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Preliminary Dose Assessment of the Chernobyl Accident*

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ABSTRACT

Early on April 26, 1986, a major accident occurred at Unit 4 of the Chernobyl nuclear power station in the U.S.S.R. The plume of airborne radioactive fission products from the accident was initially carried northwesterly toward Poland, thence northerly toward Scandinavia on April 26 - 29 and into Central Europe on April 29 - 30. It continued to spread and reached Japan and Korea on May 3 and the U. S. on May 7.

Reports of the levels of radioactivity in a variety of media and of external radiation levels were collected in the Department of Energy's Emergency Operations Center and compiled into a data bank. Portions of these and other data which were obtained directly from published and official reports were utilized to make a preliminary assessment of the extent and magnitude of the external dose to individuals downwind from Chernobyl.

Radioactive ^{131}I was the predominant fission product. The time of arrival of the plume and the maximum concentrations of ^{131}I in air, vegetation and milk and the maximum reported depositions and external radiation levels have been tabulated country by country.

A large amount of the total activity in the release was apparently carried to a significant elevation. The data suggest that in areas where rainfall occurred, deposition levels were from ten to one-hundred times those observed in nearby "dry" locations. Sufficient spectral data were obtained to establish average release fractions and to establish a reference spectru of the other nuclides in the release.

Only limited information from within the borders of the U.S.S.R. was initially available to describe the radiological situation immediately downwind from Chernobyl. Data reported by neighboring countries were employed to project it. The results suggested that, if decisions were made using U. S. Protective Action Guides, the relocation of individuals out to approximately 25 miles and the employment of protective actions for milk and fresh foods would have been appropriate downwind (northwest) of Chernobyl out to the borders of the U.S.S.R. The available information and the projected doses indicated that off-site exposures from the release did not result in an appreciable number of prompt health effects, if any. These preliminary indirectly derived estimates of the environmental consequences of the releases from the Chernobyl accident within the U.S.S.R. appear to be in general agreement with those reported by the Soviets in mid-August. However, the release of large quantities of non-volatile fission products relative to their core inventories and their dose impact close to the Chernobyl site (within approximately 180 miles or 300 km) was not recognized in the early estimates.

Preliminary calculations indicated that the collective dose equivalent to the population (approximately 1.75×10^8) in Scandinavia and Central Europe during the first year after the Chernobyl accident would be about 8×10^6 person-rem (8×10^4 Sv). From the Soviet report, it appears that a first year population dose of about 2×10^7 person-rem (2×10^5 Sv) will be received by the population (approximately 7.5×10^7) who were downwind of Chernobyl within the U.S.S.R. during the accident and its subsequent releases over the following week. This preliminary assessment has been limited to the first year

doses. Longer-term doses will accrue principally from the ingestion pathway. However, since they may for the most part be controllable at whatever level the authorities may deem appropriate, it seems premature to try to estimate them at this time.

Several lessons learned and suggested for the effective response to a large accident based on the experience to date in the response to the Chernobyl accident outside the U.S.S.R.

I. BACKGROUND

On April 26, 1986 a major accident occurred at Unit 4 of the Chernobyl Nuclear Power Station which is located about 60 miles (100 km) north of Kiev near the border between the Ukranian and Byelorussian Socialist Soviet Republics. The accident started with a power excursion, which occurred as the 1,000 MW(e) unit was at about 7% power (approximately 200 MWt) in the course of an experimental test just prior to a scheduled shutdown.[1] There followed a loss of coolant, an explosion and the subsequent burning of its graphite moderator, which continued for several days into early May.

Though the timing and quantities were not initially well defined, the accident apparently led to the airborne release of megacurie (petabequerel) quantities of the more volatile fission products which were carried by the winds and deposited far beyond the boundaries of the U.S.S.R. Initially, on April 27-29, airborne and deposited radioactivity were observed in significant concentrations and amounts in Eastern Poland and in the southern and mid-regions of Scandinavia. Subsequently on April 29 - May 2, they were observed in Central Europe and on May 3 - 5, in somewhat lesser amounts in Western Europe. From early to mid-May, components of the original or the subsequent releases reached the mid-East, China, Japan, Korea, Canada and the U. S. in observable but less significant concentrations and amounts.

In order to provide a preliminary assessment of the extent of the accident and its consequences, the Department of Energy (DOE) activated its Emergency Operations Center at Germantown, Maryland, where it obtained large amounts of data from many U. S. and foreign governmental agencies and various unofficial sources. These data have been compiled in a computer accessible data bank. As of the writing of this report, it is anticipated that they will be made available to interested parties by DOE's "Interlaboratory Task Group on the Health and Environmental Aspects of the Soviet Nuclear Accident," for which Dr. William J. Bair of the Pacific Northwest Laboratories is the Field Coordinator. Computer modeled projections by DOE's Atmospheric Release Advisory Capability (ARAC) were utilized in the initial assessment of the plume's path and anticipated radiation levels.

The purpose of this report is to provide a preliminary overview pending an official review and a detailed interpretation of these data, as well as to make some comparisons between them and ARAC's dose projections. Notes made by the author in the course of his participation at the Emergency Operations Center and information subsequently obtained directly from various published and official sources outside the U.S.S.R. were used. Only the latter can be fully referenced, pending the availability of the DOE data bank.

This report was initially compiled prior to the availability of the report in mid-August, 1986 by the Soviets on the causes and consequences of the Chernobyl accident within the U.S.S.R.[2] While some updating has been made on the basis of the information which then became available, the principal emphasis is on what was known or could be inferred prior to that time. In what follows, the principal emphasis will be on the reported levels of ^{131}I and of external radiation, since these data were most frequently reported.

For the most part, maximum reported observed levels are indicated. Accordingly, they should not be utilized directly for population dose estimates, for which average or representative data would be more appropriate. It should also be noted that most of the maximum reported levels outside the U.S.S.R. were related to precipitation associated deposition, which had considerable regional and even local variability. It therefore appears that national agencies with access to detailed meteorological and radiological data will be in the best position to provide accurate country by country population dose estimates, which can then be integrated to more reliably assess the overall impact of the Chernobyl accident.

II. FINDINGS

A. Radiation Levels:

The most frequently reported data included the time of the arrival of the plume (or of the initial observation of detectable amounts of radioactivity) and the resultant country by country concentrations of ^{131}I in air, its deposition on the ground, its concentrations in vegetation and milk, and external radiation levels.

More limited data on the levels of ^{137}Cs and other nuclides of concern were available from a number of gamma-ray spectra that were also reported by various agencies in several countries. Many were obtained by the radiological staffs of nuclear power stations, thus supplementing the information obtained directly by the national radiological agencies of the affected countries.

There seems to be a general agreement that the energy of the initial explosion and the heat from the subsequent graphite fire carried the plume to lower and mid-tropospheric elevations. As depicted in Figure 3, ARAC estimated that the major portion was carried to an elevation of between 1,000 and 1,500 m.[3] Its estimates of the core inventory of ^{131}I and ^{137}Cs and of release fractions are shown in Table 1. ARAC also projected that the release would initially have been carried northwesterly toward eastern Poland and thence more northerly toward Scandinavia, as shown in Figure 2. This is supported by other meteorological analyses, including that of the Finnish Centre for Radiation and Nuclear Safety,[4] from which Figure 3 is taken. Some confirmation of the elevation of the principal release is provided by airborne measurements by the Centre, which found on April 29 that the concentration of ^{131}I at 1,000 m was about three times that at ground level at a measuring station near Helsinki; and by the Swedish Energy Center at Studsvik, which found on April 28 - 29 that the concentration at 400 m was about ten times that at ground level.[5] The Swedish Center also found that 75 - 80% of the iodine was gaseous or desorbable from particles.

From both the ARAC and the Finnish projections, as well as from the reported data, it is apparent that the plume was carried by the prevailing winds in a generally northwesterly direction from Chernobyl for several days. The reported time of arrival and the maximum reported levels for Poland and the Scandinavian countries are set forth in Table 2.

Shortly after a reactor accident which results in a significant atmospheric release of radioactive fission products, the dose to the affected downwind population will have three components: external from the radioactive plume, internal from the inhalation of radioactivity, and external from deposited activity. Their relative contributions are indicated in Figure 4, which is based on computer calculations from the atmospheric release case of the Reactor Safety Study (WASH-1400).[9] As depicted, with an assumed relocation of the population 24-hours post-release, the deposition component would be expected to be by far the greatest contribution to the total dose.

A subsequent additional dose (beyond that from inhalation) to the thyroid due to the uptake of radioiodines (particularly by infants and children) may also result from the ingestion of milk and/or fresh foods produced in an area where deposition has occurred. Unless prompt and effective protective actions are taken (i. e., the administration of KI and/or the removal of potentially affected milk or foods from the diet), the thyroid dose from ingestion due to a one time deposition of ^{131}I may be expected to be about 100X more than that from inhalation.

The impact of the reported airborne concentrations of ^{131}I can be calculated using U. S. NRC's Regulatory Guide 1.109.[10] An adult breathing airborne ^{131}I in a concentration of 1,000 pCi/m^3 (37 Bq/m^3) for 24-hours would receive a thyroid dose of 34 mrem (0.34 mSv), a teenager 40 mrem (0.40 mSv), a child 44 mrem (0.44 mSv) and an infant 41 mrem (0.41 mSv). While it has been assumed that the data on airborne concentrations of ^{131}I reflect both particulate and gaseous forms, this cannot be assured in every instance. Even so, it is evident from Table 2 that the concentration of airborne radioiodine did not reach dosimetrically significant levels outside of the the U.S.S.R., (i. e., which could result in doses which called for protective action such as the administration of KI).

For the purpose of considering the significance of the reported depositions of ^{131}I and their concentrations in milk and foods, Table 3 is reproduced from the U. S. Food and Drug Administration (FDA) preventative Protective Action Guidance (PAG) levels. For ^{131}I they correspond to a dose commitment of 1.5 rem (.15 mSv) to the thyroid. For ^{90}Sr and $^{134-137}Cs$, they correspond to a dose commitment of 0.5 rem (.5 mSv) to the whole body or the red bone marrow of an infant. The FDA's emergency PAG's are ten times greater. Although deposition levels comparable to or in excess of the FDA's preventative guidance were reached in Poland and Scandinavia, the emergency levels do not appear to have been exceeded. There were press reports of the widespread administration of KI in Poland. In Scandinavia, few cattle were on pasture and local outdoor-grown produce was not available, so that the potential concentrations of ^{131}I in milk and other foods resulting from its deposition were not reached there, except perhaps very locally. Both Sweden and Finland adopted temporary restrictions on putting cows out to pasture and on the use of fresh foods, which were not lifted until late in May.

From both the ARAC's and Finnish projections and from the field data, it is also apparent that during April 28 - 29 the prevailing winds from Chernobyl shifted toward Central Europe and that the releases were continuing. The reported times of arrival (if available) and the maximum reported levels in the countries in which there was a significant impact (concentrations in milk or fresh food, approaching or in excess of protection action levels) are indicated in Table 4. The maximum concentrations of ^{131}I in air at ground level, as measured in Bavaria on April 29 - May 1, were comparable to those measured at ground level earlier in Scandinavia. This suggested that the release of ^{131}I in large quantities from Chernobyl was not confined to the first day or so after the accident, but that it had continued for several days.

The depositions of ^{131}I and its concentrations in milk in Central European Countries after April 29 - May 1 were also similar to those found earlier in Scandinavia, with the highest levels associated with areas in which precipitation had occurred. Widespread restrictions on the consumption of milk and fresh vegetables were adopted. Confusion was produced by country to country differences in protective action levels, some of which corresponded to the FDAs preventative PAG's while others were set at levels corresponding more closely to the FDA emergency PAG's.

From the reported data, it was not initially clear when the releases from Chernobyl were effectively terminated. The projections by both ARAC and the Finnish Centre for May 1 on through the next four days indicated that the prevailing winds would have carried any releases easterly and southerly from Chernobyl in a long trajectory within the U.S.S.R. According to mid-May press reports, the Soviet authorities indicated that the graphite fire was "under control" on May 5. This was confirmed in their August 1986 report.

Although the original plume(s) apparently continued to spread, there were no new indications of significant air concentrations or depositions of ^{131}I or other fission products outside the U.S.S.R. after early May. Some slight increases on or about May 10 appear to have been related to the second passage of the plume as it circled the northern hemisphere.[12] The spread of radioactivity contained in the original plume(s) is apparent from the reports from countries more distant from Chernobyl, as shown in Table 5. It is evident that, except for isolated cases based on very conservative PAG's, action levels were not reached in these more distant countries.

Prior to the mid-August report by the Soviets, a few data on off-site radiation levels within the U.S.S.R. were obtained from information supplied by them to the IAEA[15] and to the WHO and from other information supplied by foreign embassies[16] and other sources.[17] This relatively early information is summarized in Table 6.

An independent confirmation of the projections by the Finnish Centre and by ARAC that the winds carrying the plume from Chernobyl did not blow directly toward Kiev until May 1 (see Table 6) was suggested by a number of measurements by the BNL Safety and Environmental Protection and Safety Division of the thyroid burdens of travelers whose itineraries had included Kiev and other locations in the U.S.S.R. on various dates between April 25 and May 4. The data are summarized in Table 7. It appears that those who were in Kiev on or after May 1 had thyroid burdens which were from 10 - 100X of those who were there between April 26 and April 30.

Although extensive information on the thyroid burdens of the surrounding population was not presented in the Soviet mid-August report, such data as they did present is consistent with the very limited information contained in it or that can be inferred from Tables 6 and 7.

Only the incomplete data on external radiation levels in the vicinity of Chernobyl, as shown in Table 6, were available when this report was initially [illegible]. From a comparison of them with the more complete data on external radiation levels and the related airborne concentrations and the depositions of ^{131}I in Tables 2 and 4, it was inferred that a significant airborne inhalation dose from ^{131}I, in the order of 10 rem (0.1 Sv) to the thyroid, probably accompanied the deposition which produced the maximum reported exposure dose rate of 15 mR/hr (0.15 mSv/hr) at the unspecified location within the 30 km evacuation zone (see Table 6). The deposition which appeared to have produced initial external radiation levels of 1 - 3 mR/hr as far away as Kiev,[16] about 60 miles (100 km) from Chernobyl, suggested that restrictions on milk and fresh produce would have been called for the U.S.S.R. out to large distances downwind from Chernobyl during and for some time after the prolonged releases from it. This was confirmed by the Soviet mid-August report.

A depiction of the approximate extent of the area within which the reported external radiation levels equalled or exceeded 100 uR/hr (1 uSv/hr) and the dates when they were reached is shown in Figure 5, along with the dates on which the plume extended to and beyond it. It should be noted that this boundary contains many areas in which the deposition occurred principally in association with rainfall, so that it was not uniform. There were other areas within the boundary which were impacted only by dry deposition and within which levels generally did not reach 100 uR/hr.

B. Release Fractions:

Only a few fragmentary data on the concentrations of noble gases and/or of external radiation levels attributable to the plume from Chernobyl have been reported. As already indicated, the predominant nuclide in frequency of observation and reporting was ^{131}I. Since it was released in the largest relative amount of any fission product during the only previous analogous accident, the 1957 fire at the Windscale graphite-moderated reactor,[21] this seemed reasonable.

In the absence of definitive information, it was assumed that the noble gases would have been released in the largest relative fraction (approaching 1.0), and that ^{131}I would have been released in the next largest fraction, approaching 1.0 relative to its abundance in the inventory in the fuel of Chernobyl Unit 4 at the time of the accident. A number of gamma analyses of field samples were then examined to determine if they could provide a basis for estimates of the release fractions of other nuclides (relative to their core inventories) and their contributions to external dose rates.

Fifteen of the most extensive reported analyses of different media that were available at the time of the initial assessment (in mid-May), including air (eight) and deposition (seven), were adjudged suitable for this purpose. The ratio of the amounts of the other principal fission products to ^{131}I, as set forth in the Reactor Safety Study were used as a basis for comparison, with the assumption that their inventory in Chernobyl Unit 4 should have been similar. These ratios were appropriately adjusted for radioactive decay to the dates that the individual spectra were obtained. According to this method, had all of the nuclides been released in proportion to their abundance in the Safety Study inventory, their ratio relative to ^{131}I would have been 1.00.

