UNSCEAR 1988 REPORT

ANNEX D

Exposures from the Chernobyl accident

CONTENTS

INTRODUCTION

1. The accident in April 1986 at the Chernobyl nuclear power station in the Union of Soviet Socialist Republics, in which large amounts of radioactive materials were released into the environment, was the most serious to have occurred in connection with the use of nuclear energy to generate electricity. Swift emergency response was required, first of all in the USSR to control and contain the damaged reactor and then, also, in other countries to monitor and evaluate the radiation levels. Because of the attention focused on the accident and its aftermath and the large data base that was accumulated, the Committee has decided to assess in detail the population exposures that resulted from the accident in order to improve the comparability of results between countries and to develop further the methodology for dose assessment from this type of radiation source.

2. The radiation levels from released radionuclides were highest in the immediate vicinity of the reactor. The released radioactive materials affected then mainly the western part of the USSR and the countries of Europe. Extensive measurements have been made in these regions, allowing the radiation doses to the affected populations to be evaluated in some detail. Because the released materials became further dispersed throughout the northern hemisphere, estimates of exposures to populations in other countries have also been made.

3. In presenting the results of the assessment, a short account is given of the conditions under which the accident took place, mainly to convey information that will help to evaluate the radiological impact. General aspects of the dispersion of the released radioactive materials are described. The environmental concentrations and radiation levels encountered are systematically evaluated and then applied in a common methodology for estimating radiation doses.

4. One of the major uncertainties in this dosimetric assessment is that pertaining to projected future exposures from the residual radioactive materials in the environment. Environmental levels and radiation doses continue to be measured, and the Committee plans to use these data to refine the values of the parameters required for the calculations. It will, for example, consider further the regional variabilities due to different meteorological or ecological conditions. Such analyses would greatly help in refining the transfer factors and the models used by the Committee in dose assessments.

5. The Committee has received a great deal of assistance and co-operation from many individuals and organizations in carrying out this assessment. A team of experts was formed in the UNSCEAR Secretariat by staff seconded by the Institute of Biophysics at the Ministry of Health in Moscow, USSR; by the National Cancer Institute and the Department of Energy in the United States, by the Monitoring and Assessment Research Centre in London and the National Radiological Protection Board in the United Kingdom; and by the National Committee for the Research and Development of Nuclear Energy Alternative Energies in Italy.

6. Many countries submitted scientific data either directly to the UNSCEAR Secretariat or to the data bank set up in Vienna by the International Atomic Energy Agency. The UNSCEAR team of experts had free access to this data bank for the purpose of deriving data for the assessment. To obtain additional data, the UNSCEAR Secretariat also maintained frequent and extensive contacts with expert, in various countries and discussed with them the interpretation and evaluation of results. These contacts were so numerous that it would be impossible to acknowledge them separately. They proved essential to the conduct of the project and they are here collectively recognized with appreciation.

7. In approving this Report, the Committee wishes to acknowledge this help and express its gratitude. It would also like to draw attention to and commend the spirit of full collaboration and free exchange of data and ideas between countries, international organizations, laboratories and scientists, which has greatly enhanced the outcome of this study.

I. THE ACCIDENT

8. On 26 April 1986 at 0123 hours local time an accident occurred at the fourth unit of the Chernobyl nuclear power station. The accident destroyed the reactor core and part of the building in which the core was housed. The radioactive materials released were carried away in the form of gases and dust particles by air currents. In this manner, they were widely dispersed over the territory of the Soviet Union, over many other (mostly European) countries and, in trace amounts, throughout the northern hemisphere.

A. THE REACTOR

1. Location

9. The Chernobyl nuclear power station is located in the Ukrainian Soviet Socialist Republic in the western USSR, near the boundary with the Byelorussian Soviet Socialist Republic. It lies about 100 km northwest of Kiev and 310 km south-east of Minsk, on the River Pripyat, which flows

into the Dnieper (Figure I). The nearest boundaries with neighbouring countries, Poland (eastern part) and Romania (northern part), are 450 km away.

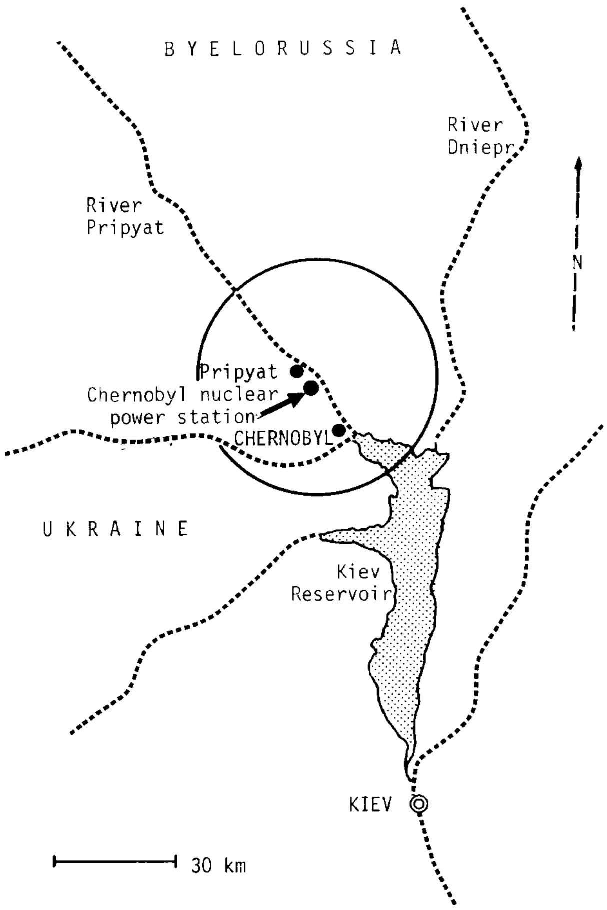

Figure I. The site of the Chernobyl nuclear power station.

10. The eastern Byelorussian-Ukrainian woodlands region is characterized by a relatively flat landscape, with minor slopes down to the river or its tributaries. The soils of the region are mostly soddy-podzolic, distinguished by low natural fertility. They are, as a rule, acid (pH 43-5.5) and have a low content of minerals. The area north of the reactor consists of about 50% agricultural land and 50% natural complexes (forests, bogs, water basins). Ploughed land makes up about half of the agricultural land, with the remainder devoted to natural fodder grasses (cereals and sedge meadows). Dairy and cattle husbandry is well developed in the region. Potato crops occupy 8% of the territory. To the south of the reactor, in the Ukraine, the agricultural use of the land increases, and only 10% of it consists of natural landscapes [I2].

11. The average population density in the region had been approximately 70 inhabitants per km^2 up to the start Of construction work on the Chernobyl power plant. At the beginning of 1986, the total population within an area of 30 km radius around the power plant was approximately 100,000; of this total, 49,000 lived in the town of Pripyat, situated to the west of the plant's 3-km safety zone, and 12,500 in the town of Chernobyl, the regional centre, about 15 km to the south-east of the plant,

12. The construction of the Chernobyl. nuclear power station was carried out in three stages; each comprised two 1,000-MW reactor units. The first stage (Units 1 and 2) was constructed between 1970 and 1977 and the second (Units 3 and 4) was completed in late 1983. In 1981, work was started on two more units of the same type at a site 1.5 km to the south-cast of the existing site [I1].

2. Design characteristics

13. The reactors of the Chernobyl nuclear power station are graphite-moderated, light-water-cooled systems known as RBMK-1000. The installed electrical generating capacity of each unit is 1,000 MW. Each pair of reactors at the station shares a turbine generator room that houses four turbine generators and their associated multiple forced circulation systems. The reactor pairs are located in separate blocks adjoining the central service unit.

14. The core matrix of the RBMK-1000 reactor consists of graphite blocks (250 min × 250 mm, 600 mm high) stacked together to form a cylindrical configuration 12 m in diameter and 7 m high. It is located in a leak-tight cavity formed by a cylindrical shroud, the bottom support structure and the upper steel cover. Apart from the solid graphite blocks forming the radial reflector, each block has a central hole providing the space for the fuel channels or absorber rod channels. There are 1,661 individual vertical fuel channels. Fuel and control rod channels penetrate the lower and upper steel structures and are connected to two separate cooling systems, below and above the core.

15. The fuel, in the form of UO, pellets, is sheathed in a zirconium-niobium alloy. Eighteen fuel pins, approximately 3.5 m long, are arranged in a cylindrical cluster; two of these clusters fit on top of each other into each fuel channel. Fuel replacement is done on-power by a fueling machine located above the core. One or two fuel channels can be refueled each day.

16. The coolant system consists of two loops. The coolant enters the fuel channels from the bottom at 270 °C, heats as it moves upward, and partially evaporates. The mass steam content at the core outlet is approximately 14.5% at full-power operation. The outlet pressure and temperature are 7 MPa (70 bars) and 284 °C. The wet steam of each channel is fed to steam drums, of which there are two for each cooling loop. The dry steam from the drums is fed into one of two 3,000 rpm 500-MW(e) turbine generators. The circulation pumps supply the coolant to headers, which distribute it to the individual fuel channels of the core. In each loop, four pumps are provided, one of which is normally on stand-by during full-power operation. The coolant flow of each fuel channel can be independently regulated by an individual valve to compensate for variations in the power distribution. The flow rate through the core is controlled by feed pumps [I1].

17. Approximately 95% of the energy from the fission reaction is transferred directly to the coolant. The remaining

5% is absorbed within the graphite moderator and mostly transferred to the coolant channels by conduction, which leads to a maximum temperature within the graphite of approximately 700°C. A mixture of helium and nitrogen gases enhances the gap conductance between the graphite blocks and provides chemical control of the graphite and pressure tubes.

18. The Chernobyl Unit 4 reactor had the following principal specifications [I1]:

Thermal power	3,200 MW
Fuel enrichment	2.0%
Mass of uranium in fuel assembly	114.7 kg
Fuel burn-up	20 MW d/kg
Maximum design channel power	3,250 kW
Isotopic composition of unloaded fuel	
U-235	4.5 kg/t
U-236	2.4 kg/t
Pu-239	2.6 kg/t
Pu-240	1.8 kg/t
Pu-241	0.5 kg/t

19. At equilibrium fuel irradiation, the reactor has a positive void reactivity coefficient. However, the fuel temperature coefficient is negative and the net effect of a power change depends on the power level. Under normal operating conditions, the power coefficient is negative at full power and becomes positive below approximately 20% of full power. The operation of the reactor below 700 MW(th) is therefore restricted by normal operating procedures. The radionuclide composition of the Chernobyl Unit 4 core is shown in Table 1.

3. Cause of the accident

20. The accident happened while a test was being carried out on a turbine generator during a normal. scheduled shutdown of the Unit 4 reactor. The test was intended to ascertain the ability of a turbine generator, during station blackout, to supply electrical energy for a short period until the stand-by diesel generators could supply emergency power. Written test procedures that were unsatisfactory from the safety point of view, and serious violations of basic operating rules put the reactor at low-power [200 MW(th)] operation in coolant flow rate and cooling conditions that could not be stabilized by manual control. In view of the design features already mentioned (the positive power coefficient at low power levels), the reactor was being operated in an unsafe regime. At the same time, the operators, deliberately and in violation of rules, withdrew most control rods from the core and switched off some important safety systems [I1].

21. The subsequent events led to the generation of an increasing number of steam voids in the reactor core, which enhanced the positive reactivity. The beginning of an increasingly rapid rise in power was detected, and a manual attempt was made to stop the chain reaction (the automatic trip, which the test would have triggered earlier, had been blocked). However, there was little possibility of rapidly shutting down the reactor as almost all the control rods had been completely withdrawn from the core. The continuous reactivity addition by void formation led to a prompt critical excursion. It was calculated that the first power peak reached 100 times the nominal power within four seconds [I1]. Energy released in the fuel by the power excursion suddenly ruptured part of the fuel into minute pieces. Small, hot fuel particles (possibly also evaporated fuel) caused a steam explosion.

22. The energy released shifted the 1,000-tonne cover plate of the reactor, cutting all the cooling channels on both sides of the reactor cover. After two or three seconds, another explosion occurred, and hot pieces of the reactor were ejected from the damaged reactor building. The damage to the reactor permitted the influx of air, which then caused the graphite to burn.

B. RADIONUCLIDE RELEASE AND DISPERSION

1. Release sequence and composition

23. Damage to the reactor containment and core structures led to the release of large amounts of radioactive materials from the plant. The release did not occur in a single massive event. On the contrary, only 25% of the materials released escaped during the first day of the accident; the rest escaped over a nine-day period. The estimated percentages of various radionuclides released from the total in the inventory are shown in Table 1. Soviet experts were able to reconstruct the overall release process, as shown in the time-dependent release-rate curve in Figure II.

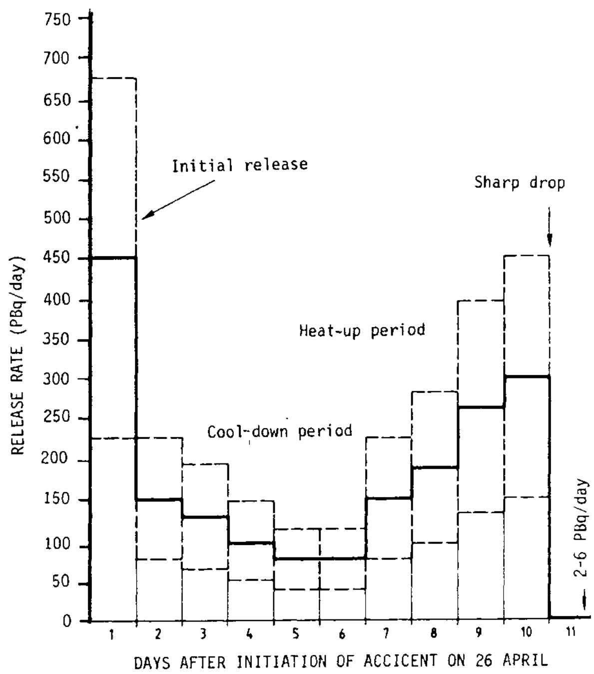

Figure II. Daily release rate to the atmosphere of radioactive materials, excluding noble gases, during the Chernobyl accident. The values are decay-corrected to 6 May 1986 and have a range of uncertainty of ±50% [I1]

24. The release-rate curve may be subdivided into four stages:

(a) The initial release on the first day of the accident. During this stage, the mechanical discharge of radioactive materials was the result of the explosion in the reactor;

(b) A period of five days during which the release rate declined to a minimum approximately six times lower than the initial release rate. In this stage, the release rate decreased owing to the measures taken to fight the graphite fire. These measures, which consisted of dropping about 5,000 tonnes of boron carbide, dolomite, clay and lead on to the core from helicopters, led to the filtration of the radioactive substances released from the core. At this stage, finely dispersed fuel escaped from the reactor directly with a flow of hot air and with the fumes from the burning of the graphite;

(c) A period of four days during which the release rate increased again to about 70% of the initial release rate. Initially, an escape of volatile components, especially iodine, was observed; subsequently, the composition of the radionuclides resembled that in spent fuel. These phenomena were attributed to heating of the fuel in the core to above 2000°C, owing to residual heat release;

(d) A sudden drop in the release rate nine days after the accident to less than 1% of the initial rate and a continuing decline in the release rate thereafter. This final stage, starting on 6 May, was characterized by a rapid decrease in the escape of fission products and a gradual termination of discharges. These phenomena were the consequence of the special measures taken, which caused the fission products to be included in compounds that were chemically more stable.

25. On the basis of radiation measurements and analyses of samples taken within a 30 km radius of the plant and throughout the USSR, it was estimated that materials with activity in the range of 1-2 EBq had been released from the fuel during the accident. An error range of ± 50% has been quoted. These figures do not include the release of the noble gases xenon and krypton, which are thought to have been released completely from the fuel. About 10-20% of the volatile radionuclides iodine, caesium and tellurium and 3-6% of other more stable radionuclides, such as barium, strontium, plutonium, cerium etc., were estimated to have been released (Table 1). The estimate of the ^{137}Cs release is compared in Section V.D. with the amount calculated from estimated deposition in the northern hemisphere. The agreement is reasonable, considering the wide uncertainties associated with both estimates.

26. Only two earlier reactor accidents caused significant releases of radionuclides: the one at Windscale (United Kingdom) in October 1957 and the other at Three Mile Island (United States) in March 1979 [U1]. While it is very difficult to estimate the fraction of the Windscale radionuclide core inventory that was released to the atmosphere, it has been estimated that that accident released twice the amount of noble gases that was released at Chernobyl, but 2,000 times less ^{131}I and ^{137}Cs [D5]. The Three Mile Island accident released approximately 2% as much noble gases and 0.00002% as much ^{131}I as the Chernobyl accident.

27. From the composition of air samples taken during the Chernobyl release and the total release-rate data, tentative isotopic release rates for individual radionuclides were constructed [I1]. These generally follow the pattern of the total release rate (Figure II), with decreasing release rates initially and increasing rates until the end of the release period. Additional information has been presented [I3] that shows changing isotopic ratios during the release period (Table 2); for example, variable ^{131}I relative to ^{137}Cs in initial emissions and higher ^{103}Ru, ^{106}Ru, ^{141}Ce and ^{144}Ce in later emissions. The changing physical conditions and, possibly, the involvement of fuel of varying burn-up may explain these features. The chemical form of the materials released as aerosols was quite variable. The particle size of aerosols ranged from less than 1 micrometre to tens of micrometres.

28. For the region around the Chernobyl site detailed maps of radionuclide deposition could be drawn in 1986 and 1987 based on measurements of external dose rates and analyses of environmental samples [A9, I12]. The pattern of deposition within other regions of the Soviet Union was also established through gamma dose-rate measurements from aircraft and analyses of the radionuclide content of soil samples taken at a limited number of locations. These procedures enabled an estimate to be made of the total amounts of radionuclides deposited in the Soviet Union. This estimate was used in deriving the total amount of radionuclides deposited in the Soviet Union. The estimate was used in deriving the total amount of radionuclides released, as mentioned before. The proportions of the core inventory deposited at various distances from Chernobyl were estimated to be as follows [I1]:

On-site:	0.3-0.5%
0-20 km:	1.5-2%
Beyond 20 km:	1-1.5%

2. Atmospheric transport

29. At the time of the accident, surface winds at the Chernobyl site were very weak and variable in direction. However, at 1,500 m altitude the winds were 8-10 m/s from the south-east. The initial explosions and heat from the fire carried some of the radioactive materials to this height, where they were transported by the stream flow along the western parts of the USSR toward Finland and Sweden. The arrival of radioactive materials outside the USSR was first noted in Sweden on 27 April [D1]. The transit time of 36 hours over a distance of some 1,200 km indicates transfer at an average wind speed of 10 m/s.

30. According to aircraft measurements within the USSR, the plume height exceeded 1,200 m on 27 April, with the maximum radiation occurring at 600 m [I4]. On subsequent days, the plume height did not exceed 200-400 m. The

volatile elements iodine and caesium, were detectable at greater altitudes (6−9 km), with traces also in the lower stratosphere [J1]. The refractory elements, such as cerium, zirconium, neptunium and strontium, were for the most part of significance only in local deposition within the USSR [I3, I4].

31. Changing meteorological conditions, with winds of different directions at various altitudes, and continuing releases over a 10-day period resulted in a very complex dispersion pattern. The plumes of contaminated air that spread over Europe are described in a highly simplified manner in Figure III, along with the reported initial arrival times of radioactive material.

32. The initial plume, depicted as A in Figure III, arrived on 27 April in Sweden and Finland. A portion of this plume at lower altitude was directed southward to Poland and the German Democratic Republic. Other eastern and central European countries became affected on 29 and 30 April (plume B). Activity in air entered north-east Italy during 30 April (also plume B). Central and southern Italy first had evidence of the plume's arrival during the following day. Switzerland reported its first arrival on 30 April. The generally northward flow air across western Europe brought detectable activity to eastern France, Belgium and the Netherlands on 1 May and to the United Kingdom on 2 May. Contaminated air (plume C) arrived in Greece on 2 May in the north and on 3 May in the south [G2]. Airborne activity was also reported in Israel, Kuwait and Turkey in early May [K1, S6, T1].

33. Long-range atmospheric transport spread the released activity throughout the northern hemisphere. Reported initial arrival times were 2 May in Japan, 4 May in China, 5 May in India, and 5-6 May in Canada and the United States [B1, C7, L2, L6, N4]. The simultaneous arrival at both western and eastern sites in Canada and the United States suggests a large-scale vertical and horizontal mixing over wide areas [L2, R8]. No airborne activity from Chernobyl has been reported in the southern hemisphere.

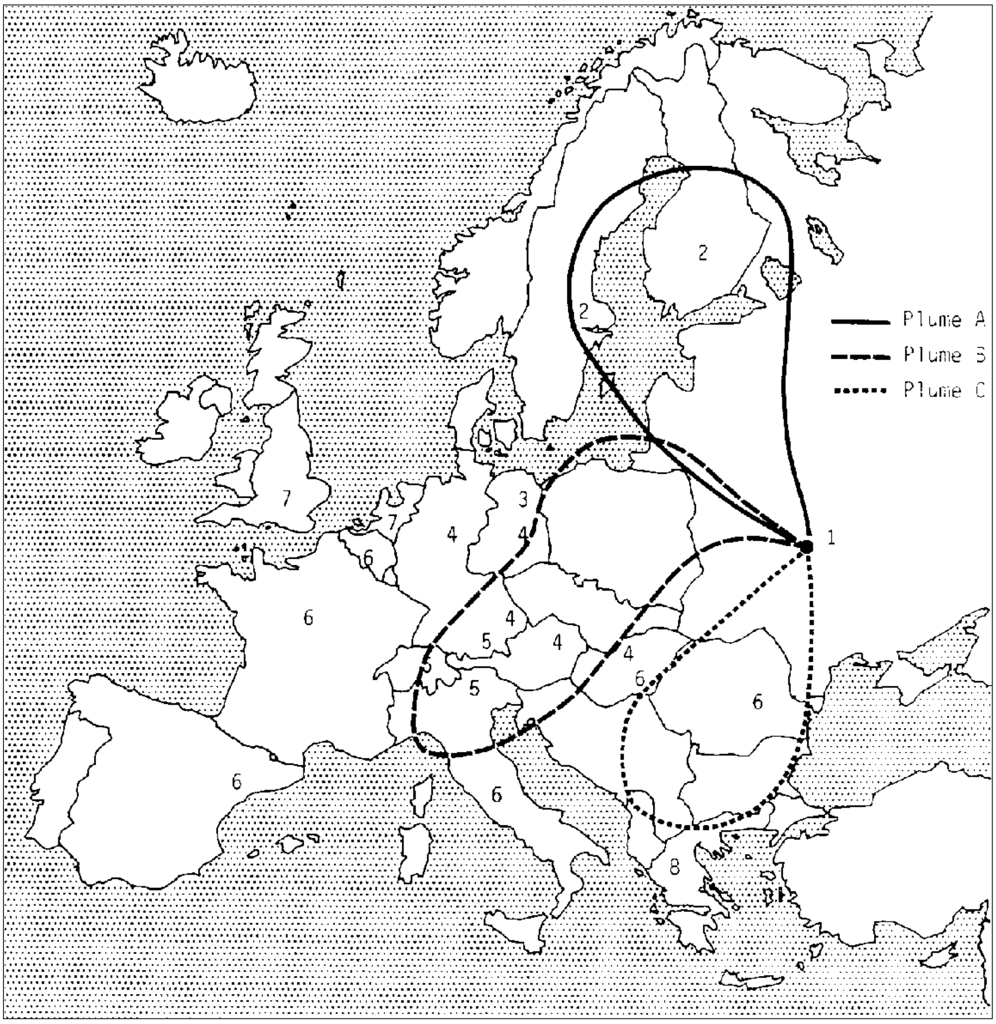

Figure III. Descriptive plume behaviour and reported initial arrival times of detectable activity in air.
Plumes A, B, and C correspond to air mass movements originating from Chernobyl on 26 April, 27-28 April, and 29-30 April, respectively. The numbers 1 to 8 indicate initial arrival times: 1 (26 April), 2 (27 April), 3 (28 April), 4 (29 April), 5 (30 April), 6 (1 May), 7 (2 May), 8 (3 May).

C. EMERGENCY MEASURES

34. After the accident, the first emergency measures taken at the nuclear station were fire-fighting and short-term operations to stabilize the reactor. During the night of 25-26 April 1986, 176 reactor operational staff and workers from different departments and maintenance services were on duty at stages one and two (Units 1-4) of the nuclear power station. In addition, 268 builders and assemblers were at work on the night shift at the construction site of the third stage.

35. Of the on-site personnel and fire-fighters, about 300 had to be hospitalized for burns and the diagnosis of possible radiation injuries. These individuals were observed and given care and, if necessary, specialized treatment. The short-term effects and treatment of radiation injuries caused by the accident are discussed in the Appendix to Annex G, "Early effects in man of high doses of radiation".

36. A system of meteorological and radiological monitoring was organized to survey the contamination levels in the surrounding area. Aerial radiological monitoring was carried out by aircraft and helicopters equipped with air samplers and radiation-detection instruments. On the morning of 26 April, people in the town of Prepaid were instructed to remain indoors and to keep their windows and doors shut. Schools and kindergarten were closed. Late at night on 26 April, radiation levels in Prepaid started rising, reaching about 10 mSv/h on 27 April. It soon became apparent that both the lower intervention level for evacuation (250 mSv whole-body dose) and eventually even the upper intervention level (750 mSv whole-body dose) could be exceeded if the population remained in their homes and no other countermeasures were taken. The evacuation of Prepaid started on the morning of 27 April, after safe evacuation routes had been established on the basis of the first results of radiological monitoring. Provisions were made for decontaminating people's skin and, in some cases, for changing their clothing.

37. In view of the duration of the release of radioactive gases and aerosols from the damaged reactor, it was decided that the accident zone should be further evacuated. As a result of this decision, over 88,000 people, including 21,000 children, were evacuated from the Kiev region and a further 25,000 people, including 6,000 children, were evacuated from the Gomel region of Byelorussia. After the radiation situation had been verified, about 1,000 people were evacuated from the Zhitomir region in the Ukraine and a similar number from the Bryansk region in the RSFSR. The total number of evacuees rose to 115,000. All of these people were medically examined and resettled in neighbouring districts [A9, I12].

38. To prevent the iodine radioisotopes (mostly ^{131}I) present in the plume from accumulating in the thyroid, potassium iodide preparations were distributed to the population in the surrounding zone starting on the morning of 26 April. During the following days, iodine prophylactics were given to 5.4 million people in the USSR, including 1.7 million children [I12, I16].

39. Some tens of thousands of cattle also had to be removed from the contaminated area. Measures were taken to prevent or reduce the contamination of water bodies and ground-water supplies. The extensive environmental radiological monitoring that took place from the very beginning revealed many foodstuffs had been contaminated. On the basis of derived intervention levels for the most important items in the diet, the consumption of locally produced milk and other foodstuffs was banned over a considerable area [I12].

40. According to measured levels of contamination, the area within a 30-km radius of the reactor was divided into three zones: (a) a zone of some 4–5 km around the plant, where no re-entry of the general population is foreseeable in the near future and where no operations other than those required at the installation will be permitted; (b) a 5–10 km zone, where partial re-entry and special operations may be allowed after some time; and (c) a 10–30 km zone, where the population may eventually be allowed to reenter and agricultural activities may be resumed, subject to strict radiological surveillance. Personnel and vehicles are being controlled at the zone boundaries to reduce the spread of contamination.

41. Great effort has been devoted to decontaminating off-site areas. In a 7,000 km^2 area surrounding the reactor, houses and, particularly, public buildings (schools, nurseries, etc.) were repeatedly treated. Houses that could not be brought to acceptable levels and contaminated, old buildings of low value were dismantled and buried. Roads and other contaminated surfaces were covered with asphalt, gravel, broken stone, sand or clean soil, which brought about 10- to 100-fold decreases in gamma dose rates. In contaminated agricultural areas, deeper ploughing was carried out and more mineral fertilizers were added. Grasslands and pastures were also ploughed and reseeded. All of these measures substantially reduced radionuclide transfers and radiation levels.

42. In many countries the countermeasures taken immediately after the accident were effective in reducing individual and collective doses. Thyroid dose equivalents were reduced by 80–90% in the most contaminated region of the USSR. Estimates of the effectiveness of the ^{137}Cs countermeasures in that country varied between 20% and 90%, depending on the level of contamination. In Austria, the Federal Republic of Germany and Norway, doses were reduced between 30% and 50% by countermeasures, and in other European countries they were reduced somewhat less [N5]. These countermeasures were taken into account in the Committee's assessment, as far as possible, by considering the reduction in intakes of contaminated foods.

II. METHODOLOGY FOR THE DOSE ASSESSMENT

A. SCOPE AND APPROACH

43. Since the accident, a sufficient number of measurements have been made to show the basic features to consider in a dosimetric evaluation. The main pathways and radionuclides contributing to doses are external irradiation from deposited radioactive materials (primarily ^{137}Cs in the longer term) and the dietary ingestion of radionuclides (^{131}I in milk and leafy vegetables during the first month and, after that, ^{134}Cs and ^{137}Cs in foods).

44. The inhomogeneous deposition of dispersed materials makes it necessary to take a regional approach to dose calculation. Enough information is available to calculate doses in the most affected region, which includes most of the European countries (some of these countries were further subdivided). The input values for the calculations make full use of measurement results through the first year following the accident. Thereafter, projections are required to estimate future environmental behaviour, primarily of ^{137}Cs, and the continued contribution to dose for a few decades. These projections were made on the basis of long-term observations of global fallout from nuclear weapons testing.

45. It may be instructive to consider the differences between this dose assessment and the previous UNSCEAR dose assessments carried out in connection with nuclear fallout or routine, low-level releases from nuclear fuel-cycle installations; namely, that (a) much of the radioactive debris from nuclear weapons tests in the atmosphere was injected into the stratosphere, from which altitude there was rather more uniform hemispheric deposition over the course of several years. Doses could be assessed on the basis of a latitudinal deposition distribution derived from a relatively small number of measurements and on the basis of transfer factors inferred from measurements in only a few countries. Representative rather than comprehensive results were required. Short-term deposition (local fallout) was largely ignored; its distribution was very uneven and its contributions to the total collective dose commitments were small, and (b) following releases from nuclear installations, environmental concentrations and body burdens are often below the detection limits of the measuring instruments. Doses are calculated using generic source terms characteristic of the particular type of nuclear installation under consideration and using environmental transfer models, the parameter values of which are largely independent of the location of the installation.

