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(Indian Point Nuclear Generating Units 2 and 3)
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ENT000362
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ANNEX C

Exposures to the public from man-made sources of radiation

CONTENTS

INTRODUCTION

1. The Committee has continually kept under review the exposures of the world population resulting from releases to the environment of radioactive materials from man-made sources. Exposures from such sources reviewed in the UNSCEAR 1993 Report [U3] included atmospheric nuclear testing, underground nuclear testing, nuclear weapons fabrication, nuclear power production, radioisotope production and uses, and accidents at various locations. New information on man-made environmental exposures is considered in this Annex.

2. The testing of nuclear weapons in the atmosphere was the most significant cause of exposure of the world population to man-made environmental sources of radiation. The practice continued from 1945 to 1980. Although the testing has ceased and the Committee's assessment of global doses based on measured ^{90}Sr deposition remains an accurate evaluation of the resulting exposures, particularly for long-lived radionuclides, new data on the yields of individual tests have been made available. These allow more detailed calculations of the dispersal of radionuclides throughout the world following the injection of debris into the atmosphere. Estimates of total deposition and doses from individual radionuclides are re-evaluated in this Annex, which also considers exposures to individuals who lived near the test sites. Previous estimates of exposures from atmospheric testing were based on accumulated average doses (dose commitments), but there is interest as well in the annual doses received by individuals. Annual dose estimates are derived in this Annex.

3. Following the cessation of atmospheric testing, nuclear weapons continued to be tested underground. Several further underground tests were conducted in 1998. Underground testing results only infrequently in releases of radionuclides to the environment and the exposure of individuals. Beyond the testing of nuclear weapons, the military fuel cycle, involving the production of weapons materials and the fabrication of the weapons, has also resulted in releases of radioactive materials to the environment. Information on exposures in areas surrounding the industrial sites of nuclear materials production and weapons fabrication are considered in this Annex. Both historical and contemporary data not previously reviewed by the Committee are presented.

4. Nuclear power production continues in a number of countries, where it is an important component of electrical energy generation. Rather complete monitoring and reporting of radionuclides released, especially from nuclear reactors, provide adequate data to allow analysing exposures from this source. Data on annual releases for 1990–1997 and analysis of longer-term trends are included in this Annex. Another continuing practice, radioisotope production and uses, involves at the production stage rather trivial doses that can be only roughly estimated from the total size of the industry worldwide and some approximate figures on fractional releases of the radionuclides produced. The Committee previously assessed these exposures. The exposures of family members of patients who received therapeutic treatments with ^{131}I are considered in this Annex.

5. Another source of exposures that may be considered to be man-made is the use of fuels or materials containing naturally occurring radionuclides. These are referred to as enhanced natural radiation exposures. It has been the practice of the Committee to evaluate these along with other exposures from natural radiation. These evaluations are included in Annex B, "*Exposures from natural radiation sources*".

I. TESTING AND PRODUCTION OF NUCLEAR WEAPONS

6. The testing of nuclear weapons in the atmosphere, which took place from 1945 until 1980, involved unrestrained releases of radioactive materials directly to the environment and caused the largest collective dose thus far from man-made sources of radiation. Previous assessments by the Committee of the total collective dose to the world population in the UNSCEAR 1982 and 1993 Reports [U3, U6] are complete and still valid. In the latter Report [U3], transfer coefficients are given for the dose per unit release or per unit deposition density for over 20 radionuclides for the inhalation, ingestion, and external exposure pathways.

7. The evaluation of doses to the hemispheric and world populations from this practice has been based on the

measured global deposition density of ^{90}Sr, limited measurements of ^{95}Zr deposition, and on estimated ratios of the deposition of other radionuclides to these. The annual depositions of ^{90}Sr were measured in some detail during the years when testing in the atmosphere took place. This has meant that the collective doses could be evaluated more directly and with less uncertainty than would be the case if uncertain estimates of the amounts of radionuclides produced in the tests and their dispersion in the environment had to be relied on. However, lack of sufficient data for other, and especially the shorter-lived, radionuclides limits the reliability of the estimated ratios to ^{95}Zr and ^{90}Sr.

8. In recent years some further details of atmospheric nuclear testing have become available. In particular, the numbers and total yields of the explosions have been officially reported, providing reliable basic input data, and estimates are being made of the local doses to populations living in the vicinities of the test sites. This information is taken note of by the Committee to complete the historical record of this practice.

9. In its previous assessments, the Committee emphasized the estimation of the collective doses from atmospheric nuclear testing and did not evaluate annual doses in detail. Approximate magnitudes of annual doses were presented in the UNSCEAR 1982 Report [U6]. The unfolding of collective doses to derive annual doses is presented below in more detail to illustrate the time dependence of contributions to the annual effective doses already received by the world population from various radionuclides and to estimate the future annual effective doses from residual contamination.

10. The production of nuclear weapons involves securing quantities of enriched uranium or plutonium for fission devices and of tritium and deuterium for fusion devices. The fuel cycle for military purposes is similar to that for nuclear electrical energy generation: uranium mining and milling, enrichment, fuel fabrication, reactor operation, and reprocessing. Releases of radionuclides may occur at all the various stages but particularly during reprocessing and plutonium separation. Initial information on exposures from the operation of military fuel cycle installations was included in the UNSCEAR 1993 Report [U3]. Some further data are summarized in this Chapter. Discharges and hence exposures were greatest in the early years when nuclear arsenals were being established.

A. ATMOSPHERIC TESTS

1. Number and yields of tests

11. Further information on the number and yields of atmospheric nuclear tests has been reported by the countries that conducted the tests. In the UNSCEAR 1993 Report [U3], the number of tests by all countries was adjusted from 423 to 520, an increase of more than 20%. The total has since been modified slightly, and at the same time the estimated total and fission yields have been revised downwards.

12. Compilations of data on atmospheric nuclear tests have been published within the last few years, first by the United States [D4], then by the former Soviet Union [M2], the United Kingdom [J3], and France [D3]. Information was provided on the date of each test, its name or designation, location, type, purpose, and the total explosive yield. To verify production amounts of important globally dispersed fission radionuclides, it would also be necessary to know the fission yield of each test or series of tests.

13. The data on atmospheric nuclear tests needed by the Committee for exposure evaluations are given in Table 1, and a summary for each country and each test site is provided in Table 2. The date, type, and total explosive yield of individual tests are as reported by the country. In a few cases, the total yields reported by the United States and the former Soviet Union were indefinite ("low", "sub megatonne", or within a designated range). Specific values for summations and analyses were estimated based on assumptions given in the footnotes to Table 1.

14. Assumptions are also needed to estimate the fission and fusion yields of individual tests. Relatively low yield explosions may be assumed to be due to fission only, and very high yield explosions were thermonuclear tests with substantial fusion yields. For the purpose of obtaining values for Table 1, all tests smaller than 0.1 Mt total yield were assumed to be due only to fission, unless otherwise indicated. For tests in the range 0.5–5 Mt, fission yields averaging about 50% have been reported to be representative [G4], and that value has been assumed here. For tests in the range 0.1–0.5 Mt, a fission yield of 67% is assumed. There were 17 tests in the range 5–25 Mt. With no other indications available, fission yields of 33% were assumed in Table 1 for these tests. However, the fission yields of tests by the United States were arbitrarily adjusted to agree with the reported total fission yields for the years 1952, 1954, and 1958. The large variation in assumed fission yields for the high-yield tests conducted in these years is consistent with unofficial reports that the test of 31 October 1952 (Mike) had a relatively high fission yield and with the confirmation that some high-yield tests had very high fission ratios [D7]. The largest test, 50 Mt, conducted by the former Soviet Union in 1961, was reported to have a fission yield of 3% and a fusion yield of 97% [M2]. Special design measures were taken to obtain such a high fusion yield.

15. It would be desirable to have further information on the fission and fusion yields of atmospheric nuclear tests to substantiate the somewhat arbitrary assumptions that must be made, particularly for the tests of the former Soviet Union. Because the largest atmospheric nuclear tests ($\geq$4 Mt) made such substantial contribution to the fission, fusion, and total yields, they are listed separately in Table 3. These 25 tests account for nearly 66% of the total explosive yield of all tests and about 55% of the estimated fission yields. Tests with yields greater than 1 Mt accounted for over 90% of the total fission yield.

16. Some exceptions to the general fission/fusion assumptions can be made for the atmospheric tests conducted by China. These tests occurred in the latter part of the test period, and the individual tests were relatively well separated in time. It was thus possible to obtain independent estimates of fission yields from the stratospheric monitoring of radionuclides that took place regularly throughout this testing period [K7, K8, K9, K10, L7, L8, T5]. The estimates of fission yields from ^{90}Sr and ^{95}Zr stratospheric inventories include some inconsistencies and uncertainties, but the direct evidence is used in preference to the assumptions.

17. The annual number and yields of atmospheric tests by all countries are summarized in Table 4 and illustrated in Figure I. The number of tests (Figure I, upper diagram) was greatest during 1951–1958 and 1961–1962. There was a moratorium in 1959, which was largely observed in 1960, as well. The most active years of testing from the standpoint of the total explosive yields (Figure I, lower diagram) were 1962, 1961, 1958, and 1954. The total number of atmospheric tests by all countries was 543, and the total yield was 440 Mt. The fission yield of all atmospheric tests is estimated at present to be 189 Mt.

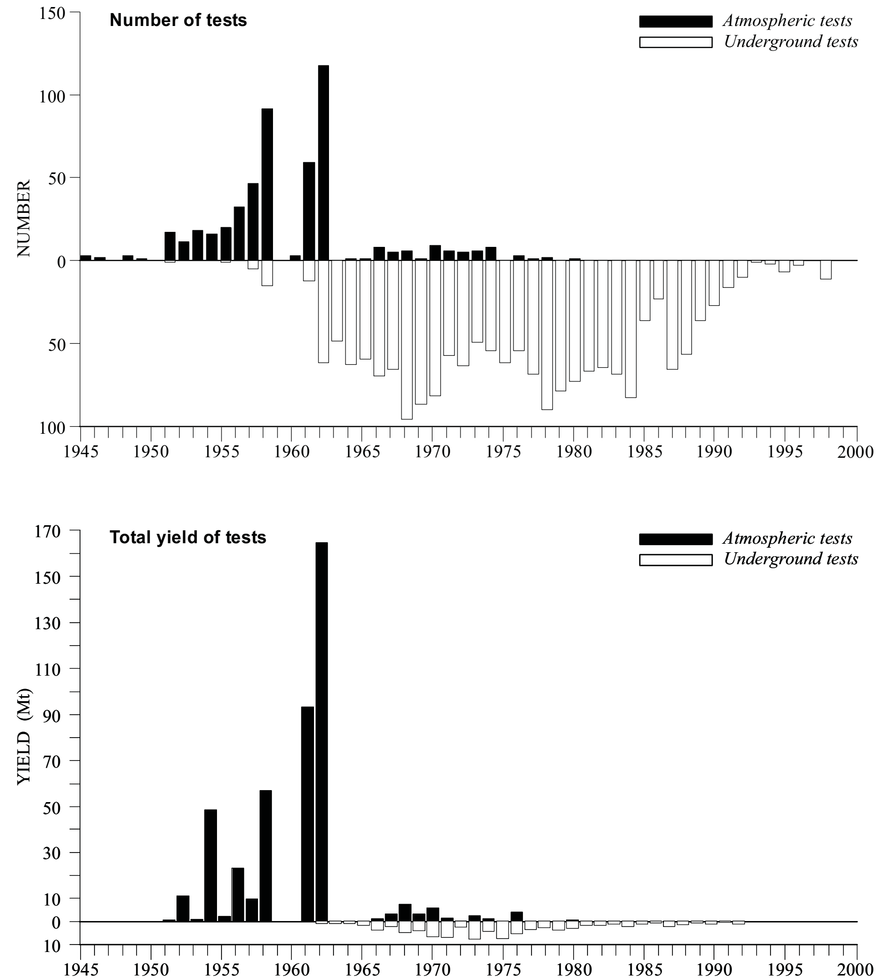


Figure I. Tests of nuclear weapons in the atmosphere and underground.

2. Dispersion and deposition of radioactive debris

18. Nuclear weapons tests were conducted at various locations on and above the earth's surface, including mountings on towers, placement on barges on the ocean surface, suspensions from balloons, drops from airplanes, and high-altitude launchings by rockets. Depending on the location of the explosion (altitude and latitude) the radioactive debris entered the local, regional, or global environment. For tests conducted on the earth's surface, a portion of the radioactive debris is deposited at the site of the test (local fallout) and regionally up to several thousand km downwind (intermediate fallout). This fraction varies from test to test depending on the meteorological conditions, height of the test, the type of surface and surrounding material (water, soil, tower, balloon, etc.). For refractory radionuclides such as ^{95}Zr and ^{144}Ce, 50% of the debris is assumed to be deposited locally in the immediate vicinity of the test site and a further 25% is deposited regionally [B9, B10, H5]. For volatile radionuclides such as ^{90}Sr, ^{137}Cs and ^{131}I, 50% of the fission yield, on average, is assumed deposited locally and regionally [P1]. The remainder of the debris and all of the debris from airbursts is widely dispersed in the atmosphere. Airbursts are defined as tests occurring at or above a height in metres of 55 $Y^{0.4}$, where Y is the total yield in kilotonnes [P1].

19. Depending on the conditions of a test, the radioactive debris can be initially partitioned or apportioned into various regions of the atmosphere. A basic compartment diagram representing atmospheric regions and the predominant atmospheric transport processes is shown in Figure II. This representation was developed to describe atmospheric dispersion and deposition of radioactive debris produced in atmospheric nuclear testing [B1, U6]. The atmosphere is divided into equatorial and polar regions (from 0° to 30° and 30° to 90° latitude, respectively). The troposphere height is variable with latitude and season, but for modelling purposes it is assumed to be at an average altitude of 9 km in the polar region and 17 km in the equatorial region. The lower stratosphere is assumed to extend to 17 km and 24 km, respectively, in the two regions and the upper stratosphere to 50 km in both regions. Only a few tests injected material above the upper stratosphere, designated the high atmosphere, which extends to several hundred kilometres and includes the remainder of the region from which debris will eventually be deposited on the earth's surface.

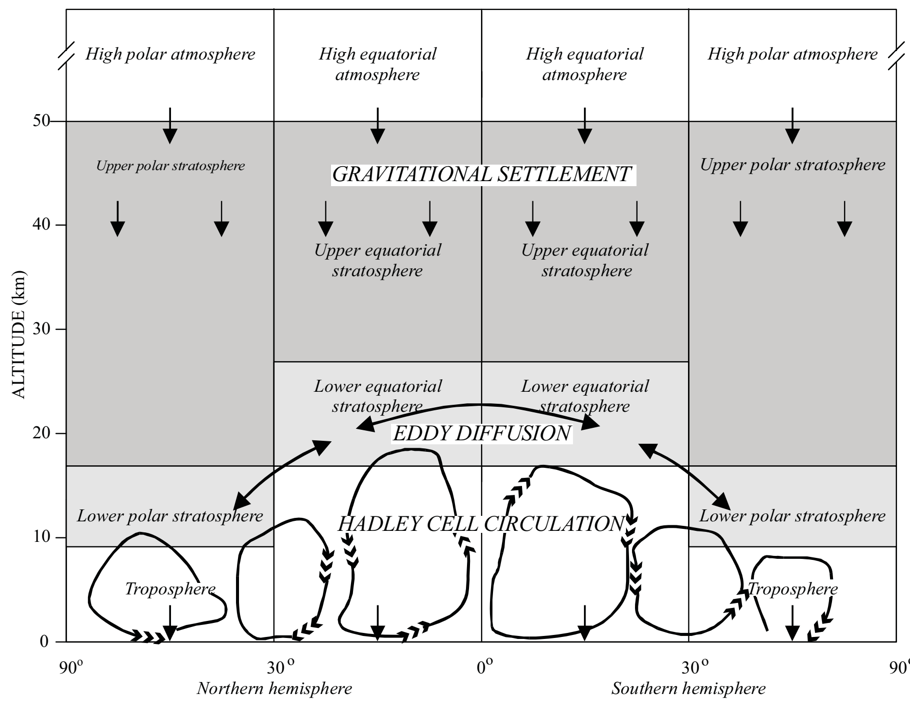


Figure II. Atmospheric regions and the predominant atmospheric transport processes.

20. Apportionment of debris in the atmosphere is based on the stabilization heights of cloud formation following the explosion. Empirical values derived from a number of observations are given in Table 5 [P1]. These results were used for the earlier estimates of fallout production from atmospheric testing that were quoted in the UNSCEAR 1982 Report [U6]. Adjustments can now be made according to the revised values of total yields and the fission yield estimates given in Table 1. The partitioned yield estimates are included in Tables 1 and 2, and annual injections into the various atmospheric regions are summarized in Table 6. The estimate of the relative fractions of debris injected into the stratosphere and troposphere for a particular test with yield less than several megatonnes is somewhat uncertain for several reasons. The empirical estimates were only available for equatorial tests and were highly variable [F5]. Values for polar latitudes are based on meteorological considerations [F5], and the height of the troposphere varies seasonally.

21. Partitioning of debris into atmospheric regions was initially formulated for the equatorial and polar regions. Injections from the Chinese test site at Lop Nor (40°N) indicate that a temperate region formulation would also be useful. This was not apparent for earlier tests at the Nevada test site (37°N) or the Semipalatinsk test site (52°N) because there was relatively little or no stratospheric input from tests at these sites. Releases from temperate sites can be partitioned by averaging the equatorial and polar results. Basically, this averaging procedure reduces the input to the upper stratospheric region compared with the partitioning for a polar release. Details of the assumptions, justified by the empirical nature of the modelling, are specified in the footnote to Table 6.

22. With the indication of the type of test given in Table 1, the apportionment of fission yield corresponding to local and more widespread tropospheric and stratospheric portions has been made in Tables 1, 2 and 4. The tropospheric and stratospheric injections listed in these Tables are for volatile radionuclides (e.g. ^{90}Sr, ^{137}Cs) and do not reflect the additional local and regional deposition that occurred for refractory radionuclides (e.g. ^{95}Zr, ^{144}Ce).

23. As indicated in the summary Tables 2 and 4, the locally and regionally deposited debris amounts to about 29 Mt (for volatile elements). Therefore, about 160 Mt is estimated to

have been widely dispersed, contributing to global fallout. This latter value, inferred from yield information, may be compared with the value of 155 Mt derived from global ^{90}Sr measurements (604 PBq deposited worldwide divided by the production estimate of 3.9 PBq Mt^{-1}). Since about 2%–3% of ^{90}Sr decayed before deposition, the total dispersed amount (injection into atmosphere) inferred from measurements is also about 160 Mt. The fission yield estimates thus provide much better agreement with the measured deposition (corresponding to 155 Mt) than the previous fission yield estimates of 189 Mt [B1, U6]. The estimate of the total debris deposited locally and regionally is somewhat uncertain due to the likely high variations from test to test, however, as seen, this component is a small fraction of the debris injected into the global atmosphere, and thus this uncertainty will have only a small impact on the uncertainty in the total global ^{90}Sr deposition.

24. From extensive monitoring following individual tests and for the entire period of dispersion and deposition, considerable information was gained on the movement and mixing processes in the atmosphere. The radioactive debris served as a tracer material. Aerosols in the atmosphere descend by gravity at the highest altitudes and are transported with the general air movements at lower levels. Eddy diffusion causes irregular migration of air masses in the general directions indicated in Figure II in the lower stratosphere and upper troposphere. The circular air flow pattern in the troposphere at lower latitudes is termed Hadley cell circulation. These cells increase or decrease in size and shift latitudinally with season. The balanced pattern shown in Figure II is that for the months of March, April, May, and September, October, November. The mean residence time of aerosols in the lower stratosphere ranges from 3 to 12 months in the polar regions and 8 to 24 months in the equatorial regions. The specific seasonal values, determined from empirical fitting to fallout radionuclide measurements, are indicated in Figure III. The most rapid removal occurs during the spring months. Removal half-times to the next lower region from the upper atmosphere are 6 to 9 months and from the high atmosphere, 24 months was found to be representative [B1]. A removal half-time of infinity (∞) in Figure III means that no transfer takes place via the particular pathway during that season of the year.

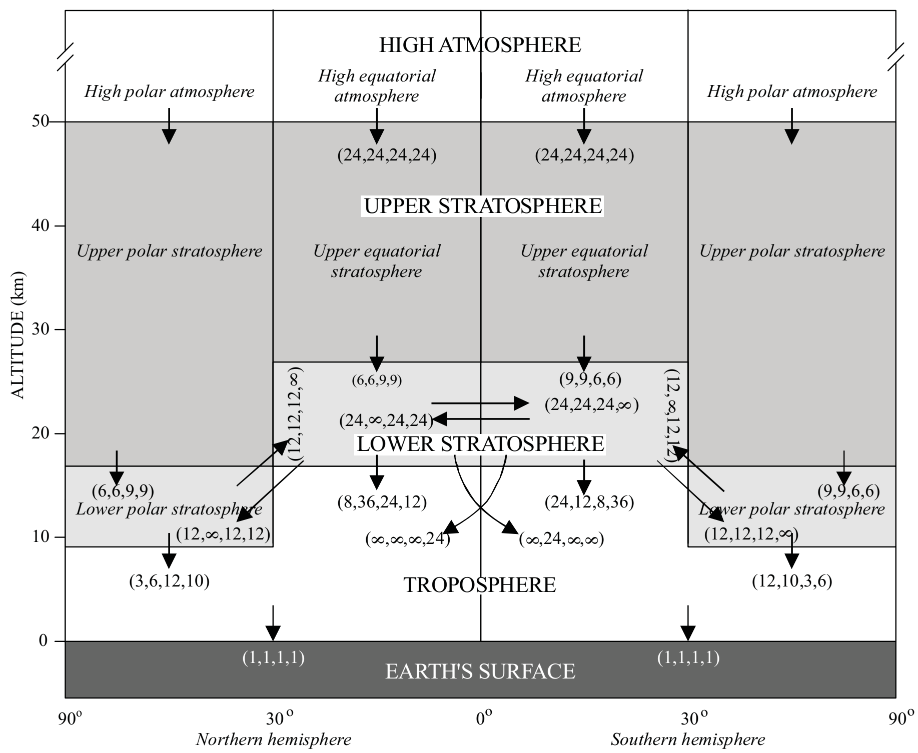


Figure III. Schematic diagram of transfers between atmospheric regions and the earth's surface considered in the empirical atmospheric model [B1].
The numbers in parentheses are the removal half-times (in months) for the yearly quarters in the following order: March-April-May, June-July-August, September-October-November, December-January-February.

25. An empirical atmospheric compartmental model based on Figures II and III had been used to estimate surface air concentrations and deposition of long-lived fallout radionuclides starting with estimated fission production yields of each test [B1]. However, since rather complete measurements of ^{90}Sr in air and deposition were available and there were uncertainties in the reported fission yields, this modelling work was not pursued. Improved estimates of fission yields changes this situation and allows the possibility of examining in greater detail the deposition of other radionuclides, such as ^{106}Ru and ^{144}Ce, and of projecting the measurement records beyond levels

of detection capabilities. Estimates can also be made for short-lived radionuclides such as ^{95}Zr, however the uncertainty will be greater, since most of the deposition from these radionuclides is from highly uncertain fractions of the total debris that were injected into the troposphere or deposited locally and regionally.

26. The parameters of the empirical model were set by comparisons with data on tracer radionuclides released in some of the tests at specific times, such as ^{185}W, ^{109}Cd, and ^{54}Mn, as well as with the longer-term records of ^{90}Sr. The fit of the calculation to the ^{90}Sr data in surface air is shown in Figure IV for the northern hemisphere (upper diagram) and for the southern hemisphere (lower diagram). With the available estimates of fission yields of individual atmospheric tests, the model matches rather well the monthly data that show seasonal variations in the concentrations. The model indicates the total ^{90}Sr inventory in the hemispheric troposphere. This has been converted to a concentration with use of a volume parameter of 0.0001 Bq m^{-3} per PBq, empirically determined from the ^{90}Sr data for mid-latitudes [B1]. Annual average calculated and measured concentrations of ^{90}Sr in surface air of the mid-latitude regions are summarized in Table 7.

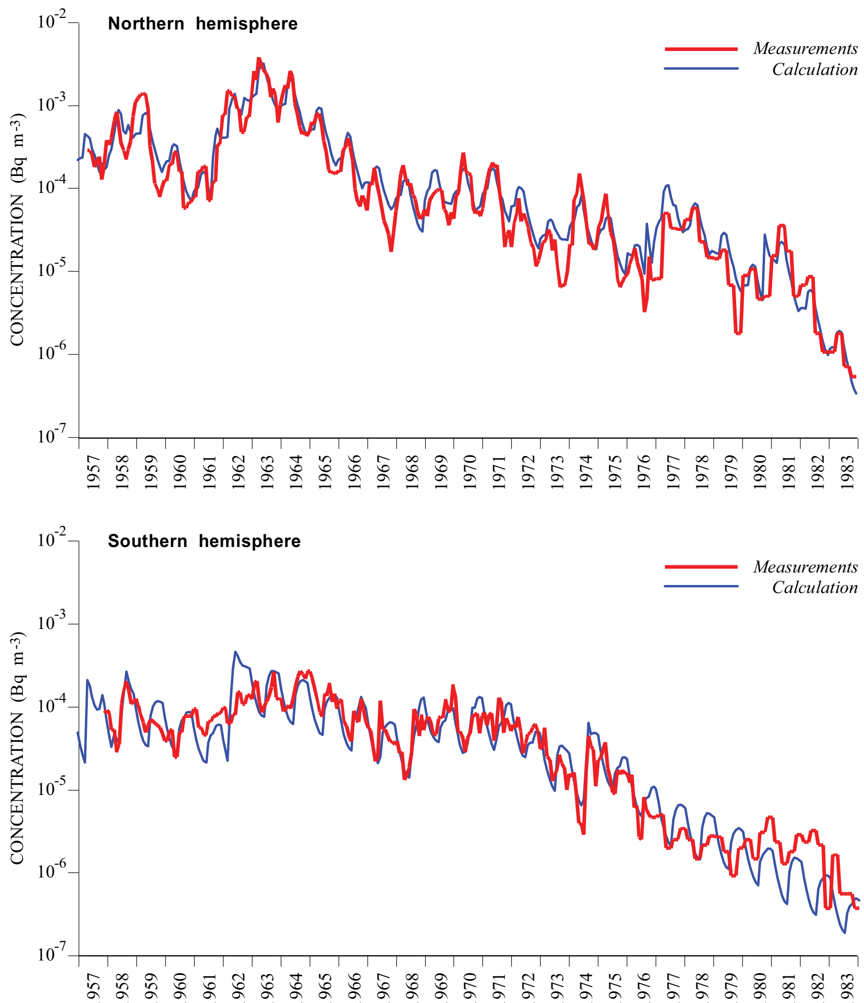


Figure IV. Strontium-90 concentration in air in the mid-latitude regions.
The measurements averaged over several sites are compared with results of the atmospheric model calculation.

27. Measurements of ^{90}Sr in surface air were made routinely at a number of locations around the world. A global surface-air monitoring network was maintained by the United States Naval Research Laboratory from 1957 to 1962 [L6] and continued by the Environmental Measurements Laboratory of the United States Department of Energy from 1963 to 1983 [F4]. After 1983, the levels were undetectable with the methods used. The representative measured concentrations of ^{90}Sr in air shown in Figure IV are derived from averaging the results of several sites in the mid-latitudes of both hemispheres (see footnotes to Table 7).

28. Some slight deviations between the measured and calculated results of ^{90}Sr in air may be due to inaccurate estimation of injection amounts or of the initial partitioning of debris in the atmosphere or to variations in the measured results or in the meteorology that may occur

from year to year. Furthermore, the measured results at the chosen representative mid-latitude sites may not be representative of the entire hemisphere as calculated from the model, particularly for years with relatively large tropospheric injections from low-latitude test sites. Debris injected into the equatorial troposphere at low latitudes will likely remain in a low latitude band due to the Hadley circulation patterns, as illustrated in Figure II. Some deviations for tests conducted at high-latitude sites have also occurred, for example the rapid depletion of the polar stratosphere in 1959 following the 1958 Soviet tests was indicated by the measurements. Also notable is the absence of a peak in 1962 in the southern hemisphere following injections into the troposphere and stratosphere of the equatorial region from tests in that year. Further deviations occur beyond 1980, when the low levels reached by the measured concentrations become uncertain and some enhancement from resuspension of ground deposits may become relatively more important.

29. Long-term monitoring of ^{90}Sr deposition based on precipitation sampling was conducted with global networks operated by the Environmental Measurements Laboratory of the United States [H1] and the Harwell Laboratory of the United Kingdom [P3]. Quite comparable results were obtained. An earlier monitoring network based on gummed-film detectors at more than a hundred stations in many countries was operated from 1952 to 1959 by the Health and Safety Laboratory, which became the Environmental Measurements Laboratory, in the United States [H8]. The results of deposition densities at individual sites have been averaged within latitude bands and multiplied by the area of the bands to obtain estimates of the hemispheric and global deposition amounts. The annual results are shown in Figure V for the northern hemisphere (upper diagram) and southern hemisphere (lower diagram) and are compared to the estimates derived from the atmospheric model. The agreement is quite close until the early 1980s, when uncertainties in the measurements began to increase.

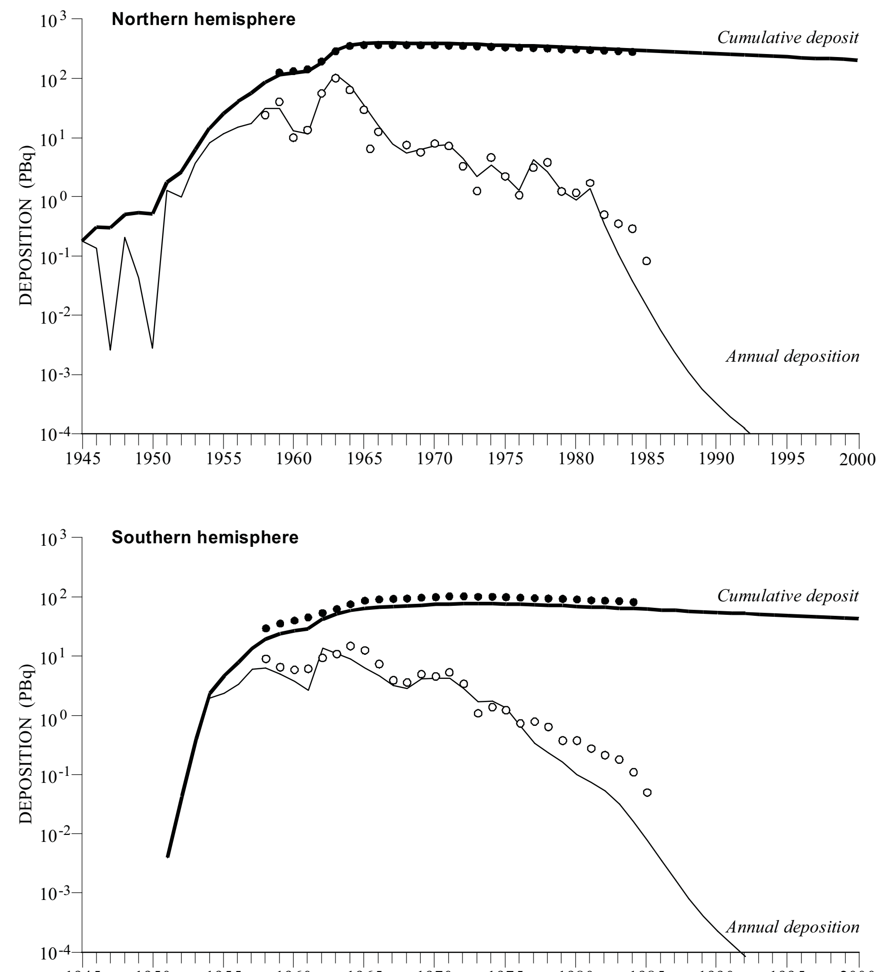


Figure V. Hemispheric depositions of ^{90}Sr determined from global network measurements (points) and from atmospheric model calculations (lines).

30. Using the atmospheric model and the estimated fission yields of individual tests, it is possible to distinguish the contributions of the test programmes of individual countries to the annual deposition of ^{90}Sr. This is illustrated in Figure VI. In the northern hemisphere the contributions from the test programme of the United States dominated before

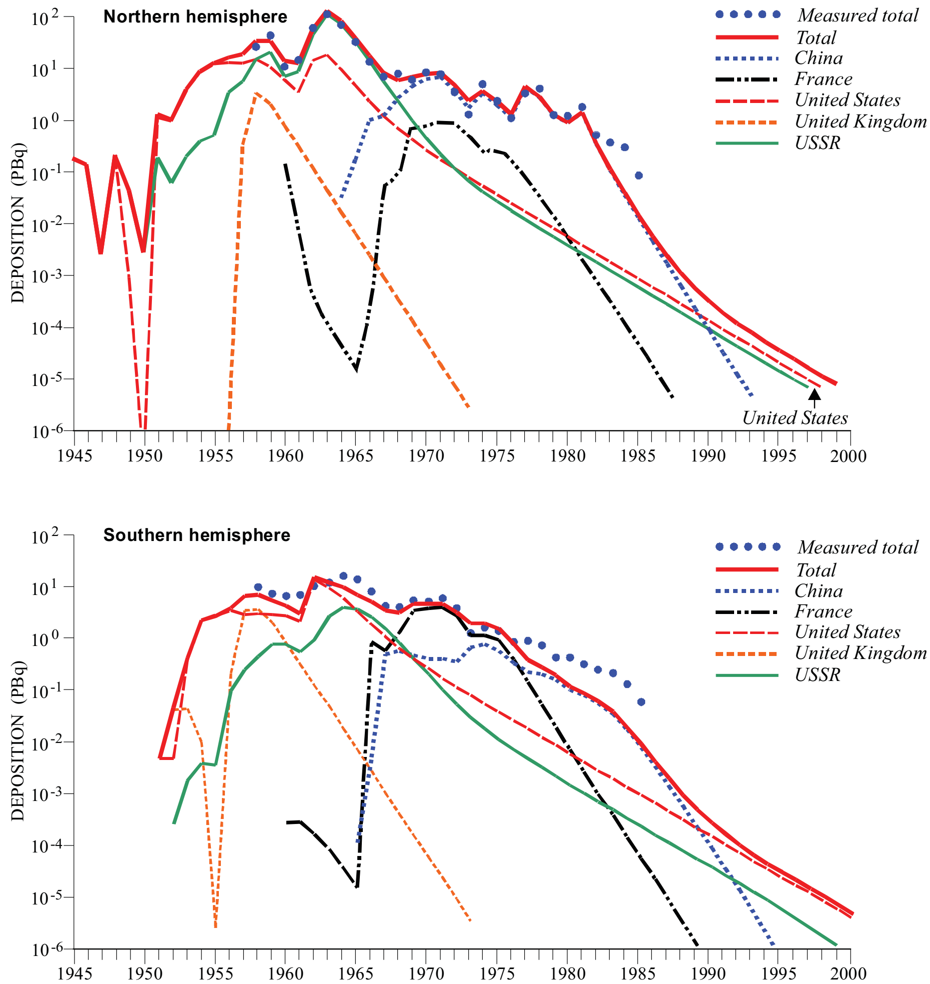


Figure VI. Components of strontium-90 deposition from test programmes of countries calculated from fission yields of tests with the atmospheric model.

1958. From 1959 until 1967 the test programme of the former Soviet Union contributed the greatest amounts to annual ^{90}Sr deposition, and from 1968 until 1988 the deposition was primarily from the Chinese tests. In the southern hemisphere, the annual deposition was greatest from the tests of the United States before 1964 except for 1957 and 1958, when the equatorial tests of the United Kingdom took place. Subsequently, the greatest contributors to annual deposition were the former Soviet Union during 1965–1967, France during 1968–1976, and China during 1977–1988. Owing to slower removal of debris from inventories in the high atmosphere and upper stratosphere, the deposition of the test programmes of the United States and the former Soviet Union predominate again in the 1990s, although at levels too low to be measurable.

31. A summary of the annual hemispheric totals of measured and calculated ^{90}Sr deposition is given in Table 7. The deposition rate of ^{90}Sr was generally greater by a factor of about 5 in the northern hemisphere from 1953 to 1965 and from 1977 to 1983. From 1967 to 1977 and since 1985, the fallout rates in both hemispheres have been roughly the same. The model results indicate a total global deposition of 610 PBq. Using the measurement results preferentially, when available, the global deposition amount of ^{90}Sr is unchanged, although the measurements indicate a slightly smaller proportion of the total deposition in the northern hemisphere than indicated by the calculations. The previous estimate of the total deposition based on measurement results and measured cumulative deposition up to 1958 was 604 PBq. The calculated results indicate a decay of about 2%–3% of the injected amount of ^{90}Sr prior to deposition (injected amount 160.5 Mt × 3.9 PBq Mt^{-1} = 626 PBq; deposited amount 610 PBq or 97.4% of the injected amount), corresponding to an average residence time of debris in the atmosphere of about 1.1 years. The measured result of 604 PBq suggests an average residence time of about 1.3 years. The global cumulative deposit reached a maximum in 1967–1972 of 460 PBq (Table 7). By the year 2000, this will have decayed to 250 PBq.

32. Since most of the atmospheric tests were conducted in the northern hemisphere, the deposition amounts are greater there than in the southern hemisphere. Because of the preferential exchange of air between the stratosphere and troposphere in the mid-latitudes of the hemisphere and the air

circulation patterns in the troposphere, there is enhanced deposition in the temperate regions and decreased deposition (by a factor of about 2) in the equatorial and polar regions. The latitudinal distribution of ^{90}Sr deposition determined from the global measurements is given in Table 8. This latitudinal variation is only valid for long-lived radionuclides, for which most of the deposition was from debris originally injected into the stratosphere. As the half-life of the radionuclide decreases, a larger fraction of the fallout was from injections into the troposphere, since larger fractions of the stratospheric amounts decay during the relatively long stratospheric residence times. The variation with latitude for these radionuclides thus will depend more on the latitude of injection. (The model indicates that about 90% of the deposited ^{90}Sr is from stratospheric debris, while for ^{95}Zr only about one third is due to stratospheric debris and for ^{131}I, less than 5%).

33. With demonstrated good agreement for ^{90}Sr obtainable with the empirical atmospheric model, the concentrations in air and the deposition of other long-lived radionuclides can be calculated. Previously, estimates were made from ratios to ^{90}Sr values. The atmospheric model can take better account of decay prior to deposition and can start with the fission production values that are independent of estimates for other radionuclides. The model can be very usefully applied for short-lived radionuclides that could not be adequately monitored at the time the testing occurred. However, because the deposition of these short-lived radionuclides is so dependent on the fractions injected into the troposphere and the amounts of local and intermediate fallout, the model deposition estimates are less reliable, and the results need to be adjusted to agree with available data.

34. The radionuclides produced and globally dispersed in atmospheric nuclear testing that are important from a dosimetric point of view are listed in Table 9. These are the radionuclides that were also considered in the UNSCEAR 1993 Report (Annex B, Table 1) [U3]. For fission radionuclides, the production per unit energy released in the tests assumes 1.45 10^{26} fissions Mt^{-1}. Multiplying by the fission yield and the decay constant gives the normalized activity production. For radionuclides produced in fusion reactions or by activation primarily in thermonuclear tests (^{3}H, ^{14}C, ^{54}Mn, ^{55}Fe), the normalized production can be estimated from measured inventories in the environment and the associated total fusion energy of all tests. The values for ^{54}Mn and ^{55}Fe are those quoted in the UNSCEAR 1993 Report [U3], which may yet be adjusted to take into account better estimates of the inventories and the total fusion energy of tests. The production of transuranic radionuclides has been inferred from ratios to ^{90}Sr, as measured in deposition. These values are thus unchanged from previous estimates [U3]. The total production of radionuclides in atmospheric testing associated with the globally dispersed debris (excluding local deposition at the test sites and regional deposition) and based on revised estimates of fission and fusion energies is given in the last column of Table 9. The fission yields in Table 9, which are assumed to be representative of all atmospheric tests, are those for thermonuclear tests, since these contributed over 90% of the debris. The fission yields for ^{89}Sr and ^{125}Sb has been revised slightly from those previously used [U3], based on the production ratios for thermonuclear tests reported by Hicks [H6].

35. The input data to the atmospheric model for the calculation of worldwide deposition of radionuclides produced in atmospheric testing are the fission and fusion yields of individual tests (Table 1), the normalized production of radionuclides (Table 9), and the atmospheric partitioning assumptions (Tables 5 and 6). Because atmospheric transport is seasonal, it is necessary to work with monthly values of input and to calculate monthly deposition. For short-lived radionuclides it is necessary to use daily values to adequately account for decay before deposition. The total annual deposition results are presented in Table 10 for each hemisphere and for the world. Because thermonuclear fission yields were used, the estimates for years with mostly low-yield tests are somewhat less certain, since the fission yields for low-yield tests for some radionuclides vary significantly depending on the mixture of fissile material used.

36. Only for ^{90}Sr are there adequate measurements of hemispheric deposition that could be used in place of the calculated results. Limited data are available for ^{89}Sr from the sampling network of the United States [H7]. Some data on other radionuclides are also available for a few sites during particular time periods. There are only minor discrepancies in calculated and measured results for ^{90}Sr, but the measured results are used preferentially in Table 10, i.e. 1958–1985. An important component of the residual global contamination from atmospheric testing is ^{137}Cs. Because of the similarity in the half-life of ^{137}Cs (30.07 a) and ^{90}Sr (28.78 a), deposition occurs according to the ratio of fission yields and (inversely) half-lives: ^{137}Cs/^{90}Sr = 1.5. Thus, the estimates of ^{137}Cs in Table 10 are based on this ratio times the measured ^{90}Sr deposition for the period 1958–1985. The estimates for ^{144}Ce, ^{106}Ru and ^{125}Sb, ^{54}Mn and ^{55}Fe are based solely on the calculated results. The calculated results for the refractory radionuclides, ^{95}Zr, ^{141}Ce, ^{144}Ce, ^{54}Mn, and ^{55}Fe take into account the higher local and intermediate deposition discussed earlier. The estimates of annual deposition of ^{95}Zr, ^{91}Y, ^{89}Sr, ^{103}Ru, ^{141}Ce, ^{140}Ba, and ^{131}I have been normalized to the total depositions reported at the bottom of Table 10. The estimates of total deposition are based on comparisons with available data, production ratios, and relative half-lives. The ratios of total deposition for these radionuclides to ^{90}Sr differ somewhat from those reported in the UNSCEAR 1993 Report [U3], because of revised assessment of the available data as well as an adjustment to account for a greater proportion of deposition at low latitudes than assumed earlier.

37. A basic indication of deposition amounts determined by measurements and needed in dose calculations is the deposition density, the activity of deposited radionuclides per unit ground surface area. Global measurements of ^{90}Sr are related to the areas of the 10° latitude bands in which the measurements were made. These areas are given in Table 8. From the evaluated fractional deposition in each band, the total hemispheric deposition is apportioned and the deposition densities determined. By weighting these results with the populations in the bands, the population-weighted deposition

density for the hemisphere is obtained. With 89% of the world population in the northern hemisphere and 11% in the southern hemisphere, the hemispheric results may be weighted accordingly to obtain the world average deposition density. This latitudinal apportionment is valid only for the long-lived radionuclides for which most of the deposition originated from debris injected into the stratosphere. For short-lived radionuclides, for which most of the deposition was from debris injected into the troposphere, adjustments must be made to account for the increased deposition at low latitudes resulting from tests of the United States and the United Kingdom in the Pacific. Since the population in the northern hemisphere is about equally divided between latitudes greater and less than 30°, an increase in the relative fraction of the deposition below 30° has only a small impact (about 10%) on the population-weighted deposition density. However, because 86% of the population of the southern hemisphere lives between 0°–30° latitude and almost all of the debris injected into the southern hemisphere troposphere was at latitudes less than 30°, the value to convert from total deposition to population-weighted deposition density for short-lived radionuclides (half-lives less than 30 days) for months in which the input was primarily from United States tests in the Pacific would be 6.7 rather than 3.74 (see Table 8). An intermediate weight of 5.7 based on 75% of the debris from tropospheric injections and 25% from stratospheric injections would be more appropriate for radionuclides with half-lives of about 30 to 100 days.

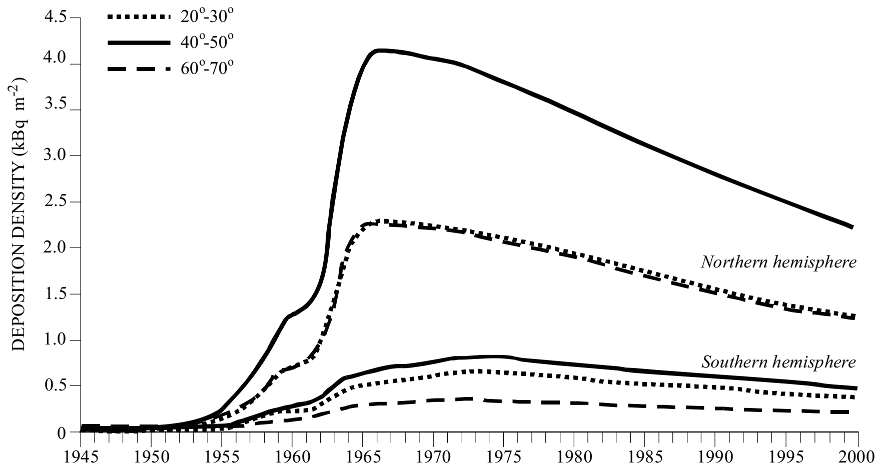


Figure VII. Caesium-137 deposition density in the northern and southern hemispheres calculated from fission production amounts with the atmospheric model.

38. The hemispheric and world average cumulative deposition densities are given in Table 11. The monthly deposition results from the atmospheric model have been averaged over the year. The model accounts for decay during the month of deposition as well as after deposition. The total deposition for long-lived radionuclides (half-life >100 d) in the hemisphere is multiplied by the parameters in Table 8 (4.65 and 3.74 Bq m^{-2} per PBq in the northern and southern hemisphere, respectively) to obtain the population-weighted deposition densities of Table 11. For radionuclides with half-lives between 30 and 100 d, and <30 d, factors of 5.7 and 6.7 Bq m^{-2} per PBq, respectively, were used for the southern hemisphere. A value of 4.0 was used for the northern hemisphere for all short-lived radionuclides. The world average is the population-weighted sum of the hemispheric values: 0.89 times the average population-weighted deposition density of the northern hemisphere plus 0.11 times the average population-weighted deposition density of the southern hemisphere. For the long-lived radionuclides, the deposition densities in particular latitudinal regions may be obtained with use of the factor given in the last column of Table 8. For example, the deposition density for ^{90}Sr in the 40°–50° latitude region of the northern hemisphere is 1.5 times the northern hemisphere average value.

39. An important component of the residual radiation background caused by deposition of radionuclides produced in atmospheric testing is that of ^{137}Cs. Calculated deposition densities of ^{137}Cs in various latitude regions are shown in Figure VII. These levels were perturbed by additional deposition from the Chernobyl accident in 1986, especially in European countries.

40. The world average deposition densities of radionuclides produced in atmospheric testing are illustrated in Figure VIII. Considerable variations are noted for the short-lived radionuclides, and these have by now decayed to negligible levels. When the tests were taking place, the deposition densities of several short-lived radionuclides, especially ^{144}Ce, ^{106}Ru, and ^{95}Zr, were highest, but since 1965, ^{137}Cs and ^{90}Sr dominate in the residual cumulative deposit.

41. The summations of the annual deposition densities of Table 11 give the integrated deposition densities (Bq a m^{-2}) for the radionuclides. Only for ^{90}Sr and ^{137}Cs are there significant contributions beyond the year 2000. The total in Table 11 extended for all time (1945 to infinity) may also be obtained from the total deposited amounts (Table 10) multiplied by the mean lives of the radionuclides ($1/\lambda$ = half-life ÷ ln2) and the appropriate population-weighted conversion factor from Table 8. This demonstrates the consistency of the annual calculation of deposition and the cumulative deposition density.