Although rigorous statistical tests were not utilized, individual data which seemed far out of line from most of those available for a given nuclide were rejected. The results are indicated in Table 8. For purposes of comparison, the estimated release fractions, as set forth in WASH-1400, NUREG-0772[22], and for the melt-down release case in NUREG/CR-1237[23] are also indicated. The presence of the refractory element Zr (and its daughter Nb) in the release mixture suggested that high temperatures were reached during the accident.

This approach admittedly did not consider the possibility of a differential releases in time of the different groups of nuclides and/or of their differential deposition and removal from the plume with time and distance.

At the time of the initial preparation of this report, a few gamma spectra analyses of the body burdens and contamination on clothing of returning travelers from Kiev (that had been performed at BNL) were also available. Since they were inconsistent with a larger number of analyses of various media which had been obtained at large distances from Chernobyl, they were not utilized. When the Soviet report became available, it became apparent that they were consistent with spectra obtained by the Soviets close to Chernobyl and which contained many of the less volatile or refractory fission products in fractions close to their relative abundance in the Chernobyl fuel.

C. Relative Activity and Exposure Rates:

The apparent release fractions as set forth in Table 8 were utilized to calculate the relative activity, the relative exposure rate (uR/hr, 0.01 uSv/hr) and the one year external dose for an initial deposition of 1 uCi/m^2 (27 kBq/m^2) at 24-hours, 72-hours and 168-hour post-accident. The results are shown in Tables 9, 10, and 11 respectively. It is of interest that although ^{131}I was found in the greatest activity (approximately 18% initially and 27% at 168 hours), ^{132}I (resulting from the decay of 3.25d ^{132}Te) is the largest contributor to the calculated initial external exposure rate and that ^{134}Cs is the largest component of the calculated one year external exposure.

From the indicated activity of ^{134}Cs and ^{137}Cs at 24-hours relative to that of ^{131}I, it can be calculated that their combination in a deposition which resulted in an initial external exposure rate of 1 mR/hr (0.01 mSv/hr) would lead to their concentration in milk which would reach or exceed the Environmental Protection Agency's (EPA) protective PAG of 0.5 rem (.5 mSv) for the milk pathway.

Data on some initial external exposure rates which were produced by the deposition of the fission products released from Chernobyl and their decrease with time in Poland, in the Scandinavian countries and in several Central

European countries are shown in Figure 6. With only a few exceptions, they appear to have decreased at about the same rate, which may be seen to be close to $t^{-.8}$ (if it is assumed that they originated at the time of the accident on April 26). This suggests that the relative composition of the plume from Chernobyl was nearly uniform throughout most of its transit beyond the U.S.S.R. The data for Eastern Poland, as reported by Polish authorities to the WHO, suggest a more rapid decline which is closer to $t^{-1.2}$. Some of the few data, as reported by the Soviet authorities to the WHO[7] or obtained by others and which are indicated in Figure 7, also suggest a decrease more consistent with $t^{-1.2}$, which may be related to the larger fractions of non-volatile nuclides within a few hundred miles (or km) of Chernobyl.

Some additional data on external radioactive levels on and subsequent to May 10 which were supplied in early June by the Soviets to the WHO are reproduced in Table 12. The data from May 9th on for Oster (which is near Kiev) and for Kishnev (500 km - SSW of Chernobyl) are consistent with those for Kiev as indicated in Table 6. Those for Vilnyus, Brest, and Rahkov are difficult to reconcile with the higher levels which were reported in Northwestern Poland (see Table 2 and Figure 6), unless the latter resulted from wet deposition.

In the absence of detailed data radiation levels within the U.S.S.R. prior to the Soviets mid-August report, some projections of them were made on the basis of the then available data, using some simple assumptions and rules of thumb which are indicated in Table 13. The results are set forth in Table 14. From this simplistic approach, it appeared that if the plume in the projected concentrations had reached ground level within 5 - 10 miles (8 - 16 km) from Chernobyl, thyroid doses in the order of 100 rem could have occured prior to the reported time of the evacuation of persons within this radius (about 36-hours after the onset of the accident). This was confirmed by the Soviets mid-August report. It also appeared that similar thyroid doses could have been received, especially by children and infants, from as little as a one-day intake of milk at concentrations approaching the projected peak of 100 uCi/l at 5 miles (8 km) from Chernobyl. It also appeared that dose rates of as much as several hundred mrem/hr (several mSv/hr) could have prevailed from deposited activity within 5 miles (8 km) of Chernobyl. It followed that external exposures to the population near Chernobyl in the order of 10 rem and thyroid doses in the order of 100 rem (1 Sv) were plausible, unless prompt protective actions, such as sheltering and the administration of KI were employed.

It should be noted that the projected external exposure rates were based on the relative activities and derived release fractions which are shown in Table 9, which is in turn based on gamma spectra of samples obtained at large distances from Chernobyl. It is now apparent from the Soviet report that larger fractions of the non-volatiles approaching those of the core inventory were released. However, they appear to have been largely deposited within the U.S.S.R. relatively close to Chernobyl.

From the projections in Table 14, it appeared that the U. S. external dose PAG's of 1 - 5 rem (0.01 - 0.05 Sv) would have been exceeded unless the persons resident downwind were promptly relocated from the area around the Chernobyl site up to a distance from 10 - 25 miles (16 - 40 km) from Chernobyl. The Soviet report indicates that the close-in population of Pripyat was evacuated about 36-hours post-accident and that the remaining population out to about 18 miles (30 km) was relocated by 96-hours post-accident. It also appeared that the U.S. preventative PAG for milk of 15 nCi/l (405 Bl) of ^{131}I could have been exceeded out to the borders of the U.S.S.R. in the northwest quadrant from Chernobyl. The Soviet report indicated that a ban was placed or the use of fresh milk containing ^{131}I in excess of 100 nCi/l, which was intended to restrict thyroid doses to less than 30 rem. If ^{134}Cs and ^{137}Cs were also present at approximately 5% of the projected deposition, their PAG's for milk (and, as an approximation, limits for other foods) would have been exceeded out to about 50 miles (80 km) from the Chernobyl site.

With due recognition of the large error band that should be assigned to the results of these rough estimates, the projected concentration of ^{131}I in air at 10 miles (16 km) was employed to make an estimate of the source term. From the disperson factors for an elevated release that continues for an extended period of time which are indicated in NRC Regulatory Guide 1.3,[26] it was assumed that a dispersion coefficient (X/Q) of between 1×10^{-7} and 5×10^{-8} sec/m^3 would be appropriate at a distance of this distance of 10 miles (16 km) for the elevated release from Chernobyl. Using the projected 24-hc·· air concentration at a distance of 85,000 pCi/cm^3 (3500 Bq/m^3), a source term estimate of between 7×10^5 and 3.5×10^6 Ci/day (2.6×10^{16} - 1.3×10^{17} Bq/day) of ^{131}I was calculated. This is somewhat less than the initial release estimates by ARAC which are shown in Table 1. However, ARAC's revised estimate is that about 25% of the Chernobyl releases of ^{131}I was dispersed at lower levels and that another 25% was lifted up to the higher jet-stream level circulation by the large thermal energy in the initial release (see Figure 3)[27]. Thus, consideration of the estimated total release over 10 days puts the lower bound close to the Soviet mid-August reported release of 7.3 MCi and the upper bound close to ARAC's estimate of 40 uCi.

III. COMPARISONS

Starting with the reported (or projected) concentrations of airborne ^{131}I, estimates of its deposition, its concentration in milk, of the total deposition and the associated external radiation level may be made using the assumptions and relationships indicated in Table 13.

When these estimates are compared with the actual measurements as shown in Tables 2 and 4 - 6, reasonable agreement in what appear to have been areas of dry deposition is apparent. However, it also appeared that estimates based on dry deposition were exceeded from ten to one hundred-fold in areas where rainfall produced deposition occurred. Further study of the large body of available meteorological and radiological data may be useful in a more precise definition of these "washout" phenomena.

The limited data which are provided in Tables 2 and 4 - 6 are insufficient to support definitive conclusions about the relationship between the deposition of ^{131}I and its concentration in milk and/or the total deposition and the related external radiation levels. However, they do suggest that the assumptions for the projection of radiation levels contained in Table 13 can provide useful first approximations of other components when only one component of a set of data is available for a given locality.

From the reported data, the ten to one relationship between deposited ^{131}I and its subsequent peak concentration in milk, which was first apparent during the Windscale accident, also appears to be a useful approximation where cows are on pasture. It should be noted that the concentrations of ^{131}I in goat and sheep milk affected by the releases from Chernobyl were larger than in milk from cows in the same regions.

It was of interest to compare the results of these preliminary calculations with the projections for ^{131}I made by ARAC.[3] Those for the adult thyroid dose from inhalation and the deposition of ^{131}I as of April 30 are shown in Figures 8 and 9 respectively. An adult inhalation dose of 0.1 rem (the "D" line in Figure 8) corresponds to a 24-hour air concentration of about 4,000 pCi/cm^3 (148 Bq/m^3). A comparison of the concentrations of ^{131}I in air, as derived from ARAC's projections, with the 24-hour effective concentrations as inferred from measurements in the south of Sweden, in Finland and in mid-Europe are shown in Tables 15A and 15B. Considering that only a few measurements over unspecified time periods were available and that some judgement was used to convert them to 24-hour effective concentrations, there is good agreement. While the reported dry deposition of ^{131}I also appeared to agree with ARAC's projections, these data have considerable scatter. Thus, a more detailed review would be needed to conclude this agreement with confidence.

IV. ESTIMATES OF FIRST YEAR DOSES AND HEALTH EFFECTS

A preliminary review has been made in the foregoing of a considerable portion of the extensive body of radiological data that became available from countries outside the U.S.S.R. which were downwind of Chernobyl during and shortly after the Chernobyl accident. The highest reported initial external radiation levels in them approached 1 mR/hr (approximately 0.01 mSv/hr). More extensively, levels in the order of the 100 uR/hr (approximately 1 uSv/hr) were reported. The highest resultant integrated one-year exposure (without relocation) would be expected to be as much as a few hundred mrem (a few mSv). More generally, it would have been in the order of a few tens of mrem (a few tenths of mSv) in Scandinavia and the Central European countries.

From the Soviet report, it appears that the nearby population at Pripyat of some 45,000 persons was not evacuated until 36-hours after the accident and that the remainder of the population out to about 18 miles (30 km) of some 90,000 persons was not completely relocated until 96-hours post-accident. The highest reported initial external radiation level at Pripyat was about 1 R/hr (0.01 Sv/hr) (at 1300 on March 27). The external radiation levels in the vicinity of the Chernobyl site on May 29 as indicated in the Soviet report are shown in Figure 10. From other information presented in the Soviet report, it may be calculated that the initial dose rates on the first day or so after the accident were about ten times those on May 29. At Kiev, about 60 miles (100 km) south of Chernobyl, a maximum level of about 1 mR/hr (0.01 mSv/hr) was reached on March 29 - 30.

As shown in Figure 11, which has been derived from information contained in the Soviet report, the initial radiation levels from dry deposition exceeded 100 uR/hr at downwind locations as far as 300 miles (500 km) from

Chernobyl. It should be noted that the higher levels at greater distances in Scandinavia and Central Europe indicated in Tables 2 and 4 were associated with wet deposition.

The Soviet report indicated that absent protective actions, the anticipated one-year dose from external radiation would be from 2,500 to 15,000 times the initial dose-rate, depending of the post-accident time of the initial deposition. As already indicated, outside the U.S.S.R, the calculated one-year dose from external radiation is from 500 - 1,000 times the initial dose rate, depending on the time post-accident of the initial deposition.

Estimates of collective dose are necessary for the calculation of anticipated health effects. Those for the first-year dose from external radiation can be made with the greatest confidence, in that they can be based on directly measurable parameters, with a minimum of assumptions. In the absence of a detailed knowledge of the food basket and consumption habits of a population of interest, the estimation of even the first year dose from the ingestion of contaminated food seems somewhat speculative. Given the additional assumptions that must be made concerning the ingestion pathway over extended periods, 50 or 70 year estimates seem quite conjectural.

Preliminary estimates of the first year average external and ingestion dose from individuals in some European countries were presented at an "expert meeting" which was sponsored by the WHO at Bilthoven, Holland in late June, 1986.[28] Those for external doses, as shown in Figure 12, and for ingestion doses, as shown in Figure 13, appear to be comparable. The estimates of doses due to inhalation (largely of ^{131}I), as shown in Figure 14 are much smaller than for the other principal pathways.

A summary of calculations of the first year collective dose to the populations of the countries in Europe that were principally impacted by the deposition of radioactivity released during the Chernobyl accident is shown in Table 16. These calculated doses are based on the author's estimates of the average first-year external dose in these countries. The collective ingestion dose has been assumed to be equal to the total collective external dose.

It should be noted that the estimation of an "average" dose for the impacted countries was complicated by variations in radiation levels from place to place within them, especially between areas of dry and wet deposition, as well as uncertainty about the location of their populations relative to these areas. While more definitive estimates are being made by individual national radiation protection agencies, it is not anticipated that they will differ materially from these contained in Table 16.

According to the WHO Report, the largest child thyroid doses outside the U.S.S.R. occurred in Northeastern Poland. Without protective actions, they may have been as much as 20 rem (0.20 Sv). With protective actions (including the distribution of stable iodine, which was reported to have been widely employed) they were estimated by the Polish authorities to have been 3.5 rem (0.035 Sv) Elsewhere in Europe, they appear to have less than 1 rem (0.01 Sv).

From the above considerations, it may reasonably be concluded that no prompt health effects related to the releases from Chernobyl occurred outside the U.S.S.R. It may also be calculated on the basis of the total collective dose estimate of approximately 8×10^6 person-rem (8×10^4 person-Sv) and from currently accepted risk coefficients that the affected population of some 1.75×10^8 persons would experience about 1,600 future fatal cancers resultant from the releases of radioactivity from the Chernobyl accident. The total number of health effects would be twice this number. Since some 2.6×10^7 fatal cancers may be anticipated in the same population (on the assumption that the cancer fatality rates in Europe are comparable to those in the U. S.),[29] it appears that no practicable study could define the actual Chernobyl related increments.

Soon after the accident, there were a few media reports of off-site fatalities in the vicinity of Chernobyl. However, they are not substantiated by the available data. The estimated collective doses from external radiation to the evacuated population of Pripyat and to the relocated population out to 18 miles (30 km), as reported by the Soviets in August, 1986 is reproduced in Table 17. That for the impacted populations in regions of the European U.S.S.R. for 1986 and for 50 years is shown in Table 18. From them, it appears that the total first year collective dose from external radiation within U.S.S.R. will be about 0.86×10^7 person-rem (0.86×10^5 person-Sv) and the average dose to the affected population will be about 115 mrem (1.15 mSv), or about twice background.

As shown in Table 19, which is also reproduced from the Soviet report, it appears that some children within 5 miles (9 km) of the Chernobyl site may have received thyroid doses of as much as 250 rem (2.5 Sv) and those within 15 miles (22 km) of as much as 100 rem (1 Sv). Presumably these doses occurred prior to the evacuation of Pripyat and the relocation of the balance of the population within 18 miles (30 km). Stable iodine was reported to have been distributed early on in Pripyat. Recommendations were made by the Soviet authorities against the consumption of fresh milk and produce elsewhere within 18 miles (30 km), but they do not appear to have been universally needed.

Thyroid measurements were reportedly made on about 100,000 children, which composed almost the entire number within the 18 mile (30 km) zone at the time of the accident. The Soviets reported that they were subsequently removed to summer health facilities, where those who had received doses in excess of 30 rem (their number was not specified) were medically supervised. Beyond 18 miles (30 km), protective actions were taken to limit thyroid doses to within 30 rem.

There was a widespread deposition of ^{131}I, $^{134-137}Cs$ and other fission products at levels that would have resulted in the contamination of milk and other foods in excess of U. S. PAG levels. This is illustrated by the reported concentration of ^{131}I in milk during May 1986 in the ten most impacted regions in the U.S.S.R., as indicated in Table 20 (the named localities appear in Figure 11). The Soviet report also indicated that a wide range of other foods including meat, greens, vegetables, berries and fish from one or more regions contained radioactivity in excess of the U.S.S.R. protective standards, which were set at levels corresponding to 5 rem (0.05 Sv) to the whole body or to internal organs.

