explore the cesium situation in more detail.

Figure 10 summarizes the information that has been received on various remedial actions taken in a number of countries. Because of the urgency of issuing this report, the information presented may not be complete, but the table nevertheless gives some indication of the types of measures considered. The table should be read in conjunction with Table 1 which gives the contamination levels that the various authorities had to deal with.

Figure 10: Remedial actions taken in various countries

Brackets indicate limited or qualified action. "NO" means advice against action.

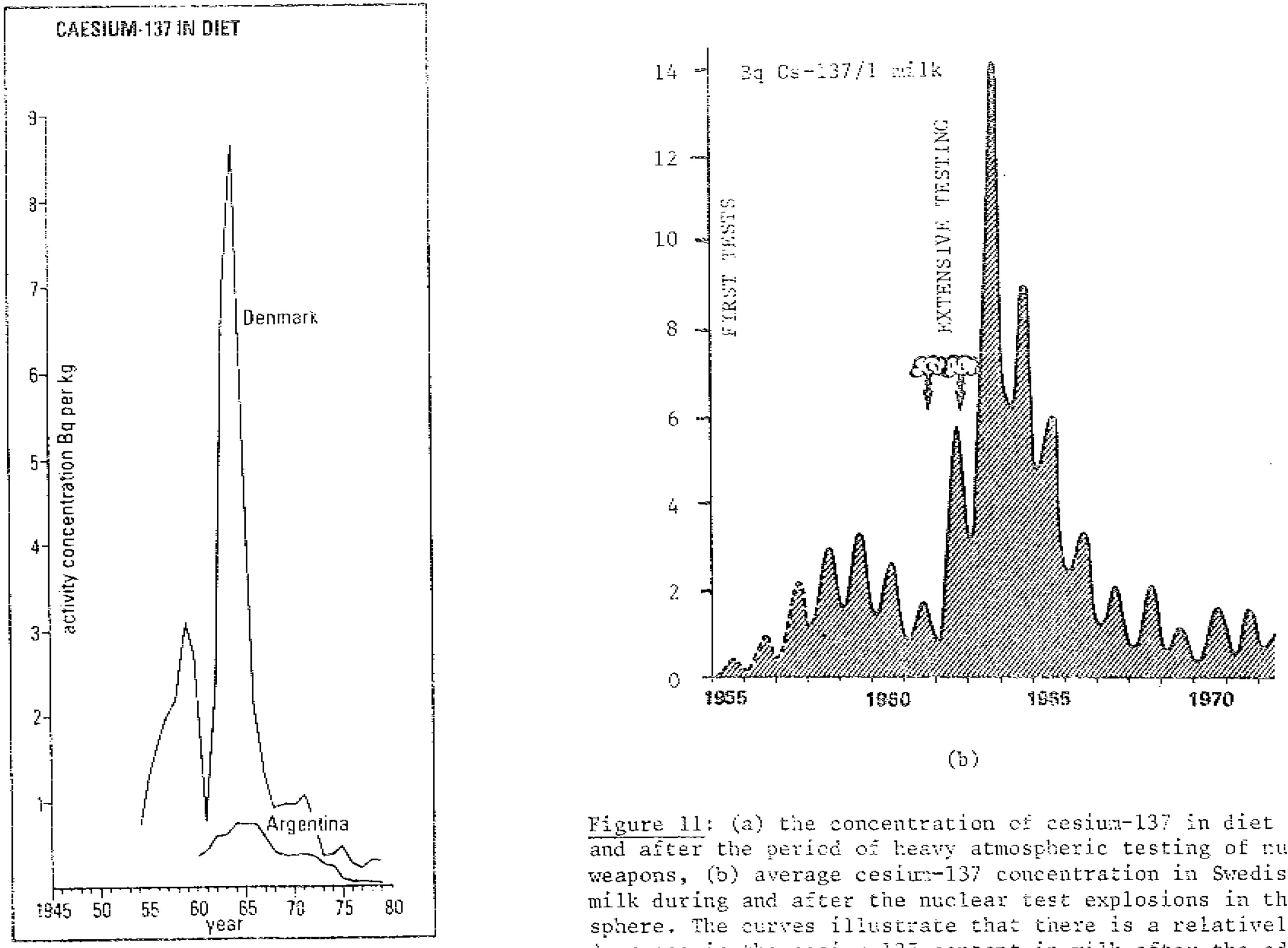
	Austria	Belgium	Denmark	Fed.Rep.Germany	Finland	France	Hungary	Ireland	Israel	Italy	Japan	Luxembourg	Monaco	The Netherlands	Norway	Poland	San Marino	Spain	Sweden	Switzerland	United Kingdom	Yugoslavia
Explicitly "No action!"						✓		✓	✓			✓	✓		✓			✓				
Advice to stay indoors or to avoid outdoor life	(✓)																		NO			
Advice to wear face mask when exchanging air filters in big industries																			(✓)			
Advice that children should not play in sand	✓																					
Advice to be careful with dust when gardening or in agriculture																			NO			
Restrictions in use of milk	NO				NO											(✓)			(✓)	✓	NO	(✓)
Milk-producing cattle taken from grazing		✓		✓			✓							✓			✓		✓	✓		
Avoiding breast feeding of infants				NO															NO			
Precautions by pregnant women																			NO			
Advice not to drink rain-water	✓				✓						✓				✓				✓	✓	(✓)	✓
Advice not to use rain-water for watering cows					✓																	✓
Precaution in the use of other water than rainwater for drinking	NO																		NO			
Advice not to eat fresh surface vegetables	✓																✓		✓		NO	
Advice to wash fresh vegetables before they are eaten	✓	✓		✓			✓				✓			✓						✓		✓
Restrictions in sale of animal thyroids														✓								
Advice to take iodine pills																						
Advice not to take iodine pills				✓															✓	✓		
Import restrictions on food from the USSR			✓							✓							(✓)		✓			
Import restrictions on food from other countries			✓							✓							(✓)		(✓)			
Advice to tourists not to go to some areas					✓														✓			
Monitoring tourists from some areas					✓			✓													(✓)	✓
Action levels stated or reconfirmed					✓														✓		✓	✓