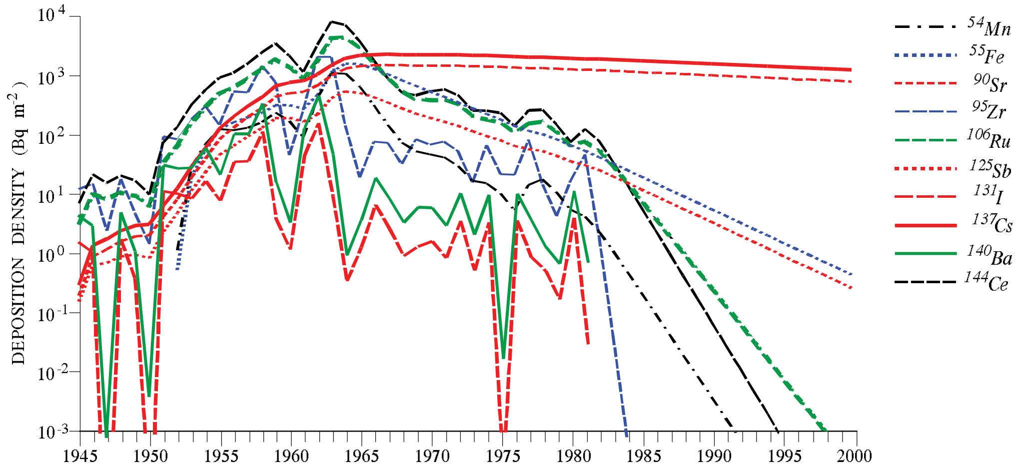


Figure VIII. Worldwide population-weighted cumulative deposition density of radionuclides produced in atmospheric testing. *The monthly calculated results have been averaged over each year. Several short-lived radionuclides with half-lives and deposition patterns intermediate between ^{140}Ba and ^{95}Zr are not shown.*

3. Annual doses from global fallout

42. The Committee provided a rough indication of the average annual doses to the world population from fallout radionuclides in the UNSCEAR 1982 Report [U6]. For 1958–1979, the maximum dose rate was estimated to be 0.14 mSv a^{-1} in 1963, and it had decreased by almost an order of magnitude by 1979. Using available empirical models, the annual doses can be estimated in much more detail. The results of this exercise are presented in this Section.

43. The basic input to dose calculations from fallout radionuclides has been the measured deposition density of ^{90}Sr. The measured annual hemispheric deposition amounts for representative mid-latitude sites are listed in Table 7. The measurements, which began in 1958, were continued until 1985. By then the stratospheric inventory from atmospheric tests was largely depleted. Some of the monitoring sites were affected by the Chernobyl accident in 1986. Subsequently, a low, constant level of deposition has been measured that reflects resuspended soil particles [A4, I5]. Longer-lived radionuclides in global fallout other than ^{90}Sr have also been monitored, but they have been present in relatively constant ratios to ^{90}Sr. For short-lived radionuclides (half-life <100 days), decay before deposition is significant. For these radionuclides, the pattern of deposition was previously taken to be that of ^{95}Zr, with the magnitude estimated from the average value of the ratio determined by available measurements. The empirical atmospheric model with input from individual nuclear tests now allows the time course of deposition of all radionuclides produced in atmospheric testing to be determined in greater detail and with better general accuracy.

44. The general procedures for deriving dose estimates from the measured or calculated deposition densities of radionuclides are presented in Annex A, "*Dose assessment methodologies*". It is only necessary to summarize here the values of transfer coefficients needed for the annual dose evaluations for the various pathways: external, inhalation, and ingestion. The transfer coefficients P_{25} used to evaluate the effective dose committed by unit deposition density of a radionuclide were given in the UNSCEAR 1993 Report (Annex B, Table 8) [U3].

45. Of the radionuclides contributing to external exposure, only ^{137}Cs has a half-life greater than a few years. For this radionuclide the depth distribution in soil has been taken to correspond to a relaxation length of 3 cm. Previous assessments of external doses from fallout assumed a plane source distribution for the other radionuclides [U3, U4]. This assumption is now altered to provide a more realistic basis for the dose estimation. A relaxation length of 3 cm is also used for the other long-lived radionuclides (half-lives >100 days). For radionuclides with half-lives between 30 and 100 days, a relaxation length of 1 cm is more appropriate. For the other short-lived radionuclides (half-lives <30 days), a relaxation length of 0.1 cm is assumed rather than a plane source, to account for ground roughness. The chosen relaxation lengths are consistent with the values used in the UNSCEAR 1988 Report [U5] to estimate external exposures from the Chernobyl accident and more adequately reflect the observed penetration of the radionuclides into the soil with time. The parameters required to calculate the annual effective doses from external irradiation are summarized in Table 12.

46. For the external irradiation pathway, the effective dose rate per unit deposition density is derived by multiplying the dose rate in air per unit deposition density by the conversion factor 0.7, which relates the dose rate in air to the effective dose, and the occupancy-shielding factor, 0.2 fractional time outdoors + 0.8 fractional time indoors × 0.2 building shielding = 0.36. The average annual effective dose is then obtained by multiplying by the average annual deposition density.

47. The values of annual doses due to external exposure from radionuclides produced in atmospheric testing are given in Table 13. The components of the world average

external dose are illustrated in Figure IX (upper diagram). The short-lived radionuclide ^{95}Zr, with its decay product ^{95}Nb, was the main contributor to external exposure during active testing. Of less significance were ^{106}Ru, ^{54}Mn, and ^{144}Ce. Beginning in 1966, ^{137}Cs became the most important contributor, and presently it is the only radionuclide contributing to continuing external exposure from deposited radionuclides.

48. Several radionuclides contribute to exposure via the ingestion pathway. They are listed, along with the transfer coefficients, in Table 12. For the short-lived radionuclides (^{131}I, ^{140}Ba, ^{89}Sr), the exposures occur within weeks or months following deposition. For annual dose rates, it is sufficient to assume that the exposures occur evenly over the mean life of the radionuclide. The transfer coefficients relating dose rate to deposition density are obtained by dividing the transfer coefficients for the committed dose [U3] by the radioactive mean lives. These are the entries in Table 12.

49. In previous UNSCEAR assessments, exposures via the ingestion pathway from the longer-lived radionuclides ^{90}Sr and ^{137}Cs have been derived from empirical transfer models applied to the measured deposition density of ^{90}Sr (the ^{137}Cs to ^{90}Sr ratio of 1.5 is used to derive the deposition density of ^{137}Cs). The parameters of the models were evaluated from regression fits to the measured concentrations of these radionuclides in diet and the human body. These models apply to continuing deposition throughout the year, as occurred during fallout deposition. Thus, the seasonal variability in transfers to diet is averaged out in a single annual value.

50. The model used to describe the transfer of ^{90}Sr or ^{137}Cs from deposition to diet is of the form

$$C_{d,i} = b_1 F_i + b_2 F_{i-1} + b_3 \sum_{n=1}^{\infty} e^{-\lambda' n} F_{i-n} \qquad (1)$$

where $C_{d,i}$ is the concentration of the radionuclide in a food component d or in the total diet in the year i due to the deposition density rate F_i in the year i, F_{i-1} in the previous year, and the sum of the deposition density rates in all previous years, reduced by exponential decay. The exponential decay with decay constant λ' reflects both radioactive decay and environmental loss of the radionuclide. The coefficients b_i and the parameter λ' are determined by regression analysis of measured deposition and diet data. The coefficients b_i represent the transfer per unit annual deposition in the first year (b_1), primarily from direct deposition, in the second year (b_2), from lagged use of stored food and uptake from the surface deposit, and in subsequent years (b_3), from transfer via root uptake from the accumulated deposit.

51. The transfer from diet to the human body (bone) for ^{90}Sr is described by a two-component model:

$$C_{b,i} = c\, C_{d,i} + g \sum_{m=0}^{\infty} e^{-\lambda_b m} C_{d,i-m} \qquad (2)$$

where $C_{b,i}$ is the concentration of ^{90}Sr in bone in the year i, c is a coefficient for short-term retention, and g is a coefficient for longer-term retention, with removal governed by the decay constant λ_b. The parameters c, g, and λ_b are determined by regression fits to monitoring data.

52. The retention of ^{137}Cs in the body is relatively short-term (retention half-time of around 100 days). The annual dose per unit intake can therefore be expressed by a single transfer coefficient, P_{34}, which applies to the year of intake. The annual doses from ^{90}Sr and ^{137}Cs in the body are evaluated using the transfer coefficient P_{45}. The values of the transfer coefficients used in calculating the annual effective dose from ingestion of ^{90}Sr and ^{137}Cs, derived from long-term monitoring, are given in Annex A, "*Dose assessment methodologies*".

53. Further exposure via ingestion of longer-lived radionuclides occurs from ^{55}Fe and the transuranium elements. The doses committed from the transuranium radionuclides are very small, and the contributions to annual doses are negligible. A transfer model does not exist for ^{55}Fe. Its half-life is only 2.73 years; therefore, it is assumed, as for the short-lived radionuclides, that the dose-rate transfer coefficient is equal to the commitment transfer coefficient [U3] divided by the radioactive mean life. This result is entered in Table 12.

54. The components of annual dose via the ingestion pathway from radionuclides produced in atmospheric testing are listed in Table 14 and illustrated in Figure IX (middle diagram). During active testing, ^{137}Cs was the most significant component, owing to its more immediate transfer to diet and delivery of dose. Because of the longer-term, continuing transfer of ^{90}Sr to diet and its longer retention in the body, this radionuclide became the most important contributor to dose beginning in 1967. The short-lived radionuclides have been relatively insignificant contributors to ingestion exposure (see Figure IX).

55. For the inhalation pathway, exposures depend on the concentrations of radionuclides in air, but because of the association between concentrations in air and deposition densities through the deposition velocity, the transfer coefficients for the dose from inhalation can be given in terms of the measured deposition densities of the radionuclides. These transfer coefficients, P_{25}, were given in the UNSCEAR 1993 Report (Annex B, Table 8) [U3] and are repeated here in Table 12. These are the committed doses per unit intake. The dose from inhalation can be assumed delivered in the same year that the deposition occurred. Subsequent exposures from resuspension are accounted for in the measured air concentrations and the derived deposition velocity, and although these exposures may continue for a few more years, including all of the exposure in the year of initial deposition does not introduce much error.

56. The estimates of annual doses from the inhalation of radionuclides produced in atmospheric testing are given in Table 15, and several of the components are illustrated in Figure IX (lower diagram). Important contributors to

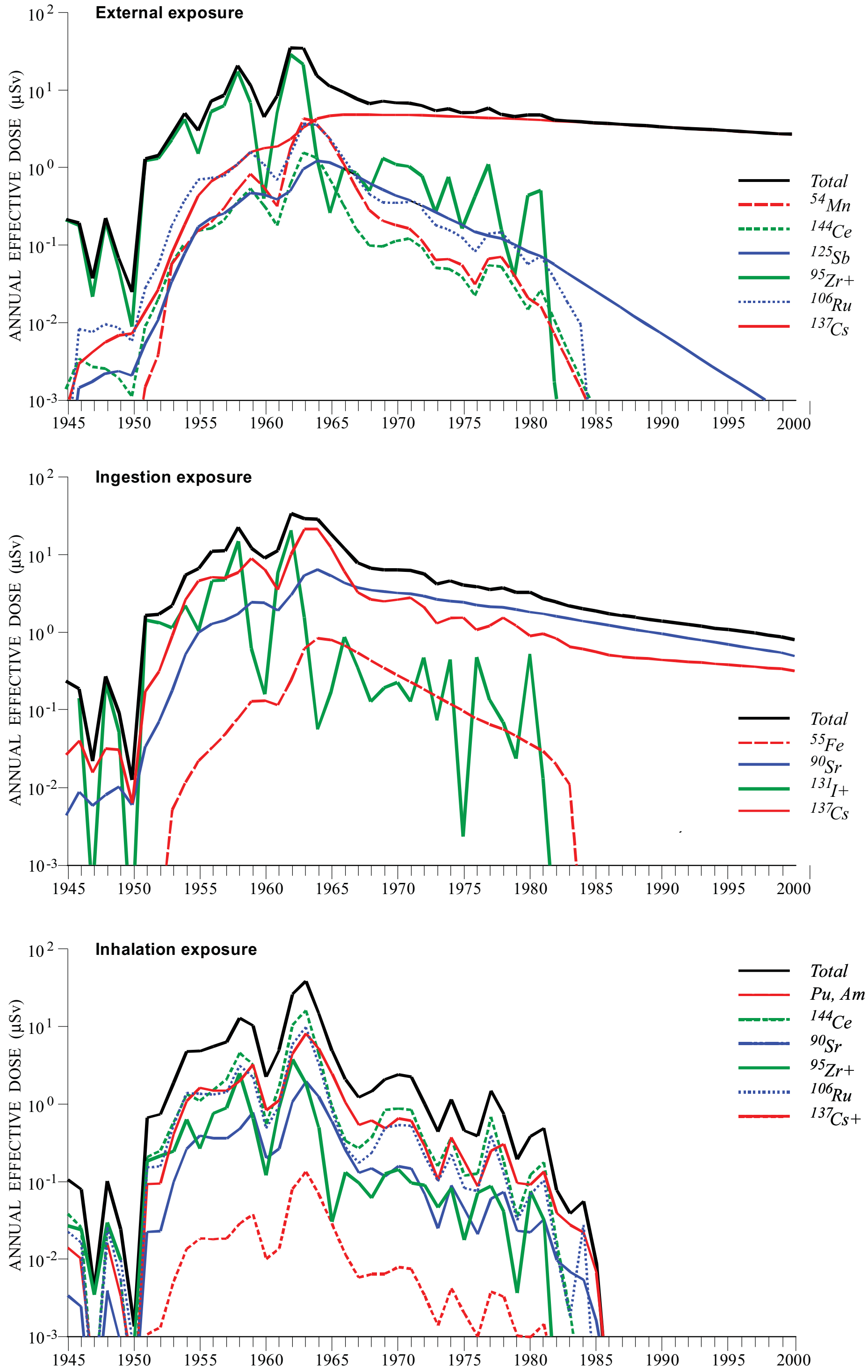


Figure IX. Worldwide average doses from radionuclides produced in atmospheric testing.
External exposure: *Contributions from radionuclides ^{131}I, ^{140}Ba, ^{144}Ce, ^{106}Ru are included with ^{95}Zr;*
Ingestion exposure: *Contributions from ^{90}Sr and ^{140}Ba are included with ^{131}I;*
Inhalation exposure: *Contributions from short-lived radionuclides (^{131}I, ^{140}Ba, ^{141}Ce, ^{103}Ru, ^{89}Sr, ^{91}Y) are included with ^{95}Zr and from intermediate-lived radionuclides (^{54}Mn, ^{125}Sb, ^{55}Fe) are included with ^{137}Cs.*

inhalation exposure were ^{144}Ce, the transuranic radionuclides, ^{106}Ru, ^{91}Y, ^{95}Zr, and ^{89}Sr. Deposition, and thus the concentrations of these radionuclides in air, dropped rapidly once atmospheric testing ceased in 1980. Even for the long-lived transuranic radionuclides, inhalation exposure became insignificant after 1985.

57. One further contribution to annual exposures comes from the globally dispersed radionuclides ^3H and ^{14}C. In both cases, there is no external exposure and only negligible exposure from inhalation. Exposure arises most entirely from the ingestion pathway. Global models have been formulated to describe the dispersion and long-term behaviours of these radionuclides in the environment. Estimates of the annual doses from ^3H and ^{14}C produced in atmospheric testing are included in Table 14 and illustrated in Figure X.

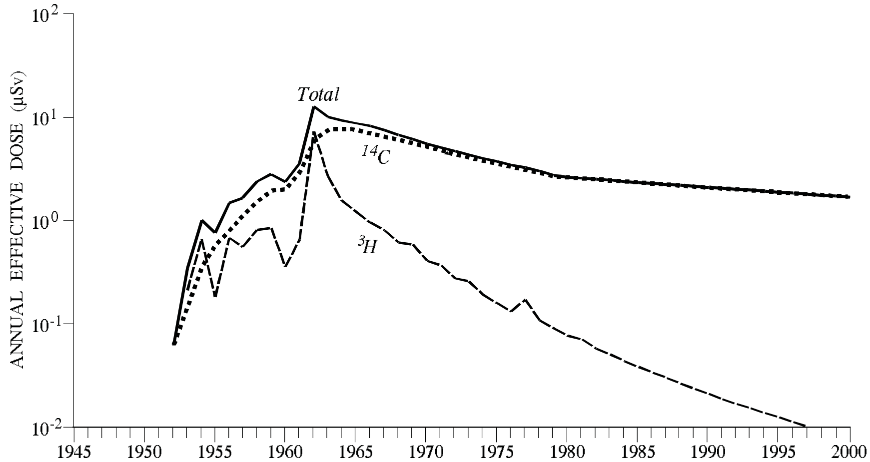


Figure X. Worldwide average dose (mainly from ingestion pathway) from globally dispersed ^3H and ^{14}C.

58. The annual doses from tritium have been evaluated using the seven-compartment model presented by the United States National Council on Radiation Protection and Measurements (NCRP) [N1]. With volumes and transfer rates applicable for the hydrological cycle of the world and intake of water by humans assumed to be 33% from the atmosphere, 53% from surface fresh waters, 13.3% from groundwater, and 0.7% from ocean surface water (through fish) [N1], the dose per unit release is 0.06 nGy PBq^{-1}. Further details of the model are presented in Annex A, "*Dose assessment methodologies*".

59. The annual doses from ^{14}C have been derived using the multi-compartment model described in Annex A, "*Dose assessment methodologies*". The estimates are only approximate, since widespread, immediate mixing in large regions is assumed in the model formulation. To compensate for this, the hemispheric values have been adjusted to an initial ratio of 4 to 1 in the northern and southern hemispheres, reflecting the deposition pattern of longer-lived radionuclides. This ratio was maintained through 1970 and then reduced uniformly to a ratio of 1 to 1 by the year 2000, representing assumed completion of uniform mixing throughout the world. This procedure provides more realistic estimates of doses in the hemispheres, but does not affect the estimated global average. The average annual global effective dose from ^{14}C produced in atmospheric nuclear testing was at a maximum, 7.7 µSv, in 1964 and has decreased by a factor of 4 since that time. The dose would be estimated to be somewhat less when account is taken of the input of stable carbon into the atmosphere from fossil fuel burning, which dilutes the ^{14}C.

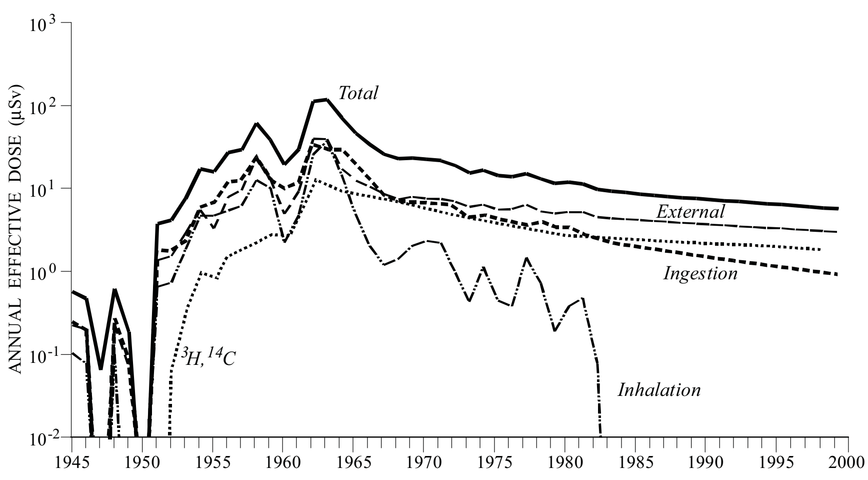


Figure XI. Contributions of pathways to worldwide average dose from radionuclides produced in atmospheric testing.

60. The estimates of the total annual effective doses from radionuclides produced in atmospheric nuclear testing are summarized in Table 16, and the world average contributions from the main pathways are illustrated in Figure XI. These results are for the hemispheric- and world-population-weighted averages of deposition of fallout radionuclides. The doses in more specific regions of the world may be obtained by adjusting to the latitudinal distribution of deposition determined from measurement of ^{90}Sr (Table 8). In the temperate zones (40°−50°), the annual doses from long-lived radionuclides are higher than the hemispheric averages by factors of 1.5 in the northern hemisphere and 1.65 in the southern hemisphere. For the short-lived radionuclides (see paragraph 37), the distribution with latitude is more uniform in the northern hemisphere, while the doses in the temperate zones of the southern hemisphere are about one third less than the hemispheric average. The hemispheric average annual dose was highest in 1963 in the northern hemisphere (0.13 mSv) and in 1962 in the southern hemisphere (0.06 mSv).

61. The estimated world average annual dose from atmospheric nuclear testing was highest in 1963 (0.11 mSv) and subsequently declined to less than 0.006 mSv in the 1990s. External exposure generally made the highest contributions to annual doses, when the annual doses from ^{14}C and ^{3}H are not included, initially by short-lived radionuclides and subsequently by ^{137}Cs. Both external and ingestion exposure peaked in 1962. The annual doses at present are due almost equally to external irradiation (53%) and ingestion exposures (47%). The dose from ^{14}C (30% of the total) now exceeds that from ingestion of other radionuclides. The doses yet to be delivered at future times are also indicated in Table 16. The summation of annual doses for all time defines the dose commitment, which is the dose quantity previously evaluated in UNSCEAR assessments of the exposure from atmospheric nuclear testing [U3]. With use of the model calculations, the revised external dose coefficients, and the re-evaluation of the total deposition of short-lived radionuclides, the present dose estimates for some radionuclides differ slightly from the previous assessment, although the current estimated total effective dose commitment to the world population, 3.5 mSv, is little different from the result given in the UNSCEAR 1993 Report [U3], 3.7 mSv.

4. Local and regional exposures

62. Since atmospheric nuclear tests were conducted in relatively remote areas, exposures of local populations did not contribute significantly to the world collective dose from this practice. Nevertheless, those individuals living downwind of the test sites received greater-than-average doses. In addition, individuals who might now or in the future occupy contaminated areas of the former test sites could receive exposures through external or internal pathways. Efforts are being made to evaluate these sites to guide possible rehabilitation and resettlement, and work is continuing to reconstruct the exposure conditions and to estimate the local and regional doses that were received at the time of the tests. Available information was presented in the UNSCEAR 1993 Report [U3] and is summarized here in Table 17. Further results, although still not systematic and complete, are presented in this Section. It will be necessary to add details as the dose reconstruction efforts progress.

63. The locations of several test sites are shown in Figures XII, XIII, and XIV. The areas within a few hundred kilometres of the site are generally designated as local and those within a few thousand kilometres, regional. Distances of 500 km and 1,000 km from the test sites are delineated in the figures for reference purposes. The exposed populations were generally only those living in downwind, generally eastward directions.

(a) Nevada test site

64. The Nevada test site in the United States was the location for 86 atmospheric nuclear tests: 83 tests were conducted from 1951 to 1958, and 3 more tests were conducted in 1962. Additional cratering tests also injected debris into the atmosphere [N10]. Local areas were affected by relatively few tests, but for those few tests they were much more affected than more distant areas of the United States, which received less deposition and exposure but were more evenly affected by a larger number of tests. The external exposures to local populations were estimated at the time of testing to be low; however, public concern about the health impact of the exposures grew. As a consequence, rather detailed dose reconstruction projects were undertaken in the 1980s.

65. Estimates of external exposures from atmospheric tests at the Nevada test site were reported by Anspaugh et al. [A1, A3]. Results were derived from survey meter and film badge measurements for 300 communities in the local areas (<300 km) around the test site in Nevada and in southwestern Utah. The distribution of individual cumulative exposures is given in Table 18. The effective dose exceeded 3 mSv in 20% of the population of 180,000. The highest effective doses were in the range 60−90 mSv, and the population-weighted average value was 2.8 mSv [A1]. The exposures resulted primarily from short-lived gamma-emitters (half-lives <100 days). The estimates were based on outdoor occupancy of 50% and a building shielding factor of 0.5; the usual UNSCEAR assumptions are 20% and 0.2, respectively. Most of the exposures resulted from relatively few events; 90% of the cumulative collective dose of 470 man Sv resulted from 17 events, the most significant being test Harry on 19 May 1953 (180 man Sv), test Bee on 22 March 1955 (70 man Sv), and test Smoky on 31 August 1957 (50 man Sv) [A3]. Collective doses that included areas further downwind, encompassing all of Nevada and Utah and parts of several other western states, were estimated to have been even greater than for the local area, about 10,000 man Sv, primarily due to the exposure of the large population areas around Salt Lake City [A7, B9]. All of the United States received some fallout from Nevada weapons tests [B10]. Beck and Krey [B11] reported cumulative doses from external exposure averaged about 1 mSv to persons living in the midwest and east of the country.

66. Internal exposures resulting from atmospheric testing at the Nevada test site have been estimated from deposition measurements and an environmental transfer model [K2, W2]. Absorbed doses to organs and tissues from internal exposure were substantially less than those from external exposure, with the exception of the thyroid, in which ^{131}I from ingestion of milk contributed relatively higher doses. Estimates of absorbed doses in the thyroid of 3,545 locally exposed individuals ranged from 0 to 4.6 Gy; the average was 98 mGy and the median 25 mGy [T4]. Five individuals received absorbed doses greater than 3 Gy, and all of them drank milk from a family-owned goat [T4]. The collective absorbed dose to the thyroid of the population of states in the western United States was estimated to be 140,000 man Gy [A7]. An extensive study has been completed by the National Cancer Institute of the United States of thyroid doses in all counties of the United States from ^{131}I deposition following the atmospheric tests in Nevada [B6, N10]. The individual thyroid doses ranged up to 100 mGy in local areas. For the entire population of the United States, the estimate was 20 mGy, with a collective absorbed dose of 4 10^6 man Gy. Although not involving exposure, it should be noted that plutonium migration from an underground nuclear test conducted at the Nevada Test Site was detected 30 years following the test in a ground water monitoring well 1.3 km from the test location [K12]. In this very arid region, no migration had been anticipated. The authors concluded that colloid-facilitated transport was implicated in the field findings.

(b) Bikini, Enewetak test sites

67. An extensive nuclear test programme was conducted by the United States at locations in the Pacific (Table 1). The test resulting in the most significant local exposures was the thermonuclear test Bravo on 28 February 1954 at Bikini Atoll. Unexpectedly heavy fallout occurred in the local area eastward of the atoll (Figure XII). Within a few hours of the explosion, fallout particles descended on Rongelap and Ailinginae atolls, 200 km from Bikini, exposing 82 persons. The Japanese fishing vessel Lucky Dragon was also in this area, and 23 fishermen were exposed. Farther east, exposures occurred at Rongerik Atoll (28 United States servicemen) and Utrik Atoll (159 persons). These individuals were evacuated within a few days of the initial exposures.

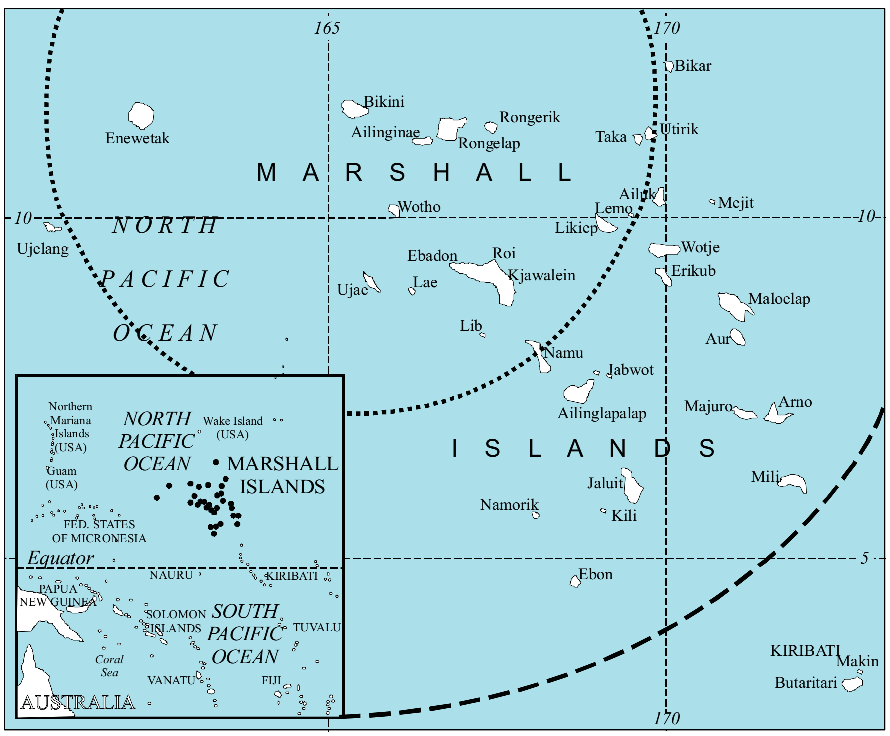


Figure XII. Bikini and Enewetak test sites.
The inner dotted circle indicates a distance of 500 km, the outer dashed circle 1,000 km from the test sites.

68. Average external exposures from the Bravo test, mainly from short-lived radionuclides, ranged from 1.9 Sv on Rongelap (67 persons, including 3 *in utero*), 1.1 Sv on Ailinginae (19 persons, including 1 *in utero*), and 0.1 Sv on Utrik (167 persons, including 8 *in utero*) [L4]. The collective dose from the exposures received by these individuals before evacuation was, therefore, 160 man Sv. Thyroid doses from several isotopes of iodine and tellurium and from external gamma radiation were estimated to be 12 Gy on average (42 Gy maximum) to adults, 22 Gy (82 Gy maximum) to children of 9 years, and 52 Gy (200 Gy maximum) to infants of 1 year [L4].

69. The external exposure from the Bravo test to the servicemen on Rongerik Atoll was 0.8 Sv [L4]. For the 23 Japanese fishermen, the external exposures from the fallout

deposition on deck ranged from 1.7 to 6 Sv, mostly received on the first day of the fallout but continuing for 14 days, until the ship arrived in its port [C9]. The thyroid doses to the fishermen were estimated to have been 0.2–1.2 Gy from ^{131}I, based on external counting, but since other short-lived iodine isotopes were also present, the total doses to the thyroid from inhalation during a period of five hours were estimated to have been 0.8–4.5 Gy [C9].

70. There seem to have been no other tests that caused significant exposures to the population in the Pacific region. The populations of the atolls where tests were conducted had been relocated prior to the testing. Exposures to residual radiation levels on Utrik and Rongelap atolls to residents who returned to these islands in 1954 and 1957, respectively, were of the order of 20–30 mSv over the following 20-year period from external irradiation and 20–140 mSv from internal exposure [C9]. During the temporary resettlement of Bikini Atoll from 1971 to 1978, total whole-body exposures were estimated to have been 2–3 mSv a^{-1} [G5]. A radiological survey of residual radiation levels, primarily due to global fallout deposition, was conducted throughout the Marshall Islands in 1994 [S2], and more detailed surveys have been made of Bikini and Enewetak atolls, in order to evaluate eventual permanent resettlement [I4, R1]. Estimated effective doses caused by residual contamination to persons who might return at present to Bikini Atoll were estimated to be 4 mSv with a diet composed of both local and imported foods and about 15 mSv for a diet of local origin only [I4]. Tests at other locations in the Pacific (Christmas Island and Johnston Island) were conducted in the high atmosphere, and there was little local fallout deposition.

(c) Semipalatinsk test site

71. The Semipalatinsk test site is located in the northeast corner of Kazakhstan (see map in Figure XIII). At this location, 456 nuclear tests were conducted, including 86 atmospheric and 30 surface tests [M2]. The most affected local populations lived mainly east and northeast of the test site, in the Semipalatinsk region of Kazakhstan and the Altai region of the Russian Federation. After some tests, traces of radioactive contamination were also formed in southern and southeastern directions [G8].

Figure XIII. Lop Nor and Semipalatinsk test sites.
The inner dotted circle indicates a distance of 500 km, the outer dashed circle 1,000 km from the test sites. The measurement areas in Gansu Province (for Lop Nor) and the Altai Region (for Semipalatinsk) are shown within elliptical areas.

72. Two tests were most significant in exposing the population of Kazakhstan: the first test on 29 August 1949 and the first thermonuclear test on 12 August 1953. These and two additional test (on 24 September 1951 and 24 August 1956) are stated in [G8] to have contributed 85% of the total collective effective dose from all tests. There are several

documents listing doses at specific locations for the population in Kazakhstan [G8, S7, T1], but the presented results differ markedly. Example results from the latest publication [S7] of accumulated effective doses for several districts indicate effective doses in the range from 0.04 to 2.4 Sv. The collective effective dose for ten districts is estimated to be 3,000–4,000 man Sv [S7]. The absorbed dose to the thyroid from the ingestion of radioiodines is quite uncertain, but is estimated to be as high as 8 Gy to children in the Akbulak settlement [S7].

73. The Altai region of the Russian Federation is about 200 km from the Semipalatinsk Test Site. This population experienced exposure following about 40 explosions [S8]. The most significant exposure was caused by the nuclear test of 29 August 1949 with other major exposures following tests on 3 September 1953, 1 August 1962, 4 August 1962, and 7 August 1962. Effective doses of about 2 Sv are estimated to have occurred in the Uglovski district following the 1949 test. The total collective dose to all residents in 58 districts with a total population of 1.9 million persons is estimated to be 42,000 man Sv [S8].

74. The results for Kazakhstan and the Altai region in the Russian Federation must at present be regarded with caution. There are significant discrepancies among the reported results for Kazakhstan, and the reported results for the Altai region differ markedly when derived from measured results or model calculations. Validation of results based upon contemporary measurements of ^{137}Cs deposition density might be useful in resolving some of these discrepancies.

75. Investigation of residual contamination levels at the Semipalatinsk site has begun. In 1993–1994, an international team performed a preliminary survey of the test site and surrounding area [I9]. More significantly contaminated areas were found at ground zero locations and surrounding Lake Balapan. Projected annual doses were estimated to be 10 mSv, mainly from external exposure, to individuals making daily visits to these sites and 100 mSv to those who might permanently reside at these locations. Present annual effective doses to persons living outside the test site boundaries were estimated to be of the order of 0.1 mSv from residual contamination levels.

(d) Novaya Zemlya test site

76. The test site Novaya Zemlya in the Russian Arctic is large and remote. Although an extensive atmospheric test programme was conducted there, most of the tests were carried out at high altitudes, thus minimizing local fallout. There was one test with a 32 kt yield on the land surface on 7 September 1957 [M2]. In addition, there were two tests on the surface of the water and three tests underwater at the site. Research programmes to investigate residual contamination both on- and off-site have been initiated. It may be that reindeer herders and those who consume reindeer meat received low internal exposures, primarily from ^{137}Cs, that could be attributed to tests at this site.

Figure XIV. Maralinga, Emu and Monte Bello test sites.
The inner dotted circle indicates a distance of 500 km, the outer dashed circle 1,000 km from the test sites.

(e) Maralinga, Emu test sites

77. The nuclear weapons testing programme of the United Kingdom included 21 atmospheric tests at sites in Australia and the Pacific. The tests in the Pacific at Malden and the Christmas Islands in 1957 and 1958 were airbursts over the ocean (six tests with submegatonne and megatonne yields) or explosions of devices suspended by balloons at 300–450 m over land (one test of 24 kt and two tests each with 25 kt yield) [D2]. Local fallout would have been minimal following those tests. Twelve tests were conducted from 1952 to 1957 at three sites in Australia: Monte Bello Islands, Emu, and Maralinga, which are shown on the map in Figure XIV. These were mainly surface tests with yields of 60 kt or less. For each of these tests, trajectories of the radioactive cloud were determined, and local and countrywide monitoring of air and deposition was performed [W1]. Estimates of external exposures in local areas were not made for the earlier tests; for the tests in 1956 and 1957, the external effective doses were less than 1 mSv [W1]. The sizes of local populations were not indicated. Estimates of internal exposures were also made for the entire Australian population. The average effective dose was 70 μSv, and the collective effective dose was 700 man Sv in this population [W1]. A number of safety tests were conducted at the Maralinga and Emu sites in South Australia, resulting in the dispersal of ^{239}Pu over some hundreds of square kilometres. The potential doses to local inhabitants of these areas have been evaluated [D1, H2, W3]. Following rehabilitation of the Maralinga test site it is estimated that potential doses to future inhabitants living a semi-traditional nomadic lifestyle will be less than 5 mSv [D1].

(f) Algerian, Mururoa, Fangataufa test sites

78. The French nuclear testing programme began with four low-yield surface tests at a site near Reggane in the Algerian Sahara in 1960 and 1961 [D3]. There is no information on local exposures following these tests. Some residual contamination remains at this site and at a nearby site, In Ecker, where 13 underground tests were conducted. Small quantities of plutonium were dispersed at these sites from safety experiments, which involved conventional explosives only. Investigations of the present radiation levels and potential exposures of individual who might utilize these areas have been initiated by the IAEA.

79. The subsequent programme of France was conducted at the uninhabited atolls of Mururoa and Fangataufa in French Polynesia in the South Pacific. Most of these tests involved the detonation of devices suspended from balloons at heights of 220–500 m [D3], limiting local fallout. Radiological monitoring has been conducted at surrounding locations. The closest inhabited atoll is Tureia (140 persons) at a distance of 120 km to the north; only 5,000 persons lived within 1,000 km of the test site. A larger population (184,000 persons in 1974) is located 1,200 km to the northwest, at Tahiti. Under the conditions that normally prevail at the test site, radioactive debris of the local and tropospheric fallout was carried to the east over uninhabited regions of the Pacific. On occasion, however, some material was transferred to the central South Pacific within a few days of the tests by westerly moving eddies. French scientists [B8] have identified five tests, following which regional population groups were more directly exposed (Table 19). A single rain-out event caused exposures in Tahiti after the test of 17 July 1974. Exposures resulted mainly from external irradiation from deposited radionuclides. Milk production on Tahiti is sufficient for only about 20% of local needs, and consumption is in any case low, which limited ingestion exposures. Estimated effective doses to maximally exposed individuals after all five events were in the range 1–5 mSv in the year following the test. A collective effective dose of 70 man Sv was estimated for all local exposures at this test site. Estimates of exposures were based on more extended measurements that were made beginning in 1982. In that year the external exposures in the region were in the range 1–10 $\mu Sv\ a^{-1}$, internal exposures were 2–32 $\mu Sv\ a^{-1}$, and total exposure was 3–33 $\mu Sv\ a^{-1}$, due mostly to residual ^{137}Cs deposition from global fallout. The collective effective dose was estimated to be about 1 man Sv in 1982 for all of French Polynesia [R2]. An international investigation of the present radiological conditions at Mururoa and Fangataufa was conducted during 1996–1998 [I7]. Residual contamination levels were, on the whole, found to be negligibly low. Small areas with surface contamination from plutonium exist, but it was regarded as only remotely conceivable that a plutonium-containing particle could enter the body of an individual, e.g. through a cut in the skin. Plutonium, tritium, and caesium in the sediments of the lagoons were considered unlikely to cause non-negligible exposures at present or in the future to any repopulated individuals or to residents of other islands throughout the Pacific region [I7].

(g) Lop Nor test site

80. The Chinese nuclear weapons testing programme was carried out at the Lop Nor test site in western China, shown on the map in Figure XIII; 22 atmospheric tests were conducted between 1964 and 1980. Limited information is available on local deposition following the tests. Balloons were used to follow the trajectory of the debris clouds, and airborne and ground-based instruments were used to monitor the radiation levels. Estimates of exposures were made over a downwind area to a distance of 800 km [Z1]. Estimates of external exposures in cities or towns within 400–800 km of the test site in Gansu Province ranged from 0.02 to 0.11 mSv (Table 20), with an average of about 0.04 mSv for three tests, which accounted for over 90% of the dose from all Chinese tests [Z1]. Indoor occupancy of 80% and a building shielding factor of 0.2 were assumed. A retrospective dose evaluation based on soil sampling was conducted in 1987–1992 [R4]. The dose commitment from ^{137}Cs was estimated to range from 1.5 to 10 mSv in the northwest Ganzu province.

B. UNDERGROUND TESTS

81. Testing of nuclear weapons underground was begun in 1951 by the United States and in 1961 by the former Soviet Union. Following the limited nuclear test ban treaty

of 1963, which banned atmospheric tests, both countries conducted extensive underground test programmes. The United Kingdom participated with the United States in a few joint underground tests. The underground test programmes of France and China continued until 1996. India conducted a single underground test in 1974 and five further tests in 1998. Pakistan reported conducting six tests in 1998. A comprehensive test ban treaty was formulated in 1996, but it has not yet been ratified by all countries or entered into force. Thus, it cannot yet be said that the practice of underground weapons testing has also ceased.

82. The number of underground tests (Figure I, upper diagram) has greatly exceeded the number of atmospheric tests, but the total yield of the former (Figure I, lower diagram) has been much less. The largest underground tests had a reported yield of 1.5–10 Mt (27 October 1973, at Novaya Zemlya by the former Soviet Union) [M2] and less than 5 Mt (6 November 1971 at Amchitka, Alaska, by the United States) [D4], but most tests have been of a much lower yield, particularly if containment of nuclear debris was desired. Only with venting or diffusion of gases following the tests, as has happened on occasion, could local populations be exposed.

83. Underground test programmes were summarized in the UNSCEAR 1993 Report [U3] and the resultant exposures were estimated. No further information has become available that could allow exposure estimates to be improved. It would be desirable to have a more complete list of those tests in which venting occurred and estimates of the amounts of radioactive materials thereby dispersed in the atmosphere. Thirty-two underground tests conducted at the Nevada test site were reported to have led to off-site contamination as a result of venting [H3].

84. The number of underground tests requires revision, based on recently published information [D4, M2]. Several tests involved the simultaneous detonation of two or more nuclear charges, either in the same or in separate boreholes or tunnels. These so-called salvo tests were done for reasons of efficiency or economy, but they also deterred detection by distant seismic measurements. The tests usually involved two to four charges; the maximum number was eight. Since each charge has now been identified, they can be properly specified as separate tests. The annual numbers of underground tests conducted by each country are given in Table 21. The total number of tests by all countries is 1,876.

85. The yields of individual underground tests have not been directly specified. Many are simply reported to be within a range of energies, for example <20 kt or 20–150 kt. The annual yields of underground tests at all locations have been compiled by the National Defense Research Establishment in Sweden [N6]. These estimates were included in the UNSCEAR 1993 Report [U3]. The total yield of all tests conducted through 1992 was 90 Mt. The yields of subsequent tests have not altered this total amount. The total yield of all underground tests conducted by the former Soviet Union has been reported to be 38 Mt [M2]. The yields apportioned to other countries are listed in Table 22.

86. Table 22 provides a summary listing of all nuclear weapons tests, both atmospheric and underground. The total number of tests was 2,419; this includes the two combat explosions of nuclear weapons in Japan and a number of safety tests. The latter had no nuclear yield, but they are conventionally included in listings of nuclear tests. The total yield of all tests was 530 Mt.

C. PRODUCTION OF WEAPONS MATERIALS

87. In addition to weapons testing, the installations where nuclear materials were produced and weapons were fabricated were another source of radionuclide releases to which local and regional populations were exposed. Some information on this practice was presented in the UNSCEAR 1993 Report [U3]. Especially in the earliest years of this activity, the pressures to meet production schedules and the lack of stringent waste discharge controls resulted in higher local exposures than in the later years. Efforts are being made to evaluate the exposures that occurred during all periods in which these installations operated. Although it may not be possible to systematically evaluate all such exposures, newly acquired information is summarized in this Section. Also, at some sites, weapons are now being dismantled.

1. United States

88. Nuclear weapons plants in the United States included Fernald, in Ohio (materials processing); Portsmouth, in Ohio, and Paducah, in Kentucky (enrichment); Oak Ridge, in Tennessee (enrichment, separations, manufacture of weapons parts, laboratories); Los Alamos, in New Mexico (plutonium processing, weapons assembly); Rocky Flats, in Colorado (manufacture of weapons parts); Hanford, in Washington (plutonium production); and Savannah River, in South Carolina (plutonium production). There are many more sites at which such operations were conducted and wastes were stored or disposed. It has been estimated that there are some 5,000 locations in the United States where contamination by radioactive materials has occurred, not all of which are associated with weapons materials production [W4]. Estimates of releases of radioactive materials during the periods of operation of the nuclear installations are summarized in Table 23. Also listed are the exposures estimated to have been received by the local populations. This information might be extended when studies now underway are concluded, thus allowing better documentation of the historical exposures from this practice.

2. Russian Federation

89. There were three main sites where weapons materials were produced in the former Soviet Union: Chelyabinsk, Krasnoyarsk, and Tomsk. Relatively large routine releases

occurred during the early years of operation of these facilities. In additions, accidents have contributed to the background levels of contamination and to the exposure of individuals living in the local and regional areas.

(a) Chelyabinsk

90. The Mayak nuclear materials production complex is located in the Chelyabinsk region between the towns of Kyshtym and Kasli near the eastern shore of Lake Irtyash. Uranium-graphite reactors for plutonium production and a reprocessing plant began operating in 1948. Relatively large discharges of radioactive materials to the Techa River occurred from 1949 to 1956 [D5]. The available information on exposures to the local population was summarized in the UNSCEAR 1993 Report [U3].

91. Estimates of releases of radionuclides during the early years of operation of the Mayak complex are presented in Table 24. Controls of releases were introduced in the early 1960s. The maximum releases in airborne effluents, primarily ^{131}I, occurred from 1949 to 1956 [D6]. During the same period, the discharges of radionuclides into the Techa River occurred [D5, K3]. Of the 100 PBq released from 1949 to 1956, 95 PBq were released in 1950 and 1951. Along with the fission products listed in Table 24, plutonium isotopes were also released.

92. The individuals most highly exposed from the releases to the Techa River were residents of villages along the river, who used the water for drinking, fishing, waterfowl breeding, watering of livestock, irrigation of gardens, bathing, and washing. In April-May 1951, a heavy flood resulted in contamination of the flood plain used for livestock grazing and hay making. The collective dose to the most exposed population from 1949 to 1956 was 6,200 man Sv (Table 25). Doses from external irradiation decreased in 1956, when residents of the upper reaches of the river moved to new places and the most highly contaminated part of the flood plain was enclosed. For some inhabitants, however, the Techa River contamination remains a significant source of exposure up to the present time.

93. On 29 September 1957, a fault in the cooling system of a storage tank containing liquid radioactive wastes led to a chemical explosion and a large release of radionuclides. The total activity dispersed off-site over the territory of the Chelyabinsk, Sverdlovak, and Tyumen regions was approximately 74 PBq. The composition of the release is indicated in Table 24. Although the release was characterized mainly by rather short-lived radionuclides (^{144}Ce, ^{95}Zr), the long-term hazard was due primarily to ^{90}Sr. An area of 23,000 km^2 was contaminated at levels of ^{90}Sr greater than 3.7 kBq m^{-2} [N8]. In 1957, 273,000 people lived in the contaminated area. Of them, 10,000 lived where the ^{90}Sr deposition density exceeded 74 kBq m^{-2} and 2,100 where the levels were over 3,700 kBq m^{-2}. In areas where ^{90}Sr contamination exceeded 74 kBq m^{-2}, the population was evacuated, and relocated first from the most severely affected area within 7–10 days and the remaining population over the next 18 months. The main pathways of exposure following the accident were external irradiation and internal exposure from the consumption of local food products.

94. The Mayak complex was responsible for further exposure of the local population in 1967, when water receded from Lake Karachy, which had been used for waste disposal, and the wind resuspended contaminated sediments from the shoreline. The dispersed material, about 0.022 PBq, consisted mainly of ^{137}Cs, ^{90}Sr, and ^{144}Ce (Table 24). The contaminated area, defined as having levels of ^{90}Sr greater than 3.7 kBq m^{-2} and of ^{137}Cs greater than 7.4 kBq m^{-2}, extended 75 km from the lake. Approximately 40,000 people lived within this area of 2,700 km^2. The exposures from external irradiation and the consumption of local foods were considerably less than those following the 1957 storage tank accident.