46. In the case of the accident at Chernobyl, a different set of conditions prevailed: (a) the release was into the troposphere and took place from a single location at a specific time of year; (b) even so, the duration of the release over several days, the large size of the affected region and changing weather throughout the region resulted in a locally varying deposition pattern; (c) the accident occurred at different stages in the agricultural growing season: in the north of Europe, the season had not yet begun, in the south it was already under way; (d) protective measures varied from country to country; (e) a large number of environmental measurements were made available, providing input data for comprehensive dose assessments.

47. In these circumstances, UNSCEAR was able to perform its dose assessment for the Chernobyl accident in some detail, accounting for regional variabilities but applying uniform calculational methods to achieve comparability of results between countries. The Committee relied as much as possible on measured results and used a general model to project the dose commitment.

48. This report includes estimates of average doses to populations of countries. Occupational exposures are not included, because dose information for workers participating in the restoration work in the USSR is not yet available.

1. Geographic coverage

49. There are practical reasons for considering countries as the basic geographic units: most measurements have been co-ordinated and averaged country by country and much of the secondary data, such as population, food production and consumption. is available only on a similar basis. This approach also allows the Committee to compare its calculations of first-year dose equivalents with the calculations of the individual countries. Dose commitments are then calculated on a regional basis.

50. Although it was the countries of Europe that were most affected by the Chernobyl accident, the radioactive materials became dispersed throughout the northern hemisphere, and so the dose assessment considers the entire hemisphere. It is well established that, for an atmospheric release into the lower troposphere, there is very little transfer of particles from one hemisphere to another. Although there may be some transfer of dose to southern hemisphere residents through imported foods, this increment in the collective dose equivalent can be accounted for by considering total production as well as consumption of foods in the affected regions.

51. Because they were closest to the release point, the countries of northern, eastern and western Europe and the western part of the USSR require the most detailed consideration. It was in these places that deposition was greatest and most non-uniform. In countries further removed from the release point, the more widely dispersed material was deposited with more regional uniformity and was, at any rate, less significant from a dosimetric standpoint.

52. For almost all the countries of eastern and western Europe, enough radiation-monitoring data and other information were available to allow detailed dose calculations for the first year. In so far as was possible,

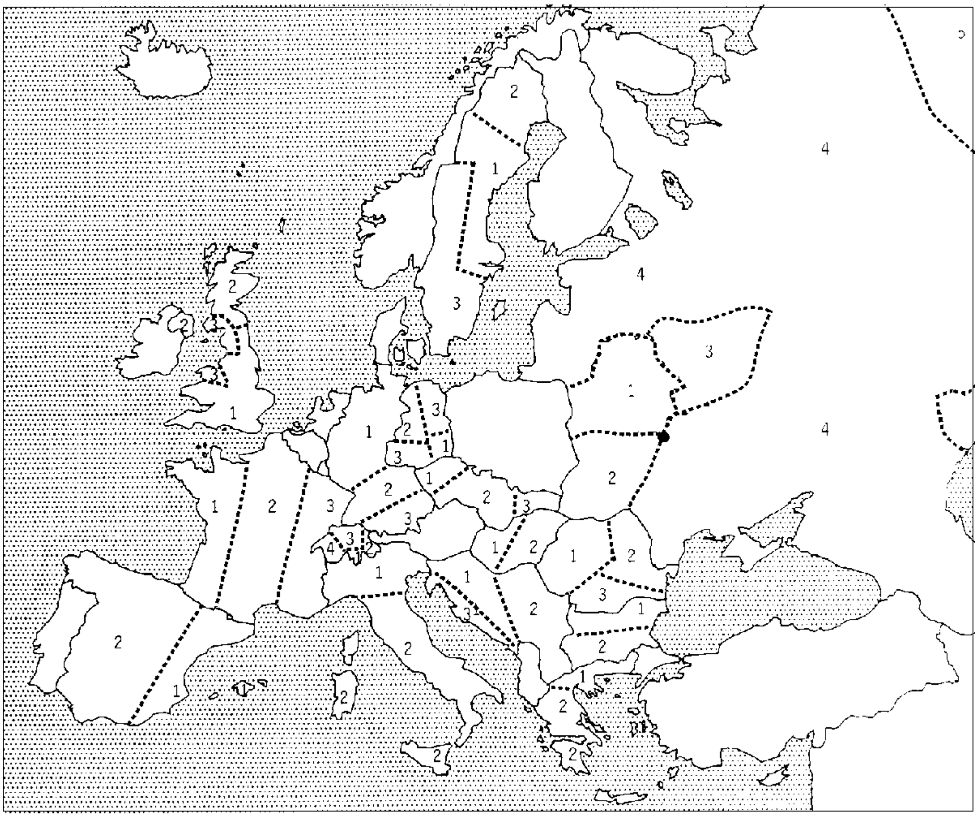

Figure IV. Division of Europe by country, or by subregions within countries, for purpose of the dose assessment.

each country was considered as a single geographic unit. However, to avoid averaging wide-ranging dosimetric data, several countries were subdivided. These geographical breakdowns within the various countries of Europe are indicated in Figure IV. For the calculation of dose equivalent commitments, countries were combined into broad geographical regions.

53. In Asia and North America, only low levels of radioactivity could be detected. The approximate dose estimates for some countries in these regions have been extrapolated to obtain estimates for larger geographic areas. Although they were not significantly affected by the airborne transport of radioactive materials from the accident, other developing countries have been concerned about the possible contamination of imported foods. Further, the accident has prompted several countries to engage in activities to evaluate and assess immediate and late effects of this and other possible accidents. It is clear that international agencies must become involved in the training of scientists and technicians; the procurement of equipment; the development of simplified techniques for measurement and assessment; and procedures on which to base setting of restrictions on imports of contaminated foods.

2. Pathways

54. There are two primary pathways to be considered in this dose assessment: (a) external irradiation from radioactive materials deposited on the ground and (b) ingestion of contaminated foodstuffs. Two secondary pathways have been considered as well, since the concentrations of radionuclides in air, on which they depend, have been generally available: (a) external irradiation from radioactive materials present in the cloud, referred to as "cloud gamma", and (b) inhalation of radionuclides during passage of the cloud. The inhalation pathway can, in fact, be important right after an accident and if people are subsequently evacuated and received no further exposure, it can turn out to have been the most important pathway.

55. Some data available from different countries show a small amount of resuspension of the deposited material that led to measurable concentrations in air some weeks or months after the accident. The contribution of resuspension to further inhalation doses is considered to be small in comparison to that of the other exposure pathways.

56. The pathways of cloud-gamma exposure and inhalation of radionuclides are effective only for the short period before the airborne material has been deposited. Transfers along the two primary pathways continue for a length of time that depends on the half-lives of the radionuclides, some tens of days for ^{131}I , for example, and some tens of years for ^{137}Cs.

57. For the ingestion pathway, only the basic food items have been considered: milk products, grain products, leafy vegetables, other vegetables and fruit, and meat. Those five categories are sufficient to account for the food ingestion of most individuals. Radionuclide uptakes in other foods, such as mushrooms and lake fish, have been noted. Although these other foods may be important for some consumers,

they, like other possible, but minor, pathways, have little effect on collective dose estimates.

3. Radionuclides considered

58. Only ^{131}I, ^{134}Cs and ^{137}Cs, the most important contributors to the total dose, have been considered systematically by the various countries. Other radionuclides (^{95}Zr, ^{103}Ru, ^{106}Ru, ^{132}Te, ^{140}Ba and ^{141}Ce) were reported in air or deposition. Several of the latter were important short-term contributors to external irradiation from deposited material; when not measured directly, they may be accounted for by scaling to ^{137}Cs or ^{131}I deposition. The long-lived radionuclides ^{3}H, ^{14}C, ^{85}Kr and ^{129}I are discussed later. They, too, are but minor contributors to the total dose.

4. Doses evaluated

59. The assessment of doses has two components: (a) the committed dose equivalents resulting from exposures and intakes during the first year following the accident and (b) the collective effective dose equivalent commitment due to the accident. In assessed countries and subregions, estimates are made of the first-year effective dose equivalent, i.e. the dose received in the first year from external irradiation and the dose committed from first-year inhalation and ingestion of radioactive materials. First-year dose equivalents to the thyroid of adults and one-year-old infants are also estimated.

60. The evaluations of dose for the first year reflect as nearly as possible the prevailing conditions, taking into account not only measured values but also shielding and occupancy factors and protective measures. The recently observed and reported reduction in exposure levels in urban areas as a result of runoff has been incorporated into the dose models. Other factors are introduced and described along, with the calculational methods.

61. The second component of the dose assessment is the collective effective dose equivalent commitment, which requires projection of doses to be received in the future from deposited materials. For this purpose the models developed by the Committee for estimating dose commitments from fallout have been used. Because the parameters for these models were obtained by averaging results from widely separated regions, wider groupings of countries have been selected to reflect regional deposition patterns. The dose commitments have been evaluated for each large region and used for calculating the collective dose commitment. The estimates are based on both consumption and production of foods.

B. CALCULATIONAL METHODS FOR FIRST-YEAR DOSES

62. For the most part, the calculations simply involve multiplying integrated concentrations by dose factors, with reduction factors taken into account. The integrated concentrations in food are derived, where possible, from measurements through the first year following the accident. To supply missing data, use is made of ratios to other measurements or to "default" values, which are values derived from measurements at other sites or averaged from representative results from neighbouring locations. The methods for each pathway are described below.

1. External irradiation during cloud passage

63. During a very brief period, usually only hours but sometimes a few days, the passing cloud of contaminated air exposes people to external irradiation. This exposure is referred to as cloud-gamma irradiation. Although this exposure rate could in theory be measured directly, in practice it is not possible to distinguish this component from radiation caused by deposited activity on the ground. The doses from cloud-gamma exposure can be easily calculated from measured air concentrations. The equation for radionuclide i is

$$H_{E,c}(i) = C^*_a(i)\ \Phi_c\ (1-F_0) + C^*_a\ \Phi_c(i)\ F_0F_s$$

where $H_{E,c}$ (i) is the cloud-gamma effective dose equivalent (Sv); $C^*_a(i)$ is the integrated concentration in outdoor air (Bq d/m^3); $\Phi_c(i)$ is the effective dose equivalent factor per unit integrated air concentration (Sv per Bq d/m^3); F_0 is the indoor occupancy factor (the fractional time spent indoors); and F_s is the building shielding factor (the ratio of indoor to outdoor dose rates).

64. The first term in the equation is the outdoor component of effective dose equivalent and the second term is the indoor component. An additional small component of dose from contaminated air indoors has been neglected in this calculation. The effective dose equivalent factors have been derived for uniform semi-infinite cloud geometry. A list of effective dose equivalent factors is given in Table 3. The same values are assumed to apply to both infants and adults.

65. For the calculations here, an indoor occupancy factor of 0.8 and a building shielding factor of 0.2 have been used for all countries. The values of these factors had been previously used by the Committee [U1, U2]. It is to be noted, however, that measurements as well as calculations of the shielding factor afforded by buildings show a large range of variation depending on the kind of building: from 0.0 1 to 0. 1 for multi-storey buildings and from 0.1 to 0.7 for single-family houses in Sweden [C25], while in Norway the mean shielding factor of houses was reported as 0.5 during the first month and 0.29 during the sixth month following the accident [S14]. For typical European houses, calculations for ^{137}Cs deposition yield values of 0.44, 0.084, and 0.0063 for the ground floors of prefabricated, semi-detached, and multi-storey houses, respectively [M8].

66. To calculate cloud-gamma (and also inhalation) doses, it is necessary to know the integrated concentrations in air of many short-lived radionuclides. In some countries, complete data were available. In others, only one or a few

radionuclides were reported, so concentrations of other radionuclides were inferred from ratios measured in nearby countries. In a few cases, no measured air concentrations were available, so the integrated air concentration of ^{137}Cs was inferred from its ground-deposition density and a nominal quotient of ground deposition to integrated air concentration of 1,000 m/d; the integrated concentrations of other radionuclides were then inferred from ratios to ^{137}Cs measured at nearby locations.

2. Inhalation

67. Contaminated air is inhaled during the short time that the radioactive materials remain airborne. This is a straightforward calculation from measured integrated concentrations in air. The equation for radionuclide i is:

$$H_{E,h}(i) + C^*_a(i)\ B\ \Phi_h(i)\ (1-F_0) + C^*_a(i)\ B\ \Phi_h(i)\ F_0\ F_r$$

where $H_{E,h}(i)$ is the inhalation effective dose equivalent (Sv); $C^*_a(i)$ is the integrated concentration in outdoor air (Bq d/m^3); B is the breathing rate (m^3/d); $\Phi_h(i)$ is the dose per unit intake from inhalation (Sv/Bq); F_0 is the indoor occupancy factor; and F_r is the indoor air concentration reduction factor (the ratio of indoor to outdoor air concentrations).

68. The first term is the outdoor component and the second term is the indoor component. The breathing rates are taken to be 22 m^3/d for adults and 3.8 m^3/d for infants [I6]. Indoor occupancy is the same as in the previous calculation. Air concentrations are assumed to be lower indoors due to filtration effects. For all countries, the value of the indoor air concentration reduction factor is taken to be 0.3. Experiments in Finland and Norway showed a range of values, from 0.23 to 0.47, for this factor [C23]; in Denmark they ranged from 0.1 to 0.5 [R9]. Calculations have been made both for the thyroid and for the effective dose equivalents. This calculation also depends upon data of integrated concentration in air with ^{131}I being of particular importance. Such data were inferred where needed as discussed under the section above. Dose equivalent factors are listed in Table 4.

3. External irradiation from deposited material

69. External irradiation from radioactive materials deposited on the ground makes a significant contribution to the total dose equivalent. During the first month after deposition, a number of short-lived emitters, including ^{132}Te, ^{132}I, ^{131}I, ^{140}Ba, ^{140}La and ^{136}Cs, were important components of the total external gamma exposure rate. For several months, ^{103}Ru and ^{106}Ru made contributions, but since then only ^{134}Cs and ^{137}Cs have been of significance. External gamma exposure rates will remain elevated for some years due to ^{134}Cs and for some tens of years due to ^{137}Cs.

70. Calculation of the effective dose equivalent from external irradiation from deposited material proceeds in two steps: the exposure in the first month is considered separately from exposure in subsequent months.

(a) During the first month

71. The outdoor exposure X_1 (C/kg) during the first month was assessed by four different methods, with the choice dependent upon the data available. If continuous or daily data were provided, the exposure rates were integrated. If incomplete data were provided, an attempt was made to fit a power function of the form at^b to the data, where t is time (days) and a and b are constants to be determined. X_1 is then the integral of this function from arrival day 1 to day 30.

72. If measurements of external gamma-exposure rate were not available, two approaches were used. If data on the ground deposition of the radionuclides were provided, the exposure rate from each was computed using the factors published by. Beck [B10] for a relaxation depth of 0.1 cm. The term relaxation depth follows from the assumption that the activity mass concentration S(z) of a radionuclide decreases exponentially with depth z in soil:

$$S(z) = S(0)\ e^{-az}$$

and the relaxation depth is defined by a^{-1}. In this case. X_1 was evaluated as the sum of the integrated exposure rate from each radionuclide.

73. In several cases, only data on the deposition of ^{137}Cs were available, and X_1 was evaluated on the basis of the relationship of the exposure to ^{137}Cs deposition density as measured at a specific location, e.g. Neuherberg, Federal Republic of Germany [G1].

74. The effective dose equivalent during the first month was calculated from X_1 by:

$$H_{E,e1} = AX_1\ (1 - F_o) + AX_1\ F_o\ F_s$$

where $H_{E,e1}$ is the effective dose equivalent from external exposure during the first month (Sv), A is the conversion factor (23.6 Sv per C/kg, i.e., 33.7 Gy per C/kg × 0.7 Sv/Gy), F_o is the indoor occupancy factor and F_s is the building-shielding factor. The values of the latter two factors are 0.8 and 0.2, the same as used for the calculation of effective dose equivalent from cloud-gamma irradiation.

(b) After the first month

75. The calculation of external gamma dose beyond one month is based on the measured total deposition of ^{134}Cs and ^{137}Cs and, although less important, ^{103}Ru, ^{106}Ru and ^{131}I. The conversion factors for long-term deposition to dose rate depend on the penetration of these radionuclides in soil. Change with time is accounted for by using factors appropriate for a relaxation depth of 1 cm during the first year and 3 cm thereafter. The latter value had been previously used by the Committee for its assessment of doses from nuclear weapons fallout [U1, U2].

76. Following the deposition of radioactive material from the Chernobyl accident, several groups observed that the measured external gamma exposure rate decreased more

rapidly over urban surfaces than over grass surfaces [J2, K6, S18]. Although varied, these results are consistent with the loss of half of the material with a half time of 7 days and the other half being firmly fixed on urban surfaces. This urban runoff effect has been reflected in this assessment by applying these factors to that portion of a country's population considered to be urban.

77. The equation for the calculation of external gamma effective dose equivalent for the time period between one month and one year for radionuclide i is

$$H_{E,e2}(i) = [F(i) / \lambda(i)]\ [\Phi_{e2}(i)\ (e^{-\lambda(i)1a/12} - e^{-\lambda(i)1a})]$$
$$[1 - F_o\ (1 - F_s]\ [1 - F_p\ (1 - F_u)]$$

where $H_{E,e2}(i)$ is the external gamma effective dose equivalent for the time from one month to one year (Sv); F(i) is the deposition density (Bq/m^2); $\Phi_{e2}(i)$ is the deposition density to effective dose equivalent conversion factor during the period between one month and one year (relaxation depth of 1 cm) (Sv per Bq /m^2); $\lambda(i)$ is the radioactive decay constant (a^{-1}); F_p is the urban fraction of a country's population; F_u is the fraction of the deposition that remains fixed on urban surfaces (assumed in this Annex to be equal to 0. 5) and F_o and F_s are as previously defined.

78. The equation applies to the period between 30 days and 1 year. The overall reduction for occupancy and shielding of buildings is 0.36 and the reduction for urban areas is 0.75 with the assumed parameters. The proportion of populations living in urban and rural areas is given in national statistical reports. The urban proportion is around 80% in most European countries, according to the various definitions of urban areas. However, as urban populations also include people living in suburban locations, the urban fraction (F_P), for purposes of this calculation, was assumed not to exceed 0.5. Effective dose equivalent conversion factors are listed in Table 5.

79. Data were available from almost all countries in Europe and elsewhere on the deposition of ^{137}Cs. If data were not reported for ^{134}Cs, a measured ratio in air was used, or a nominal ratio of 0.5. Data were also typically available for ^{131}I, but if not, deposition "as inferred based on ratios measured on airborne particles or ratios of deposition in nearby countries. Data on ^{103}Ru and ^{106}Ru were available from about half of the countries; if they were not, the calculations were made on the basis of the ratio to ^{137}Cs measured in air or deposition in nearby countries.

4. Ingestion

80. The ingestion of radionuclides in foods is a second primary pathway for radiation doses. As determined by an initial sensitivity analysis, only the radionuclides ^{131}I, ^{134}Cs and ^{137}Cs make significant contributions and need be considered. The dose estimation is based on measured or inferred concentrations during the first year, but projections are required to take account of caesium transfer in future years.

81. The food categories considered include milk and milk products, grain products, leafy vegetables, other vegetables and fruit, and meat. The occurrence of ^{131}I in foods was of significance only for milk and milk products and leafy vegetables, with the exception of high relative values reported for the radish in Japan [N4]. Root vegetables and fruits were, in general, less affected, and they have been considered together. An integrated food concentration (Bq a/kg) has been calculated or inferred for each food category; it is based on all types of individual foods to the extent data were available, weighted by consumption amounts. For example, the concentration for meat was calculated on the weighted average concentration in beef, pork, lamb, poultry, game and fish. Similarly, the concentration in milk products was calculated as a weighted average of the concentration in milk (of cows, sheep and goats), cheese, butter etc.

82. Food consumption by adults has been taken from national estimates or from data tabulated by the United Nations Food and Agriculture Organization [F10]. There are substantial variations in these values from country to country. National consumption estimates for infants were more variable than would be reasonable, probably because different age groups were considered. Accordingly, consumption estimates for infants up to one year old were standardized and used uniformly in calculations for all countries: milk products, 200 kg/a; grain products, 20 kg/a; leafy vegetables, 5 kg/a; vegetables/fruit, 15 kg/a; and meat, 5 kg/a.

83. Doses from ingestion of contaminated foods are calculated simply as the product of integrated concentrations in foods during the first year (from the beginning of May 1986 to the end of April 1987), consumption amounts and dose equivalent factors. The integrated concentrations are summations of measured values averaged over the regions considered. In some cases, extrapolations were required to complete the full year of data.

84. If countermeasures were known to have been taken in different countries, the effects were included in the integrated concentrations in foods. For example, Austria banned leafy vegetables, so the concentration of ^{131}I in leafy vegetables is given as 0.0 [M3]. In other countries, foods with radionuclide concentrations above certain limits were withheld from markets; any reported concentrations in foods above that limit were therefore, disregarded.

85. Nearly all countries reported measurements of ^{131}I in milk and leafy vegetables. Levels of ^{134}Cs and ^{137}Cs were usually reported for milk and leafy vegetables. The reporting of concentrations in grain, meat and other vegetables and fruits was more limited. Methods of inferring concentration varied depending upon what other data had been reported and the general relationships among food categories deduced previously [U1]. The concentration of ^{134}Cs or ^{137}Cs, if necessary, was typically inferred using a first-year transfer factor. Specific values varied from region to region. As an example, ^{137}Cs in meat

was estimated from ^{137}Cs deposition using a first-year transfer factor of 3-4 Bq a/kg per kBq/m^2, in some west European countries; in others, it was inferred from a ratio of integrated concentrations of meat to milk of 2-3. The concentration in other vegetables and fruits was similarly deduced using a transfer factor of 0.8-1.6 Bq a/kg per kBq/m^2 or by using a ratio of 0.3 for integrated concentration relative to milk. Grain presented a special difficulty because measurements were lacking and because some data showed a very strong effect of time of contamination before harvest, as noted earlier by Aarkrog [A4]. A more complete discussion of how concentrations in grain were calculated is provided in the next section.

86. The equation for this part of the ingestion pathway calculation for food category g and radionuclide i is

$$H_{E,g1}(i) = C^*_g(i)\ I_g\ \Phi_g(i)$$

where $H_{E,g1}(i)$ is the effective dose equivalent from first-year ingestion of food group g (Sv); C^*_g (i) is the weighted integrated concentration in food group g (Bq a/kg); I_g is the consumption rate for food group g (kg/a); $\Phi_g(i)$ is the effective dose equivalent per unit intake from ingestion (Sv/Bq). Summation is required over the relevant food categories for the total dose equivalent from each radionuclide. Values of the dose factors are listed in Table 6. Specific values of consumption rates are taken as reported by the individual countries or as derived from FAO data [F10].

87. The dose assessment for the first year after the Chernobyl accident depends on the use of measured concentrations of radionuclides in foodstuffs. Such concentrations are assumed to represent consumption-weighted averages for the area concerned. Reliable estimates of such averages depend on systematic sampling plans specially designed for this purpose. For some types of foodstuffs, the prime example being dairy milk, it is relatively easy to achieve reasonably reliable estimates, because a measurement on a single sample can be assumed to typify both a large production area and a large consumer group. For other dietary components, reliable estimates necessitate both large numbers of samples and well-designed sampling plans. This is especially the case when there has been both small-scale and large-scale variability of the deposition density, as was the case after the Chernobyl accident.

88. After the Chernobyl accident, the affected countries started sampling and measurement programmes. These programmes were in many cases control programmes, designed to assure that foodstuffs contaminated above a particular level did not reach consumers. Such programmes are often characterized by, a planned or unplanned bias, such that sampling is concentrated in areas where high contamination levels are suspected. The average calculated from such programmes therefore tends to overestimate consumption-weighted averages, and there is little possibility of correcting afterwards for a bias of this kind.

89. For the long-lived caesium isotopes, there will be a time-averaging that results in less variability for contamination levels in such foodstuffs as milk, green vegetables and meat. Since the short half-life of ^{131}I precluded such averaging, the estimated average levels must in many cases be regarded as tentative.

C. CALCULATIONAL METHODS FOR PROJECTED DOSES

1. External irradiation

90. External exposure from radioactive materials deposited on the ground was evaluated by the following equation:

$$H_{E,e3}(i) = [F(i) / \lambda(i)]\ [\Phi_{e3}(i)\ e^{-\lambda(i)1a}]$$
$$[1 - F_o\ (1 - F_s)]\ [1 - F_p\ (1 - F_u)]$$

The symbols were defined in paragraph 77. The deposition density to effective dose equivalent factor, Φ_{e3},(i), to be used beyond one year after deposition, uses a relaxation depth of 3 cm, as has been assumed previously in UNSCEAR assessments. Values of this factor are listed in Table 5.

2. Ingestion

91. Projections are required to estimate ingestion doses beyond the periods for which measurements are available. Over many years, a deposition-diet transfer model has been developed and used by the Committee to describe the behaviour of fallout radionuclides, ^{90}Sr and ^{137}Cs, in the environment and to estimate dose equivalent commitments [U1]. The basic transfer relationship for radionuclide i and for food category g of the weighted diet total is:

$$C^*_g(i) = P_{23}(g,i)\ F(i)$$

where $C^*_g(i)$ is the integrated concentration in food over all time (Bq a/kg); $P_{23}(g,i)$ is the transfer factor from deposition density (compartment 2) to food or total diet (compartment 3) (Bq a/kg per Bq/m^2); and F(i) is the total deposition density (Bq/m^2).

92. The values of deposition density and concentrations in food have been determined on an annual basis and the parameters in the transfer function evaluated by regression fitting. The model for the transfer function is

$$P_{23} = b_1 + b_2 + b_3\ e^{-\lambda t}$$

where b_1 is the component of first-year transfer; b_2 is the second-year transfer; and $b_3\ e^{-\lambda t}$ is the subsequent transfer (the latter accounts for both environmental loss and radioactive decay). This model was developed for the rather more uniform and continuing deposition pattern of radioactive fallout from atmospheric nuclear weapons testing. Thus it is not specifically intended to predict time-integrated concentrations in foods in specific countries for a release such as that which occurred from the Chernobyl reactor. However, in so far as seasonal and local conditions are largely accounted for by direct measurements of the first year, the model may be applied to obtain projected behaviour for the second year and beyond over large areas, such as groups of countries. The part of the transfer function that accounts for the time-integrated concentrations beyond the first year, the second and third terms, is referred to as $P_{23,2+}$:

$$P_{23,2+} = b_2 + b_3\, e^{-\lambda t}$$

93. Detailed evaluation of the P_{23} factor for ^{137}Cs for all food categories is available from fallout measurements in Denmark and Argentina, reported in [U1]. A similar analysis has been made for Chicago in the United States [E7]. The values of these parameters are listed in Table 7. The three locations are far apart, and the results show some of the variability that can be expected as a result of different soil types, agricultural practices and other local conditions. These results have been combined and the averaged values of $P_{23,2+}$ used in the dose calculations for all food categories except grain products.

94. A separate assessment is required for grain products, whose contamination has been shown to be very dependent on the maturity of the plant [A4, C13]. Contamination by root uptake is negligible in comparison to contamination by direct deposition, as is generally the case for any vegetable product. Under controlled conditions, the transfer of caesium to grain has been studied in relation to time of harvest [A4]. Uniform deposition to a test area of a barley field three months before harvest resulted in a 100-fold lower concentration in grain than applications two months before harvest. There was little difference in transfer for applications at other times within two months of harvest.

95. Grain is usually harvested in the summer months and later processed into flour and bran or used as animal feed. The transfer factors from grain to bread or other products for human consumption and the composition of grains in the consumed products have been reported for Denmark [A5].

	Transfer from grain to bread	*Percentage of grain consumption*
Rye	1	36
Wheat	0.5	55
Oats	0.5	9

Applying these factors to the measured ^{137}Cs activity mass concentrations in grains harvested in 1986 results in P_{23} transfer factors of 0.5 Bq a/kg per kBq/m^2 in Finland; 0.25 in Norway, 3.3 in Denmark, 4 in France, 4.5 in Czechoslovakia and 16 in Japan. The average P_{23} for grain products delivered after the atmospheric testing of nuclear weapons was 15 Bq a/kg per kBq/m^2 (Table 7). The latitudinal dependence of the Chernobyl contamination reflects the different stages of grain maturity at the time of the accident. Where grain contamination is not reported for a particular country, values of P_{23} for grain products have been assumed to be 0.5 Bq a/kg per kBq/m^2 for latitudes above 55°N, 5 for temperate latitudes (40-55°N), and 20 for latitudes below 40°N. Higher values are not likely because the grain at latitudes below 40°N was about to be harvested when the contamination occurred.

96. Assuming that the grain products derived from a given summer harvest are available from November of that year to November of the following year, the grain contaminated by the deposition in May 1986 can be considered to have been distributed for six months (November to April) during the first year after the accident and for six months during the second year, so that $b_1 = P_{23}/2$ and $P_{23,2+} = P_{23}/2$.

97. Estimates of projected doses from the ingestion pathway are obtained by multiplying the factor $P_{23,2+}$ by the deposition in the region, the consumption rate and the dose per unit intake from ingestion:

$$H_{E,g2}(i) = P_{23,2+}(g,i)\; F(i)\; I_g\; \Phi_g(i)$$

where $H_{E,g2}(i)$ is the effective dose equivalent from ingestion of radionuclide i in food group g beyond the first year (Sv); $P_{23,2+}(g,i)$ is the deposition density to diet transfer factor; F(i) is the total deposition density (Bq/m^2); I_g is the consumption rate (kg/a), and $\Phi_g(i)$ is the effective dose equivalent per unit intake (Sv /Bq).