THE CESIUM-137 PROBLEM

The world-wide contamination with radioactive fission products after the nuclear weapons explosions in the air, mainly during the period 1956 - 1962, has been thoroughly studied. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has published a number of reports where the resulting radiation doses have been assessed. The highest contribution to the population exposure from this source comes from cesium-137, which has a long half-life (about 30 years), is readily transported through various food chains, and exposes man both externally from depositions on the ground and internally after ingestion of food. Cesium-137 was found to contaminate most of the common food-stuffs such as milk, meat and cereals.

Figure 11 shows the variation with time of the cesium-137 content in diet and milk in some countries. Following the Chernobyl accident, cesium-137 has been found in air and in deposited material on the ground in unexpectedly high proportions, indicating that it was as easily released from the reactor as iodine. In the local areas where the deposition of iodine-131 has been high, the deposition of cesium-137 has also been found to be high, for example 40 kBq/m^2 in the Munich area and 1 - 4 kBq/m^2 in parts of Scotland. In areas with less precipitation, the values are considerably lower, and where there has been no direct exposure to the early plumes still lower, for example 0.01 - 0.02 kBq/m^2. The main difference with the present situation is that the cesium deposition is now much more unevenly distributed.

Based on the UNSCEAR assessments of the consequences of the nuclear fallout, the cesium contamination outside the USSR is not likely to cause any serious problems. However, since cesium-137 dominates the long-term exposure, it will not be possible to assess the overall impact of the contamination unless the distribution of the cesium-137 deposition is better known. Some uncommon food chains, such as from lichen to reindeer, would also need to be studied to ascertain that there are no activity concentrations of concern.