Since there appears to have been considerable variability in the deposition patterns and in protective actions within the U.S.S.R. beyond those taken within the 30 km radius from Chernobyl, sufficient information does not appear to have been available for the Soviets to make reliable estimates of ingestion-related doses in their August, 1986 report. They did indicate that the measured levels of internal burdens of ^{137}Cs up to that time had averaged about 1/10 of those predicted.

If the ingestion dose for the first year for the U.S.S.R. population of 74.5×10^6 persons is assumed to be comparable to their external dose (as assumed for the affected European populations), then their total first-year collective-dose can be estimated at about 2×10^7 person-rem (2×10^5 person-Sv). Using currently associated risk coefficients, the associated number of estimated future fatal cancers would be about 4,000. It also appears that no practicable study could identify their actual occurrence, given that about 1.1×10^7 such fatalities would be anticipated from other causes (again assuming that the U.S.S.R. cancer fatality rates are comparable to those in the U.S.).

It may be noted that the Soviets estimated 50 year dose from external radiation to this same population was 29×10^7 person-rem (2.9×10^5 person-Sv). The 70 year population dose from the ingestion pathway was initially estimated at 210×10^6 person-rem (2.1×10^6 person-Sv). After discussion with Western experts at the August 1986 IAEA meeting, the Soviets revised this estimate downward to 21×10^6 person-rem (2.1×10^5 person-Sv).

It has been proposed that a follow-up study be made of the approximate 100,000 - 200,000 who were close to Chernobyl at the time of the accident.[30] Since this number and their collective dose are comparable to those of the Japanese A-bomb survivors, such a study seems practicable and desirable. While the lower dose-rate of the radiation from the Chernobyl releases is a factor which some believe will substantially reduce the resultant number of observable health effects, a negative result should supply useful input for the future estimation of risk coefficients at the experienced doses and dose rates.

The doses to the thyroids at the affected children who were in the proximity of Chernobyl at the time of the accident appear to be lower than those to the thyroids of the children in the Marshall Islands at the time of the atmospheric weapons tests in the Pacific in 1954. However, the total number of the former and their collective thyroid dose appears to be much greater. Thus, a follow-up study of them for thyroid abnormalities also appears desirable. It could, for example, help resolve the argument about the effectiveness of ^{131}I vs. external photon radiation in the production of thyroid cancer.

A very recent book, the first on Chernobyl, has the title, "The Worst Accident in the World."[32] Although this title may be valid on the basis of the financial loss to the U.S.S.R. and/or to the degree of media coverage it recieved, on the basis of its apparent toll to either the worker or off-site populations, it does not appear to be substatiated by the available evidence.

The amounts of radioactivity that were released, spread, and deposited virtually around the Northern hemisphere during the Chernobyl accident appear to have been a surprise to most of its inhabitants. This apparently included many radiation protection specialists, with the possible exception of those old enough to have been engaged in studies of fallout during the large scale atmospheric weapons tests during the 1950's and early 1960's when similar amounts were released and similar amounts of deposited fission products were observed.

Since the Chernobyl accident and its consequences are not yet fully defined, it is too early to offer a comprehensive list of lessons learned (or relearned in that some were from the fallout studies and from the Windscale and TMI reactor accidents, but since virtually forgotten). However, some preliminary suggestions of them can be offered, as follows:

1. Although improbable (particularly for U. S. design light-water reactor with many layers of defense), uncontrolled releases of large amounts of radioactivity during a reactor accident are possible.

2. As evidenced by the Windscale, the TMI and the Chernobyl accidents, it is unlikely that accident assessors will have a good handle on the source term until some time post-accident, if ever. The most reliable initial estimates will probably be those based on environmental measurements.

3. Given a sufficient driving force and facilitating meteorological conditions, an elevated long-range transport of some or even much of the released radioactivity may occur, thus complicating the early definition of the source term from nearby environmental measurements.

4. Precipitation from or through airborne radioactivity can result in wet deposition levels at distances up to hundreds of miles from the release which may approach or even exceed those produced by dry deposition much closer to it. Local levels of wet deposition may exceed those from nearby dry deposition by from 10 to 100 fold.

5. Numerous facilities such as research laboratories, power reactors and hospitals have a capability to make prompt measurements of environmental levels of radiation and radioactivity. Once an accident is reported, they will begin making measurements.

6. Many of these measurements (and the makers' comments, some informed and some speculative) will be reported in the media, along with the reporters' interpretations and embellishments.

7. Public concern will ensue. It will feed on uncertainty.

8. The sooner the responsible authorities can provide an authoritative, informed and comprehensive account of the environmental radiation levels and their significance, the lower the concern, and vice versa if only fragmentary and uninterpreted information is available.

9. For the prompt definition of the general pattern of environmental levels of radioactivity and the potential dose, it is neither necessary or desirable (in fact it is a waste of resources, except possibly for the value of the training), to make widespread measurements of every radionuclide in every component of the environment - the atmosphere, the deposition, the milk/food pathway and of external radiation levels. A few early comprehensive measurements of atmospheric concentrations (with particular attention to the distribution of the species of radioiodines), of their area deposition on the ground and their concentrations in fresh milk and fresh vegetation/food (if any) can be invaluable. Particular attention should be given to the radioiodines and radiocesiums which are the dosimetrically most significant. With reliable "foot-prints" of the airborne and deposited activity (which may differ markedly), a reasonably accurate definition of the distribution of radioactivity and of its dose implications over a wide area may be estimated by scaling from a more widespread number of measurements of external radiation levels.

10. The resources and trained persons to make the required measurements in order to provide a prompt and comprehensive data base are scattered throughout the U. S., in academic and research institutions, in the nuclear industry, in hospitals and in local and state environmental and civil defense agencies. What is needed is their organization for a prompt and coordinated response in the event of any future major incident which has a potential for a large release of radioactivity.

11. The "bottom-line" is the dose to human beings. Estimates of this dose may be made by the measurements of air-concentrations, deposition levels and of the concentrations of radioactivity in milk (and in other foods) and the employment of models. However, the measurement of the body burdens of representative human "samplers" who may have been in an impacted locality and whose intakes can be established can furnish valuable confirmatory evidence.

VI. ACKNOWLEDGMENTS

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FIGURES

Figure 1 - Assumed Vertical Distribution of Source Material

Figure 2 - Computer Modeled Spatial Distribution of Radioactive Material 48-Hours After the Accident Started.

Figure 3 - 850 mb Level Height Meteorological Analysis at 00GMT, April 26, 1986 at 00 GMT.

Figure 4 - Whole Body Dose Versus Distance for Atmospheric Release Category Accidents.

Figure 5 - Initial Data and Areas Reporting External Radioactive Levels $\geq$ 100 uR/hr.

Figure 6 - External Exposure Levels for Locations in Scandinavia and Central Europe following the Chernobyl Accident.

Figure 7 - External Exposure Levels for Locations within the U.S.S.R. following the Chernobyl Accident.

Figure 8 - Radiation Exposure Rate, May 10, 1986.

Figure 9 - Adult Thyroid ^{131}I Dose, Integrated from April 26, 1986 00GMT to April 30, 1986 00GMT.

Figure 10 - ^{131}I Dry Deposition Dose, Integrated from April 26, 1986 00GMT to April 30, 1986 00GMT.

Figure 11 - Post-Chernobyl External Exposure in European Countries.

Figure 12 - Post-Chernobyl Ingestion Dose in European Countries.

Figure 13 - Post-Chernobyl Inhalation Dose from ^{131}I in European Countries.

Figure 14 - Estimated External Gamma-Explosive Rate Isocontours at 15 Days Post-Accident.

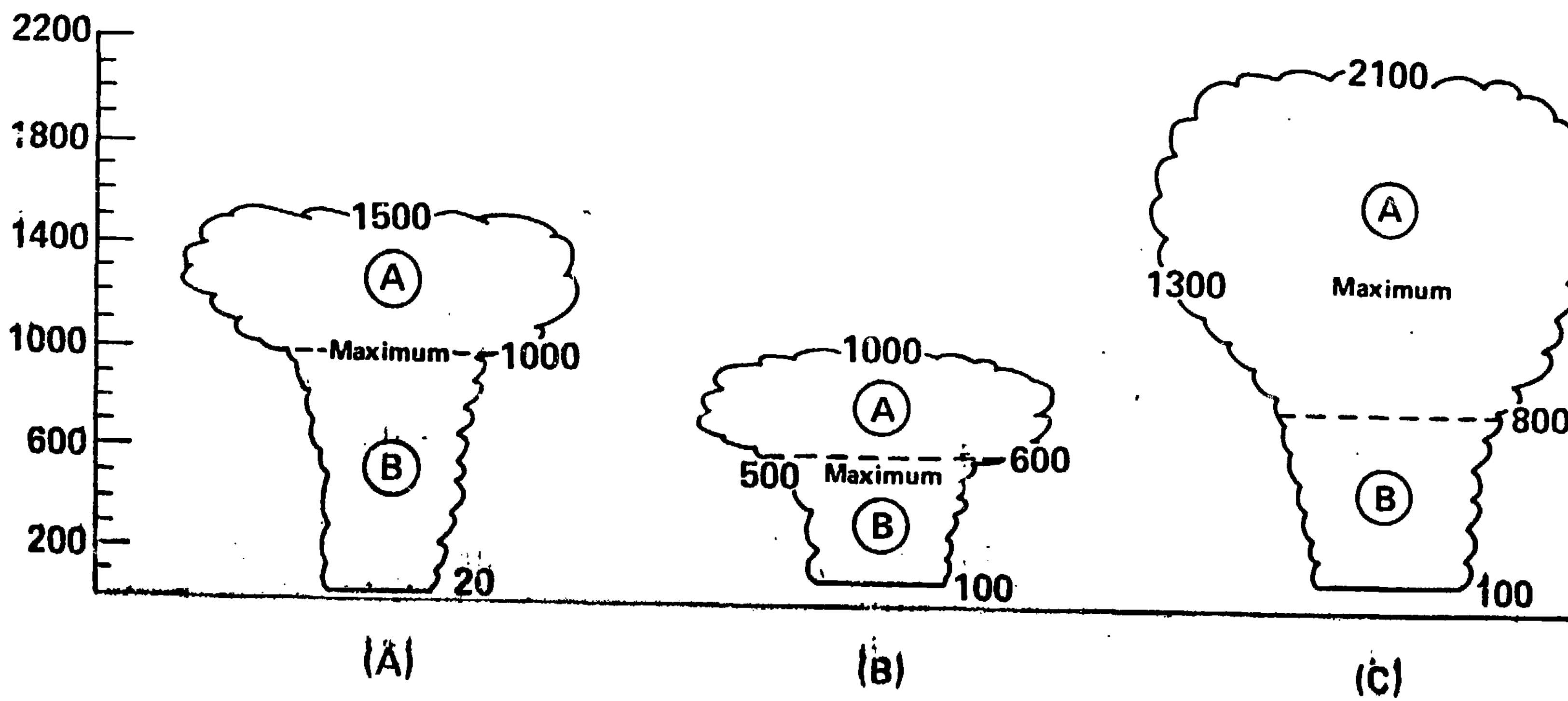

FIGURE 1

Assumed vertical distribution of source material (explosion and fire cloud): a) average distribution as used in calculations; (b) night time c) dry time

(From Reference 3)

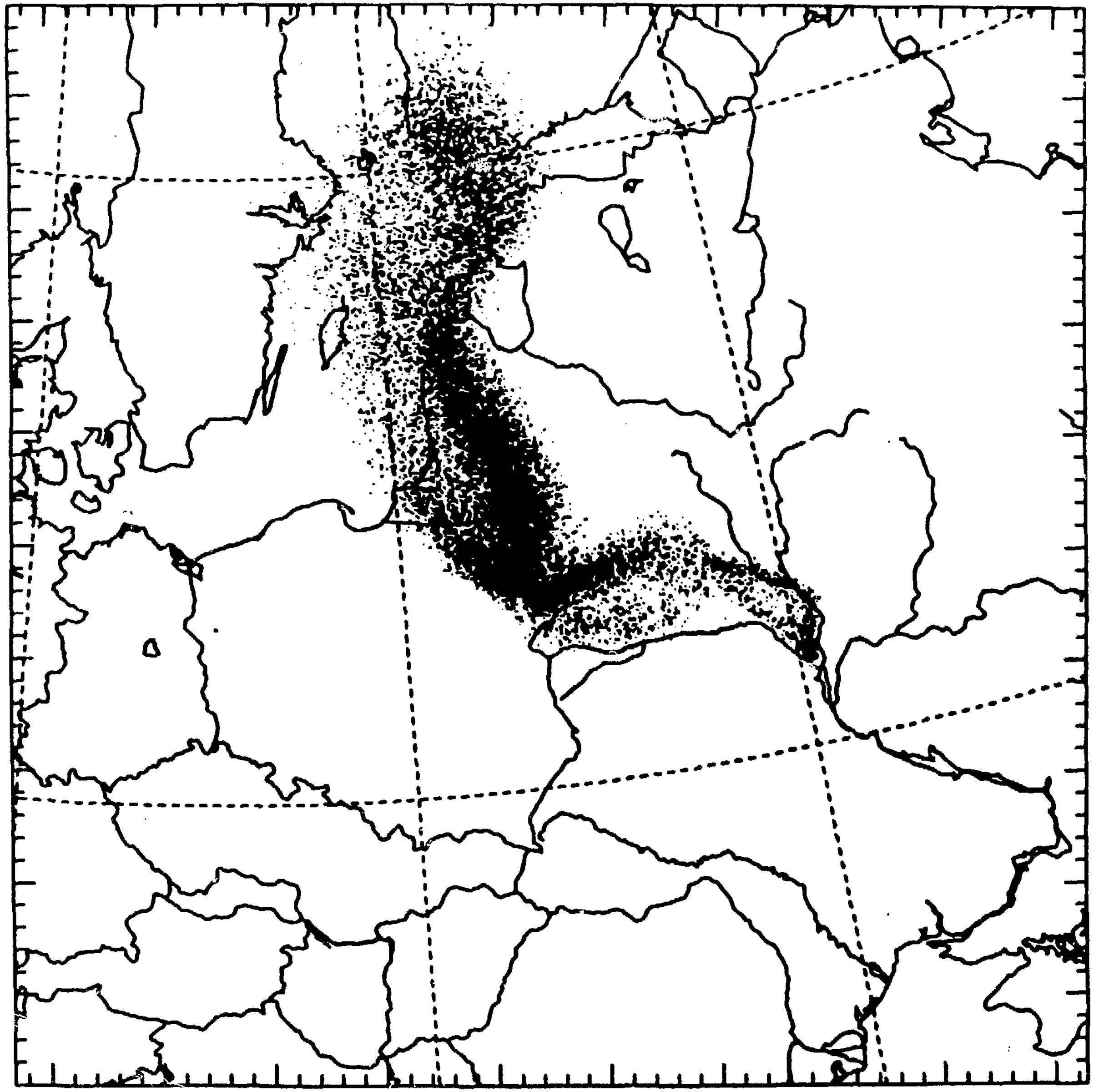

FIGURE 2

Computer Modeled Spatial Distribution of Radioactive Material (48 Hours) Post-Accident.