95. Present levels of exposure associated with operation of the Mayak complex have been estimated from the residual contamination [K4]. For internal exposure, the average (and range) of daily consumption of food were determined to be milk 0.7 (0.5–1.0) kg, meat 0.14 (0.09–0.18) kg, bread 0.36 (0.27–0.52) kg, potatoes 0.57 (0.2–1.0) kg, vegetables 0.24 (0.14–0.43) kg, fish 0.05 (0.03–0.11) kg, mushrooms 0.02 (0.01–0.03) kg, and berries 0.04 (0.01–0.06) kg [K4]. These values were used with the concentrations given in Table 26 to estimate the average annual dose from internal exposure of 100 μSv. Average annual dose from external exposure is estimated to be 10 μSv. For the population of 320,000 surrounding the Mayak complex, the annual collective effective dose from present operations (1993–1996) is estimated to be 35 man Sv (Table 27).

(b) Krasnoyarsk

96. The Krasnoyarsk nuclear materials production complex is located about 40 km from the city of Krasnoyarsk. The first two reactors at Krasnoyarsk were direct-flow type commissioned in 1958 and 1961. A third, closed-circuit reactor, was commissioned in 1964. A radiochemical plant for irradiated fuel reprocessing began operation in 1964. In 1985, a storage facility for spent fuel assemblies from reactors in the Soviet republics of Russia and Ukraine was put into service. There are plans to reprocess this fuel from the civilian nuclear fuel cycle in the future at the Krasnoyarsk site.

97. Radioactive wastes discharges from the Krasnoyarsk complex enter the Yenisei River. Trace contamination can be found from the complex to the estuary, about 2,000 km away [V1]. An estimate of the collective dose from radioactive discharges of the Krasnoyarsk complex during 1958–1991 is presented in Table 25 [K5]; the estimate is derived from data on the content of radionuclides in water, fish, flood plain, and other components of the river ecosystem [N9, V1]. On the whole, the collective dose was about 1,200 man Sv. The most important contributor (70%) to this dose was fish consumption [K6]. External exposure from the contaminated flood plain accounted for 17% of the collective dose. The main radionuclides contributing to the internal dose from fish consumption were ^{32}P, ^{24}Na, ^{54}Mn, and ^{65}Zn. The main contributor to

the external dose (over 90%) was gamma-emitting radionuclides, primarily ^{137}Cs, ^{60}Co, and ^{152}Eu. Individual doses to the population varied over a wide range, from 0.05 to 2.3 mSv a^{-1}. The main portion of the collective dose (about 84%) was received by the population living within 350 km of the site of the radioactive discharges.

98. In 1992, the direct-flow reactors of the Krasnoyarsk complex were shut down. This considerably reduced the amount of radioactive discharges to the Yenisei River, and the annual collective dose to the population was decreased by a factor of more than 4. Present estimates of average doses (1993–1996) are 30 μSv a^{-1} (external) and 20 μSv a^{-1} (internal). With a local population of 200,000, the annual collective effective dose is estimated to be 10 man Sv (Table 27).

(c) Tomsk

99. The Siberian nuclear materials production complex is located in the town of Tomsk-7 on the right bank of the Tom River 15 km north of the city of Tomsk. The Siberian complex was commissioned in 1953. It is the largest complex for the production of plutonium, uranium, and transuranic elements in the Russian Federation. The Siberian complex includes five uranium-graphite production reactors that began operation in 1958–1963, enrichment and fuel fabrication facilities, and a reprocessing plant [B7].

100. Radionuclides in liquid wastes are discharged into the Tom River, which flows into the Ob River. An estimate of the collective dose from radioactive discharges of the Siberian complex from 1958 to 1992 is presented in Table 25. The exposure pathways considered in the dose evaluation were the ingestion of fish, drinking water, waterfowl, and irrigated products and external exposure from the contaminated flood plain. The collective effective dose was estimated to be 200 man Sv. The largest contributor (73%) to this dose was fish consumption. The main radionuclides contributing to the internal dose from fish consumption were ^{32}P and ^{24}Na. The largest portion of the collective dose (about 80%) was received by the population living within 30 km of the site of radioactive discharges.

101. In 1990–1992, three of the five reactors of the Siberian complex were shut down. This considerably reduced the amount of radioactive discharges to the Tom River and the annual collective dose to the population. The average annual doses to the local population are estimated to be 0.4 μSv (external) and 5 μSv (internal). For the local population of 400,000, the collective effective dose at present (1993–1996) is estimated to be 2.2 man Sv (Table 27).

102. On 6 April 1993, an accident occurred at the radiochemical plant of the Siberian complex that resulted in the release of radioactive materials [B7, G6, I6]. A narrow trace of radioactive contamination 35–45 km long was formed in a northeasterly direction from the complex (based on trace concentrations of ^{95}Zr and ^{95}Nb in soil). The total area of the contamination with dose rate levels at the time of the accident higher than the natural radiation background was estimated to be about 100 km^2 [M8]. The dominant radionuclides in snow samples from the contaminated area were ^{95}Zr, ^{95}Nb, ^{106}Ru, and ^{103}Ru. Traces of ^{239}Pu and ^{144}Ce were also detected. A non-uniformity of contamination was noted, with the presence of hot particles in the composition of radioactive materials deposited on the snow. There are no populated places in the area of the pattern, except for the village of Georgievka, which has a population of 73 persons (including 18 children). The cumulative dose from external exposure to the inhabitants of Georgievka from the accident during 50 years of permanent residence will amount to 0.2–0.3 mSv [B7], which is negligible, compared to the dose from natural background radiation over the same period.

3. United Kingdom

103. The production of nuclear materials and the fabrication of weapons began in the 1950s in the United Kingdom. The work was carried on for several years at sites such as Springfields (uranium processing and fuel fabrication), Capenhurst (enrichment), Sellafield (production reactors and reprocessing), Aldermaston (weapons research), and Harwell (research). Subsequently, work related to the commercial nuclear power programme was incorporated at some of these sites. In the earliest years of operation of these installations, the radionuclide discharges may be associated almost wholly with the military fuel cycle.

104. Plutonium production reactors were operated in the United Kingdom at Sellafield (two graphite-moderated, gas-cooled reactors known as the Windscale piles) and, later, at Calder Hall on the Sellafield site and Chapelcross in Scotland. A fire occurred in one of the Windscale reactors in 1957, resulting in the release of radionuclides, most notably ^{131}I, ^{137}Cs, ^{106}Ru, ^{133}Xe, and ^{210}Po. The prompt imposition of a ban on milk supplies in the affected region reduced exposures to ^{131}I. The collective effective dose from the accident was estimated to be 2,000 man Sv.

4. France

105. A nuclear programme in France began in 1945 with the creation of the Commissariat à l'Energíe Atomique (CEA). The nuclear research laboratory at Fontenay-aux-Roses began activities in the following year. The first experimental reactor, named EL1 or Zoé, went critical in 1948, and a pilot reprocessing plant began operation in 1954. A second experimental reactor, EL2, was constructed at the Saclay centre. From 1956 to 1959, three larger production reactors began operation at the Marcoule complex on the Rhône River. These gas-cooled, graphite-moderated reactors, designated G1, G2, and G3, operated until 1968, 1980, and 1984. A full-scale reprocessing plant, UP1, was built and operated from 1958, also at the Marcoule site. Two more plants to reprocess fuel from commercial reactors were constructed at La Hague in the north of France: UP2, completed in 1966, and UP3, in 1990.

106. Although some systematic reporting of radionuclide discharge data is available beginning in 1972 [C10], some

of this may reflect the reprocessing of commercial reactor fuel. It should be possible to estimate plutonium production amounts at the various installations, and some reports of environmental monitoring (e.g. [M9]) may give indications of early operating experience.

5. China

107. A nuclear weapons development programme was initiated in China that led to the first nuclear explosion of that country, conducted in 1964. The Institute of Atomic Energy was created in 1950. The first experimental reactor was constructed in Beijing, and a uranium enrichment plant was built at Lanzhou in Ganzu Province in western China. The first nuclear test was of an enriched uranium device. Plutonium production and reprocessing were conducted at the Jiuquan complex, also located in Ganzu Province. The production reactor began operation in 1967 and the reprocessing plant in 1968. Production and reprocessing also occurred in Guangyuan in Sichuan Province, where larger installations were constructed. The weapons were assembled at the Jiuquan complex.

108. Assessment of exposures from nuclear weapons production in China have been reported by Pan et al. [P4, P5, P6]. Exposures to populations surrounding specific installations were estimated. This experience relates to the military fuel cycle, since the commercial nuclear power programme started only in the last decade.

II. NUCLEAR POWER PRODUCTION

109. The Committee has routinely collected data on releases of radionuclides from the operation of nuclear fuel cycle installations. In the UNSCEAR 1993 Report [U3], an overview was provided of annual releases of radionuclides for the general types of reactors and other fuel cycle installations since the beginning of the practice of commercial nuclear power generation. Data for individual mines, mills, reactors, and reprocessing plants were given for the years 1985–1989. In this Annex, the data for another five-year period, 1990–1994, and a three-year period, 1995–1997, are assessed.

110. The generation of electrical energy by nuclear means has grown steadily from the start of the industry in 1956. The relatively rapid rate of expansion that occurred from 1970 to 1985, an increase in energy generation of more than 20% per year, slowed to a pace averaging just over 2% per year from 1990 to 1996 [I1]. At the end of 1997, there were 437 nuclear reactors operating in 31 countries. The total installed capacity was 352 GW, and the energy generated in 1997 was 254 GW a [I1]. It is projected [I1] that nuclear energy will continue to supply about 17% of the total electrical energy generated in the world, as at present, or possibly a few percent less.

111. The nuclear fuel cycle includes the mining and milling of uranium ore and its conversion to nuclear fuel material; the fabrication of fuel elements; the production of energy in the nuclear reactor; the storage of irradiated fuel or its reprocessing, with the recycling of the fissile and fertile materials recovered; and the storage and disposal of radioactive wastes. For some types of reactors, enrichment of the isotopic content of ^{235}U in the fuel material is an additional step in the fuel cycle. The nuclear fuel cycle also includes the transport of radioactive materials between the various installations.

112. Radiation exposures of members of the public resulting from discharges of radioactive materials from installations of the nuclear fuel cycle were assessed in previous UNSCEAR reports [U3, U4, U6]. In this Annex, the trends in normalized releases and the resultant doses from nuclear reactor operation are presented for the years 1970–1997. The doses are estimated using the environmental and dosimetric models described in Annex A, "*Dose assessment methodologies*".

113. The doses to the exposed individuals vary widely from one installation to another, between different locations and with time. Generally, the individual doses decrease markedly with distance from a specific source. To evaluate the total impact of radionuclides released at each stage of the nuclear fuel cycle, the results are evaluated in terms of collective effective dose per unit electrical energy generated, expressed as man Sv $(GW\,a)^{-1}$. Only exposures to members of the public are considered in this Annex. Occupational exposures associated with nuclear power production are included in Annex E, "*Occupational radiation exposures*".

A. MINING AND MILLING

114. Uranium mining involves the removal from the ground of large quantities of ore containing uranium and its decay products. Underground and open-pit mining are the main techniques. Underground mines produced 40% of the world´s total uranium production in 1996 and open-pit mines, 39% [O1]. Uranium is also mined using *in situ* leaching, which produced 13% of the world uranium in 1996 [O1]. The remaining 8% was recovered as a by-product of other mineral processing. Milling operations involve the processing of the ore to extract the uranium in a partially refined form, known as yellowcake.

115. Uranium mining and milling operations are conducted in several countries. Production in recent years is given in Table 28. In 1997 about 90% of world uranium production took place in 9 countries: Australia, Canada, Kazakhstan, Namibia, Niger, the Russian Federation, South Africa, the United States, and Uzbekistan. It is noted that oversupply, leading to large stockpiles and low prices,

has led to considerable reductions in output since 1989 [O1]. However, beginning in 1995, production of uranium was substantially increased in some countries, mainly Australia, Canada, Namibia, Niger, and the United States. The world production in 1997 was 35,700 t uranium.

1. Effluents

116. There are few new data on releases of radionuclides, mainly radon, in mining and milling operations. Limited data for underground mines, based on concentrations in exhaust air, were given in the UNSCEAR 1993 Report [U3] for Australia, Canada, and Germany. There were no estimates of releases in open-pit operations. For underground mines the release of radon, normalized to the production of uranium oxide (U_3O_8), ranged from 1 to 2,000 GBq t^{-1}, with a production-weighted average of 300 GBq t^{-1}. Based on the estimated uranium (fuel) requirements for the reactor types presently in use, 250 t uranium oxide are required to produce 1 GW a of electrical energy [U3]. This leads to an average normalized radon release from mines of approximately 75 TBq $(GW\ a)^{-1}$.

117. In the UNSCEAR 1993 Report [U3], the average normalized radon release from mills in Australia and Canada, also from the limited data available, was estimated to be 3 TBq $(GW\ a)^{-1}$ [U3]. These values are not expected to change with current mining and milling practices. For mining operations in arid areas, liquid effluents are minimal, and radionuclide releases via this pathway are estimated to be of little consequence.

118. The mining and milling processes create various waste residues in addition to the uranium product. The tailings consist of the crushed and milled rock from which the mineral has been extracted, together with any chemicals and fluids remaining after the extraction process. The long-lived precursors of ^{222}Rn, namely ^{226}Ra (half-life 1,600 a) and ^{230}Th (half-life 80,000 a), present in the mill tailings provide a long-term source of radon release to the atmosphere. Based on available data, the radon emission rates were estimated in the UNSCEAR 1993 Report [U3] to be 10 Bq s^{-1} m^{-2} of tailings during the operational phase of the mill (assumed to be five years) and 3 Bq s^{-1} m^{-2} from abandoned but stabilized tailings (assumed period of unchanged release of 10,000 years). Assuming that the production of a mine generates about 1 ha $(GW\ a)^{-1}$, the normalized radon releases are 3 and 1 TBq $(GW\ a)^{-1}$ for the operational and abandoned tailings, respectively. The *in situ* leach facilities have no surface tailings and little radon emissions after closure. Release estimates from mining and milling operations are summarized in Table 29.

119. In a recent study of eight major uranium production facilities in Australia, Canada, Namibia, and Niger [S6], measured emission rates were reported to range from background to 35 Bq s^{-1} m^{-2} from the tailings of presently operating mills. Following decommissioning, the release rates are at present or are expected to be no more than 7 Bq s^{-1} m^{-2} [S6]. For many of the uranium mill tailings, the long-term management involves substantial water-saturated cover, which reduces the radon emission rate to 0–0.2 Bq s^{-1} m^{-2}. Taking into account present tailings areas yet to be rehabilitated with good present techniques and the anticipated future practice, the emission rate from abandoned mill tailings can be assumed to be less than 1 Bq s^{-1} m^{-2}. This value is adopted for the present evaluation. The previous estimate was 3 Bq s^{-1} m^{-2} [U3]. For comparison, the average emission rate corresponding to soils in normal background areas is 0.02 Bq s^{-1} m^{-2} [U3].

2. Dose estimates

120. The methodology used by the Committee to estimate the collective dose from mining and milling is described in the UNSCEAR 1977 and 1982 Reports [U4, U6]. The dose estimate is based on representative release rates from a model mine and mill site having the typical features of existing sites. An air dispersion model is used to estimate the radon concentrations from releases as a function of distance from the site, and the most common environmental pathways are included to estimate dose. Thus, the results are not applicable to any given site without duly considering site-specific data but are meant to reflect the overall impact of mining and milling facilities.

121. The previously estimated exposures for the model mine and mill site assumed population densities of 3 km^{-2} at 0–100 km and 25 km^{-2} at 100–2,000 km. The collective effective dose factor for atmospheric discharges in a semi-arid area with an effective release height of 10 m was 0.015 man Sv TBq^{-1} [U3], based on the dose coefficient for radon of 9 nSv h^{-1} per Bq m^{-3} (EEC). As the dilution factor at 1 km has been reduced from 3 10^{-6} to 5 10^{-7} s m^{-3}, the dose per unit release of radon becomes 0.0025 man Sv TBq^{-1}. Using this factor, the collective effective dose per unit electrical energy generated is estimated to be 0.2 man Sv $(GW\ a)^{-1}$ during operation of the mine and mill and 0.00075 man Sv $(GW\ a)^{-1}$ per year of release from the residual tailings piles. For the assumed 10,000-year period of constant, continued release from the tailings, the normalized collective effective dose becomes 7.5 man Sv $(GW\ a)^{-1}$ (Table 29). The various revisions in the parameters have led to a considerable reduction from the previously estimated value of 150 man Sv $(GW\ a)^{-1}$ [U3].

122. An alternative assessment of exposures from mill tailings has been proposed in a study prepared for the Uranium Institute [S6]. In this study, site-specific data relating to currently operating mills in four countries (Australia, Canada, Namibia, and Niger) were utilized. Differences from the UNSCEAR results arise from the use of a more detailed dispersion model, much-reduced population densities (<3 km^{-2} within 100 km and from 2 to 7 km^{-2} in the region between 100 and 2,000 km), and more ambitious future tailings management with substantial covers to reduce radon emissions. The overall result (adjusting for the radon dose coefficient of 9 nSv h^{-1} per Bq m^{-3}, as used above) is 1.4 man Sv $(GW\ a)^{-1}$ over a 10,000-year

period, which although less by a factor of 5, it is in reasonable agreement with the estimate derived in the previous paragraph.

123. In France, exposures from mill tailings at Lodeve mining site were assessed considering measurements of radon releases prior to and after remediation [T6]. Calculations were based on a Gaussian plume dispersion model, and actual population densities of 63 km^{-2} at 0–100 km and 44 km^{-2} at 100–2,000 km were used. Before remediation the average measured flux was found to be 28 Bq m^{-2} s^{-1}. The average annual effective dose to individuals within 10 km from the tailings was assessed to be about 20 μSv. Considering that 12,850 tonnes of uranium were extracted during the whole duration of processing, the collective effective dose to the population living within 2,000 km of the tailings and over a period of 10,000 years was estimated to be 380 man Sv $(GWa)^{-1}$. This value is much higher than the estimate of the previous paragraph, which is due to higher radon fluxes and population densities and to the different atmospheric dispersion model. After remediation of the site, the radon fluxes were found not to be different from the background, and the collective dose was assess to be almost zero.

124. For the model mining and milling operations, the annual release of radon is of the order of 80 TBq $(GW\ a)^{-1}$ (Table 29). With annual average production of 4,000 t in the main producing countries (Table 28: 36,000 t mostly from 9 countries) and assuming the collective dose is received by the population within 100 km from the mine and mill sites (3 km^{-2} to 100 km = 90,000 persons), the annual dose is estimated to be about 40 μSv [4,000 t ÷ 250 t $(GW\ a)^{-1}$ × 80 TBq $(GW\ a)^{-1}$ × 0.0025 man Sv TBq^{-1} ÷ 90,000 persons]. This dose rate would be imperceptible from variations of the normal background dose rate from natural sources.

125. The Committee recognizes that considerable deviations are possible from the representative values of parameters selected for the more general conditions of present practice. For example, much higher population densities are reported in areas surrounding the mills in China [P4], and previously abandoned tailings may not have been so carefully secured as is evidently possible. Although careful management of tailings areas would be expected in the future, the extremes of leaving the tailings uncovered to providing secure and covered impoundment could increase or decrease the estimated exposure by at least an order of magnitude. Further surveys of site-specific conditions would be useful to establish realistic parameters for the worldwide practice.

B. URANIUM ENRICHMENT AND FUEL FABRICATION

126. For light-water-moderated and -cooled reactors (LWRs) and for advanced gas-cooled, graphite-moderated reactors (AGRs), the uranium processed at the mills needs to be enriched in the fissile isotope ^{235}U. Enrichments of 2%–5% are required. Before enrichment, the uranium oxide (U_3O_8) must be converted to uranium tetrafluoride (UF_4) and then to uranium hexafluoride (UF_6). Enrichment is not needed for gas-cooled, graphite-moderated reactors (GCRs) or heavy-water-cooled and -moderated reactors (HWRs).

127. In fuel fabrication for LWRs (PWRs and BWRs) and AGRs, the enriched UF_6 is chemically converted to UO_2. The UO_2 powder is sintered, formed into pellets, and loaded into tubes (cladding) of Zircaloy and stainless steel, which are sealed at both ends. These fuel rods are arranged in arrays to form the reactor fuel assemblies. The fuel pins for HWRs are produced from natural uranium or slightly enriched uranium sintered into pellets and clad in zirconium alloy. The natural uranium metal fuel for GCRs is obtained by compressing the UF_4 with shredded magnesium and heating. The reduced uranium is cast into rods that are machined and inserted into cans.

128. The releases of radioactive materials from the conversion, enrichment, and fuel fabrication plants are generally small and consist mainly of uranium series isotopes. Available data from operating installations were reported in the UNSCEAR 1993 Report [U3]. For the model installations, the normalized collective effective dose from these operations was estimated to be 0.003 man Sv $(GW\ a)^{-1}$. Inhalation is the most important exposure pathway. The collective doses from liquid discharges comprise less than 10% of the total exposure.

C. NUCLEAR REACTOR OPERATION

129. The reactors used for electrical energy generation are classified, for the most part, by their coolant systems and moderators: light-water-moderated and -cooled pressurized or boiling water reactors (PWRs, BWRs), heavy-water-cooled and -moderated reactors (HWRs), gas-cooled, graphite-moderated reactors (GCRs), and light-water-cooled, graphite-moderated reactors (LWGRs). These are all thermal reactors that use the moderator material to slow down fast fission neutrons to thermal energies. In fast breeder reactors (FBRs), there is no moderator, and the fission is induced by fast neutrons; the coolant is a liquid metal. FBRs are making only minor contributions to energy production. The electrical energy generated by these various types of reactors from 1970 through 1997 is illustrated in Figure XV and the data since 1990 for individual reactor stations are given in Table 30 [I3].

130. The Committee derives average releases of radionuclides from reactors based on reported data, and these averages are used to estimate the consequent exposures for a reference reactor. Mathematical models for the dispersion of radionuclides in the environment are used to calculate, for each radionuclide or a combination of radionuclides, the doses resulting from released activity. The geographical location of the reactor, the release points, the distribution of the population, food production and consumption habits, and the

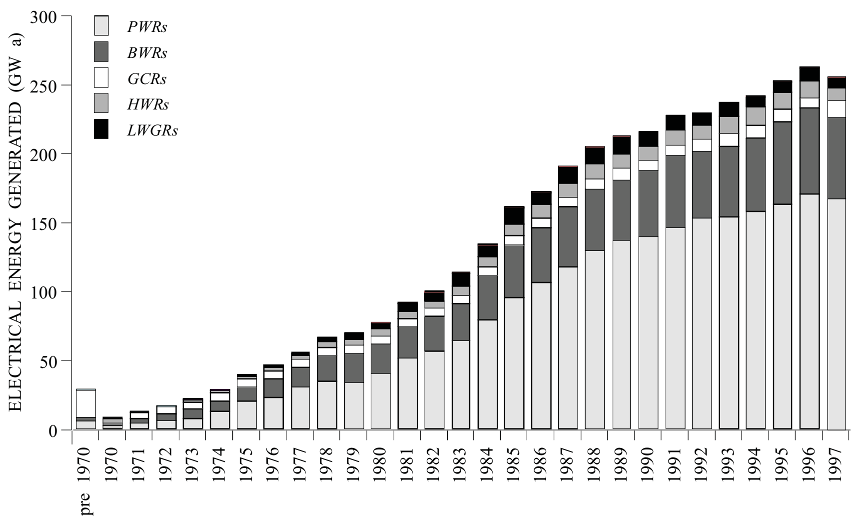


Figure XV. Contributions by reactor type to total electrical energy generated worldwide by nuclear means.

environmental pathways of radionuclides are factors that influence the calculated dose. The same release of activity and radionuclide composition from different reactors can give rise to different radiation doses to the public. Thus, the calculated exposures for a reference reactor provide only a generalized measure of reactor operating experience and serve as a standardized parameter for analysing longer-term trends from the practice.

1. Effluents

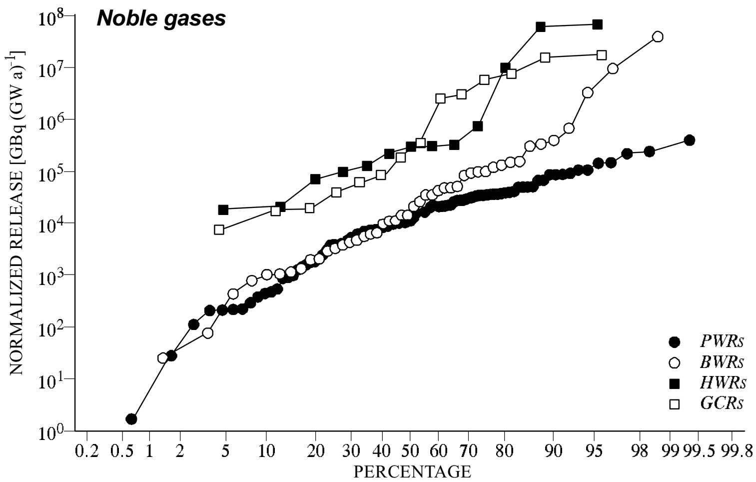
131. The radioactive materials released in airborne and liquid effluents from reactors during routine operation are reported with substantial completeness. The data for 1990–1997 are included in Tables 31–36: noble gases in airborne effluents (Table 31), tritium in airborne effluents (Table 32), iodine-131 in airborne effluents (Table 33), particulates in airborne effluents (Table 34), tritium in liquid effluents (Table 35), and radionuclides other than tritium in liquid effluents (Table 36). Each table also includes a summary of the total releases and the normalized releases (amount of radionuclide released per unit electrical energy generated) for each year of the five-year period 1990–1994 and for the three-year period 1995–1997 for each type of reactor and for all reactors together. Average normalized releases of radionuclides from each reactor type in five-year periods beginning in 1970 and for the three-year period 1995–1997 are presented in Table 37.

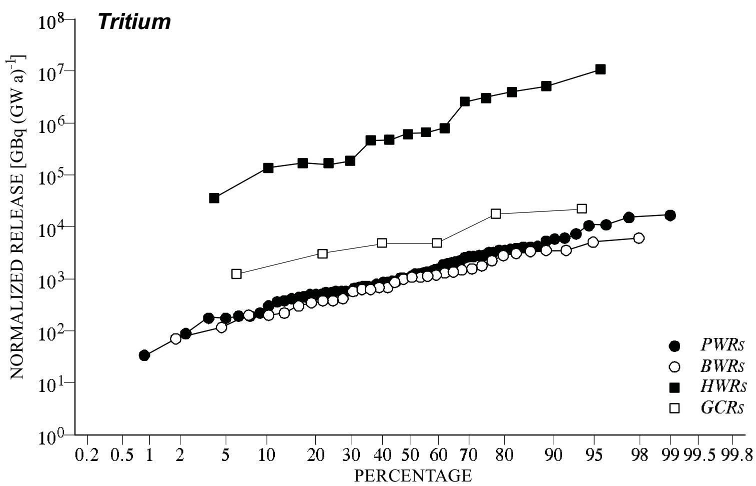
132. The normalized releases have traditionally been compiled for each reactor type. This is justified by the different composition of the releases, e.g. for noble gases, ^{41}Ar from GCRs and krypton and xenon isotopes from other types of reactors. In this case, different dose factors are required to estimate the doses. For other release components, e.g. ^{14}C or ^{131}I, there may be no inherent differences between reactor types, and atypical releases from one or a few reactors may dominate the normalized release values. In this case, the average normalized releases reflect only the prevailing operating experience, which cannot be taken as representative of the releases from a particular reactor type. With relatively complete data, little extrapolation is needed for estimating the collective doses from the total releases, and the normalized values are retained by reactor type mainly for convenience.

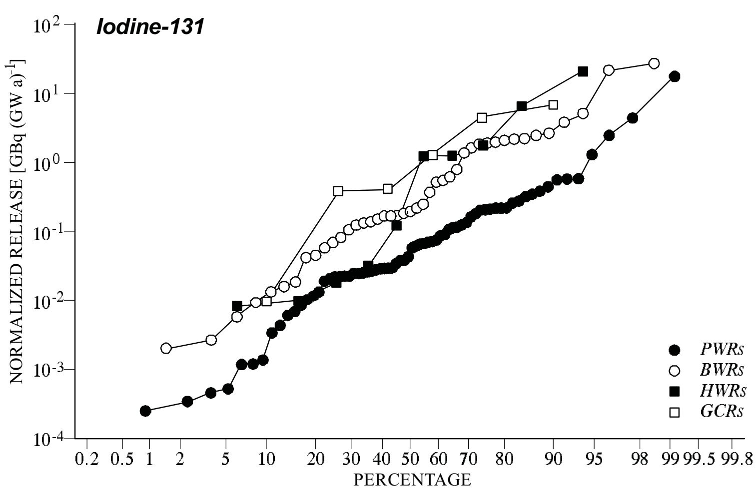
133. The release experience of individual reactors during the last five-year period (1990–1994) is evaluated in Figure XVI and shown as the characteristic distributions of the different reactor types. All reactors with relatively complete entries in Tables 31–36 (four or five years of data for both release amount and energy generated) are included in the figures. Each point has been derived from the total release of the radionuclide in 1990–1994 divided by the electrical energy generated in the same period. This evaluation of normalized release partly eliminates variations in annual values during the five-year period. There are, however, substantial differences in values from one reactor to another. Some factors affecting releases of radionuclides include the integrity of the fuel, the waste management systems, and procedures and maintenance operations conducted during the period of interest.

134. To obtain the characteristic distribution diagrams, the data are put in ranked order. The cumulative fractional value of point i of n points is specified as i/(n + 1). The inverse of the standard normal cumulative distribution of each fractional point is then derived. The value expresses the standard deviation of the data point from the centre of the distribution. In Figure XVI, the abscissa has been transformed to a percentage scale (0 = 50%, 1 SD = 84.14%, 2 SD = 97.73%, etc.). With a logarithmic scale on the ordinate, a straight line indicates a log-normal distribution. A steep slope indicates wide variations in the data. Breaks in the line indicate separate subpopulations of the available data. Outlier points are readily identified in these plots.

135. The distribution of normalized releases from reactors are approximately log-normal, often with a wide distribution of the data. The normalized releases of noble gases (Figure XVI) span seven orders of magnitude. There may be some differences in the composition of noble gases reported in airborne effluents, particularly the short-lived isotopes. The


Noble gases
NORMALIZED RELEASE [GBq (GW a)-1]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8
PERCENTAGE
PWRs
BWRs
HWRs
GCRs


Tritium
NORMALIZED RELEASE [GBq (GW a)-1]
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8
PERCENTAGE
PWRs
BWRs
HWRs
GCRs


Iodine-131
NORMALIZED RELEASE [GBq (GW a)-1]
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8
PERCENTAGE
PWRs
BWRs
HWRs
GCRs

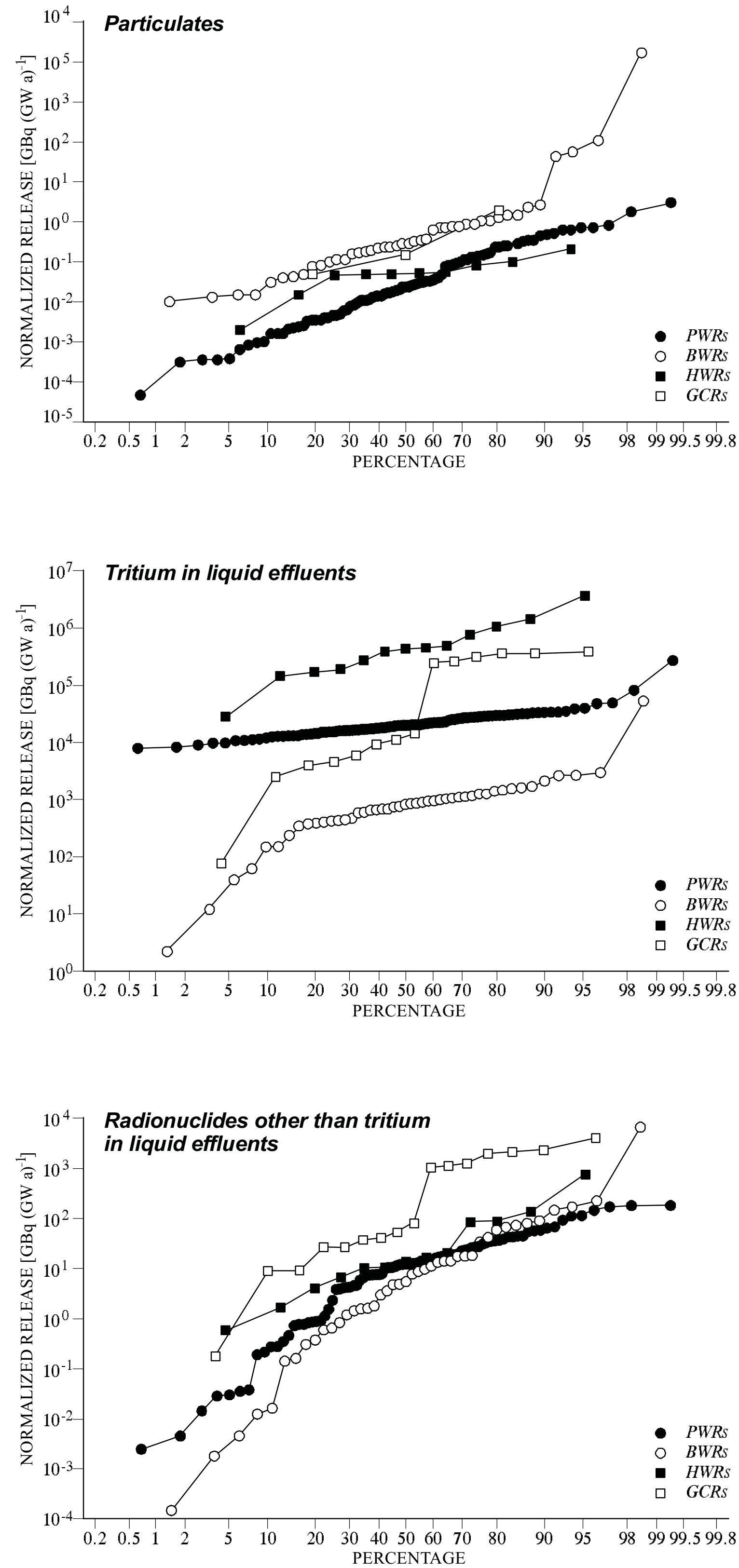


Figure XVI. Normalized release of noble gases, tritium, iodine-131 and particulates in airborne effluents and tritium and other radionuclides in liquid effluents from reactors during 1990–1994.

distributions for PWRs and BWRs are similar, but with deviations to higher normalized releases from BWRs in the upper range of the distribution. The highest values for BWRs are from the reactors Big Rock Point, Ringhals 1, and Tarapur 1–2, ranging from 3,400 to 41,000 TBq (GW a)$^{-1}$. The mean value for all BWRs is 18 TBq (GW a)$^{-1}$. The distributions for GCRs and HWRs are similar and somewhat higher than those for PWRs and BWRs.

136. The normalized releases of tritium in airborne effluents (Figure XVI) are less wide ranging. The distributions for PWRs and BWRs are identical; the distribution for GCRs is somewhat higher, with fewer values available, however. The distribution for HWRs is much higher, reflecting the large amounts of tritium produced in the moderator of these reactors. Among HWRs, those in Canada and the reactors Fugen, Embalse, and Wolsong 1 are all below 800 TBq (GW a)$^{-1}$, while Karachi, Atucha 1, and the Indian reactors are at higher values.

137. The distribution of ^{131}I releases in airborne effluents (Figure XVI) are quite wide and are somewhat higher for BWRs and HWRs than for PWRs. There are fewer values for GCRs; however, when several reactors with data for three years in 1990–1994 are included, the distribution is similar to that of BWRs and HWRs.

138. The distributions of particulate releases are also shown in Figure XVI. The strikingly high values in Table 34 for the Swedish BWR Ringhals 1 in 1994 and 1995 are attributable to damage in fuel elements beginning in 1993 and a problem in delaying releases of radionuclides entering turbine room air [N3]. These releases were to a large extent due to rather short-lived nuclei. Nuclei with half-lives of less than 83 minutes gave rise to 98% of the released activity. Authorized discharge limits were not exceeded; the atmospheric releases reached a maximum of 36% of the total dose limit for individuals (0.1 mSv a^{-1}) of the hypothetical critical group. The average value for 1990–1994 for this reactor [17 TBq (GW a)$^{-1}$] is the highest in the distribution for BWRs (Figure XVI). Relatively high values [0.04–0.1 TBq (GW a)$^{-1}$] were also derived for the BWRs Forsmark 1–3, Tarapur 1–2, and Oskarshamn 1–3. The distributions of particulate releases are very different for the different reactor types and are somewhat higher for BWRs and GCRs than for PWRs.

139. Normalized releases of tritium in liquid effluents (Figure XVI) are fairly uniform about the mean values for most of the reactors. The distribution for BWRs is lowest and for HWRs, highest. Intermediate are the distributions for PWRs and GCRs. The mean value for the group is about 1 TBq (GW a)$^{-1}$. The GCRs seem to form two distributions, with newer reactors at the higher end and the older reactors at the lower end, the opposite of the case for the noble gas releases. The HWRs are gathered about a mean normalized release of tritium in liquid effluents of about 400 TBq (GW a)$^{-1}$; at the lower extreme is the Pickering 5–8 station [28 TBq (GW a)$^{-1}$] and at the higher end [1,100–3,700 TBq (GW a)$^{-1}$] are Bruce 1–4, Kalpakkam 1–2, and Atucha 1.

140. A wide range (eight orders of magnitude) is necessary to illustrate the normalized releases of radionuclides other than tritium in liquid effluents (Figure XVI); this may be a result of the radionuclides identified and of the hold-up times provided in the waste treatment systems. The distributions are similar, although that for GCRs is somewhat higher. A duality in the GCR distribution is again noted, this time taking the pattern for noble gases mentioned above (higher normalized releases from the older reactors).

141. The radionuclide composition of releases has been examined for the various reactor types. In general, the releases of noble gases from PWRs are dominated by ^{133}Xe, with a half-life of 5.3 days, but short-lived radionuclides such as ^{135}Xe (half-life = 9.2 h) are also present. For the BWRs the composition of the noble gas releases is more varied, with most krypton and xenon radionuclides included. The releases of particulates from BWRs are also variable and difficult to generalize from the limited data available. The radionuclides ^{88}Rb (half-life = 17.8 min), ^{89}Rb (half-life = 15.2 min), ^{138}Cs (half-life = 33.4 min), and ^{139}Ba (half-life = 83.1 min) were prominent in the large releases mentioned above from the Ringhals 1 reactor. The radionuclide compositions of liquid releases from PWRs seem to vary from reactor to reactor; the cobalt isotopes (^{58}Co, ^{60}Co) as well as the caesium isotopes (^{134}Cs, ^{137}Cs) are usually present. In some cases, large relative proportions of ^{110m}Ag and ^{124}Sb are reported. It may be that some differences are accentuated by the various measuring and reporting practices at reactor stations.

142. The longer-term temporal trends in normalized releases of radionuclides for the various reactor types are illustrated in Figure XVII. The trends are shown for the time designated "pre-1970" to 1994, averaged over five-year time periods, and for the three-year period from 1995 to 1997. Except for the atmospheric releases of particulates, the normalized releases are either fairly constant or slightly decreasing. The increased release of particulates to air reflects the operation of a specific reactor and is not characteristic of all reactors.

2. Local and regional dose estimates

143. The concentrations of the released radionuclides in the environment are generally too low to be measurable except close to the nuclear facility and then for a limited number of radionuclides only. Therefore, dose estimates for the population (individual and collective doses) are generally based on modelling the atmospheric and aquatic transport and environmental transfer of the released radioactive materials and then applying a dosimetric model.

144. The environmental and dosimetric models previously used for dose estimates were described in the UNSCEAR 1982 and 1988 Reports [U4, U6]. Based on the review in Annex A, "*Dose assessment methodologies*", the values of the dose coefficients for some radionuclides have been revised. The dose assessment procedures are applied to a model site with representative environmental conditions. The average population density is 20 km^{-2} within 2,000 km of the site. Within 50 km of the site, the population density is taken to be

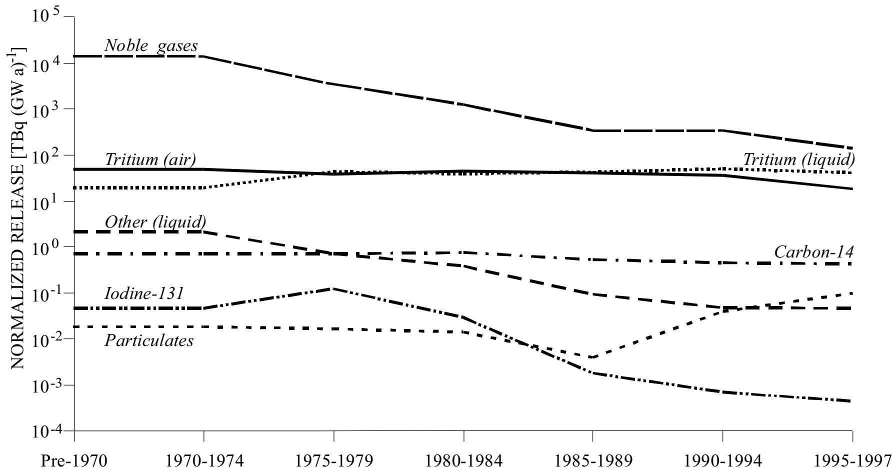


Figure XVII. Trends in releases of radionuclides from reactors.
Values of 1970−1974 are assumed to apply prior to 1970.

400 km^{-2}. For the model site the collective effective doses per unit release (man Sv PBq^{-1}) for the different release categories and reactor types are presented in Table 38. Because of the variability in annual releases, normalized releases [TBq (GW a)$^{-1}$] have been averaged over a five-year period (Table 37) to assess the collective dose.

145. The collective effective dose per unit electrical energy generated [man Sv (GW a)$^{-1}$] is obtained by multiplying the normalized releases per unit electrical energy generated (Table 37) by the collective effective dose per unit release (Table 38). The resulting estimates for 1990−1994 are given in Table 39. The total normalized collective effective dose for all reactors, weighted by the relative energy production of each reactor type (Table 39), is 0.43 man Sv (GW a)$^{-1}$. The radionuclide releases were generally similar to those that prevailed in the preceding five-year assessment period [U3], but revisions in the dose coefficients have reduced the normalized collective effective dose by a factor of 3.

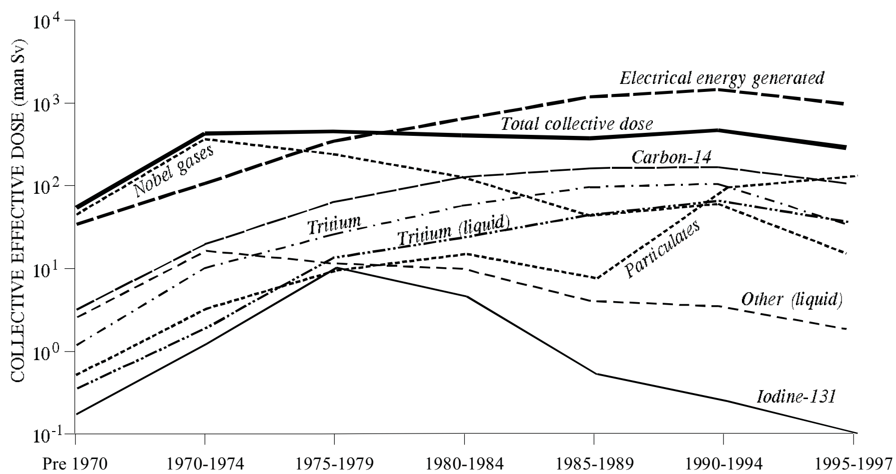


Figure XVIII. Local and regional collective effective doses from average annual releases of radionuclides from reactors. *The increasing trend in electrical energy generated is indicated with scale on left in units of GW a.*

146. From the total energy generated and the normalized collective dose, the local and regional collective dose from the operation of nuclear power plants during 1990−1994 is estimated to be 490 man Sv. During 1985−1989 the corresponding collective dose was 390 man Sv. This is an increase of just over 25%, which is nearly the same as the increase in the energy generated by nuclear reactors (1985−1989: 936 GW a; 1990−1994: 1,147 GW a). To reduce the effect of variability in annual releases, the calculation of the collective dose is based on normalized releases averaged over five-year periods (Table 37). However, outliers in the data set can still have a substantial impact on the dose estimate. If, for example, the particulate releases from the Ringhals 1 reactor are excluded, the corresponding dose estimates will be 0.39 man Sv (GW a)$^{-1}$ and 450 man Sv, respectively. However, this point could not be taken out of the data set without examining other possible outliers for 1990−1994 and for earlier years.

147. It should be noted that the average normalized doses derived here may not apply to specific reactors of a particular type. There may be further variations in release compositions,

population densities, and local environmental pathways that could significantly change the collective dose contributions. In a few cases, reactor operators report estimates of doses to local residents based on possible exposure scenarios. The data have, however, not been collected or assessed by the Committee.

148. The temporal trends of the local and regional collective effective doses for the different radionuclide categories over a longer time are shown in Figure XVIII. The collective dose from ^{131}I has decreased for a number of years, and this decrease continues for the latest five-year and three-year periods. The collective doses from tritium (airborne and liquid), ^{14}C, and particulates have been increasing through the 1990–1994 period. Overall, the total collective dose has been relatively constant since 1970–1979, even though the electrical energy generated has continuously increased.

149. For the model site, the annual average effective doses to individuals, estimated from the release data and assuming the total collective dose for a reactor type exposes a single local population group (400 km^{-2} to 50 km), are 5 μSv for PWRs and GCRs, 10 μSv for BWRs and HWRs, 2 μSv for LWGRs, and 0.04 μSv for FBRs. In comparison, reported annual individual doses from a number of reactor sites are in the range 1–500 μSv.

D. FUEL REPROCESSING

150. Fuel reprocessing is carried out to recover uranium and plutonium from spent fuel for reuse in reactors. Most spent fuel from reactors is retained on-site in interim storage, pending decisions on ultimate disposal or retrievable storage. Only about 5%–10% of fuel is submitted to the reprocessing stage of the nuclear fuel cycle. The main commercial reprocessing plants are in France, Japan, and the United Kingdom.

1. Effluents

151. Relatively large quantities of radioactive materials are involved at the fuel reprocessing stage. The radionuclides are freed from their contained state as the fuel is brought into solution, and the potential for release in waste discharges is greater than for other stages of the fuel cycle. Routine releases have been largely in liquid effluents to the sea. Operating standards have been considerably improved at these plants over the years, with substantial reductions occurring in released amounts.

152. Some revisions and additions have been made to the release quantities previously reported by the Committee. Also, more direct data on fuel throughput, which were previously estimated from ^{85}Kr discharges, are available. Therefore, the annual release data for fuel reprocessing plants from 1970 through 1997 are given in Table 40. The average normalized releases per unit of energy generated in five-year periods (except for 1970–1979, a 10-year period) are summarized in Table 41 and shown in Figure XIX. It can be observed that the releases to both air and sea of most radionuclides have been decreasing over the long term. This is particularly so for the releases of ^{106}Ru, ^{90}Sr, and ^{137}Cs to the sea and for ^{137}Cs and ^{131}I to the air (Table 41).

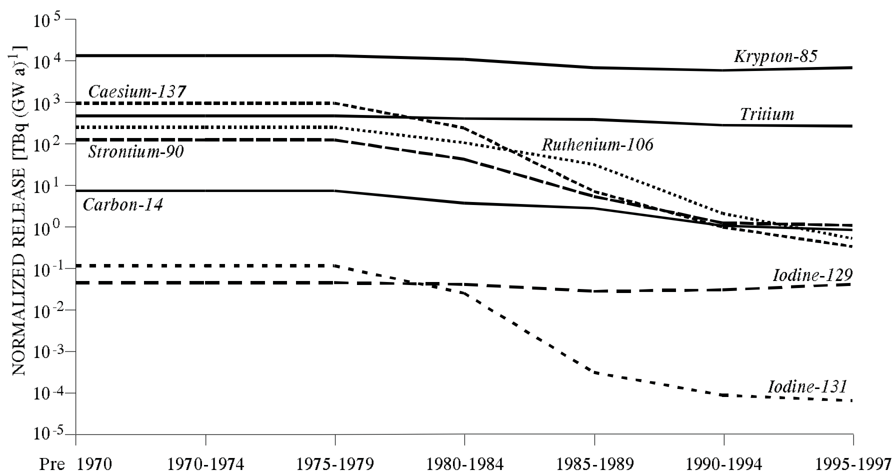


Figure XIX. Trends in releases of radionuclides from fuel reprocessing plants.
Average values ere derived for 1970-1979 and assumed to apply also prior to 1970.