98. Collective dose estimates are made for each pathway by multiplying doses by the relevant population of each region. For the ingestion pathway two estimates are made; namely, (a) a consumption-based estimate, whereby the intake per individual is multiplied by the number of individuals and (b) a production-based estimate which is derived from the country's total production. The estimates are usually in fairly close agreement, certainly within the uncertainty of the two methods. The production-based estimates account for any additional collective dose outside the country if large amounts of food are exported.

99. Countries were grouped together, and population-weighted values of deposition density and transfer factors were used in evaluating the collective effective dose equivalent commitments.

III. EVALUATED INPUT DATA

100. Following the Chernobyl accident, extensive national monitoring programmes were undertaken to determine the extent and degree of contamination from the radionuclides released and to evaluate the need for countermeasures. Continued measurements in many countries of the environmental levels and of concentrations in the diet and in the human body provide a basis for evaluating the radiation exposures.

101. The material in this Chapter is not intended to document the many results obtained; rather, it comprises, in summary form, the representative input data required for the dose calculations. In most cases, these data are the first-year integrated concentrations for each country or subregion. Relationships between integrated quantities have been used to check the consistency of the results and to form the basis for estimates where data are incomplete or missing, as indicated in the previous Chapter. The input data used in the dose assessment are presented in tabular form, and measured and inferred data are carefully distinguished.

102. Various types of input data are required to complete the dose calculations. These include non-radiological data, such as population, area, food production and consumption, and radiation data, such as integrated concentrations in air and foods and deposition densities. The values of the non-radiological parameters for each country or subregion are listed in Table 8. Food-production estimates, when not reported directly by countries, were obtained from reports of the Food and Agriculture Organization of the United Nations [F10, F11], adjusted to reflect food-use amounts by accounting for feed and non-food processed amounts. Other sources for non-radiological data included publications of the United Nations and European and other regional publications [E4, E5, E6, P5, U3].

103. It has not been possible to substantiate fully all of the reported radiation measurement results. In selecting representative values for specific regions, considerable care and judgement are required. Although scientists in each country were asked to review the input data, some inconsistencies and questionable values remain. However, these should not affect the more general results of the assessment.

104. The sources of radiological data have been numerous; some of the data was obtained directly from scientists in the relevant countries and some of it came from published reports. The references for the countries are as follows: North Europe: Denmark [A3, R1, R2]; Finland [A8, F1, I14, I15, N6, P1, R3, R7, R10, R11, R12, R13, S22, S23, S24, S25, S26, S27]; Norway [B4, B5, S14, S15, W3]; Sweden [A6, E1, E8, F4, F5, F6, H5, K2, K3, K6, L3, S1, S8, S9, S13]; Central Europe: Austria [A1, B7, D2, F7, K7, M3, O1, S18, S19, S20]; Czechoslovakia [B12, I11, M7, M9]; German Democratic Republic [L1], Federal Republic of Germany [B13, D4, D6, G1, I10, J5, K4, S2, S16, W2, W4]; Hungary [A2, B9, H1, H4, S7]; Poland [C1, C2]; Romania [R6]; Switzerland [B2, B3, C14, H2, P2, S12, V2, W2]; West Europe: Belgium [C10, G4, S4, S5]; France [C5, C21, C22, D3, L5, S3, S17, S21]; Ireland [C9]; Luxembourg [C10, S4, S5]; Netherlands [C8, C26]; United Kingdom [C3, C11, F2, F3, F12, M2, W1]; South Europe: Bulgaria [C4, P4]; Greece [G2, G3]; Italy [C15, C16, C17, C18, C19, C20, E2, M4, M5, M6, R4, R5]; Portugal [L4]; Spain [C6, G5, G6]; Yugoslavia [F8, F9, I7, I8, J3]; USSR: [A9, I1, I2, I3, I4, I12, I13, I16, P6, U5, U6]; West Asia: Cyprus [C12]; Israel [S6]; Syrian Arab Republic [S11]; Turkey [T1, T2]; East Asia: China [B8, C24, L6]; India [B1]; Japan [A7, N2, N4, S10]; North America: Canada [C7, R8]; United States [D5, E3, U4].

A. AIR

1. Radionuclide composition

105. Radionuclides in air, identified by filter sampling. were predominantly volatile elements (iodine, caesium, tellurium) rather than non-volatile ones. The radionuclides detected by gamma spectrometry included ^{99}Mo, ^{99m}Tc, ^{103}Ru, ^{127}Sb, ^{129}Te, ^{132}Te, ^{131}I, ^{132}I, ^{133}I, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{140}Ba, and ^{140}La. Some additional radionuclides (^{95}Nb, ^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{129m}Te, ^{141}Ce, ^{144}Ce) could be detected only after the decay of interfering gamma lines.

106. Other radionuclides in air were determined by beta or alpha spectrometry. Strontium radionuclides were present in low concentrations, the ^{137}Cs/^{90}Sr ratio being approximately 110 to 1 as measured at Munich-Netiherberg and the ^{89}Sr/^{90}Sr ratio about 10 to 1 (on 1 May). Transuranic elements were estimated to be present on 1 May at concentrations of 130 μBq/m^3 (^{238}Pu), 200 μBq/m^3 (^{239,240}Pu) and 1,500 μBq/m^3 (^{242}Cm) [W4]. Other radionuclides assumed to have been present but which were below the detection limits were ^{129}I and ^{14}C [W4]. The noble gases ^{85}Kr and ^{133}Xe were detectable in air, as was ^{3}H in rain water.

107. The composition of iodine activity in air at the Munich site on initial arrival was found to be 40% aerosol form, 35% elemental gaseous form and 25% organically bound; however, these fractions changed somewhat in subsequent days as rainfall depleted the aerosol and elemental forms more than the organic form (Figure V) [W4]. The particulate iodine fraction measured at Nurmijärvi in Finland on 28 April was 15% [S7] in a sample collected between 29 April and 2 May and 3-24% in samples collected through June [S1]. Other determinations were 33% in Belgium on 2 May [S4], 29-31% at two sites in Hungary on 2 and 4 May [H1], 50% on 29 April and about 33% on following days in Austria [A1], 20% on 4 May and decreasing to 10% thereafter in Switzerland [H2], 25% in the United Kingdom during

7–12 May [C3], about 33% in China on 4–5 May [L6] and 30% on 5–6 May in Japan [A7]. Over the monitoring period shown in Figure V, the integrated concentration of ^{131}I was 23% aerosol, 27% gaseous and 50% organically bound. Approximately similar results were obtained for ^{133}I. Ninety-eight per cent of ^{132}Te was associated with particles, as was 65% of its daughter ^{132}I. Of the remaining ^{132}I, 30% was gaseous and 5% organically bound.

2. Concentrations in air

108. The first arrival of contaminated air at the affected places usually brought the peak concentrations of radionuclides in air. The continuing releases from the reactor and the complex air movements often caused secondary peaks on subsequent days, as illustrated in Figure V. The integrated concentrations of radionuclides in air for the duration of elevated levels are listed in Table 9.

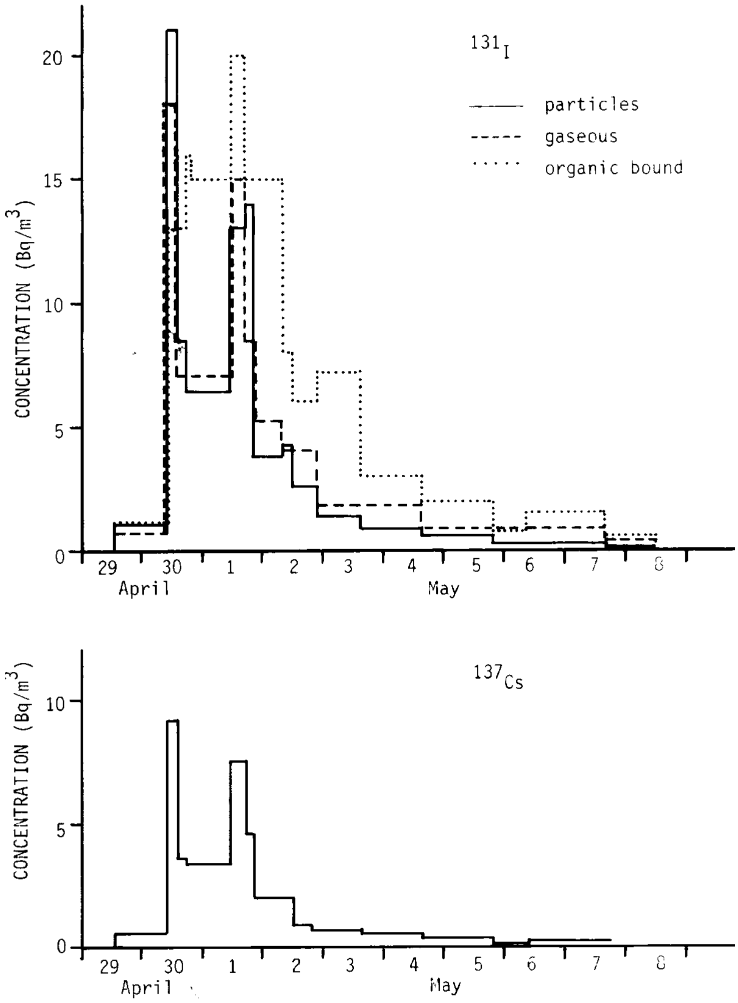

Figure V. Measured concentrations of iodine-131 and caesium-137 in air at Munich-Neuherberg, Federal Republic of Germany [W4].

109. Reported peak concentrations of ^{131}I and ^{137}Cs in air at several locations gives an indication of the levels encountered. For ^{131}I, the peak values were 400 Bq/m^3 at the Berezinsky National Park 120 km north-east of Minsk, 300 Bq/m^3 at Varyshevka 140 km south-east of Chernobyl [I3], 210 Bq/m^3 at Helsinki, 170 Bq/m^3 at Vienna, 52 Bq/m^3 at Munich-Neuherberg, 31 Bq/m^3 at Brussels, 2.5 Bq/m^3 at Fukui and 0.3 Bq/m^3 at Beijing. For ^{137}Cs, the peak values were 12 Bq/m^3 at Helsinki and Berlin, 9.6 Bq /m^3 at Vienna, 9 Bq/m^3 at Munich-Neuherberg, 6 Bq/m^3 at Brussels, 0.04 Bq/m^3 in Japan, and 0.02 Bq/m^3 at Beijing.

110. Relationships between peak and integrated concentrations of radionuclides in air varied with local meteorological conditions, the sampling times, and whether more than one wave of contaminated air passed the site. The quotients of integrated to peak air concentrations (Bq h/m^3 per Bq/m^3) were comparable for ^{131}I and ^{137}Cs and at individual sites. Values of this quotient were determined to be 15 at Helsinki and Nurmijärvi in Finland, where a sharp peak occurred, 39 at four sites in Germany (West Berlin, Braunschweig, Karlsruhe, Neuherberg), 83 at two sites in Hungary (Budapest, Paks), where three peaks occurred, and about 70 in Japan (Chiba), where a more diffuse peak occurred.

3. Ratios of integrated concentrations

111. The radionuclide composition of contaminated air masses varied depending on when the material had been released from the reactor and the time it took for dispersion to the particular location. The ratios of radionuclides of ruthenium, cerium and caesium suggest that the average irradiation periods of fuel in the reactor had been 400-600 days during the initial release period [C3].

112. The ratios of integrated concentrations in air relative to ^{137}Cs are listed in Table 10. The ^{131}I /^{137}Cs ratio was around 25 in Scandinavia and 5-10 in most other European locations. The ^{134}Cs /^{137}Cs ratio varied from 0.4 to 0.7 on separate days during May [C3, W4], but the ratio of integrated concentrations was relatively constant, around 0.5, in most places. The ratios of other radionuclides to ^{137}Cs showed some variability, but there were no significant differences between regions. The median values for all countries are indicated in Table 10.

113. The ratios of refractory elements relative to ^{137}Cs differed significantly with distance from the reactor. For example, the ratios of ^{90}Sr, ^{141}Ce and ^{239}Pu to ^{137}Cs in dust samples from within the Soviet Union were 35 times higher than in air samples in western Europe [A4]. The refractory components of the debris and also ^{90}Sr were deposited closer to the accident site than the more volatile constituents.

B. DEPOSITION

1. Deposition of caesium-137

114. The deposition of radioactive materials is associated mainly with rainfall, and since rainfall occurred very sporadically throughout Europe during the passage of the contaminated air, the deposition pattern was very irregular. The highest deposition of ^{137}Cs outside the USSR was recorded in Sweden north of Stockholm, where the deposition density exceeded 85 kBq/m^2. The region of Tessin (Region 1) in Switzerland received 43 kBq/m^2 and southern Bavaria in the Federal Republic of Germany up to 45 kBq/m^2. The provinces of Upper Austria, Salzburg and Carinthia in Austria received estimated average deposition densities of 59, 46 and 33 kBq/m^2, respectively.

115. Average deposition densities for ^{137}Cs of >1 and >5 kBq/m^2 in Europe are illustrated in Figure VI. Country-wide deposition densities of >5 kBq/m^2 for entire country averages are indicated for Austria, German Democratic Republic and Poland. Table 11 lists these average deposition densities.

116. The deposition of ^{137}Cs and other radionuclides outside Europe and the USSR was, accordingly, much less. Representative values of ^{137}Cs deposition densities were 16-300 Bq/m^2 in Japan, 20-90 Bq/m^2 in the United States and 20-40 Bq/m^2 in Canada.

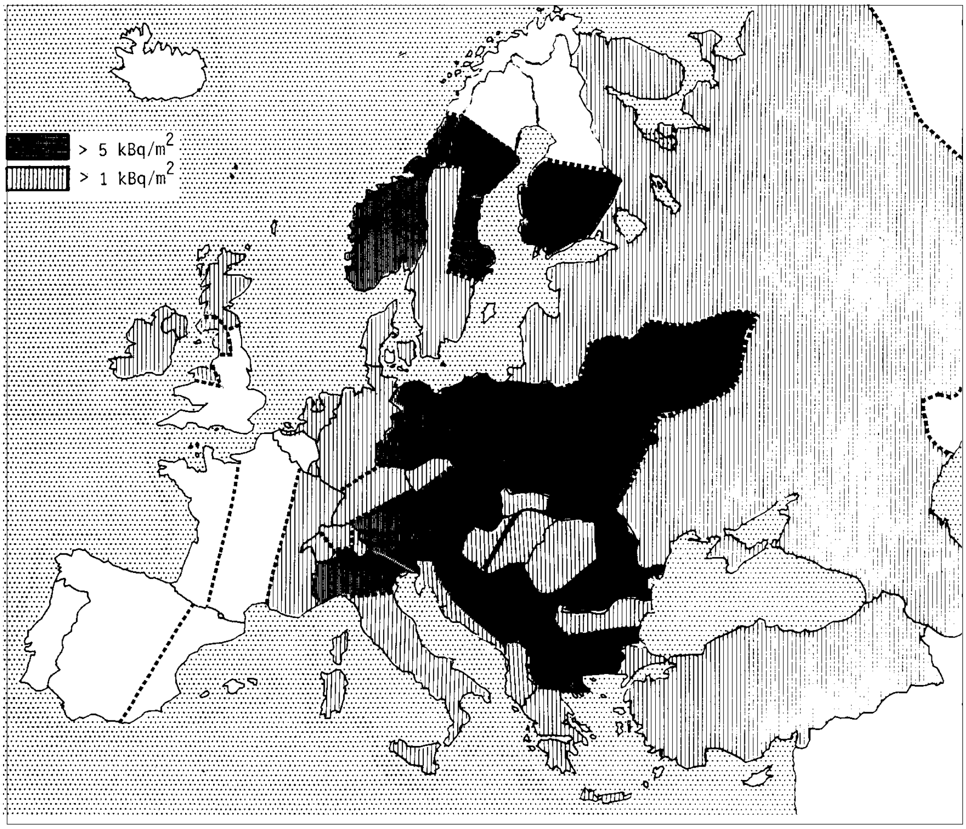

Figure VI. Average caesium-137 deposition density in countries or larger subregions in Europe.

2. Deposition of other radionuclides

117. Radionuclides of importance to the external gamma-irradiation dose from deposited materials beyond the first month include ^{137}Cs, ^{134}Cs, ^{106}Ru and ^{103}Ru. The deposition of ^{131}I, ^{134}Cs and ^{137}Cs is of importance in determining doses from the ingestion pathway. The deposition densities of these radionuclides in different countries and the ratios to ^{137}Cs are given in Table 11. The ratio of ^{131}I to ^{137}Cs is higher in Norway and Sweden than in other countries. The ratios of other radionuclides to ^{137}Cs are relatively uniform. The median ratios of radionuclide deposition to that of ^{137}Cs for all countries are ^{103}Ru, 1. 6; ^{106}Ru, 0.5; ^{131}I, 6.2; and ^{134}Cs, 0.5.

118. On an individual measurement basis, there are differences of more than an order of magnitude in the ratios of radionuclide depositions, particularly in the iodine/caesium ratio. There appear to be two reasons for this: the first is the difference in isotopic release at different times during the course of the accident itself; the second is the effect of different rates of precipitation during the passage of the radioactive plume.

119. The release of radionuclides took place over about 10 days and the fire spread through fuel of varying burn-up and power rating, resulting in a different relative release of nuclides over the 10-day period. Moreover, the plumes of radioactive material left the Chernobyl site travelling in different directions and were subjected to different meteorological conditions. Some experience showed that where the plume radionuclide content was fairly similar, deposition was related to the intensity of rainfall. Where the plume passed and there was no rainfall, caesium deposition was significantly less than that of iodine. Where it rained through the plume, iodine deposition was higher, and caesium deposition was similar to that of iodine [C 11].

3. Quotient of deposition density and integrated air concentration

120. Values of the quotient of the deposition density of a radionuclide to its integrated concentration in air depend on the proportions of wet and dry deposition, as well as on the nature of the particles or vapour and of the receiving surface. Table 12 lists these country average results for ^{137}Cs. The quotients are mostly in the range between 0.6 and 1.2 cm/s. The higher values (those observed, for instance, in Sweden and in Ireland) are strongly influenced by rainfall.

4. External exposure from deposited materials

121. External irradiation from deposited radioactive materials is, in the long term, due primarily to ^{134}Cs and ^{137}Cs. In the first month after initial deposition, however. a number of short-lived emitters, including ^{132}Te, ^{132}I, ^{131}I , ^{14}0La, ^{103}Ru and ^{106}Ru, were more significant contributors to the external exposure rate.

122. The exposure rate in air from natural background is about 0.7 pC/(kg s). Off-site external exposure rates in air following the accident were, at maximum, 40-60 pC/(kg s) at Kiev, USSR, 27 in south-west Finland; 12 at Sofia, Bulgaria; 12 at Salzburg, Austria; 7.9 at Munich-Neuherberg and 1.5 at Karlsruhe, Federal Republic of Germany; and 1.4 at Athens, Greece. The component of the external exposure rate attributable to the Chernobyl release was typically lower than the initial value by a factor of 5 by the end of the first month.

123. The exposure rates in air over the first month have been summed in order to evaluate the specific contribution of short-term emitters to effective dose equivalent. These results have been normalized to ^{137}Cs deposition density in Table 13. While the outdoor effective dose equivalent in the first month is not due primarily to ^{137}Cs, the normalized values can be useful for estimating effective dose equivalents where measurements were incomplete or absent. Anomalies in results can point to errors in data. With a few exceptions, the results range from 5 to 40 µSv per kBq/m^2. The median value is 15 µSv per kBq/m^2. These results are illustrated in Figure VII.

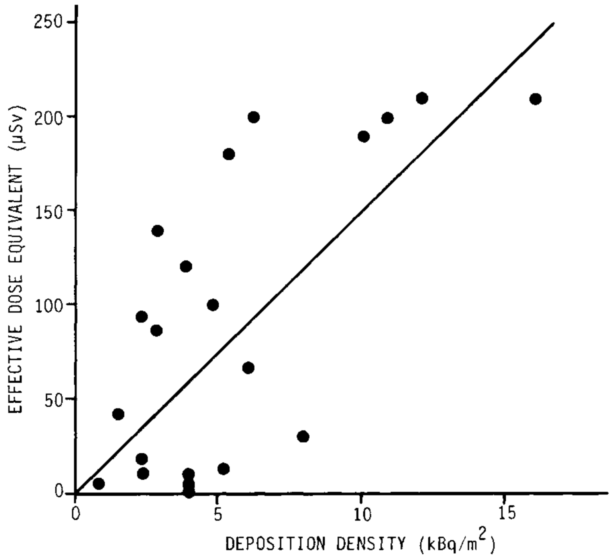

Figure VII. Outdoor effective dose equivalent from external irradiation in the first month after the accident relative to caesium-137 deposition density. The regression line corresponds to 15 µSv per kBq/m^2.

C. DIET

124. Ingestion of contaminated foods is an important pathway leading to radiation doses from ^{131}I and ^{137}Cs, and all countries paid particular attention to this pathway following the accident. These radionuclides are rapidly transferred to man through the consumption of milk and leafy vegetables, following their direct deposition on to pasture grass and plants. Other basic foods, such as cereals, root vegetables, fruit and meat, are produced during longer growing periods and are, therefore, not so relevant for short-lived ^{131}I.

125. Numerous measurements are available for ^{131}I and ^{137}Cs concentrations in foods in the first weeks after the accident (data for ^{137}Cs are available for longer periods). The great variability in results reflected the irregular deposition pattern. As indicated in Chapter II, attention often centred on the highest levels in foods from areas of greater deposition; however, for the dose assessment, it is representative levels in widely consumed foods that are needed. Assessed results of representative integrated concentrations of ^{131}I and ^{137}Cs in foods during the first year are given in Tables 14 and 15.

126. A degree of comparability between areas can be achieved by considering the integrated concentrations in foods normalized to the deposition densities, and this is the basis for the discussion below. Such relative transfer factors can be used to help establish representative levels in foods from more widely based deposition measurements and to fill in gaps in food data. Of course, the relative transfer depends on local conditions, such as feeding practice during May 1986, so differences in widely separated regions can be expected.

1. Iodine-131 in foods

127. Integrated concentrations of ^{131}I in milk and leafy vegetables relative to ^{131}I deposition density are listed in Table 14. In the case of ^{131}I, there may be some additional variability because of uncertainties in determining total ^{131}I deposition, but a general pattern emerges. In Scandinavia, cows were not yet on pasture at the time of the accident. By keeping cows indoors for some days more, the integrated concentrations of ^{131}I in milk were kept rather low. Some grazing restrictions were also imposed in the Netherlands. In other areas, cows were already on pasture. Normalized transfer of ^{131}I to milk ranges from 0.01 Bq a/kg per kBq/m^2 in Scandinavia to 0.1-1 in central Europe and to 1-3 in some southern and Asian countries. This suggests a latitudinal dependence, which in turn reflects agricultural conditions; this is illustrated in Figure VIII. Only results based largely on measurements are included. The probability distribution of normalized integrated concentrations of ^{131}I in milk is illustrated in Figure IX.

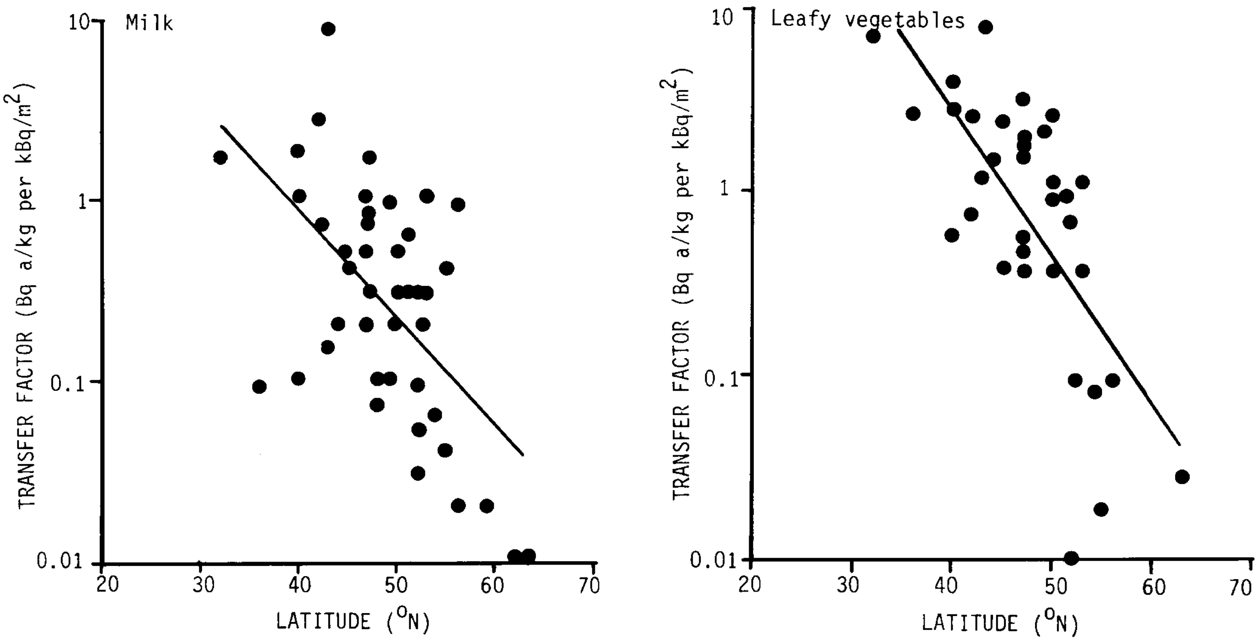

Figure VIII. Integrated concentrations of ^{131}I in milk and leafy vegetables per unit ^{131}I deposition density.

128. At several locations, concentrations of radioactivity in milk were higher for sheep and goats than for cows; this phenomenon is associated with differences in metabolism and feeding habits. For example, during the first week after the accident, the average concentrations of ^{131}I in milk in Greece were 9,000 Bq/l (sheep), 2,000 Bq/l (goats) and 200 Bq/l (cows) [G2]. If a non-typical food makes an important contribution to radionuclide intake in a food category (milk or milk products in this case), the food has been included, weighted by consumption amount.

129. The extent to which ^{131}I is transferred to leafy vegetables depends on the growing season, which was not far advanced in Scandinavia but was well under way in southern Europe. The values of normalized integrated concentrations in Table 14 generally reflect this. The latitudinal dependence of all measured values is illustrated in Figure VIII. The probability distribution is shown in Figure IX.

130. The ratios of integrated concentrations of ^{131}I in leafy vegetables to those in milk are given in Table 14. This comparison removes uncertainties in ^{131}I deposition, but there is still great variability among regions, suggesting differences in definition of the individual results, the use of milk of different sources, differences in local agricultural practice and the effect of various countermeasures. The majority of values of this ratio lie in the range 1-5 with a median of 2.

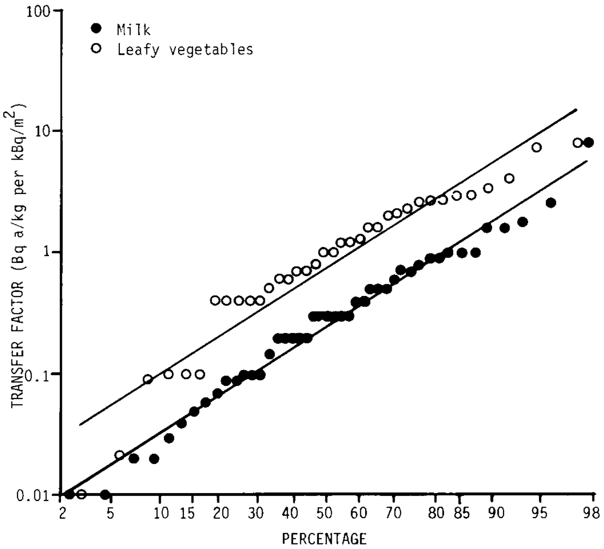

Figure IX. Probability distribution of integrated concentrations of iodine-131 in milk and leafy vegetables per unit iodine-131 deposition density.

2. Caesium-137 in foods

131. The assessed first-year integrated concentrations, normalized to unit deposition density, of ^{137}Cs in the basic food categories are listed in Table 15. These concentrations are based on measurements, as reported and averaged over the countries or subregions. Generally the transfer for all food categories is higher in southern Europe. The latitudinal dependence of integrated concentrations Of ^{137}Cs in foods is illustrated in Figure X. The probability distributions of all measured values are shown in Figure XI.

132. The ratios for leafy vegetables/milk and for meat/milk are compared in Table 15. Relative to its concentrations in milk, the integrated concentrations Of ^{137}Cs in leafy vegetables are lower by a factor of about 2 and in meat are higher by a factor of about 2, with some deviations.

133. The longer-term monitoring of ^{137}Cs in milk from a dairy farm in the south-eastern part of the Federal Republic of Germany [J5] gave the results shown in Figure XII. Concentrations of ^{137}Cs in milk decreased through the summer of 1986, primarily because the ^{137}Cs was diluted in pasture grass of fresh growth. Increases later in the year were due to the use of animal feeds produced earlier in the year. These changes can be adequately modelled by an appropriate choice of parameters [J5]. Similar variations have been noted elsewhere. Also shown in Figure XII is the country-wide average concentration of ^{137}Cs in milk in Finland [R3]. The initial peak was relatively small and occurred a few weeks after the accident because the cows had initially been off pasture; also, the variability with time was less marked, presumably because the data came from wider-ranging samples.

134. Country-wide monitoring results for ^{137}Cs in meat in Finland are shown in Figure XIII. For reference, the concentrations in milk are also shown. The curve labelled "average meat" is weighted to reflect average consumption of three parts pork for every two parts beef. A beef/milk ratio of about 4 is seen to prevail and an average meat/milk ratio of about 2, as referred to in paragraph 132. Owing to differences in feed sources, the concentrations of ^{137}Cs were generally lowest in pork and poultry, higher in beef and lamb and highest in game.