(From Reference 3)

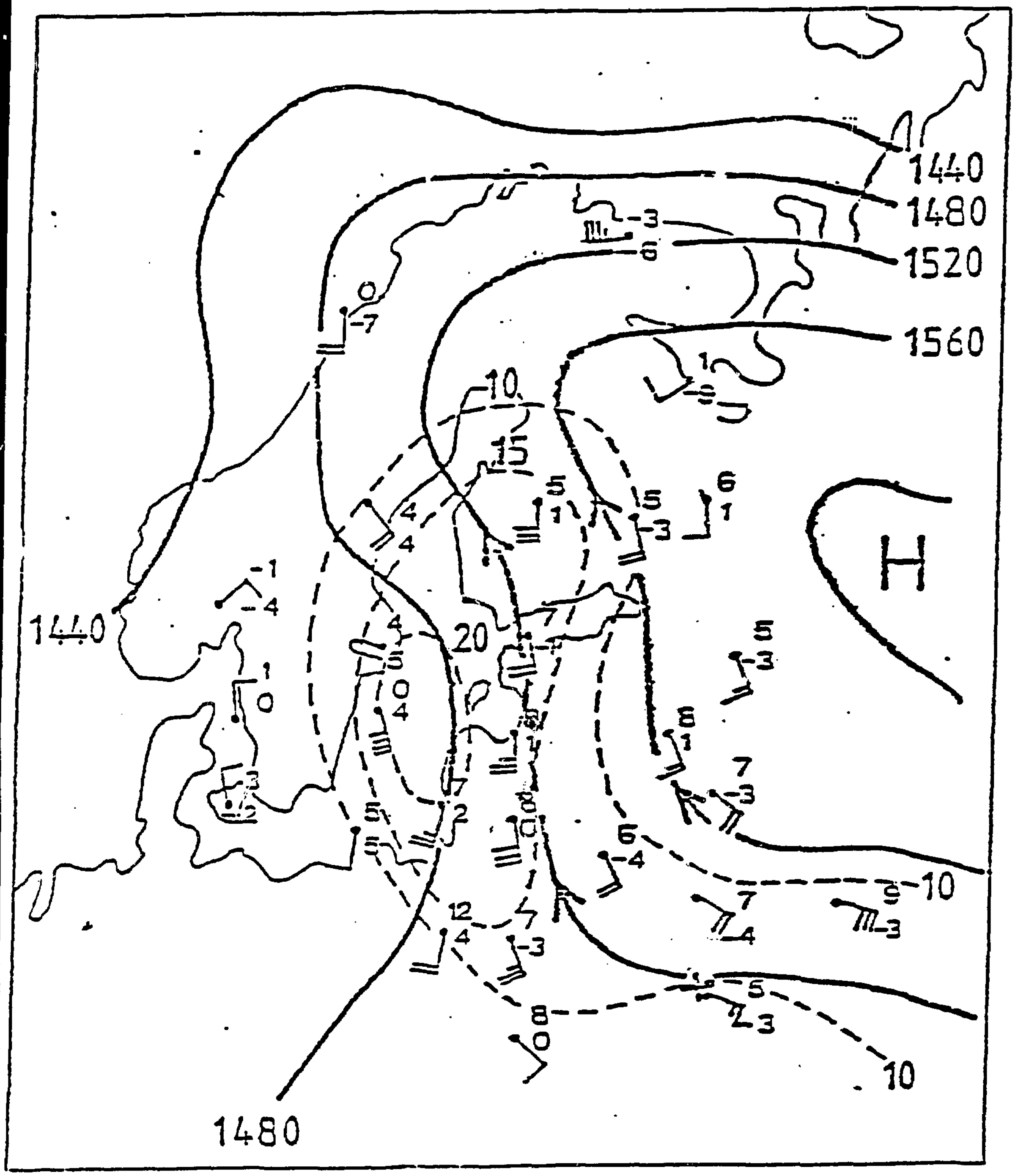

FIGURE 3

Meteorological Analysis on April 26 at 00 GMT for 850 mb Level. (The dashed line shows the analysis of wind speeds. The unit of speed is m/s)

(From Reference 4)

Components of Mean Projected Whole Body Dose (REM) Given a PWR Atmospheric Release (PWR 1-5)

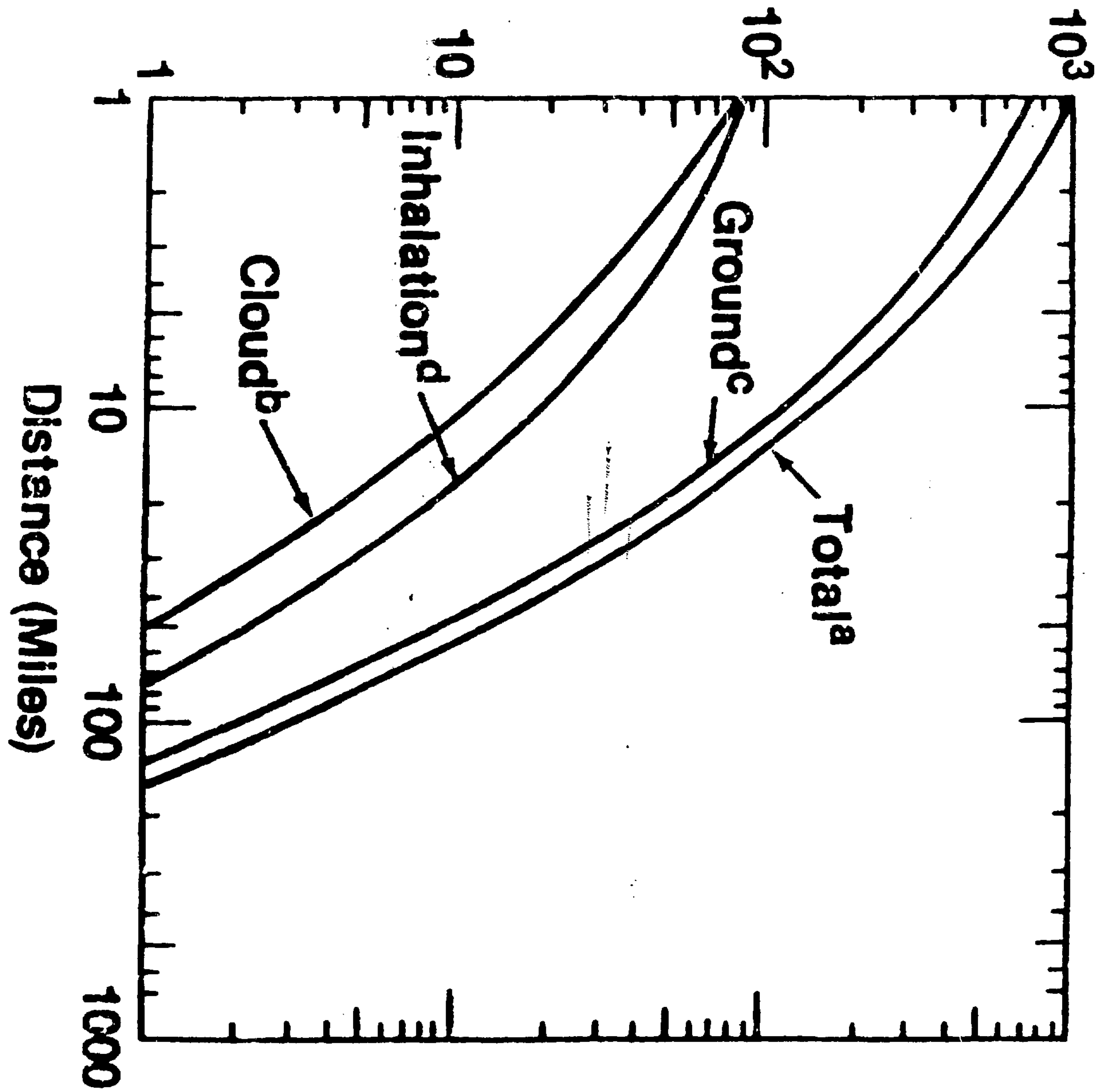

FIGURE 4

Whole-Body Dose Versus Distance for Atmospheric Release Category Accidents.

(From Reference 8)

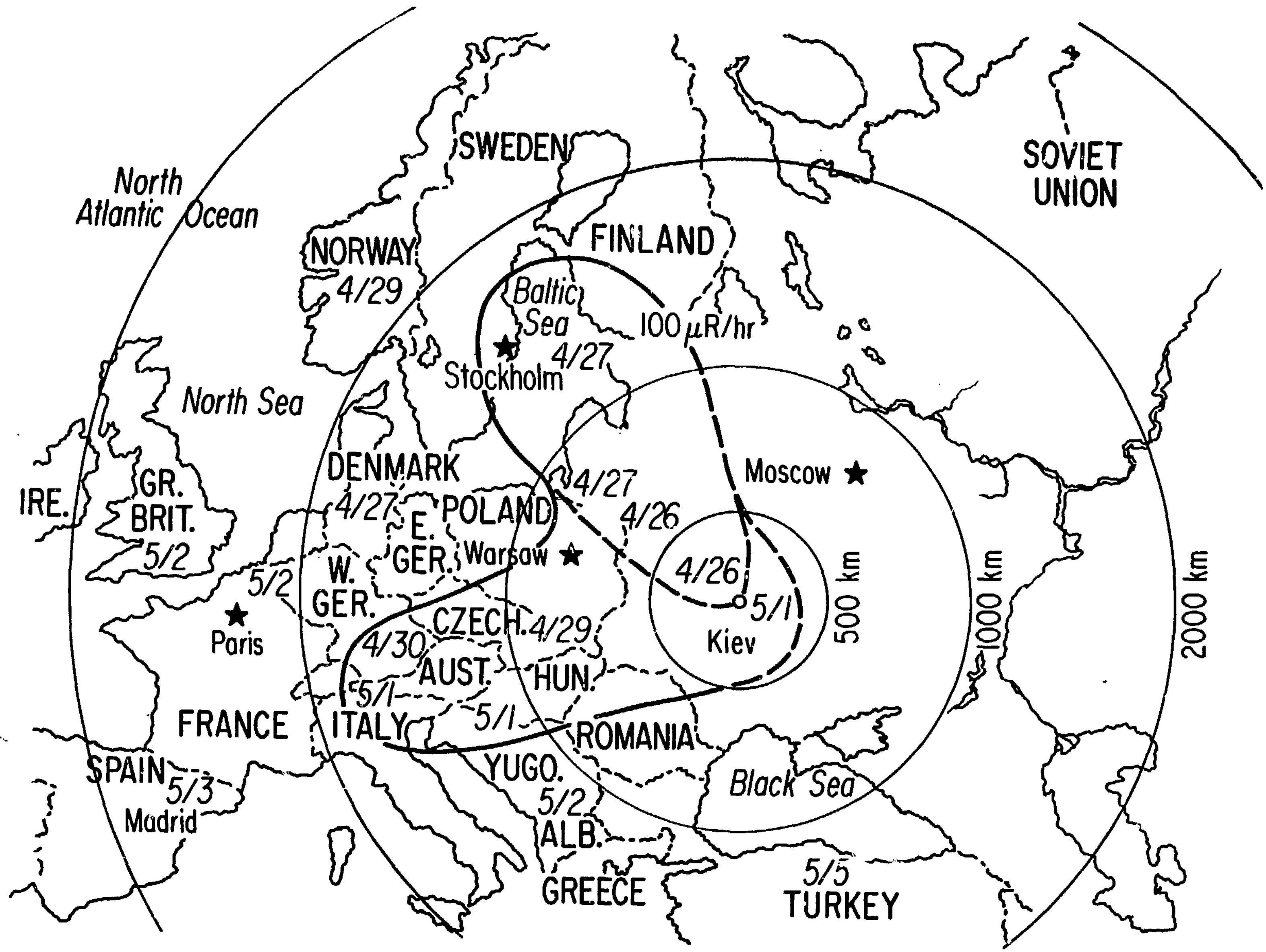

FIGURE 5

Initial Data and Areas Within Which External Exposure Level ≥ 100 uR/hr Were Reported (Dashed lines interpolated in the absence of data).

FIGURE 6 - KEY

Esternal Exposure Levels for Locations in
Scandinavia and Central Europe
Following the Chernobyl Accident

Locale	(Top to Bottom)	Reference
◇———◇	Blaystock, Poland	7
□— —□	Romania (average)	7
○— — —○	Olstzyn, Poland	7
○— —○	Poland (northeast)	16
●— — —●	Vusikaupunki, Finland	4
▽ — — ▽	Romania	16
△— — △	Pelgrade, Yugoslavia	7
□ — □	Salzburg, Austria	7
* – *	Munich, FGR (south)	7
† — — †	Bulgaria	7
+ — — +	Austria (average)	17
○———○	Louvisa, Finland	7
● — — ●	Helsinki, Finland	4
× —— ×	Hungary	7
○ — — ○	Vienna	7
□———□	Switzerland (north)	25

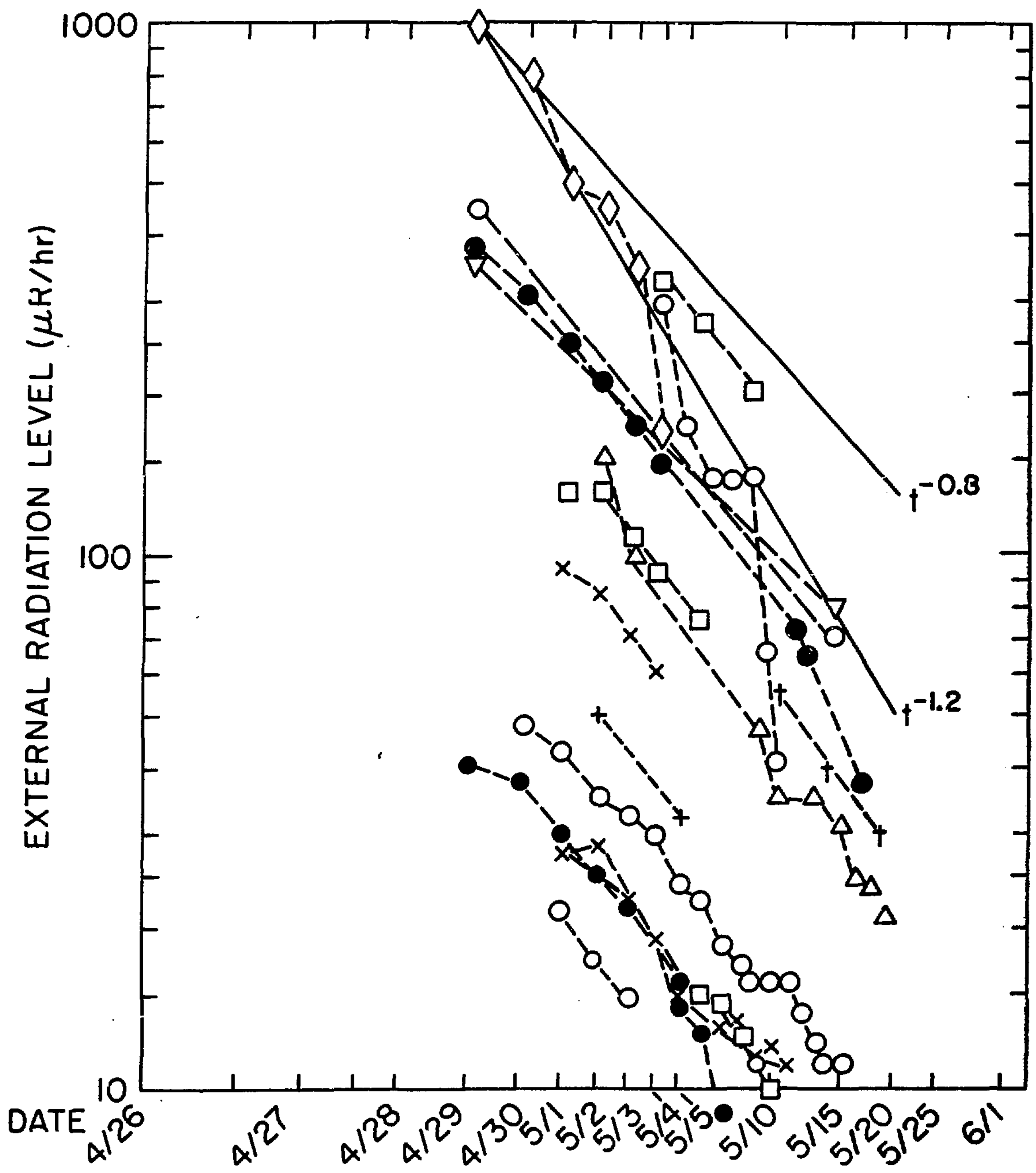

FIGURE 6

External Exposure Levels for Location in Scandanavia and Central Europe Following the Chernobyl Accident.