(a)

(b)

Figure 11: (a) the concentration of cesium-137 in diet during and after the period of heavy atmospheric testing of nuclear weapons, (b) average cesium-137 concentration in Swedish dairy milk during and after the nuclear test explosions in the atmosphere. The curves illustrate that there is a relatively rapid decrease in the cesium-137 contant in milk after the addition of new atmospheric activity ceased after 1962.

(Source: A UNEP booklet on UNSCEAR (a) and a Swedish book on nuclear power and radiation by B. Lindell and S. Löfveberg(b).

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PART II - CONCLUSIONS AND RECOMMENDATIONS OF CONSULTATION

Copenhagen, 6 May 1986

Following the nuclear accident in Chernobyl, USSR, the World Health Organization, both at the Regional Office for Europe in Copenhagen and at the Headquarters in Geneva, was approached by Member States for urgent advice on the existing situation, the prediction of consequences and advice on action to be taken at national level.

The Director General of WHO has entrusted the Regional Office for Europe with follow-up action and a team has been assembled for the period of the emergency.

Following an analysis of the situation, it was decided to urgently convene a group of senior experts. This group, composed of senior scientists with knowledge in the fields of meteorology, radiation protection, biological effects, reactor technology, emergency procedures, public health and psychology, met in Copenhagen on Tuesday, 6 May 1986, to analyse the development of events and their consequences.

On the assumption that there will be no new major release of radioactive substances, the experts advised WHO on the need for public health actions in the present situation as of 6 May 1986. The radioactive substances in the atmosphere over Europe have now been diluted in the air masses and the most short-lived radionuclides have decayed. Some of the actions that were recommended by some countries in the early phase of the accident are therefore no longer required and it is unlikely that new situations will develop that would warrant such actions outside the immediate accident area in the USSR.

The experts agreed that the following actions are not justified at the present time: the need for the public to stay indoors, precautions with regard to inhaling dust in agriculture or in gardening, and advice against the use of surface and ground water as a drinking water source. In particular, the use of iodine pills is not now advisable.

Any necessary control measures at a distance from an accident site are aimed at reducing radiation doses as far as reasonably possible. In general, the use of dairy milk, even by infants and pregnant women, and the breast feeding of infants cause no radiation doses of concern, as marketed milk is usually a blend from different sources. On the other hand, heavy rainfall coincidental with the passage of the radioactive cloud has caused localized high depositions of iodine-131, which may then be found in elevated concentrations in raw milk at some farms. Restriction of the immediate consumption of such milk may still be justified on the basis of national action levels, e.g. the 2000 Bq/l adopted in a number of countries, as a guide above which restrictions may be considered. The usual washing of fresh vegetables and not using rain water for drinking are in most cases simple actions which may still be advised as a measure for avoiding unnecessary exposure.

The group considered that there was no reason for travel restrictions between countries, with the obvious exception of travel to the immediate surroundings of the accident site.

Imports of foodstuffs have raised a number of questions and several countries have taken control measures. There is no public health justification to support such restrictions - with the exception of products coming from the contaminated area around the site of the accident and possibly from limited areas of enhanced contamination which might exist in certain countries where there was rainfall during the passage of the cloud in the first few days after the accident. However, lack of information about the level and the area of contamination in the USSR, as well as difficulties in clearly identifying the precise origin of products, may prompt administrative measures which should preferably be based on measurements of the actual degree of contamination. The direct deposition of radioactive aerosols on skin, clothing, vehicles and other objects is not a cause for concern, with the possible exception of exposure to processes that concentrate atmospheric dust, such as large air through-put units. For the proper assessment of the long-term impact of the accident it is necessary to have more detailed knowledge of the deposition of cesium-137. It is recommended that the magnitude and geographical distribution of these depositions be studied.

There is a need to establish an international system to collect and interpret information on any future large-scale accident. This system should be based on existing national systems and international networks, and should provide for early exchange of information within and among countries.

There is a necessity for maintaining systems at national and local levels to provide information and advice to the public from well defined focal points.

Guidelines have been published by a number of international organizations on emergency response planning. The experience gained in relation to this accident should be fully utilized in reviewing and consolidating such guidance.

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