135. Some foodstuffs that are consumed in small amounts by most people or in large amounts by relatively few people had, on average, much higher activity mass concentrations of ^{137}Cs than the foods presented in Table 15. Foods that should be mentioned in this regard are reindeer meat, mushrooms and lake fish: (a) the feeding habits of reindeer (consuming lichens) lead to exceptionally high levels of ^{137}Cs, as was observed in the 1960s following atmospheric nuclear testing. After the accident, a large fraction of the reindeer in Sweden had ^{137}Cs levels of more than 10,000 Bq/kg [S1]; (b) enhanced levels of ^{137}Cs have been found in mushrooms, although there was considerable variability depending on type and location. The highest levels were measured in mushrooms of the family Boletaceae that live in symbiosis with trees (mycorrhiza), e.g., in *Xerocomus badius* (Maronenröhrling). In this species, the ^{137}Cs levels were around 250 Bq/kg, but peak values of around 20,000 Bq/kg were measured at the beginning of September 1986 in the Federal Republic of Germany [W2], and 800 Bq/kg average and 7,800 Bq/kg maximum were measured in the German Democratic Republic, also in September 1986 [L1]. In other Boletaceae, e.g., the popular *Boletus edulis* (Steinpilz or cèpe), the levels were lower, usually below 100 Bq/kg. In non-mycorrhizal mushrooms, e.g., mushrooms of the genus *Agaricus,* such as the common mushroom, ^{137}Cs levels were very low; and (c) concentration of ^{137}Cs in freshwater fish were in some places, e.g., Sweden, found to be many thousands of Bq/kg, though there were large differences between types of fish and even between nearby lakes [S1]. Values of about 300 Bq/kg in plankton-eating lake fish were measured in the Federal Republic of Germany [W2]. Marine fish accumulate only very low concentrations of ^{137}Cs.

D. THE HUMAN BODY

136. Following the accident, extensive measurements were made of ^{131}I in the thyroid or ^{137}Cs in the body. The thyroid measurements were not always made in a standardized way, and much variability was encountered. These results cannot, therefore, be easily interpreted, although they served as a guide to general exposure levels. Measurements of thyroid burdens the Federal Republic of Germany that were intended to evaluate estimates of ^{131}I intakes through inhalation and ingestion showed that those intakes were overestimated by a factor of about 5 [S16].

137. The amount of ^{137}Cs in the body is generally measured by whole-body counting, which can be performed in a reliable, comparable way. These measurements enable a

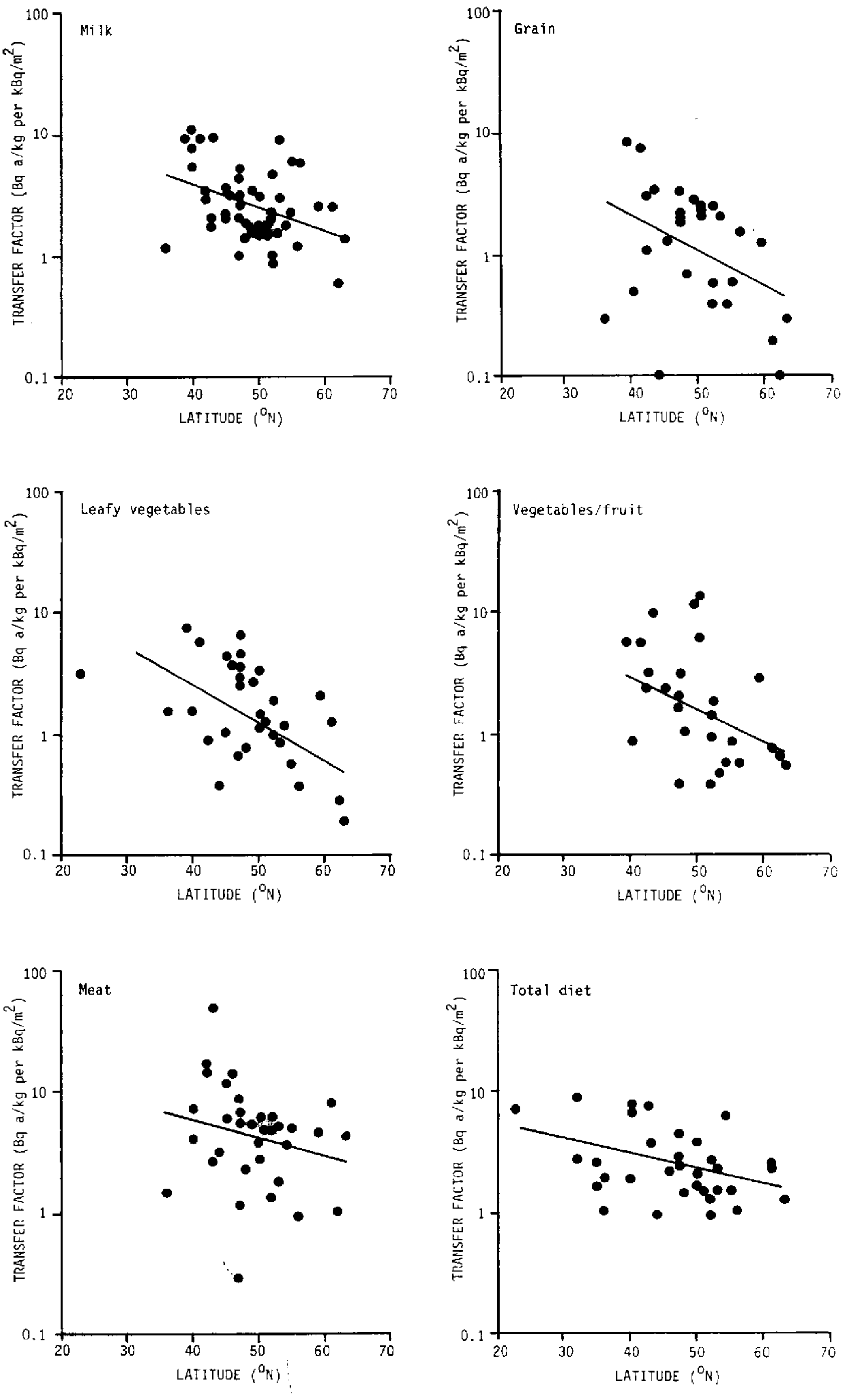

Figure X. Integrated concentrations of caesium-137 in foods and total diet in the first year after the accident per unit caesium-137 deposition density.

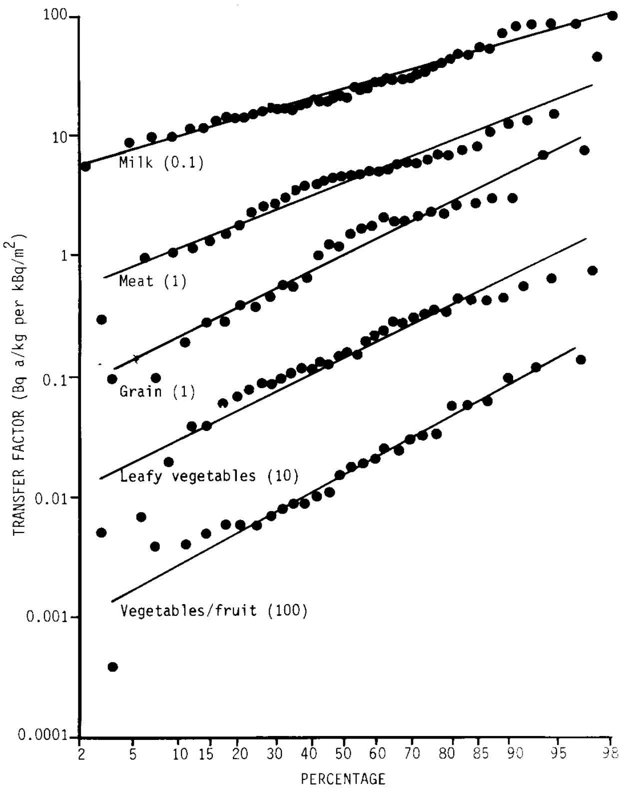

Figure XI. Probability distribution of integrated concentrations of caesium-137 in foods in the first year per unit caesium-137 deposition density.
Because of sliding scale on left axis, multiply values by numbers in parenthesis. Geometric mean values are 2.7 milk, 4.5 meat, 1.1 grain, 1.5 leafy vegetables and 1.6 vegetables/fruit (Bq a/kg per kBq/m^2).

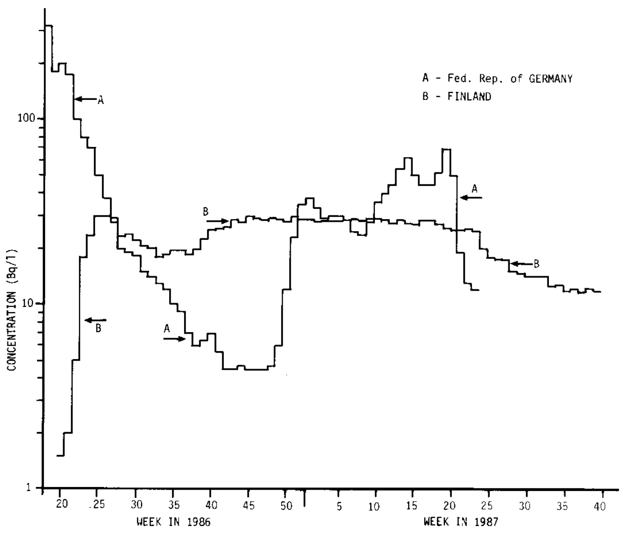

Figure XII. Weekly monitoring results of caesium-137 concentrations in milk from the Federal Republic of Germany (dairy farm in south-east Bavaria) and Finland (country-wide mean) [J5, R3].

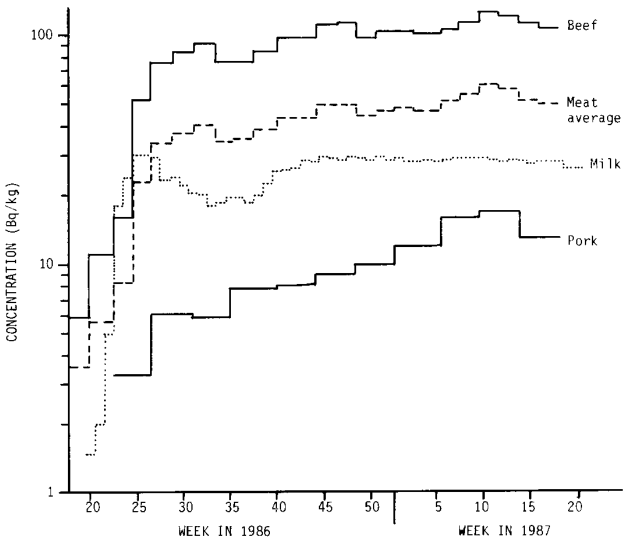

Figure XIII. Country-wide mean concentrations of caesium-137 in meat and milk in Finland (Meat average obtained by weighting according to consumption) [R3, R7].

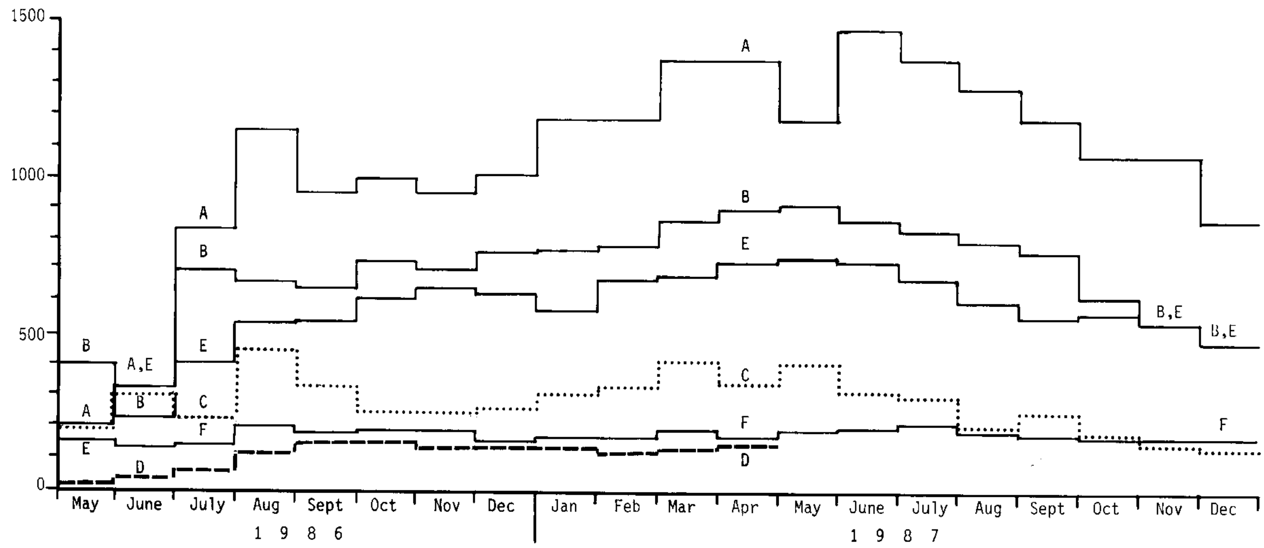

Figure XIV. Caesium-137 in the human body at Munich, Federal Republic of Germany (A: males; B: females; C: children) [S16]; in Oxfordshire, United Kingdom (D: adults) [F2]; and in France (E: Grenoble, adults; F: Saclay, adults) [J4, L5].

direct assessment of internal doses from ^{137}Cs. Although ingestion was responsible for most of the dose, the contribution from inhalation could also be measured during the first few weeks following the accident [O1].

138. Examples of ^{137}Cs body measurements in the Federal Republic of Germany, France and the United Kingdom are presented in Figure XIV. Generally the amounts increased until late spring or early summer 1987. Regional differences are accounted for by the varying levels of ^{137}Cs in the diet. Lower body burdens are accumulated in children and adult females than in adult males as a result of shorter retention half-times in the body [NI].

139. It is of interest to compare the internal doses estimated directly from body burden measurements and those estimated indirectly from concentrations in foodstuffs. Accordingly, the information on measured body burdens in adults that was available to the Committee was processed to obtain time-integrated body burdens corresponding to the ^{137}Cs intakes during the first year after the accident. The results, presented in Table 16, are the integrated amounts in the body (Bq a) for one year (May 1986 to April 1987) and include retention beyond one year of the acquired body burden. The integrated ^{137}Cs body measurements range from 100–200 Bq a in areas of the United Kingdom and France to 2,000–3,000 Bq a in Austria, Bulgaria, Finland, Italy and Norway; in Japan, they were 34 Bq a. The retention function for the adult was taken to be 10% of the burden retained with a half-life of 2 days and 90% of that retained with a half-life of 110 days [I9]. This retention function was used to estimate the time-integrated body burdens during the first year, when the measured information was limited to one or two points in time, and also to calculate the fraction of the time-integrated body burden attributable to retention beyond one year. Continuous intake of ^{137}Cs at a rate of 1 Bq/d gives an integrated concentration in the body of 87 Bq a at the end of one year and a further integrated concentration of 56 Bq a from continued retention with no further intake. Thus, 1 Bq/d for one year gives 143 Bq a in the body or 2.0 Bq a/kg, which results in an effective dose equivalent of 5.0 μSv to reference man.

140. The body burdens expected from the ^{137}Cs concentrations in diet have also been calculated, using reported concentrations in foods for the area considered, when available, or, when not, assuming that the concentrations in foods are proportional to the deposition density of ^{137}Cs. The ratios of the body burdens derived from measurements in man and expected from concentrations in diet are presented in the last column of Table 16.

141. In general, the body burdens are less than would be expected based on deposition in the country or subregion and on local concentrations of ^{137}Cs in foods. The retention function was tested in a controlled study and was found to be adequate [V1]. When food basket or total diet samples were measured, as was done in regions 2 and 3 in France, in Sweden and in the Federal Republic of Germany, the agreement was better. These findings call into question the representativeness of the concentrations in foods and the amounts consumed. This was certainly a factor in the places where people refrained from eating foodstuffs expected to present higher-than-average ^{137}Cs concentrations. Ingestion of less typical foods explain why the measured body burdens of some people, e.g., Lapps (see the Norwegian data in Table 16), are greater than those predicted from the average diet.

142. The ^{137}Cs concentrations in foodstuffs may be over-estimates. These overestimates could have come from a sampling bias towards high deposition areas or they could

have been due to the fact that losses during food processing or preparation are usually not taken into account; also commercial distribution could cause large scale movements of food and a smoothing of the concentrations over entire countries. This may explain why the measured body burdens in Oslo, Vienna, and regions 1 of Finland and France (low-deposition areas) were higher than predicted and why the reverse was true in the high-deposition regions of Finland and France.

IV. FIRST-YEAR DOSE ESTIMATES

143. Exposures of populations to radionuclides released in the accident have been calculated for all countries for which measurements are available. These include the USSR, most countries in Europe and a few countries in Asia and North America. Thirty-four countries are considered here. The results are used, first, as direct determinations of first-year doses and, second, as a basis for establishing transfer factors to be applied for estimating doses in other countries of the northern hemisphere.

144. The dose equivalents to individuals in the assessed countries during the first year following the accident are presented in Table 17. These are the thyroid dose equivalents to infants and adults, primarily from ^{131}I, and the effective dose equivalents from all radionuclides and all pathways; they are average results for subregions or for the country as a whole. In each country, there were more localized areas where exposures were both higher and lower than these broad averages.

A. THYROID DOSE EQUIVALENTS

145. Thyroid dose equivalents have been evaluated because there were significant amounts of ^{131}I in the released materials. Doses to ^{131}I in the environment are generally higher to infants than to adults because the main pathway is through milk consumption, and also because infants are characterized by greater ^{131}I uptake and smaller thyroid mass.

146. The estimated average infant (one year old) and adult thyroid dose equivalents during the first year in countries or subregions are listed in Table 17. While these doses were primarily due to ^{131}I, the contributions from other radionuclides and all pathways are included.

147. The calculated results for thyroid dose equivalents, and also for effective dose equivalents, take into account, where possible, the application of countermeasures. This was usually done by adjusting the integrated concentrations in foods so that the values represented what was actually consumed. However, the Committee has not taken into consideration the use of thyroid blocking agents or stable iodine preparations. By reducing uptake, these would have afforded some additional protection against inhaled and ingested radioiodine.

148. The country averages of infant and adult thyroid dose equivalents are listed in Table 18 and shown in Figures XV and XVI. Infant thyroid dose equivalents in Europe generally ranged from 1 to 20 mSv, but there were higher doses in some parts of Romania, Greece, Switzerland, Bulgaria and the USSR. Adult thyroid doses were usually smaller than infant doses in the same country by a factor of about 5 in central and western Europe, but the differences were smaller in northern Europe, where milk was less contaminated because the cows had not been on pasture, and in regions of southern Europe and Asia, where the contamination of leafy vegetables increased adult thyroid doses.

149. The thyroid dose estimates are compared with the estimates reported by individual countries in Table 18. The country-reported results are those collected by the Nuclear Energy Agency of the OECD [N5]. Differences from unity in the ratios of the estimates to the country-reported results reflect differences in the various assumptions regarding intake, the age groupings for infants and the ways of accounting for countermeasures. The dose estimates are both higher and lower than those reported by the countries, but the differences are generally not greater than a factor of 4 for infants and a factor of 3 for adults.

B. EFFECTIVE DOSE EQUIVALENTS

150. The effective dose equivalents received by individuals (adults) during the first year following the accident are presented in Table 17, which also shows rural-urban differences. Contributions to dose from the ingestion pathway also include committed doses from caesium in the body following the first-year intake of caesium in diet.

151. The highest average first-year committed effective dose equivalent in subregions was 2 mSv, in the Byelorussian Soviet Socialist Republic. Subregions where effective dose equivalents were 1–2 mSv were located in Romania and Switzerland and 0.5–1 mSv in Austria, Bulgaria, Federal Republic of Germany, Greece and Yugoslavia. The effective dose equivalent in the Byelorussian Soviet Socialist Republic approached the yearly effective dose equivalent due to natural radiation sources. The mean values for each country are listed in Table 18 and plotted in Figure XVII.

152. These estimates of first-year committed effective dose equivalent are in reasonable agreement with the results reported by individual countries [N5], as is also shown in Table 18. While there are some greater discrepancies between these estimates and other, provisional dose estimates

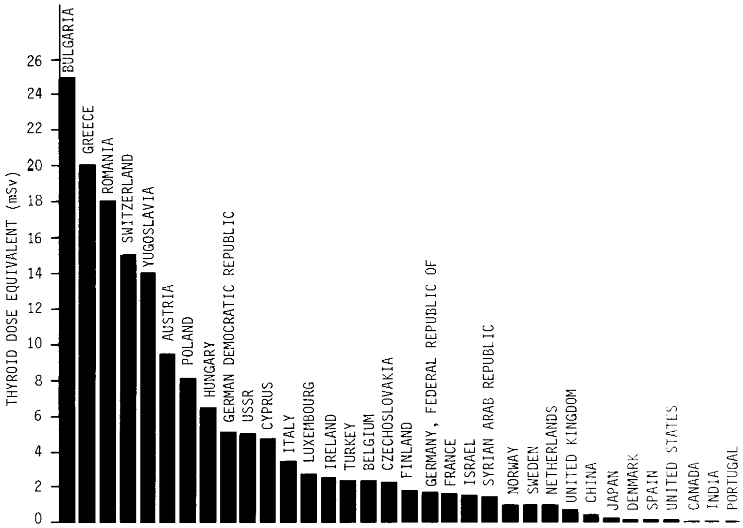

Figure XV. Country-wide average infant thyroid dose equivalents from the Chernobyl accident.

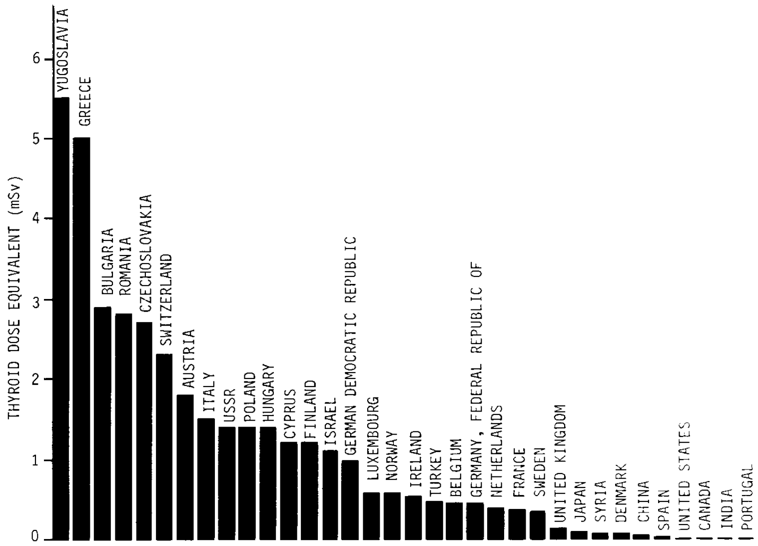

Figure XVI. Country-wide average adult thyroid dose equivalents from the Chernobyl accident.

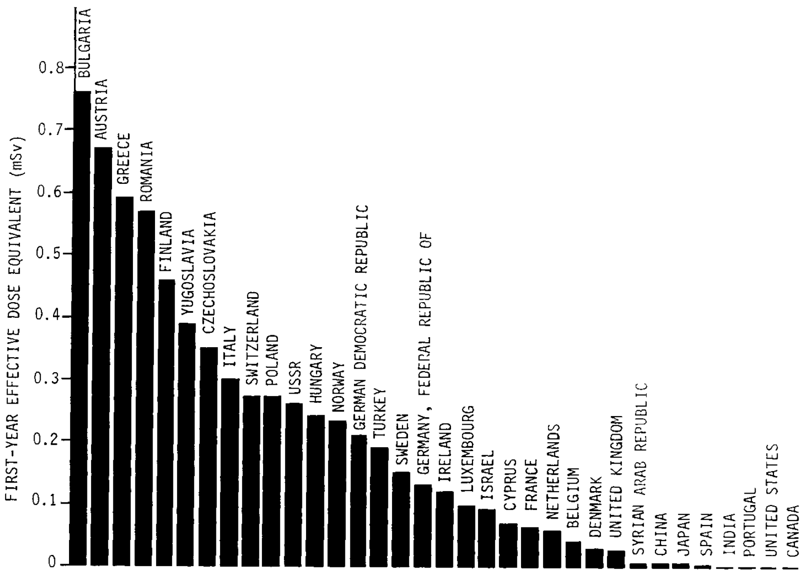

Figure XVII. Country-wide average first-year committed effective dose equivalents from the Chernobyl accident.

[M1, D5], the latter were based on measurements made in the first months after the accident. Differences in estimates from country-reported results can be attributed to the averaging of results over larger subregions, the inclusion of additional food groups and the use of different assumptions for occupancy, shielding and food consumption. Most results from individual countries did not account for urban run-off. On average, however, the comparability of the Committee's estimates and those of individual countries is good, the average ratio being 1.06 with a standard error of 0.6.

C. PATHWAY CONTRIBUTIONS

153. The pathway contributions to the first-year committed effective dose equivalents varied substantially by location for all pathways except cloud gamma, which was everywhere less than 1%. The contribution from inhalation averaged 5%, with a range from 0. 1% in Ireland to 22% in Turkey.

154. The first-year committed effective dose equivalents resulted primarily from the ingestion pathway, which in most countries accounted for over 60% of the total dose and in southern countries for over 80%. The differences in pathway contributions are illustrated in Figure XVIII for three groupings of countries: southern countries (<40°N latitude), temperate countries (41°-55°N latitude) and northern (Scandinavian) countries (>55°N latitude). The contributions to committed first-year effective dose equivalents average 11%, 19% and 27% from external irradiation and 86%, 76% and 69% from ingestion in the southern, temperate and northern countries, respectively.

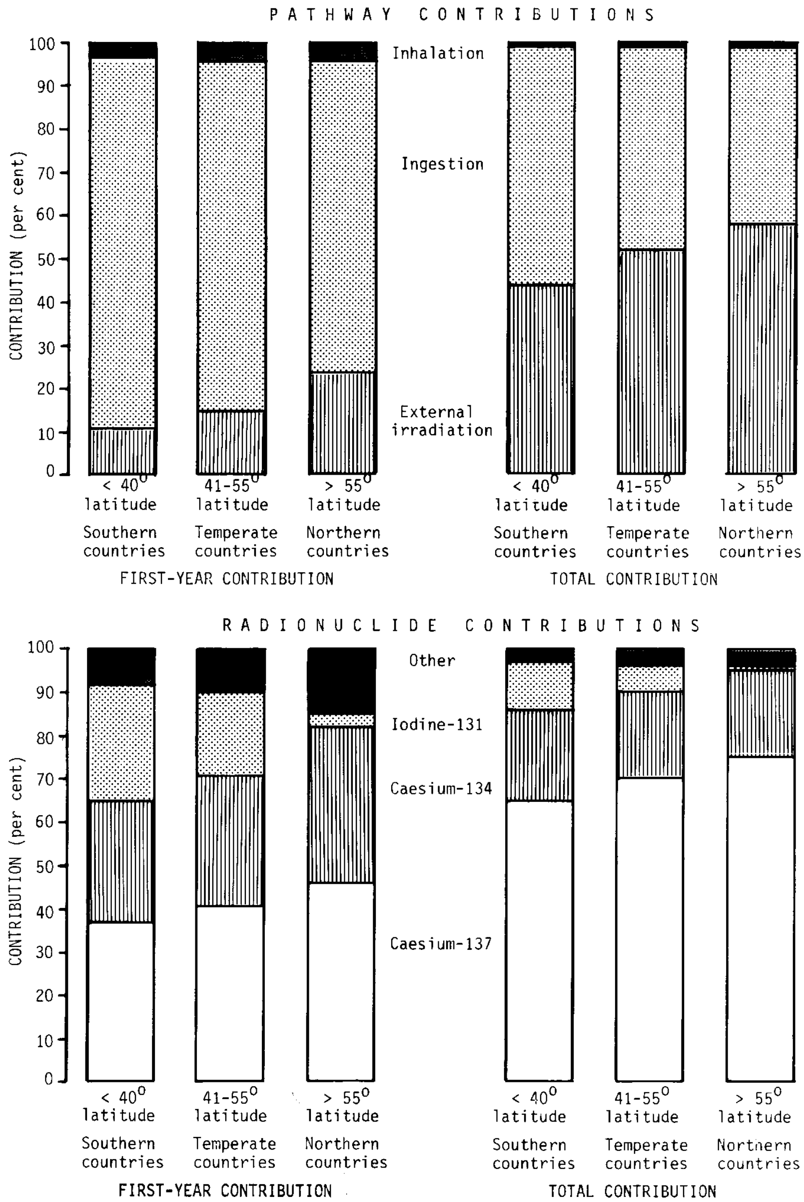

Figure XVIII. Pathway and radionuclide contributions to the first-year effective dose equivalents and the effective dose equivalent commitments.

155. The pathway contributions to the thyroid dose equivalents in the first year also varied from north to south. Average results for all age groups showed the significance of the ingestion pathway (through milk and leafy vegetables), which was generally responsible for over 70% of the total dose but in northern Europe was responsible for only 40%. The inhalation pathway contributed 20–50% of the first-year thyroid dose in some northern countries.

D. RADIONUCLIDE CONTRIBUTIONS

156. Contributions to the first-year committed effective dose equivalents were dominated by the radionuclides ^{131}I, ^{134}Cs and ^{137}Cs. For the cloud gamma and inhalation pathways, some other radionuclides in air were important, specifically ^{132}Te and ^{103}Ru. For the external irradiation and the ingestion pathways, some other short-lived radionuclides were also significant. Caesium-137 and ^{134}Cs together contributed over 50% of the dose from ingestion in most countries. For the committed first-year thyroid dose equivalent, ^{131}I typically contributed over 90%.

157. A seasonal dependence of the radionuclide contribution to the committed first-year effective dose equivalent is indicated in Figure XVIII. The dose from ^{131}I ranged from less than 4% in Scandinavia, where cows were not on pasture and leafy vegetable production was minimal, to some 20% in countries at lower latitudes, where quite different agricultural conditions prevailed. The remainder of the main dose contribution from ^{137}Cs varied in an inverse way, becoming increasingly more important in northern countries.