(From Reference

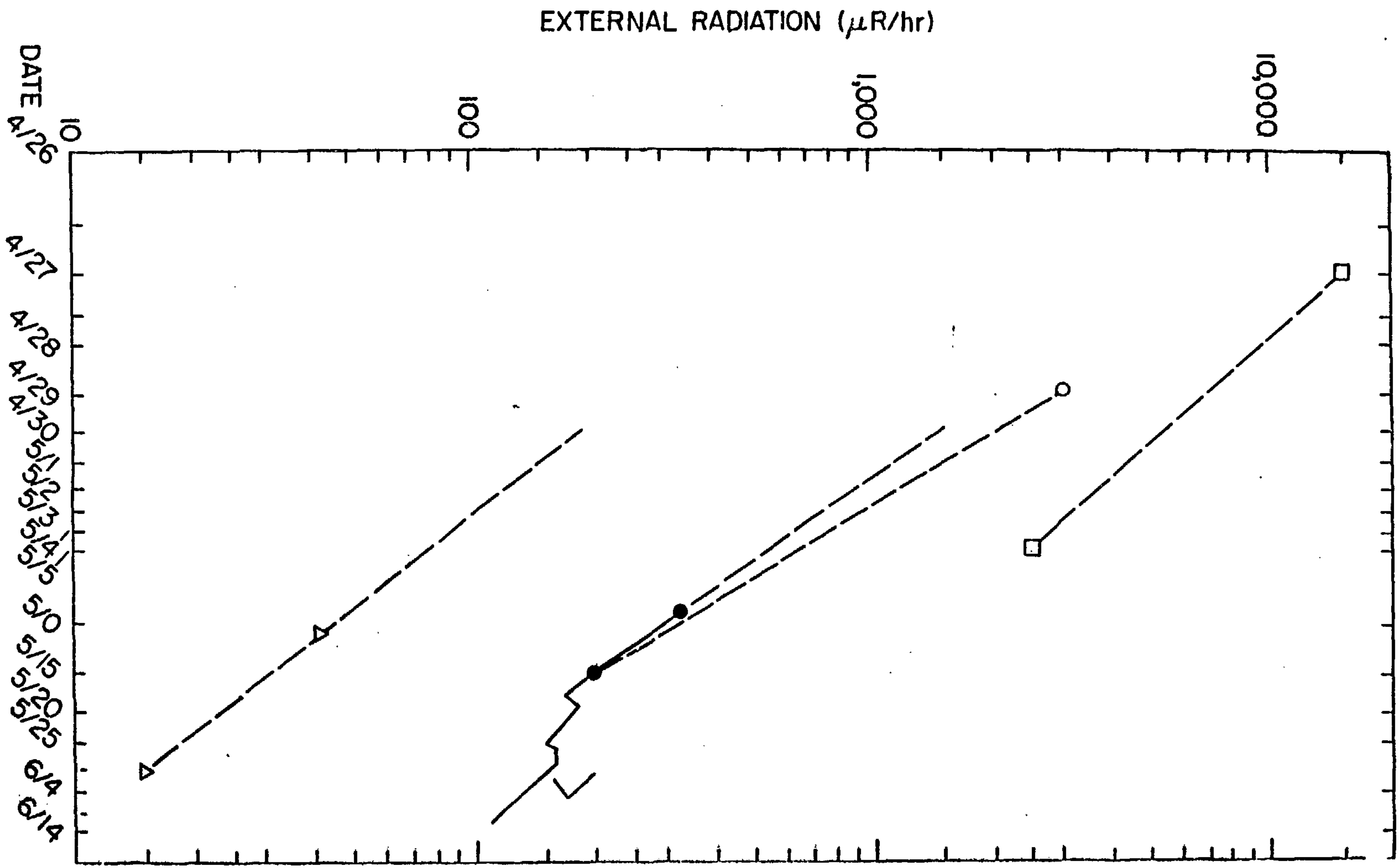

FIGURE 7

External Exposure Levels for Locations Within the U.S.S.R. Following the Chernobyl Accident.

Location (top to bottom)		Reference
● – – ●	Oster, U.S.S.R.	7
Δ – – Δ	Kishinow, U.S.S.R.	7
o——o	Kiev, U.S.S.R.	15
□——□	"Nearby Town"	15

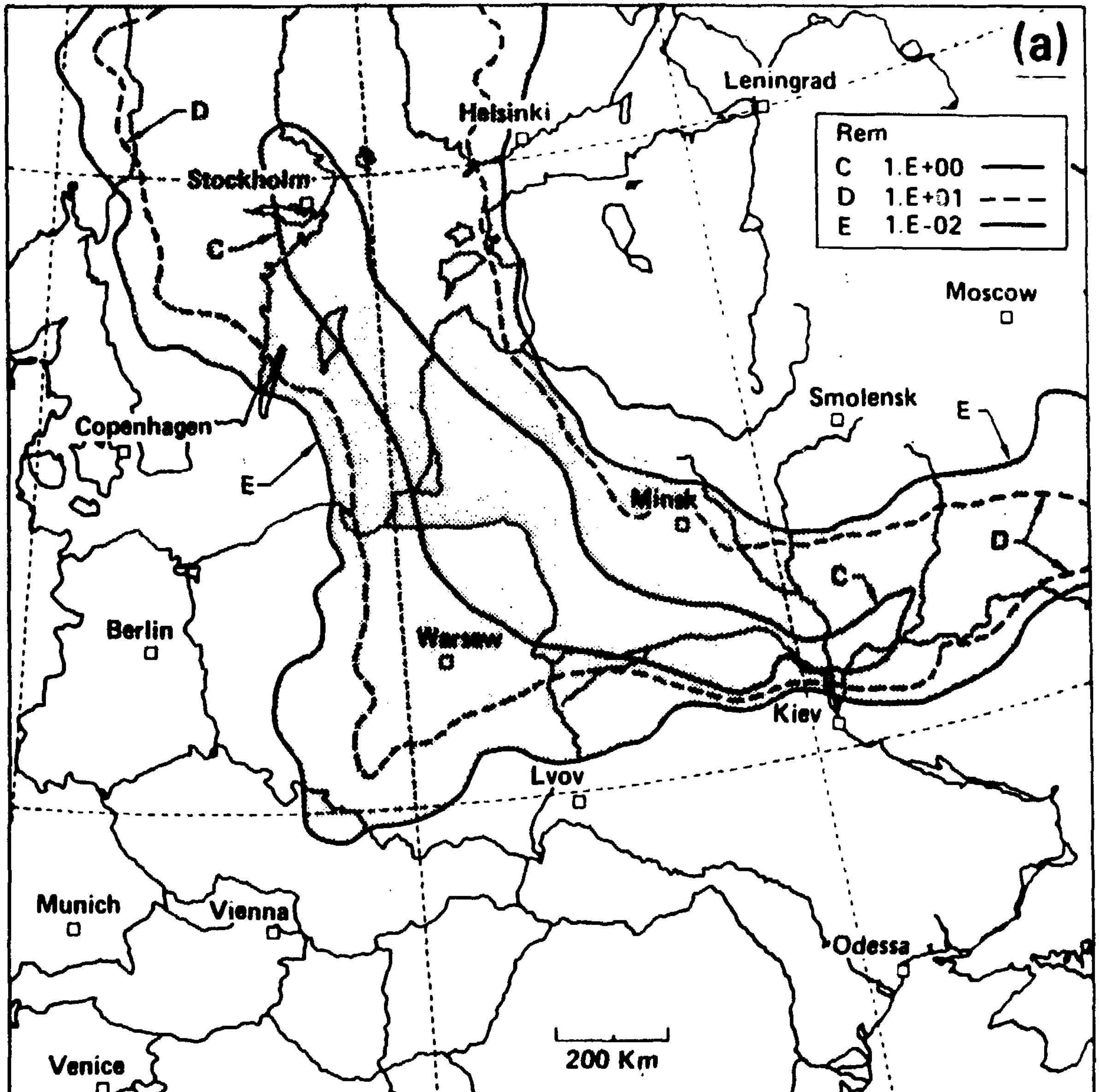

FIGURE 8

I-131 Adult Thyroid Dose 00Z April 30.

(From Reference 3)

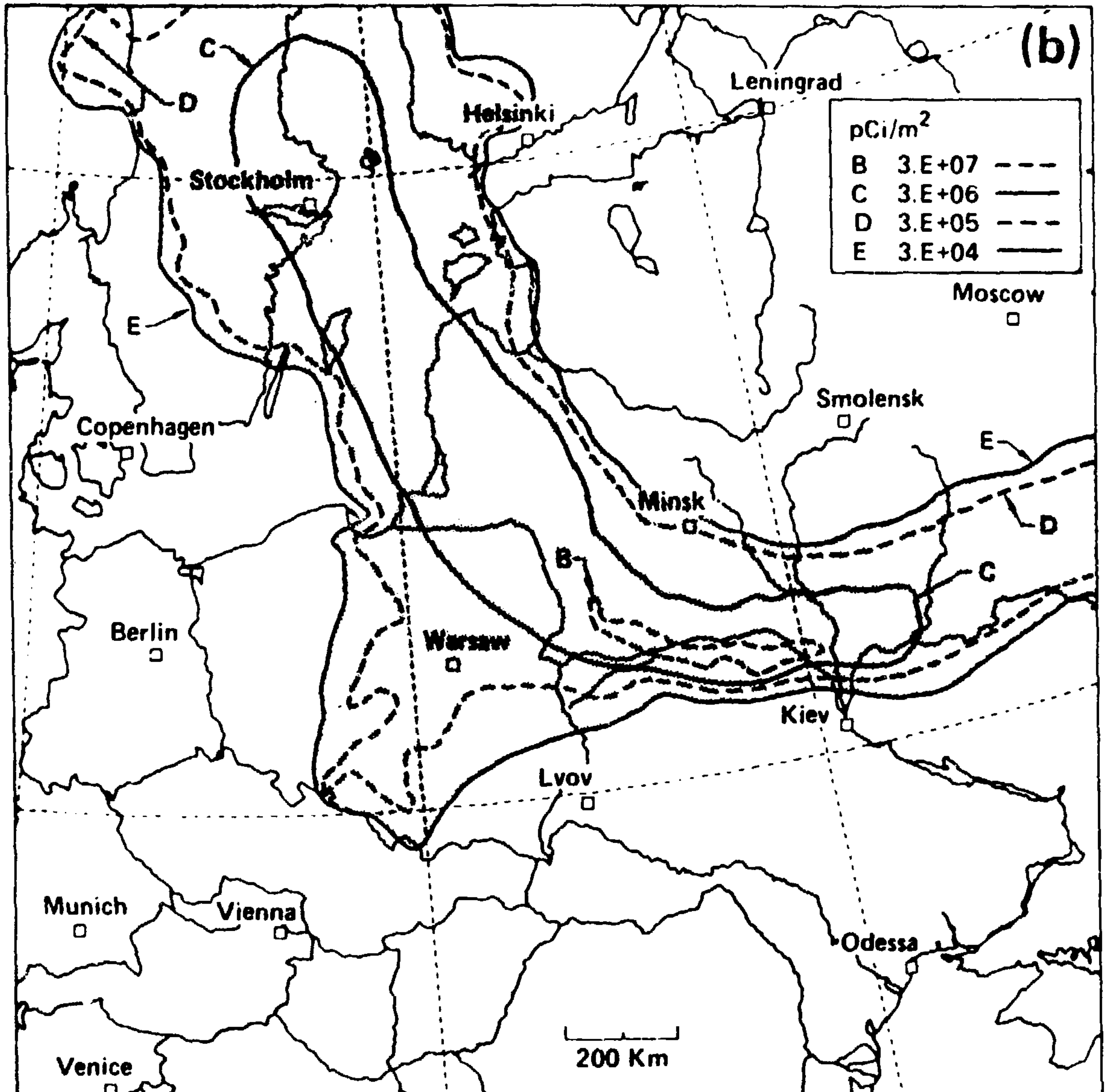

FIGURE 9

I-131 Deposition 00Z April 30.

(From Reference 3)

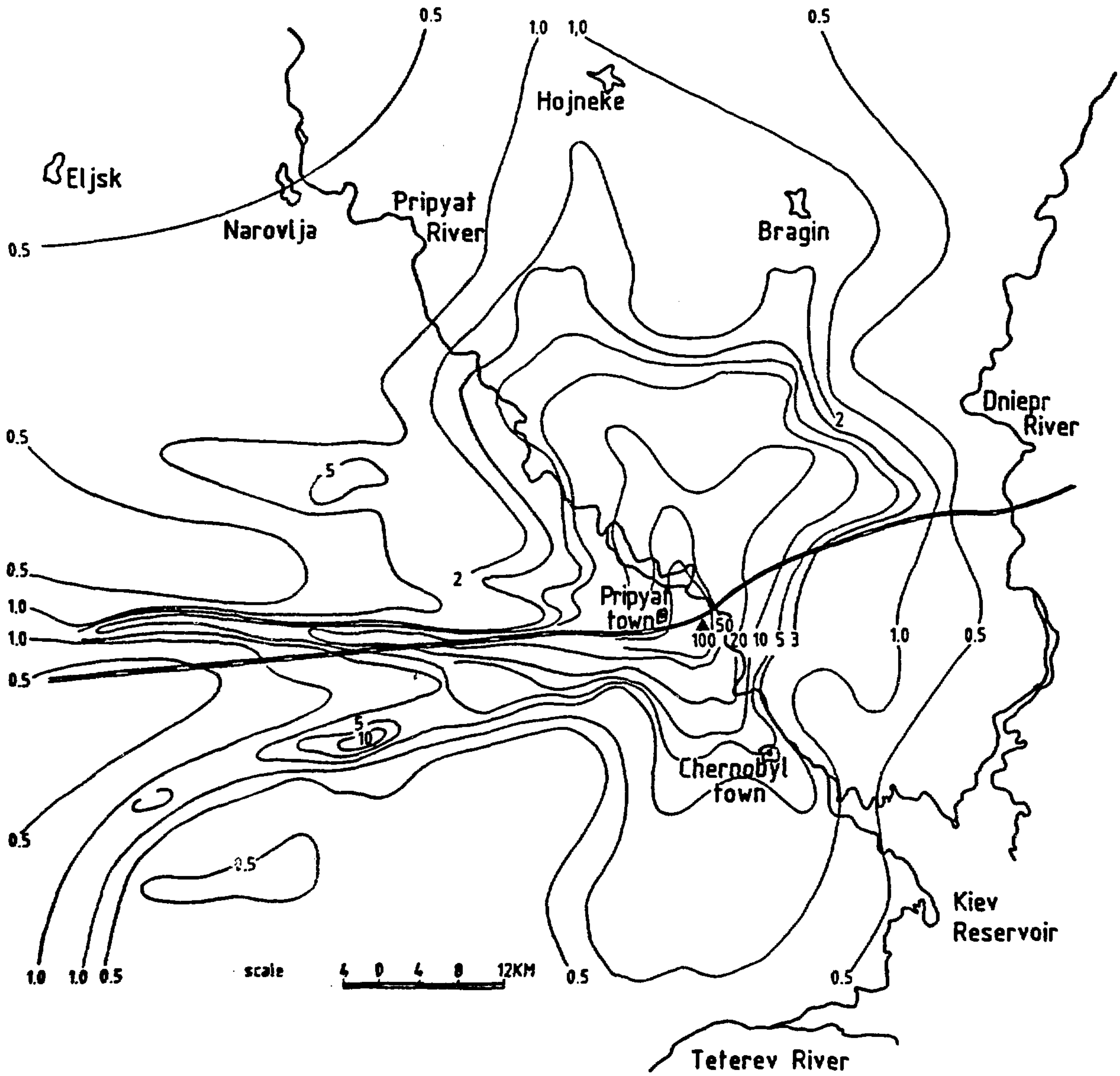

FIGURE 10

External Radiation Levels in mR/hr in the Vicinity of Chernobyl on May 29, 1986.