2. Local and regional dose estimates

153. Collective doses from nuclear fuel reprocessing can be estimated from the normalized releases per unit of energy generated, the electrical energy equivalent of the fuel reprocessed, and the collective dose per unit release of radionuclides [U3]. This analysis is given in Table 41. For the entire period of fuel reprocessing, the total collective effective dose is estimated to be 4,700 man Sv. Liquid releases of ^{137}Cs contributed 87% of the total dose. The collective effective dose from each radionuclide is shown in Figure XX. In the most recent five-year period (1990–1994) the dose from ^{14}C exceeded that from ^{137}Cs. During the 1980s and 1990s, the collective dose from fuel reprocessing has been decreasing, even though the amount of fuel reprocessed has been increasing (Figure XX).

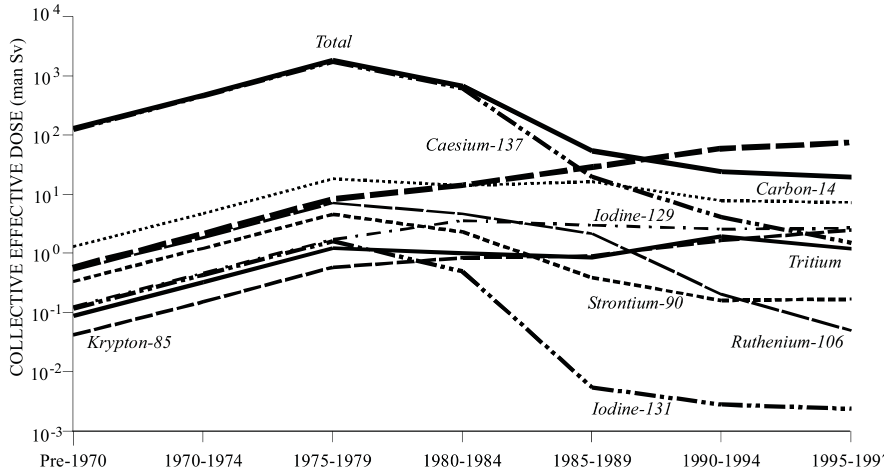


Figure XX. Local *and regional collective effective doses from average annual release of radionuclides from fuel reprocessing plants.* *The amount of fuel reprocessed is indicated by the heavy dashed line (units GW a).*

154. From the data provided in Table 41, it may be determined that the annual components of collective dose from fuel reprocessing are of the order of 20–30 man Sv. If this were received only by a single local population (3.1 10^6 persons within 50 km), the effective dose commitment to individuals would be about 10 µSv per year of operation. This dose commitment is delivered over a longer-term, especially from ^{14}C, and is distributed, as well, among separate installations (in three countries).

E. GLOBALLY DISPERSED RADIONUCLIDES

155. Radionuclides that are sufficiently long-lived and easily dispersed in the environment can give rise to global doses. The radionuclides of specific interest are ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I, with half-lives of 12.26, 5,730, 10.7, and 1.6 10^7 years, respectively. The large uncertainties involved in estimating doses over prolonged time periods are due to problems in predicting environmental pathways, population distributions, dietary habits, climate change, etc. The uncertainties of dose calculations increase when the integration is carried out for very long periods of time, hundreds or thousands of years or even longer. In this assessment, as was done for the case of collective dose from mill tailings, the global dose commitments are truncated at 10,000 years.

156. The normalized releases of the globally dispersed radionuclides given in Tables 37 and 41 are summarized in Table 42. From the electrical energy generated or the energy equivalent of fuel reprocessed, the total activity release of these radionuclides may be calculated (Table 43). Applying the factors of collective dose per unit release to these results gives estimates of the collective effective dose commitments (Table 44). For the very long-lived radionuclides (^{14}C and ^{129}I), a world population of 10^{10} was assumed at the time of the release, and for ^{3}H and ^{85}Kr, a population of 5 10^9 was assumed.

157. The total collective effective dose per unit electrical energy generated is obtained from the normalized releases from reactors and reprocessing plants (Table 42) and the factors of collective dose per unit release (as revised in Annex A, "*Dose assessment methodologies*"). In normalizing to the total energy generated, the contribution from the reprocessing plants is weighted according to the fraction of the fuel reprocessed (0.11 for 1990–1994). The estimates of the normalized collective dose commitments are 41 and 43 man Sv (GW a)$^{-1}$ for 1990–1994 and 1995–1997, respectively, which are due mostly to ^{14}C (Table 44).

158. The commitment calculations may be used to indicate the maximum dose rate for a continuing practice. The ^{14}C collective dose commitment (10,000 years) based on present practice is roughly 40 man Sv (GW a)$^{-1}$. This means that a continuing practice of 250 GW a energy production each year into the future, as at present, would result in an maximum dose rate of 1 µSv a^{-1} [40 man Sv (GW a)$^{-1}$ × 250 GW a/a ÷ 10^{10} persons]. A limited practice of nuclear power generation would result in progressively less annual dose, e.g. a 100 or 200 year practice would cause 0.1 or 0.16 µSv a^{-1}, respectively (1950–2000 actual practice with 50 or 150 year projected releases as at present). This is illustrated in Figure XXI.

159. In a similar fashion, the maximum dose rates for the other globally dispersed radionuclides may be determined. These are of the order of 0.1 µSv a^{-1} for ^{85}Kr and 0.005 µSv a^{-1} for ^{3}H and ^{129}I. For limited duration practice, the maximum annual dose rates reached will be less. These are thus negligible annual dose rates for these globally dispersed radionuclides.

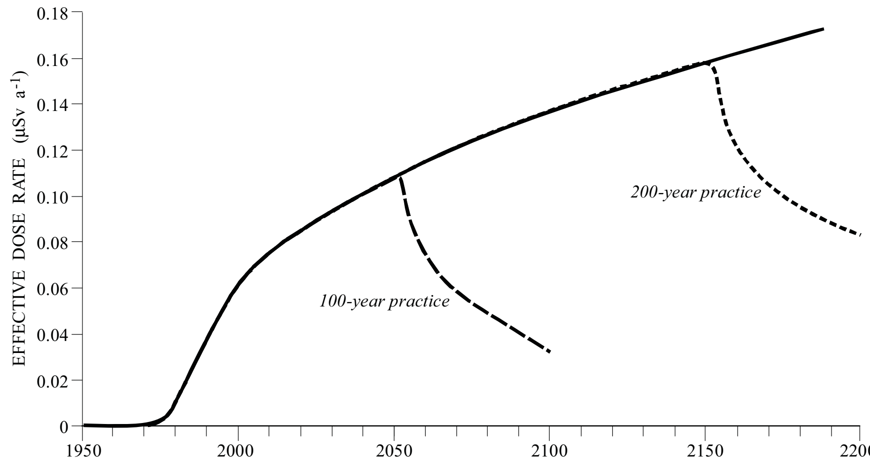


Figure XXI. Average annual dose rate from globally dispersed ^{14}C released from nuclear installations based on actual practice 1950–2000 and projection of current releases for the duration of the practice.
The equilibrium annual dose rate for a constant, continuing practice is 1 µSv a^{-1}.

F. SOLID WASTE DISPOSAL AND TRANSPORT

160. Solid wastes arise at various stages of the nuclear fuel cycle. They include low- and intermediate-level wastes, mainly from reactor operations, high-level wastes from fuel reprocessing, and spent fuel for direct disposal. Low- and intermediate-level wastes are generally disposed of by shallow burial in trenches or concrete-lined structures, but there are also more advanced disposal sites. High-level wastes and spent fuel are retained in interim storage tanks until adequate solutions for disposal have been devised and disposal sites have been selected.

161. Doses from solid waste disposal have been estimated based on the projected eventual migration of radionuclides through the burial site into groundwater. These estimates depend critically on the assumptions used for the containment of the solid wastes and the site characteristics and are, accordingly, highly uncertain in a general sense. The approximate normalized collective effective dose from low- and intermediate-level waste disposal is, however, quite low, of the order of 0.5 man Sv (GW a)$^{-1}$, due almost entirely to ^{14}C [U3, U4].

162. A repository for high-level waste and spent fuel has not yet been constructed. The radiological impact assessment of such a repository has to rely on modelling of the long-term behaviour of the waste packages and the migration of released radionuclides near the site and at greater distance over a long period of time. To carry out such performance assessments, a number of site-specific data, including waste characterization and transport models, are needed. Such assessments have been performed, mainly to help in formulating design criteria for the hypothetical repositories.

163. The transportation of radioactive materials of various types between nuclear fuel cycle installations may cause members of the public who happen to be near the transport vehicles to be exposed. Doses can be estimated only by applying hypothetical assumptions. A conservative estimate is, in this case, of the order of 0.1 man Sv (GW a)$^{-1}$ [U4].

164. Decommissioning of nuclear facilities gives rise to radioactive waste, and some experience is accumulating. The information available indicates that exposures of the public from the decommissioning practice will be very small.

G. SUMMARY OF DOSE ESTIMATES

165. The normalized collective effective doses to members of the public from radionuclides released in the various stages of the nuclear fuel cycle are summarized in Table 45. The local and regional collective dose in the two most recent assessment periods is 0.9 man Sv (GW a)$^{-1}$. The largest part of this dose is received within a limited number of years after the releases and is mainly due to the normal operation of nuclear reactors and mining operations. The global dose, which is estimated for 10,000 years, amounts to 50 man Sv (GW a)$^{-1}$. The main contribution is from globally dispersed ^{14}C (reactors and reprocessing). The longer-term trends in collective effective doses per unit electrical energy generated show decreases, attributable to reductions in the release of radionuclides from reactors and fuel reprocessing plants. The components of normalized collective effective dose have decreased by much more than an order of magnitude for releases from reprocessing plants, by a factor of 7 for releases from reactors, and by a factor of 2 for globally dispersed radionuclides, compared to the earliest assessment period, 1970–1979.

166. The local and regional collective dose from the beginning of nuclear power production can be derived from the normalized collective doses (Table 45) and the electrical energy generated in each period (Table 43). The result is about 5,000 man Sv from fuel reprocessing, 3,000 man Sv from reactor operations, and 900 man Sv from mining and

milling. This analysis is summarized in Table 46. In recent years, the annual total from all these operations amounts to 200 man Sv received by the local and regional population. Assuming that the current practice of nuclear power production continues for 100 years, the maximum per caput dose can be estimated from the truncated collective dose per unit electrical energy generated. Figure XXI shows that about 10% of the dose from globally dispersed radionuclides is committed in the first hundred years, and using Table 45, the collective effective dose in the hundredth year of the practice, from globally dispersed radionuclides, would be 5 man Sv (GW a)$^{-1}$. For an annual production of 250 GW a this amounts to 1,250 man Sv per year, which when added to the local and regional dose of 200 man Sv per year gives a total dose of nearly 1,500 man Sv in the last year of the practice. The maximum annual effective dose arising from 100 years of the practice of nuclear power production is then less than 0.2 μSv per caput for a global population of 10^{10} persons.

III. OTHER EXPOSURES

A. RADIOISOTOPE PRODUCTION AND USE

167. Radioisotopes are widely used in industry, medicine, and research. Exposures may occur from trace amounts released in production or at subsequent stages of the use or disposal of the radionuclide-containing products. For very long-lived radionuclides such as ^{14}C, all of the amount utilized may ultimately reach the environment. For short-lived radionuclides such as most radiopharmaceuticals, radioactive decay prior to release is an essential consideration. The isotopes used most widely in medical examinations and nuclear medicine procedures are ^{131}I and ^{99m}Tc.

168. Estimates of doses from radioisotope production and use are uncertain, owing to limited data on the commercial production of the radioisotopes and on the release fractions from production and use. The main radionuclides of interest are ^{3}H, ^{14}C, ^{125}I, ^{131}I, and ^{133}Xe. The estimated annual collective effective dose from the practice is of the order of 100 man Sv [U3].

169. An important use of radionuclides is in medical diagnostic examinations and in therapeutic treatments. Medical radioisotopes or their parent radionuclides can be produced in a reactor (by fission of uranium, e.g. ^{99}Mo, ^{131}I, or by activation, e.g. ^{59}Fe) or in a cyclotron (by nuclear reaction, e.g.^{123}I, ^{201}Tl). The main radioisotope, used in 80% of all diagnostic examinations, is ^{99}Mo. In many countries the production, isolation, and incorporation of the radioisotopes into generators, diagnostic kits, or pharmaceuticals are often subdivided in different facilities [K11]. As an example, several research reactors in neighbouring countries supply ^{99}Mo to the radioisotope production plant in Belgium [W6]. Three different facilities are involved in the Netherlands in the generation of ^{99}Mo, its extraction and incorporation into ^{99m}Tc generators [L10]. This subdivision of the manufacturing process hampers quantification of the fractional release amounts from the overall production phase.

170. In its request for a permit in 1996, a medical radioisotope production plant in the Netherlands reported a controlled annual release of ^{131}I to the atmosphere of at most 300 MBq. Since it handles more than 52 TBq in a year, the release fraction would be less than 0.001%. The maximum annual dose to an individual from this release would 1 μSv [L10]. This plant receives the ^{131}I as raw material delivered from another company. Therefore, the data are unsuited for the entire production phase.

171. Over the period 1989–1992, a single facility supplied 90% of the annual amount of ^{131}I (35.9 TBq) used in China and 100% of the ^{125}I (0.98 TBq) [P7]. The average release fraction was reported to be 0.01% for ^{131}I (a reduction from 4.6% in 1975–1978) and 0.7% for ^{125}I. The annual collective dose was estimated to be 0.13 man Sv for ^{131}I and 0.1–0.6 man Sv for ^{125}I, assuming a local population density of 500 km^{-2}. The collective dose per unit release of ^{131}I is thus 36 man Sv TBq^{-1}. This may be compared with 0.3 man Sv TBq^{-1} that was estimated for release from a representative nuclear installation (Table 38).

172. Global usage of ^{131}I in nuclear therapy is approximately 600 TBq (Table 47). With application of the above dose factors, and assuming the release fraction on production to be 0.01%, the global annual collective dose from ^{131}I production and usage is 0.02–2 man Sv. A further contribution to the collective dose arises from wastes discharged from hospitals.

173. Limited data on ^{131}I releases from hospitals were cited in the UNSCEAR 1993 Report [U3]. Discharges of ^{131}I from hospitals in Australia and Sweden in the late 1980s corresponded to 110–190 GBq per 10^{6} population [U3]. There is high excretion of ^{131}I from patients following oral administration, but waste treatment systems with hold-up tanks are effective in reducing the amounts in liquid effluents to 5 10^{-4} of the amounts administered to patients [J4]. This seems to be confirmed by the very low concentrations of ^{131}I measured in the surface waters and sewage systems of several countries [U3]. This information seems not to be systematically collected.

174. With the estimated global annual usage of ^{131}I in therapeutic treatments of 600 TBq, a release fraction of 5 10^{-4} and a dose coefficient of 0.03 man Sv TBq^{-1} for ^{131}I released in liquid effluents (from Annex A, "*Dose assessment methodologies*"), the further contribution to the collective dose is just 0.009 man Sv. The presence of the hold-up tanks should reduce the release of ^{99m}Tc, the other major radionuclide, to negligible levels.

175. Several recent studies consider the external exposure of the groups that are mainly exposed, i.e. parents, infants, who come in contact with therapeutically treated patients or fellow travellers on the journey home from the hospital [B12, C12, D8, G9, M11]. These assessments are based either on use of integrating dosimeters or on dose-rate measurements close to the patients with appropriate occupancy factors. Assessments based on the first approach gave doses of 0.04–7 mSv to partners and children of the patients treated for hyperthyroidism with 200–800 MBq of ^{131}I [B12, M11]. Average doses were 1 mSv to partners and 0.1 mSv to children [M11]. Treatment of thyroid cancer patients with 4–7 GBq of ^{131}I resulted in doses below 0.5 mSv to family members [M11]. All of about 200 family members involved in these studies were given advice, according to current practice, about limiting close contact with the patient. Dose rates to fellow travellers ranged from 0.02–0.5 mSv h^{-1}.

176. An approximate estimate of the collective dose to family members of patients therapeutically treated with ^{131}I can be derived as follows. In developed countries about 20% of therapeutic treatments with ^{131}I are for thyroid cancer and 80% for hyperthyroidism with average administered amounts of 5 GBq and 0.5 GBq, respectively. The weighted average amount administered is thus 1.4 GBq per patient. For global usage of 600 TBq of ^{131}I, 430,000 patients could be treated. With average exposures of 0.5 mSv to 2–3 family members, the collective dose to those other than the patients could be 400–600 man Sv.

177. The importance of inhalation of radioiodine exhaled by patients treated with radioiodine (0.3–1.3 GBq), was assessed by whole body measurements of their relatives [W7]. The effective dose ranged from 0.3 to about 60 µSv (17 persons) with a median value of about 4 µSv. Diagnostic procedures with most radionuclides are estimated to result in cumulative doses of less than 40 µSv to someone who remains in the close vicinity of the patient [B13]. Breast feeding following maternal radiopharmaceutical administration may result in an effective dose to the infant of more than 1 mSv, if the feeding is not temporarily interrupted or ceased. This is the case for a limited number of treatments with radioiodine but also for some with ^{99m}Tc and ^{67}Ga [M11, M12].

178. The most important component in the overall dose to the general population from radioisotope production and usage is that to relatives of patients given therapeutic treatments. The dominant component of the global collective dose is from ^{131}I. It was assumed that decay between production and use of the isotope can be neglected, which means that the data on isotope consumption can be used. The resulting global annual collective dose is estimated to range up to about 600 man Sv. The small doses to relatives of patients after diagnostic procedures may add up to a comparable collective dose, since their number exceeds that of the therapeutic treatments by two orders of magnitude. The dose to family members was not considered in the previous assessment by the Committee in the UNSCEAR 1993 Report [U3]. The earlier estimate of 100 man Sv, of which 80% was from ^{14}C, represented possible releases mainly at the production stage. Since this estimate is quite uncertain and likely an overestimate, it is seen that the exposure of family members of patients treated with ^{131}I may be considered to be the most important component of exposure to radioisotopes used in medicine, industry and education.

B. RESEARCH REACTORS

179. Research reactors differ from reactors producing electrical energy in their wide variety of designs and modes of operation, as well as a wide range of use. Research reactors are used for tests of nuclear fuels and different materials, for investigations in nuclear and neutron physics, biology, and medicine, and for the production of radioisotopes. At the end of 1999, there were 292 nuclear research reactors operating in the world, with a total thermal energy of 3,000 MW. The total operating experience exceeds 13,000 reactor-years. The Committee has not previously collected data on releases of radionuclides from research reactors.

180. Exposures resulting from the operation of research reactors are exemplified by some data reported from the Russian Federation. From 1993 to 1996, annual releases from two research reactors in Obninsk averaged 0.7 PBq of noble gases, 5 GBq ^{131}I, 0.3 GBq ^{90}Sr, 0.6 GBq ^{137}Cs, and 0.1 GBq plutonium [M8, M10]. The annual effective doses to individuals in Obninsk were estimated not to exceed 30 µSv [M8]. Further data on research reactors are not available.

C. ACCIDENTS

181. Accidents involving releases of radionuclides to the environment occur from time to time. To the extent that these result in significant human exposures, they are reviewed and analysed. A separate Chapter on accidents was included in the UNSCEAR 1993 Report [U3], and a brief account was given of all earlier accidents. Since then only one accident has occurred at a nuclear installation involving some exposure of the local population. This was the accident on 30 September 1999 at the Tokaimura nuclear fuel processing plant in Japan [J6]. A criticality event took place because of improper procedures. During the 24-hour event and because of only limited shielding provided by the building, some direct irradiation was measurable outside the plant site. There was only trace release of gaseous fission products. Three workers inside the plant received serious overexposures. Their doses were estimated to be in the range 16–20 Gy, 6–10 Gy, and 1–4.5 Gy (gamma equivalent dose). The doses to 169 other employees were determined from personal dosimeters, whole-body counting, and survey of their locations during the accident [I8, J6, S9]. Doses to members of the public, about 200 in all, who were living or working within 350 m of the facility were estimated individually [F6]. Direct exposures to persons outside the site were estimated to be up to 21 mGy (gamma plus neutron). The highest dose, estimated by whole-body counting, was received by a person at a construction company just beyond the plant boundary.

182. The misuse or mishandling of radiation sources is generally a hazard to workers. Improper administration of thera-

peutic treatment sometimes result in accidental overexposures of patients. Lost or unregulated (orphaned) sources can cause exposures of the public. These topics are considered further in the separate assessments by the Committee of occupational and medical radiation exposures. The Committee has no other information on recent accidents that may have involved exposures of the public. The Committee has begun a more complete analysis of the doses and effects from the Chernobyl accident in the populations living nearest to the reactor in areas of the former Soviet Union. These results are presented separately in Annex J, "*Exposures and effects of the Chernobyl accident*".

CONCLUSIONS

183. Releases of radioactive materials to the environment and exposures of human populations have occurred in several activities, practices, and events involving radiation sources. The main contribution to the collective doses to the world population in such cases has come from the testing of nuclear weapons in the atmosphere. This practice occurred from 1945 through 1980. Each nuclear test resulted in unrestrained release to the environment of substantial quantities of radioactive materials. These were widely dispersed in the atmosphere and deposited everywhere on the earth's surface.

184. The Committee has given special attention to the evaluation of exposures from atmospheric nuclear testing. Numerous measurements of the global deposition of ^{90}Sr and ^{137}Cs and of the occurrence of these and other fallout radionuclides in diet and the human body were made at the time the testing was taking place. The worldwide collective dose from this practice was evaluated in the UNSCEAR 1982 Report [U6], and a systematic listing of transfer coefficients for a number of fallout radionuclides was given in the UNSCEAR 1993 Report [U3].

185. New information has become available on the numbers and yields of nuclear tests. These data were not fully revealed earlier by the countries that conducted the tests because of military sensitivities. An updated listing of atmospheric nuclear tests conducted at each of the test sites is included in this Annex. Although the total explosive yields of each test have been divulged, the fission and fusion yields are still mostly suppressed. Some general assumptions have been made to allow specifying the fission and fusion yields of each test in order to estimate the amounts of radionuclides produced in the explosions. The estimated total of fission yields of individual tests is in agreement with the global deposition of the main fission radionuclides ^{90}Sr and ^{137}Cs, as determined by worldwide monitoring networks.

186. With improved estimates of the production of each radionuclide in individual tests and using an empirical atmospheric transport model, it is possible to determine the time course of the dispersion and deposition of radionuclides and to estimate the annual doses from various pathways in each hemisphere of the world. In this way it has been estimated that the world average annual effective dose reached a peak of 110 μSv in 1963 and has since decreased to about 5 μSv, from residual levels in the environment, mainly of ^{14}C, ^{90}Sr, and ^{137}Cs. The average annual doses are 10% higher than the world average in the northern hemisphere, where most of the testing took place, and much lower in the southern hemisphere. Although there was considerable concern at the time of testing, the exposures remained relatively low, reaching at most about 5% of the background level from natural radiation sources.

187. The exposures to local populations surrounding the test sites have also been assessed using available information. The level of detail is still not sufficient to document the exposures with great accuracy. Attention to the local conditions and the possibilities of exposure was not great in the early years of the test programmes. However, dose reconstruction efforts are proceeding to clarify this experience and to document the local and regional exposures that occurred.

188. Underground testing caused exposures beyond the test sites only if radioactive gases leaked or were vented. Most underground tests had a much lower yield than atmospheric tests, and it was usually possible to contain the debris. Underground tests were conducted at the rate of 50 or more per year from 1962 to 1990. Although it is the intention of most countries to agree to ban all further tests, both atmospheric and underground, the treaty has not yet come into force. Further underground testing occurred in 1998. Thus, it cannot yet be stated that the practice has ceased.

189. During the time when nuclear weapons arsenals were being built up and especially in the earlier years (1945–1960), there were releases of radionuclides and exposures of local populations downwind or downstream of nuclear installations. Since there was little recognition of exposure potentials and monitoring of releases was limited, the exposure evaluations must be based on the reconstruction of doses. Results are still being obtained that document this experience. Practices have greatly improved and arsenals are now being reduced.

190. A continuing practice is the generation of electrical energy by nuclear power reactors. In recent years, 17% of the world's electrical energy has been generated by this means. During routine operation of nuclear installations, the releases of radionuclides are low, and exposures must be estimated with environmental transfer models. For all fuel cycle operations (mining and milling, reactor operation, and fuel reprocessing) the local and regional exposures are estimated

at present to be 0.9 man Sv $(GW\ a)^{-1}$. With present world nuclear energy generation of 250 GW a, the collective dose per year of practice is of the order of 200 man Sv. The assumed representative local and regional population surrounding a single installation is about 250 million persons, and the per caput dose to this population would be less than 1 μSv. The collective doses from globally dispersed radionuclides are delivered over very long periods and to the projected maximum population of the world. If the practice of nuclear power production is limited to the next 100 years at the present capacity, the maximum annual effective dose per caput to the global population would be less than 0.2 μSv. This dose rate is small compared to that from natural background radiation.

191. Except in the case of accidents, in which more localized areas can be contaminated to significant levels, there are no other practices that result in important exposures from radionuclides released to the environment. Estimates of releases of isotopes produced and used in industrial and medical applications are being reviewed, but these seem to be associated with rather insignificant levels of exposure. The highest exposures, averaging about 0.5 mSv, may be received by family members of patients who have received ^{131}I therapeutic treatments. Possible future practices, such as weapons dismantling, decommissioning of installations, and waste management projects, can be reviewed as experience is acquired, but these should all involve little or no release of radionuclides and consequently little or no exposure.

Table 1
Atmospheric nuclear tests

CHINA

Date	Type of test	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Lop Nor							
1964: 16 October	Land surface	0.02	0	0.02	0.01	0.01	
1965: 14 May	Air	0.04	0	0.04		0.037	0.003
1966: 9 May	Air	0.2	0.1	0.3		0.11	0.09
27 October	Air	0.02	0	0.02		0.02	
28 December	Land surface	0.2	0.1	0.3	0.10	0.056	0.044
1967: 17 June	Air	1.7	1.3	3			1.7
24 December	Air	0.02	0	0.02		0.02	
1968: 28 December	Air	1.5	1.5	3			1.5
1969: 29 September	Air	1.9	1.1	3			1.9
1970: 14 October	Air	1.9	1.1	3			1.9
1971: 18 November	Land surface	0.02	0	0.02	0.01	0.01	
1972: 7 January	Air	0.02	0	0.02		0.02	
18 March	Air	0.1	0	0.1		0.08	0.02
1973: 27 June	Air	1.4	1.1	2.5			1.4
1974: 17 June	Air	0.3	0.3	0.6		0.065	0.235
1976: 23 January	Land surface	0.02	0	0.02	0.01	0.01	
26 September	Air	0.1	0	0.1		0.08	0.02
17 November	Air	2.2	1.8	4			2.2
1977: 17 September	Air	0.02	0	0.02		0.02	
1978: 15 March	Land surface	0.02	0	0.02	0.01	0.01	
14 December	Land surface	0.02	0	0.02	0.01	0.01	
1980: 16 October	Air	0.5	0.1	0.6		0.11	0.39

FRANCE

Date	Type of test	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Algeria							
1960: 13 February	Tower	0.067 [b]	0	0.067	0.0335	0.0326	0.0009
1 April	Land surface	0.003 [b]	0	0.003	0.0015	0.0015	
27 December	Tower	0.002 [b]	0	0.002	0.001	0.001	
1961: 25 April	Tower	0.0007 [b]	0	0.0007	0.00035	0.00035	
Test site: Fangataufa							
1966: 24 September	Barge	0.125 [b]	0	0.125	0.0625	0.0595	0.003
1968: 24 August	Balloon	1.3	1.3	2.6			1.3
1970: 30 May	Balloon	0.4725	0.4725	0.945			0.4725
3 August	Balloon	0.072	0	0.072		0.07	0.002

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Mururoa							
1966: 2 July	Barge	0.028 [b]	0	0.028	0.014	0.014	
19 July	Air drop	0.05 [b]	0	0.05		0.049	0.001
11 September	Balloon	0.11 [b]	0	0.11			0.11
4 October	Barge	0.205 [b]	0	0.205	0.1025	0.0921	0.0104
1967: 5 June	Balloon	0.015 [b]	0	0.015		0.015	
27 June	Balloon	0.12 [b]	0	0.12			0.12
2 July	Barge	0.022 [b]	0	0.022	0.011	0.011	
1968: 7 July	Balloon	0.115 [b]	0	0.115			0.115
15 July	Balloon	0.45 [b]	0	0.45			0.45
3 August	Balloon	0.15 [b]	0	0.15			0.15
8 September	Balloon	0.64	0.64	1.28			0.64
1970: 15 May	Balloon	0.013 [b]	0	0.013		0.013	
22 May	Balloon	0.150	0.074	0.224			0.150
24 June	Balloon	0.012 [b]	0	0.012		0.012	
3 July	Balloon	0.457	0.457	0.914			0.457
27 July	Balloon	0.00005 [b]	0	0.00005		0.00005	
6 August	Balloon	0.297	0.297	0.594			0.297
1971: 5 June	Balloon	0.034 [b]	0	0.034		0.034	
12 June	Balloon	0.29	0.15	0.44			0.29
4 July	Balloon	0.009 [b]	0	0.009		0.009	
8 August	Balloon	0.004 [b]	0	0.004		0.004	
14 August	Balloon	0.478	0.477	0.955			0.478
1972: 25 June	Balloon	0.0005 [b]	0	0.0005		0.0005	
30 June	Balloon	0.004 [b]	0	0.004		0.004	
27 July	Balloon	0.006 [b]	0	0.006		0.006	
1973: 21 July	Balloon	0.011 [b]	0	0.011		0.011	
28 July	Balloon	0.00005 [b]	0	0.00005		0.00005	
18 August	Balloon	0.004 [b]	0	0.004		0.004	
24 August	Balloon	0.0002 [b]	0	0.0002		0.0002	
28 August	Air drop	0.006 [b]	0	0.006		0.006	
1974: 16 June	Balloon	0.004 [b]	0	0.004		0.004	
7 July	Balloon	0.10	0.05	0.15			0.10
17 July	Balloon	0.004 [b]	0	0.004		0.004	
25 July	Air drop	0.008 [b]	0	0.008		0.008	
15 August	Balloon	0.096	0	0.096		0.093	0.003
24 August	Balloon	0.014 [b]	0	0.014		0.014	
14 September	Balloon	0.221	0.111	0.332			0.221

UNITED KINGDOM

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Monte Bello Islands, Australia							
1952: 3 October	Water surface	0.025	0	0.025	0.0125	0.0125	
1956: 16 May	Tower (31 m)	0.015	0	0.015	0.0075	0.0075	
19 June	Tower (31 m)	0.06	0	0.06	0.03	0.0293	0.0007
Test site: Emu, Australia							
1953: 14 October	Tower (31 m)	0.01	0	0.01	0.005	0.005	
26 October	Tower (31 m)	0.008	0	0.008	0.004	0.004	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Maralinga, Australia							
1956: 27 September	Tower (31 m)	0.015	0	0.015	0.0075	0.0075	
4 October	Land surface	0.0015	0	0.0015	0.00075	0.00075	
11 October	Air drop (150 m)	0.003	0	0.003		0.003	
22 October	Tower (31 m)	0.01	0	0.01	0.005	0.005	
1957: 14 September	Tower (31 m)	0.001	0	0.001	0.0005	0.0005	
25 September	Tower (31 m)	0.006	0	0.006	0.003	0.003	
9 October	Balloon (300 m)	0.025	0	0.025		0.025	
Test site: Malden Island, Pacific							
1957: 15 May	Air burst	0.2	0.1	0.3		0.17	0.03
31 May	Air burst	0.36	0.36	0.72		0.265	0.095
19 June	Air burst	0.13	0.07	0.20		0.12	0.01
Test site: Christmas Island, Pacific							
1957: 8 November	Air burst	0.9	0.9	1.8		0.315	0.585
1958: 28 April	Air burst	1.5	1.5	3		0.12	1.38
22 August	Air burst	0.024	0	0.024		0.024	
2 September	Air burst	0.5	0.5	1		0.325	0.175
11 September	Air burst	0.4	0.4	0.8		0.285	0.115
23 September	Air burst	0.025	0	0.025		0.025	

UNITED STATES

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: New Mexico							
1945: 16 July	Tower	0.021	0	0.021	0.011	0.01	
Hiroshima and Nagasaki, Japan (combat use)							
1945: 5 August	Air drop	0.015	0	0.015		0.015	
9 August	Air drop	0.021	0	0.021		0.021	
Test site: Nevada							
1951: 27 January	Air drop (320 m)	0.001	0	0.001		0.001	
28 January	Air drop (330 m)	0.008	0	0.008		0.008	
1 February	Air drop (330 m)	0.001	0	0.001		0.001	
2 February	Air drop (335 m)	0.008	0	0.008		0.008	
6 February	Air drop (340 m)	0.022	0	0.022		0.022	
22 October	Tower (100 m)	0.0001	0	0.0001	0.00005	0.00005	
28 October	Air drop (340 m)	0.0035	0	0.0035		0.0035	
30 October	Air drop (340 m)	0.014	0	0.014		0.014	
1 November	Air drop (430 m)	0.021	0	0.021		0.021	
5 November	Air drop (900 m)	0.031	0	0.031		0.031	
19 November	Surface	0.012	0	0.0012	0.0006	0.0006	
29 November	Surface (-5 m)	0.001	0	0.001	0.0005	0.0005	
1952: 1 April	Air drop (240 m)	0.001	0	0.001		0.001	
15 April	Air drop (320 m)	0.001	0	0.001		0.001	
22 April	Air drop (1050 m)	0.031	0	0.031		0.031	
1 May	Air drop (300 m)	0.019	0	0.019		0.019	
1952: 7 May	Tower (90 m)	0.012	0	0.012	0.006	0.006	
25 May	Tower (90 m)	0.011	0	0.011	0.0055	0.0055	
1 June	Tower (90 m)	0.015	0	0.015	0.0075	0.0075	
5 June	Tower (90 m)	0.014	0	0.014	0.007	0.007	

Table 1 (continued)

Date	Type of test	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Nevada (continued)							
1953: 17 March	Tower (90 m)	0.016	0	0.016	0.008	0.008	
24 March	Tower (90 m)	0.024	0	0.024	0.012	0.012	
31 March	Tower (90 m)	0.0002	0	0.0002	0.0001	0.0001	
6 April	Air drop (1835 m)	0.011	0	0.011		0.011	
11 April	Tower (30 m)	0.0002	0	0.0002	0.0001	0.0001	
18 April	Tower (90 m)	0.023	0	0.023	0.012	0.011	
25 April	Tower (90 m)	0.043	0	0.043	0.022	0.021	
8 May	Air drop (740 m)	0.027	0	0.027		0.027	
19 May	Tower (90 m)	0.032	0	0.032	0.016	0.016	
25 May	Airburst (160 m)	0.015	0	0.015		0.015	
4 June	Air drop (400 m)	0.061	0	0.061		0.0595	0.0015
1955: 18 February	Air drop (230 m)	0.001	0	0.001		0.001	
22 February	Tower (90 m)	0.002	0	0.002	0.001	0.001	
1 March	Tower (90 m)	0.007	0	0.007	0.0035	0.0035	
7 March	Tower (150 m)	0.043	0	0.043	0.0215	0.0215	
12 March	Tower (90 m)	0.004	0	0.004	0.002	0.002	
22 March	Tower (150 m)	0.008	0	0.008	0.004	0.004	
29 March	Tower (150 m)	0.014	0	0.014	0.007	0.007	
29 March	Air drop (225 m)	0.003	0	0.003		0.003	
6 April	Air drop (1120 m)	0.003	0	0.003		0.003	
9 April	Tower (90 m)	0.002	0	0.002	0.001	0.001	
15 April	Tower (120 m)	0.022	0	0.022	0.011	0.011	
5 May	Tower (150 m)	0.029	0	0.029	0.0145	0.0145	
15 May	Tower (1560 m)	0.028	0	0.028	0.014	0.014	
1957: 28 May	Tower (150 m)	0.012	0	0.012	0.006	0.006	
2 June	Tower (90 m)	0.00014	0	0.00014	0.00007	0.00007	
5 June	Balloon (150 m)	0.0000005	0	0.0000005		0.0000005	
18 June	Balloon (150 m)	0.01	0	0.01		0.01	
24 June	Balloon (210 m)	0.037	0	0.037		0.037	
5 July	Balloon (460 m)	0.074	0	0.074		0.072	0.002
15 July	Tower (150 m)	0.017	0	0.017	0.0085	0.0085	
19 July	Rocket (6100 m)	0.002	0	0.002		0.002	
24 July	Tower (150 m)	0.01	0	0.01	0.005	0.005	
25 July	Balloon (150 m)	0.0097	0	0.0097		0.0097	
7 August	Balloon (460 m)	0.019	0	0.019		0.019	
18 August	Tower (150 m)	0.017	0	0.017	0.0085	0.0085	
23 August	Balloon (460 m)	0.011	0	0.011		0.011	
30 August	Balloon (230 m)	0.0047	0	0.0047		0.0047	
31 August	Tower (210 m)	0.044	0	0.044	0.022	0.022	
2 September	Tower (150 m)	0.011	0	0.011	0.0055	0.0055	
6 September	Balloon (150 m)	0.0002	0	0.0002		0.0002	
8 September	Balloon (230 m)	0.001	0	0.001		0.001	
14 September	Tower (150 m)	0.011	0	0.011	0.0055	0.0055	
16 September	Balloon (460 m)	0.012	0	0.012		0.012	
23 September	Tower (150 m)	0.019	0	0.019	0.0095	0.0095	
28 September	Balloon (460 m)	0.012	0	0.012		0.012	
7 October	Balloon (460 m)	0.008	0	0.008		0.008	
1958: 19 September	Balloon (150 m)	0.000083	0	0.000083		0.000083	
29 September	Balloon (460 m)	0.002	0	0.002		0.002	
10 October	Tower (30 m)	0.000079	0	0.000079	0.00004	0.000039	
13 October	Balloon (460 m)	0.0014	0	0.0014		0.0014	
15 October	Tower (15 m)	0.0000012	0	0.0000012	0.0000006	0.0000006	
16 October	Balloon (140 m)	0.000037	0	0.000037		0.000037	
18 October	Tower (22 m)	0.00009	0	0.00009	0.000045	0.000045	
22 October	Balloon (440 m)	0.006	0	0.006		0.006	
22 October	Balloon (460 m)	0.00012	0	0.00012		0.00012	
22 October	Balloon (150 m)	0.00019	0	0.00019		0.00019	
26 October	Balloon (460 m)	0.0049	0	0.0049		0.0049	
26 October	Balloon (460 m)	0.0022	0	0.0022		0.0022	
29 October	Tower (10 m)	0.0000078	0	0.0000078	0.0000039	0.0000039	
29 October	Tower	0	0	0	0	0	
30 October	Balloon(460 m)	0.0013	0	0.0013		0.0013	
1962: 11 July	Surface (- 1 m)	0.0005	0	0.0005	0.00025	0.00025	
7 July	Surface	0.02	0	0.02 [c]	0.01	0.01	
14 July	Tower	0.02	0	0.02 [c]	0.01	0.01	
17 July	Surface	0.02	0	0.02 [c]	0.01	0.01	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Bikini, Pacific							
1946: 30 June	Air drop	0.021	0	0.021		0.021	
24 July	Underwater (-30 m)	0.021	0	0.021	0.011	0.01	
1954: 28 February	Surface	9 [d]	6	15	4.5		4.5
26 March	Barge	7.3 [d]	3.7	11	3.65		3.65
6 April	Surface	0.075	0.035	0.11	0.037	0.037	0.001
25 April	Barge	4.6 [d]	2.3	6.9	2.3		2.3
4 May	Barge	9.0 [d]	4.5	13.5	4.5		4.5
1956: 20 May	Air drop	1.6 [d]	2.2	3.8		0.076	1.52
27 May	Surface	1.25 [d]	2.25	3.5	0.625	0.038	0.587
11 June	Barge	0.183 [d]	0.182	0.365	0.092	0.077	0.014
25 June	Barge	0.55	0.55	1.1	0.275	0.168	0.107
10 July	Barge	1.5 [d]	3.0	4.5	0.75	0.018	0.732
20 July	Barge	2.3 [d]	2.7	5	1.15	0.005	1.145
1958: 11 May	Barge	0.68	0.68	1.36	0.34	0.175	0.165
21 May	Barge	0.0251	0	0.0251	0.0126	0.0125	
31 May	Barge	0.092	0	0.092	0.046	0.0446	0.0014
10 June	Barge	0.142	0.071	0.213	0.071	0.063	0.008
14 June	Barge	0.212	0.107	0.319	0.106	0.091	0.015
27 June	Barge	0.275	0.137	0.412	0.137	0.164	0.024
29 June	Barge	0.014	0	0.014	0.007	0.007	
2 July	Barge	0.15	0.07	0.22	0.075	0.076	
12 July	Barge	3.2 [d]	6.1	9.3	1.6		1.6
22 July	Barge	0.065	0	0.065	0.0325	0.0316	0.0009
Test site: Enewetak, Pacific							
1948: 14 April	Tower	0.037	0	0.037	0.019	0.018	
30 April	Tower	0.049	0	0.049	0.025	0.024	
14 May	Tower	0.018	0	0.018	0.009	0.009	
1951: 7 April	Tower	0.081	0	0.081	0.041	0.039	0.001
20 April	Tower	0.047	0	0.047	0.024	0.023	
8 May	Tower	0.15	0.075	0.225	0.075	0.066	0.009
24 May	Tower	0.0455	0	0.0455	0.0228	0.0227	
1952: 31 October	Surface	5.7 [d]	4.7	10.4	2.85		2.85
15 November	Air drop	0.25	0.25	0.5		0.2	0.05
1954: 13 May	Barge	0.845	0.845	1.69	0.423	0.164	0.258
1956: 4 May	Surface	0.04	0	0.04	0.02	0.02	
27 May	Tower	0.00019	0	0.00019	0.000095	0.000095	
30 May	Tower	0.0149	0	0.0149	0.00745	0.00745	
6 June	Surface	0.0137	0	0.0137	0.00685	0.00685	
11 June	Tower	0.008	0	0.008	0.004	0.004	
13 June	Tower	0.00149	0	0.00149	0.000745	0.000745	
16 June	Air drop	0.0017	0	0.0017		0.0017	
21 June	Tower	0.0152	0	0.0152	0.0076	0.0076	
2 July	Tower	0.24	0.12	0.36	0.12	0.10	0.020
8 July	Barge	0.925	0.925	1.85	0.463	0.153	0.309
21 July	Barge	0.167	0.083	0.25	0.084	0.074	0.009
1958: 5 May	Surface	0.018	0	0.018	0.009	0.009	
11 May	Barge	0.081	0	0.081	0.041	0.0388	0.0012
12 May	Surface	0.685	0.685	1.37	0.343	0.175	0.167
16 May	Under water	0.009	0	0.009	0.0045	0.0045	
20 May	Barge	0.0059	0	0.0059	0.003	0.0029	
26 May	Barge	0.22	0.11	0.33	0.11	0.094	0.016
26 May	Barge	0.057	0	0.057	0.0285	0.0278	0.0007
30 May	Barge	0.0116	0	0.0116	0.0058	0.0058	
2 June	Barge	0.015	0	0.015	0.0075	0.0075	
8 June	Under water	0.008	0	0.008	0.004	0.004	
14 June	Barge	0.725	0.725	1.45	0.363	0.174	0.188
18 June	Barge	0.011	0	0.011	0.0055	0.0055	
27 June	Barge	0.44	0.44	0.88	0.22	0.151	0.069
28 June	Barge	3 [d]	5.9	8.9	1.5		1.5
1 July	Barge	0.0052	0	0.0052	0.0026	0.0026	
5 July	Barge	0.265	0.132	0.397	0.133	0.109	0.024
17 July	Barge	0.170	0.085	0.255	0.085	0.074	0.011
22 July	Barge	0.135	0.067	0.202	0.067	0.060	0.007
26 July	Barge	1	1	2	0.5	0.138	0.363
6 August	Surface	0	0	0	0	0	
18 August	Surface	0.00002	0	0.00002	0.00001	0.00001	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Pacific							
1955: 14 May	Under water	0.03	0	0.03	0.015	0.015	
1958: 28 April	Balloon	0.0017	0	0.0017		0.0017	
1962: 5 May	Rocket	0.05	0	0.05 [c]			0.05
11 May	Under water	0.02	0	0.02 [c]	0.01	0.01	
Test site: Atlantic, 38°–50°S							
1958: 27 August	Rocket	0.0015	0	0.0015			0.0015
30 August	Rocket	0.0015	0	0.0015			0.0015
6 September	Rocket	0.0015	0	0.0015			0.0015
Test site: Johnston Island, Pacific							
1958: 1 August	Rocket	1.9	1.9	3.8			1.9
12 August	Rocket	1.9	1.9	3.8			1.9
1962: 9 July	Rocket	0.7	0.7	1.4			0.7
2 October	Air drop	0.075	0	0.075		0.073	0.002
6 October	Air drop	0.0113	0	0.0113		0.0113	
18 October	Air drop	0.795	0.795	1.59		0.341	0.454
20 October	Rocket	0.02	0	0.02 [c]			0.02
26 October	Rocket	0.25	0.25	0.5 [c]			0.25
27 October	Air drop	0.4	0.4	0.8		0.285	0.115
30 October	Air drop	4.15	4.15	8.3			4.15
1 November	Rocket	0.25	0.25	0.5 [c]			0.25
4 November	Rocket	0.02	0	0.02 [c]			0.02
Test site: Christmas Island, Pacific							
1962: 25 April	Air drop	0.127	0.063	0.19		0.114	0.014
27 April	Air drop	0.27	0.14	0.41		0.226	0.047
2 May	Air drop	0.545	0.545	1.09		0.336	0.209
4 May	Air drop	0.335	0.335	0.67		0.252	0.083
8 May	Air drop	0.1	0	0.1		0.097	0.003
9 May	Air drop	0.1	0	0.1		0.097	0.003
11 May	Air drop	0.05	0	0.05		0.049	0.001
12 May	Air drop	0.25	0.25	0.5		0.2	0.05
14 May	Air drop	0.097	0	0.097		0.094	0.003
19 May	Air drop	0.073	0	0.073		0.071	0.002
25 May	Air drop	0.0026	0	0.0026		0.0026	
27 May	Air drop	0.043	0	0.043		0.043	
8 June	Air drop	0.391	0.391	0.782		0.281	0.110
9 June	Air drop	0.14	0.07	0.21		0.124	0.016
10 June	Air drop	1.5	1.5	3		0.12	1.38
12 June	Air drop	0.6	0.6	1.2		0.345	0.255
15 June	Air drop	0.4	0.4	0.8		0.28	0.12
17 June	Air drop	0.052	0	0.052		0.051	0.001
19 June	Air drop	0.0022	0	0.0022		0.0022	
22 June	Air drop	0.0815	0	0.0815		0.0791	0.0024
27 June	Air drop	3.83	3.82	7.65			3.83
30 June	Air drop	0.63	0.64	1.27		0.346	0.284
10 July	Air drop	0.5	0.5	1		0.325	0.175
11 July	Air drop	1.94	1.94	3.88		0.089	1.851