E. TRANSFER RELATIONSHIPS

158. The input data for the assessment of the committed first-year dose equivalents have been based on measurements through the first year. These can be analysed to infer transfer relationships to dose equivalents. Because of the differences in local conditions and varying assumptions with regard to food consumption and in determining integrated concentrations, it would not be reasonable to expect uniformly consistent values of transfer factors. Nevertheless, it is useful to indicate the range of values that applied to conditions at the time.

1. Transfer from deposition to dose from external irradiation

159. Doses due to external irradiation from deposited radionuclides are delivered directly. The transfer factor for external radiation in the first month after the accident depended upon the presence of many short-lived radionuclides. As shown in Figure VII, the average outdoor effective dose equivalent was around 15 μSv per kBq/m^2 of ^{137}Cs. This multiplied by the shielding/occupancy factor of 0.36 [0.2 (outdoor occupancy) plus the product of 0.8 (indoor occupancy) and 0.2 (shielding)] gives an average contribution of 5 μSv per kBq/m^2.

160. Transfer factors for the period between one month and one year may be taken directly from Table 5. For ^{137}Cs, the value is 8.04 μSv per kBq/m^2. When this is multiplied by the shielding/occupancy factor of 0.36 and the urban population/runoff factor of 0.75 [0.5 (rural population) plus the product of 0.5 (urban population) and 0.5 (urban removal)], the average contribution from ^{137}Cs alone is seen to be 2.2 μSv per kBq/m^2.

161. The one-month to one-year transfer factors for other important radionuclides in deposited material, from Table 5, are 18.6, 0.691, 2.09 and 0.015 μSv per kBq/m^2 of ^{134}Cs, ^{103}Ru, ^{106}Ru and ^{131}I, respectively. It is convenient to relate these further to ^{137}Cs deposition density by using median values of the ratios of these radionuclides to ^{137}Cs in deposition. These ratios are 0.5 for ^{134}Cs and ^{106}Ru, 1.6 for ^{103}Ru and 6.2 for ^{131}I (Table 11). The total contribution, using the same factors (shielding/occupancy and urban population/runoff), to the effective dose equivalent from these radionuclides per unit ^{137}Cs deposition density is 3.1 μSv per kBq/m^2.

162. The components of the first-year transfer to effective dose equivalent due to external irradiation from deposited radionuclides relative to unit ^{137}Cs deposition density may be summarized as follows:

Radionuclide	*Outdoor effective dose equivalent (μSv per kBq/m^2)*	*Shielding/ occupancy factor*	*Urban population/ runoff factor*	*Ratio to caesium-137*	*Transfer factor components (μSv per kBq/m^2)*
First month					
All	15	0.36			5
Second to twelfth month					
^{137}Cs	8.04	0.36	0.75		2.2
^{137}Cs	18.6	0.36	0.75	0.5	2.5
^{103}Ru	0.691	0.36	0.75	1.6	0.30
^{106}Ru	2.09	0.36	0.75	0.5	0.28
^{131}I	0.015	0.36	0.75	6.2	0.025
Total (first year)					10

2. Transfer from deposition to thyroid dose equivalent of iodine-131

163. The derivation of the transfer factor from deposition to thyroid dose equivalent in the first year is presented in Table 19. Since the thyroid dose calculation includes inhalation and ingestion contributions, some differences may result from relating the total dose only to ^{131}I deposition.

164. The results vary by orders of magnitude. The very low values for Scandinavian countries reflect the early stage of the growing season there and the consequently low transfer to milk and leafy vegetables. The relatively high values are due to several factors. In southern countries, animals were already on pasture and in addition, in some areas contributions from extensive use of sheep's milk was included, in which the concentrations were about 10 times higher than in cow's milk. Protective actions that were taken further increased the variability of these results. The latitudinal dependencies in the transfer factor from deposition to thyroid dose equivalent from ^{131}I for infants and adults are shown in Figures XIX and XX.

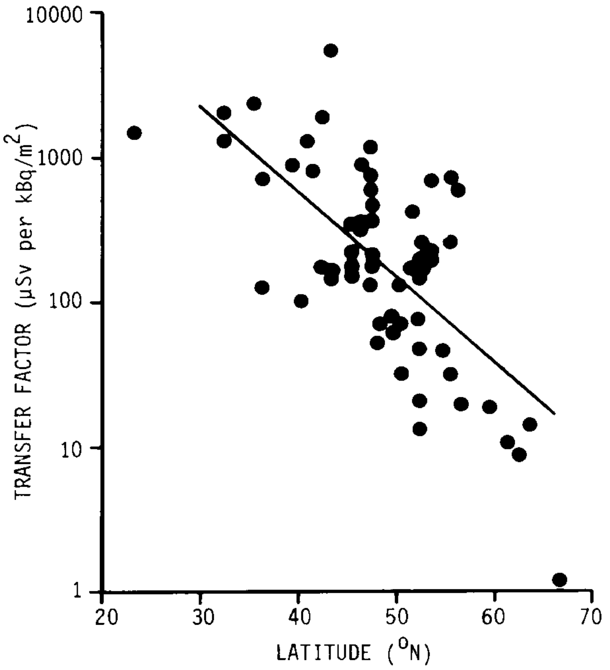

Figure XIX. Transfer factor for infant thyroid dose equivalent from ingestion and inhalation relative to iodine-131 deposition density.

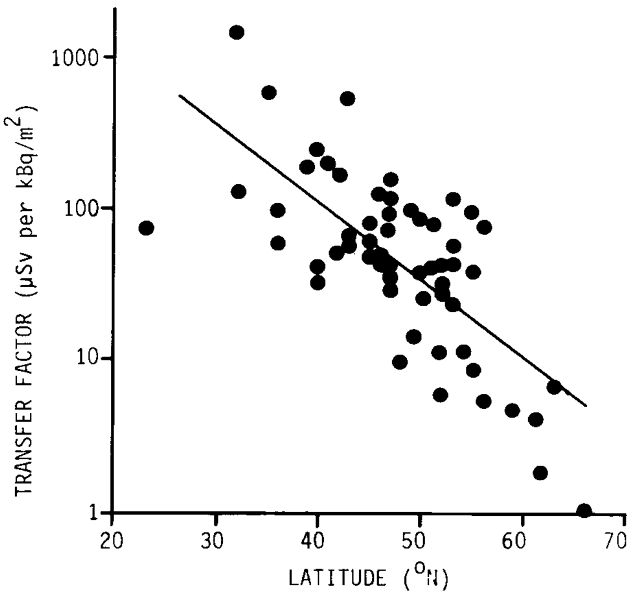

Figure XX. Transfer factor for adult thyroid dose equivalent from ingestion and inhalation relative to iodine-131 deposition density.

3. Transfer from deposition to dose from ingestion of caesium-137

(a) Transfer from deposition to diet

165. The quotients of the first-year integrated concentrations of ^{137}Cs in foods and the ^{137}Cs deposition density, which were presented in Chapter III (Table 15) for the individual food categories, define the first-year deposition to diet transfer factors for ^{137}Cs the b_1 values. These values have been combined and weighted by consumption amounts to obtain the average deposition to first-year total diet transfer factors for each country or subregion listed in Table 20. Also listed are the average integrated concentrations of ^{137}Cs in diet and the total first-year intakes of ^{137}Cs.

166. The results of first-year transfers of ^{137}Cs to total diet under the conditions that prevailed at the time of the accident are included in Figure X. The least-squares fit through the measured values shows a trend toward increasing transfer per unit deposition at southern latitudes, as seen also in the individual components of diet from first-year measurements (also in Figure X). Most countries and subregions in temperate latitudes are in the range 1−4 Bq a/kg per kBq/m^2. There are, however, greater deviations in some countries that reported higher levels in foods than would have been expected from estimated deposition. In some cases, there is uncertain transfer to some food items as well as higher transfer to diet due to the inclusion of certain foods, such as milk and meat from goats and sheep. It would be of interest to study in more detail the local conditions that cause deviations from the more widely applicable transfer factors derived here.

167. The log-normal distribution of b_1 transfer factors for ^{137}Cs in total diet is shown in Figure XXI. A single population-weighted value is plotted for each country; for some countries, the values were largely inferred, but these have also been included. The values range from 1 to 9 Bq

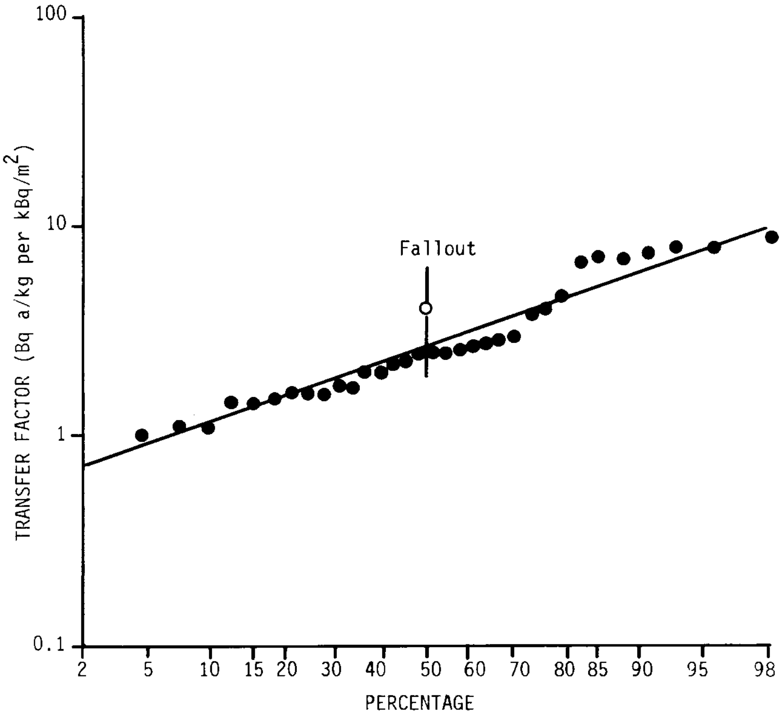

Figure XXI. Probability distribution of caesium-137 in first year total diet relative to caesium-137 deposition density.

a/kg per kBq/m^2, with a geometric mean of 2.6 Bq a/kg per kBq/m^2. This mean may be compared with the average value of 4.1 Bq a/kg per kBq/m^2 (range 1.9 to 6.3) for the first-year transfer of fallout ^{137}Cs, derived from long-term measurements (Table 7).

(b) Transfer from diet to body

168. The transfer factor from diet to body burden, P_{34}, is derived in Table 20. The integrated concentration of ^{137}Cs in the body is obtained by multiplying the dietary intake of ^{137}Cs in the first year by a standard factor, 143 d/70 kg (the mean residence time of ^{137}Cs in the body divided by the body mass). The integrated concentration includes retention in the body beyond the first year. The transfer factor from total diet to body burden is the ratio of integrated concentrations in the body and in diet. Variability in this factor reflects only differences in food consumption. The median value for this transfer factor is 2.9 Bq a/kg per Bq a/kg.

(c) Transfer from body to effective dose equivalent

169. The transfer factor from ^{137}Cs in the body to the effective dose equivalent, P_{45}, is based on the dose factor given in Table 6. For adults, this factor is 0.014 µSv per Bq intake. The retention function for caesium in the body was discussed in paragraph 139. Since the mean retention time is 143 days, an intake of 1 Bq corresponds to 1 Bq × 143 d ÷ 70 kg = 5.6 10^{-3} Bq a/kg in the body. The transfer factor from integrated concentration in the body to the effective dose equivalent is 0.014 ÷ 5.6 10^{-3}, or 2.5 µSv per Bq a/kg.

170. The overall transfer factor from deposition to the first year effective dose equivalent, $P_{25,1}$, is obtained by sequential multiplication of the transfer factors P_{23} (which is referred to as b_1 for the first-year transfer), P_{34} and P_{45}. These values for the ingestion of ^{137}Cs in countries or subregions are listed in the last column of Table 20.

V. DOSE COMMITMENTS

171. Dose equivalent commitments have been calculated using transfer factors developed and used by the Committee for its assessments of the dose commitments resulting from atmospheric nuclear weapons tests [U1, U2]. Since those transfer factors were developed for the rather more uniform and continuous deposition patterns of fallout, they are here applied only to regional groups of countries. Because first-year doses were for the most part calculated from measured data, only the components of the fallout models corresponding to transfers beyond the first year following deposition were taken into consideration. For that time, i.e., more than one year after the accident, the only pathways to be considered are external irradiation due to activity deposited on the ground and ingestion of foodstuffs, and the only radionuclides that contribute significantly to the dose equivalents are ^{134}Cs and ^{137}Cs. For these radionuclides, the effective dose equivalent and the thyroid dose equivalent have the same value for a given exposure.

172. The methods for obtaining projected dose estimates were discussed in Section II.C. After specific values for the transfer factors have been derived, they are applied to the average ^{134}Cs and ^{137}Cs deposition. Since the ^{134}Cs to ^{137}Cs deposition ratio was uniform in all countries, the contributions to the dose from both radionuclides may be related to the ^{137}Cs deposition value.

A. TRANSFER RELATIONSHIPS

1. Transfer from deposition to dose from external irradiation

173. Values of the effective dose equivalent per unit deposition density of radionuclides for the period after one year are given in Table 5. These apply to a soil relaxation depth of 3 cm. Assuming an initial runoff loss of one half of deposition in urban areas, equal proportions of urban and rural residents, a shielding factor of 0.2 indoors and an indoor occupancy factor of 0.8, the transfer factors for the dose per unit deposition from external irradiation beyond one year are 71 µSv per kBq/m^2 for ^{137}Cs and 9.8 µSv per kBq/m^2 for ^{134}Cs. An additional small contribution of 0.4 µSv per kBq/m^2 comes from ^{106}Ru. Using a value of 0.5 for the deposition ratio ^{134}Cs /^{137}Cs as well as for ^{106}Ru/^{137}Cs, 17CS, the total dose may be estimated directly from ^{137}Cs deposition: 76 µSv per kBq/m^2. The derivation of this transfer factor may be summarized as follows:

Radionuclide	*Outdoor effective dose equivalent (µSv per kBq/m^2)*	*Shielding/ occupancy factor*	*Urban population/ runoff factor*	*Ratio to caesium-137*	*Transfer factor components (µSv per kBq/m^2)*
^{137}Cs	264	0.36	0.75		71.3
^{137}Cs	36.2	0.36	0.75	0.5	4.9
^{106}Ru	1.65	0.36	0.75	0.5	0.2
Total for the period beyond 1 year					76

2. Transfer from deposition to dose from ingestion

(a) Transfer from deposition to diet

174. The model for the transfer from deposition to diet is:

$$P_{23} = b_1 + b_2 + b_3 e^{-\lambda t}$$

where b_2 is the second-year transfer and $b_3 e^{-\lambda t}$ is the subsequent transfer, in which the elimination of radiocaesium by environmental and physical processes is taken into account. The transfer from deposition to diet beyond the first year is thus represented by:

$$P_{23,2+} = P_{23} - b_1$$

Values of $P_{23,2+}$ and P_{23} derived from long-term fallout measurements of ^{137}Cs are given in Table 7. For all foodstuffs except grain products, the average values of $P_{23,2+}$ given in Table 7 were used for ^{137}Cs in all of the large regions considered in the assessment: 2.1, 1.4, 2.0 and 8.0 Bq a/kg per kBq/m^2 for milk products, leafy vegetables, vegetables/fruit and meat, respectively. In the case of grain products, the value of $P_{23,2+}$ for ^{137}Cs in a large region was assumed to equal the population-weighted mean of the b_1 values estimated for that region (see paragraph 96).

175. The deposition to total diet transfer factor is obtained by weighting the values for the food groups by consumption amounts. Population-weighted food consumption estimates for the large regions considered in the commitment assessment are listed in Table 21. The regional value for the transfer factor for grain products is given along with the weighted total diet transfer factor.

(b) Transfer from diet to body

176. The transfer factor from total diet to body burden, P_{34}, is the quotient of normalized body burden and normalized dietary concentration. These values vary only because of consumption differences. The value can be derived by multiplying total food Consumption (kg/a) by 143 Bq d per Bq (residence time in body) and dividing by 365 d/a and 70 kg (body mass). The results are listed in Table 21. The median value for these large regions is 2.8 Bq a/kg per Bq a/kg.

(c) Transfer from body to effective dose equivalent

177. The transfer factor from the time-integrated concentration in the body to the effective dose equivalent, P_{45}, is, for ^{137}Cs, equal to 2.5 µSv per Bq a/kg, as derived in para. 169.

178. The overall transfer factor for ^{137}Cs from deposition to total diet to body to effective dose equivalent in the time period beyond the first year, $P_{25,2+}$, is given in Table 21. The values average 20 µSv per kBq/m^2 in the northern and temperate countries and about 25 µSv per kBq/m^2 in southern countries.

179. The transfer of ^{134}Cs from deposition to effective dose equivalent may be related to ^{137}Cs deposition, taking into account the lower deposition (^{134}Cs/^{137}Cs = 0.5) and the higher dose per unit intake (^{134}Cs/^{137}Cs = 1.4). This gives effective dose equivalents from ^{134}Cs 70% of those from ^{137}Cs in the first year. Subsequent transfer is less because of the shorter half-life of ^{134}Cs, but most significant transfer to most foods occurs within the first few years of deposition. Average results for all countries show the ^{134}Cs ingestion dose to be 65% of that from ^{137}Cs, corresponding to 70% of the first-year ^{137}Cs dose and 60% of the subsequent ^{137}Cs dose.

B. AVERAGE DOSE EQUIVALENT COMMITMENTS IN LARGE REGIONS

180. The effective dose equivalent commitments from all radionuclides released in the accident are evaluated in Table 22. These are the average results for the large regions. The first-year dose is the population-weighted result of the effective dose equivalents given in Table 18. The component of dose from exposure or intake after the first year is determined by multiplying the population-weighted ^{137}Cs deposition density in the region by the total $P_{25,2+}$ transfer factor, comprising external gamma exposure (invariant across regions and derived in paragraph 173) and doses from ^{137}Cs and ^{134}Cs in foods (derived in paragraphs 178 and 179).

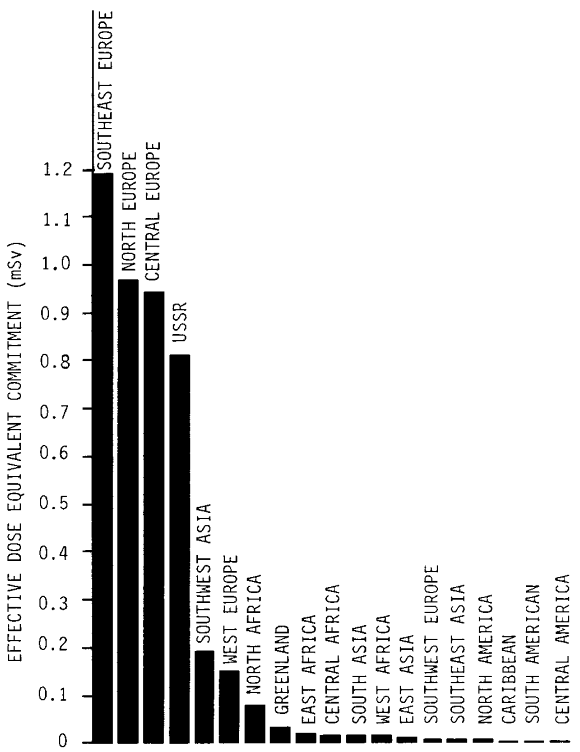

Figure XXII. Regional average effective dose equivalent commitments from the Chernobyl accident.

181. The results range from 1,200 µSv in southeastern Europe (Bulgaria, Greece, Italy, Yugoslavia), 970 µSv in Scandinavia, 940 µSv in central Europe, 820 µSv in the USSR and 510 µSv in eastern Mediterranean countries to 20 µSv or less in other regions. These results are illustrated in Figure XXII. Further evaluations of regional effective dose equivalent commitments are presented in the following Section, VI.C.

C. PATHWAY AND RADIONUCLIDE CONTRIBUTIONS

182. The relative contributions of external and internal irradiation to the effective dose equivalent commitment vary from one region to another. The external irradiation dose pathway becomes relatively more important as time goes on, and is the dominant contributor to the effective dose equivalent commitment in all but the southern countries. The median contributions to the effective dose equivalent commitments from external irradiation and ingestion are approximately 60–40% in northern countries, 55–45% in temperate countries and 45–55% in southern countries.

183. Caesium-137 is the dominant radionuclide contributing to the effective dose equivalent commitment, accounting for about 75%, 70% and 65% in northern, temperate and southern countries, respectively. Because of its shorter half-life, ^{134}Cs contributes much less to the effective dose equivalent commitment than ^{137}Cs via the external exposure pathway. Overall, the contribution of ^{134}Cs to the effective dose equivalent commitment is about 20% of the total in all regions. The contribution from ^{131}I ranges from less than 1% in northern countries to about 10% in southern countries. The remaining 4% or 5% of the effective dose equivalent commitment comes from other radionuclides that caused exposures within the first year.

184. The pathway and radionuclide contributions to the effective dose equivalents, including both the first- year components and the contributions over all time, are illustrated in Figure XVIII.

VI. COLLECTIVE DOSE COMMITMENT

185. On the basis of available measurements, calculations have been completed of the first~year doses in 34 countries and the dose commitments in several large regions. Using transfer factors derived from these results, dose estimates may be made for the remaining areas of the northern hemisphere. These areas, generally far removed from the accident site, received only trace deposition of radioactive materials and therefore make only small contributions to the total collective dose equivalent. Nevertheless, for completeness, the entire northern hemisphere is considered in the dose assessment. This is done in two steps: (a) by considering the relationship between deposition and distance to estimate ^{137}Cs deposition in all regions; and (b) by applying a general transfer factor based on ^{137}Cs deposition to estimate the effective dose equivalent commitment from all pathways and radionuclides.

A. CAESIUM- 137 DEPOSITION WITH DISTANCE FROM CHERNOBYL

186. It may be expected that radionuclide deposition and radiation doses generally decrease with distance from a

release by virtue of geographic spreading and dilution in the atmosphere. Of course, there may be significant variations within the first hundreds of kilometres, depending on the exact course of the plumes and the rainfall pattern. In the case of the accident at Chernobyl, however, the release lasted several days, during which the wind changed to all directions, so even these variations were minimized.

187. Figure XXIII shows the relationship between ^{137}Cs deposition and distance, based on measurements in the 33 assessed countries outside the USSR. There is seen to have been a relatively uniform decrease in the average ^{137}Cs deposition density with distance from Chernobyl. An envelope of points is shown along with the central power-function curve, from which the ^{137}Cs deposition densities in the various regions are estimated. The average ^{137}Cs deposition densities in the five main regions of Europe, based on measurements, are shown.

188. In Figure XXIII the distance to a particular region is the population-weighted average of the distances to the capital cities or to the approximate population centres of the countries in the region. The average ^{137}Cs deposition density in the region is then selected from the central curve in Figure XXIII.

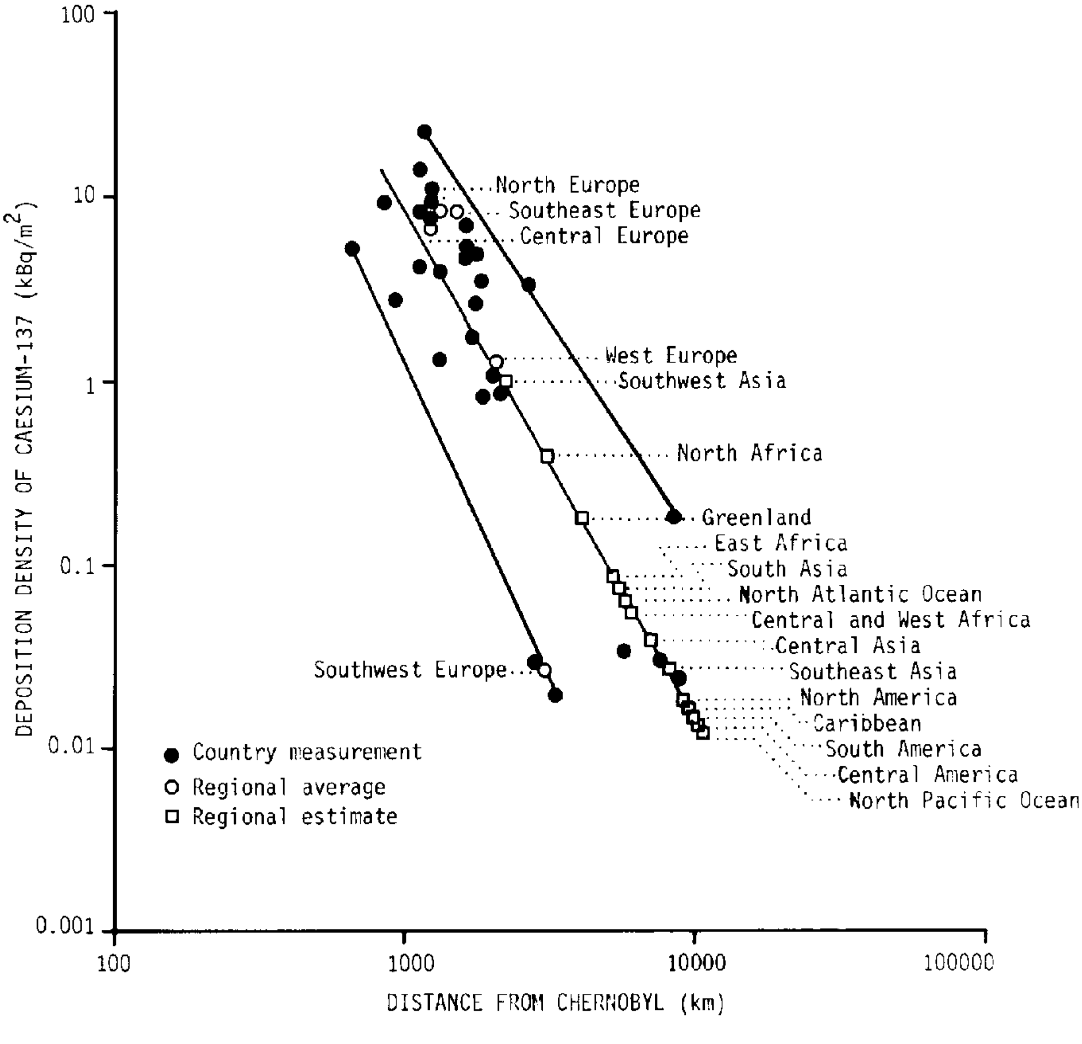

Figure XXIII. Deposition density of caesium-137 with distance from the Chernobyl reactor.

B. TRANSFER FACTOR FOR TOTAL DOSE COMMITMENT BASED ON CAESIUM-137 DEPOSITION

189. For the purpose of estimating exposures from the Chernobyl accident in countries for which measurements are unavailable, it is necessary to have a general transfer factor that accounts for the total effective dose equivalent commitment from all radionuclides and all pathways based on extrapolated estimates of ^{137}Cs deposition density.

190. The first component of this transfer factor from external irradiation was derived in paragraphs 159-161 and 173. The summary values are entered in Table 23, which compiles the general transfer factors for southern (<40°), temperate (41–55°) and northern (>55°) latitudinal regions. For external irradiation, the same assumptions are used for all regions, so the components of the transfer factor per unit ^{137}Cs deposition are the same.

191. Because of differences in agricultural conditions in countries at the time of the accident, some latitudinal

dependence must be introduced into the components of the transfer factor from the ingestion pathway. The transfer factors to effective dose equivalent for ^{137}Cs from first-year ingestion were derived in Table 20. The population-weighted values for northern, temperate and southern latitudes are approximately 15, 20 and 25 µSv per kBq/m^2. The values for ^{134}Cs, based on ^{137}Cs deposition amounts, are 70% of the corresponding values for ^{137}Cs. These estimates are entered in Table 23.

192. After the first year, the transfer factor components for ^{137}Cs ingestion are 20 µSv per kBq/m^2 at northern and temperate latitudes and 25 µSv per kBq/m^2 at southern latitudes (Table 21 and paragraph 178). The corresponding estimates for ^{134}Cs are 60% of the ^{137}Cs estimates (paragraph 179).

193. Regional (i.e., northern, temperate or southern) values of ^{131}I transfer factors may be selected from Table 19 and from Figure XX. Based on the fit to calculated values for individual countries or their subregions, approximate average values are 5, 50 and 100 µSv per kBq/m^2 for countries at northern, temperate and southern latitudes, respectively. These are the thyroid dose equivalents relative to ^{131}I deposition density. The contribution to the effective dose equivalent is obtained by multiplying them by the weighting factor for the thyroid (0.03). The transfer factor may be based on ^{137}Cs deposition by multiplying further by the average ratio of ^{131}I to ^{137}Cs deposition, 6.2 (Table 11). The resulting transfer factor components for ^{131}I, for the first year only, are 1, 10 and 20 µSv per kBq/m^2.

194. The components of the transfer factor based on ^{137}Cs deposition to effective dose equivalent commitment from the two major pathways and from the dominant radionuclides are summarized in Table 23. It must be understood that these factors apply to the conditions at the time following the accident and to the average composition of radionuclides in the dispersed material as observed. The latitudinal differences apply only to the ingestion pathway.

C. ESTIMATES OF COLLECTIVE EFFECTIVE DOSE EQUIVALENT COMMITMENT

195. Estimates of collective dose equivalent commitments for all regions of the northern hemisphere are compiled in Table 24. To allow an estimate to be made of the total release of ^{137}Cs, this listing includes also the ocean areas north of the equator. The country populations given in [U3] have been adjusted, based on individual country growth rates, to values appropriate for 1986. The population of the northern hemisphere (4.3 10^9) makes up 88% of the total world population.

196. The effective dose equivalent commitments in the large regions (Table 22) were estimated on the basis of measurements in the first year and projections for subsequent times. The estimates for European regions are carried forward to Table 24, with a few additional countries having been included in some regions. The product of population and effective dose equivalent commitment is the estimated collective effective dose equivalent commitment.