(From Reference 2)

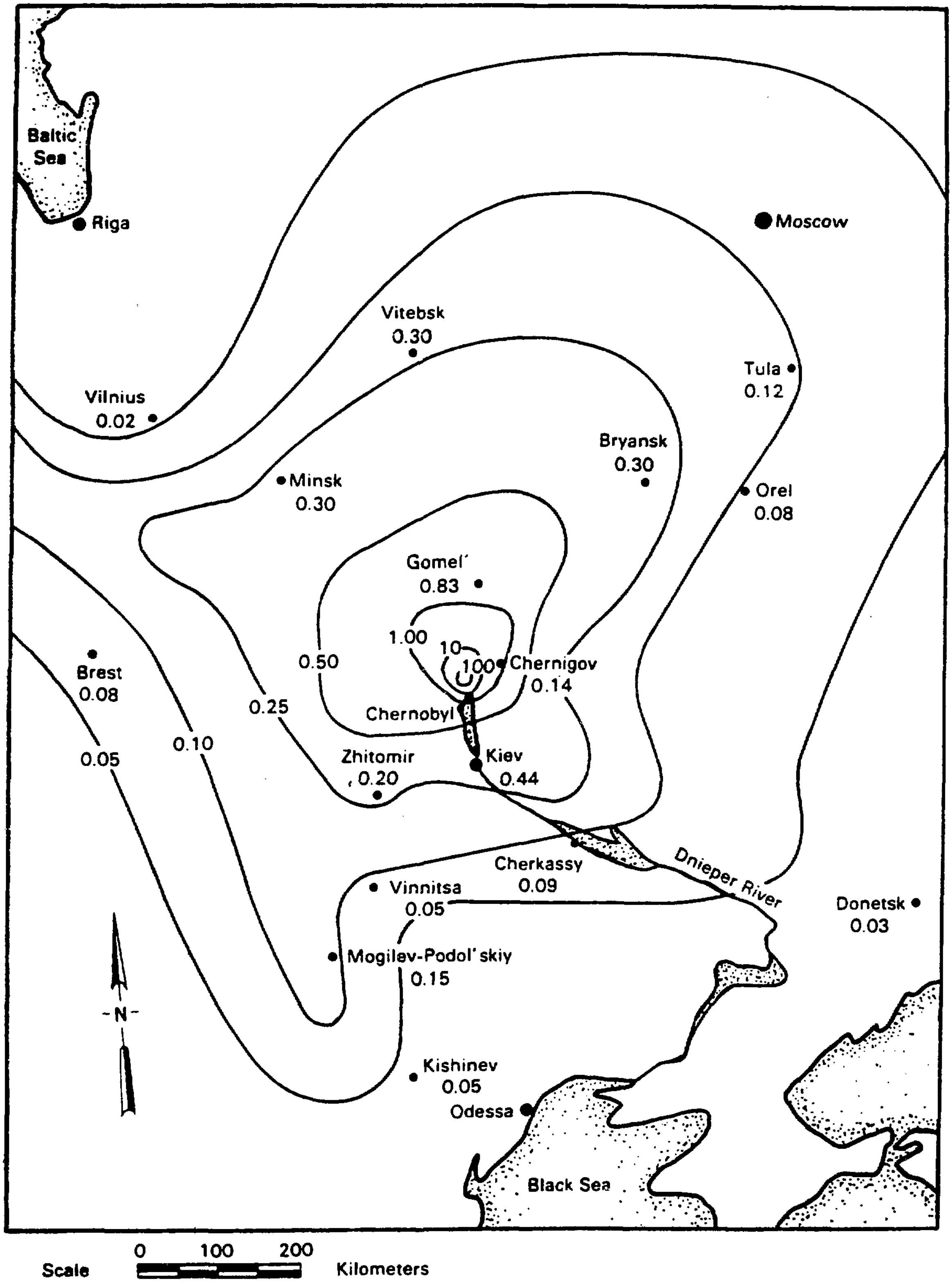

FIGURE 11

Estimated External Gamm-Exposure Rate Isocontours (mR/hr) at 15 Days Post-Accident.

Committed External Dose to Adults uSv (100 urem)

NOTE: 1-year exposure with modification factors (except Poland April 28 - May 12)

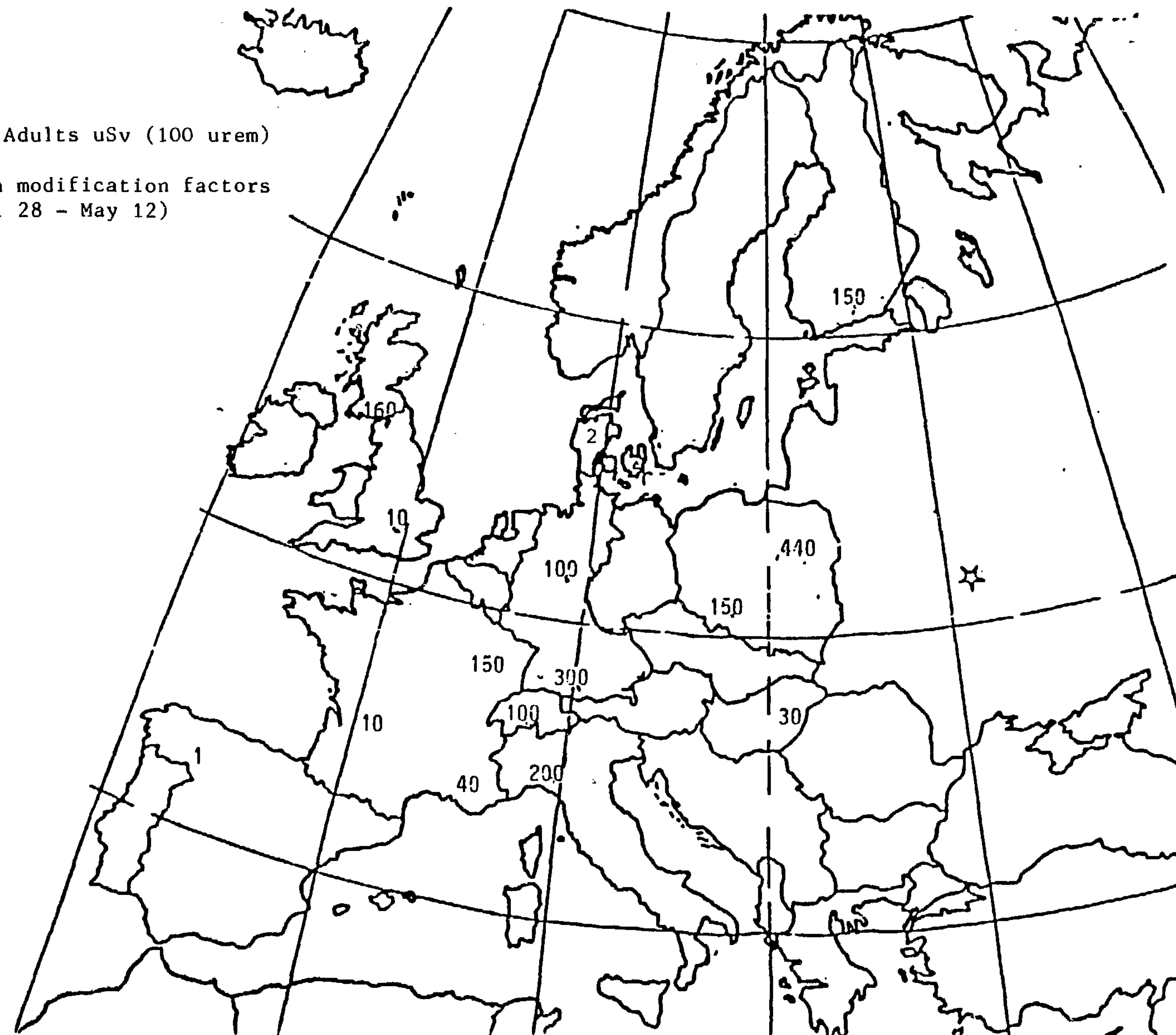

FIGURE 12

Post-Chernobyl External Exposure in European Countries.

(From Reference 28)

Committed Ingestion Dose to Adults uSv (100 urem)

Period of Intake

UK	-	1 year
France	-	1 year
Netherlands	-	1 year
West Germany	-	1 year
Switzerland	-	?
Italy	-	1 year
Finland		1 year
Poland	-	28 April to 12 May
Hungary	-	all year

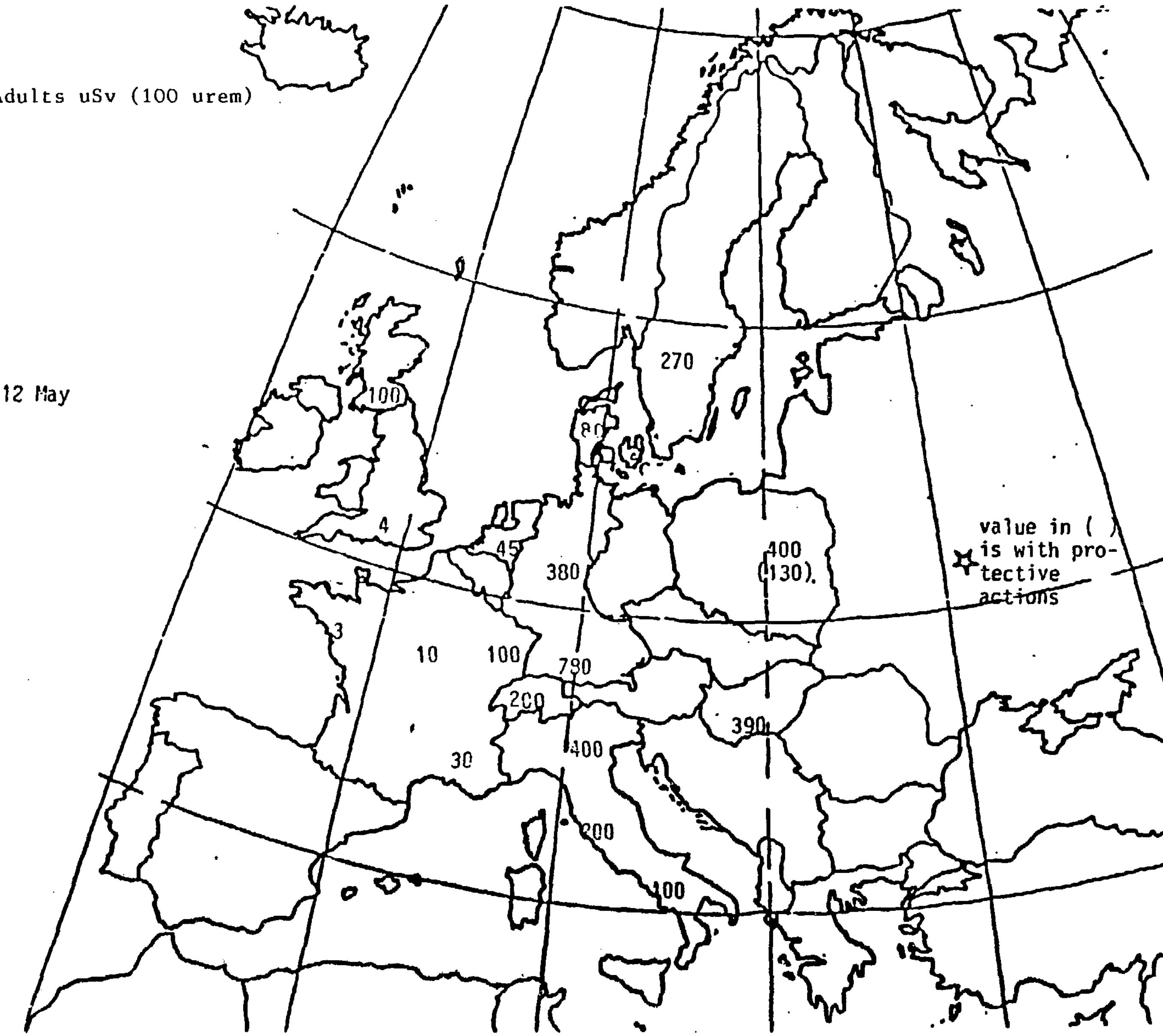

FIGURE 13

Post-Chernobyl Ingestion Dose in European Countries.

(From Reference 28)

Inhalation Dose Committed EDE uSv (100 urem)
Adults

NOTE: Primarily I-131

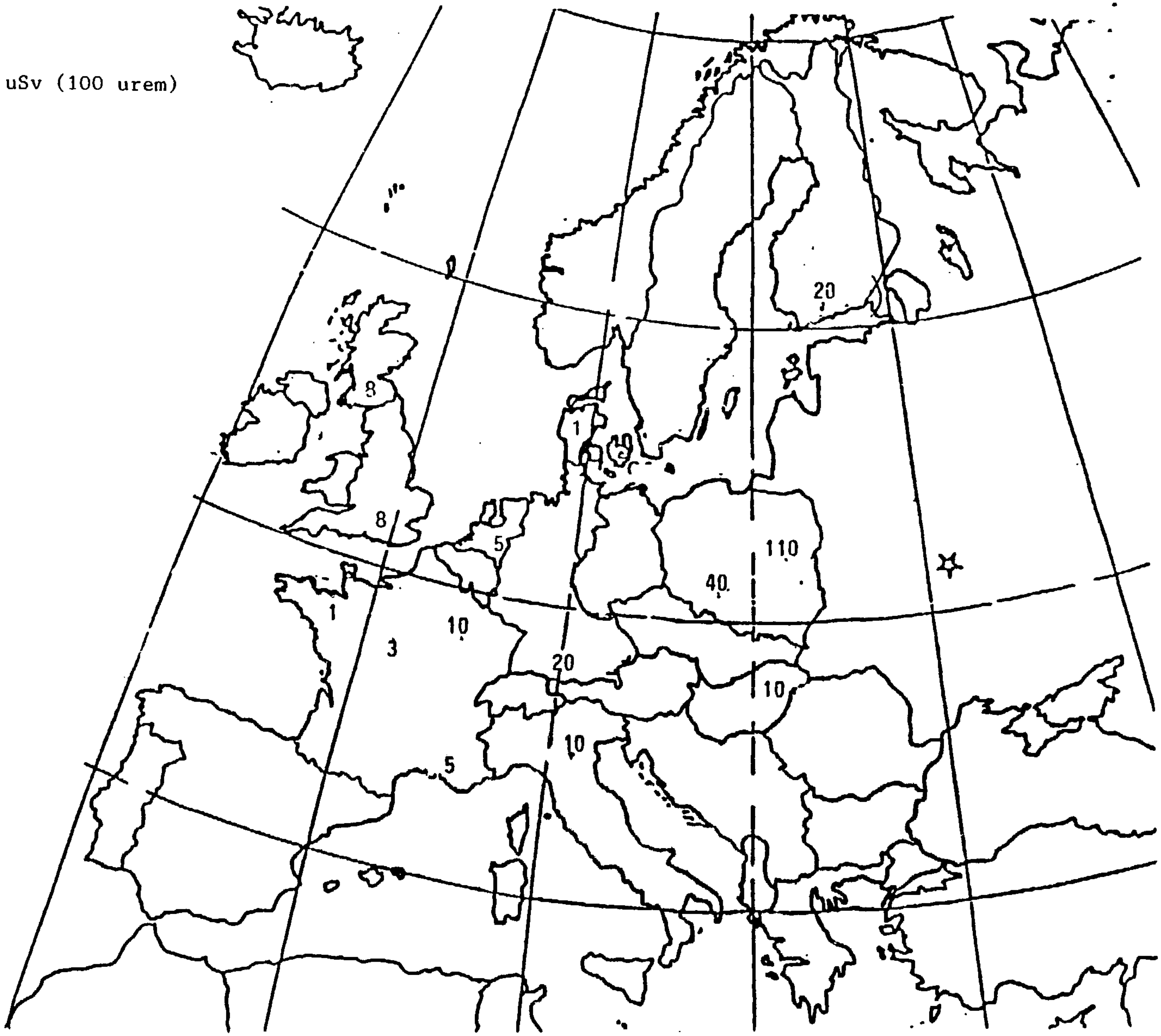

FIGURE 14

Post-Chernobyl Inhalation Dose from ^{131}I in European Countries.

(From Reference 28)

INVENTORY (MCi)

I-131	80
C-137	6

Released Fraction (MCi)

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
I-131	32.0	1.6	1.6	1.6	1.6	1.6
Cs-137	2.4	0.12	0.12	0.12	0.12	0.12

TABLE 1

Assumed Inventory and Released Fraction (MCi) of ^{131}I and ^{137}Cs Entering Low-Level Plume from Chernobyl.