USSR

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Semipalatinsk							
1949: 29 August	Surface	0.022	0	0.022	0.011	0.011	
1951: 24 September	Surface	0.038	0	0.038	0.019	0.018	0.001
18 October	Air	0.042	0	0.042		0.039	0.003
1953: 12 August	Surface	0.04	0.36	0.4 [e]	0.02	0.0089	0.011
23 August	Air	0.028	0	0.028		0.028	
3 September	Air	0.0058	0	0.0058		0.0058	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
1953: 8 September	Air	0.0016	0	0.0016		0.0016	
10 September	Air	0.0049	0	0.0049		0.0049	
1954: 29 September	Air	0.0002	0	0.0002		0.0002	
1 October	Air	0.00003	0	0.00003		0.00003	
3 October	Air	0.002	0	0.002		0.002	
5 October	Surface	0.004	0	0.004	0.002	0.002	
8 October	Air	0.0008	0	0.0008		0.0008	
19 October	Surface	0.000001	0	0.000001	0.0000005	0.0000005	
23 October	Air	0.062	0	0.062		0.054	0.008
26 October	Air	0.0028	0	0.0028		0.0028	
30 October	Surface	0.01	0	0.01	0.005	0.005	
1955: 29 July	Surface	0.0013	0	0.0013	0.00065	0.00065	
2 August	Surface	0.012	0	0.012	0.006	0.006	
5 August	Surface	0.0012	0	0.0012	0.0006	0.0006	
6 November	Air	0.167	0.083	0.25		0.106	0.061
22 November	Air	0.8	0.8	1.6		0.003	0.797
1956 16 March	Surface	0.014	0	0.014	0.007	0.007	
25 March	Surface	0.0055	0	0.0055	0.00275	0.00275	
24 August	Surface	0.027	0	0.027	0.0135	0.0135	
30 August	Air	0.45	0.45	0.9		0.020	0.430
2 September	Air	0.051	0	0.051		0.046	0.005
10 September	Air	0.038	0	0.038		0.036	0.002
17 November	Air	0.45	0.45	0.9		0.020	0.430
14 December	Air	0.04	0	0.04		0.037	0.003
1957: 8 March	Air	0.019	0	0.019		0.019	
3 April	Air	0.042	0	0.042		0.039	0.003
6 April	Air	0.057	0	0.057		0.050	0.007
10 April	High atmosphere	0.34	0.34	0.68			0.34
12 April	Air	0.022	0	0.022		0.022	
16 April	Air	0.213	0.107	0.32		0.115	0.098
22 August	Air	0.26	0.26	0.52		0.078	0.182
26 August	Air	0.0001	0	0.0001		0.0001	
13 September	Air	0.0059	0	0.0059		0.0059	
26 September	Air	0.013	0	0.013		0.013	
28 December	Air	0.012	0	0.012		0.012	
1958: 4 January	Air	0.0013	0	0.0013		0.0013	
17 January	Air	0.0005	0	0.0005		0.0005	
13 March	Air	0.0012	0	0.0012		0.0012	
14 March	Air	0.035	0	0.035		0.033	0.002
15 March	High atmosphere	0.014	0	0.014			0.014
18 March	Air	0.00016	0	0.00016		0.00016	
20 March	High atmosphere	0.012	0	0.012			0.012
22 March	Air	0.018	0	0.018		0.018	
1961: 1 September	Air	0.016	0	0.016		0.016	
4 September	Air	0.009	0	0.009		0.009	
5 September	Air	0.016	0	0.016		0.016	
6 September	Air	0.0011	0	0.0011		0.0011	
9 September	Surface	0.00038	0	0.00038	0.00019	0.00019	
10 September	Air	0.00088	0	0.00088		0.00088	
11 September	Air	0.0003	0	0.0003		0.0003	
13 September	Air	0.004	0	0.004 [f]		0.004	
14 September	Surface	0.0004	0	0.0004	0.0002	0.0002	
17 September	Air	0.04	0	0.04 [f]		0.037	
18 September	Surface	0.000004	0	0.000004	0.000002	0.000002	
18 September	Air	0.00075	0	0.00075		0.00075	
19 September	Surface	0.00003	0	0.00003	0.000015	0.000015	
20 September	Air	0.0048	0	0.0048		0.0048	
21 September	Air	0.0008	0	0.0008		0.0008	
26 September	Air	0.0012	0	0.0012		0.0012	
1 October	Air	0.003	0	0.003		0.003	
4 October	Air	0.013	0	0.013		0.013	
12 October	Air	0.015	0	0.015		0.015	
17 October	Air	0.0066	0	0.0066		0.0066	
19 October	Air	0.004	0	0.004 [e]		0.004	
25 October	Air	0.0005	0	0.0005		0.0005	0.003
30 October	Air	0.00009	0	0.00009		0.00009	
1 November	Air	0.0027	0	0.0027		0.0027	
2 November	Air	0.0006	0	0.0006		0.0006	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
1961: 3 November	Surface	0.000001	0	0.000001	0.0000005	0.0000005	
3 November	Air	0.0009	0	0.0009		0.0009	
4 November	Surface	0.0002	0	0.0002	0.0001	0.0001	
1962: 1 August	Air	0.0024	0	0.0024		0.0024	
3 August	Air	0.0016	0	0.0016		0.0016	
4 August	Air	0.0038	0	0.0038		0.0038	
7 August	Surface	0.0099	0	0.0099	0.00495	0.00495	
18 August	Air	0.0074	0	0.0074		0.0074	
18 August	Air	0.0058	0	0.0058		0.0058	
21 August	Air	0.04	0	0.04 [e]		0.037	0.003
22 August	Air	0.003	0	0.003		0.003	
23 August	Air	0.0025	0	0.0025		0.0025	
25 August	Air	0.004	0	0.004 [e]		0.004	
27 August	Air	0.011	0	0.011		0.011	
31 August	Air	0.0027	0	0.0027		0.0027	
22 September	Surface	0.00021	0	0.00021	0.00011	0.0001	
24 September	Air	0.0012	0	0.0012		0.0012	
25 September	Surface	0.007	0	0.007	0.0035	0.0035	
28 September	Air	0.0013	0	0.0013		0.0013	
9 October	Air	0.008	0	0.008		0.008	
10 October	Air	0.0092	0	0.0092		0.0092	
13 October	Air	0.0049	0	0.0049		0.0049	
14 October	Air	0.004	0	0.004 [e]		0.004	
20 October	Air	0.0067	0	0.0067		0.0067	
28 October	Air	0.0078	0	0.0078		0.0078	
28 October	Air	0.0078	0	0.0078		0.0078	
30 October	Surface	0.0012	0	0.0012	0.0006	0.0006	
31 October	Air	0.01	0	0.01		0.01	
1 November	Air	0.003	0	0.003		0.003	
3 November	Air	0.0047	0	0.0047		0.0047	
4 November	Air	0.0084	0	0.0084		0.0084	
5 November	Surface	0.0004	0	0.0004	0.0002	0.0002	
11 November	Surface	0.0001	0	0.0001	0.00005	0.00005	
13 November	Surface	0.000001	0	0.000001	0.0000005	0.0000005	
14 November	Air	0.012	0	0.012		0.012	
17 November	Air	0.018	0	0.018		0.018	
24 November	Surface	0.000001	0	0.000001	0.0000005	0.0000005	
26 November	Surface	0.000031	0	0.000031	0.000016	0.000015	
1 December	Air	0.0024	0	0.0024		0.0024	
23 December	Surface	0.000001	0	0.000001	0.0000005	0.0000005	
24 December	Surface	0.000007	0	0.000007	0.00000035	0.00000035	
24 December	Surface	0.000028	0	0.000028	0.000014	0.000014	
Test site: Novaya Zemlya							
1955: 21 September	Under water	0.0035	0	0.0035	0.00175	0.00175	
1957: 7 September	Surface	0.032	0	0.032	0.016	0.0154	0.0006
24 September	Air	0.8	0.8	1.6		0.003	0.797
6 October	Air	1.45	1.45	2.9			1.45
10 October	Under water	0.01	0	0.01	0.005	0.005	
1958: 23 February	Air	0.43	0.43	0.86		0.025	0.405
27 February	Air	0.163	0.087	0.25		0.103	0.060
27 February	Air	0.75	0.75	1.5		0.004	0.746
14 March	Air	0.04	0	0.04		0.037	0.003
21 March	Air	0.325	0.325	0.65		0.054	0.271
30 September	Air	0.6	0.6	1.2		0.005	0.595
30 September	Air	0.45	0.45	0.9		0.020	0.430
2 October	Air	0.193	0.097	0.29		0.112	0.071
2 October	Air	0.04	0	0.04		0.037	0.003
4 October	Air	0.009	0	0.009		0.009	
5 October	Air	0.015	0	0.015		0.015	
6 October	Air	0.0055	0	0.0055		0.0055	
10 October	Air	0.068	0	0.068		0.059	0.009
12 October	Air	0.725	0.725	1.45		0.004	0.721
15 October	Air	0.75	0.75	1.5		0.004	0.746
18 October	Air	1.45	1.45	2.9			1.45
19 October	Air	0.04	0	0.04		0.037	0.003
19 October	Air	0.000001	0	0.000001		0.000001	
20 October	Air	0.293	0.147	0.44		0.115	0.178
21 October	Air	0.002	0	0.002		0.002	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
1958: 22 October	Air	1.4	1.4	2.8			1.4
24 October	Air	0.5	0.5	1		0.005	0.495
25 October	Air	0.127	0.063	0.19		0.090	0.037
25 October	Air	0.0001	0	0.0001		0.0001	
1961: 10 September	Air	1.35	1.35	2.7			1.35
10 September	Air	0.012	0	0.012		0.012	
12 September	Air	0.575	0.575	1.15		0.005	0.570
13 September	Air	0.006	0	0.006		0.006	
14 September	Air	0.6	0.6	1.2		0.005	0.595
16 September	Air	0.415	0.415	0.83		0.029	0.386
18 September	Air	0.5	0.5	1		0.005	0.495
20 September	Air	0.266	0.134	0.4 [e]		0.118	0.148
22 September	Air	0.173	0.087	0.26		0.107	0.066
2 October	Air	0.167	0.083	0.25		0.106	0.061
4 October	Air	2	2	4 [e]			2
6 October	Air	2	2	4			2
8 October	Air	0.015	0	0.015		0.015	
20 October	Air	0.725	0.725	1.45		0.004	0.721
23 October	Under water	0.0048	0	0.0048	0.0024	0.0024	
23 October	Air	4.17	8.33	12.5			4.17
25 October	Air	0.2	0.1	0.3		0.113	0.087
27 October	Water surface	0.016	0	0.016	0.008	0.008	
30 October	Air	1.5 [b]	48.5 [b]	50			1.5
31 October	Air	2.5	2.5	5			2.5
31 October	Air	0.267	0.133	0.4 [e]		0.118	0.149
2 November	Air	0.08	0.04	0.12		0.063	0.017
2 November	Air	0.187	0.093	0.28		0.111	0.076
4 November	Air	0.015	0	0.015		0.015	
4 November	Air	0.267	0.133	0.4 [e]		0.118	0.149
4 November	Air	0.006	0	0.006		0.006	
1962: 5 August	Air	7.03	14.07	21.1			7.03
10 August	Air	0.267	0.133	0.4 [f]		0.118	0.149
20 August	Air	1.4	1.4	2.8			1.4
22 August	Air	0.8	0.8	1.6		0.003	0.797
22 August	Water surface	0.006	0	0.006	0.003	0.003	
25 August	Air	2	2	4 [f]			2
27 August	Air	2.1	2.1	4.2			2.1
2 September	Air	0.08	0	0.08		0.067	0.013
8 September	Air	0.95	0.95	1.9		0.001	0.949
15 September	Air	1.55	1.55	3.1			1.55
16 September	Air	1.625	1.625	3.25			1.625
18 September	Air	0.675	0.675	1.35		0.004	0.671
19 September	Air	2	2	4 [f]			2
21 September	Air	1.2	1.2	2.4			1.2
25 September	Air	6.37	12.73	19.1			6.37
27 September	Air	8.07	16.13	24.2 [f]			8.07
7 October	Air	0.32	0	0.32		0.173	0.147
9 October	Air	0.015	0	0.015		0.015	
22 October	Air	4.1	4.1	8.2			4.1
27 October	Air	0.173	0.087	0.26		0.107	0.066
29 October	Air	0.24	0.12	0.36		0.118	0.122
30 October	Air	0.187	0.093	0.28		0.111	0.076
1 November	Air	0.16	0.08	0.24		0.104	0.056
3 November	Air	0.26	0.13	0.39		0.119	0.141
3 November	Air	0.045	0	0.045		0.041	0.004
18 December	Air	0.073	0.037	0.11		0.058	0.015
18 December	Air	0.069	0	0.069		0.059	0.010
20 December	Air	0.0083	0	0.0083		0.0083	
22 December	Air	0.0063	0	0.0063		0.0063	
23 December	Air	0.287	0.143	0.43		0.117	0.170
23 December	Air	0.0083	0	0.0083		0.0083	
23 December	Air	0.0024	0	0.0024		0.0024	
24 December	Air	0.55	0.55	1.1		0.005	0.545
24 December	Air	8.07	16.13	24.2			8.07
25 December	Air	1.55	1.55	3.1			1.55
25 December	Air	0.0085	0	0.0085		0.0085	

Table 1 (continued)

Date	*Type of test*	*Yield (Mt)* [a]			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
Test site: Totsk, Aralsk							
1954: 14 September	Air	0.04	0	0.04		0.037	0.003
1956: 2 February	Surface	0.0003	0	0.0003	0.00015	0.00015	
Test site: Kapustin Yar							
1957: 19 January	Air	0.01	0	0.01		0.01	
1958: 1 November	Air	0.01	0	0.01		0.01	
3 November	Air	0.01	0	0.01		0.01	
1961: 6 September	Air	0.011	0	0.011		0.011	
6 October	Air	0.04	0	0.04		0.037	0.003
27 October	High atmosphere	0.0012	0	0.0012			0.0012
27 October	High atmosphere	0.0012	0	0.0012			0.0012
1962: 22 October	High atmosphere	0.2	0.1	0.3			0.2
28 October	High atmosphere	0.2	0.1	0.3			0.2
1 November	High atmosphere	0.2	0.1	0.3			0.2

a Estimated fission and fusion yields unless otherwise indicated; reported total yields.
b Reported fission or fusion yield.
c Indefinite reported yield; value assigned as follows: low, 0.02 Mt; no indication, 0.05 Mt; submegatonne, 0.5 Mt.
d Fission yield arbitrarily adjusted to obtain agreement with reported total fission yields for test series: 1952–1954 = 37 Mt (36 Mt from >1 Mt events), 1956 = 9 Mt (8 Mt from >1 Mt events), 1957–1958 = 19 Mt (14 Mt from >1 Mt events) [D7].
e Thermonuclear explosion; fission yield estimated [G7].
f Indefinite reported yield; value assigned as follows: 0.000001–0.02 Mt, 0.004 Mt; 0.02–0.15 Mt, 0.04 Mt; 0.15–1.5 Mt, 0.4 Mt; 1.5–10 Mt, 4 Mt; >10 Mt, 24.2 Mt.

Note: The dates of tests have been reported as Greenwich Mean Time.

Table 2
Atmospheric nuclear tests at each test site

Test site	*Number of tests*	*Yield (Mt)*			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Stratosphere*
China							
Lop Nor	22	12.2	8.5	20.72	0.15	0.66	11.40
France							
Algeria	4	0.073	0	0.073	0.036	0.035	0.001
Fangataufa	4	1.97	1.77	3.74	0.06	0.13	1.78
Mururoa	37	4.13	2.25	6.38	0.13	0.41	3.59
Total	45	6.17	4.02	10.20	0.23	0.57	5.37
United Kingdom							
Monte Bello Island	3	0.1	0	0.1	0.050	0.049	0.0007
Emu	2	0.018	0	0.018	0.009	0.009	0
Marilinga	7	0.062	0	0.062	0.023	0.038	0
Malden Island	3	0.69	0.53	1.22	0	0.56	0.13
Christmas Island	6	3.35	3.30	6.65	0	1.09	2.26
Total	21	4.22	3.83	8.05	0.07	1.76	2.39
United States							
New Mexico	1	0.021	0	0.021	0.011	0.010	0
Japan (combat use)	2	0.036	0	0.036	0	0.036	0
Nevada	86	1.05	0	1.05	0.28	0.77	0.004
Bikini	23	42.2	34.6	76.8	20.3	1.07	20.8
Enewetak	42	15.5	16.1	31.7	7.63	2.02	5.85
Pacific	4	0.102	0	0.102	0.025	0.027	0.050
Atlantic	3	0.0045	0	0.0045	0	0	0.005
Johnston Island	12	10.5	10.3	20.8	0	0.71	9.76
Christmas Island	24	12.1	11.2	23.3	0	3.62	8.45
Total	197	81.5	72.2	153.8	28.2	8.27	44.9
USSR							
Semipalatinsk	116	3.74	2.85	6.59	0.097	1.23	2.41
Novaya Zemlya	91	80.8	158.8	239.6	0.036	2.93	77.8
Totsk, Aralsk	2	0.040	0	0.040	0	0.037	0.003
Kapustin Yar	10	0.68	0.30	0.98	0	0.078	0.61
Total	219	85.3	162.0	247.3	0.13	4.28	80.8
All countries							
Total	543 [a]	189	251	440	29	16	145

a Includes 22 safety tests of the United States, 12 safety tests of the United Kingdom, and 5 safety tests of France not listed inTable 1.

Table 3
Estimated fission and fusion yields of atmospheric nuclear tests of total yields equal to or greater than 4 Mt

Date	*Designation*	*Type of test*	*Test site*	*Yield (Mt)*		
				Fission	*Fusion*	*Total*
China						
17 November 1976		Air	Lop Nor	2.2 [a]	1.8	4
United States						
28 February 1954	Bravo	Surface	Bikini	9.0 [b]	6.0	15
4 May 1954	Yankee	Barge	Bikini	9.0 [b]	4.5	13.5
26 March 1954	Romeo	Barge	Bikini	7.3 [b]	3.7	11
31 October 1952	Mike	Surface	Enewetak	5.7 [b]	5.7	10.4
12 July 1958	Poplar	Barge	Bikini	3.2 [b]	6.1	9.3
28 June 1958	Oak	Barge	Enewetak	3.0 [b]	5.9	8.9
30 October 1962	Housatonic	Air drop	Johnston Island	4.15	4.15	8.3
27 June 1962	Bighorn	Air drop	Christmas Island	3.83	3.82	7.65
25 April 1954	Union	Barge	Bikini	4.6 [b]	2.3	6.9
20 July 1956	Tewa	Barge	Bikini	2.3 [b]	2.7	5
10 July 1956	Navaho	Barge	Bikini	1.5 [b]	3.0	4.5
USSR						
30 October 1961	Test 130	Air	Novaya Zemlya	1.5 [c]	48.5	50
24 December 1962	Test 219	Air	Novaya Zemlya	8.07	16.13	24.2
5 August 1962	Test 147	Air	Novaya Zemlya	7.03	14.07	21.1
25 September 1962	Test 173	Air	Novaya Zemlya	6.37	12.73	19.1
27 September 1962	Test 174	Air	Novaya Zemlya	8.07	16.13	24.2 [d]
23 October 1961	Test 123	Air	Novaya Zemlya	4.17	8.33	12.5
22 October 1962	Test 183	Air	Novaya Zemlya	4.1	4.1	8.2
31 October 1961	Test 131	Air	Novaya Zemlya	2.5	2.5	5
27 August 1962	Test 160	Air	Novaya Zemlya	2.1	2.1	4.2
4 October 1961	Test 113	Air	Novaya Zemlya	2	2	4 [e]
6 October 1961	Test 114	Air	Novaya Zemlya	2	2	4
25 August 1962	Test 158	Air	Novaya Zemlya	2	2	4 [c]
19 September 1962	Test 168	Air	Novaya Zemlya	2	2	4 [c]
Total						
		25 tests		106	183	289

a Estimated from measured stratospheric inventories [L7, L8] and global deposition [F7].
b Fission yield arbitrarily adjusted to obtain agreement with reported total fission yields for test series: 1952–1954 = 37 Mt (36 Mt from >1 Mt events), 1956 = 9 Mt (8 Mt from >1 Mt events), 1957–1958 = 19 Mt (14 Mt from >1 Mt events) [D7].
c Officially reported value [M2].
d Reported yield: >10 Mt.
e Reported yield: 1.5–10 Mt.

Table 4
Annual fission and fusion yields of nuclear tests and atmospheric partitioning, all countries

Year	*Number of tests*	*Yield (Mt)*			*Partitioned fission yield (Mt)*		
		Fission	*Fusion*	*Total*	*Local and regional*	*Troposphere*	*Fission*
1945	3 [a]	0.057	0	0.057	0.011	0.046	0
1946	2	0.042	0	0.042	0.011	0.031	0
1947							
1948	3	0.10	0	0.10	0.053	0.051	0
1949	1	0.022	0	0.022	0.011	0.011	0
1950							
1951	18	0.51	0.08	0.59	0.18	0.32	0.014
1952	11	6.08	4.95	11.0	2.89	0.28	2.91
1953	18	0.35	0.36	0.71	0.099	0.24	0.013
1954	16	30.9	17.4	48.3	15.4	0.31	15.2
1955	20	1.18	0.88	2.06	0.10	0.22	0.86
1956	32	10.0	12.9	22.9	3.68	0.99	5.31
1957	46	5.25	4.37	9.64	0.14	1.61	3.50
1958	91	26.5	30.3	56.8	5.86	3.31	17.3
1959							
1960	3	0.072	0	0.072	0.036	0.035	0.0009
1961	59	18.2	68.3	86.5	0.011	1.15	17.1
1962	118	71.8	98.5	170.4	0.052	5.77	66.0
1963							
1964	1	0.02	0	0.02	0.010	0.010	0
1965	1	0.04	0	0.04	0	0.037	0.003
1966	8	0.94	0.20	1.14	0.28	0.41	0.25
1967	5	1.88	1.30	3.18	0.011	0.046	1.82
1968	6	4.16	3.44	7.60	0	0	4.16
1969	1	1.9	1.1	3	0		1.90
1970	9	3.38	2.40	5.78	0	0.095	3.28
1971	6	0.84	0.62	1.46	0.01	0.057	0.77
1972	5	0.13	0	0.13	0	0.11	0.02
1973	6	1.42	1.1	2.52	0	0.021	1.40
1974	8	0.75	0.46	1.21	0	0.19	0.56
1975							
1976	3	2.32	1.8	4.12	0.01	0.09	2.22
1977	1	0.02	0	0.02	0	0.02	0
1978	2	0.04	0	0.04	0.02	0.02	0
1979							
1980	1	0.5	0.1	0.6	0	0.11	0.39
Total							
Total	543 [b]	189	251	440	29	16	145
Total worldwide dispersion (troposphere and stratosphere)						160.5	
Total measured global deposition						155 [c]	

a Includes two cases of military combat use in Japan.
b Total includes additional 39 safety tests: 22 by the United States, 12 by the United Kingdom, and 5 by France.
c Inferred from ^{90}Sr measurements. Since radioactive decay of 2%–3% occurred prior to deposition of ^{90}Sr, the estimated dispersed amount (injection into atmosphere) would also be about 160 Mt.

Table 5
Empirical estimates of the partitioning of yields from atmospheric tests into the troposphere and stratosphere [P1]

Total yield (Mt)	*Partitioned yield (Mt)*					
	Equatorial airburst [a] (0 °–30 ° latitude)			*Polar airburst [b] (30 °–90 ° latitude)*		
	Troposphere	*Lower stratosphere*	*Upper stratosphere*	*Troposphere*	*Lower stratosphere*	*Upper stratosphere*
0.03	0.03	0		0.029	0.001	
0.05	0.049	0.001		0.045	0.005	
0.07	0.068	0.002		0.06	0.01	
0.1	0.097	0.003		0.08	0.02	
0.2	0.18	0.02		0.14	0.06	
0.3	0.26	0.04		0.17	0.13	
0.5	0.40	0.10		0.16	0.34	
0.7	0.52	0.18		0.08	0.62	
1	0.65	0.35		0.01	0.99	
2	0.55	1.45			1.6	0.4
3	0.24	2.76			1.45	1.55
5	0.02	4.43	0.55		0.95	4.05
7		4.97	2.03		0.56	6.44
10		5.25	4.75		0.06	9.94
20		3.00	17.0			20
30		2.1	27.9			30
50		0.5	49.5			50

a Atmospheric heights: Troposphere <17 km, lower stratosphere 17–24 km, upper stratosphere 24–50 km.
b Atmospheric heights: Troposphere <9 km, lower stratosphere 9–17 km, upper stratosphere 17–50 km.

Table 6
Estimated annual injections of nuclear debris into atmospheric regions [a]

Year	*Fission energy (Mt)*										
	High equatorial atmosphere		*Polar stratosphere north*		*Equatorial stratosphere north*		*Equatorial stratosphere south*		*Troposphere*		*Total*
	North	*South*	*Upper*	*Lower*	*Upper*	*Lower*	*Upper*	*Lower*	*North*	*South*	
1945									0.046		0.046
1946									0.031		0.031
1947											
1948									0.051		0.051
1949									0.011		0.011
1950											
1951				0.004		0.010			0.32		0.33
1952					1.35	1.55			0.27	0.013	3.19
1953						0.013			0.23	0.009	0.25
1954				0.011	7.95	7.26			0.31		15.5
1955			0.096	0.76					0.22		1.08
1956				0.44	0.27	4.61		0.0007	0.94	0.053	6.30
1957	0.34		0.80	1.46		0.48		0.43	0.87	0.74	5.11
1958	1.93	1.90	1.58	6.05	1.30	3.70		0.84	2.92	0.39	20.6
1959											
1960						0.0009			0.035		0.036
1961	0.002		11.0	6.14					1.15		18.25
1962	1.28	0.62	41.5	9.48	1.91	7.02	0.63	3.58	3.96	1.81	71.8
1963											
1964									0.010		0.010
1965				0.003					0.037		0.040
1966				0.13				0.12	0.19	0.21	0.66
1967					0.44	1.26		0.12	0.020	0.026	1.87
1968			0.78	0.73			1.09	1.56			4.16
1969			0.98	0.92							1.90
1970			0.98	0.92				1.38		0.095	3.38
1971								0.77	0.010	0.047	0.83
1972				0.02					0.10	0.011	0.13
1973					0.25	1.15				0.021	1.42
1974						0.24		0.32	0.065	0.12	0.75
1975											
1976			1.46	0.76					0.090		2.31
1977									0.020		0.02
1978									0.020		0.02
1979											
1980				0.39					0.11		0.5
Total											
North	3.84		59.2	28.2	13.5	27.3			12.1		144
South		2.52					1.72	9.12		3.55	16.9
Global	6.36		139						15.6		161

a Yields were partitioned according to values of Table 5. For sites at temperate locations (30°–60° latitude) and yields of 1–4 Mt, input to the upper stratospheric region was reduced by one half, essentially averaging equatorial and polar partitioning assumptions; polar partitioning was maintained for the tropospheric portion. For tests in June, July, and August, inputs from temperate sites were assumed to be to the equatorial atmosphere and from all other months to the polar atmosphere. Partitioning from equatorial sites (Christmas Island and high altitude tests at Johnston Island) were assumed equally divided between the northern and southern hemispheres.

Table 7
Annual concentrations in air and deposition amounts of ^{90}Sr produced in atmospheric nuclear testing

Year	*Average annual concentration in air of mid-latitudes (mBq m^{-3})*				*Annual hemispheric deposition (PBq)*				*Cumulative deposit (PBq)*		
	Northern hemisphere		*Southern hemisphere*		*Northern hemisphere*		*Southern hemisphere*		*North*	*South*	*Total*
	Calculated [a]	*Measured* [b]	*Calculated* [a]	*Measured* [c]	*Calculated* [a]	*Measured* [d]	*Calculated* [a]	*Measured* [d]	*Measured* [e]	*Measured* [e]	*Measured* [e]
1945	0.002		-		0.017		-		0.17	0.00	0.17
1946	0.002		-		0.13		-		0.29	0.00	0.29
1947	- [f]		-		0.00		-		0.29	0.00	0.29
1948	0.002		-		0.20		-		0.47	0.00	0.47
1949	0.001		-		0.04		-		0.50	0.00	0.50
1950	-		-		-		-		0.49	0.00	0.49
1951	0.014		-		1.16		-		1.61	0.00	1.61
1952	0.014		0.001		1.18		0.05		2.72	0.05	2.77
1953	0.061		0.009		5.00		0.71		7.52	0.75	8.27
1954	0.16		0.053		13.0		4.38		20.1	5.02	25.1
1955	0.24		0.055		19.4		4.55		38.5	9.35	47.8
1956	0.22		0.057		17.9		4.70		55.0	13.7	68.7
1957	0.22	0.23	0.072		17.6		6.34		70.9	19.6	90.4
1958	0.36	0.48	0.081	0.11	29.4	23.3	6.73	9.45	92.2	28.5	121
1959	0.33	0.72	0.061	0.074	27.2	38.9	4.82	6.84	128	34.5	163
1960	0.14	0.15	0.043	0.056	11.3	9.69	3.52	6.22	135	39.9	175
1961	0.14	0.17	0.030	0.075	11.5	13.0	2.49	6.44	145	45.3	190
1962	0.67	0.99	0.185	0.11	54.6	53.4	15.2	9.75	194	53.8	248
1963	1.41	2.17	0.139	0.16	115	97.0	11.5	11.4	285	63.8	349
1964	0.87	1.25	0.109	0.18	71.2	61.3	8.97	15.6	339	77.7	416
1965	0.40	0.45	0.073	0.16	32.9	28.6	6.02	13.2	359	88.9	448
1966	0.18	0.19	0.054	0.085	14.6	12.1	4.48	7.66	362	94.3	457
1967	0.086	0.075	0.036	0.050	7.00	6.24	2.99	4.07	360	96.1	456
1968	0.062	0.098	0.041	0.046	5.11	7.22	3.40	3.76	358	97.5	456
1969	0.078	0.070	0.051	0.089	6.34	5.45	4.20	5.21	355	100	455
1970	0.088	0.12	0.056	0.066	7.18	7.62	4.60	4.74	354	103	457
1971	0.090	0.11	0.049	0.078	7.37	6.97	4.04	5.56	353	106	458
1972	0.051	0.035	0.029	0.053	4.15	3.19	2.40	3.55	347	107	454
1973	0.026	0.018	0.018	0.024	2.17	1.18	1.46	1.13	340	105	445
1974	0.037	0.056	0.020	0.018	3.06	4.46	1.68	1.45	336	104	441
1975	0.020	0.032	0.012	0.019	1.67	2.16	0.99	1.27	331	103	433
1976	0.014	0.011	0.006	0.007	1.14	1.00	0.46	0.77	324	101	425
1977	0.052	0.032	0.003	0.003	4.25	3.01	0.27	0.81	319	100	418
1978	0.031	0.035	0.003	0.002	2.50	3.70	0.21	0.67	315	97.8	413
1979	0.014	0.011	0.002	0.002	1.11	1.16	0.15	0.39	308	95.8	404
1980	0.011	0.008	0.001	0.003	0.91	1.11	0.09	0.39	302	93.9	396
1981	0.015	0.019	0.001	0.002	1.23	1.85	0.07	0.29	297	92.0	387

Table 7 (continued)

Year	*Average annual concentration in air of mid-latitudes (mBq m⁻³)*				*Annual hemispheric deposition (PBq)*				*Cumulative deposit (PBq)*		
	Northern hemisphere		*Southern hemisphere*		*Northern hemisphere*		*Southern hemisphere*		*North*	*South*	*Total*
	Calculated [a]	*Measured* [b]	*Calculated* [a]	*Measured* [c]	*Calculated* [a]	*Measured* [d]	*Calculated* [a]	*Measured* [d]	*Measured* [e]	*Measured* [e]	*Measured* [e]
1982	0.003	0.005	-	0.002	0.30	0.47	0.055	0.22	289	90.3	379
1983	0.002	0.001	-	-	0.09	0.33	0.033	0.19	283	88.2	370
1984	-		-		0.04	0.27	0.017	0.11	276	86.1	362
1985	-		-		0.013	0.078	0.008	0.052	269	84.0	353
1986	-		-		0.005		0.004		263	82.0	344
1987	-		-		0.002		0.002		256	80.0	336
1988	-		-		0.001		-		250	78.1	328
1989	-				-		-		244	76.2	320
1990	-		-		-		-		238	74.4	313
1991	-		-		-		-		233	72.6	305
1992	-		-		-		-		227	70.9	298
1993	-		-		-		-		222	69.2	291
1994	-		-		-		-		216	67.5	284
1995	-		-		-		-		211	65.9	277
1996	-		-		-		-		206	64.3	270
1997	-		-		-		-		201	62.8	264
1998	-		-		-		-		196	61.3	258
1999	-		-		-		-		192	59.8	251
2000	-		-		-		-		187	58.4	245
Total [g]	6.1 mBq a m^{-3}	8.9 mBq a m^{-3}	1.3 mBq a m^{-3}	1.7 mBq a m^{-3}	499 PBq	470 PBq 460 PBq [h]	111 PBq	142 PBq 144 PBq [h]			

a Annual average of monthly calculated value.
b Average of measurements performed monthly at Washington, D.C., and Miami (1957-1962), at New York City, Miami, and Sterling, Virginia (1963-1973) and at New York City and Miami (1974-1963) [F4, L6].
c Average of measurements performed monthly at Antofagasta and Santiago, Chile (1958-1976) and at Lima, Peru and Santiago, Chile (1977-1983) [F4, L6].
d Measured in global monitoring network [L9, V2].
e Calculated from decayed monthly measured deposition; prior to 1958 only calculated monthly deposition values are available.
f Less than 0.001 mBq m^{-3} or 0.001 PBq.
g Measured values included preferentially in total.
h Previously derived value based on measured cumulative deposition prior to 1958 [U6].

Table 8
Latitudinal distribution of radionuclide deposition from atmospheric nuclear testing based on measurements of ^{90}Sr [a]

Latitude band (degrees)	*Area of band (10^{12} m^2)*	*Population distribution (%)*	*Integrated deposition of ^{90}Sr (PBq)*	*Fractional deposition in band*	*Deposition density per unit deposition (Bq m^{-2} per PBq)*	*Latitudinal value relative to hemispheric value*
Northern hemisphere						
80–90	3.9	0	1	0.002	0.56	0.12
70–80	11.6	0	7.9	0.017	1.48	0.32
60–70	18.9	0.4	32.9	0.071	3.78	0.81
50–60	25.6	13.7	73.9	0.161	6.27	1.35
40–50	31.5	15.5	101.6	0.221	7.01	1.51
30–40	36.4	20.4	85.3	0.185	5.09	1.09
20–30	40.2	32.7	71.2	0.155	3.85	0.83
10–20	42.8	11	50.9	0.111	2.58	0.56
0–10	44.1	6.3	35.7	0.078	1.76	0.38
Total	255	100	460	1.0		
Population-weighted value [b]					4.65	1.00
Southern hemisphere						
80–90	3.9	0	0.3	0.002	0.53	0.14
70–80	11.6	0	2.5	0.017	1.50	0.40
60–70	18.9	0	6.7	0.046	2.46	0.66
50–60	25.6	0.5	12.1	0.084	3.28	0.88
40–50	31.5	0.9	28.1	0.195	6.19	1.65
30–40	36.4	13	27.6	0.191	5.26	1.40
20–30	40.2	14.9	28.1	0.195	4.85	1.29
10–20	42.8	16.7	17.8	0.123	2.89	0.77
0–10	44.1	54	21	0.146	3.30	0.88
Total	255	100	144	1.0		
Population-weighted value [c]					3.74	1.00

a Distributions valid only for long-lived radionuclides where majority of fallout is from debris originally injected into the stratosphere.

b Valid only for long-lived radionuclides. Value of 4.0 used for radionuclides with half-lives less than 100 d to reflect greater proportion of fallout from debris injected into the troposphere at low latitudes.

c Valid only for long-lived radionuclides. Value of 6.7 and 5.7 used for nuclides with half-lives less than 30 d and 30–100 d, respectively, to reflect greater proportion of fallout from debris injected into the troposphere at low latitudes.

Table 9
Radionuclides produced and globally dispersed in atmospheric nuclear testing

Radionuclide	*Half-life*	*Fission yield (%)*	*Normalized production* [a] *(PBq Mt^{-1})*	*Global release* [b] *(PBq)*
^{3}H	12.33 a		740 [c, d]	186 000 [f]
^{14}C	5 730 a		0.85 [c, e]	213 [f]
^{54}Mn	312.3 d		15.9 [c]	3 980
^{55}Fe	2.73 a		6.1 [c]	1 530
^{89}Sr	50.53 d	3.17	730	117 000
^{90}Sr	28.78 a	3.50	3.88	622
^{91}Y	58.51 d	3.76	748	120 000
^{95}Zr	64.02 d	5.07	921	148 000
^{103}Ru	39.26 d	5.20	1 540	247 000
^{106}Ru	373.6 d	2.44	76.0	12 200
^{125}Sb	2.76 a	0.40	4.62	741
^{131}I	8.02 d	2.90	4 210	675 000
^{140}Ba	12.75 d	5.18	4 730	759 000
^{141}Ce	32.50 d	4.58	1 640	263 000
^{144}Ce	284.9 d	4.69	191	30 700
^{137}Cs	30.07 a	5.57	5.90	948
^{239}Pu	24 110 a			6.52 [g]
^{240}Pu	6 563 a			4.35 [g]
^{241}Pu	14.35 a			142 [g]

a For fission products, the value is 1.45 10^{26} fissions per Mt times the fission yield times the decay constant (ln2 / half-life) divided by 3.15 10^{7} s a^{-1}.
b Corresponds to total globally dispersed fission energy of atmospheric tests of 160.5 Mt or fusion energy of 250.6 Mt (excludes releases associated with local and regional deposition).
c Estimate of Miskel [M3].
d Production per unit fusion energy of atmospheric tests.
e Estimated from total production up to 1972 [U6] and present data on fusion yields.
f Because of mobility and half-lives of ^{3}H and ^{14}C, the release is associated with a total fusion energy of 251 Mt.
g Estimated from ratios to ^{90}Sr in global deposition.

Table 10
Annual deposition of radionuclides produced in atmospheric nuclear testing

Year	Annual deposition (PBq) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
Northern hemisphere														
1945	13.7	24.3	15.8	18.2	9.23	11.9	14.0	6.95	0.00	3.19	0.20	0.00	0.18	0.26
1946	9.82	17.2	10.3	12.6	6.39	8.24	9.19	4.70	0.00	2.28	0.15	0.00	0.13	0.19
1947	- [b]	-	-	0.011	0.011	0.019	0.023	0.050	0.00	0.029	0.002	0.00	0.002	0.003
1948	15.9	28.0	10.1	20.6	10.5	13.5	8.91	4.48	0.00	3.67	0.24	0.00	0.202	0.30
1949	3.34	5.95	2.15	4.40	2.23	2.86	1.89	0.93	0.00	0.76	0.049	0.00	0.042	0.062
1950	-	-	0.01	0.028	0.023	0.038	0.028	0.040	0.00	0.035	0.003	0.00	0.002	0.004
1951	96.5	171	88.8	124	62.7	80.5	76.8	37.1	0.24	21.2	1.35	0.10	1.16	1.73
1952	90.5	165	107	123	62.4	80.2	92.3	45.0	2.39	21.4	1.37	0.95	1.18	1.77
1953	69.5	129	98.3	143	84.4	119	118	103	5.80	72.4	5.35	2.89	5.00	7.50
1954	144	322	240	437	253	350	284	231	12.1	183	13.7	6.08	13.0	19.5
1955	70.1	127	71.5	97.8	55.5	80.4	79.6	193	9.13	182	17.7	6.51	19.4	29.1
1956	303	556	300	489	263	350	322	263	21.1	178	16.1	11.3	17.9	26.9
1957	278	511	412	434	234	314	421	355	25.0	186	16.2	14.6	17.6	26.5
1958	961	1 780	1 110	1 550	822	1089	1 136	791	57.7	417	30.5	28.6	23.3	34.9
1959	0.25	5.31	79.1	128	109	182	264	572	52.3	299	26.0	31.4	38.9	58.4
1960	10.4	18.4	6.66	13.7	7.19	9.84	7.84	97.5	9.85	65.2	8.61	10.4	9.69	14.5
1961	395	740	593	619	319	4 14	547	297	19.0	130	10.5	10.9	13.0	19.5
1962	1 260	2 320	1 960	2 110	1 160	1 580	2 160	1 790	299	777	57.3	158	53.4	80.1
1963	40.7	124	435	627	501	825	1 270	2 820	408	1 310	112	265	97.0	146
1964	3.04	5.39	2.07	4.76	4.85	11.7	21.6	791	131	447	56.5	138	61.3	91.9
1965	11.0	19.7	14.5	15.0	7.71	10.0	13.3	162	27.9	110	20.9	50.2	28.6	42.9
1966	46.5	81.9	60.4	62.4	32.1	41.6	55.2	57.3	6.44	35.8	7.77	17.1	12.1	18.2
1967	18.5	37.1	38.7	43.7	25.3	35.1	48.4	45.2	3.08	22.4	3.55	6.34	6.24	9.36
1968	2.99	6.61	7.85	9.97	7.37	12.2	18.8	59.1	3.83	29.0	3.26	4.03	7.22	10.8
1969	11.4	33.7	68.9	85.9	55.8	82.1	117	143	11.0	64.4	5.46	6.47	5.45	8.17
1970	5.88	16.8	33.4	43.5	30.7	47.8	70.9	145	8.54	68.8	6.31	5.84	7.62	11.4
1971	3.13	6.27	18.0	29.5	24.0	39.7	59.1	142	7.88	68.4	6.46	5.47	6.97	10.5
1972	30.3	54.5	41.1	43.3	22.7	30.1	40.2	54.9	2.25	28.1	3.18	2.35	3.19	4.78
1973	2.40	6.84	13.4	16.5	10.4	15.0	21.2	26.1	1.74	12.9	1.51	1.42	1.18	1.77
1974	20.2	36.6	29.4	32.1	18.6	26.6	37.7	62.1	4.55	29.1	2.66	2.81	4.46	6.69
1975	-	0.01	0.58	1.09	1.14	2.12	3.46	20.2	1.52	10.7	1.26	1.33	2.16	3.23
1976	34.0	63.0	45.2	48.2	24.4	31.3	39.5	22.6	0.61	10.4	0.93	0.57	1.00	1.50
1977	6.70	15.3	36.5	49.4	35.6	55.4	81.6	122	8.24	54.4	4.29	4.41	3.01	4.51
1978	5.53	9.23	3.04	6.10	3.19	4.38	3.70	32.2	2.34	17.9	2.06	2.12	3.70	5.55
1979	0.47	1.45	0.91	2.00	1.08	1.45	0.98	6.40	0.48	4.38	0.74	0.75	1.16	1.74
1980	35.6	65.4	49.7	51.0	25.9	33.3	43.9	22.2	0.42	9.47	0.78	0.38	1.11	1.67
1981	0.023	0.52	6.87	10.4	8.19	13.2	19.8	32.1	0.58	14.4	1.18	0.37	1.65	2.47
1982	-	-	0.0005	0.003	0.011	0.038	0.083	3.04	0.120	1.69	0.22	0.077	0.47	0.71
1983	-	-	-	-	-	0.0002	0.0005	0.37	0.025	0.25	0.054	0.019	0.33	0.5
1984	-	-	-	-	-	-	-	0.051	0.0050	0.043	0.014	0.0054	0.27	0.41
1985	-	-	-	-	-	-	-	0.0074	0.0010	0.008	0.0039	0.0015	0.078	0.12
1986	-	-	-	-	-	-	-	0.0011	0.0001	0.002	0.0011	0.0004	0.0053	0.0081

Table 10 (continued)

Year	Annual deposition (PBq) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
Northern hemisphere (continued)														
1987	-	-	-	-	-	-	-	0.0002	-	0.0004	0.0003	0.0001	0.0023	0.0035
1988	-	-	-	-	-	-	-	-	-	-	-	-	0.0011	0.0016
1989	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0008
1990	-	-	-	-	-	-	-	-	-	-	-	-	0.0003	0.0005
1991	-	-	-	-	-	-	-	-	-	-	-	-	0.0002	0.0003
1992	-	-	-	-	-	-	-	-	-	-	-	-	0.0001	0.0002
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0001
1994	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-		-	-	-	-	-	-
Total	4 000	7 500	6 000	7 500	4 300	6 000	7 500	9 560	1 144	4 892	446	797	474	706
Southern hemisphere														
1945	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1946	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1947	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1948	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1949	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1950	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1951	0.004	0.024	0.043	0.12	0.077	0.12	0.088	0.071	0.003	0.061	0.004	0.001	0.004	0.006
1952	4.33	7.72	2.73	6.04	2.99	4.14	2.75	1.12	0.009	0.92	0.059	0.004	0.051	0.077
1953	3.07	5.41	2.16	5.31	3.37	5.60	4.27	8.88	0.61	8.19	0.70	0.373	0.71	1.065
1954	1.39	9.48	24.51	73.2	51.5	85.1	62.4	66.5	3.21	59.0	4.55	1.72	4.38	6.57
1955	0.0001	-	0.116	0.74	1.23	3.15	2.97	33.2	1.69	35.1	3.89	1.44	4.55	6.83
1956	28.2	62.5	47.0	90.4	50.8	75.1	68.8	53.0	5.13	39.0	3.92	2.85	4.70	7.05
1957	251	442	273	343	172	240	282	140	10.5	73.0	5.91	5.39	6.34	9.51
1958	147	273	218	278	150	218	270	169	15.0	82.4	6.48	7.58	9.45	14.2
1959	0.0007	0.045	1.84	4.06	4.27	8.85	12.9	61.4	6.24	37.4	4.00	4.78	6.84	10.3
1960	0.0000	0.000	0.002	0.010	0.035	0.13	0.28	22.4	2.42	16.0	2.46	3.01	6.22	9.34
1961	0.012	0.060	0.16	0.212	0.13	0.19	0.27	7.79	0.88	6.39	1.43	1.80	6.44	9.66
1962	642	1 160	921	1 060	554	791	1 070	550	43.1	231	16.1	20.2	9.75	14.6
1963	0.0056	0.095	4.87	11.2	13.1	28.0	47.5	206	22.8	102	10.1	17.0	11.4	17.1
1964	0.0000	0.000	0.007	0.040	0.14	0.52	1.21	74.0	9.96	44.2	6.41	12.3	15.6	23.4
1965	0.0001	0.001	0.002	0.004	0.003	0.010	0.027	22.1	3.40	16.0	3.47	7.04	13.2	19.8
1966	74.0	130	58.3	102	50.9	70.6	60.1	30.8	1.78	20.8	2.66	3.76	7.66	11.5
1967	13.9	30.0	35.2	44.2	25.3	37.8	50.9	34.6	1.42	16.3	1.78	2.02	4.07	6.11
1968	14.09	40.8	68.9	87.5	51.1	76.9	107	75.8	3.42	33.2	2.74	2.25	3.76	5.65
1969	0.003	0.091	4.33	8.37	7.98	15.5	24.9	74.5	4.84	36.2	3.49	3.40	5.21	7.82
1970	40.5	81.7	88.9	109	62.1	92.7	129	102	6.73	46.2	4.04	4.16	4.74	7.11
1971	21.2	44.2	50.6	62.8	36.6	55.8	78.5	81.2	5.50	37.9	3.48	3.68	5.56	8.34

Table 10 (continued)