197. Countries outside Europe but still in the northern hemisphere (i.e., the countries of Asia, North America and parts of Africa and South America) have been grouped in several regions. The population-weighted distances to individual countries are used as the distances to the regions for the purpose of estimating average ^{137}Cs deposition (Figure XXIII). For these regions, all of which lie at southern latitudes (<40°), the transfer factor 190 µSv per kBq/m^2 (Table 23) is used. The estimated effective dose equivalent commitments for all geographical regions are illustrated in Figure XXII. Multiplication by the populations of the regions gives the collective effective dose equivalent commitments.

198. The total collective effective dose equivalent commitment from the accident is estimated to be 600,000 man Sv. From Table 24, it is seen that 53% is experienced in European countries, 36% in the USSR, 8% in Asia, 2% in Africa and 0.3% in North, Central and South America.

199. Alternative estimates of collective effective dose equivalent commitment have been made for the 34 countries for which more detailed radiological data were available. These estimates are based on the total production for human consumption of foods in all the countries. There is no need to consider where the foods are consumed. The collective effective dose equivalent commitment estimates based on production are generally in close agreement with the estimates based on individual consumption rates in countries and populations. The production-based estimated total for all 34 countries is just 10% greater than the consumption-based estimate.

200. It is difficult to assess the uncertainty in the Committee's estimates. Much of the dose commitment has not yet been experienced, and can only be 20 calculated on the basis of projection models. The general methodology for projections used by the Committee, has been developed after some years of ^{137}Cs studying the transfer factors for ^{137}Cs, the radionuclide of primary concern. The comparison of the calculations by the Committee for the first year and the calculations by individual countries (Table 18) showed reasonable agreement. When the first-year integrated body burdens calculated by the Committee are compared with the actual measurements (Table 16), it can be seen that the estimate of effective dose equivalent commitment from ingestion may be high by perhaps 50%. As discussed above, a possible explanation for this discrepancy is the difficulty of knowing the radionuclide content of what is actually being consumed, given the limitations of food-sampling techniques. The Committee believes, accordingly, that its estimate is unlikely to be an underestimate of the effective dose equivalent commitment that will actually occur but that it might be an overestimate by a few tens of per cent.

D. COLLECTIVE DOSE COMMITMENT PER UNIT RELEASE

201. From estimates of the average ^{137}Cs deposition density in the regions included in Table 24, an estimate can be made of the total amount of ^{137}Cs released in the accident, independent of estimates that could be made near the reactor site at the time of the accident. The sum of the products of average deposition density and area for all land and ocean regions gives an estimated total ^{137}Cs deposit of 70 PBq. Of this total, some 42% was deposited within the USSR, 37% in Europe, 6% in the oceans and the remainder in the other regions of the northern hemisphere.

202. This estimated ^{137}Cs total deposit in the northern hemisphere may be compared with the original ^{137}Cs release estimate of 38 PBq ± 50% (Table 1). These estimates are in reasonable agreement, given the magnitude of the uncertainties associated with each estimate. The estimated release of 70 PBq would correspond to about 25% of the ^{137}Cs calculated to have been in the reactor core.

203. The reported release of ^{134}Cs from the damaged reactor was about 10% of the core inventory (Table 1). Based on the higher estimate of ^{137}Cs release and on the activity relationship, the ^{134}Cs release could have been 35 PBq, corresponding to a percentage release of 18%. If the release of ^{131}I, originally estimated to have been 20% of the total ^{131}I in the core, was, instead, 25%, the estimated release would be 330 PBq.

204. From the calculations or estimates of the collective effective dose equivalent commitments listed in Table 24, it may be determined that 430,000 man Sv, is due to ^{137}Cs, 120,000 man Sv to ^{134}Cs and 37,000 man Sv (collective effective dose) to ^{131}I. The remaining 20,000 man Sv was contributed by shorter-lived radionuclides deposited immediately after the accident.

205. From these values, the collective effective dose equivalent commitments per unit release of the major radionuclides may be estimated as follows:

^{137}Cs: 430,000 man Sv/ 70 PBq = 6 10^{-12} man Sv per Bq
^{134}Cs: 120,000 man Sv/ 35 PBq = 3 10^{-12} man Sv per Bq
^{131}I : 37,000 man Sv/330 PBq = 1 10^{-12} man Sv per Bq

For the thyroid dose equivalent from ^{131}I, the estimate would be the above value divided by the thyroid weighting factor of 0.03.

206. These estimates pertain to the particular conditions that prevailed at the time of the accident, but they may be a useful point of reference for this type of radiation source. For comparison, the collective effective dose equivalent commitments per unit release from another source, atmospheric nuclear testing, are as follows [Ul]:
^{137}Cs: 2,200,000 man Sv/960 PBq = 2 10^{-12} man Sv per Bq
^{131}I : 110,000 man Sv/700 EBq = 2 10^{-16} man Sv per Bq
These resulted from releases largely into the stratosphere and apply to world populations of 3.2 10^9 persons (for ^{131}I) at the time of the main releases and 4 10^9 persons (for ^{137}Cs) during the main exposure period. Because the fallout from weapons tests was injected into the stratosphere, a longer time elapsed for decay of ^{131}I before deposition.

207. Estimates of collective effective doses per unit release have also been made for modelled dispersion from nuclear installations (Annex B). Based on a population density of 25 persons per km^2, these estimates are [W5]:
^{137}Cs: 5 10^{-12} man Sv per Bq
^{131}I: 4 10^{-13} man Sv per Bq

E. COLLECTIVE DOSE COMMITMENTS FROM OTHER RADIONUCLIDES

208. This assessment has accounted for the main radionuclides contributing to the collective dose. A few other radionuclides in the release from the accident were widely dispersed and could be considered as additional contributors to the total collective dose commitment. For completeness, the collective effective dose equivalent commitments may be summarized as follows:

Radio-nuclide	*Release (PBq)*	*Dose factor (man Sv per PBq)*	*Collective effective dose equivalent commitment (man Sv)*
^{3}H	2	0.4	1
^{14}C	0.005	110,000	550
^{85}Kr	33	0.21	7
^{133}Xe	1,700	0.05	85
^{129}I	0.00003	170,000	5
Total			650

209. The amounts of noble gases ^{85}Kr and ^{133}Xe in the reactor core, which were assumed to be entirely released, were given in Table 1. Releases of ^{3}H, ^{14}C, and ^{129}I were not reported, but their generation rates in the reactor are assumed, roughly, to be 1,000, 10 and 0.05 GBq per MW a, respectively, which may be compared to the ^{85}Kr generation rate of 14,000 GBq per MW a [W5]. The percentage release has been taken as 100% for ^{3}H and (as for ^{137}Cs) 25% for ^{14}C and ^{129}I. The ^{129}I dose has been truncated at 10,000 years. The doses from ^{129}I and ^{14}C are delivered over long times but at very low dose rates. The collective effective dose equivalent commitment from these radionuclides is negligible.

VII. SUMMARY

210. The accident at the Chernobyl nuclear power station was a serious occurrence, indeed a tragic event for the people most closely affected in the USSR. The material costs of control, resettlement and decontamination have been enormous. Some of the people who dealt with the emergency lost their lives. Although populations were exposed in the countries of Europe and, to a lesser extent, in countries throughout the northern hemisphere, the radiation exposures were, in perspective, not of great magnitude.

211. The detectability of radiation in very small concentrations has allowed extensive measurement of the released radioactive materials in the environment, and it has been possible to make a complete inventory of ^{137}Cs, the main component of the release. The amount 70 PBq of ^{137}Cs corresponds to 22 kg of caesium, which was, however, dispersed across an entire hemisphere of the earth. Radionuclides are a unique class of substance whose environmental behaviour can be studied in detail at such trace levels.

212. In Europe, the highest effective dose equivalents in the first year were 760 µSv in Bulgaria, 670 µSv in Austria, 590 µSv in Greece and 570 µSv in Romania, followed by other countries of northern, eastern and south-eastern Europe (Table 18). For reference, the average annual effective dose equivalent from natural sources is 2,400 µSv. The doses in countries farther to the west in Europe and in the countries of Asia, Africa and North and South America were much less, which is in accord with the deposition pattern.

213. Exposures, mainly from released ^{137}Cs, will continue for a few tens of years from the external irradiation and ingestion pathways. Estimates of dose commitments have been made for larger geographical regions, based on projection models developed from fallout measurement experience. Transfer factors derived for northern, temperate and southern latitudes provide estimates of the effective dose equivalent commitment from all radionuclides and all pathways referred to the deposition density of ^{137}Cs . From the ^{137}Cs deposition versus distance relationship, dose estimates for the entire northern hemisphere are obtained. The estimated collective effective dose equivalent commitment from the accident is of the order of 600,000 man Sv.

214. This assessment of radiation exposures from the Chernobyl accident has dealt with the main radionuclides and pathways that contribute to the collective dose. It is recognized that many more features of exposure from other radionuclides and other pathways have been and continue to be investigated in various countries. The Committee will undoubtedly wish to review these findings in the expectation that they will lead to a better understanding of the behaviour and effects of radionuclides in the environment and to improved methods for assessing radiation exposure.

Table 1
Core inventory and estimate of total release of radionuclides
[I1]

Radionuclide	*Half-life* [a]	*Inventory (EBq)* [b]	*Percentage released* [c]
^{85}Kr	10.72 a	0.033	~100
^{133}Xe	5.25 d	1.7	~100
^{131}I	8.04 d	1.3	20
^{132}Te	3.26 d	0.32	15
^{137}Cs	30.0 a	0.29	13
^{134}Cs	2.06 a	0.19	10
^{89}Sr	50.5 d	2.0	4
^{90}Sr	29.12 a	0.2	4
^{95}Zr	64.0 d	4.4	3
^{99}Mo	2.75 d	4.8	2
^{103}Ru	39.3 d	4.1	3
^{106}Ru	368 d	2.1	3
^{140}Ba	12.7 d	2.9	6
^{141}Ce	32.5 d	4.4	2
^{144}Ce	284 d	3.2	3
^{239}Np	2.36 d	0.14	3
^{238}Pu	87.74 a	0.001	3
^{239}Pu	24065 a	0.0008	3
^{240}Pu	6537 a	0.001	3
^{241}Pu	14.4 a	0.17	3
^{242}Cm	163 d	0.026	3

a Reference [I5].
b Decay corrected to 6 May 1986.
c Stated accuracy: ±50%, except for noble gases.

Table 2
Activity ratios of radionuclides released in the Chernobyl accident relative to caesium-137
[I3]

Date	^{95}Zr	^{103}Ru	^{106}Ru	^{131}I	^{140}Ba	^{141}Ce	^{144}Ce
30 April 1986	0.4	2.1	0.3	4.0		0.6	0.7
1 May 1986	1.5	5.2	0.8	13		3.2	5.5
2 May 1986	6.7	2.9	0.8	4.1	5.7	5.5	4.3
4 May 1986	5.3	5.2	1.1	6.2	9.6	4.8	3.8
6 May 1986	11	6.4	3.8	4.1	5.1	10	11

Table 3
Effective dose equivalent factors for cloud gamma irradiation
[K5]

Radionuclide	*Effective dose equivalent per unit time-integrated concentration in air (nSv per Bq d m⁻³)*	*Radionuclide*	*Effective dose equivalent per unit time-integrated concentration in air (nSv per Bq d m⁻³)*
^{89}Sr	0.033	^{131}I	1.44
^{90}Sr	0.008	^{132}Te [a]	9.78
^{95}Zr	2.88	^{133}I	2.33
^{95}Nb	2.99	^{134}Cs	6.03
^{99}Mo [a]	1.04	^{136}Cs	8.47
^{103}Ru [a]	1.81	^{137}Cs [a]	2.30
^{106}Ru [a]	0.874	^{140}Ba	0.718
^{110m}Ag	10.7	^{140}La	9.26
^{115}Cd [a]	1.39	^{141}Ce	0.293
^{125}Sb	1.61	^{143}Ce	1.01
^{127}Sb	2.55	^{144}Ce [a]	0.275
^{129m}Te [a]	0.324	^{239}Np	0.636
^{131m}Te [a]	2.90		

a Includes daughter radionuclide.

Table 4
Dose equivalent factors for the inhalation of radionuclides
[H3, N3]

Radionuclide	*Inhalation class* [a]	*Thyroid dose equivalent per unit inhaled activity (nSv Bq⁻¹)*		*Effective dose equivalent per unit inhaled activity (nSv Bq⁻¹)*	
		Infants	*Adults*	*Infants*	*Adults*
^{89}Sr	D	8.0	0.41	21	1.8
^{90}Sr	D	22	2.2	130	59
^{95}Zr	W	2.2	0.78	26	4.3
^{95}Nb	Y	0.42	0.36	27	1.6
^{99}Mo [b]	Y	0.23	0.033	7.9	1.1
^{103}Ru [b]	Y	0.82	0.26	8.0	2.4
^{106}Ru [b]	Y	12	1.7	900	130
^{110m}Ag [b]	Y	38	6.4	210	22
^{115}Cd	Y	0.12	0.018	8.9	1.1
^{125}Sb	W	2.1	0.32	27	3.3
^{127}Sb	W	0.39	0.062	12	1.6
^{129m}Te [b]	W	1.1	0.16	4.7	6.5
^{131m}Te [b]	W	180	33	21	1.6
^{132}Te [b]	W	260	58	37	2.5
^{131}I	D	2200	270	66	8.1
^{133}I	D	420	44	14	1.5
^{134}Cs	D	6.5	11	7.3	13
^{136}Cs	D	4.2	1.7	4.7	2.0
^{137}Cs [b]	D	5.6	7.9	6.4	8.6
^{140}Ba	D	1.5	0.26	8.2	1.0
^{140}La	W	0.20	0.069	8.6	1.3
^{141}Ce	Y	0.039	0.025	17	2.4
^{143}Ce	Y	0.045	0.0062	6.8	0.92
^{144}Ce [b]	Y	1.4	0.29	700	100
^{239}Np	W	0.043	0.0058	4.7	0.66

a D, W, Y refer to retention times in the lungs (days, weeks and years, respectively).
b Includes daughter radionuclide.

Table 5
Effective dose equivalent factors for external irradiation from deposited radionuclides
[B10]

Radionuclide	*Effective dose equivalent per unit deposition density for outdoor exposure (nSv per Bq m^{-2})*	
	30 days to 1 year	*After 1 year*
^{103}Ru	0.691	0.00128
^{106}Ru	2.09	1.65
^{131}I	0.015	0.0
^{134}Cs	18.6	36.2
^{137}Cs	8.04	264

Table 6
Dose equivalent factors for the ingestion of radionuclides
[H3, N3]

Radionuclide	*Thyroid dose equivalent per unit ingested activity (nSv Bq^{-1})*		*Effective dose equivalent per unit ingested activity (nSv Bq^{-1})*	
	Infants	*Adults*	*Infants*	*Adults*
^{131}I	3500	430	110	13
^{134}Cs	11	18	12	20
^{137}Cs	9	13	9.3	14

Table 7
Parameters of caesium-137 deposition to diet transfer function derived from long-term fallout measurements
(Bq a kg^{-1} per kBq m^{-2})
[U1, E7]

Country	*First year transfer* b_1	*Transfer beyond first year* $P_{23, 2+}$	*Total transfer* P_{23}
Milk products			
Argentina	7.7	1.1	8.8
Denmark	3.0	2.8	5.8
United States	3.3	2.4	5.7
Average	4.7	2.1	6.8
Grain products			
Argentina	2.0	6.9	8.9
Denmark	3.3	23	27
United States	1.5	7.1	8.6
Average	2.3	12	15
Vegetables			
Argentina	2.1	2.3	4.4
Denmark	2.4	1.1	3.5
United States	1.4	0.7	2.1
Average	2.0	1.4	3.3
Fruit			
Argentina	0.5	2.6	3.1
Denmark	1.8	1.7	3.5
United States	1.7	1.8	3.6
Average	1.3	2.0	3.4
Meat			
Argentina	22	4.1	26
Denmark	12	12	24
United States	2.0	8.2	10
Average	12	8	20
Total diet			
Argentina	6.3	1.8	8.1
Denmark	4.0	8.0	12
United States	1.9	3.5	5.4
Average	4.1	4.4	8.5

Table 8
Area, population, food production and food consumption in assessed countries

Country	*Area (10^3 km^2)*	*Population (10^6)*		*Food production (10^6 kg a^{-1})*					*Food consumption per caput (kg a^{-1})*				
		Infants	*Total*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*
North Europe													
Denmark	43.1	0.07	5.11	1100	420	250	140	340	173	80	18	150	66
Finland	338.1	0.07	4.87	1340	460	61	420	330	263	73	6	169	71
Norway	323.9	0.06	4.16	1060	280	190	400	210	202	65	37	120	76
Sweden													
Region 1	115.8	0.02	1.30	280	25	-	46	54	222	77	36	121	56
Region 2	105.9	0.004	0.26	43	5	-	8	7	222	77	36	121	56
Region 3	219.2	0.09	6.79	1530	676	13	1190	413	222	77	36	121	56
Central Europe													
Austria	83.9	0.09	7.56	1260	653	253	1420	673	145	66	71	136	99
Czechoslovakia													
Region 1	18.7	0.03	2.06	800	430	67	220	200	134	132	25	107	86
Region 2	75.0	0.15	10.40	4900	2900	270	870	1300	134	132	25	107	86
Region 3	34.2	0.04	3.02	1000	530	120	390	250	134	132	25	107	86
German Dem. Rep.													
Region 1	19.3	0.03	2.34	380	350	230	190	410	115	97	45	266	92
Region 2	25.8	0.04	2.62	620	420	280	230	540	115	97	45	266	92
Region 3	63.2	0.16	11.67	1600	1000	680	4100	1500	115	97	45	266	92
Germany, Fed. Rep.													
Region 1	142.4	0.48	40.96	3000	2600	1440	4600	3200	108	80	23	112	55
Region 2	59.5	0.15	12.39	1200	890	580	1900	750	108	80	23	112	55
Region 3	46.8	0.09	7.68	1700	700	150	470	750	108	80	23	112	55
Hungary													
Region 1	35.2	0.06	5.16	252	391	301	137	815	185	110	25	160	80
Region 2	57.8	0.07	5.46	503	783	776	678	1630	185	110	25	160	80
Poland	312.7	0.64	37.46	16000	23200	3440	6900	2740	160	180	20	132	67
Romania													
Region 1	99.2	0.12	7.63	1360	1660	390	2570	905	150	190	40	240	86
Region 2	59.9	0.09	5.62	820	1000	235	1550	546	150	190	40	240	86
Region 3	78.4	0.15	9.48	1080	1310	310	2030	716	150	190	40	240	86
Switzerland													
Region 1	3.7	0.003	0.30	102	31	11	72	48	180	99	29	230	110
Region 2	12.4	0.02	2.03	345	105	38	244	162	180	99	29	230	110
Region 3	12.5	0.03	2.36	347	105	38	246	163	180	99	29	230	110
Region 4	12.7	0.02	1.80	355	107	39	251	167	180	99	29	230	110

Table 8 (continued)

Country	*Area (10^3 km^2)*	*Population (10^6)*		*Food production (10^6 kg a^{-1})*					*Food consumption per caput (kg a^{-1})*				
		Infants	*Total*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*
West Europe													
Belgium	30.5	0.14	9.86	920	520	540	750	440	180	65	55	150	40
France													
Region 1	148.0	0.15	10.50	4150	1500	1300	1700	2100	130	84	84	132	73
Region 2	270.0	0.41	28.90	2520	5800	2900	6200	1300	130	84	84	132	73
Region 3	133.0	0.20	14.20	1330	600	1850	700	500	130	84	84	132	73
Ireland	70.3	0.08	3.54	100	220	270	390	220	163	68	40	69	50
Luxembourg	2.6	0.005	0.37	80	40	12	60	30	110	95	33	150	88
Netherlands	37.3	0.22	14.49	2100	310	2800	490	2200	145	65	65	135	70
United Kingdom													
Region 1	138.1	0.72	48.06	11000	5000	1200	4500	530	163	68	40	100	71
Region 2	86.5	0.10	6.56	730	780	88	1200	210	163	68	40	100	71
Region 3	19.5	0.02	1.25	730	220	13	180	96	163	68	40	100	71
South Europe													
Bulgaria													
Region 1	48.6	0.06	3.71	630	460	280	580	280	123	179	20	76	64
Region 2	62.3	0.08	5.18	760	550	340	700	340	123	179	20	76	64
Greece													
Region 1	56.8	0.04	4.22	300	400	170	800	200	80	100	30	250	60
Region 2	75.2	0.10	5.61	500	500	220	2000	300	80	100	30	250	60
Italy													
Region 1	119.8	0.23	26.03	10000	3000	1000	10000	1000	90	110	50	150	60
Region 2	181.5	0.39	30.88	2000	5000	2000	10000	600	90	110	50	150	60
Portugal	91.7	0.14	9.94	530	615	1630	953	425	45	125	113	105	42
Spain													
Region 1	100.9	0.10	7.50	820	828	1370	2100	478	104	88	124	132	62
Region 2	403.8	0.40	29.80	3280	3310	5490	8400	1910	104	88	124	132	62
Yugoslavia													
Region 1	89.5	0.13	7.87	2200	3400	230	4200	880	146	146	55	128	55
Region 2	153.5	0.22	13.5	3700	5700	380	7200	150	146	146	55	128	55
Region 3	12.8	0.02	1.12	300	400	40	60	70	146	146	55	128	55
USSR													
Region 1	207.6	0.17	10.01	6360	1300	217	754	1040	332	133	37	118	63
Region 2	269.4	0.35	21.94	10800	3050	785	2270	1800	332	133	37	118	63
Region 3	485.1	0.51	29.80	8270	1780	474	1510	1300	332	133	37	118	63
Region 4	4532.6	2.47	139.70	49300	20900	4630	14800	9400	332	133	37	118	63
Region 5	16696.3	2.12	77.37	17900	10000	1780	5670	3600	332	133	37	118	63

Table 8 (continued)

Country	Area (10^3 km^2)	Population (10^6)		Food production (10^6 kg a^{-1})					Food consumption per caput (kg a^{-1})				
		Infants	Total	Milk products	Grain products	Leafy vegetables	Vegetables /fruit	Meat	Milk products	Grain products	Leafy vegetables	Vegetables /fruit	Meat
West Asia													
Cyprus	9.3	0.01	0.64	50	20	100	100	50	83	94	87	315	83
Israel	20.7	0.08	3.87	470	200	660	950	220	120	130	140	190	60
Syria	185.2	0.18	8.98	1100	1900	300	1500	200	70	190	30	340	22
Turkey	774.8	1.00	52.00	5000	20000	5000	20000	2000	125	200	100	150	40
East Asia													
China	9571.3	18.63	1046.39	5380	216000	28400	170000	30000	5	229	29	173	30
India	3287.3	25.38	750.90	26300	120000	18900	61000	3060	39	183	28	89	5
Japan	358.8	1.43	121.01	4660	13500	5600	16800	16900	50	193	30	180	120
North America													
Canada	9215.4	0.38	25.36	4550	10600	281	5080	3980	181	93	21	301	130
United States	9372.6	3.75	238.74	39400	71800	5970	61600	31700	174	91	25	260	146

Table 9
Time-integrated concentration of radionuclides in ground level air

Country	Radionuclide (Bq d m⁻³)													
	^{90}Sr	^{95}Zr	^{99}Mo	^{103}Ru	^{106}Ru	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{137}Cs	^{140}Ba	^{141}Ce	^{144}Ce	^{239}Np
North Europe														
Denmark	0.012	0.15		1.1	0.33	6.7	2.1	0.26	0.10	0.49	0.31	0.15	0.10	
Finland		0.43	1.4	1.8	0.53	210	14	3.8	1.5	6.5	3.4	0.47	0.36	2.1
Norway				(11)	(2.4)	(85)	(14)	(2.8)	(1.2)	(5.3)	(2.7)	(0.37)		
Sweden														
Region 1		0.22		1.0	0.37	23	0.83	0.44	0.14	0.78	0.47		0.14	
Region 2		0.002		0.33	0.096	4.6		0.13	0.032	0.23	0.07		0.003	
Region 3		0.39		2.1	0.60	28	1.2	0.60	0.20	1.10	0.76		0.25	
Central Europe														
Austria	(0.58) [a]		(12)	(28)	5.8	120	69	8.14	(1.6)	14	(6.9)	(0.32)	(0.14)	(0.14)
Czechoslovakia														
Region 1				16	(3.6)	140	43	6.0	(1.8)	12				
Region 2				23	1.1	170	94	6.8	(2.1)	14				
Region 3				26	4.0	140	85	5.4	(1.7)	11				
German Dem. Rep.														
Region 1		0.21		14	(6.9)	160	72	11	2.8	23		0.60	0.21	
Region 2		0.22		6.1	(2.6)	66	27	4.1	0.58	8.5		0.045	0.026	
Region 3		(0.22)		(6.1)	(2.6)	(66)	(27)	(4.1)	(0.58)	(8.5)		(0.045)	(0.026)	
Germany, Fed. Rep.														
Region 1				3.3	0.78	16	20	1.4	0.52	2.6	1.3		0.052	
Region 2				9.7	2.3	52	64	4.2	1.5	7.7	3.9		0.15	
Region 3				16	3.9	84	100	7.0	2.6	13	6.5		0.26	
Hungary														
Region 1			1.3	14	(1.8)	34	33	1.9	(0.54)	3.5	0.72	0.08	0.0006	
Region 2		0.04	1.3	17	2.2	25	20	2.3	0.74	4.8	2.6	0.17	0.13	
Poland		0.31	7.9	20	2.2	72	69	4.1	1.6	8.2	1.4	0.24	0.14	
Romania														
Region 1	(1.2)	(8.4)		14	3.6	43	(70)	5.1	(1.2)	11	(5.2)			
Region 2	(1.9)	(13)		84	21	340	(110)	8.0	(1.9)	17	(8.1)			
Region 3	(1.5)	(11)		(49)	(12)	(190)	(89)	(6.6)	(1.6)	(14)	(6.6)			
Switzerland														
Region 1			(2.3)	(7.8)	(2.6)	33	(22)	(2.1)	(0.43)	4.2	(2.0)	(0.073)		(0.27)
Region 2			(1.9)	(6.2)	(2.1)	30	(18)	(1.7)	(0.34)	3.3	(1.6)	(0.058)		(0.22)
Region 3			(2.6)	(8.5)	(2.9)	28	(24)	(2.3)	(0.47)	4.6	(2.2)	(0.080)		(0.30)
Region 4			(1.6)	(5.4)	(1.8)	28	(15)	(1.5)	(0.30)	2.9	(1.4)	(0.051)		(0.19)

Table 9 (continued)

Country	Radionuclide (Bq d m^{-3})													
	^{90}Sr	^{95}Zr	^{99}Mo	^{103}Ru	^{106}Ru	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{137}Cs	^{140}Ba	^{141}Ce	^{144}Ce	^{239}Np
West Europe														
Belgium	0.05			6.5	1.5	30	20	2.0	1.0	5.0	2.0			
France														
Region 1				(0.09)	(0.018)	0.30	(0.29)	0.03	(0.009)	0.06	(0.024)	(0.002)	(0.002)	
Region 2				0.81	0.16	2.7	2.7	0.27	0.081	0.54	0.22	0.016	0.016	
Region 3				(4.8)	(0.96)	24	(16)	1.4	(0.48)	3.2	(1.3)	(0.096)	(0.096)	
Ireland				0.16	0.044	1.0	0.37	0.058	0.022	0.11	0.086			
Luxembourg	0.05			6.5	1.5	30	20	2.0	1.0	5.0	2.0			
Netherlands			0.69	2.7	0.67	19	6.9	0.92	0.35	2.1	0.92			
United Kingdom														
Region 1, 2				1.4	0.75	5.0	10	0.38	0.17	0.75	0.39			
Region 3				5.6	3.0	12	23	1.5	0.58	3.0	1.5			
South Europe														
Bulgaria														
Region 1, 2		0.39	2.5	28	6.9	41	38	4.5		9.1	22	1.2	1.3	
Greece														
Region 1	1.0	2.0		40	8.0	40	70	7.5		10	2.5	2.3	1.9	
Region 2	1.0	2.0		40	7.0	40	70	7.5		10	2.5	2.3	1.9	
Italy														
Region 1				11	4.7	46	41	2.9	0.59	5.9	3.0			
Region 2				4.9	2.2	26	23	1.6	0.27	2.7	1.4			
Portugal				(0.04)	(0.012)	(0.07)	(0.004)	(0.01)	(0.004)	(0.02)	(0.001)		(0.006)	
Spain														
Region 1				(0.11)	(0.021)	(0.40)		(0.035)	(0.011)	(0.07)	(0.028)			
Region 2				(0.03)	(0.006)	(0.07)		(0.010)	(0.003)	(0.02)	(0.008)			
Yugoslavia														
Region 1			3.6	14	2.7	72	53	3.4		7.4	3.7			
Region 2			3.0	8.7	1.9	57	45	2.5		5.9	2.6			
Region 3			3.6	14	2.7	72	53	3.4		7.4	3.7			
USSR														
Region 1	3.7	15	6	58	12	490	110	29		54	56	12	7.6	190
Region 2	2.4	8.6	11	26	4	160	43	13		21	42	3.7	2.7	63
Region 3	0.7	2.7	8.7	18	4.5	120	34	6.9		13	11	2.7	1.8	28
Region 4	(0.5)	(0.7)	(1.3)	5.7	1.7	33	7.2	2.1		4.1	(3.1)	(0.68)	(0.47)	(4.6)
Region 5	(0.02)	(0.04)	(0.02)	(0.4)	(0.1)	(2.7)	(0.4)	(0.2)		(0.3)	(0.1)	(0.033)	(0.025)	(0.07)

Table 9 (continued)

Country	Radionuclide (Bq d m-3)												
	^{90}Sr	^{95}Zr	^{99}Mo	^{103}Ru	^{106}Ru	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{137}Cs	^{140}Ba	^{141}Ce	^{144}Ce	^{239}Np
West Asia														
Cyprus						(20)		(3.5)		(7.0)				
Israel				14		20	14	3.4		6.5	15			
Syria						(0.16)		(0.015)		(0.03)				
Turkey				24		17	40	3.8	5.8	7.4	36	5.1	36	
East Asia														
China			(0.22)	(0.92)	(0.20)	4.4	(2.6)	(0.34)	(0.099)	(0.66)	(0.39)			
India				(0.074)	(0.010)	0.17	0.016	0.010	0.003	0.035	0.010			
Japan		(0.0006)	(0.01)	(0.70)	(0.14)	3.4	(1.1)	0.14	(0.033)	0.28	(0.020)			
North America														
Canada				(0.073)	0.029	0.14	(0.22)	(0.028)	(0.011)	0.055	(0.028)			
United States				(0.063)	(0.008)	0.27	(0.046)	(0.013)		(0.027)				

a Numbers in parentheses are inferred values.