(From Reference 3)

TABLE 2

Reported Time of Arrival and Maximum Levels of ^{131}I
in Air, Deposition, Vegetation, and Milk; and External Radiation
Levels in Poland and Scandanavian Countries*

Country	Initial Activity Detected	Air Cmax pCi/m^3	Date	Deposition Dmax nCi/m^2	Date	Vegetation Cmax nCi/kg	Date	Milk Cmax nCi/l	Date	External Rmax uR/hr	Date	Remarks
Poland	Northeast,	2,349	4/28	5,400	?	1,350	4/29	54	4/29	450	4/29	Rain 4/30. (Reference 6)
	4/27, p.m.	15,417	4/29			2,825	4/30	48	4/30	1,000	4/29	(Reference 7)
		13,878	4/30			2,349	5/1	26	5/1			
						1,404	5/2	42	5/6			
Denmark	4/27, p.m.	28				5	4/30			20	5/1	
						27	?					
Sweden	East, 4/27	270	4/28	30	4/28			2	5/2	60	4/28-29	Dry - Stockholm
	400m -	2,700	4/28	176	4/29			60	5/6	500-900	4/29	Rain approximately 100 miles (150 km) north of Stockholm
		300	4/29	1,350	5/1			78	4/30			Raw milk from Gotland (Reference 6)
Finland	4/27-28	5,535	4/28	3,750	?	1,137	4/30	40	4/30	100	4/27	4/27, Rain (east), 4/28 Rain (west)
	1,000m -	16,200	4/29					54	5/2	400	4/30	4/29 Rain (central-south).
Norway	4/29	81		55				15		22		
		600	?	2,100?								

*Note: Some of the data were reported in SI and some in conventional units. For consistency and to facilitate comparisons with U. S. standards and protective action guidance levels, they have been converted where necessary to conventional units which would result in small whole numbers (1 pCi = 0.037 Bq, 1 nCi = 37 Bq). Most of the external levels were reported in uR/hr (1 uR ~ 10^{-8} Sv).

TABLE 3

Response Levels for Grass-Cow-Milk Pathway Equivalent to Preventive PAG Dose Commitment of 1.5 rem Thyroid, 0.5 rem Whole-Body, or Red Bone Marrow to Infant[a] (From Reference 11)

Response Levels for Preventive PAG	I-131[b]	Cs-134[d]	Cs-137[d]	Sr-90	Sr-89
Initial Activity Area Deposition (nCi/m^2)	130	2,000	3,000	50	8,000
Forage Concentration[c] (nCi/kg)	50	800	1,300	180	3,000
Peak Milk Activity (nCi/l)	15	150	240	9	140
Total Intake (nCi)	90	4,000	7,000	200	2,600

[a] Newborn infant (includes fetus, pregnant women) as critical segment of population for iodine-131. For other radionuclides, "infant" refers to child less than 1 year of age.

[b] From fallout, iodine-131 is the only radioiodine of significance with respect to milk contamination beyond the first day. In case of a reactor accident, the cumulative intake of iodine-133 via milk is about 2 percent of iodine-131 assuming equivalent deposition.

[c] Fresh weight.

[d] Intake of cesium via the meat-man pathway for adult may exceed that of the milk pathway; therefore, such levels in milk should cause surveillance and protective actions for meat as appropriate. If both Cs-134 and Cs-137 are equally present, as might be expected for reactor accidents, the response levels should be reduced by a factor of two.

TABLE 4

Reported Time of Arrival and Maximum Levels of ^{131}I
in Air, Deposition, Vegetation, and Milk; and External Radiation Levels
in Central European Countries*

Country	Initial Activity Detected	Air Cmax pCi/m^3	Date	Deposition Dmax nCi/m^2	Date	Vegetation Cmax nCi/kg	Date	Milk Cmax nCi/l	Date	External Rmax uR/hr	Date	Remarks
Hungary	4/29-30			4,050	5/3	219	5/1-4	34	5/3	70	4/30	
						122	5/5	70	5/5	90	5/5	
								27	5/4-5			(Reference 7)
								42	5/10			
Czechoslovakia	4/29?							27	?	200	?	(Reference 7)
										70	5/6	
Austria	4/29	810	?			100	5/3	70	5/2	230	5/2	Light Rain, 4/29-30, 5/1, NE Austria
										32	5/1	
South Germany	4/29-30	3,051	4/29	3,370	4/30	1,215	5/2	44	5/3	250	4/30	
(Bavaria)		3,429	4/30	1,460	5/1	3,340	5/3					
						6,750	5/5					
Switzerland	North, 4/30 (a.m.)	200	5/1	250	5/3	100	?	50	5/4	20	?	Dry
	East, 4/30 (p.m.)							12	?	180	5/4	Post-Rain, South
Rumania	5/1-2	600	5/1 (a.m.)					12	?	1,100	?	
		1,000	5/1 (a.m.)							350	5/3-4	
(South)		2,000	?							250	5/7-8	
Yugoslavia	5/1	Belgrade-405	5/1					10	5/2, 5/7	160	5/2	5/1-2, Overnight Rain
		Zagreb-540	5/1							178	5/4	
Italy	5/1-2	1,000	5/2	100	5/2			35	5/8	27	5/1	
Greece	5/2			89	5/3			4	?	16	?	
				151	5/10			11	5/10	90	5/5	
Albania	5/2							3	5/11-14	70	?	(Reference 7)

*Note: Some of the data were reported in SI and some in conventional units. For consistency and to facilitate comparisons with U. S. standards and protective action guidance levels, they have been converted where necessary to conventional units which would result in small whole numbers (1 pCi – 0.037 Bq, 1 nCi = 37 Bq). Most of the external levels were reported in uR/hr (1 uR ~ 10^{-8} Sv).

TABLE 5

Reported Time of Arrival and Maximum Levels of ^{131}I
in Air, Deposition, Vegetation, and Milk; and External Radiation Levels
After May 1, 1986 in Countries Distant from Chernobyl

Country	Initial Activity Detected	Air Cmax pCi/m^3	Date	Deposition Dmax nCi/m^2	Date	Vegetation Cmax nCi/kg	Date	Milk Cmax nCi/l	Date	External Rmax uR/hr	Date	Remarks
FGR-North (Julich)	5/2-3	500		90	5/6	38	5/6	6	?			(Reference 13)
Belgium	5/2	1,620 540	5/2 5/3					8 2	5/4 4/7			
Netherlands	5/2	1,400	5/2	30	5/4			5	5/4	40	5/2	
France	5/2	130	5/2	24	5/7			10	5/7			
Ireland	5/2	600	5/2			4		12	5/5	55	5/3*	*Belfast (Reference 14)
Spain	5/3	11										
Portugal	5/5	5				.02				20		
Turkey	5/5							10	5/6	60 100	5/5 5/7	
Kuwait	5/7	10										
Japan	5/3, a.m.	22	5/5			1		0.06	5/5			
Korea	5/5											
U. S.	5/7, Northwest	.005		0.1		0.049		0.4				
UK (South)	5/2	50	5/2	14		27		1.5	5/6	50	?	(Reference 14)
*North)	5/5		5/5	216		54		11	?	100	5/4	
				2,130	5/4**							**Scotland (Reference 7)

*Note: Some of the data were reported in SI and some in conventional units. For consistency and to facilitate comparisons with U. S. standards and protective action guidance levels, they have been converted where necessary to conventional units which would result in small whole numbers (1 pCi = 0.037 Bq, 1 nCi = 37 Bq). Most of the external levels were reported in uR/hr (1 uR ~ 10^{-8} Sv).

TABLE 6

Reported Radiation Levels Within the U.S.S.R.
Subsequent to April 26, 1986*

Country	Initial Activity Detected	Air Cmax pCi/m³	Date	Deposition Dmax nCi/m²	Date	Vegetation Cmax nCi/kg	Date	Milk Cmax nCi/l	Date	External Rmax uR/hr	Date	Remarks
U.S.S.R.												
Kiev	5/1									3,000	4/30?	British Embassy (Reference 16)
										1,200	5/1	Finnish Airlines (Reference 17)
										320	5/10	Kiev. (Reference 7)
Moscow	5/4?									16	5/4	
	5/17							3.6	5/17			(New York Times, May 25, 1986)
Leningrad	5/6?									34	5/6	
Miscellaneous:										330	5/10	At 60 km. (Reference 15)
										15,000	?	In 30 km evacuation zone, maximum dose-rate at nearby township "soon after accident." (Reference 15)

*Note: The data are presented as reported in conventional units in order to facilitate comparisons with U. S. standards and protective action guidance levels (1 nCi = 37 Bq, 1 uR ~ 10^{-8} Sv).

TABLE 7

Measured Thyroid Burdens of Travellers within U.S.S.R. and Central Europe between April 25, 1986 - May 4, 1986*

Reference	No. of Persons	Number With Positive Thyroid Burden	Average Burden of Positive (nCi)	Itinerary Dates: Kiev	Moscow	Leningrad	Helsinki	Other
BNL-A	36	0	-		4/25-29	4/29-30	5/1	
BNL-B	39	25	10	4/29-30	4/24-28	4/30	5/1	
BNL-C	18	17	7.8	4/27-29	4/24-26	4/30	5/1	
BNL-D	25	7	3.5	4/25,	5/1-3	4/27-5/1		Odessa-4/25; Amsterdam-5/3
BNL-E	12	12	8.5	4/26-29	4/30-5/4			Minsk-4/29-30
BNL-F	1	1	7.3					Central Europe-4/28-5/4
BNL-G	2	0	-		4/26-28	4/28-5/2	5/2	
BNL-H	2	0	-		4/26-28	4/28-5/2	5/2	
BNL-I	2	2	195	4/28-5/1 5/1-5/3	4/26-28	5/4-7	5/7	Novograd-5/3-4
Hill et al	5	5	1.1-4.1					Warsaw-4/28-5/4
Hill et al	2	2	30-46	4/28-5/4?				
Hill et al	11	5	<1 nCi		5/4	5/4		
Finnar	?	All?	27-810	?-5/4				
Japan	43	0	<5	4/29-30				
Japan	25	0	<5?	4/28-30				
Japan	54	27	10-60	4/30-5/1	(Portable WBC recount of six of "heavily contaminated" persons)			

References:

BNL - 18
Hill et al - 19
Finnar - 17
Japan - 20

*Note: Some of the data were reported in SI and some in conventional units. For consistency and to facilitate comparisons with U. S. standards and protective action guidance levels, they have been converted where necessary to conventional units which would result in small whole numbers 1 pCi - 0.037 Bq, 1 nCi = 37 Bq). Most of the external levels were reported in uR/hr (1 uR ~ 10^{-8} Sv).

TABLE 8

Apparent Release Fraction of Principal Fission Products, as Determined from Spectra of Media at Large Distances Downwind from Chernobyl

	T-1/2 Day	Apparent Average Release Fraction*	Estimated Release Fraction WASH-1400†	NUREG-0772(22)	NUREG-CR-1237(23)
^{95}Zr	65.2	0.003	-	-	0.003
^{95}Nb	35.0	(0.003)	-	-	(0.003)
^{99}Mo	2.8	.03	0.03	0.03	0.03
^{103}Ru	39.5	.05	0.03	0.03	0.03
^{106}Ru	368	.05	0.03	0.03	0.03
^{127}Sb	3.88	.10	-	-	-
^{m129}Te	0.34	.35	0.30	1.00	0.15
^{m131}Te	1.25	.35	0.30	1.00	0.15
^{131}I	8.05	1.0*	0.90	1.00	0.89
^{132}Te	3.25	.50	0.30	1.00	0.15
^{132}I	(0.214)	(.50)	0.90	1.00	0.89
^{133}I	0.875	1.0*	0.90	1.00	0.89
^{135}I	0.28	1.0*	0.90	1.00	0.89
^{134}Cs	750	0.70	0.50	1.00	0.76
^{136}Cs	13.0	(1.00)	0.50	1.00	0.76
^{137}Cs	11,000	1.35**	0.50	1.00	0.76
^{140}Ba	12.9	0.10	0.10	0.50	0.10
^{140}La	(1.57)	0.67	(0.10)	(0.50)	(0.10)
^{141}Ce	32.3	0.15***	0.004	0.30	0.003
^{144}Ce	284	0.15***	0.004	0.30	0.003
^{239}Np	2.35	0.07	0.004	-	0.003

*I assumed to be 1.00

**There is evidence that the affected fuel in Chernobyl-4 may have been in operation for a longer time than assumed in WASH-1400 (see Reference 4), and thus might have had a larger inventory of ^{137}Cs, relative to ^{131}I.

***Limited data, values questionable.

†See Reference 9, Appendix VI, Table 3.1.

TABLE 9

Calculated Exposure Rate for 24-Hour Post-Accident "Reference" Spectrum Which has Deposited 1 uCi/m^2 Total Activity*

	T-1/2 Day	Apparent Release Fraction	Relative Activity	Exposure*** Rate uR/hr	Relative Activity Exposure Rate uR/hr	1-Year Exposure mR
^{95}Zr	65.2	0.003	0.0009	13.9	0.01	0.03
^{95}Nb**	35.0	(0.003)	(0.0009)	14.4	0.01	0.03
^{99}Mo	2.8	0.03	0.0095	3.0	0.03	<0.01
^{103}Ru	39.5	0.05	0.012	8.9	0.11	0.15
^{106}Ru	368	0.05	0.0028	3.8	0.01	0.07
^{m131}Te	1.25	0.50	0.0087	26.0	0.23	<0.01
^{131}I	8.05	1.00	0.177	7.3	1.29	0.36
^{132}Te	3.25	0.50	0.110	3.8	0.42	0.05
^{132}I**	(0.214)	(0.50)	(0.110)	42.1	4.62	0.52
^{133}I	0.875	1.00	0.175	11.4	2.00	0.06
^{135}I	0.28	1.00	0.030	27.0	0.81	0.01
^{134}Cs	750	0.70	0.011	29.1	0.33	2.45
^{136}Cs	13.0	1.00	0.0064	41.0	0.25	0.13
^{137}Cs	11,000	1.35	0.014	10.7	0.15	1.33
^{140}Ba	12.9	0.10	0.034	2.7	0.09	0.04
^{140}La**	(1.157)	(0.07)	0.025	38.8	0.97	0.43
^{141}Ce	32.3	0.15	0.049	1.2	0.06	0.07
^{144}Ce-Pr	284	0.15	0.030	0.8	0.02	0.14
^{239}Np	2.35	0.07	0.193	2.9	0.56	0.05
			1.0		11.97	5.92

1 uR/hr initial exposure rate at 24 hours = 495 uR integrated first year exposure, if weathering and shelter factors are not considered.

* Conventional Units have been utilized to facilitate comparison with U. S. standards and protective action guidance (1 uCi = 37 kBq, 1 uR ~ 10^{-8} Sv, 1 mR 10^{-5} Sv).

** Decay rates and release fractions of parent nuclides have been utilized.

***H. L. Beck, "Exposure Rate Conversion Factors for Radionuclides Deposited on the Ground," EML - 320 (July 1980). Surface plane source assumed, allowance for ground roughness would reduce exposure rate by approximately 15%.

TABLE 10

Calculated Exposure Rate for 72-Hour Post-Accident "Reference" Spectrum Which has Deposited 1 uCi/m^2 Total Activity*

	T-1/2 Day	Apparent Release Fraction	Relative Activity	Exposure*** Rate uR/hr	Relative Activity Exposure Rate uR/hr	1-Year Exposure mR
^{95}Zr	65.2	0.003	0.0014	13.9	0.02	0.05
^{95}Nb**	35.0	(0.003)	(0.0014)	14.4	0.02	0.05
^{99}Mo	2.8	0.03	0.0071	3.0	0.02	<0.01
^{103}Ru	39.5	0.05	0.017	8.9	0.15	0.21
^{106}Ru	368	0.05	0.0041	3.8	0.02	0.10
^{m131}Te	1.25	0.50	0.0041	26.0	0.08	<0.01
^{131}I	8.05	1.00	0.217	7.3	1.61	0.45
^{132}Te	3.25	0.50	0.130	3.8	0.50	0.06
^{132}I**	(0.214)	(0.50)	(0.130)	42.1	5.56	0.63
^{133}I	0.875	1.00	0.053	11.4	0.60	0.02
^{135}I	0.28	1.00	0.0001	27.0	<0.01	<0.01
^{134}Cs	750	0.70	0.017	29.1	0.51	3.81
^{136}Cs	13.0	1.00	0.0085	39.2	0.34	0.15
^{137}Cs	11,000	1.35	0.021	10.7	0.23	1.96
^{140}Ba	12.9	0.10	0.046	2.7	0.12	0.05
^{140}La**	(1.57)	(0.07)	0.030	38.8	1.16	0.52
^{141}Ce	32.3	0.15	0.071	1.2	0.08	0.10
^{144}Ce-Pr	284	0.15	0.042	0.8	0.03	0.19
^{239}Np	2.35	0.07	0.184	2.9	0.54	0.04
			1.0		11.66	8.40

1 uR/hr initial exposure rate at 72 hours = 720 uR integrated first year exposure, if weathering and shelter factors are not considered.