Year	Annual deposition (PBq) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
Southern hemisphere (continued)														
1972	3.58	6.22	5.37	6.95	4.57	7.65	11.5	30.8	2.25	15.8	1.81	1.95	3.55	5.32
1973	11.0	23.4	25.0	30.0	16.4	23.9	32.7	22.9	1.37	10.7	1.09	1.06	1.13	1.70
1974	44.5	82.1	66.4	76.1	39.6	56.4	76.1	43.7	1.37	19.1	1.52	0.92	1.45	2.17
1975	0.0005	0.029	1.03	1.89	1.69	3.16	5.00	14.6	0.77	7.31	0.78	0.64	1.27	1.90
1976	0.0003	0.001	0.001	0.003	0.006	0.021	0.048	2.80	0.17	1.73	0.28	0.25	0.77	1.15
1977	0.0000	-	0.041	0.11	0.135	0.30	0.51	2.25	0.16	1.21	0.17	0.16	0.81	1.22
1978	0.0000	-	-	0.001	0.004	0.015	0.033	1.45	0.11	0.86	0.13	0.14	0.67	1.01
1979	0.0000	-	-	0.000	0.000	0.000	0.001	0.54	0.045	0.38	0.08	0.08	0.39	0.59
1980	0.0007	0.003	0.005	0.006	0.003	0.005	0.007	0.15	0.014	0.13	0.040	0.042	0.39	0.59
1981	-	-	0.010	0.024	0.032	0.071	0.12	0.56	0.013	0.29	0.039	0.024	0.29	0.43
1982	-	-	-		0.0023	0.0068	0.14	0.35	0.0078	0.19	0.029	0.013	0.22	0.33
1983	-	-	-	-	-	-	0.0003	0.11	0.0026	0.075	0.015	0.0060	0.19	0.28
1984	-	-	-	-	-	-	-	0.026	0.0006	0.021	0.0062	0.0023	0.11	0.17
1985	-	-	-	-	-	-	-	0.0005	0.0001	0.0050	0.0022	0.0008	0.052	0.077
1986	-	-	-	-	-	-	-	0.0009	-	0.0012	0.0008	0.0003	0.0036	0.0055
1987	-	-	-	-	-	-	-	0.0001	-	0.0002	0.0002	0.0001	0.0017	0.0026
1988	-	-	-	-	-	-	-	-	-	-	-	-	0.0008	0.0012
1989	-	-	-	-	-	-	-	-	-	-	-	-	0.0004	0.0006
1990	-	-	-	-	-	-	-	-	-	-	-	-	0.0002	0.0004
1991	-	-	-	-	-	-	-	-	-	-	-	-	0.0001	0.0002
1992	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0001
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	--	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1 300	2 400	1 900	2 400	1 300	1 900	2 400	1 934	155	998	94	110	142	213
World														
1945	13.6	24.3	15.8	18.2	9.23	11.9	14.0	6.95	0	3.19	0.20	0	0.18	0.26
1946	9.82	17.2	10.3	12.6	6.39	8.24	9.20	4.70	0	2.28	0.15	0	0.13	0.19
1947	-	-	0.004	0.011	0.011	0.019	0.023	0.050	0	0.029	0.002	0	0.002	0.003
1948	15.9	28.0	10.0	20.6	10.4	13.5	8.91	4.48	0	3.67	0.24	0	0.20	0.30
1949	3.34	5.95	2.15	4.40	2.23	2.86	1.89	0.93	0	0.76	0.049	0	0.042	0.062
1950	-	-	0.009	0.028	0.023	0.038	0.028	0.040	0	0.035	0.003	0	0.002	0.004
1951	96.5	171	88.8	125	62.8	80.7	76.9	37.1	0.25	21.2	1.35	0.10	1.16	1.74
1952	94.9	172	109	129	65.4	84.4	95.0	46.1	2.40	22.3	1.43	0.96	1.23	1.84
1953	72.6	134	100	149	87.8	125	122	112	6.41	80.5	6.06	3.26	5.71	8.57
1954	145	331	265	510	304	435	346	298	15.3	242	18.3	7.80	17.4	26.1
1955	70.1	127	71.6	98.5	56.8	83.6	82.5	227	10.8	217	21.6	7.95	24.0	35.9
1956	331	618	347	579	314	426	391	317	26.3	217	20.0	14.1	22.6	33.9

Table 10 (continued)

Year	*Annual deposition (PBq)* [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
1957	529	953	685	777	406	554	702	495	35.6	259	22.1	20.0	24.0	36.0
1958	1 110	2 050	1 330	1 820	972	1 310	1 410	960	72.7	500	37.0	36.2	32.7	49.1
1959	0.25	5.35	81.0	132	113	191	277	633	58.6	336	37.0	36.2	45.8	68.6
1960	10.4	18.4	6.67	13.7	7.23	9.98	8.12	120	12.3	81.3	11.1	13.4	15.9	23.9
1961	395	740	593	619	319	414	548	305	19.9	136	11.9	12.7	19.4	29.2
1962	1 900	3 470	2 880	3 170	1 720	2 370	3 220	2 340	342	1 010	73.4	178	63.2	94.8
1963	40.7	124	440	638	514	853	1 310	3 030	430	1 420	122	282	108	163
1964	3.04	5.39	2.07	4.80	4.99	12.2	22.8	865	141	491	63.0	150	76.9	115
1965	11.0	19.7	14.5	15.0	7.71	10.0	13.3	184	31.3	126	24.3	57.3	41.8	62.7
1966	121	212	119	165	83.0	112	115	88.1	8.22	56.5	10.5	20.9	19.8	29.7
1967	32.4	67.1	73.9	87.9	50.6	72.9	99.3	79.7	4.50	38.7	5.33	8.36	10.3	15.5
1968	17.1	47.5	76.8	97.5	58.5	89.1	126	135	7.24	62.1	6.00	6.28	11.0	16.5
1969	11.4	33.8	73.2	94.3	63.8	97.5	142	217	15.9	101	8.95	9.87	10.7	16.0
1970	46.4	98.5	122	153	92.8	141	199	247	15.3	115	10.4	9.99	12.4	18.5
1971	24.4	50.5	68.6	92.4	60.7	95.4	138	223	13.4	106	9.94	9.15	12.5	18.8
1972	33.9	60.7	46.5	50.2	27.3	37.7	51.7	85.7	4.49	43.9	4.99	4.30	6.74	10.1
1973	13.4	30.2	38.4	46.4	26.8	39.0	54.0	49.1	3.11	23.7	2.60	2.48	2.31	3.47
1974	64.7	119	95.8	108	58.2	82.9	114	106	5.92	48.2	4.18	3.73	5.91	8.86
1975	0.001	0.039	1.61	2.98	2.82	5.28	8.46	34.8	2.29	18.0	2.04	1.98	3.42	5.13
1976	34.0	63.0	45.2	48.2	24.4	31.3	39.6	25.4	0.79	12.1	1.21	0.81	1.77	2.66
1977	6.71	15.3	36.5	49.5	35.8	55.7	82.1	124	8.40	55.6	4.45	4.58	3.82	5.73
1978	5.53	9.23	3.04	6.10	3.20	4.39	3.73	33.6	2.46	18.8	2.19	2.26	4.37	6.56
1979	0.47	1.45	0.92	2.00	1.08	1.45	0.98	6.94	0.53	4.77	0.82	0.84	1.55	2.33
1980	35.6	65.4	49.7	51.0	25.9	33.3	43.9	22.4	0.44	9.60	0.82	0.42	1.50	2.25
1981	0.023	0.518	6.88	10.4	8.22	13.3	19.9	32.6	0.59	14.7	1.22	0.39	1.93	2.90
1982	-	-	-	-	0.013	0.045	0.22	3.39	0.12	1.88	0.25	0.090	0.69	1.04
1983	-	-	-		-	-	0.001	0.48	0.026	0.33	0.07	0.025	0.52	0.78
1984	-	-	-	-	-	-	-	0.077	0.005	0.064	0.02	0.008	0.39	0.58
1985	-	-	-	-	-	-	-	0.008	0.001	0.013	0.006	0.002	0.13	0.19
1986	-	-	-	-	-	-	-	0.002	0.0001	0.003	0.002	0.001	0.0089	0.014
1987	-	-	-	-	-	-	-	0.0003	-	0.0002	0.0005	0.0001	0.0039	0.0060
1988	-	-	-	-	-	-	-	-	-	-	0.0002	-	0.0019	0.0029
1989	-	-	-	-	-	-	-	-	-	-	-	-	0.0010	0.0015
1990	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0008
1991	-	-	-	-	-	-	-	-	-	-	-	-	0.0003	0.0005
1992	-	-	-	-	-	-	-	-	-	-	-	-	0.0002	0.0003
1993	-	-	-	-	-	-	-	-	-	-	-	-	0.0001	0.0002
1994	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0001
1995	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	-	-		-	-		-	-	-	-	-	-	-	-
Total	5 300	9 900	7 900	9 900	5 600	7 900	9 900	11 494	1 299	5 890	540	907	612	919

a Derived from estimated fission/fusion yields of tests with atmospheric model. Measured results used preferentially for ^{90}Sr and ^{137}Cs during 1958-1985. Model values for ^{131}I, ^{144}Ba, ^{141}Ce, ^{103}Ru, ^{89}Sr, ^{91}Y, and ^{95}Zr normalized to total hemispheric deposition estimated from available measurements. Latitudinal distributions for long-lived radionuclides may be estimated by use of parameters in Table 8.

b Indicates estimated value less than 0.0001 PBq.

Table 11
Population-weighted cumulative deposition density of radionuclides produced in atmospheric nuclear testing

Year	Cumulative deposition density ($Bq\ m^{-2}$) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
Northern hemisphere														
1945	1.73	4.92	7.53	9.99	5.96	8.33	10.2	8.70	0.00	4.17	0.28	0.00	0.25	0.38
1946	1.17	3.31	5.28	7.84	5.27	7.99	10.1	21.7	0.00	11.4	0.96	0.00	0.96	1.44
1947	- [b]	-	0.22	0.61	0.72	1.43	1.96	17.0	0.00	10.4	1.15	0.00	1.36	2.05
1948	1.94	5.49	5.02	12.3	7.80	11.3	8.04	16.2	0.00	13.2	1.46	0.00	1.85	2.78
1949	0.43	1.21	1.02	2.51	1.73	2.76	2.10	12.1	0.00	11.8	1.58	0.00	2.25	3.39
1950	-	-	0.15	0.52	0.51	0.91	0.73	6.99	0.00	7.83	1.38	0.00	2.35	3.54
1951	12.2	33.7	36.9	63.1	38.5	54.7	51.3	57.2	0.49	39.5	3.61	0.23	4.62	6.95
1952	11.2	29.6	41.1	55.9	36.0	53.6	67.3	128	1.30	77.8	7.41	0.69	8.99	13.5
1953	9.33	30.6	70.9	119	87.5	139	155	362	20.2	251	23.	11.5	25.9	38.9
1954	18.2	65.0	121	261	187	289	255	637	36.2	526	52.7	25.8	61.4	92.2
1955	8.70	23.5	27.6	56.1	50.6	96.0	95.1	982	52.0	976	116	48.7	146	219
1956	38.0	111	151	285	186	276	276	1 050	68.4	1 020	152	71.1	222	333
1957	33.5	96.1	182	235	165	261	358	1 340	104	1 090	175	106	281	423
1958	121	356	522	869	568	845	944	2 340	179	1 570	234	172	368	554
1959	4.06	17.2	135	249	237	429	605	3 460	290	2 240	322	280	535	805
1960	1.31	3.69	3.57	9.38	8.97	20.0	30.6	2 100	197	1 560	306	288	604	910
1961	49.8	141	200	225	126	169	229	1 150	109	959	262	253	634	955
1962	155	449	896	1 140	774	1 180	1 730	3 940	625	2 100	341	548	795	1 200
1963	10.2	51.6	434	710	667	1 200	1 950	10 300	1 560	5 290	665	1 390	1 140	1 710
1964	0.38	1.05	1.75	7.18	19.4	60.8	133	8 740	1 430	5 250	849	1 890	1 480	2 220
1965	1.40	4.04	7.70	10.1	6.70	10.7	16.3	4 660	825	3 390	801	1 810	1 620	2 440
1966	5.39	15.3	28.0	34.4	22.0	32.1	45.8	2 170	407	1 910	673	1 530	1 670	2 520
1967	2.57	8.05	21.3	28.7	20.9	33.0	49.3	1 040	193	1 050	543	1 230	1 670	2 520
1968	0.65	2.02	5.53	8.78	8.68	16.7	28.0	619	98.8	633	435	972	1 660	2 510
1969	1.46	6.63	30.6	45.3	37.1	62.1	95.8	582	70.0	483	355	777	1 650	2 490
1970	0.74	3.23	16.8	27.1	25.5	46.6	76.3	693	61.5	475	301	629	1 640	2 480
1971	0.39	1.43	14.2	25.3	24.9	46.0	75.0	749	54.5	482	260	512	1 630	2 480
1972	3.88	11.3	21.8	28.3	19.4	30.4	44.3	566	37.1	388	221	412	1 620	2 460
1973	0.30	1.37	6.03	8.40	6.27	10.0	15.2	308	20.6	241	179	326	1 590	2 410
1974	2.58	7.35	15.3	20.5	15.6	25.9	40.2	302	21.9	211	148	263	1 560	2 380
1975	0.00	0.00	0.89	2.03	2.64	5.58	9.86	235	18.4	167	121	213	1 540	2 350
1976	4.08	11.4	15.2	18.3	10.4	14.3	18.0	134	10.2	107	98.6	168	1 510	2 300
1977	0.96	4.05	25.5	40.2	35.2	60.6	94.8	350	23.1	193	88.9	142	1480	2 260
1978	0.57	1.43	1.94	4.31	3.95	7.85	12.2	340	24.4	205	81.6	124	1470	2 240
1979	0.19	0.75	0.91	2.32	1.59	2.48	2.02	184	14.2	134	68.5	101	1 440	2 200
1980	4.50	12.6	16.6	18.3	9.94	13.2	17.8	94.4	7.14	78.7	55.1	80.4	1 410	2 160
1981	0.03	0.78	12.5	19.9	17.1	29.1	45.2	168	5.51	100	48.3	64.2	1 380	2 120
1982	-	-	0.005	0.032	0.11	0.39	0.165	69.0	2.45	50.8	37.4	49.9	1 350	2 080
1983	-	-	-	0.0001	0.001	0.005	0.0006	28.4	1.09	25.7	29.0	38.7	1 320	2 040
1984	-	-	-	-	-	-	-	11.7	0.48	13.0	22.5	30.1	1 290	1 990
1985	-	-	-	-	-	-	-	4.80	0.22	6.58	17.5	23.4	1 260	1 950
1986	-	-	-	-	-	-	-	1.97	0.10	3.33	13.6	18.1	1 230	1 900

Table 11 (continued)

Year	Cumulative deposition density (Bq m⁻²) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
Northern hemisphere (continued)														
1987	-	-	-	-	-	-	-	0.81	0.043	1.68	10.5	14.1	1 200	1 860
1988	-	-	-	-	-	-	-	0.33	0.019	0.85	8.16	10.9	1 170	1 820
1989	-	-	-	-	-	-	-	0.14	0.0084	0.43	6.33	8.49	1 150	1 780
1990	-	-	-	-	-	-	-	0.057	0.0038	0.22	4.91	6.60	1 120	1 740
1991	-	-	-	-	-	-	-	0.023	0.0017	0.11	3.81	5.12	1 090	1 700
1992	-	-	-	-	-	-	-	0.010	0.0007	0.056	2.96	3.98	1 070	1 660
1993	-	-	-	-	-	-	-	0.0039	0.0003	0.028	2.29	3.09	1 040	1 620
1994	-	-	-	-	-	-	-	0.0016	0.0001	0.014	1.78	2.40	1 020	1 580
1995	-	-	-	-	-	-	-	0.0007	0.0001	0.0072	1.38	1.86	991	1 550
1996	-	-	-	-	-	-	-	0.0003	-	0.0037	1.07	1.45	967	1 510
1997	-	-	-	-	-	-	-	0.0001	-	0.0019	0.83	1.12	944	1 480
1998	-	-	-	-	-	-	-	-	-	0.0009	0.64	0.87	921	1 440
1999	-	-	-	-	-	-	-	-	-	0.0005	0.50	0.68	899	1 410
Total [c]														
1945-1999	510	1 520	3 080	4 660	3 440	5 560	7 590	50 000	6 560	33 300	8 160	14 600	52 900	81 000
2000-2099										0.0003	1.75	2.3	33 900	55 300
2100-2199													3 000	5 550
2200-∞													292	620
1945-∞	510	1 520	3 080	4 660	3 440	5 560	7 590	50 000	6 560	33 300	8 160	14 600	90 000	142 000
Southern hemisphere														
1945	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1946	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1947	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1948	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1949	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1950	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1951	0.0009	0.008	0.029	0.095	0.073	0.12	0.093	0.072	0.003	0.064	0.005	0.001	0.004	0.007
1952	0.92	2.53	1.44	3.47	1.89	2.75	1.87	0.76	0.009	0.66	0.049	0.006	0.047	0.070
1953	0.65	1.83	1.70	5.09	4.03	7.43	5.95	11.5	0.66	10.8	0.97	0.43	1.01	1.51
1954	0.30	3.29	17.3	59.6	49.5	88.8	68.3	85.9	4.58	81.4	7.42	3.12	7.92	11.9
1955	-	0.001	1.09	7.01	11.6	29.1	27.0	175	9.1	186	21.1	8.19	25.4	38.1
1956	5.97	20.9	31.4	69.4	46.0	74.1	71.5	168	11.5	188	29.0	12.5	41.8	62.8
1957	50.1	137	163	248	155	246	296	289	23.8	232	36.1	21.5	57.0	85.7
1958	31.5	96.1	169	253	170	281	380	484	41.6	320	49.0	37.5	84.5	127
1959	0.85	3.23	25.1	51.2	50.4	101.1	151	540	50.9	358	58.9	53.3	117	177
1960	-	-	0.017	0.13	0.57	2.26	4.76	314	32.8	248	55.5	53.7	137	206
1961	0.002	0.02	0.059	0.080	0.055	0.12	0.24	165	18.7	155	49.6	49.9	156	235
1962	135	389	642	861	541	847	1 210	717	57.4	364	61.8	66.4	185	278
1963	0.006	0.17	31.3	78.5	99.6	221	382	1 290	118	672	94.9	118	219	330

Table 11 (continued)

Year	Cumulative deposition density (Bq m^{-2}) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
Southern hemisphere (continued)														
1964	-	-	0.067	0.46	1.84	7.16	17.0	867	94.5	539	102	142	262	394
1965	-	-	0.002	0.0041	0.023	0.16	0.52	470	58.9	353	95.9	144	313	472
1966	15.6	43.1	35.2	67.2	37.9	56.0	51.6	245	32.4	218	83.9	130	341	514
1967	2.96	10.7	31.4	57.8	43.4	74.9	88.4	188	18.2	167	730	110	355	536
1968	2.99	13.6	39.8	57.0	39.3	65.4	96.8	178	12.4	134	62.5	91.5	359	542
1969	0.00	0.25	15.1	31.2	32.3	65.2	107	313	18.7	186	60.4	81.3	368	557
1970	8.59	27.6	58.6	81.6	53.8	86.9	127	305	20.3	187	57.8	74.1	377	571
1971	4.54	15.0	38.9	60.7	48.3	87.7	137	375	26.7	220	58.3	71.8	388	587
1972	0.73	2.08	8.12	15.3	15.3	31.0	51.7	306	22.8	191	54.8	65.9	396	601
1973	2.33	7.86	17.0	23.5	15.3	24.7	36.0	180	13.9	127	46.9	55.8	395	599
1974	9.46	27.7	44.1	58.6	36.9	58.6	84.7	147	9.49	99	40.2	46.4	389	591
1975	0.0014	0.120	6.84	13.9	13.9	27.7	45.3	150	7.49	95	35.8	39.0	386	587
1976	-	-	0.005	0.036	0.15	0.57	1.33	79.9	4.42	59.1	29.5	31.8	380	578
1977	-	-	0.028	0.084	0.13	0.31	0.56	37.8	2.31	33.2	23.6	25.3	374	570
1978	-	-	0.002	0.011	0.033	0.11	0.24	20.4	1.40	19.7	18.8	20.1	368	561
1979	-	-	-	0.000	0.0006	0.0036	0.0113	11.0	0.83	11.8	14.9	16.0	361	551
1980	0.0001	0.001	0.002	0.002	0.0011	0.0017	0.0026	5.32	0.44	6.63	11.8	12.7	353	541
1981	-	-	0.009	0.023	0.033	0.0780	0.1400	2.93	0.23	3.83	9.26	9.93	346	530
1982	-	-		-	-	0.0010	0.0005	1.20	0.10	1.94	7.19	7.71	339	520
1983	-	-	-	-	-	-	-	0.50	0.045	0.98	5.57	5.99	331	509
1984	-	-	-	-	-	-	-	0.20	0.020	0.50	4.32	4.65	324	498
1985	-	-	-	-	-	-	-	0.084	0.0089	0.25	3.36	3.61	317	487
1986	-	-	-	-	-	-	-	0.035	0.0040	0.13	2.60	2.80	309	476
1987	-	-	-	-	-	-	-	0.014	0.0018	0.064	2.02	2.18	302	466
1988	-	-	-	-	-	-	-	0.0058	0.0008	0.033	1.57	1.69	294	455
1989	-	-	-	-	-	-	-	0.0024	0.0003	0.017	1.22	1.31	287	445
1990	-	-	-	-	-	-	-	0.0010	0.0002	0.0083	0.94	1.02	281	435
1991	-	-	-	-	-	-	-	0.0004	0.0001	0.0042	0.73	0.79	274	425
1992	-	-	-	-	-	-	-	0.0002	-	0.0021	0.57	0.61	267	415
1993	-	-	-	-	-	-	-	0.0001	-	0.0011	0.44	0.48	261	406
1994	-	-	-	-	-	-	-	-	-	0.0005	0.34	0.37	255	396
1995	-	-	-	-	-	-	-	-	-	0.0003	0.27	0.29	249	387
1996	-	-	-	-	-	-	-	-	-	0.0001	0.21	0.22	243	379
1997	-	-	-	-	-	-	-	-	-	-	0.16	0.17	237	370
1998	-	-	-	-	-	-	-	-	-	-	0.12	0.13	231	362
1999	-	-	-	-	-	-	-	-	-	-	0.10	0.10	226	353
Total [c]														
1945-1999	273	808	1 380	2 100	1 470	2 490	7 130	8 120	714	5 470	1 380	1 630	12 600	19 200
2000-2099											0.40	0.30	8 480	13 400
2100-2199													752	1 390
2200-∞													73	155
1945-∞	273	808	1 380	2 100	1 470	2 490	7 130	8 120	714	5 470	1 380	1 630	21 900	35 000

Table 11 (continued)

Year	*Cumulative deposition density (Bq m⁻²)* [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
World														
1945	1.54	4.38	6.70	8.89	5.31	7.41	9.06	7.74	-	3.71	0.25	-	0.22	0.33
1946	1.04	2.94	4.70	6.98	4.69	7.11	8.99	19.3	-	10.1	0.85	-	0.86	1.28
1947	-	-	0.20	0.54	0.64	1.27	1.74	15.1	-	9.24	1.03	-	1.21	1.82
1948	1.73	4.89	4.47	10.9	6.94	10.1	7.15	14.4	-	11.7	1.30	-	1.65	2.47
1949	0.38	1.07	0.91	2.24	1.54	2.45	1.87	10.8	-	10.5	1.40	-	2.01	3.02
1950	-	-	0.13	0.47	0.45	0.81	0.65	6.22	-	6.97	1.23	-	2.09	3.15
1951	10.9	30.0	32.9	56.1	34.2	48.7	45.7	50.9	0.44	35.2	3.22	0.21	4.11	6.19
1952	10.0	26.6	36.8	50.1	32.3	48.0	60.1	114	1.16	69.3	6.60	0.61	8.01	12.0
1953	8.38	27.4	63.3	107	78.3	124	139	323	18.0	224	20.7	10.3	23.2	34.8
1954	16.3	58.2	110	239	172	267	234	576	32.7	477	47.7	23.3	55.5	83.4
1955	7.74	20.9	24.7	50.7	46.3	88.7	87.6	893	47.2	889	106	44.3	133	199
1956	34.5	101	138	261	171	254	253	949	62.2	926	139	64.6	202	304
1957	35.3	101	180	236	164	259	352	1 230	95.0	992	160	96.7	257	386
1958	111	327	483	802	525	782	882	2 130	164	1 428	214	157	337	507
1959	3.71	15.7	123	228	216	393	555	3 140	263	2 030	293	255	489	736
1960	1.17	3.29	3.18	8.36	8.05	18.0	27.8	1 900	179	1 420	278	262	553	833
1961	44.3	125	178	200	112	151	204	1 040	99.5	871	239	230	581	876
1962	153	443	868	1 110	748	1 140	1 670	3 590	562	1 900	311	495	728	1 100
1963	9.11	45.9	390	641	604	1 090	1 770	9 290	1 400	4 780	602	1 250	1 040	1 560
1964	0.34	0.93	1.56	6.44	17.5	54.9	120	7 870	1 280	4 730	767	1 690	1 340	2 020
1965	1.25	3.60	6.86	8.95	5.97	9.58	14.6	4 200	741	3 060	723	1630	1 480	2 230
1966	6.51	18.4	28.8	38.0	23.7	34.8	46.4	1 960	366	1 720	608	1 370	1 520	2 300
1967	2.62	8.34	22.5	31.9	23.4	37.6	53.6	942	174	954	491	1 100	1 520	2 300
1968	0.91	3.29	9.30	14.1	12.1	22.0	35.6	570	89.3	578	394	875	1 520	2 290
1969	1.30	5.93	28.9	43.8	36.5	62.4	97.1	553	64.3	450	323	700	1 510	2 280
1970	1.60	5.91	21.4	33.1	28.6	51.1	81.9	650	57.0	444	274	568	1 500	2 270
1971	0.84	2.92	17.0	29.2	27.5	50.6	81.9	708	51.4	453	238	463	1 500	2 270
1972	3.53	10.3	20.3	26.9	19.0	30.4	45.2	538	35.5	366	202	374	1 480	2 250
1973	0.52	2.08	7.24	10.1	7.26	11.7	17.5	294	19.9	229	164	296	1 460	2 210
1974	3.34	9.59	18.5	24.7	17.9	29.5	45.1	285	20.6	198	137	239	1 430	2 180
1975	0.00	0.02	1.54	3.33	3.89	8.01	13.8	225	17.2	159	113	194	1 410	2 150
1976	3.63	10.1	13.6	16.3	9.29	12.8	16.2	128	9.59	102	91.0	153	1 380	2 110
1977	0.86	3.61	22.7	35.8	31.3	54.0	84.5	316	20.8	176	81.7	129	1 360	2 080
1978	0.51	1.27	1.73	3.84	3.51	7.00	10.9	305	21.9	185	74.7	112	1 340	2 060
1979	0.17	0.67	0.81	2.06	1.41	2.21	1.79	165	12.7	121	62.6	91.8	1 320	2 020
1980	4.00	11.2	14.8	16.2	8.84	11.8	15.8	84.6	6.41	70.8	50.3	72.9	1 290	1 980
1981	0.029	0.70	11.2	17.7	15.3	25.9	40.3	150	4.92	89.7	44.0	58.3	1 270	1 950
1982	-	-	0.0046	0.0280	0.102	0.34	0.15	61.5	2.19	45.4	34.1	45.3	1 240	1 910
1983	-	-	-	-	0.0007	0.0045	0.0005	25.3	0.97	23.0	26.5	35.1	1 210	1 870
1984	-	-	-	-	-	-	-	10.4	0.43	11.6	20.5	27.3	1 190	1 830
1985	-	-	-	-	-	-	-	4.28	0.19	5.88	15.9	21.2	1 160	1 790
1986	-	-	-	-	-	-	-	1.76	0.086	2.98	12.4	16.5	1 130	1 750

Table 11 (continued)

Year	Cumulative deposition density (Bq m^{-2}) [a]													
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs
World (continued)														
1987	-	-	-	-	-	-	-	0.72	0.038	1.51	9.58	12.8	1 100	1 710
1988	-	-	-	-	-	-	-	0.30	0.017	0.76	7.44	9.92	1 080	1 670
1989	-	-	-	-	-	-	-	0.120	0.0076	0.39	5.77	7.70	1 050	1 630
1990	-	-	-	-	-	-	-	0.050	0.0034	0.20	4.48	5.98	1 030	1 590
1991	-	-	-	-	-	-	-	0.021	0.0015	0.10	3.47	4.65	1 000	1 560
1992	-	-	-	-	-	-	-	0.0085	0.0007	0.050	2.69	3.61	978	1 520
1993	-	-	-	-	-	-	-	0.0035	0.0003	0.025	2.09	2.80	954	1 490
1994	-	-	-	-	-	-	-	0.0014	0.0001	0.013	1.62	2.18	932	1 450
1995	-	-	-	-	-	-	-	0.0006	0.0001	0.0065	1.26	1.69	909	1 420
1996	-	-	-	-	-	-	-	-	-	0.0033	0.98	1.31	887	1 390
1997	-	-	-	-	-	-	-	-	-	0.0017	0.76	1.02	866	1 360
1998	-	-	-	-	-	-	-	-	-	0.0008	0.59	0.79	845	1 330
1999	-	-	-	-	-	-	-	-	-	0.0004	0.46	0.61	825	1 300
Total [c]														
1945-1999	482	1 440	2 900	4 380	3 220	5 220	7 130	45 400	5 920	30 300	7 420	13 200	48 440	74 100
2000-2099										0.0007	1.8	2.1	31 000	50 700
2100-2199													2 750	5 090
2200-∞													268	569
1945-∞	482	1 440	2 900	4 380	3 220	5 220	7 130	45 400	5 920	30 300	7 420	13200	83 000	131 000

a Derived from estimated fission/fusion yields of tests with atmospheric model. Includes residual deposition from previous years. Measured results used preferentially for ^{90}Sr and ^{137}Cs during 1958-1985. Latitudinal values may be derived by use of parameters in Table 8. The results for the world are the population-weighted averages of the northern and southern hemispheres (89% and 11% of the world population, respectively).

b Indicates estimated value less than 0.0001 Bq m^{-2}.

c Integrated deposition density with units Bq a m^{-2}.

Table 12
Coefficients for evaluating annual effective doses from radionuclides produced in atmospheric nuclear testing

Radionuclide	*Dose coefficient (nSv a⁻¹ per Bq m⁻²)*		
	External [a]	*Ingestion* [b]	*Inhalation* [c]
^{131}I	3.28	133	0.17
^{140}Ba	18.5 [d]	0.357	0.014
^{141}Ce	0.376	–	0.034
^{103}Ru	2.72	–	0.033
^{89}Sr	–	0.601	0.16
^{91}Y	–	–	0.18
^{95}Zr	11.3 [d]	–	0.104
^{144}Ce	0.175 [d]	–	1.30
^{54}Mn	3.26	–	0.022
^{106}Ru	0.809 [d]	–	1.70
^{125}Sb	1.64	–	0.045
^{55}Fe	–	0.506	0.0043
^{90}Sr	–	– [e]	4.60
^{137}Cs	2.24	– [e]	0.11
^{238}Pu	–	–	800
^{239}Pu	–	–	840
^{240}Pu	–	–	840
^{241}Pu	–	–	12
^{241}Am	–	–	920

a Values from Beck [B2], converted with 0.869 rad R^{-1}, 0.01 Gy rad^{-1}, 0.7 Sv Gy^{-1} and applying a shielding/occupancy factor of 0.36. Relaxation length of 0.1 cm assumed for ^{131}I and ^{140}Ba, 1 cm for ^{141}Ce, ^{103}Ru and ^{95}Zr; 3 cm for remainder.
b Transfer coefficient P_{25} [U3 (page 127)] divided by the mean life of the radionuclide ($T_{½}$ divided by ln 2) applied to the average cumulative deposition.
c Transfer coefficient P_{25} [U3 (page 127)] applied to the annual deposition density (nSv per Bq m^{-2}). The exposure occurs only in the year of deposition.
d Includes decay product.
e Time-dependent model used for components of annual dose.

Table 13
External exposure to radionuclides produced in atmospheric nuclear testing

Year	*Worldwide average annual effective dose (μSv)*										
	^{131}I	$^{140}Ba,La$	^{141}Ce	^{103}Ru	$^{95}Zr,Nb$	$^{144}Ce,Pr$	^{54}Mn	$^{106}Ru,Rh$	^{125}Sb	^{137}Cs	*Total*
1945	0.0051	0.081	0.0025	0.02	0.10	0.0014	-	0.0030	0.0004	0.0007	0.22
1946	0.0034	0.055	0.0018	0.02	0.10	0.0034	-	0.0082	0.0014	0.0029	0.20
1947	- [a]	-	0.0001	-	0.020	0.0026	-	0.0075	0.0017	0.0041	0.037
1948	0.0057	0.091	0.0017	0.03	0.082	0.0025	-	0.0095	0.0021	0.0055	0.23
1949	0.0012	0.020	0.0003	0.01	0.021	0.0019	-	0.0085	0.0023	0.0068	0.068
1950	-	0.0001	-	-	0.0074	0.0011	-	0.0056	0.0020	0.0071	0.025
1951	0.036	0.56	0.012	0.15	0.52	0.0089	0.0014	0.028	0.0053	0.014	1.34
1952	0.033	0.50	0.014	0.14	0.69	0.020	0.0038	0.056	0.011	0.027	1.48
1953	0.027	0.51	0.024	0.29	1.58	0.057	0.059	0.18	0.034	0.078	2.84
1954	0.053	1.08	0.041	0.65	2.67	0.10	0.11	0.39	0.079	0.19	5.36
1955	0.025	0.39	0.009	0.14	1.00	0.16	0.15	0.72	0.17	0.45	3.21
1956	0.11	1.89	0.052	0.71	2.89	0.17	0.20	0.75	0.23	0.68	7.67
1957	0.12	1.87	0.068	0.64	4.01	0.21	0.31	0.80	0.26	0.86	9.16
1958	0.37	6.09	0.18	2.19	10.1	0.37	0.53	1.15	0.35	1.14	22.4
1959	0.012	0.29	0.046	0.62	6.32	0.55	0.86	1.64	0.48	1.65	12.5
1960	0.0038	0.061	0.0012	0.02	0.32	0.33	0.58	1.15	0.46	1.86	4.79
1961	0.15	2.33	0.067	0.55	2.32	0.18	0.32	0.70	0.39	1.96	8.97
1962	0.50	8.23	0.33	3.03	19.0	0.63	1.83	1.54	0.51	2.46	38.1
1963	0.030	0.85	0.15	1.75	20.2	1.63	4.54	3.86	0.99	3.49	37.5
1964	0.0011	0.017	0.0006	0.018	1.37	1.38	4.17	3.82	1.27	4.53	16.6
1965	0.0041	0.07	0.0026	0.024	0.17	0.74	2.41	2.47	1.19	4.98	12.1
1966	0.021	0.34	0.011	0.10	0.53	0.34	1.19	1.39	1.00	5.15	10.1
1967	0.0086	0.16	0.0084	0.087	0.61	0.16	0.56	0.77	0.81	5.16	8.34
1968	0.0030	0.06	0.0035	0.038	0.41	0.10	0.29	0.47	0.65	5.13	7.15
1969	0.0043	0.11	0.011	0.12	1.11	0.10	0.21	0.36	0.53	5.11	7.66
1970	0.0053	0.11	0.0081	0.090	0.93	0.11	0.19	0.36	0.45	5.09	7.35
1971	0.0028	0.054	0.0064	0.080	0.93	0.12	0.17	0.37	0.39	5.08	7.21
1972	0.012	0.19	0.0076	0.073	0.51	0.094	0.12	0.30	0.33	5.04	6.68
1973	0.0017	0.039	0.0027	0.027	0.20	0.051	0.065	0.18	0.27	4.96	5.80
1974	0.011	0.18	0.0069	0.067	0.51	0.050	0.067	0.16	0.23	4.89	6.17
1975	-	0.0003	0.0006	0.009	0.16	0.039	0.056	0.13	0.19	4.83	5.40
1976	0.012	0.19	0.0051	0.045	0.18	0.022	0.031	0.08	0.15	4.73	5.45
1977	0.0028	0.067	0.0085	0.098	0.96	0.055	0.068	0.14	0.13	4.65	6.19
1978	0.0017	0.024	0.0006	0.010	0.12	0.053	0.071	0.15	0.12	4.60	5.16
1979	0.0006	0.012	0.0003	0.006	0.020	0.029	0.041	0.10	0.10	4.53	4.84

Table 13 (continued)

Year	Worldwide average annual effective dose (µSv)										
	^{131}I	$^{140}Ba,La$	^{141}Ce	^{103}Ru	$^{95}Zr,Nb$	$^{144}Ce,Pr$	^{54}Mn	$^{106}Ru,Rh$	^{125}Sb	^{137}Cs	Total
1980	0.013	0.21	0.0056	0.044	0.18	0.015	0.021	0.057	0.083	4.44	5.07
1981	0.0001	0.013	0.0042	0.048	0.46	0.026	0.016	0.072	0.073	4.36	5.07
1982	-	-	-	-	0.0017	0.011	0.0071	0.037	0.056	4.27	4.39
1983	-	-	-	-	-	0.0044	0.0032	0.019	0.044	4.18	4.25
1984	-	-	-	-	-	0.0018	0.0014	0.0094	0.034	4.09	4.14
1985	-	-	-	-	-	0.0007	0.0006	0.0048	0.026	4.00	4.03
1986	-	-	-	-	-	0.0003	0.0003	0.0024	0.020	3.91	3.93
1987	-	-	-	-	-	0.0001	0.0001	0.0012	0.016	3.82	3.84
1988	-	-	-	-	-	0.0001	0.0001	0.0006	0.012	3.73	3.75
1989	-	-	-	-	-	-	-	0.0003	0.0095	3.65	3.66
1990	-	-	-	-	-	-	-	0.0002	0.0074	3.57	3.57
1991	-	-	-	-	-	-	-	0.0001	0.0057	3.49	3.49
1992	-	-	-	-	-	-	-	-	0.0044	3.41	3.41
1993	-	-	-	-	-	-	-	-	0.0034	3.33	3.33
1994	-	-	-	-	-	-	-	-	0.0027	3.25	3.26
1995	-	-	-	-	-	-	-	-	0.0021	3.18	3.18
1996	-	-	-	-	-	-	-	-	0.0016	3.11	3.11
1997	-	-	-	-	-	-	-	-	0.0012	3.04	3.04
1998	-	-	-	-	-	-	-	-	0.0010	2.97	2.97
1999	-	-	-	-	-	-	-	-	0.0008	2.90	2.90
1945-1999	1.58	26.7	1.09	12.0	81.3	7.94	19.2	24.5	12.2	166	353
2000-2099									0.003	114	114
2100-2199										11.4	11.4
2200-∞										1.3	1.3
1945-∞	1.58	26.7	1.09	12.0	81.3	7.94	19.2	24.5	12.2	292	479

a Estimated value less than 0.0001 µSv.

Table 14
Ingestion exposure to radionuclides produced in atmospheric nuclear testing

Year	Worldwide average annual effective dose (μSv)									
	^{131}I	$^{140}Ba,La$	^{89}Sr	^{55}Fe	^{90}Sr	^{137}Cs	*Total*	^{3}H	^{14}C	*Total*
1945	0.21	0.0016	0.0032	-	0.0044	0.027	0.24	0	0	0
1946	0.14	0.0011	0.0028	-	0.0088	0.040	0.19	0	0	0
1947	- [a]	-	0.0004	-	0.0059	0.016	0.022	0	0	0
1948	0.23	0.0017	0.0042	-	0.0082	0.032	0.28	0	0	0
1949	0.051	0.0004	0.0009	-	0.010	0.031	0.093	0	0	0
1950	-	-	0.0003	-	0.0060	0.0063	0.013	0	0	0
1951	1.45	0.011	0.021	0.0001	0.034	0.18	1.69	-	-	-
1952	1.33	0.010	0.019	0.0003	0.072	0.32	1.75	-	0.06	0.06
1953	1.11	0.010	0.05	0.0052	0.18	0.92	2.28	0.2	0.1	0.3
1954	2.16	0.021	0.10	0.012	0.53	2.69	5.53	0.7	0.3	1.0
1955	1.03	0.0075	0.028	0.022	1.02	4.69	6.80	0.2	0.6	0.8
1956	4.59	0.036	0.10	0.033	1.32	5.25	11.3	0.7	0.8	1.5
1957	4.69	0.036	0.10	0.049	1.46	5.10	11.4	0.6	1.1	1.7
1958	14.8	0.12	0.32	0.079	1.77	6.06	23.2	0.8	1.6	2.4
1959	0.49	0.0056	0.13	0.13	2.50	9.15	12.4	0.8	1.9	2.7
1960	0.16	0.0012	0.0048	0.13	2.45	6.53	9.27	0.4	2.0	2.4
1961	5.89	0.045	0.067	0.12	1.94	3.62	11.7	0.7	2.9	3.6
1962	20.4	0.16	0.45	0.25	3.11	10.3	34.6	7.2	5.5	12.7
1963	1.21	0.016	0.36	0.63	5.58	21.9	29.7	2.7	7.4	10.1
1964	0.046	0.0003	0.010	0.86	6.56	21.8	29.3	1.6	7.7	9.3
1965	0.17	0.0013	0.0036	0.82	5.47	12.7	19.2	1.2	7.5	8.7
1966	0.87	0.0066	0.014	0.69	4.45	6.29	12.3	1.0	7.1	8.1
1967	0.35	0.0030	0.014	0.56	3.83	3.32	8.07	0.8	6.6	7.4
1968	0.12	0.0012	0.0072	0.44	3.57	2.71	6.85	0.6	6.1	6.7
1969	0.17	0.0021	0.022	0.35	3.42	2.57	6.54	0.6	5.5	6.1
1970	0.21	0.0021	0.017	0.29	3.30	2.70	6.51	0.4	5.0	5.4
1971	0.11	0.0010	0.017	0.23	3.22	2.86	6.44	0.4	4.6	5.0
1972	0.47	0.0037	0.011	0.19	3.00	2.17	5.85	0.3	4.3	4.6
1973	0.069	0.0007	0.0044	0.15	2.72	1.33	4.28	0.3	4.0	4.3
1974	0.44	0.0034	0.011	0.12	2.60	1.55	4.73	0.2	3.8	4.0
1975	-	-	0.0023	0.10	2.50	1.57	4.18	0.2	3.5	3.7
1976	0.48	0.0036	0.0056	0.077	2.30	1.10	3.97	0.1	3.3	3.4
1977	0.11	0.0013	0.019	0.065	2.19	1.25	3.64	0.2	3.1	3.3
1978	0.068	0.0005	0.0021	0.057	2.15	1.57	3.85	0.1	2.9	3.0
1979	0.023	0.0002	0.0009	0.046	2.02	1.25	3.33	0.09	2.6	2.7

Table 14 (continued)

Year	Worldwide average annual effective dose (µSv)									
	^{131}I	$^{140}Ba,La$	^{89}Sr	^{55}Fe	^{90}Sr	^{137}Cs	*Total*	^{3}H	^{14}C	*Total*
1980	0.53	0.0040	0.0053	0.037	1.85	0.92	3.35	0.08	2.5	2.6
1981	0.0038	0.0002	0.0092	0.029	1.77	0.98	2.79	0.07	2.5	2.6
1982	-	-	-	-	1.66	0.85	2.51	0.06	2.4	2.5
1983	-	-	-	-	1.53	0.67	2.20	0.05	2.4	2.5
1984	-	-	-	-	1.44	0.63	2.07	0.04	2.3	2.3
1985	-	-	-	-	1.35	0.57	1.92	0.04	2.3	2.3
1986	-	-	-	-	1.26	0.52	1.78	0.03	2.2	2.2
1987	-	-	-	-	1.18	0.50	1.68	0.03	2.2	2.2
1988	-	-	-	-	1.11	0.48	1.59	0.03	2.2	2.2
1989	-	-	-	-	1.04	0.47	1.51	0.02	2.1	2.1
1990	-	-	-	-	0.98	0.45	1.43	0.02	2.1	2.1
1991	-	-	-	-	0.92	0.44	1.36	0.02	2.0	2.0
1992	-	-	-	-	0.86	0.43	1.29	0.02	2.0	2.0
1993	-	-	-	-	0.81	0.41	1.22	0.02	1.9	1.9
1994	-	-	-	-	0.76	0.40	1.16	0.01	1.9	1.9
1995	-	-	-	-	0.71	0.39	1.10	0.01	1.9	1.9
1996	-	-	-	-	0.67	0.38	1.05	0.01	1.8	1.8
1997	-	-	-	-	0.63	0.37	1.00	0.01	1.8	1.8
1998	-	-	-	-	0.59	0.36	0.95	0.009	1.7	1.7
1999	-	-	-	-	0.56	0.35	0.90	0.009	1.7	1.7
1945-1999	64.2	0.51	1.9	6.6	97.0	154	324	23.7	144	167
2000-2099					8.6	10	19	0.10	120	120
2100-2199					0.02	0.50	0.52		50	50
2200-∞					-	0.03	0.03		2 180	2 180
1945-∞	64.2	0.51	1.9	6.6	106	165	344	23.8	2 494	2 517

a Indicates estimated value less than 0.0001 µSv.