Table 10
Ratios of integrated concentrations of radionuclides in air to caesium-137

Country	*Radionuclides*							
	^{103}Ru	^{106}Ru	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{140}Ba	^{131}Ce
North Europe								
Denmark	2.2	0.67	14	4.2	0.53	0.21	0.63	0.30
Finland	0.28	0.08	32	2.2	0.58	0.23	0.52	0.07
Norway	(2.0) [a]	(0.45)	(16)	(2.6)	(0.53)	(0.23)	(0.51)	(0.07)
Sweden								
Region 1	1.3	0.47	29	1.1	0.56	0.18	0.59	
Region 2	1.4	0.42	20		0.57	0.14	0.30	
Region 3	1.9	0.55	25	1.1	0.55	0.18	0.69	
Central Europe								
Austria	(2.0)	0.40	8.2	4.8	0.57	(0.11)	(0.48)	(0.02)
Czechoslovakia								
Region 1	1.3	(0.30)	12	3.6	0.50			
Region 2	1.6	0.30	12	6.8	0.49			
Region 3	2.4	0.37	13	7.7	0.49			
German Dem. Rep.								
Region 1	0.61	(0.30)	6.9	3.2	0.50	0.12		0.03
Region 2, 3	0.72	(0.30)	7.7	3.1	0.48	0.07		0.01
Germany, Fed. Rep.								
Region 1	1.3	0.30	6.2	7.6	0.54	0.20	0.50	
Region 2	1.3	0.30	6.8	8.3	0.55	0.20	0.50	
Region 3	1.3	0.30	6.5	8.0	0.54	0.20	0.50	
Hungary								
Region 1	4.0	(0.52)	9.7	9.3	0.54	(0.16)		0.01
Region 2	3.5	(0.46)	5.3	4.3	0.48	0.16		0.04
Poland	2.5	0.26	8.8	8.4	0.50	0.19	0.16	0.03
Romania								
Region 1	1.3	0.33	4.0	(6.4)	0.48	(0.11)	(0.48)	
Region 2	5.0	1.3	20	(6.4)	0.48	(0.11)	(0.48)	
Region 3	(3.6)	(0.89)	(14)	(6.4)	(0.48)	(0.11)	(0.48)	
Switzerland								
Region 1	(1.9)	(0.63)	8.0	(5.3)	(0.50)	(0.10)	(0.48)	(0.02)
Region 2	(1.9)	(0.63)	9.0	(5.3)	(0.50)	(0.10)	(0.48)	(0.02)
Region 3	(1.9)	(0.63)	6.2	(5.3)	(0.50)	(0.10)	(0.48)	(0.02)
Region 4	(1.9)	(0.63)	9.7	(5.3)	(0.50)	(0.10)	(0.48)	(0.02)
West Europe								
Belgium	1.3	0.30	6.0	4.0	0.40	0.20	0.40	
France								
Region 1, 2, 3	1.5	0.30	5.0	(4.8)	0.50	0.15	0.40	0.03
Ireland	1.5	0.40	9.1	3.4	0.53	0.20	0.78	
Luxembourg	1.3	0.30	6.0	4.0	0.40	0.20	0.40	
Netherlands	1.3	0.32	8.9	3.3	0.44	0.17	0.44	
United Kingdom								
Region 1, 2	1.9	1.0	6.7	13	0.51	0.23	0.52	
Region 3	1.9	1.0	3.9	7.7	0.50	0.19	0.50	
South Europe								
Bulgaria								
Region 1, 2	3.1	0.76	4.5	4.2	0.49		2.4	0.13
Greece								
Region 1	4.0	0.80	4.0	7.0	0.75		0.25	0.23
Region 2	4.0	0.70	4.0	7.0	0.75		0.25	0.23
Italy								
Region 1	1.8	0.80	7.8	7.0	0.49	0.10	0.50	
Region 2	1.8	0.81	9.6	8.5	0.59	0.10	0.50	
Portugal	(2.0)	(0.60)	(3.5)	(0.2)	(0.50)	(0.20)	(0.06)	
Spain								
Region 1	(1.5)	(0.30)	(5.7)		(0.50)	(0.15)	(0.40)	
Region 2	(1.5)	(0.30)	(3.5)		(0.50)	(0.15)	(0.40)	

Country	*Radionuclides*							
	^{103}Ru	^{106}Ru	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{140}Ba	^{131}Ce
Yugoslavia								
Region 1	1.8	0.36	9.7	7.2	0.46		0.50	
Region 2	1.5	0.32	9.7	7.6	0.42		0.44	
Region 3	1.8	0.36	9.7	7.2	0.46		0.50	
USSR								
Region 1	1.1	0.23	9.1	2.1	0.55		1.0	0.22
Region 2	1.2	0.19	7.6	2.0	0.62		2.0	0.17
Region 3	1.4	0.34	8.7	2.6	0.52		0.82	0.20
Region 4	1.4	0.40	8.1	1.8	0.50		(0.75)	(0.16)
Region 5	(1.3)	(0.33)	(9.0)	(1.3)	(0.67)		(0.33)	(0.11)
West Asia								
Cyprus			(2.9)		(0.50)			
Israel	2.2		3.1	2.2	0.52		2.3	
Syria			(5.3)		(0.50)			
Turkey	3.3		2.4	5.4	0.51	0.78	4.8	0.69
East Asia								
China	(1.4)	(0.30)	(6.7)	(3.9)	(0.51)	(0.15)	(0.59)	
India	(2.1)	(0.30)	5.0	(0.47)	0.29	0.10	0.29	
Japan	(2.5)	(0.50)	12	(3.9)	0.50	(0.12)	(0.07)	
North America								
Canada	(1.3)	0.52	2.5	(4.0)	(0.50)	(0.20)	(0.50)	
United States	(2.4)	(0.30)	(10)	(1.7)	(0.50)			
Median values								
	1.5	0.37	8.2	4.2	0.50	0.19	0.50	0.13

a Numbers in parentheses are inferred values.

Table 11
Deposition of radionuclides

Country	Deposition density (kBq m^{-2})					Ratios of deposition densities to ^{137}Cs			
	^{103}Ru	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{103}Ru	^{106}Ru	^{131}I	^{134}Cs
North Europe									
Denmark	1.9	0.59	(6.1)	0.65	1.29	1.5	0.5	(4.7)	0.5
Finland	19	12	100	7.6	15	1.3	0.8	7.0	0.5
Norway	(11) [a]	2.4	(85)	2.8	5.3	(2.0)	0.5	(16)	0.5
Sweden									
Region 1	9.9	3.7	160	17	31	0.3	0.1	5.2	0.6
Region 2	2.3	0.85	13	0.45	0.81	2.8	1.0	16	0.6
Region 3	5.3	2.0	41	1.2	2.3	2.3	0.9	18	0.5
Central Europe									
Austria	31	(6.3)	120	(12)	23	1.3	(0.3)	5.0	(0.5)
Czechoslovakia									
Region 1	4.0	(0.72)	(26)	1.3	2.3	1.7	(0.3)	(11)	0.6
Region 2	6.3	(1.6)	(58)	2.7	5.3	1.2	(0.3)	(11)	0.5
Region 3	6.1	(0.85)	(30)	1.3	2.8	2.2	(0.3)	(11)	0.5
German Dem. Rep.									
Region 1	14	(1.8)	(45)	2.9	6.1	2.4	(0.3)	(7.4)	0.5
Region 2	23	(3.2)	42	5.7	11	2.1	(0.3)	3.9	0.5
Region 3	(14)	(1.8)	(19)	(2.9)	(6.1)	(2.4)	(0.3)	(3.1)	(0.5)
Germany, Fed. Rep.									
Region 1	2.5	0.6	12	1.0	2.0	1.3	0.3	6.2	0.5
Region 2	5.0	1.2	27	2.0	4.0	1.3	0.3	6.8	0.5
Region 3	20	4.8	100	8.0	16	1.3	0.3	6.5	0.5
Hungary									
Region 1	12	(2.9)	30	2.4	4.8	2.5	(0.6)	6.3	0.5
Region 2	3.8	(0.90)	9.3	0.75	1.5	2.5	(0.6)	6.2	0.5
Poland	(13)	(1.6)	38	2.6	5.2	(2.5)	(0.3)	7.3	0.5
Romania									
Region 1	(13)	(3.3)	(24)	(2.1)	(4.5)	(2.9)	(0.7)	(5.2)	(0.5)
Region 2	(52)	(13)	(94)	(8.6)	(18)	(2.9)	(0.7)	(5.2)	(0.5)
Region 3	26	(6.5)	47	(4.3)	9.0	2.9	(0.7)	5.2	(0.5)
Switzerland									
Region 1	(28)	(9.3)	(30)	8.9	15	(1.9)	(0.6)	(2.0)	0.6
Region 2	(6.5)	(2.2)	25	2.1	3.5	(1.9)	(0.6)	7.2	0.6
Region 3	(3.8)	(1.3)	15	1.2	2.0	(1.9)	(0.6)	7.2	0.6
Region 4	(2.4)	(0.82)	9.4	0.78	1.3	(1.9)	(0.6)	7.2	0.6
West Europe									
Belgium	(1.4)	0.4	5.2	0.4	0.84	(1.7)	0.5	6.2	0.5
France									
Region 1	(0.27)	(0.054)	(0.9)	0.09	(0.18)	(1.5)	(0.3)	(5.0)	(0.5)
Region 2	(0.99)	(0.2)	(5.3)	0.33	(0.66)	(1.5)	(0.3)	(8.0)	(0.5)
Region 3	(3.2)	(0.96)	(24)	1.6	(3.2)	(1.0)	(0.3)	(7.5)	(0.5)
Ireland	4.9	1.3	10	1.7	3.4	1.5	0.4	3.1	0.5
Luxembourg	(4.5)	(1.3)	19	1.3	2.7	(1.7)	(0.5)	7.0	0.5
Netherlands	3.4	0.85	11	0.92	1.8	1.9	0.5	6.3	0.5
United Kingdom									
Region 1	0.18	0.06	0.8	0.05	0.1	1.8	0.6	8.0	0.5
Region 2	3.1	0.8	2.0	0.85	1.7	1.8	0.5	1.2	0.5
Region 3	5.5	1.4	6.0	1.5	3.0	1.8	0.5	2.0	0.5
South Europe									
Bulgaria									
Region 1	9.9	2.6	4.2	2.0	3.9	2.5	0.7	1.1	0.5
Region 2	30	7.9	13	6.2	12	2.5	0.7	1.1	0.5
Greece									
Region 1	33	3.0	36	4.0	8.0	4.1	0.4	4.5	0.5
Region 2	3.0	0.7	14	1.3	2.4	1.3	0.3	5.8	0.5
Italy									
Region 1	14	3.8	25	3.0	6.0	2.3	0.6	4.2	0.5
Region 2	7.0	2.0	15	2.0	4.0	1.8	0.5	3.8	0.5
Portugal	(0.04)	(0.012)	0.07	(0.01)	0.02	(2.0)	(0.6)	3.5	(0.5)

Country	*Deposition density (kBq m^{-2})*					*Ratios of deposition densities to ^{137}Cs*			
	^{103}Ru	*^{106}Ru*	*^{131}I*	*^{134}Cs*	*^{137}Cs*	*^{103}Ru*	*^{106}Ru*	*^{131}I*	*^{134}Cs*
Spain									
Region 1	(0.11)	(0.021)	0.4	(0.035)	0.07	(1.5)	(0.3)	5.7	(0.5)
Region 2	(0.03)	(0.006)	(0.07)	(0.01)	(0.02)	(1.5)	(0.3)	(3.5)	(0.5)
Yugoslavia									
Region 1	33	7.0	140	9.0	23	1.4	0.3	5.9	0.4
Region 2	15	3.0	60	4.0	10	1.5	0.3	6.0	0.4
Region 3	6.0	1.3	24	1.7	4.0	1.5	0.3	6.0	0.4
USSR									
Region 1	41	8.8	590	21	39	1.1	0.2	15	0.6
Region 2	17	2.6	480	8.7	15	1.2	0.2	33	0.6
Region 3	13	3.2	160	5.2	10	1.3	0.3	16	0.5
Region 4	(3.7)	(1.1)	20	1.4	2.8	(1.4)	(0.4)	7.2	0.5
Region 5	(0.1)	(0.04)	(0.4)	(0.05)	0.09	(1.1)	(0.4)	(4.3)	(0.5)
West Asia									
Cyprus			(2.0)	(0.3)	(0.6)	-	-	(3.3)	(0.5)
Israel	(1.6)		(0.7)	(0.2)	(0.4)	(4.0)	-	(1.8)	(0.5)
Syria				(0.06)	(0.13)	-	-	-	(0.5)
Turkey				2.0	4.0	-	-	-	(0.5)
East Asia									
China	(0.21)	(0.044)	0.29	(0.075)	(0.15)	(1.4)	(0.3)	(2.0)	(0.5)
India	(0.073)	(0.011)	(0.044)	(0.010)	0.035	(2.1)	(0.3)	(1.3)	(0.3)
Japan	(0.45)	(0.090)	1.6	0.087	0.18	(2.5)	(0.5)	9.0	0.5
North America									
Canada	(0.04)	(0.016)	0.10	0.015	0.030	(1.3)	(0.5)	3.4	0.5
United States	(0.062)	(0.0079)	0.15	0.013	0.026	(2.4)	(0.3)	5.7	0.5
Median values									
						1.6	0.5	6.2	0.5

a Numbers in parentheses are inferred values.

Table 12
Quotients of deposition density and time-integrated concentration in air for caesium-137

Country	*Deposition density* [a] *(kBq m^{-2})*	*Integrated concentration in air* [a] *(Bq d m^{-3})*	*Quotient (cm s^{-1})*
North Europe			
Denmark	1.3	0.49	3.1
Finland	11	6.5	1.9
Norway	7.1	(5.3)	(1.6)
Sweden	9.5	0.8	14
Central Europe			
Austria	23	14	1.9
Czechoslovakia	4.2	13	0.4
German Dem. Rep.	7.2	11	0.8
Germany, Fed. Rep.	5.1	5.8	1.0
Hungary	2.7	4.3	0.7
Poland	5.2	8.2	0.7
Romania	(9.4)	(13)	(0.8)
Switzerland	3.4	3.7	1.1
West Europe			
Belgium	0.84	5	0.2
France	1.1	1.1	1.2
Ireland	3.3	0.11	35
Luxembourg	2.7	5	0.6
Netherlands	1.8	2.1	1.0
United Kingdom	0.9	0.9	1.2
South Europe			
Bulgaria	8.5	9.1	1.1
Greece	4.8	10	0.6
Italy	4.8	4.0	1.4
Portugal	0.02	(0.02)	(1.2)
Spain	0.03	(0.03)	(1.2)
Yugoslavia	14	7.0	2.4
USSR	1.4	2.1	0.8
West Asia			
Cyprus	(0.6)	(7.0)	(0.1)
Israel	(0.4)	(6.5)	(0.07)
Syria	(0.13)	(0.03)	(5.0)
Turkey	4.0	7.4	0.6
East Asia			
China	(0.15)	(0.66)	(0.3)
India	0.035	0.035	1.2
Japan	0.18	0.28	0.7
North America			
Canada	0.030	0.055	0.6
United States	0.026	(0.027)	(1.1)

a Area-weighted average values.

Table 13
Outdoor effective dose equivalent in the first month from external irradiation per unit caesium-137 deposition

Country	*Effective dose equivalent in first month (μSv)*	*Population-weighted deposition density of caesium-137 (kBq m⁻²)*	*Effective dose equivalent per unit caesium-137 deposition (μSv per kBq m⁻²)*
North Europe			
Denmark	(17) [a]	1.3	(13)
Finland	(210)	15	(14)
Norway	(74)	5.3	(14)
Sweden			
Region 1	25	31	0.8
Region 2	6.6	0.8	8
Region 3	18	2.3	8
Central Europe			
Austria	(220)	22	(10)
Czechoslovakia			
Region 1	93	2.3	40
Region 2	180	5.3	34
Region 3	140	2.8	52
German Dem. Rep.			
Region 1	200	6.1	33
Region 2	200	11	19
Region 3	100	(6.1)	(17)
Germany, Fed. Rep.			
Region 1	(26)	2.0	(13)
Region 2	(51)	4.0	(13)
Region 3	210	16	13
Hungary			
Region 1	100	4.8	21
Region 2	42	1.5	28
Poland	14	5.2	3
Romania			
Region 1	(70)	(4.5)	(16)
Region 2	(280)	(18)	(16)
Region 3	(140)	9.0	(16)
Switzerland			
Region 1	(200)	15	(14)
Region 2	(120)	3.5	(34)
Region 3	(64)	2.0	(32)
Region 4	(48)	1.3	(37)
West Europe			
Belgium	(11)	0.8	(13)
France			
Region 1	(2.5)	0.2	(14)
Region 2	(9.2)	0.7	(14)
Region 3	(45)	3.2	(14)
Ireland	(40)	3.4	(12)
Luxembourg	(35)	2.7	(13)
Netherlands	(22)	1.8	(12)
United Kingdom			
Region 1	(1.2)	0.1	(12)
Region 2	(21)	1.7	(12)
Region 3	(36)	3.0	(12)
South Europe			
Bulgaria			
Region 1	120	3.9	32
Region 2	210	12	18
Greece			
Region 1	31	8.0	4
Region 2	12	2.4	5
Italy			
Region 1	67	6.0	11
Region 2	11	4.0	3
Portugal	(0.3)	0.02	(14)

Country	*Effective dose equivalent in first month (μSv)*	*Population-weighted deposition density of caesium-137 ($kBq\ m^{-2}$)*	*Effective dose equivalent per unit caesium-137 deposition (μSv per $kBq\ m^{-2}$)*
Spain			
Region 1	(1.0)	0.07	(14)
Region 2	(0.3)	(0.02)	(15)
Yugoslavia			
Region 1	5.3	23	0.2
Region 2	0.6	10	0.06
Region 3	0.9	4	0.2
USSR			
Region 1	1200	39	31
Region 2	860	15	59
Region 3	190	10	19
Region 4	86	2.8	31
Region 5	(1.3)	0.09	(14)
West Asia			
Cyprus	(5.6)	(0.6)	(9)
Israel	(5.6)	(0.4)	(14)
Syria	(3.9)	(0.1)	(39)
Turkey	5.6	4.0	1
East Asia			
China	(1.3)	(0.15)	(9)
India	(0.2)	0.04	(5)
Japan	(1.7)	0.18	(9)
North America			
Canada	(0.13)	0.03	(4)
United States	(0.13)	0.026	(5)

a Numbers in parentheses are inferred values.

Table 14
Iodine-131 in foods

Country	*Latitude (degrees north)*	*Integrated concentration (Bq a kg^{-1})*		*Normalized integrated concentration (Bq a kg^{-1} per kBq m^{-2})*		*Ratio of integrated concentration leafy vegetables/ milk products*
		Milk products	*Leafy vegetables*	*Milk products*	*Leafy vegetables*	
North Europe						
Denmark	56	0.14	(0.6)	0.02	0.1	(4.3)
Finland	63	0.9	3.5	0.01	0.03	3.9
Norway	61	(0.8) [a]	(3.0)	(0.01)	(0.04)	(3.8)
Sweden						
Region 1	62	2	(2)	0.01	(0.01)	(1.0)
Region 2	66	(0)	(0)	(0)	(0)	(1.0)
Region 3	59	1	(1)	0.02	(0.02)	(1.0)
Central Europe						
Austria	48	12	(0)	0.1	(0)	-
Czechoslovakia						
Region 1	50	14	68	0.5	2.7	5.1
Region 2	50	15	68	0.3	1.2	4.6
Region 3	49	28	68	0.9	2.3	2.5
German Dem. Rep.						
Region 1	52	15	32	0.3	0.7	2.1
Region 2	53	10	15	0.2	0.4	1.5
Region 3	52	3.8	8.0	0.2	0.4	2.1
Germany, Fed. Rep.						
Region 1	52	0.7	5.5	0.05	0.4	8.5
Region 2	49	2.6	12	0.1	0.4	4.6
Region 3	48	6.8	46	0.07	0.4	6.8
Hungary						
Region 1	47	10	15	0.3	0.5	1.5
Region 2	47	6	6	0.2	0.6	1.0
Poland	52	11	4	0.3	0.1	0.4
Romania						
Region 1	46	(11)	(9.1)	(0.5)	(0.4)	(0.8)
Region 2	46	(44)	(36)	(0.5)	(0.4)	(0.8)
Region 3	45	22	18	0.5	0.4	0.8
Switzerland						
Region 1	46	37	55	(1.2)	(1.9)	1.5
Region 2	47	26	54	1.0	2.1	2.0
Region 3	47	23	30	1.6	2.0	1.3
Region 4	47	7.3	32	0.8	3.4	4.4
West Europe						
Belgium	51	2.9	5.0	0.6	1.0	1.7
France						
Region 1	47	0.6	1.4	0.7	1.6	2.3
Region 2	47	1.5	3.3	0.3	0.6	2.2
Region 3	47	4.4	10	0.2	0.4	2.3
Ireland	53	3.1	12	0.3	1.2	4.0
Luxembourg	50	3.1	18	0.2	1.0	5.8
Netherlands	52	1.0	8.0	0.09	0.7	8.0
United Kingdom						
Region 1	53	0.8	(0.8)	1.0	(1.0)	(1.0)
Region 2	56	1.7	(1.7)	0.9	(0.9)	(1.0)
Region 3	55	2.1	(2.1)	0.4	(0.4)	(1.0)
South Europe						
Bulgaria						
Region 1	43	34	(34)	8.1	8.2	(1.0)
Region 2	42	34	(34)	2.6	2.7	(1.0)
Greece						
Region 1	41	36	150	1.0	4.1	4.1
Region 2	39	14	56	1.0	4.0	4.0
Italy						
Region 1	45	11	65	0.4	2.6	5.9
Region 2	42	11	12	0.7	0.8	1.1
Portugal	40	0.01	0.04	0.1	0.6	4.0

Country	*Latitude (degrees north)*	*Integrated concentration (Bq a kg⁻¹)*		*Normalized integrated concentration (Bq a kg⁻¹ per kBq m⁻²)*		*Ratio of integrated concentration leafy vegetables/ milk products*
		Milk products	*Leafy vegetables*	*Milk products*	*Leafy vegetables*	
Bulgaria						
Region 1	43	34	(34)	8.1	8.2	(1.0)
Region 2	42	34	(34)	2.6	2.7	(1.0)
Greece						
Region 1	41	36	150	1.0	4.1	4.1
Region 2	39	14	56	1.0	4.0	4.0
Italy						
Region 1	45	11	65	0.4	2.6	5.9
Region 2	42	11	12	0.7	0.8	1.1
Portugal	40	0.01	0.04	0.1	0.6	4.0
Spain						
Region 1	40	0.7	1.2	1.8	3.0	1.7
Region 2	40	(0.01)	(0.04)	(0.1)	(0.6)	(4.0)
Yugoslavia						
Region 1	45	24	210	0.2	1.6	8.8
Region 2	43	11	90	0.2	1.5	8.2
Region 3	43	3.6	31	0.15	1.3	8.6
USSR						
Region 1	55	25	13	0.04	0.02	0.5
Region 2	54	31	42	0.06	0.09	1.4
Region 3	52	4.4	2.2	0.03	0.01	0.5
Region 4	51	4.9	(0)	0.3	(0)	-
Region 5	53	(0.1)	(0)	(0.3)	(0)	-
West Asia						
Cyprus	35	(6.0)	(24)	(3.0)	(12)	(4.0)
Israel	32	(1.6)	(15)	(2.3)	(21)	(9.4)
Syria	35	(2.0)	(0.6)	-	-	(0.3)
Turkey	40	3.0	2.5	-	-	0.8
East Asia						
China	32	0.48	2.2	1.6	7.4	4.5
India	23	0.094	0.095	(2.2)	(2.2)	(1.0)
Japan	36	0.14	4.6	0.09	2.9	33
North America						
Canada	55	(0.10)	(0.10)	(1.0)	(1.0)	(1.0)
United States	36	(0.15)	(0.15)	(1.0)	(1.0)	(1.0)

a Numbers in parentheses are inferred values.

Table 15
Caesium-137 in foods during the first year

Country	Integrated concentration (Bq a kg^{-1})					Normalized integrated concentration (Bq a kg^{-1} per kBq m^{-2})					Ratio of integrated concentrations	
	Milk products	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Leafy vegetables/milk*	*Meat / milk*
North Europe												
Denmark	1.6	2.1	0.5	0.8	1.3	1.2	1.6	0.4	0.6	1.0	0.3	0.8
Finland	21	3.8	2.9	9.4	66	1.4	0.3	0.2	0.6	4.5	0.1	3.1
Norway	14	1.2	7.0	4.3	44	2.6	0.2	1.3	0.8	8.3	0.5	3.1
Sweden												
Region 1	18	3	10	20	33	0.6	0.1	0.3	0.7	1.1	0.6	1.8
Region 2	(6) [a]	(3)	(5)	(7)	(11)	(7.4)	(3.7)	(6.2)	(8.6)	(14)	(0.8)	(1.8)
Region 3	6	3	5	7	11	2.6	1.3	2.2	3.0	4.8	0.8	1.8
Central Europe												
Austria	44	15	18	26	57	1.9	0.7	0.8	1.1	2.5	0.4	1.3
Czechoslovakia												
Region 1	7.4	4.9	8	33	15	3.2	2.1	3.4	14	6.5	1.1	2.0
Region 2	7.8	13	8	33	15	1.5	2.5	1.5	6.3	2.9	1.0	1.9
Region 3	9.6	8.1	8	33	15	3.5	2.9	2.9	12	5.5	0.8	1.6
German Dem. Rep.												
Region 1	6.0	15	0.3	2.6	8.4	1.0	2.5	0.05	0.4	1.4	0.05	1.4
Region 2	17	23	0.8	5.1	20	1.6	2.1	0.07	0.5	1.9	0.05	1.2
Region 3	4.2	12	0.3	3.3	12	(0.7)	(2.0)	(0.05)	(0.5)	(2.0)	0.07	2.9
Germany, Fed. Rep.												
Region 1	4.6	4.5	2.3	3	8	2.3	2.3	1.2	1.5	4.0	0.5	1.7
Region 2	6.7	9.0	4.5	6	16	1.7	2.3	1.2	1.5	4.0	0.7	2.4
Region 3	24	36	18	24	64	1.5	2.3	1.2	1.5	4.0	0.8	2.7
Hungary												
Region 1	13	9	12	10	25	2.7	1.9	2.5	2.1	(5.2)	0.9	1.9
Region 2	8	5	7	5	25	5.3	3.3	4.7	3.3	(17)	0.9	3.1
Poland	25	2	10	10	34	4.8	0.4	2.0	1.9	6.4	0.4	1.3
Romania												
Region 1	(9.7)	(12)	(4.8)	(3.6)	(28)	(2.2)	(2.7)	(1.1)	(0.8)	(6.3)	(0.5)	(2.9)
Region 2	(39)	(49)	(19)	(14)	(110)	(2.2)	(2.7)	(1.1)	(0.8)	(6.3)	(0.5)	(2.9)
Region 3	19	(24)	9.5	(7.2)	56	2.2	(2.7)	1.1	(0.8)	6.3	0.5	2.9
Switzerland												
Region 1	48	(30)	54	(12)	200	3.2	(2.0)	3.7	(0.8)	14	1.1	4.3
Region 2	11	(7.0)	16	(2.8)	24	3.2	(2.0)	4.5	(0.8)	6.9	1.4	2.1
Region 3	8.9	(4.1)	9.1	(1.6)	12	4.4	(2.0)	4.5	(0.8)	5.8	1.0	1.3
Region 4	2.7	(2.6)	4.8	(1.0)	12	2.1	(2.0)	3.7	(0.8)	9.0	1.8	4.4

Table 15 (continued)

Country	Integrated concentration (Bq a kg^{-1})					Normalized integrated concentration (Bq a kg^{-1} per kBq m^{-2})					Ratio of integrated concentrations	
	Milk products	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Leafy vege-tables/milk*	*Meat / milk*
West Europe												
Belgium	1.5	(1.7)	1.1	(0.7)	(2.6)	1.8	(2.0)	1.3	(0.8)	(3.1)	0.7	(1.7)
France												
Region 1	0.18	0.37	0.13	0.08	0.05	1.0	2.1	0.7	0.4	0.3	0.7	0.3
Region 2	2.7	1.2	4.4	1.2	0.8	4.1	1.8	6.7	1.8	1.2	1.6	0.3
Region 3	13	6.2	9.6	5.6	4.0	4.1	1.9	3.0	1.8	1.3	0.7	0.3
Ireland	10	(6.7)	3.0	(2.7)	18	3.0	(2.0)	0.9	(0.8)	5.4	0.3	1.8
Luxembourg	4.9	(5.4)	(3.5)	(2.2)	(8.1)	1.8	(2.0)	(1.3)	(0.8)	(3.0)	(0.7)	(1.7)
Netherlands	1.5	(3.6)	(2.3)	(1.4)	(5.4)	0.9	(2.0)	(1.3)	(0.8)	(3.0)	(1.5)	(3.5)
United Kingdom												
Region 1	0.9	(0.2)	(0.2)	(0.08)	(1.8)	9	(2.0)	(2.0)	(0.8)	(18)	(0.2)	(2.0)
Region 2	10	(3.4)	(2)	(1.4)	(20)	5.9	(2.0)	(1.2)	(0.8)	(12)	(0.2)	(2.0)
Region 3	18	(6.0)	(4)	(2.4)	(36)	6	(2.0)	(1.3)	(0.8)	(12)	(0.2)	(2.0)
South Europe												
Bulgaria												
Region 1	38	13	(27)	41	200	9.7	3.3	(6.9)	10	51	(0.7)	5.3
Region 2	38	13	(27)	41	200	3.1	1.1	(2.3)	3.4	17	(0.7)	5.3
Greece												
Region 1	76	60	46	46	61	9.5	7.5	5.8	5.8	7.6	0.6	0.8
Region 2	23	20	19	14	18	9.6	8.3	7.9	5.8	7.5	0.8	0.8
Italy												
Region 1	22	8	27	15	70	3.7	1.3	4.5	2.5	12	1.2	3.2
Region 2	13	12	3.5	10	60	3.3	3.0	0.9	2.5	15	0.3	4.6
Portugal	0.16	(0.2)	(0.1)	(0.04)	(0.4)	8.0	(10)	(5.0)	(2.0)	(20)	(0.6)	(2.6)
Spain												
Region 1	0.8	(0.7)	(0.5)	(0.2)	(2)	11	(10)	(7.1)	(2.9)	(29)	(0.6)	(2.6)
Region 2	(0.16)	(0.2)	(0.1)	(0.04)	(0.4)	(8.0)	(10)	(5.0)	(2.0)	(20)	(0.6)	(2.6)
Yugoslavia												
Region 1	49	2.6	10	1.	77	2.1	0.1	0.4	0.04	3.3	0.2	1.6
Region 2	20	1.1	4.3	0.5	33	2.0	0.1	0.4	0.05	3.3	0.2	1.6
Region 3	7	0.4	1.5	0.15	11	1.8	0.1	0.4	0.04	2.8	0.2	1.6
USSR												
Region 1	90	23	25	33	200	2.3	0.6	0.6	0.9	5.2	0.3	2.2
Region 2	26	6.0	17	8.0	55	1.8	0.4	1.2	0.6	3.8	0.7	2.1
Region 3	21	6.0	10	10	50	2.1	0.6	1.0	1.0	5.0	0.5	2.4
Region 4	4.2	(1.7)	(2.1)	(2.6)	14	1.5	(0.6)	(0.8)	(0.9)	5.1	(0.5)	3.3
Region 5	(0.16)	(0.05)	(0.04)	(0.06)	(0.50)	(1.7)	(0.5)	(0.4)	(0.6)	(5.3)	(0.3)	(3.1)

Table 15 (continued)

Country	Integrated concentration (Bq a kg^{-1})					Normalized integrated concentration (Bq a kg^{-1} per kBq m^{-2})					Ratio of integrated concentrations	
	Milk products	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Milk products*	*Grain products*	*Leafy vegetables*	*Vegetables /fruit*	*Meat*	*Leafy vege-tables/milk*	*Meat / milk*
West Asia												
Cyprus	(3.0)	(2.0)	(3.0)	(0.6)	(2.0)	(5.0)	(3.3)	(5.0)	(1.0)	(3.3)	(1.0)	(0.7)
Israel	(0.8)	(4.0)	(5.0)	(2.0)	(10)	(2.0)	(10)	(13)	(5.0)	(25)	(6.3)	(13)
Syria	(1.0)	(0.3)	(0.05)	(0.02)	(0.3)	(7.7)	(2.3)	(0.4)	(0.2)	(2.3)	(0.05)	(0.3)
Turkey	21	2.0	6.5	3.5	17	5.3	0.5	1.6	0.9	4.3	0.3	0.8
East Asia												
China	(0.18)	(0.47)	(1.1)	(0.19)	(0.78)	(1.2)	(3.2)	(7.4)	(1.3)	(5.4)	(6.2)	(4.5)
India	(0.16)	(0.39)	0.11	(0.046)	(0.18)	(4.7)	(11.2)	3.2	(1.3)	(5.1)	(0.7)	(1.1)
Japan	0.22	0.056	0.29	(0.28)	0.29	1.2	0.3	1.6	(1.6)	1.6	1.3	1.4
North America												
Canada	(0.05)	(0.08)	(0.03)	(0.02)	(0.09)	(1.5)	(2.5)	(1.0)	(0.8)	(3.0)	(0.7)	(2.0)
United States	(0.04)	(0.13)	(0.03)	(0.02)	(0.08)	(1.5)	(5)	(1.0)	(0.8)	(3.0)	(0.7)	(2.0)

a Numbers in parentheses are inferred values.