* Conventional Units have been utilized to facilitate comparison with U. S. standards and protective action guidance (1 uCi = 37 kBq, 1 uR ~ 10^{-8} Sv, 1 mR 10^{-5} Sv).

** Decay rates and release fractions of parent nuclides have been utilized.

***H. L. Beck, "Exposure Rate Conversion Factors for Radionuclides Deposited on the Ground," EML - 320 (July 1980). Surface plane source assumed, allowance for ground roughness would reduce exposure rate by approximatley 15%.

TABLE 11

Calculated Exposure Rate for 168-Hour Post-Accident "Reference" Spectrum Which has Deposited 1 uCi/m^2 Total Activity*

	T-1/2 Day	Apparent Release Fraction	Relative Activity	Exposure*** Rate uR/hr	Relative Activity Exposure Rate uR/hr	1-Year Exposure mR
^{95}Zr	65.2	0.003	0.0024	13.9	0.03	0.07
^{95}Nb**	35.0	(0.003)	(0.0024)	14.4	0.03	0.08
^{99}Mo	2.8	0.03	0.0048	3.0	0.01	<0.01
^{103}Ru	39.5	0.05	0.028	8.9	0.25	0.33
^{106}Ru	368	0.05	0.0072	3.8	0.03	0.17
^{m131}Te	1.35	0.50	0.0008	26.0	0.02	<0.01
^{131}I	8.05	1.00	0.267	7.3	1.95	0.54
^{132}Te	3.25	0.50	0.290	3.8	1.80	0.03
^{132}I**	(0.214)	(0.50)	(0.290)	42.1	3.26	0.37
^{133}I	0.875	1.00	0.004	11.4	0.05	<0.01
^{135}I	0.28	1.00	<0.001	27.0	<0.01	<0.01
^{134}Cs	750	0.70	0.030	29.1	0.88	6.53
^{136}Cs	13.6	1.00	0.012	39.2	0.47	0.21
^{137}Cs	11,000	1.35	0.036	10.7	0.39	3.37
^{140}Ba	12.9	0.10	0.063	2.7	0.17	0.07
^{140}La**	(1.57)	(0.07)	(0.044)	38.8	1.71	0.76
^{141}Ce	32.3	0.15	0.111	1.2	0.13	0.06
^{144}Ce-Pr	284	0.15	0.072	0.8	0.45	0.34
^{239}Np	2.35	0.07	0.158	2.9	0.45	0.04
			1.0		10.13	12.99

1 uR/hr initial exposure rate at 168 hours = 1,280 uR integrated first year exposure, if weathering and shelter factors are not considered.

* Conventional Units have been utilized to facilitate comparison with U. S. standards and protective action guidance (1 uCi = 37 kBq, 1 uR ~ 10^{-8} Sv, 1 mR 10^{-5} Sv).

** Decay rates and release fractions of "parent" nuclides have been utilized.

***H. L. Beck, "Exposure Rate Conversion Factors for Radionuclides Deposited on the Ground," EML - 320 (July 1980). Surface plane source assumed, allowance for ground roughness would reduce exposure rate by approximately 15%.

TABLE 12

Reported Measurement Results Relevant for Dose Assessment

Russia

Exposure	28	At 30 km from accident site						
Rate by Day	29							
uR/hr	30	27 April ? 10,000 - 15,000						
	1							
	2							
	3							
	4							
	5	2,000 - 3,000 ?						
	6							
	7							
	8	150						
		Oster	Leningrad	Riga	Vilnyus	Brest	Rakhov	Kishinev
	9	330	8	10	10	10	2	9
	10	360	10	10	10	10	25	50
	11	220	10	10	10	25	24	60
	12	240	10	10	10	25	25	30
	13	180	20	10	10	33	25	30
	14	200	19	12	10	25	25	30
	15	200	16	10	25	46	25	60
	16	190	17	10	10	10	25	30
	17	180	17	10	10	10	25	40
	18	170	17	10	16	10	25	50
	19	180	17	10	16	10	25	40
	20	170	17	10	25	10	24	40
	21	170	16	11	16	10	25	50
	22	170	15	10	25	10	25	40
	23	170	15	10	20	10	23	50
	24	150	14	11	12	10	25	40
	25	150	14	11	11	10	25	30
	26	160	16	9	12	10	25	30
	27	160	14	14	15	10	25	40
	28	160	15	10	15	10	25	30
	29	160	10	10	13	10	25	30
	30	160	10	9	20	10	25	25
	31	150	10	9	25	32	23	25
	1	160	10	10	20	32	23	25
	2	140	10	14	20	10	25	25
	3	130	10	9	20	10	25	23
	4	130	10	10	10	10	25	26
	5	130	10	10	15	10	23	25
	6	130	10	10	15	10	25	25
	7	130	10	10	20	10	24	20
	8	120	10	10	10	10	25	22
	9	120	10	10	10	10	23	25
	10	120	10	10	10	10	20	25
	11	110	10	10	15	10	25	23

(From Reference 7)

TABLE 13

Assumptions for Projection of Radiation Levels*

Assumptions:

"Peak" air concentration of ^{131}I was of 24 hours duration.

Deposition velocity of "fresh" radioiodine 0.5 cm/sec.

Deposit of 1 uCi/m^2 of ^{131}I will result in "peak" milk concentration of 0.1 uCi/l, 2 - 3 days, thereafter.

Concentrations decrease with distance from source: $C_r = C_1 \, r^{-1.5}$.

Observations:

^{131}I 20% of total activity (see Tables 10 - 12)

Calculations:

Dose rate from deposition of 1 uCi/m^2 "average" mixture of gamma emitters in the Chernobyl release is approximately 10 uR/hr (see Tables 9 - 11)

Dose rate decrease: $\frac{R}{R_o} = t \text{ (hours)}^{-.8}$ (see Figure 6)

* Conventional units have been employed to facilitate comparisons with U. S. standards and proteciton action guidance levels (1 uCi = 37 kBq, 1 uR ~ 0.01 uSv).

TABLE 14

Projections of Radiation Levels within U.S.S.R.
Downwind from Chernobyl on April 26 - 27, 1986**

(d) Distance mi	km	Estimated Max.* 24 Hour Concentration pCi/m^3*	^{131}I Deposition (Vg = 0.5 cm/sec) nCi/m^2*	Estimated Peak Milk Concentration nCi/l*	Estimated Total Deposition (^{131}I = 20%) nCi/m^2*	Estimated Initial External Exposure Rate (1 uCi/m^2 = 10 uR/hr) uR/hr*	Extimated 1-Year External Exposure*** rem
5	8	2,400,000	1,037,000	103,700	5,185,000	51,850	22.0
10	17	850,000	367,000	36,700	1,468,000	14,680	4.40
25	40	220,000	75,000	7,500	300,000	3,000	0.90
36	60	125,000	54,000	5,400	216,000	2,160	0.66
50	80	76,000	32,800	3,280	131,000	1,310	0.39
80-160 (Kiev see Table 6 for data)							
100	170	27,000	11,700	1,177	46,800	468	0.14
300	500	5,200	2,250	225	9,000	90	0.030
500	800	2,400	1,040	104	4,160	42	0.013
500-800 (N.E. Poland see Table 2 for data)							
700	1150	1,500	650	65	2,600	26	0.08
900	1500	1,000**	430	43	1,720	17	0.05
1,000	1650	850	370	37	1,480	15	0.05
1,250	2100	610	260	26	1,040	10	0.03
1 Rem - Thyroid							
Child		23,000	(86)	10			
Adult		40,000	(1,200)	133			

Note: Those projections are based on an extrapolation from "representative" 24-hour concentration at ground level in Sweden and Finland (900 mi. or 1,500 km) of 1 x 10^{-9} uCi/cm^3 (27 Bq/m^3).

* Conventional units have been employed at facilitate comparison with U. S. standards and protection action guidance (1 mi - 1.6 km, 1 uCi = 37 kBq, 1 nCi = 37 Bq, 1 pCi = 0.037 Bq, 1 uR ~ 10^{-8} Sv, 1 R ~ 0.01 Sv).

** The thyroid dose from the inhalation of ^{131}I in a concentration of 1,000 pCi/m^3 (27 Bq/m^3) for 24 hours would be about 40 mrem (0.4 mSv).

***If measured at 24 hours post-accident, the integrated 1 year exposure would be approximately 500 times initial dose rate (see Table 9).

TABLE 15A

Comparison of ARAC's Estimated Air Concentrations with Measured Maximum

	4/28 (00 GMT)		4/30 (00 GMT)		5/3 (00 GMT)		Measured Maximum (pCi/m^3)		
	Adult Thyroid Dose (mrem)*	Equivalent 24-Hour Air Conc. (pCi/m^3)	Adult Thyroid Dose (mrem)*	Equivalent 24-Hour Conc. (pCi/m^3)	Adult Thyroid Dose (mrem)*	Equivalent 24-Hour Conc. (pCi/m^3)	4/28	4/29	4/30
Poland									
NE	1,000	20,000	2,000	40,000	2,000	40,000	2,000	15,000	14,000
Sweden									
East (Stockholm)	0	0	1,000	20,000	1,000	20,000	300	300	
Gotland							**25,000		
Finland									
Helsinki	0	0	0.01	200	0.06	1,200	16,000	1,000	100

*From Reference 3, 1 mrem ~ 0.01 Sv, 1 pCi/m^3 = 27 mBq/m^3

**Inferred from reported maximum concentration in milk.

TABLE 15B

Comparison of ARAC's Estimated Air Concentrations with Measured Maximum

	4/28 (00 GMT)		5/3 (00 GMT)		Measured Maximum (pCi/cm^3)			
	Adult Thyroid Dose (mrem)*	Equivalent 24-Hour Air Conc. (pCi/cm^3)	Adult Thyroid Dose (mrem)*	Equivalent 24-Hour Conc. (pCi/cm^3)	4/29	4/30	5/1	5/2
Hungary								
Budapest	0	0	30	600				
Czechsolovakia								
Pergve	0	0	50	1,000				
Austria								
Vienna	0	0	100	2,000	800			
Germany								
Munich	0	0	30	600	3,000	3,400		
Julich	0	0	0	0			Avg=500	
Switzerland								
(North)	0	0	30	600			200	
Rumania								
Bucharest	0	0	50	1,000			1,000	
Yugoslovia								
Belgrade	0	0	50	1,000			500	
Italy								
(North)	0	0	50	1,000				1,000

*From Reference 3, 1 mrem ~ 0.01 mSv, 1 pCi/m^3 = 27 Bq/m^3.

TABLE 16

Collective European First Year Population Dose

Country	Population (10^6)*	Estimated Average Dose Equivalent (rem) **	Collective Dose Equivalent 10^6 Person-rem **
Europe			
Poland	35.1	0.030	1.05
Denmark	4.9	0.003	0.01
Sweden	4.2	0.015	0.06
Finland	2.4	0.015	0.04
Norway	2.0	0.003	0.01
Hungary	10.7	0.015	0.16
Czchoslovakia	15.3	0.015	0.23
Austria	7.6	0.015	0.11
South Germany	15.0	0.030	0.45
Switzerland	6.4	0.015	0.10
Rumania	21.6	0.030	0.65
Yugoslovia	20.5	0.030	0.62
Italy	56.6	0.0075	0.42
Greece	9.7	0.0075	0.07
Albania	1.6	0.0075	0.01
TOTAL	173.6	0.023	3.99
AVERAGE			(x 2 = 7.98 ***)

* From Reference 29

** It has been assumed that 1 R ~ 1 rem (1 rem ~ 0.01 Sv).

*** Total Collective Dose based on the assumption that first-year effective dose from ingestion is equal to that from external radiation.

TABLE 17

Estimated Collective Doses from External Irradiation to the Evacuated Population

Area Around Chernobyl NPS	Number of Population (10^3)	Average Dose (rem)*	Collective Dose 106 Person-Rem
Pripyat	45	3.3	0.15
3 - 7 km	7.0	54.3	0.38
7 - 10 km	9.0	45.6	0.41
10 - 15 km	8.2	35.4	0.29
15 - 20 km	11.6	5.2	0.06
20 - 25 km	14.9	6.0	0.09
25 - 30 km	39.2	4.6	0.18
TOTAL	135.0	11.9	1.6

*1 rem ~ 10^{-2} Sv

(From Reference 2)

TABLE 18

Predicted Individual and Collective from External Exposure
to the Population in Regions of the European Part of the U.S.S.R.

Region	Populations Millions	Dose for 1986 Rem/Year*		Collective Dose 10^6 person-rem	
		Rural	Urban	For 1986	For 50 Years
Central Ukranian S.S.R.	13.6	0.270	0.150	2.750	9.31
West Ukranian S.S.R.	8.3	0.067	0.036	0.440	1.47
East Ukranian S.S.R.	14.5	0.077	0.041	0.750	2.52
South Ukranian S.S.R.	14.4	0.045	0.024	0.730	2.47
SE Byelorussian S.S.R.	2.9	0.980	0.520	2.050	6.94
NW Byelorussian S.S.R.	7.0	0.094	0.050	0.470	1.58
Moldavia	4.1	0.084	0.045	0.270	0.92
Bryanskaya Region	1.5	0.500	0.270	0.440	1.49
Kaliningrad Region	0.8	0.012	0.003	0.006	0.02
Kalujskaya-Tulksaya-					
Smolensk Region	4.0	0.120	0.064	0.320	1.08
Lipetsk Region	3.4	0.140	0.075	0.350	1.17
TOTAL AVERAGE	74.5	-	-	8.6 0.115	29.0 0.389

*1 rem ~ 0.01 Sv

(From Reference 2)

TABLE 19

Estimated Doses within Some Populated Areas in the 30 km - Zone Around the Chernobyl Site

Settlement	Distance from Chernobyl Site (km)	Dose-Rate* (mR/hr)**	Dose from Cloud (R)**	Dose to Child's Thyroid (rem)**	7-Day Dose from Deposition (R)**	
					Estimate	Actual
Chistowka	5.5	12.0	10.0	8.4	8.4	3.2
Lelev	9.0	25.0	7.0	17.0	17.0	10.0
Chernobyl	16.0	8.0	1.2	5.6	5.6	3.0
Rudki	22.0	8.0	0.6	5.6	5.6	2.2
Crevichi	29.0	2.5	0.2	1.8	1.8	4.4

*Fifteen days post-accident.

**1 mR/hr ~ 0.01 mSv/hr, 1 rem = 1 Gy, 1 rem ~ 0.01 Sv

(Adapted from Reference 2)

TABLE 20

Comparison of Estimated and Actual Levels of Concentration of ^{131}I in Milk During May 1986 for Ten Regions in the U.S.S.R Subject to the Largest Deposition of Radioactivity Released from the Chernobyl Accident*

Region	Distance-Direction From Chernobyl (km)	Estimated Levels (uCi/l)**	Measured Levels (uCi/l)**
Gomelskaya	160 NE	0.2 - 14	0.02 - 10
Kievskaya	120 SSE	0.06 - 7.3	
Pryarikaya	? ?	0.04 - 5.0	0.02 - 1.3
Zhitomirskaya	150 SW	0.03 - 3.3	
Mosoleysaya	350 SW	0.02 - 2.5	0.02 - 2.0
Orlovskaya	440 ENE	0.02 - 2.3	0.01 - 0.8
Chernogovskaya	90 NNE	0.02 - 2.3	
Tulskaya	580 NE	0.02 - 2.0	0.06 - 6.5
Cherkassyskya	270 SSE	0.01 - 1.5	
Brestskaya	440 WNW	0.01 - 1.3	0.02 - 9.0

*Adapted from Reference 2, Table 7.2.8

**1 uCi/l = 27 kBq/l

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