Table 15
Inhalation exposure to radionuclides produced in atmospheric nuclear testing

Year	Worldwide average annual effective dose (µSv)														
	^{131}I	^{140}Ba	^{141}Ce	^{103}Ru	^{89}Sr	^{91}Y	^{95}Zr	^{144}Ce	^{54}Mn	^{106}Ru	^{125}Sb	^{55}Fe	^{90}Sr	^{137}Cs	*Pu, Am*	*Total*
1945	0.0083	0.0012	0.0019	0.0021	0.0052	0.0076	0.0001	0.038	-	0.022	-	-	0.0033	0.0001	0.014	0.10
1946	0.0059	0.0009	0.0012	0.0015	0.0036	0.0053	0.0052	0.025	-	0.016	-	-	0.0024	0.0001	0.010	0.078
1947	- [a]	-	-	-	-	-	0.0034	0.0003	-	0.0002	-	-	-	-	0.0002	0.006
1948	0.0096	0.0014	0.0012	0.0024	0.0059	0.0086	-	0.024	-	0.026	-	-	0.0038	0.0001	0.016	0.097
1949	0.0020	0.0003	0.0003	0.0005	0.0013	0.0018	0.0033	0.0050	-	0.0054	-	-	0.0008	-	0.003	0.026
1950	-	-	-	-	-	-	0.0007	0.0002	-	0.0002	-	-	-	-	0.0002	0.002
1951	0.058	0.0085	0.011	0.015	0.036	0.052	-	0.20	-	0.15	0.0003	-	0.022	0.0008	0.090	0.63
1952	0.055	0.0083	0.013	0.015	0.036	0.052	0.029	0.24	0.0002	0.15	0.0003	-	0.023	0.0008	0.092	0.72
1953	0.042	0.0065	0.012	0.017	0.048	0.077	0.034	0.56	0.0005	0.52	0.0010	0.0001	0.097	0.0035	0.40	1.81
1954	0.087	0.016	0.030	0.053	0.15	0.23	0.048	1.28	0.0011	1.33	0.0026	0.0001	0.26	0.0092	1.05	4.51
1955	0.042	0.0063	0.0087	0.012	0.032	0.052	0.11	1.06	0.0008	1.30	0.0034	0.0001	0.38	0.014	1.55	4.61
1956	0.19	0.028	0.037	0.059	0.15	0.23	0.034	1.45	0.0020	1.28	0.0031	0.0002	0.35	0.013	1.43	5.21
1957	0.20	0.030	0.056	0.058	0.15	0.23	0.14	1.98	0.0024	1.36	0.0031	0.0003	0.35	0.013	1.43	6.00
1958	0.60	0.092	0.14	0.19	0.45	0.72	0.17	4.35	0.0054	2.99	0.0058	0.0005	0.46	0.017	1.89	12.0
1959	0.0002	0.0003	0.0096	0.015	0.062	0.12	0.42	3.11	0.0048	2.13	0.0049	0.0006	0.75	0.027	3.09	9.91
1960	0.0063	0.0009	0.0008	0.0016	0.0041	0.0063	0.097	0.54	0.0009	0.47	0.0016	0.0002	0.20	0.0070	0.81	2.15
1961	0.24	0.037	0.072	0.073	0.18	0.27	0.0029	1.60	0.0017	0.92	0.0020	0.0002	0.26	0.0093	1.06	4.65
1962	0.84	0.13	0.26	0.27	0.71	1.10	0.27	9.93	0.028	5.63	0.011	0.0029	1.04	0.037	4.24	24.3
1963	0.025	0.0062	0.053	0.074	0.29	0.53	0.80	15.3	0.037	9.31	0.021	0.0047	1.87	0.067	7.66	36.2
1964	0.0018	0.0003	0.0003	0.0006	0.0028	0.0075	0.47	4.29	0.012	3.17	0.011	0.0025	1.20	0.043	4.90	14.2
1965	0.0067	0.0010	0.0018	0.0018	0.0044	0.0064	0.0080	0.88	0.0026	0.79	0.0040	0.0009	0.57	0.020	2.34	4.63
1966	0.037	0.0054	0.0085	0.0094	0.023	0.035	0.0088	0.33	0.0006	0.27	0.0015	0.0003	0.25	0.0088	1.01	1.98
1967	0.013	0.0022	0.0054	0.0061	0.017	0.027	0.0237	0.26	0.0003	0.17	0.0007	0.0001	0.13	0.0045	0.52	1.18
1968	0.0036	0.0008	0.0024	0.0030	0.0093	0.016	0.025	0.36	0.0004	0.23	0.0007	0.0001	0.15	0.0052	0.59	1.39
1969	0.0069	0.0017	0.0084	0.010	0.032	0.054	0.0086	0.81	0.0010	0.48	0.0011	0.0001	0.11	0.0041	0.47	1.99
1970	0.0086	0.0017	0.0059	0.0074	0.024	0.041	0.052	0.84	0.0008	0.52	0.0013	0.0001	0.15	0.0055	0.63	2.29
1971	0.0046	0.0008	0.0033	0.0048	0.017	0.032	0.031	0.81	0.0008	0.51	0.0013	0.0001	0.14	0.0051	0.59	2.15
1972	0.019	0.0028	0.0051	0.0052	0.013	0.020	0.023	0.31	0.0002	0.21	0.0006	-	0.067	0.0024	0.28	0.95
1973	0.0028	0.0006	0.0021	0.0026	0.0075	0.012	0.017	0.15	0.0002	0.10	0.0003	-	0.025	0.0009	0.10	0.43
1974	0.018	0.0027	0.0050	0.0053	0.015	0.023	0.013	0.36	0.0004	0.22	0.0005	0.0001	0.088	0.0031	0.36	1.11
1975	-	-	0.0001	0.0002	0.0008	0.002	0.014	0.12	0.0001	0.08	0.0002	-	0.043	0.0016	0.18	0.44
1976	0.021	0.0031	0.0055	0.0057	0.014	0.020	0.0013	0.12	0.0001	0.075	0.0002	-	0.021	0.0007	0.084	0.37
1977	0.004	0.0008	0.0044	0.0058	0.020	0.036	0.015	0.66	0.0008	0.38	0.0008	0.0001	0.059	0.0021	0.24	1.43
1978	0.0033	0.0005	0.0004	0.0007	0.0018	0.0028	0.030	0.17	0.0002	0.13	0.0004	-	0.072	0.0026	0.29	0.71
1979	0.0003	0.0001	0.0001	0.0002	0.0006	0.0009	0.0014	0.035	-	0.031	0.0001	-	0.023	0.0008	0.094	0.19
1980	0.022	0.0033	0.0060	0.0060	0.015	0.021	0.0004	0.12	-	0.067	0.0001	-	0.022	0.0008	0.090	0.37
1981	-	-	0.0008	0.0012	0.005	0.009	0.016	0.17	0.0001	0.102	0.0002	-	0.032	0.0011	0.13	0.48
1982	-	-	-	-	-	-	-	0.016	-	0.012	-	-	0.0094	0.0003	0.038	0.048
1983	-	-	-	-	-	-	-	0.0020	-	0.0018	-	-	0.0066	0.0002	0.027	0.034
1984	-	-	-	-	-	-	-	0.0003	-	0.0271	-	-	0.0053	0.0002	0.022	0.027
1985	-	-	-		-	-	-	-	-	0.0001	-	-	0.0016	0.0001	0.0065	0.008
Total	2.58	0.40	0.77	0.93	2.56	4.07	2.92	52.5	0.11	35.2	0.085	0.014	9.22	0.33	37.8	149

a Estimated value less than 0.0001 µSv.

Table 16
Annual effective dose from radionuclides produced in atmospheric nuclear testing

Year	Average annual effective dose (µSv)											
	Northern hemisphere				Southern hemisphere				World			
	External	*Ingestion* [a]	*Inhalation*	*Total*	*External*	*Ingestion* [a]	*Inhalation*	*Total*	*External*	*Ingestion* [a]	*Inhalation*	*Total*
1945	0.25	0.27	0.12	0.64	- [b]	-	-	-	0.22	0.24	0.10	0.57
1946	0.22	0.21	0.087	0.52	-	-	-	-	0.20	0.19	0.077	0.47
1947	0.042	0.025	0.0046	0.071	-	-	-	-	0.037	0.02	0.0041	0.06
1948	0.26	0.31	0.11	0.68	-	-	-	-	0.23	0.28	0.10	0.60
1949	0.077	0.10	0.027	0.21	-	-	-	-	0.068	0.09	0.024	0.19
1950	0.028	0.014	0.0016	0.043	-	-	-	-	0.025	0.01	0.0014	0.039
1951	1.50	1.90	0.72	4.12	0.0016	0.0010	0.0014	0.0039	1.34	1.69	0.64	3.67
1952	1.65	2.02	0.80	4.48	0.082	0.15	0.032	0.27	1.48	1.81	0.72	4.01
1953	3.17	2.92	2.01	8.10	0.14	0.34	0.17	0.65	2.84	2.58	1.81	7.23
1954	5.88	7.17	4.95	18.0	1.14	1.35	1.28	3.77	5.36	6.53	4.55	16.4
1955	3.52	8.26	5.03	16.8	0.66	1.89	0.79	3.34	3.21	7.60	4.57	15.4
1956	8.40	14.0	5.76	28.2	1.83	3.03	1.15	6.01	7.67	12.8	5.26	25.8
1957	9.38	13.5	6.40	29.3	7.38	9.47	2.72	19.6	9.16	13.1	6.00	28.3
1958	24.2	27.7	13.2	65.2	7.82	8.15	2.99	19.0	22.4	25.6	12.1	60.1
1959	13.6	16.6	10.8	41.0	2.98	4.17	1.16	8.31	12.5	15.1	9.75	37.3
1960	5.26	12.6	2.30	20.2	0.97	3.45	0.76	5.18	4.79	11.7	2.13	18.6
1961	9.98	16.7	5.23	31.9	0.83	3.79	0.65	5.26	8.97	15.3	4.73	29.0
1962	39.6	50.0	26.5	116	25.3	25.5	8.16	59.0	38.1	47.3	24.5	110
1963	41.3	43.7	40.2	125	6.62	7.36	2.73	16.7	37.5	39.8	36.0	113
1964	18.3	42.3	15.6	76.2	2.14	8.32	2.02	12.5	16.6	38.6	14.1	69.3
1965	13.3	30.4	5.04	48.7	1.78	8.53	1.38	11.7	12.1	27.9	4.63	44.6
1966	10.9	21.8	2.07	34.8	3.25	9.11	1.24	13.6	10.1	20.4	1.98	32.5
1967	9.01	16.7	1.23	26.9	2.93	5.68	0.76	9.37	8.34	15.5	1.18	25.0
1968	7.66	14.6	1.42	23.7	3.03	4.84	1.15	9.02	7.15	13.6	1.39	22.1
1969	8.25	13.6	2.11	24.0	2.93	4.49	1.09	8.52	7.66	12.6	1.99	22.3
1970	7.77	12.7	2.38	22.9	3.88	5.62	1.53	11.0	7.35	11.9	2.28	21.5
1971	7.63	12.2	2.25	22.1	3.78	5.08	1.31	10.2	7.21	11.4	2.15	20.8
1972	7.21	11.2	1.00	19.4	2.39	4.21	0.59	7.19	6.68	10.4	0.96	18.1
1973	6.24	9.17	0.43	15.8	2.23	3.54	0.36	6.14	5.80	8.58	0.42	14.8
1974	6.53	9.27	1.16	17.0	3.22	4.08	0.69	7.98	6.17	8.73	1.11	16.0
1975	5.82	8.51	0.46	14.8	2.06	2.72	0.24	5.01	5.40	7.88	0.44	13.7
1976	5.95	7.97	0.41	14.3	1.43	2.47	0.093	4.00	5.45	7.37	0.37	13.2
1977	6.79	7.43	1.59	15.8	1.36	2.33	0.091	3.78	6.19	6.94	1.43	14.6
1978	5.64	7.39	0.79	13.8	1.32	2.20	0.072	3.59	5.16	6.85	0.71	12.7
1979	5.28	6.56	0.21	12.0	1.27	2.03	0.040	3.34	4.84	6.02	0.19	11.1
1980	5.54	6.46	0.41	12.4	1.24	1.92	0.036	3.20	5.07	5.93	0.37	11.4
1981	5.55	5.77	0.52	11.8	1.21	1.87	0.030	3.11	5.07	5.36	0.47	10.9
1982	4.78	5.41	0.083	10.3	1.18	1.81	0.022	3.01	4.39	4.97	0.076	9.43

Table 16 (continued)

Year	Average annual effective dose (μSv)											
	Northern hemisphere				Southern hemisphere				World			
	External	*Ingestion* [a]	*Inhalation*	*Total*	*External*	*Ingestion* [a]	*Inhalation*	*Total*	*External*	*Ingestion* [a]	*Inhalation*	*Total*
1983	4.64	5.01	0.040	9.69	1.15	1.77	0.018	2.93	4.03	4.65	0.038	8.94
1984	4.51	4.79	0.060	9.36	1.12	1.72	0.010	2.85	3.93	4.41	0.055	8.60
1985	4.40	4.57	0.0087	8.98	1.10	1.68	0.005	2.78	3.84	4.26	0.008	8.30
1986	4.29	4.36	0.0006	8.65	1.07	1.64	0.0003	2.71	3.75	4.01	0.0006	7.94
1987	4.18	4.19	0.0003	8.38	1.05	1.62	0.0002	2.66	3.66	3.91	0.0002	7.75
1988	4.08	4.04	-	8.12	1.02	1.61	-	2.63	3.57	3.82	-	7.57
1989	3.99	3.90	-	7.89	1.00	1.60	-	2.60	3.49	3.63	-	7.29
1990	3.90	3.76	-	7.65	0.97	1.60	-	2.58	3.41	3.55	-	7.12
1991	3.81	3.63	-	7.43	0.95	1.61	-	2.56	3.33	3.38	-	6.87
1992	3.72	3.50	-	7.22	0.93	1.62	-	2.55	3.26	3.31	-	6.72
1993	3.63	3.37	-	7.01	0.91	1.63	-	2.54	3.18	3.14	-	6.48
1994	3.55	3.26	-	6.81	0.89	1.65	-	2.54	3.11	3.07	-	6.33
1995	3.47	3.14	-	6.61	0.87	1.68	-	2.55	3.04	3.01	-	6.20
1996	3.39	3.03	-	6.42	0.85	1.72	-	2.57	2.97	2.86	-	5.97
1997	3.31	2.92	-	6.23	0.83	1.76	-	2.59	2.90	2.81	-	5.85
1998	3.24	2.81	-	6.05	0.81	1.82	-	2.63		2.66	-	5.63
1999	3.16	2.71	-	5.87	0.79	1.89	-	2.68		2.61	-	5.51
1945-1999	382	531	164	1 076	115	178	35	328	353	492	149	994
2000-2099	124	141		264	31	126		157	114	139		253
2100-2199	12	51		63	3.1	50		53	11	51		62
2200-∞	1.4	2 180		2 181	0.3	2 180		2 180	1.3	2 180		2 181
1945-∞	520	2 900	164	3 580	149	2 530	35	2 720	479	2 860	149	3 490

a Includes contribution from globally dispersed ^{3}H and ^{14}C.
b Estimated value less than 0.0001 μSv.

Table 17
Local doses from atmospheric nuclear testing

Test site	*Population*	*Maximum absorbed dose in thyroid of children (Gy)*	*Maximum effective dose (Sv)*	*Collective effective dose (man Sv)*	*Ref.*
United States					
Nevada	180 000	1		500 [b]	[A1]
Pacific [a]	245	200	1.9	160	[L4]
Former USSR					
Semipalatinsk	10 000 [c]	20		4 600	[T1]
United Kingdom					
Australian sites [d]				700	[W1]

a Exposures from Bravo test of 28 February 1954 to residents of Rongelap, Utrik, and Ailinginae atolls.
b External exposure to local population only.
c Population in settlements bordering the test site. The extended population of Semipalatinsk and Altai regions was 1.7 million in 1960.
d Maralinga, Emu, and Monte Bello Island.

Table 18
Distribution of cumulative effective doses to individuals exposed in local areas downwind of the Nevada test site
[A1]

Effective dose (mSv)		*Number of individuals*		*Collective effective dose (man Sv)*	
Range	*Mean* [a]	*1951–1958*	*1961–1963*	*1951–1958*	*1961–1963*
<0.06–0.6	0.2	61 000	180 000	12	36
0.6–3	1.3	80 000	480	104	0.6
3–6	4.2	19 000	0	80	
6–30	13	20 000	0	260	
30–60	42	520	0	22	
60–90	73	45	0	3.2	
Total (rounded)		180 000	180 000	460	40

a Assumed to be geometric mean of range.

Table 19
Estimated local exposures from atmospheric nuclear tests conducted by France at the South Pacific test site
[B8]

Location	*Date of test*	*Population*	*Effective dose (mSv)*				*Collective effective dose (man Sv)*
			External	*Inhalation*	*Ingestion*	*Total*	
Gambier Islands	2 July 1966 8 August 1971	40 68	3.4 0.9	0.18 0.002	1.9 0.24	5.5 1.2	0.2 0.5
Tureia Atoll	2 July 1967 12 June 1971	516 545	0.7 0.9	0.023 0.003	0.17 0.043	0.9 1.3	0.7 0.08
Tahiti (Mahina)	17 July 1974	84,000	0.6	0.08	0.06	0.8	67
Total							70

Table 20
Effective dose estimates from external exposures at locations 400–800 km downwind of the Lop Nor test site
[Z1]

City	*Population*	*Distance from test site (km)*	*Absorbed dose in air (mGy)*	*Effective dose (mSv)*
Xihu)			0.07	0.2
Anxi)	60 000	500	0.06	0.2
Tashi)		500	0.10	0.3
Qiaowan	(Village)	560	0.14	0.04
Yumenzhen)	159 000	600	0.12	0.03
Yumanshi)			0.02	0.006
Jinta	99 000	740	0.45	0.11
Jiayuguan	89 000	720	0.44	0.11

Table 21
Underground nuclear tests [a]

Year	*Number of tests*						
	China	*France*	*India*	*Pakistan*	*United Kingdom*	*United States*	*USSR*
1955						1	
1957						5	
1958						14	
1961		1				10	1
1962		1			2	57	1
1963		3				45	
1964		3			2	48	9
1965		4			1	39	15
1966		1				49	19
1967						42	23
1968						72	23
1969	1					61	24
1970						60	21
1971						28	29
1972						32	31
1973						27	22
1974			1		1	25	27
1975	1	2				23	35
1976	1	5			1	20	27
1977		9				23	36
1978	1	11			2	20	55
1979		10			1	15	52
1980		12			3	14	43
1981		12			1	16	37
1982	1	10			1	18	34
1983	2	9			1	19	37
1984	2	8			2	18	52
1985		8			1	17	10
1986		8			1	14	
1987	1	8			1	16	39
1988	1	8				18	29
1989		9			1	15	11
1990	2	6			1	10	8
1991		6			1	9	
1992	2					8	
1993	1						
1994	2						
1995	2	5					
1996	2	1					
1997							
1998			5	6			
Total	22	160	6	6	24	908	750
All countries	1 876						

a Includes cratering tests carried out by the United States and the USSR, some of which released radionuclides to the atmosphere.

Table 22
Summary of nuclear testing

Country	Number of tests			Yield (Mt)		
	Atmospheric	*Underground*	*Total*	*Atmospheric*	*Underground*	*Total*
China	22	22	44	20.7	1	22
France	50 [a]	160	210	10.2	3	13
India	-	6	6			
Pakistan	-	6	6			
United Kingdom	33 [b]	24	57	8.1	2	10
United States	219 [c]	908	1 127	154	46	200
USSR	219	750	969	247	38	285
All countries	543	1 876	2 419	440	90	530

a Includes 5 safety tests.
b Includes 12 safety tests.
c Includes 22 safety tests and 2 combat explosions.

Table 23
Radionuclide releases and estimated local exposures from nuclear weapons material production and fabrication plants in the United States

Location	*Release period*	*Airborne release (GBq)*	*Liquid release (GBq)*	*Cumulative effective dose (mSv)*		*Reference*
				Airborne	*Liquid*	
Fernald	1954-1980	50-150 (U)				[S5]
Oak Ridge	1942-1984	~1 000 000 (^{131}I)	25 400 (^{137}Cs)			[H9, W5]
Rocky Flats	1953-1983 (routine) 1957 (fire) 1965-1969 (storage area)	8.8 (U) / 1.7 (Pu) 1.9 (Pu) 260 (Pu)		0.0015 0.013 0.072		[R3] [M4] [M5]
Hanford	1944-1987	27 300 000 (^{131}I)	481 000 000 (^{24}Na)	12	15	[H4, S3]
Savannah River	1954-1989	140 (Pu)	23 (Pu)	0.12	0.0024	[C1]

Table 24
Releases of radioactive materials associated with the early operation of the materials production complex at Chelyabinsk-40 in the eastern Urals region of the Russian Federation
[D5, K4, N8]

Circumstances of release	*Time period*	*Radionuclide composition (%)*					*Total activity release (PBq)*
		^{90}Sr	^{95}Zr	^{106}Ru	^{137}Cs	^{144}Ce	
Routine operation Atmospheric effluents Liquid effluents to Techa River [a]	 1948-1956 1949-1956	11.6	13.6	25.9	12.2		100
Accident at waste storage site	1957	5.4	24.9	3.7	0.036	66.0	74
Resuspension from shoreline of Lake Karachay	1967	34			48	18	0.022

a Radionuclide composition included, additionally, ^{89}Sr (8.8%) and other (27.9%).

Table 25
Estimated collective effective dose from operation of weapons material production centres in the former Soviet Union [D5, K4, K5, N8]

Production centre	*Time period*	*Population exposed*	*Collective effective dose (man Sv)*
Chelyabinsk			
Discharges to Techa River	1949–1956	28 000	6 200
Waste storage accident	1957	273 000	2 500
Krasnoyarsk			
Discharges to Yenesei River	1958–1991	200 000	1 200
Tomsk			
Discharges to Tom/Ob Rivers	1958–1992	400 000	200
Total			10 100

Table 26
Present (1990–1993) levels of contamination surrounding the Chelyabinsk site [K4]

Location	*Material*	*Deposition density ($kBq\ m^{-2}$)*		*Concentration ($Bq\ kg^{-1}$)*	
		^{90}Sr	*^{137}Cs*	*^{90}Sr*	*^{137}Cs*
Techa River	Water			7–23	0.06–0.23
	Bottom sediments			40–2 000 [a]	100–280 000 [a]
	Fish			50–560	4–10
Eastern Urals					
Agricultural areas	Soil	3.7–74	7.4–37		
	Potatoes			0.2–6.7	0.5–3.8
	Grain			0.5–12.6	0.3–2.9
	Milk			0.2–6.3	0.2–4.5
	Beef			0.2–1.7	0.3–2.6
Forest areas	Soil	37–74 000	37–740		
	Mushrooms			400–1 100	110–1 600
	Berries			700–16 000	150
Lakes removed from use	Water			17–120	0.7
	Bottom sediments				250–860 [a]
	Fish			70 000–110 000	1 700
Lakes of multipurpose use	Water			0.10–0.34	0.06–0.36
	Bottom sediments			20–300 [a]	80–240 [a]
	Fish			30–220	8–26

a Dry weight.

Table 27
Present (1993–1996) exposures from nuclear materials production/processing centres in the Russian Federation [B7, K4]

Installation	*Population*	*Annual effective dose (mSv)*			*Annual collective effective dose (man Sv)*
		External	*Internal*	*Total*	
Chelyabinsk	320 000	0.01	0.10	0.11	35
Krasnoyarsk	200 000	0.03	0.02	0.05	10
Tomsk	400 000	0.0004	0.005	0.0054	2.2

Table 28
Production of uranium
[O1]

Country	Annual production of uranium (t) [a]							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Argentina	9	18	123	126	80	65	28	35
Australia	3 530	3 776	2 334	2 256	2 208	3 712	4 974	5 520
Belgium [b]	39	38	36	34	40	25	28	27
Brazil	5	0	0	24	106	106	0	0
Bulgaria	405	240	150	100	70	0	0	0
Canada	8 729	8 160	9 297	9 155	9 647	10 473	11 788	12 029
China	(800)	(800)	(955)	(780)	(780)	(500)	(500)	(500)
Czech Republic	2 142	1 778	1 539	950	541	600	598	590
France	2 841	2 477	2 149	1 730	1 053	1 016	940	748
Gabon	709	678	589	556	650	652	560	472
Germany	2 972	1 207	232	116	47	35	40	40
Hungary	524	415	430	380	413	210	200	200
India	(230)	(200)	150	148	155	(155)	(200)	(200)
Kazakhstan	(7 120)	(7 350)	(2 802)	2 700	2 240	1 630	1 320	1 000
Mongolia	89	101	105	54	72	20	0	0
Namibia	3 211	2 450	1 660	1 679	1 895	2 016	2 452	2 905
Niger	2 839	2 963	2 965	2 914	2 975	2 974	3 160	3 497
Pakistan	(30)	(30)	(23)	(23)	(23)	(23)	(23)	(23)
Portugal	111	28	28	32	24	18	15	17
Romania	210	160	120	(120)	120	120	100	100
Russian Federation	3 780	3 050	2 640	2 697	2 541	2 160	2 000	(2 000)
Slovenia	53	0	2 [c]	0	0	0	0	0
South Africa	2 460	1 712	1 669	1 699	1 671	1 421	1 436	1 100
Spain	213	196	187	184	256	255	255	255
Ukraine	(1 000)	(1 000)	1 000	1 000	1 000	1 000	500	500
United States	3 420	3 060	2 170	1 180	1 279	2 324	2 420	2 170
Uzbekistan	(2 100)	2 100	2 680	2 600	2 015	1 644	1 459	2 000
Total	49 571	43 987	36 035	33 237	31 611	33 154	34 996	35 692

a Values in parentheses are estimates.
b Uranium is produced as a byproduct from imported phosphates.
c Decommissioning product.

Table 29
Radon releases in airborne effluents and collective dose from uranium mining and milling

Source	*Release per unit production* ($GBq\ t^{-1}$)	*Release rate per unit area* ($Bq\ s^{-1}\ m^{-2}$)	*Normalized release* [a] [$TBq\ (GWa)^{-1}$]	*Normalized collective effective dose* [$man\ Sv\ (GWa)^{-1}$] [b]
Mining	300		75	0.19
Milling	13		3	0.0075
Mill tailings				
Operational mill		10	3 [c]	0.04 [d]
Closed mill		1	0.3 [c]	7.5 [e]

a Normalization basis: production, 250 t $(GW\ a)^{-1}$; tailings, 1 ha $(GWa)^{-1}$.
b Dose coefficient: 0.0025 man Sv TBq^{-1}.
c Normalized release rate: $TBq\ a^{-1}\ (GWa)^{-1}$.
d Assuming release period of five years.
e Assuming release period of 10,000 years and unchanging population density.

Table 30
Worldwide installed capacity and electrical energy generated by nuclear reactors
[I3]

Country	*Capacity (GW)*	*Electrical energy generated (GW a)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
PWRs									
Armenia									
Armenia 1-2	0.376	0	0	0	0	0	0	0.239	0.163
Belgium									
Doel 1-4	2.71	2.191	2.284	2.296	2.080	1.923	2.221	2.235	2.478
Tihange 1-3	2.791	2.442	2.359	2.413	2.468	2.489	2.266	2.472	2.643
Brazil									
Angra 1	0.626	0.235	0.149	0.172	0.046	0.005	0.266	0.261	0.341
Bulgaria									
Kozloduy 1-6	3.538	1.542	1.387	1.213	1.417	1.612	1.852	1.919	1.877
China									
Guangdong 1-2	1.812	-	-	-	-	1.331	1.149	1.316	1.416
Qinshan	0.288	-	-	-	0.199	0.188	0.236	0.237	0.230
Maanshan 1-2	1.78	1.397	1.446	1.369	1.462	1.522	1.468	1.585	1.411
Czech Republic									
Dukovany 1-4	1.632	1.343	1.272	1.398	1.441	1.481	1.396	1.375	1.426
Finland									
Loviisa 1-2	0.89	0.743	0.776	0.751	0.798	0.756	0.736	0.779	0.868
France									
Belleville 1-2	2.62	1.625	1.888	1.913	1.917	1.691	1.792	1.666	2.088
Blayais 1-4	3.64	2.541	2.688	2.556	2.582	2.315	2.841	3.081	2.977
Bugey 2-5	3.64	2.076	1.908	1.380	2.355	2.306	2.415	2.367	2.548
Cattenom 1-4	5.2	1.994	2.385	3.718	3.579	3.624	3.713	4.078	4.038
Chinon B1-B4	3.55	2.585	2.494	2.825	2.598	2.573	2.884	2.789	2.842
Chooz-A (Ardennes)	0.305	0.169	0.152	0	0	0	0	0	0
Chooz B1-B2	-	-	-	-	-	-	-	-	0.998
Cruas 1-4	3.555	2.663	2.350	2.490	2.579	2.547	2.547	2.802	2.485
Dampierre 1-4	3.56	2.078	2.486	2.461	2.700	2.345	2.513	2.666	2.486
Fessenheim 1-2	1.76	0.980	1.069	0.807	1.293	1.311	1.250	1.411	1.328
Flamanville 1-2	2.66	1.702	1.581	1.878	1.973	1.773	1.898	2.053	1.758
Golfech 1-2	2.62	0.208	1.089	0.807	1.154	1.717	1.704	2.041	2.032
Gravelines 1-6	5.46	3.995	3.918	3.943	3.976	4.012	4.245	4.070	4.020
Nogent 1-2	2.62	1.615	1.735	1.841	1.929	1.687	1.701	1.907	1.997
Paluel 1-4	5.32	3.334	3.563	3.195	3.786	3.276	3.742	3.398	3.814
Penly 1-2	2.66	0.330	0.963	1.492	1.899	1.910	1.946	2.202	1.892
St. Alban 1-2	2.67	1.583	1.815	1.277	1.576	1.678	1.859	1.880	1.731
St. Laurent B1-B2	1.795	1.288	1.147	1.268	1.223	1.418	1.114	1.324	1.266
Tricastin 1-4	3.66	2.554	2.381	2.673	2.698	2.703	2.784	2.991	2.677
Germany									
Biblis A-B	2.386	1.616	1.238	1.657	1.790	1.765	1.183	1.355	1.880
Brokdorf	1.326	0.952	1.084	1.232	1.078	1.168	1.132	1.205	1.284
Emsland	1.242	1.146	1.060	1.160	1.196	1.202	1.198	1.205	1.216
Grafenrheinfeld	1.235	0.903	1.113	1.102	1.010	1.104	1.135	1.088	1.157
Greifswald	1.632	0	0	0	0	0	0	0	0
Grohnde	1.3	1.156	1.137	1.190	1.219	1.172	1.230	1.209	1.354
Isar 2	1.31	1.058	1.107	1.124	1.164	1.199	1.146	1.172	1.245
Mülheim-Kärlich	1.219	0	0	0	0	0	0	0	0
Neckarwestheim 1-2	2.02	1.763	1.694	1.767	1.766	1.898	1.883	1.903	1.866
Obrigheim	0.34	0.135	0.120	0.215	0.299	0.300	0.247	0.317	0.316
Philippsburg 2	1.268	0.972	1.131	1.073	1.196	1.174	1.204	1.281	1.269
Stade	0.64	0.480	0.262	0.485	0.514	0.611	0.498	0.575	0.565
Unterweser	1.23	0.969	0.740	0.997	1.236	0.877	0.911	1.131	1.134
Hungary									
Paks 1-4	1.84	1.472	1.473	1.594	1.575	1.510	1.507	1.531	1.501

Table 30 (continued)

Country	Capacity (GW)	Electrical energy generated (GW a)							
		1990	1991	1992	1993	1994	1995	1996	1997
Japan									
Genkai 1-4	2.185	0.843	0.809	0.771	0.964	1.751	1.746	1.759	2.420
Ikata 1-3	1.922	0.952	0.904	0.815	0.809	1.198	1.691	1.460	1.648
Mihama 1-3	1.57	1.356	0.807	0.655	0.707	0.934	0.768	1.195	1.318
Ohi 1-4	4.49	1.385	1.671	2.780	3.614	3.379	2.855	3.845	3.346
Sendai 1-2	1.692	1.406	1.285	1.491	1.420	1.295	1.306	1.432	1.503
Takahama 1-4	3.22	2.277	2.140	2.462	2.520	2.341	2.552	2.415	2.631
Tomari 1-2	1.10	0.514	0.778	0.832	0.987	0.961	0.926	0.877	0.982
Tsuruga 2	1.115	0.822	1.057	0.924	0.895	0.892	1.053	0.921	0.745
Netherlands									
Borssele	0.481	0.329	0.311	0.323	0.380	0.379	0.387	0.402	0.248
Republic of Korea									
Kori 1-4	2.951	2.388	2.415	2.457	2.500	2.502	2.563	2.623	2.458
Ulchin 1-2	1.84	1.337	1.588	1.604	1.622	1.572	1.708	1.686	1.582
Yonggwang 1-4	3.7	1.468	1.530	1.522	1.559	1.754	2.389	3.185	3.298
Russian Federation									
Balakovo 1-4	3.8	1.362	1.674	2.038	1.730	1.565	1.428	1.936	1.763
Kalinin 1-2	1.9	1.368	1.280	1.402	1.232	1.016	1.195	1.030	1.036
Kola 1-4	1.644	1.317	1.279	1.139	1.085	0.774	0.982	0.938	0.933
Novovoronezh 2-5	1.72	1.033	1.064	1.049	1.183	0.793	0.940	1.015	1.234
Slovakia									
Bohunice 1-4	1.632	1.274	1.240	1.261	1.163	1.280	1.296	1.286	1.233
Slovenia									
Krsko	0.62	0.501	0.539	0.430	0.430	0.503	0.522	0.498	0.547
South Africa									
Koeberg 1-2	1.844	0.966	1.047	1.062	0.835	1.106	1.289	1.342	1.441
Spain									
Almaraz 1-2	1.86	1.611	1.625	1.515	1.626	1.579	1.530	1.504	1.448
Asco 1-2	1.86	1.549	1.556	1.593	1.542	1.583	1.448	1.596	1.636
José Cabrera 1	0.16	0.109	0.120	0.128	0.104	0.002	0.040	0.112	0.093
Trillo 1	1.07	0.727	0.740	0.906	0.844	0.905	0.853	0.871	0.886
Vandellos 2	1.00	0.837	0.820	0.767	0.789	0.823	0.864	0.857	0.827
Sweden									
Ringhals 2-4	2.63	1.987	2.177	1.969	1.790	2.211	1.966	2.153	2.184
Switzerland									
Beznau 1-2	0.7	0.593	0.584	0.554	0.549	0.656	0.618	0.629	0.662
Gösgen	0.94	0.814	0.815	0.846	0.846	0.875	0.893	0.905	0.910
Ukraine									
Khmelnitski 1	0.95	0.742	0.590	0.694	0.626	0.720	0.651	0.513	0.702
Rovno 1-3	1.695	1.341	1.197	1.501	1.237	1.238	1.180	1.229	1.317
South Ukraine 1-3	2.85	1.556	1.808	2.034	1.886	1.671	1.806	1.814	2.173
Zaporozhe 1-6	4.75	2.680	2.933	3.500	2.944	2.614	2.645	3.712	3.884
United Kingdom									
Sizewell B	1.188	-	-	-	-	-	0.614	0.966	0.959
United States									
Arkansas One 1-2	1.694	1.287	1.446	1.294	1.538	1.589	1.333	1.524	1.622
Beaver Valley 1-2	1.643	1.194	1.196	1.364	1.093	1.430	1.312	1.197	1.163
Braidwood 1-2	2.24	1.669	1.320	1.816	1.833	1.602	1.843	1.784	1.864
Byron 1-2	2.21	1.485	1.723	1.825	1.711	1.861	1.814	1.678	1.857
Callaway 1	1.118	0.914	1.139	0.924	0.958	1.142	0.942	1.015	1.022
Calvert Cliffs 1-2	1.65	0.153	1.039	1.222	1.405	1.286	1.477	1.381	1.500
Catawba 1-2	2.258	1.530	1.593	1.864	1.801	1.994	1.904	1.778	2.030
Comanche Peak 1-2	2.3	0.287	0.612	0.792	1.288	1.670	1.937	1.727	2.002
Crystal River 3	0.821	0.473	0.623	0.607	0.694	0.678	0.826	0.276	0
Davis-Besse 1	0.86	0.475	0.667	0.873	0.694	0.729	0.876	0.737	0.820
Diablo Canyon 1-2	2.16	1.860	1.722	1.907	1.921	1.743	1.858	1.909	1.950
Donald Cook 1-2	2.08	1.269	1.772	0.733	1.862	1.061	1.598	1.872	1.190

Table 30 (continued)

Country	*Capacity (GW)*	*Electrical energy generated (GW a)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*									
Farley 1-2	1.654	1.391	1.388	1.265	1.384	1.508	1.238	1.471	1.451
Fort Calhoun 1	0.478	0.276	0.371	0.290	0.354	0.470	0.384	0.357	0.436
R. E. Ginna	0.47	0.394	0.398	0.398	0.399	0.385	0.415	0.331	0.445
Haddam Neck	0.565	0.136	0.423	0.444	0.427	0.434	0.418	0.317	0
Harris 1	0.86	0.724	0.677	0.620	0.859	0.692	0.681	0.807	0.675
Indian Point 1-3	1.829	1.171	1.276	1.443	0.813	0.872	0.727	1.564	0.858
Kewaunee	0.503	0.445	0.420	0.450	0.436	0.452	0.433	0.362	0.270
Maine Yankee	0.81	0.555	0.715	0.612	0.655	0.757	0.023	0.578	0
McGuire 1-2	2.258	1.284	1.868	1.629	1.411	1.774	2.049	1.806	1.559
Millstone 2-3	2.005	1.544	0.779	1.064	1.461	1.495	1.225	0.402	0
North Anna 1-2	1.83	1.508	1.519	1.334	1.360	1.631	1.583	1.492	1.711
Oconee 1-2-3	2.538	2.300	2.174	2.017	2.301	2.044	2.261	1.764	1.567
Palisades	0.73	0.343	0.556	0.555	0.405	0.515	0.532	0.607	0.662
Palo Verde 1-3	3.663	2.351	2.865	2.923	2.515	2.645	3.080	3.293	3.369
Point Beach 1-2	0.97	0.836	0.835	0.830	0.873	0.874	0.819	0.794	0.192
Prairie Island 1-2	1.003	0.871	0.967	0.767	0.927	0.944	0.969	0.939	0.818
Rancho Seco 1	0.873	0.004	0	0	0	0	0	0	0
H. B. Robinson 2	0.665	0.379	0.547	0.464	0.479	0.531	0.575	0.623	0.707
Salem 1-2	2.212	1.307	1.652	1.148	1.307	1.300	0.528	0	0.293
San Onofre 1-3	2.586	1.881	1.882	2.118	1.688	2.107	1.598	1.985	1.541
Seabrook 1	1.15	0.467	0.778	0.898	1.033	0.708	0.957	1.124	0.907
Sequoyah 1-2	2.296	1.601	1.894	1.790	0.386	1.365	1.794	1.938	1.946
South Texas 1-2	2.5	1.430	1.656	2.010	0.155	1.626	2.195	2.361	2.266
St. Lucie 1-2	1.678	1.124	1.509	1.435	1.160	1.346	1.235	1.393	1.395
Surry 1-2	1.562	1.211	1.207	1.330	1.230	1.272	1.286	1.509	1.380
Three Mile Island 1	0.808	0.607	0.647	0.792	0.681	0.752	0.729	0.811	0.676
Trojan	1.095	0.697	0.171	0.526	0	0	0	0	0
Turkey Point 3-4	1.332	0.887	0.244	0.921	1.188	1.115	1.256	1.246	1.221
Virgil C. Summer 1	0.885	0.698	0.610	0.858	0.697	0.509	0.863	0.817	0.830
Vogtle 1-2	2.166	1.623	1.872	1.959	1.973	2.072	2.186	1.962	2.121
Waterford 3	1.075	0.982	0.830	0.870	1.043	0.905	0.886	1.019	0.767
Watts Bar	1.170	-	-	-	-	-	-	0.633	0.868
Wolf Creek	1.135	0.901	0.673	0.969	0.903	0.976	1.149	0.940	0.964
Yankee NPS	0.167	0.094	0.113	0	0	0	0	0	0
Zion 1-2	2.08	0.810	1.072	1.082	1.406	1.176	1.415	1.477	0.123
BWRs									
China									
Chin Shan 1-2	1.208	0.731	0.933	0.930	0.954	0.870	0.918	0.921	1.063
Kuosheng 1-2	1.902	1.472	1.488	1.407	1.349	1.430	1.472	1.641	1.526
Finland									
Olkiluoto 1-2	1.465	1.325	1.325	1.323	1.348	1.337	1.333	1.353	1.421
Germany									
Brunsbüttel	0.771	0.546	0.436	0.398	0	0	0.343	0.536	0.583
Gundremmingen B,C	2.488	1.907	1.866	1.912	1.679	1.864	2.061	2.155	2.080
Isar 1	0.87	0.577	0.772	0.670	0.636	0.588	0.736	0.664	0.685
Krümmel	1.26	1.008	0.883	0.950	0.749	0.283	1.052	0.941	1.056
Philippsburg 1	0.864	0.594	0.705	0.743	0.527	0.750	0.721	0.791	0.732
Würgassen	0.64	0.125	0.466	0.432	0.449	0.384	0	0	0
India									
Tarapur 1-2	0.3	0.206	0.162	0.181	0.199	0.128	0.198	0.087	0.201
Japan									
Fukushima Daiichi 1-6	4.546	2.780	3.383	3.028	2.453	3.248	3.837	3.321	3.295
Fukushima Daini 1-4	4.268	2.562	3.202	3.239	2.933	3.076	3.572	3.528	3.593
Hamaoka 1-4	3.469	1.652	1.624	1.552	2.610	2.258	3.161	2.847	2.878
Kashiwazaki Kariwa 1-7	7.965	2.201	2.599	2.622	3.405	3.969	4.552	5.151	6.613
Onagawa 1-2	1.294	0.325	0.382	0.470	0.263	0.391	0.849	1.016	1.169
Shika 1	0.505	-	-	-	0.324	0.378	0.399	0.394	0.506
Shimane 1-2	1.23	1.012	0.988	0.932	1.062	0.970	0.953	0.291	1.122
Tokai 2	1.056	0.832	0.802	0.718	0.994	0.836	0.781	0.861	1.014
Tsuruga 1	0.341	0.224	0.258	0.227	0.300	0.172	0.266	0.286	0.221

Table 30 (continued)

Country	*Capacity (GW)*	*Electrical energy generated (GW a)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico									
Laguna Verde 1-2	1.30	0.232	0.464	0.428	0.539	0.464	0.860	0.858	1.144
Netherlands									
Dodewaard	0.05	0.047	0.047	0.048	0.049	0.048	0.045	0.045	0.008
Spain									
Confrentes	0.99	0.807	0.799	0.880	0.801	0.798	0.935	0.878	0.787
S. Maria de Garona	0.46	0.291	0.420	0.305	0.419	0.358	0.437	0.366	0.384
Sweden									
Barsebeck 1-2	1.2	0.974	1.040	0.629	0.682	0.946	0.899	0.903	0.871
Forsmark 1-3	3.008	2.355	2.661	2.484	2.534	2.774	2.674	2.680	2.466
Oskarshamn 1-3	2.207	1.619	1.871	1.473	1.250	1.477	1.484	1.673	1.862
Ringhals 1	0.75	0.517	0.644	0.386	0.456	0.615	0.647	0.741	0.255
Switzerland									
Leibstadt	0.99	0.867	0.806	0.860	0.838	0.798	0.876	0.880	0.886
Mühleberg	0.322	0.283	0.276	0.276	0.293	0.302	0.305	0.302	0.291
United States									
Big Rock Point	0.067	0.049	0.056	0.031	0.049	0.047	0.059	0.042	0.022
Browns Ferry 1-3	3.195	0.012	0.434	0.958	0.659	0.838	1.137	1.923	1.929
Brunswick 1-2	1.58	0.960	0.921	0.364	0.457	1.231	1.369	1.244	1.474
Clinton 1	0.946	0.411	0.690	0.563	0.671	0.846	0.697	0.606	0
Cooper	0.764	0.583	0.548	0.711	0.424	0.254	0.471	0.724	0.623
Dresden 2-3	1.545	1.058	0.636	0.829	0.916	0.657	0.613	0.585	1.099
Duane Arnold-1	0.538	0.345	0.473	0.392	0.370	0.469	0.427	0.450	0.474
Enrico Fermi 2	1.093	0.813	0.706	0.840	0.946	0	0.586	0.547	0.637
Fitzpatrick	0.757	0.525	0.385	0	0.542	0.568	0.548	0.604	0.756
Grand Gulf 1	1.142	0.845	1.041	0.933	0.902	1.098	0.892	1.053	1.235
Hatch 1-2	1.525	1.214	1.100	1.239	1.137	1.231	1.315	1.455	1.375
Hope Creek 1	1.031	0.465	0.845	0.806	1.007	0.813	0.807	0.773	0.733
Lasalle 1-2	2.072	1.696	1.776	1.400	1.492	1.527	1.615	1.021	0
Limerick 1-2	1.055	1.469	1.744	1.681	1.851	1.876	1.889	1.957	2.002
Millstone 1	0.654	0.582	0.203	0.413	0.602	0.376	0.497	0	0
Monticello	0.536	0.514	0.411	0.508	0.441	0.452	0.543	0.442	0.418
Nine Mile Point 1-2	1.682	0.623	1.191	0.922	1.318	1.515	1.299	1.527	1.322
Oyster Creek	0.62	0.491	0.337	0.517	0.533	0.415	0.593	0.495	0.579
Peach Bottom 2-3	2.086	1.625	1.169	1.468	1.600	1.863	1.888	1.950	1.956
Perry 1	1.141	0.758	1.025	0.818	0.454	0.524	1.040	0.854	0.931
Pilgrim 1	0.67	0.484	0.391	0.541	0.496	0.437	0.512	0.608	0.492
Quad Cities 1-2	1.538	1.109	1.009	0.871	0.931	0.649	0.957	0.839	0.935
River Bend 1	0.936	0.638	0.763	0.315	0.600	0.558	0.905	0.783	0.779
Susquehanna 1-2	2.07	1.682	1.811	1.551	1.549	1.749	1.784	1.927	1.920
Vermont Yankee	0.504	0.413	0.469	0.426	0.385	0.493	0.440	0.434	0.487
WPPSS 2	1.095	0.661	0.488	0.651	0.815	0.771	0.793	0.635	0.700
HWRs									
Argentina									
Atucha 1	0.335	0.197	0.311	0.255	0.274	0.303	0.305	0.233	0.311
Embalse	0.600	0.571	0.514	0.497	0.545	0.589	0.445	0.558	0.541
Canada									
Bruce 1-4	3.394	1.623	2.163	1.889	1.132	1.612	1.665	1.478	0.973
Bruce 5-8	3.371	2.759	3.019	2.699	2.277	2.742	2.648	2.857	2.704
Darlington 1-4	3.524	0.132	0.251	0.258	2.502	3.042	3.153	2.962	2.118
Gentilly-2	0.64	0.466	0.448	0.562	0.588	0.617	0.516	0.598	0.481
Pickering 1-4	2.06	0.804	1.143	1.264	1.650	1.475	0.858	0.746	1.142
Pickering 5-8	2.064	1.584	1.838	1.522	1.669	1.732	1.705	1.026	1.211
Point Lepreau	0.635	0.609	0.621	0.551	0.607	0.598	0.184	0.524	0.394
India									
Kakrapar 1-2	0.202	-	-	-		0.015	0.219	0.299	0.228
Kalpakkam 1-2	0.44	0.222	0.181	0.200	0.170	0.210	0.155	0.192	0.211
Narora 1-2	0.44	-	0.051	0.150	0.048	0.087	0.226	0.273	0.360
Rajasthan 1-2	0.414	0.176	0.125	0.106	0.151	0.060	0	0	0.030
Japan									
Fugen	0.165	0.099	0.128	0.109	0.119	0.110	0.143	0.115	0.077

Table 30 (continued)

Country	Capacity (GW)	Electrical energy generated (GW a)							
		1990	1991	1992	1993	1994	1995	1996	1997
Pakistan									
Karachi	0.125	0.043	0.042	0.057	0.042	0.060	0.053	0.035	0.044
Republic of Korea									
Wolsong 1	0.629	0.545	0.578	0.553	0.641	0.523	0.530	0.513	1.026
Romania									
Cernavoda 1	0.650	-	-	-	-	-		0.135	0.565
United Kingdom									
Winfrith	0.092	0.042	0	0	0	0	0	0	0
GCRs									
France									
Bugey 1	0.54	0.229	0.155	0.131	0.179	0.166	0	0	0
Chinon A2-3	0.54	0.143	0	0	0	0	0	0	0
St. Laurent A1-2	0.84	0.100	0.282	0.152	0	0	0	0	0
Japan									
Tokai 1	0.159	0.103	0.102	0.120	0.021	0.072	0.095	0.134	0.109
Spain									
Vandellos 1	0.48	0	0	0	0	0	0	0	
United Kingdom									
Berkeley	0.138	0	0	0	0	0	0	0	0
Bradwell	0.245	0.169	0.184	0.135	0.187	0.207	0.176	0.173	0.136
Calder Hall	0.198	0.157	0.155	0.162	0.168	0.170	0.163	0.159	0.157
Chapelcross	0.192	0.163	0.155	0.165	0.174	0.177	0.176	0.178	
Dungeness A	0.424	0.342	0.365	0.428	0.368	0.404	0.382	0.313	0.405
Dungeness B1-B2	0.72	0.169	0.471	0.390	0.662	0.566	0.170	0.689	0.606
Hartlepool A1-A2	0.84	0.564	0.549	0.825	0.995	0.913	0.828	1.008	0.967
Heysham 1A-B, 2A-B	2.07	0.811	1.183	1.586	1.924	1.928	1.803	1.883	1.989
Hinkley Point A	0.47	0.303	0.326	0.242	0.391	0.372	0.403	0.307	0.394
Hinkley Point B, A-B	1.25	0.864	0.794	0.858	0.980	1.025	1.062	0.905	0.993
Hunterston A1	0.3	0	0	0	0	0	0	0	0
Hunterston B1-B2	1.15	0.910	0.772	0.718	0.828	0.968	0.970	0.333	0.977
Oldbury A	0.434	0.333	0.363	0.390	0.404	0.398	0.389	0.381	0.402
Sizewell A	0.42	0.307	0.314	0.259	0.345	0.385	0.321	0.045	0.199
Torness A-B	1.25	0.444	0.590	0.944	0.872	0.891	0.994	0.314	1.045
Trawsfynydd	0.39	0.302	0.037	0	0	0	0	0	0
Wylfa	0.84	0.770	0.851	0.890	0.824	0.698	0.764	0.813	0.858
LWGRs									
Lithuania									
Ignalina 1-2	2.76	1.792	1.782	1.671	1.260	0.757	1.214	1.446	1.239
Russian Federation									
Bilibino 1-4	0.044	0.034	0.029	0.032	0.024	0.021	0.014	0.015	0.014
Kursk 1-4	3.7	2.605	2.401	2.120	2.334	1.852	1.857	2.001	1.930
Leningrad 1-4	3.7	2.431	2.395	2.092	2.329	2.111	1.888	2.075	2.409
Smolensk 1-3	1.85	1.999	2.175	2.334	2.228	1.711	1.762	2.088	1.738
Ukraine									
Chernobyl 1-3	2.575	1.815	1.509	0.602	1.327	1.089	1.228	1.210	0.463
FBRs									
France									
Creys-Malville	1.2	0.067	0	0	0	0.001		0.387	
Phenix	0.233	0.112	0	0	0.004	0.003		0.0003	
Kazakhstan									
Bn-350	0.135	-	-	0.053	0.051	0.043	0.009	0.010	0.035
Russian Federation									
Beloyarsky 3	0.56	0.365	0.387	0.467	0.447	0.435	0.390	0.425	0.405