Table 16
Comparison of body burdens of caesium-137 derived from measurements in man and expected from foodstuff concentrations (first-year intakes)

Country	*Number of persons*	*Deposition density of ^{137}Cs (kBq m^{-2})*	*Time-integrated body burdens (Bq a)*		*Body burden ratio (Measured/ expected)*	*Ref.*
			Measured in man	*Expected from diet*		
Austria						
Vienna	4	4	2500	1200	2.1	[O1]
Country average	200	23	2800	7000	0.4	[S19]
Bulgaria						
Country average	308	8.6	2600	9200	0.3	[C4]
Czechoslovakia						
Country average	404	4.4	960	3000	0.3	[M7]
Finland						
Region 1	102	2	1500	610	2.5	[R14]
Region 2	27	6	1650	1800	0.9	[R14]
Region 3	31	15	3300	4600	0.7	[R14]
Region 4	41	34	4500	10000	0.4	[R14]
Region 5	16	52	5400	16000	0.3	[R14]
Country average		15	2730	4500	0.6	[R14]
France						
Region 1		0.18	130	40	3.3	[L5]
Region 2		0.66	270	430	0.6 [c]	[L5]
Region 3		3.2	540	1700	0.3 [a]	[L5]
German Dem. Republic						
Country average	300	6.8	1000	1700	0.6	[L1]
Germany, Fed. Republic						
Region 1		2	490	670	0.7	[S16]
Regions 2, 3		8.6	1200	2600	0.5	[S16]
Hungary						
Country average	39	3.1	770	2300	0.3	[H4]
Italy						
Region 1	43	6	3500	4200	0.8	[M6]
Region 2	67	4	2600	3100	0.8	[M6]
Japan						
Country average	19	0.18	34	43	0.8	[N4]
Netherlands						
Country average	20	1.8	250	480	0.5	[C26]
Norway						
Oslo	38	1.0	1400	550	2.5	[B11]
Oppland	151	27.8	3100	15000	0.2	[B11]
N. Tr.	78 [a]	18.7	21000	10000	2.1	[B11]
Finmark	45 [b]	0.4	5600	210	27	[B11]
Poland						
Country average	535	5.2	1700	3100	0.6	[C2]
Sweden						
Region 1	50	31	1900	3300	0.6	[F6]
Country average	218	6.8	820	1200	0.7	[F6]
Switzerland						
Mitteland		2.0	750	1500	0.5	[P2]
Turkey						
Country average	30	4	1700	1900	0.9	[T2]
United Kingdom						
Region 1	30	0.1	190	120	1.6	[F12]
Region 3	300	3	710	2500	0.3	[F12]

a Southern Lapps.
b Northern Lapps.
c Measured composited diet samples give relative results of 0.8 and 0.7 for regions 2 and 3, respectively [S21].

Table 17
First-year dose equivalents

Country	Thyroid dose equivalent (μSv)		Effective dose equivalent (μSv)	
	Infants	Adults	Rural	Urban
North Europe				
Denmark	160	64	33	28
Finland	1800	1200	490	440
Norway	1000	570	240	220
Sweden				
Region 1	1800	700	440	340
Region 2	47	92	87	83
Region 3	870	280	110	99
Central Europe				
Austria	9400	1800	710	630
Czechoslovakia				
Region 1	2000	2300	280	270
Region 2	2200	2600	370	350
Region 3	2100	3200	340	340
German Dem. Rep.				
Region 1	12000	2000	270	250
Region 2	7700	1300	360	320
Region 3	3100	690	180	160
Germany, Fed. Rep.				
Region 1	660	200	70	63
Region 2	2300	530	140	120
Region 3	6200	1500	510	460
Hungary				
Region 1	7500	1300	290	270
Region 2	4500	770	180	170
Poland	8100	1400	280	260
Romania				
Region 1	8200	1200	270	250
Region 2	33000	5300	1100	1000
Region 3	17000	2700	550	520
Switzerland				
Region 1	27000	4600	1300	1200
Region 2	20000	3000	320	310
Region 3	17000	2300	210	200
Region 4	5800	1100	120	120
West Europe				
Belgium	2300	460	42	39
France				
Region 1	450	90	6.7	6.1
Region 2	1100	240	40	37
Region 3	3400	810	160	150
Ireland	2500	540	130	120
Luxembourg	2700	580	100	93
Netherlands	940	390	61	54
United Kingdom				
Region 1	600	97	12	12
Region 2	1300	260	110	100
Region 3	1700	400	200	190
South Europe				
Bulgaria				
Region 1	25000	2800	720	700
Region 2	25000	2900	810	770
Greece				
Region 1	30000	7600	960	930
Region 2	12000	3000	330	320
Italy				
Region 1	4400	2300	380	360
Region 2	2700	970	240	230
Portugal	9	4	1.9	1.8
Spain				
Region 1	520	100	12	12
Region 2	9	5	2.2	2.1

Country	*Thyroid dose equivalent (μSv)*		*Effective dose equivalent (μSv)*	
	Infants	*Adults*	*Rural*	*Urban*
Bulgaria				
Region 1	25000	2800	720	700
Region 2	25000	2900	810	770
Greece				
Region 1	30000	7600	960	930
Region 2	12000	3000	330	320
Italy				
Region 1	4400	2300	380	360
Region 2	2700	970	240	230
Portugal	9	4	1.9	1.8
Spain				
Region 1	520	100	12	12
Region 2	9	5	2.2	2.1
Yugoslavia				
Region 1	22000	8500	660	590
Region 2	10000	4000	290	260
Region 3	3600	1500	110	99
USSR				
Region 1	21000	6900	2000	1900
Region 2	24000	6300	930	880
Region 3	3800	1400	460	420
Region 4	3600	910	140	130
Region 5	82	25	4.3	3.9
West Asia				
Cyprus	4700	1200	67	66
Israel	1500	1100	94	92
Syria	1400	74	7.7	7.3
Turkey	2300	480	200	180
East Asia				
China	390	47	7.9	7.4
India	69	5	2.1	2.0
Japan	210	100	7.9	7.2
North America				
Canada	75	11	1.4	1.3
United States	110	15	1.5	1.4

Table 18
Country average of first-year dose equivalents

Country	Thyroid dose equivalent (μSv)		Effective dose equivalent	Ratio to result reported from country [N5]		
				Thyroid dose		Effective dose
	Infant	Adult	(μSv)	Infant	Adult	
Europe						
Bulgaria	25000	2900	760			
Austria	9400	1800	670	1.2	1.0	1.0
Greece	20000	5000	590	3.6	2.6	1.6
Romania	18000	2800	570			
Finland	1800	1200	460	1.0	1.7	0.9
Yugoslavia	14000	5500	390			
Czechoslovakia	2200	2700	350			
Italy	3400	1500	300	0.5	0.5	0.6
Poland	8100	1400	270			
Switzerland	15000	2300	270	9.3	2.1	1.2
Hungary	6000	1000	230			
Norway	1000	570	230	0.8	1.5	1.4
German Dem. Republic	5100	970	210			
Sweden	1000	340	150	2.0	0.9	0.7
Germany, Fed. Republic	1700	440	130	0.6	0.5	0.4
Ireland	2500	540	120	0.2	2.3	1.1
Luxembourg	2700	580	98	3.5	1.7	0.8
France	1600	360	63	1.8	4.1	2.6
Netherlands	940	390	58	0.6	1.3	0.8
Belgium	2300	460	41	1.7	2.2	1.0
Denmark	160	64	30	0.6	1.3	1.1
United Kingdom	710	130	27	0.3	0.8	0.7
Spain	110	24	4.2			
Portugal	9	4	1.8	0.1	0.4	0.3
USSR	5000	1400	260			
Asia						
Turkey	2300	480	190	0.7	1.2	2.2
Israel	1500	1100	92			
Cyprus	4700	1200	68			
Syria	1400	74	8.3			
China	390	47	7.8			
Japan	210	100	7.6	1.4	2.1	1.2
India	69	5	2.1			
North America						
Canada	75	11	1.4	4.2	6.5	0.6
United States	110	15	1.5			

Table 19
Transfer factor from deposition to thyroid dose for iodine-131

Country	*Deposition density of ^{131}I (kBq m^{-2})*	*Thyroid dose equivalent in first year from ^{131}I (μSv)*		*Transfer factor (P_{25}) deposition to thyroid dose for ^{131}I (μSv per kBq m^{-2})*	
		Infants	*Adults*	*Infants*	*Adults*
North Europe					
Denmark	6.1	130	33	21	5.4
Finland	100	1500	690	15	6.7
Norway	85	930	350	11	4.1
Sweden					
Region 1	160	1500	280	9.4	1.8
Region 2	13	17	13	1.3	1.0
Region 3	41	820	190	20	4.6
Central Europe					
Austria	120	9000	1100	78	9.5
Czechoslovakia					
Region 1	26	1900	2100	74	82
Region 2	58	2000	2200	34	38
Region 3	30	1900	2900	63	96
German Dem. Rep.					
Region 1	45	12000	1800	260	40
Region 2	42	7500	970	180	23
Region 3	19	3000	520	160	28
Germany, Fed. Rep.					
Region 1	12	610	130	50	11
Region 2	27	2200	380	81	14
Region 3	100	5900	1000	57	9.7
Hungary					
Region 1	30	7400	1000	250	33
Region 2	9.3	4400	610	470	66
Poland	38	8000	1100	210	29
Romania					
Region 1	24	8100	980	340	42
Region 2	94	33000	4400	350	47
Region 3	47	17000	2200	360	47
Switzerland					
Region 1	30	27000	3600	910	120
Region 2	25	20000	2800	790	110
Region 3	15	17000	2200	1200	150
Region 4	9.4	5800	1000	620	110
West Europe					
Belgium	5.2	2200	420	420	81
France					
Region 1	0.9	450	85	500	94
Region 2	5.3	1100	210	210	40
Region 3	24	3300	670	140	28
Ireland	10	2400	430	230	41
Luxembourg	19	2600	480	140	25
Netherlands	11	910	340	80	30
United Kingdom					
Region 1	0.8	590	84	740	110
Region 2	2.0	1200	160	600	80
Region 3	6.0	1600	220	270	37
South Europe					
Bulgaria					
Region 1	4.2	24000	2200	5700	520
Region 2	13	24000	2200	1900	170
Greece					
Region 1	36	30000	6900	830	190
Region 2	14	12000	2700	860	190
Italy					
Region 1	25	4400	1900	180	76
Region 2	15	2700	750	180	50
Portugal	0.07	8.0	2.3	110	33

Country	*Deposition density of ^{131}I (kBq m^{-2})*	*Thyroid dose equivalent in first year from ^{131}I (µSv)*		*Transfer factor (P_{25}) deposition to thyroid dose for ^{131}I (µSv per kBq m^{-2})*	
		Infants	*Adults*	*Infants*	*Adults*
Spain					
Region 1	0.4	510	96	1280	240
Region 2	0.07	8.0	2.8	110	40
Yugoslavia					
Region 1	140	22000	8100	160	60
Region 2	60	10000	3800	170	63
Region 3	24	3500	1400	150	58
USSR					
Region 1	590	20000	5100	34	8.6
Region 2	480	23000	5500	48	11
Region 3	160	3500	980	22	6.0
Region 4	20	3600	790	180	40
Region 5	0.4	80	22	200	55
West Asia					
Cyprus	2.0	4700	1200	2400	600
Israel	0.7	1500	1000	2100	1400
Syria	-	1400	69		
Turkey	-	2200	320		
East Asia					
China	0.3	390	40	1300	130
India	0.04	68	3.2	1500	73
Japan	1.6	210	96	130	60
North America					
Canada	0.1	75	9.4	750	94
United States	0.15	110	14	740	94

Table 20
Transfer factor from deposition to first-year effective dose equivalent from ingestion of caesium-137

Country	Deposition density (kBq m^{-2})	First-year diet: Integrated concentration (Bq a kg^{-1})	First-year diet: Intake (Bq)	Body burden integrated concentration (Bq a kg^{-1})	Effective dose equivalent (µSv)	Transfer factors: b_1 [a]	Transfer factors: P_{34} [b]	Transfer factors: $P_{25,1}$ [c]
North								
Denmark	1.3	1.35	660	3.7	9.2	1.0	2.7	7.2
Finland	14.7	20.8	12100	68	170	1.4	3.3	12
Norway	5.3	14.1	7030	39	98	2.7	2.8	19
Sweden								
Region 1	31	17.3	8860	50	120	0.6	2.9	4.0
Region 2	0.81	(6.3)	(3210)	(18)	(45)	(7.7)	2.9	(55)
Region 3	2.3	6.3	3210	18	45	2.7	2.9	20
Temperate								
Austria	23	34.5	17800	100	250	1.5	2.9	11
Belgium	0.84	1.3	650	3.6	9.1	1.6	2.7	11
Bulgaria								
Region 1	3.9	50.8	23500	130	330	13	2.6	84
Region 2	12	50.8	23500	130	330	4.2	2.6	27
Canada	0.03	(0.05)	(35)	(0.2)	(0.5)	(1.6)	4.1	(16)
Czechoslovakia								
Region 1	2.3	13.8	6660	37	93	5.9	2.7	40
Region 2	5.3	16.1	7780	44	110	3.1	2.7	21
Region 3	2.8	15.2	7380	41	100	5.5	2.7	38
France								
Region 1	0.18	0.16	80	0.45	1.1	0.9	2.8	6.2
Region 2	0.66	2.1	1040	5.8	15	3.1	2.8	22
Region 3	3.2	8.0	4050	23	57	2.5	2.8	18
German Dem. Rep.								
Region 1, 3	6.1	6.0	3660	20	51	1.0	3.4	8.4
Region 2	11	12.1	7470	42	100	1.1	3.4	9.7
Germany, Fed. Rep.								
Region 1	2	4.5	1690	9.4	24	2.2	2.1	12
Region 2	4	8.2	3100	17	43	2.0	2.1	11
Region 3	16	31.9	12000	67	170	2.0	2.1	11
Hungary								
Region 1	4.8	13.0	7300	41	100	2.7	3.1	21
Region 2	1.5	8.9	5000	28	70	6.0	3.1	47
Ireland	3.4	8.4	3280	18	46	2.5	2.2	14
Italy								
Region 1	6	23.2	10700	60	150	3.9	2.6	25
Region 2	4	16.9	7770	43	110	4.2	2.6	27
Luxembourg	2.7	4.6	2210	12	31	1.7	2.7	11
Netherlands	1.8	2.4	1170	6.6	16	1.4	2.7	9.1
Poland	5.2	14.6	8160	46	110	2.8	3.1	22
Romania								
Region 1	4.5	(10.3)	(7250)	(41)	(100)	(2.3)	4.0	(23)
Region 2	18	(41.0)	(29000)	(160)	(410)	(2.3)	4.0	(23)
Region 3	9	20.5	14500	81	200	2.3	4.0	23
Switzerland								
Region 1	14.8	59.1	37900	210	530	4.0	3.6	36
Region 2	3.5	10.0	6430	36	90	2.9	3.6	26
Region 3	2.0	6.1	3890	22	54	3.0	3.6	27
Region 4	1.3	3.7	2390	13	33	2.9	3.6	26
United Kingdom								
Region 1	0.1	0.69	300	1.7	4.3	6.9	2.5	43
Region 2	1.7	7.9	3500	20	49	4.7	2.5	29
Region 3	3.0	14.2	6300	35	88	4.7	2.5	29
USSR								
Region 1	38.8	73.7	50400	280	700	1.9	3.8	18
Region 2	14.5	21.2	14500	81	200	1.5	3.8	14
Region 3	10.0	18.3	12500	70	170	1.8	3.8	18
Region 4	2.8	4.2	2890	16	40	1.5	3.8	15
Region 5	0.094	(0.15)	(100)	(0.6)	(1.4)	(1.6)	3.8	(15)

Country	*Deposition density (kBq m^{-2})*	*First-year diet*		*Body burden integrated concentration (Bq a kg^{-1})*	*Effective dose equivalent (µSv)*	*Transfer factors*		
		Integrated concentration (Bq a kg^{-1})	*Intake (Bq)*			b_1 [a]	P_{34} [b]	$P_{25,1}$ [c]
Yugoslavia								
Region 1	23	23.5	12400	70	170	1.0	3.0	7.6
Region 2	10	9.8	5200	29	73	1.0	3.0	7.3
Region 3	4	3.4	1780	10	25	0.8	3.0	6.2
South								
China	0.15	(0.42)	(200)	(1.1)	(2.8)	(2.8)	2.6	(18)
Cyprus	0.6	(1.6)	(1050)	(5.9)	(15)	(2.7)	3.7	(25)
Greece								
Region 1	8	55.0	28600	160	400	6.9	2.9	50
Region 2	2.4	17.3	8990	50	130	7.2	2.9	52
India	0.035	(0.25)	(86)	(0.5)	(1.2)	(7.1)	1.9	(34)
Israel	0.4	(3.6)	(2300)	(13)	(32)	(9.0)	3.6	(80)
Japan	0.18	0.20	120	0.6	1.6	1.1	3.2	9.0
Portugal	0.02	0.15	65	0.4	0.9	7.5	2.4	45
Spain								
Region 1	0.07	0.70	360	2.0	5.0	10	2.9	71
Region 2	0.02	(0.15)	(77)	(0.4)	(1.1)	(7.5)	2.9	(54)
Syrian Arab Rep.	0.13	(0.22)	(140)	(0.8)	(2.0)	(1.7)	3.6	(15)
Turkey	4	7.9	4880	27	68	2.0	3.4	17
United States	0.026	(0.05)	(36)	(0.2)	(0.5)	(2.0)	3.9	(20)

a Deposition to first-year total diet; units: Bq a kg^{-1} per kBq m^{-2}.
b Diet to body; units: Bq a kg^{-1} per Bq a kg^{-1}.
c Deposition to first-year committed effective dose equivalent; units: µSv per kBq m^{-2}.

Table 21
Transfer factor from deposition to effective dose equivalent from ingestion of caesium-137 after the first year

Region [a]	*Food consumption (kg a^{-1})*						*Transfer factors*			
	Milk products	*Grain products*	*Leafy vege-tables*	*Vegetables /fruit*	*Meat*	*Total*	*$P_{23,2+}$* [b]		*P_{34}* [c]	*$P_{25,2+}$* [d]
							Grain	*Total diet*		
North Europe	220	75	25	140	65	525	0.9	2.6	2.9	19
Central Europe	140	120	30	150	70	510	1.9	2.8	2.8	20
West Europe	150	75	60	120	70	475	2.0	2.8	2.6	19
Southeast Europe	105	125	45	150	60	485	2.3	3.0	2.7	20
Southwest Europe	90	95	120	125	60	490	10	4.3	2.8	30
USSR	330	130	35	120	65	680	0.6	2.3	3.8	22
West Asia	115	190	95	180	40	620	1.3	2.3	3.5	20
East Asia	20	210	30	140	25	425	6.0	4.4	2.4	26
North America	175	90	25	265	145	700	4.8	3.9	3.9	38

a *North Europe:* Denmark, Finland, Norway, Sweden.
Central Europe: Austria, Czechoslovakia, German Democratic Republic, Federal Republic of Germany, Hungary, Poland, Romania, Switzerland.
West Europe: Belgium, France, Ireland, Luxembourg, Netherlands, United Kingdom.
Southeast Europe: Bulgaria, Greece, Italy, Yugoslavia.
Southwest Europe: Portugal, Spain.
West Asia: Cyprus, Israel, Syrian Arab Republic, Turkey.
East Asia: China, India, Japan.
North America: Canada, United States.
b Deposition to total diet after first year; units: Bq a kg^{-1} per kBq m^{-2}.
c Diet to body; units: Bq a kg^{-1} per Bq a kg^{-1}.
d Deposition to effective dose equivalent commitment after first year; units: µSv per kBq m^{-2}.

Table 22
Regional transfer factor applicable after first year and components of the effective dose equivalent commitment

Region [a]	*Population-weighted deposition density of ^{137}Cs (kBq m^{-2})*	*Transfer factor related to deposition of ^{137}Cs*				*Effective dose equivalent commitment (µSv)*		
		$P_{25,2+}$ External gamma	*$P_{25,2+}$ ingestion*		*$P_{25,2+}$ Total*	*First year*	*After first year*	*Total*
			^{137}Cs	*^{134}Cs*				
North Europe	7.0	76	20	12	110	210	760	970
Central Europe	6.1	76	20	12	110	270	670	940
West Europe	1.0	76	20	12	110	48	110	160
Southeast Europe	7.4	76	20	12	110	390	810	1200
Southwest Europe	0.03	76	30	18	120	3.7	3.4	7
USSR	5.1	76	20	12	110	260	560	820
West Asia	3.2	76	20	12	110	160	350	510
East Asia	0.1	76	30	18	120	5.6	13	19
North America	0.03	76	30	18	120	1.5	3.2	5

a *North Europe:* Denmark, Finland, Norway, Sweden.
Central Europe: Austria, Czechoslovakia, German Democratic Republic, Federal Republic of Germany, Hungary, Poland, Romania, Switzerland.
West Europe: Belgium, France, Ireland, Luxembourg, Netherlands, United Kingdom.
Southeast Europe: Bulgaria, Greece, Italy, Yugoslavia.
Southwest Europe: Portugal, Spain.
West Asia: Cyprus, Israel, Syrian Arab Republic, Turkey.
East Asia: China, India, Japan.
North America: Canada, United States.

Table 23
Total transfer factor for effective dose equivalent based on deposition of caesium-137
(μSv per kBq m^{-2})

Radionuclide	North			Temperate			South		
	First year	*After first year*	*Total*	*First year*	*After first year*	*Total*	*First year*	*After first year*	*Total*
External gamma									
^{137}Cs	2.2	71	73	2.2	71	73	2.2	71	73
^{134}Cs	2.5	4.9	7	2.5	4.9	7	2.5	4.9	7
Other	5.6	0.2	6	5.6	0.2	6	5.6	0.2	6
Subtotal	10	76	86	10	76	86	10	76	86
Ingestion									
^{137}Cs	15	20	35	20	20	40	25	25	50
^{134}Cs	11	12	23	14	12	26	18	15	33
^{131}I	1	-	1	10	-	10	20	-	20
Subtotal	27	32	59	44	32	76	63	40	103
Total (rounded)	40	110	150	50	110	160	70	120	190

Table 24
Total caesium-137 deposit and dose commitments in the northern hemisphere

Region	Area (10^3 km^2)	Population (10^6)	Distance from Chernobyl (km)	^{137}Cs deposition ($kBq\ m^{-2}$) weighted by		^{137}Cs deposit (PBq)	Effective dose equivalent commitment			
							Per caput (µSv)		Collective (man Sv)	
				Area	Population		1st year	Total	1st year	Total
Europe										
North [a]	1249	22.8	1300	8.2	7.0	10.2	210	970	4700	22000
Central [b]	1253	178.0	1200	7.0	6.0	8.8	280	930	49000	166000
West [c]	936	137.7	2000	1.3	1.0	1.2	48	150	6600	21000
Southeast [d]	829	101.6	1500	8.2	7.2	6.8	380	1200	39000	121000
Southwest [e]	596	47.2	2900	0.03	0.03	0.02	4	7	180	340
USSR	22190	279.1	-	1.4	5.0	30.9	260	810	72000	226000
Asia										
Southwest [f]	4611	114.9	2200	1.0	1.0	4.6	70	190	8000	22000
South [g]	6786	1082	5400	0.08	0.08	0.5	6	15	6100	16000
Southeast [h]	2575	240.6	7800	0.03	0.03	0.08	2	6	510	1400
East [i]	11720	1268	6600	0.04	0.04	0.5	3	8	3600	9600
America										
North [j]	20560	347.0	9000	0.02	0.02	0.4	1	4	490	1300
Caribbean [k]	216	30.1	9200	0.018	0.018	0.004	1	3	40	100
Central [l]	517	26.9	10700	0.012	0.012	0.006	0.7	2	20	60
South [m]	2520	49.7	10100	0.013	0.013	0.03	1	2	50	120
Africa										
North [n]	8438	128.4	3000	0.4	0.4	3.4	28	76	3600	9800
West [o]	6118	172.3	5600	0.08	0.08	0.5	6	15	970	2600
Central [p]	2415	18.3	5300	0.08	0.08	0.2	5	15	100	280
East [q]	2117	59.5	5100	0.09	0.09	0.2	6	17	380	1000
Greenland	2176	0.06	4000	0.18	0.18	0.4	7	30	0.4	2
North Atlantic	53000	-	5700	0.07	-	3.7				
North Pacific	102000	-	10900	0.01	-	1.0				
Northern hemisphere Total (rounded)	252800	4304	5700	0.3	0.9	70	45	140	200000	600000

a Denmark, Finland, Iceland, Norway, Sweden.
b Austria, Czechoslovakia, German Democratic Republic, Federal Republic of Germany, Hungary, Poland, Romania, Switzerland.
c Belgium France, Ireland, Luxembourg, Netherlands, United Kingdom.
d Albania, Bulgaria, Greece, Italy, Malta, Yugoslavia.
e Portugal, Spain.
f Bahrain, Cyprus, Dem. Yemen, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Turkey, United Arab Emirates, Yemen.
g Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, Sri Lanka.
h Burma, Dem. Kampuchea, Laos Dem. Republic, Malaysia, Philippines, Singapore, Thailand, VietNam.
i China, Dem. Korea, Hong Kong, Japan, Korean Rep., Mongolia.
j Canada, Mexico, United States of America.
k Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, Trinidad and Tobago.
l Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama.
m Colombia, Guyana, Suriname, Venezuela, French Guiana.
n Algeria, Egypt, Libya, Morocco, Sudan, Tunisia.
o Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo.
p Cameroon, Central African Republic, Chad, Equatorial Guinea.
q Ethiopia, Somalia, Uganda, Djibouti.

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