Table 30 (continued)

Country	*Capacity (GW)*	*Electrical energy generated (GW a)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United Kingdom									
Dounreay PFR	0.25	0.061	0.089	0	0.103	0.038	0	0	0
All reactors									
All countries									
PWRS	224.1	138.7	145.3	151.8	152.9	157.1	161.7	169.4	167.7
BWRs	72.9	48.0	51.9	49.2	51.2	52.8	60.0	59.6	61.6
HWRs	19.8	9.9	11.4	10.7	12.4	13.8	12.8	12.5	12.4
GCRs	13.9	7.2	7.6	8.4	9.3	9.3	8.7	7.6	9.2
LWGRs	15.0	10.7	10.3	8.9	9.5	7.5	8.0	8.8	7.8
FBRs	2.4	0.61	0.48	0.52	0.61	0.52	0.40	0.82	0.44
Total	347.9	215.1	227.0	229.5	236.0	241.0	251.6	258.9	259.2

Table 31
Noble gases released from reactors in airborne effluents

Country / reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
PWRs								
Armenia [A5]								
Armenia 2							25 600	29 000
Belgium [M1]								
Doel 1-4	15 600	31 300	26 400	5 190	972	4 120	2 050	73.8
Tihange 1-3	34 100	16 600	10 900	40 500	11 900	4 120	14 600	9 810
Brazil [C7]								
Angra 1	318	688	20 100	44 800	176	229	7 720	61 600
Bulgaria [C6]								
Kozloduy 1-6	541 000	402 000	202 000	210 000	264 000	250 000	390 000	203 000
China [C8, T2]								
Guangdong 1-2	-	-	-		22 700	80 200	43 600	31 100
Qinshan	-	-	6.4	27.5	30.7	55.2	36.6	15.1
Maanshan 1-2	770	354	148	74	166	467	866	28.4
Czech Republic [N2]								
Dukovany 1-4	1 670	10 700	11 800	18 600	20 000	48 300	31 500	5 590
Finland [F1]								
Loviisa 1-2	1 000	1 000	1 800	1 600	1 400	24 000	1 100	3 400
France [E1]								
Belleville 1-2	60 000	44 000	16 000	46 000	22 000	20 000	22 000	23 000
Blayais 1-4	179 000	149 000	29 000	53 000	67 000	57 000	17 000	16 000
Bugey 2-5	42 000	45 000	12 000	19 000	11 000	13 000	12 000	10 000
Cattenom 1-4	81 000	99 000	48 000	22 000	26 000	24 000	22 000	24 000
Chinon B1-B4	139 000	169 000	76 000	40 000	41 000	44 000	34 000	25 000
Chooz-A (Ardennes)	71 000	129 000	50 000	37 000	45 000	40 000	240	210
Chooz B1-B2	-	-	-	-	-	-	16 000	10 000
Cruas 1-4	22 000	27 000	14 000	27 000	34 000	19 000	25 000	17 000
Dampierre 1-4	179 000	75 000	34 000	38 000	56 000	34 000	18 000	19 000
Fessenheim 1-2	8 200	13 000	6 200	7 900	5 500	6 800	9 200	7 100
Flamanville 1-2	5 900	6 500	15 000	14 000	11 000	11 000	11 000	31 000
Golfech 1-2	6 400	10 000	7 700	10 000	16 000	14 000	14 000	22 000
Gravelines 1-6	60 000	43 000	57 000	36 000	20 000	24 000	25 000	21 000
Nogent 1-2	46 000	28 000	24 000	29 000	16 000	16 000	12 000	15 000
Paluel 1-4	129 000	129 000	40 000	40 000	30 000	29 000	28 000	25 000
Penly 1-2	8 600	11 000	9 400	12 000	17 000	9 900	13 000	13 000
St. Alban 1-2	10 000	15 000	13 000	13 000	12 000	12 000	10 000	13 000
St. Laurent B1-B2	4 600	1 900	8 600	9 100	9 300	18 000	10 000	11 000
Tricastin 1-4	30 000	34 000	28 000	29 000	25 000	26 000	26 000	28 000
Germany [B3]								
Biblis A-B	9 800	7 000	10 500	10 600	12 100	8 300	2 600	4 490
Brokdorf	410	720	300	180	1 000	35 000	800	3 700
Emsland	98	110	100	270	610	600	120	100
Grafenrheinfeld	4 800	51	150	0	0	0	160	0
Greifswald	360 000	0	0	0	0	0	0	0
Grohnde	140	1 100	680	930	4 600	18 000	25 000	240
Isar 2	220	240	280	330	150	220	170	170
Mülheim-Kärlich	0	0	0	0	0	0	0	0
Neckarwestheim 1-2	18 200	13 500	15 500	6 100	4 000	3 700	4 600	2 150
Obrigheim	130	50	150	1 200	430	620	330	200
Philippsburg 2	110	480	1 800	360	11 000	1 700	1 100	5 800
Stade	2 200	1 900	1 600	1 300	2 100	1 700	1 900	1 200
Unterweser	3 200	2 700	4 500	4 700	3 100	3 600	3 500	3 500
Hungary [F2]								
Paks 1-4	178 000	146 800	195 400	166 000	183 700	174 300	81 300	44 200

Table 31 (continued)

Country / reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Genkai 1-4	650	520	370	230	170	130	85	66
Ikata 1-3	4.2	28	480	7.2	0.57	1.1	0.45	0.60
Mihama 1-3	250	280	1 100	200	110	160	190	190
Ohi 1-4	680	560	530	470	600	510	430	430
Sendai 1-2	59	32	38	30	32	39	37	34
Takahama 1-4	350	1 800	440	620	200	210	330	370
Tomari 1-2	0.73	3.8	1.6	0.17	0.41	2.5	3.0	2.4
Tsuruga 2	9.6	6.5	2.9	2.7	3.6	0.38	3.8	3.0
Netherlands [N7]								
Borssele	7 860	4 300	1 130	763	27 900	6 530	1 950	6 410
Republic of Korea [K1]								
Kori 1-4	12 600	18 500	102 000	206 000	14 000	4 100	6 000	6 790
Ulchin 1-2	6 180	241	104	56.6	20.0	41.0	215	680
Yonggwang 1-4	5 770	7 290	6 590	59 20	5 000	11 000	5 500	4 220
Russian Federation [M6]								
Balakovo 1-4	40 700	26 800	62 900	60 100	15 800	13 500	6 880	6 380
Kalinin 1-2	56 700	30 300	36 700	31 900	27 000	20 300	18 400	24 700
Kola 1-4	272 000	359 900	275 500	178 300	78 800	129 600	101 300	75 600
Novovoronezh 2-5	47 400	44 400	33 500	27 000	24 300	24 300	33 800	38 000
Slovakia [N2, S4]								
Bohunice 1-4	20 100	26 600	22 200	17 700	17 600	17 800	24 400	26 400
Slovenia [S1]								
Krsko	1 630	620	2 530	5 030	9 960	24 800	12 580	2 500
South Africa [C11]								
Koeberg 1-2	14 520	16 970	25 190	44 600	45 480	67 610	132 300	12 200
Spain [C2]								
Almaraz 1-2	4 790	7 480	7 060	13 200	4 830	29 700	52 900	46 700
Asco 1-2	168 700	64 110	13 960	23 400	40 500	19 410	3 550	2 380
José Cabrera 1	45 900	34 900	50 100	56 200	4 670	31 100	21 800	15 600
Trillo 1	10 800	17.1	17.2	1 260	436	5 060	87.2	8 030
Vandellos 2	79 600	23 400	4 330	306	57.2	144	264	283
Sweden [N3]								
Ringhals 2-4	218 000	69 700	58 700	25 100	18 600	15 300	24 200	1 330
Switzerland [F3]								
Beznau 1-2	29 000	46 000	30 000	19 000	28 000	2 600	2 600	2 500
Gösgen	7 400	5 100	4 500	11 000	3 800	19 000	13 000	24 000
Ukraine [G3]								
Khmelnitski 1	56 200	32 000	74 800	21 300	14 300	57 000	74 100	21 700
Rovno 1-3	87 100	69 300	89 800	44 000	113 000	100 000	93 200	89 100
South Ukraine 1-3	51 400	52 800	78 200	98 300	32 800	48 900	70 200	50 400
Zaporozhe 1-6	101 000	154 000	200 000	122 000	117 000	122 000	80 600	112 000
United Kingdom [M7]								
Sizewell B	-	-	-	-	-	-	6 110	4 360
United States [T3]								
Arkansas One 1-2	32 900	77 100	95 900	2 590	14 400	153 000	16 650	127
Beaver Valley 1-2	3 020	5 510	5 740	20 600	7 620	5 810	10 500	5 660
Braidwood 1-2	90 300	389 000	8 620	102 000	56 100	1 100		
Byron 1-2	45 900	3 850	13 900	4 510		4 260	1 010	
Callaway 1	33 400	5 030	14 800	29 900	1 220	1 820	5 150	14 900
Calvert Cliffs 1-2	24 900	95 100	217 000	7 920	5 740	3 130	2 940	7 960
Catawba 1-2	39 500	29 700	31 700	48 000	33 400	8 810	5 330	6 310
Comanche Peak 1-2	33 500	218 000	65 100	7 100	81	1 046	932	95
Crystal River 3	270 000	52 200	29 100	1 410	4 320		386	
Davis-Besse 1	40 300	42 900	1 340	12 900	5 460	11 100	17 800	164
Diablo Canyon 1-2	2 080	1 710	91.0	79.2	7 230	16 500	6 180	82.5
Donald Cook 1-2	6 960	2 620	7 570	76 200	10 730	5 030	3 860	639

Table 31 (continued)

Country / reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*								
Farley 1-2	4 480	17 200	26 200	8 140	7 780	2 690	2 530	5 210
Fort Calhoun 1	17 000	13 200	5 590	343	1 960	20 000	307 000	
R. E. Ginna	22 000	19 000	20 000	5 180	1 840	1 660	3 170	
Haddam Neck	54 000	226 000	103	77 000				
Harris 1	22 100	31 900	50 300	12 900	7 070	8 210	1 590	1 380
Indian Point 1-3	106 000	54 400	195 000	63 700				
Kewaunee	85.5	67.0	59.2	1 360	16.2	6.4	1.5	0
Maine Yankee	35 000	41 800	14 800	1 670	720	618	456	1 530
McGuire 1-2	38 400	33 200	30 000	35 800	38 300	9 320	962	292
Millstone 2-3	114 400	15 300	23 500	1 600	1 740	3 650	667	0
North Anna 1-2	35 300	8 300	45 400	9 300	1 600	1 300	700	900
Oconee 1-2-3	327 000	128 000	122 000	24 300	129 500	47 730	3 370	2 340
Palisades	4 480	2 320	2 760	3 440	656	6 180	2 140	823
Palo Verde 1-3	95 600	143 000	91 200	38 400	16 500	12 100	9 810	
Point Beach 1-2	297	740	1 870	374	359	910	271	66.2
Prairie Island 1-2	3 060	2 070	940	1 360	879	3 120	40.3	27.7
Rancho Seco 1	8.14	0	2.56	0				
H. B. Robinson 2	258	83.6	281	12 430	2 140	99.2	470	36.9
Salem 1-2	17 100	20 600	34 900	54 100	27 500	7 130	0.39	360
San Onofre 1-3	110 000	140 000	205 000	72 600	13 500	25 800	15 800	8 320
Seabrook 1	3 960	1 080	33.8	4.0				
Sequoyah 1-2	225 000	52 500	7 660	2 850	4 200		1 390	
South Texas 1-2	10 400	4 890	33 700	1 560	2 020	1 170	1 170	7 210
St. Lucie 1-2	42 700	94 000	36 600	12 800	6 310	13 900		
Surry 1-2	16 600	1 300	600	1 500	10 200	8 400	14 800	18 400
Three Mile Island 1	24 600	4 500	21 200	88 600	12 500	22 600	55.9	540
Trojan	7 620	6 140	7 660	1 980	914	415	711	325
Turkey Point 3-4	47 400	682	4 580	16 800	1 090			
Virgil C. Summer 1	27 800	16 100	12 500	8 990	5 000	103	21.9	9.4
Vogtle 1-2	6 960	13 200	4 200	8 680	2 900	41 400	67 800	8 300
Waterford 3	212 000	79 600	25 600	33 800	76 800	64 380	2 970	20 500
Watts Bar	-	-	-				7 190	
Wolf Creek	37 000	111 000	11 400	19 200			53 600	
Yankee NPS	4 250	7 970	0	0	0	0	0	0
Zion 1-2	4 070	10 200	12 400	98 200	68 600	49 100	1 710	132
BWRs								
China [T2]								
Chin Shan 1-2	26 700	33 000	99 200	26 500	7 510	11 900	2 290	1 210
Kuosheng 1-2	3 550	2 910	1 280	784	995	1 870	227	334
Finland [F1]								
Olkiluoto 1-2	22 000	43 000	29 000	9 500	41 000	52 000	18 000	1 100
Germany [B3]								
Brunsbüttel	4 800	1 300	1 600	0	0	6 600	7 200	3 900
Gundremmingen B,C	7 000	130	11	2.8	21	1.2	0	310
Isar 1	0.2	1.2	0	150	93	400	150	810
Krümmel	690	450	6 100	540	160	17 000	14 000	11 000
Philippsburg 1	14	130	1 200	340	1 800	880	520	860
Würgassen	610	2 100	1 400	1 000	960	0	21	0
India [B4]								
Tarapur 1-2	5 940 000	7 629 000	6 348 000	9 410 000	6 560 000			
Japan [J1, J5]								
Fukushima Daiichi 1-6	0	0	0	0	0	0	0	0
Fukushima Daini 1-4	0	0	0	0	0	0	0	0
Hamaoka 1-4	0	0	0	0	190	0	0	0
Kashiwazaki Kariwa 1-7	0	0	0	0	0	0	0	0
Onagawa 1-2	0	0	0	0	0	0	0	0
Shika 1	-	-	0	0	0	0	0	0
Shimane 1-2	0	0	0	0	0	0	0	0
Tokai 2	0	0	0	0	0	0	0	0
Tsuruga 1	0.55	3.9	0	0	0	0	0	0

Table 31 (continued)

Country / reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico [C5]								
Laguna Verde 1-2	3 400	2 240	567	134	25	1 570	374	345
Netherlands [N7]								
Dodewaard	33 000	6 410	11 800	13 500	12 800	3 190	3 880	23 300
Spain [C2]								
Confrentes	26 700	119 000	136 000	46 100	21 400	9 320	5 150	8 000
S. Maria de Garona	53 500	73 700	58 100	73 100	17 100	7 470	648	294
Sweden [N3]								
Barsebeck 1-2	59 100	407 000	24 600	16 000	20 500	22 100	17 900	7 320
Forsmark 1-3	450 000	654 000	501 000	394 000	68 300	19 800	87 000	25 600
Oskarshamn 1-3	1 970 000	1 260 000	546 000	279 000	266 000	112 000	138 000	794 000
Ringhals 1	56 670	71 800	1 440 000	12 700 000	24 300 000	15 700 000	6 690 000	1 310 000
Switzerland [F3]								
Leibstadt	48 000	38 000	19 000	29 000	74 000	17 000	8 700	8 500
Mühleberg	110 000	16 000	3 600	3 800	2 700	2 000	2 000	2 000
United States [T3]								
Big Rock Point	205 000	167 000	66 200	190 000	246 000	181 300	129 000	81 800
Browns Ferry 1-3	0	77 700	618 000	148 000	23 800			
Brunswick 1-2	41 400	25 000	18 100	12 600	17 660	159 600	26 400	35 000
Clinton 1	356	26.2	273	309	43	5.62	4.80	0
Cooper	6 920	958	519	238	1 470	662	71 700	536 000
Dresden 2-3	755	466	488	1 790	276	3 260	2 440	8 970
Duane Arnold 1	1 690	1 220	1 750	2 110	1 970	1 820	1 490	1 790
Enrico Fermi 2	5 960	2 300	7 700	5 740	18.1	888	2 450	30 100
Fitzpatrick	50 000	75 900	6 330	15 400	14 500	3 950	23 800	2 510
Grand Gulf 1	5 030	1 170	7 840	3 490	1 240	2 170	3 460	1 440
Hatch 1-2	40 800	10 400	38 700	141 000	63 800	53 700	157 000	183 500
Hope Creek 1	30 700	7 100	5 140	2 710	16.3	5 550	960	852
Lasalle 1-2	25 400	3 920	4 370	38 600	1 540	145		
Limerick 1-2	1 270	2 630	31 700	5 960	2 910	16 900		
Millstone 1	4 330	870	165	12 200	400	13 200	0	0
Monticello	110 000	73 600	48 100	22 200	20 100	16 700	14 400	12 600
Nine Mile Point 1-2	6 030	5 570	13 800	20 000	8 580			
Oyster Creek	27 200	17 000	15 200	8 100	12 500	2 900	2 360	810
Peach Bottom 2-3	414 000	888 000	312 000	411 000	646 000	656 000	35 300	
Perry 1	3 100	4 110	12 100	25 300	8 690	19 700	4 150	
Pilgrim 1	33 600	82 300	43 400	34 900	68 600	86 600	17 800	7 160
Quad Cities 1-2	2 950	1 560	1 820	1 410	1 110	2 050	1 030	998
River Bend 1	38 100	41 400	17 200	25 800	25 000	6 150	7 510	8 460
Susquehanna 1-2	2 670	2 130	2 120	625	439	566	629	667
Vermont Yankee	188 000	112 000	219 000	140 000	117 000	329	228	127
WPPSS 2	32 900	26 800	5 590	5 220	259	888	666	
HWRs								
Argentina [C3]								
Atucha 1	89 000	11 000	3 000	110 000	240 000	360 000	320 000	960 000
Embalse	660 000	1 200 000	150 000	42 000	17 000	44 000	180 000	30 000
Canada [A2]								
Bruce 1-4	518 000	903 000	564 000	435 000	248 000	100 000	88 000	54 000
Bruce 5-8	37 000	35 000	41 000	101 000	70 300	67 000	70 000	74 000
Darlington 1-4	21 000	67 000	73 000	146 000	141 000	110 000	380 000	295 000
Gentilly 2	60 000	48 000	33 000	69 000	59 000	73 000	54 000	21 000
Pickering 1-4	407 000	500 000	326 000	370 000	344 000	310 000	310 000	290 000
Pickering 5-8	237 000	212 000	207 000	215 000	222 000	220 000	200 000	210 000
Point Lepreau	0	13 000	11 000	4 900	5 100	2 200	5 600	5 900
India [B4]								
Kakrapar 1-2	-	-	-					
Kalpakkam 1-2	18 110 000	12 790 000	13 910 000	5 539 000	11 440 000			
Narora 1-2	22 240	34 730	635 000	226 100	2 579 000			
Rajasthan 1-2	11 620 000	10 380 000	4 760 000	12 430 000	4 443 000			

Table 31 (continued)

Country / reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Fugen	0	22	0	0	0	0	0	0
Pakistan [P2]								
Karachi	0	0	0	0	0	0	0	0
Republic of Korea [K1]								
Wolsong 1-2	112 000	114 000	65 900	219 000	120 000	750 000	3 200 000	60 300
Romania								
Cernavoda 1	-	-	-	-	-	-	60 300	61 700
United Kingdom [N5]								
Wilfrith		0	3.27	7.85	2.1			0.42
GCRs								
France [E1]								
Bugey 1	77 000	53 000	11 000	15 000	9 200	3 800	-	0
Chinon A2-3	32 000	9 100	6 700	110	110	210	250	220
St. Laurent A1-2	78 000	43 000	16 000	200	140	-	-	-
Japan [J1, J4]								
Tokai 1	270 000	250 000	300 000	0	280 000	250 000	310 000	360 000
Spain [C2]								
Vandellos 1	891	432	959	334	0	0	0	
U. K. [M7, N4, N5]								
Berkeley	0	0	0	0				
Bradwell	595 000	650 000	410 000	693 000	773 000	662 000	647 000	510 000
Calder Hall	2 500 000	2 500 000	2 560 000	2 700 000	2 800 000	2 700 000		2 600 000
Chapelcross	2 900 000	3 000 000	3 000 000	3 200 000	3 200 000	3 200 000	3 210 000	2 730 000
Dungeness A	1 123 000	1 170 000	1 310 000	1 192 000	1 244 000	1 195 000	1 190 000	977 000
Dungeness B1-B2	16 800	30 000	22 000	30 000	23 000	7 000	27 900	19 300
Hartlepool A1-A2	6 600	12 900	12 500	20 200	44 000	13 000	23 900	37 800
Heysham 1A-B, 2A-B	15 300	15 600	55 200	24 000	23 000	50 000	23 600	28 900
Hinkley Point A	2 148 000	2 511 000	2 118 000	3 171 000	3 060 000	3 200 000	33 200	3 030 000
Hinkley Point B, A-B	82 000	89 000	95 000	39 000	39 000	42 000	33 200	16 700
Hunterston A1	86 000	0	0	0	0	0	0	0
Hunterston B1-B2	60 000	29 000	21 000	30 000	30 000	55 000	49 500	66 100
Oldbury A	108 000	81 000	143 000	207 000	170 000	250 000	112 000	111 000
Sizewell A	1 872 000	1 8010 00	1 676 000	2 0230 00	2 347 000	1 952 000	295 000	1 230 000
Torness A-B	5 600	5 300	3 800	5 000	8 100	7 000	6 990	12 200
Trawsfynydd	1 489 000	219 000	0	0	0	0	0	0
Wylfa	70 500	30 000	56 000	55 500	36 000	19 000	43 900	51 400
LWGRs								
Lithuania [E2]								
Ignalina 1-2	2 370 000	1 800 000	700 000	480 000	290 000	283 000	158 000	99 700
Russian Federation [M6]								
Bilibino 1-4	297 300	276 900	345 400	326 000	418 700	293 100	395 700	270 100
Kursk 1-4	8 700 000	6 030 000	6 075 000	6 285 000	3 009 000	1 113 000	1 152 000	611 700
Leningrad 1-4	1 606 000	1 539 000	1 392 000	1 614 000	1 789 000	1 073 000	1 036 000	958 900
Smolensk 1-3	7 170 000	4 473 000	3 815 000	2 257 000	1 121 000	1 022 000	675 300	686 600
Ukraine [G3]								
Chernobyl 1-3	3 730 000	3 770 000	3 200 000	3 800 000	1 700 000	900 000	610 000	91 900
FBRs								
France [E1]								
Creys-Malville	46 000	43 000	43 000	44 000	45 000	45 000	44 000	43 000
Phenix								
Kazakhstan [A6]								
Bn-350	140 000	165 000	139 000	117 000	108 000	48 300	48 400	102 000

Table 31 (continued)

Country / reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Russian Federation [M6]								
Beloyarsky 3	12 900	11 000	8 100	8 100	13 500	4 070	4 070	8 100
United Kingdom [N5]								
Dounreay PFR	12 100	18 900	0	6 050	11 100	0	0	0

Summary parameter	*Reactor*	*Release (TBq)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
All reactors									
Total release (TBq)	PWRs	5 900	4 888	3 714	3 041	2 242	2 393	2 321	1 436
	BWRs	10 090	11 990	10 730	24 280	32 680	17 220	7 499	3 112
	HWRs	31 890	26 310	20 780	19 910	19 930	2 036	4 868	2 062
	GCRs	13 540	12 500	11 820	13 410	14 090	13 610	6 006	11 780
	LWGRs	23 870	17 890	15 530	14 760	8 328	4 682	4 027	2 719
	FBRs	211	238	190	175	178	97	96	153
	All	85 500	73 810	62 760	75 570	77 440	40 040	24 820	21 260
Annual normalized release [TBq $(GW\ a)^{-1}$]	PWRs	43	34	25	20	15	16	14	9.5
	BWRs	210	231	218	474	619	300	141	59
	HWRs	3 250	2 310	1 950	1 600	1 450	167	413	178
	GCRs	1 880	1 630	1 410	1 440	1 510	1 560	803	1 280
	LWGRs	2 240	1 740	1 750	1 550	1 100	588	456	349
	FBRs	428	500	365	292	343	244	117	348
	All	399	327	275	321	329	166	102	93
Average normalized release 1990-1994 and 1995-1997 [TBq $(GW\ a)^{-1}$]	PWRs	27					13		
	BWRs	354					171		
	HWRs	2 050					252		
	GCRs	1 560					1 240		
	LWGRs	1 720					465		
	FBRs	380					209		
	All	330					120		

Table 32
Tritium released from reactors in airborne effluents

Country/reactor	Release (GBq)							
	1990	1991	1992	1993	1994	1995	1996	1997
PWRs								
Armenia								
Armenia 2								
Belgium [M1]								
Doel 1-4	752	548	774	2 020	1 990	613	287	227
Tihange 1-3	-	-	-	12 800	4 950	5 970	4 420	5 050
Brazil [C7]								
Angra 1	5.85	27.8	2 930	611	2.26	17.4	110	3 480
Bulgaria [C6]								
Kozloduy 1-6	Not reported							
China [C8, T2]								
Guangdong 1-2	-	-	-		330	232	411	
Qinshan	-	-		26.6	193	264	405	
Maanshan 1-2	847	2 270	5 330	6 290	5 110	6 590	5 580	8 430
Czech Republic [N2]								
Dukovany 1-4	447	432	416	325	466	410	412	308
Finland [F1]								
Loviisa 1-2	740	480	230	210	210	190	220	250
France [E1]								
Belleville 1-2	Amounts included with noble gases (Table 31)							
Blayais 1-4								
Bugey 2-5								
Cattenom 1-4								
Chinon B1-B4								
Chooz-A (Ardennes)								
Chooz B1-B2								
Cruas 1-4								
Dampierre 1-4								
Fessenheim 1-2								
Flamanville 1-2								
Golfech 1-2								
Gravelines 1-6								
Nogent 1-2								
Paluel 1-4								
Penly 1-2								
St. Alban 1-2								
St. Laurent B1-B2								
Tricastin 1-4								
Germany [B3]								
Biblis A-B	590	550	610	690	580	530	220	490
Brokdorf	110	220	180	210	330	350	370	320
Emsland	480	670	510	780	1 300	1 600	2 000	1 900
Grafenrheinfeld	460	440	540	610	520	520	550	290
Greifswald	0	68	10	12	20	7.6	2.6	1.7
Grohnde	760	730	500	720	530	360	680	190
Isar 2	890	950	1 300	1 400	1 300	1 300	1 300	970
Mülheim-Kärlich	270	180	150	100	110	90	80	40
Neckarwestheim 1-2	1 090	1 230	900	980	630	600	450	390
Obrigheim	230	100	130	130	72	99	150	130
Philippsburg 2	1 600	1 400	1 500	1 200	1 100	960	970	1 100
Stade	1 100	430	340	400	670	790	330	2 100
Unterweser	1 100	1 200	410	480	1 100	1 300	560	350
Hungary [F2]								
Paks 1-4	480	2 100	3 400	4 000	4 500	4 630	4 330	4 780

Table 32 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Genkai 1-4	700	540	580	560	1 100	690	850	880
Ikata 1-3	450	410	490	710	620	730	810	730
Mihama 1-3	6 000	6 500	7 100	8 100	6 900	6 800	6 700	6 200
Ohi 1-4	1 900	3 900	3 800	4 700	8 000	6 300	8 300	7 500
Sendai 1-2	360	320	530	420	550	640	750	650
Takahama 1-4	2 600	2 900	4 600	5 200	5 400	5 900	8 200	8 400
Tomari 1-2	370	270	500	360	280	350	430	510
Tsuruga 2	900	1 200	720	1 400	2 300	2 300	2 200	3 400
Netherlands [N7]								
Borssele	446	210	353	565	386	343	371	177
Republic of Korea [K1]								
Kori 1-4	10 000	7 580	12 500	8 760	9 100	14 000	15 200	14 000
Ulchin 1-2	346	825	1 250	1 120	1 900	1 900	1 900	3 590
Yonggwang 1-4	592	3 050	1 930	1 820	3 400	8 100	8 800	8 660
Russian Federation [M6]								
Balakovo 1-4								
Kalinin 1-2	Reported to be ≈ 0							
Kola 1-4								
Novovoronezh 2-5								
Slovakia [N2, S4]								
Bohunice 1-4	963	1 045	1 066	924	890	1 090	922	581
Slovenia [S1]								
Krsko	2 460	2 050	1 510	1 960	1 720	1 310	1 160	1 050
South Africa [C11]								
Koeberg 1-2	3 640	7 070	5 610	5 270	3 130	2 840	4 610	10 200
Spain [C2]								
Almaraz 1-2	1 300	4 180	6 970	10 100	5 450	5 660	5 260	6 370
Asco 1-2	1 322	1 144	1 103	1 185	2 121	19 410	3 550	2 290
José Cabrera 1	517	266	661	193	34.9	25.3	26.6	88.9
Trillo 1	0	0	355	239	904	902	877	743
Vandellos 2	170	85.8	34.7	25.3	42.6	84.2	56.7	180
Sweden [N3]								
Ringhals 2-4	Not measured							
Switzerland [F3]								
Beznau 1-2	Not measured							
Gösgen								
Ukraine [G3]								
Khmelnitski 1								
Rovno 1-3	Reported to be ≈ 0							
South Ukraine 1-3								
Zaporozhe 1-6								
United Kingdom [M7]								
Sizewell B	-	-	-	-	-	-	579	565
United States [T3]								
Arkansas One 1-2	478	869	1 120	644	852	1 130	959	825
Beaver Valley 1-2	3 240	4 960	8 030	12 800	12 400	12 800	13 100	9 070
Braidwood 1-2	3 180	3 610	10 000	1 440	1 280	525		
Byron 1-2	39.6	33.3	114	34		158	1 380	
Callaway 1	1 370	1 360	1 950	3 370	3 310	3 690	3 240	2 980
Calvert Cliffs 1-2	16.7	428	362	909	46.3	93.0	98.9	213
Catawba 1-2	3 370	4 610	6 150	4 230	3 450	5 270	6 850	6 280
Comanche Peak 1-2	225	86.2	112	222	316	857	1 625	2 160
Crystal River 3	980	500	555	488	1 550		576	
Davis-Besse 1	1 070	2 390	799	829	831	779	1 350	1 310
Diablo Canyon 1-2	2 070	3 470	5 110	5 770	16 900	5 440	4 660	5 110
Donald Cook 1-2	366	1 070	725	955	1 370	3 490	3 300	10 900

Table 32 (continued)

Country/reactor	Release (GBq)							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*								
Farley 1-2	3 240	5 140	3 490	2 680	3 970	1 410	1 830	3 360
Fort Calhoun 1	273	12.6	225	44	9.9	30.5	144	
R. E. Ginna	4 590	3 090	2 130	1 910	1 630	1 940	1 520	
Haddam Neck	2 890	11 500	6 960	2 380				
Harris 1	57.7	30.0	16.2	1 880	0.5	25.5	924	340
Indian Point 1-3	116	281	225	182				
Kewaunee	221	289	451	60	161	2 430	819	58
Maine Yankee	1 380	338	147	270	770	1 170	378	1 110
McGuire 1-2	1 850	2 390	2 220	3 060	2 120	2 180	2 570	3 010
Millstone 2-3	4 060	3 570	3 690	4 060	1 390	43.6	1 810	618
North Anna 1-2	1 150	1 810	1 830	1 720	4 100	7 500	1 300	2 900
Oconee 1-2-3	3 740	4 030	2 390	1 640	1 590	1 600	2 650	2 420
Palisades	206	181	231	314	233	381	390	420
Palo Verde 1-3	27 900	49 300	36 400	47 100	55 200	43 800	70 000	
Point Beach 1-2	4 740	4 180	3 660	5 290	3 030	3 140	2 710	5 510
Prairie Island 1-2	4 660	2 600	1 570	2 330	2 480	1 460	1 600	1 200
Rancho Seco 1	1 080	703	681	279				
H. B. Robinson 2	164	166	158	294	206	542	445	505
Salem 1-2	5 710	4 110	5 250	6 250	2 530	1 250	6 920	11 700
San Onofre 1-3	4 590	1 650	2 870	2 290	1 970	1 580	1 080	2 460
Seabrook 1	9.32	507	58.1	23.4				
Sequoyah 1-2	433	1 070	1 850	1 470	548		2 350	
South Texas 1-2	1 530	847	3 970	541	5 990	6 300	5 450	1 390
St. Lucie 1-2	3 910	4 160	2 240	924	1 070	2 750		
Surry 1-2	800	900	900	900	600	600	800	1 500
Three Mile Island 1	1 220	18 100	3 520	6 780	601	694	388	4 800
Trojan	3 410	7 330	1 090	1 600	1 610	2 090	401	526
Turkey Point 3-4	2 940	10.8	1.47	306	53.1			
Virgil C. Summer 1	84.4	308	9.14	82.9	1 120	345	514	207
Vogtle 1-2	7 960	7 230	7 890	8 260	4 380	10 600	6 390	3 900
Waterford 3	7 590	16 200	11 500	3 770	5 590	4 510	3 330	7 290
Watts Bar	-	-	-	-			317	
Wolf Creek	690	555	640	951			1 490	
Yankee NPS	138	231	108	48	31	18.6	14.3	9.78
Zion 1-2	666	2 630	2 090	9 880	4 810	5 000	10 500	87.0
BWRs								
China [T2]								
Chin Shan 1-2	833	1 230	662	821	1 340	1 250	1 930	1 590
Kuosheng 1-2	1 290	2 500	1 760	1 540	1 250	1 080	765	535
Finland [F1]								
Olkiluoto 1-2	100	130	350	430	310	130	210	300
Germany [B3]								
Brunsbüttel	89	62	99	32	22	19	40	35
Gundremmingen B,C	200	380	470	300	470	1 300	2 200	1 200
Isar 1	430	560	74	82	88	44	56	60
Krümmel	79	99	51	31	13	45	46	42
Philippsburg 1	52	61	130	66	75	81	71	54
Würgassen	95	390	290	200	150	23	9.3	6
India [B4]								
Tarapur 1-2								
Japan [J1, J5]								
Fukushima Daiichi 1-6	2 500	2 100	1 900	1 500	1 600	1 600	1 500	1 900
Fukushima Daini 1-4	1 100	1 100	1 200	1 200	1 200	1 400	1 600	1 500
Hamaoka 1-4	820	730	720	780	570	640	810	860
Kashiwazaki Kariwa 1-7	510	560	660	790	1 100	1 400	1 700	2 000
Onagawa 1-2	190	210	190	200	210	210	310	370
Shika 1	-	-	0	13	66	90	79	100
Shimane 1-2	310	410	750	880	990	820	870	770
Tokai 2	580	560	570	550	570	390	460	420
Tsuruga 1	270	250	220	160	140	170	160	160

Table 32 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico [C5]								
Laguna Verde 1-2	0	105	73	540	657	1 520	651	1 180
Netherlands [N7]								
Dodewaard	10.8	119	71.8	39.6	15.2	25.9	9.5	11.2
Spain [C2]								
Confrentes	35.6	33.1	178	496	497	290	459	1 180
S. Maria de Garona	497	882	312	347	273	543	370	264
Sweden [N3]								
Barsebeck 1-2	Not measured							
Forsmark 1-3								
Oskarshamn 1-3								
Ringhals 1								
Switzerland [F3]								
Leibstadt						220	330	590
Mühleberg								
United States [T3]								
Big Rock Point	179	175	122	84.7	100	77	96.6	85.5
Browns Ferry 1-3	22	102	703	346	1 290			
Brunswick 1-2	984	718	400	740	836	1 350	999	860
Clinton 1	70	193	176	422	1 160	570	440	126
Cooper	0	0	0	0	0	0	0	0
Dresden 2-3	485	236	191	261	213	177	97.4	221
Duane Arnold 1	603	514	278	1 370	436	547	423	2 690
Enrico Fermi 2	0	0	1 070	87	0	0	0	0
Fitzpatrick	448	188	53	293	295	271	701	3 770
Grand Gulf 1	123	206	328	847	1 970	1 680	3 250	5 770
Hatch 1-2	1 480	1 260	1 850	2 450	2 660	1 610	793	630
Hope Creek 1	3 030	903	836	6 140	160	11.6	702	237
Lasalle 1-2	6.29	25	1 360	4 810	4 870	4 330		
Limerick 1-2	-	-	-	31	0	0		
Millstone 1	1 430	1 210	1 450	944	218	10.8	0	0
Monticello	3 160	2 380	3 850	2 060	2 680	1 570	807	556
Nine Mile Point 1-2	2 060	1 140	2 060	3 570	4 320			
Oyster Creek	424	283	404	136	1 310	440	558	5 500
Peach Bottom 2-3	1 150	1 480	1 470	844	388	6 170	11 400	
Perry 1	0	0	2.11	0	0	24.3	0	
Pilgrim 1	588	805	850	670	1 330	1 770	2 690	
Quad Cities 1-2	4 290	5 550	1 670	1 690	1 050	1 150	1 920	1 570
River Bend 1	1 670	507	86.2	200	344	90	106	2 720
Susquehanna 1-2	3 420	1 710	1 940	1 610	1 990	2 300	3 100	250
Vermont Yankee	3 580	3 130	948	877	813	824	902	2 050
WPPSS 2	1 370	448	1 780	5 550	370	211	285	596
HWRs								
Argentina [C3]								
Atucha 1	620 000	230 000	410 000	2 600 000	1 400 000	53 000	1 100 000	1 300 000
Embalse	75 000	55 000	69 000	140 000	130 000	83 000	69 000	77 000
Canada [A2]								
Bruce 1-4	1 628 000	1 193 000	1 100 000	1 650 000	999 000	610 000	700 000	350 000
Bruce 5-8	777 000	385 000	340 000	391 000	366 000	230 000	310 000	270 000
Darlington 1-4	118 000	231 000	110 000	130 000	330 000	270 000	200 000	190 000
Gentilly 2	227 000	270 000	322 000	200 000	258 000	310 000	220 000	160 000
Pickering 1-4	629 000	635 000	592 000	518 000	481 000	590 000	370 000	440 000
Pickering 5-8	277 000	183 000	192 000	244 000	226 000	190 000	190 000	170 000
Point Lepreau	250 000	170 000	400 000	640 000	520 000	310 000	240 000	200 000
India [B4]								
Kakrapar 1								
Kalpakkam 1-2	830 000	854 000	1 119 000	2 100 000	1 620 000			
Narora 1-2	66 000	182 500	244 600	118 400	264 700			
Rajasthan 1-2	2 561 000	1 768 000	820 000	703 300	765 900			

Table 32 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Fugen	1 200	1 300	1 600	1 200	1 800	1 300	1 000	1 200
Pakistan [P2]								
Karachi	89 400	77 300	56 800	281 000	220 000	309 000	184 700	130 900
Republic of Korea [K1]								
Wolsong 1-2	231 000	257 000	389 000	368 000	480 000	440 000	310 000	625 000
Romania								
Cernavoda	-	-	-	-	-	-	1 370	25 500
United Kingdom [N5]								
Winfrith	8 390	3 990	4 620	4 250	10 930			366
GCRs								
France [E1]								
Bugey 1								
Chinon A2-3	Amounts included with noble gases (Table 31)							
St. Laurent A1-2								
Japan [J1, J5]								
Tokai 1	480	570	420	170	260	540	480	290
Spain [C2]								
Vandellos 1	0	0	0	0	0	0	0.002	
U. K. [M7, N4, N5]								
Berkeley			14	22	51	11	9.6	11
Bradwell			-	814	676	1 270	786	1 100
Calder Hall	2 760	2 640	3 210	3 000	5 100	5 600		4 400
Chapelcross								
Dungeness A			-	-	145	620	1 030	570
Dungeness B1-B2			-	-	2 540	2 440	1 520	4 780
Hartlepool A1-A2			-	-	-	1 120	1 560	1 610
Heysham 1A-B, 2A-B	670	1 170	2 530	2 000	2 050	3 260	3 060	2 720
Hinkley Point A			1 570	1 550	2 610	2 620	2 100	2 980
Hinkley Point B, A-B			897	1 620	1 830	2 500	2 100	1 960
Hunterston A1	460	130	69	35	31	16	0.6	4.9
Hunterston B1-B2	5 800	2 900	2 600	4 600	2 900	5 000	2 180	2 810
Oldbury A			1 680	1 960	1 860	1 890	1 730	1 480
Sizewell A-B			-	-	990	1 470	871	639
Torness A-B	1 300	1 900	1 300	1 700	1 700	1 300	1 260	1 810
Trawsfynydd			-	79	134	155	63	277
Wylfa	12 810	10 190	9 030	7 790	14 980	10 300	6 700	5 290
LWGRs								
Lithuania								
Ignalina 1-2	Only average normalized release reported							
Russian Federation [M6]								
Bilibino 1-4								
Kursk 1-4	Only average normalized release reported							
Leningrad 1-4								
Smolensk 1-3								
Ukraine [G3]								
Chernobyl 1-3								
FBRs								
France								
Creys-Malville								
Phenix								
Kazakhstan								
Bn-350								

Table 32 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Russian Federation								
Beloyarsky 3								
United Kingdom [N5]								
Dounreay PFR	3 200	3 100	2 300	3 700	2 000	1 700	790	570

Summary parameter	*Reactor*	*Release (TBq)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
All reactors									
Total release (TBq)	PWRs	168	236	217	239	230	243	260	196
	BWRs	40.6	35.7	34.6	47.0	40.4	38.7	43.9	42.8
	HWRs	8 388	6 496	6 171	10 090	6 615	3 873	3 896	39 400
	GCRs	24.3	19.5	23.3	25.3	37.9	40.1	25.5	32.7
	LWGRs								
	FBRs	3.2	3.1	2.3	3.7	2.0	1.7	0.79	0.57
	All	8 624	6 791	6 448	10 400	6 925	4 196	4 226	4 212
Annual normalized release [TBq (GW a)$^{-1}$]	PWRs	1.9	2.6	2.3	2.5	2.4	2.5	2.6	2.2
	BWRs	1.0	0.86	0.85	1.1	0.90	0.75	0.94	0.91
	HWRs	850	569	578	813	481	317	331	340
	GCRs	7.6	5.3	3.9	3.8	4.7	4.7	3.5	3.5
	LWGRs								
	FBRs	52	35	-	36	53	-	-	-
	All	62	46	42	65	42	25	25	27
Average normalized release 1990-1994 and 1995-1997 [TBq (GW a)$^{-1}$]	PWRs	2.3					2.4		
	BWRs	0.94					0.86		
	HWRs	650					329		
	GCRs	4.7					3.9		
	LWGRs	26					26		
	FBRs	49					-		
	All	51					26		

Table 33
Iodine-131 released from reactors in airborne effluents

Country/reactor	Release (GBq)							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
PWRs								
Armenia [A5]								
Armenia 2							0.331	0.365
Belgium [M1]								
Doel 1-4	0.485	0.657	0.192	0.097	0.01	0.032	0.008	0.0057
Tihange 1-3	0.295	0.086	0.039	0.027	0.016	0.0055	0.052	0.016
Brazil [C7]								
Angra 1		0.00047	0.356	0.481		0.00036	0.299	0.936
Bulgaria [C6]								
Kozloduy 1-6	5.6	4.5	10.6	8.0	2.2	1.50	1.98	2.68
China[C8, T2]								
Guangdong 1-2	-	-	-		0.424	0.720	0.229	0.116
Qinshan	-	-						
Maanshan 1-2	0	0	0	0	0	0	0	0
Czech Republic [N2]								
Dukovany 1-4	0.01	0.014	0.06	0.097	0.024	0.013	0.122	0.011
Finland [F1]								
Loviisa 1-2	0.017	0.16	0.025	0.033	0.00017	0.77	0.00087	0.000072
France [E1]								
Belleville 1-2	Amounts included with particulates (Table 34)							
Blayais 1-4								
Bugey 2-5								
Cattenom 1-4								
Chinon B1-B4								
Chooz-A (Ardennes)								
Chooz B1-B2								
Cruas 1-4								
Dampierre 1-4								
Fessenheim 1-2								
Flamanville 1-2								
Golfech 1-2								
Gravelines 1-6								
Nogent 1-2								
Paluel 1-4								
Penly 1-2								
St. Alban 1-2								
St. Laurent B1-B2								
Tricastin 1-4								
Germany [B3]								
Biblis A-B	0.0032	0.0015	0.024	0.012	0.042	0.017	0.030	0.0069
Brokdorf	0.0007	0.00084	0	0	0.00035	0.026	0.0006	0.0032
Emsland	0	0	0.000074	0.00034	0.0026	0.0013	0	0
Grafenrheinfeld	0.0022	0.0011	0.0028	0	0.000041	0	0.00015	0.0013
Greifswald	5.2	0	0	0	0	0	0	0
Grohnde	0	0	0.0013	0.0007	0.005	0.031	0.0082	0
Isar 2	0	0	0.00054	0	0	0	0	0
Mülheim-Kärlich	0	0	0	0	0	0	0	0
Neckarwestheim 1-2	0.0262	0.000082	0.00096	0.0067	0.0193	0.02	0.00071	0.0042
Obrigheim	0.00004	0.0001	0	0.031	0.000052	0.0087	0.000006	0.00007
Philippsburg 2	0	0.00018	0.00042	0	0.018	0.00074	0.00043	0.0045
Stade	0.0028	0.061	0.034	0.0031	0.00021	0.00026	0.002	0.004
Unterweser	0.00029	0.000056	0.00076	0	0.0001	0.0019	0.000097	0.00047
Hungary [F2]								
Paks 1-4	0.45	0.63	0.14	0.28	0.14	0.18	0.34	0.36

Table 33 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Genkai 1-4	0	0	0	0	0	0	0	0
Ikata 1-3	0	0	0.0095	0	0	0	0	0
Mihama 1-3	0.0015	0.0061	0.019	0.010	0.0003	0.0002	0	0.0018
Ohi 1-4	0.0009	0.0011	0.0034	0.0003	0.0002	0	0	0.0009
Sendai 1-2	0	0	0	0	0	0	0	0
Takahama 1-4	0.0003	0.22	0.043	0.0004	0.0003	0.0002	0	0.0038
Tomari 1-2	0	0	0	0	0	0	0	0
Tsuruga 2	0	0	0	0	0	0	0	0
Netherlands [N7]								
Borssele	0	0.046	0	0.017	0.029	0.0095	0	0.03
Republic of Korea [K1]								
Kori 1-4	0.14	0.19	16.0	13.2	0.066	0.0170	0.0046	0.0078
Ulchin 1-2	0.19	0.086	0.00022	0.0043	0.00052	0.00019	0.030	0.86
Yonggwang 1-4	0.00033	0.0077	0.0015	0.0062	0.018	0.156	0.017	0.011
Russian Federation [M6]								
Balakovo 1-4	1.55	0.16	0.32	1.62	0.12	0.14	0.68	0.13
Kalinin 1-2	1.02	0.11	0.19	0.41	0.54	0.68	0.14	0.07
Kola 1-4	2.07	3.78	11.61	5.54	3.11	3.65	1.89	3.30
Novovoronezh 2-5	0.71	2.70	0.27	0.14	0.27	0.41	1.08	1.10
Slovakia [N2, S4]								
Bohunice 1-4	1.72	1.79	1.43	1.59	1.38	2.05	1.88	0.87
Slovenia [S1]								
Krsko	0.012	0.007	0.096	0.41	0.30	0.75	2.74	1.45
South Africa [C11]								
Koeberg 1-2	0.55	1.28	0.56	0.32	0.26	0.31	0.13	0.16
Spain [C2]								
Almaraz 1-2	0.0006	0.124	0.026	0.011	0.014	0.014	0.089	0.095
Asco 1-2	0.025	0.0125	0.008	0.013	0.007	0.048	0.0002	0.00033
José Cabrera 1	0.903	1.49	4.84	0.702	0.025	0.003	0.008	0.18
Trillo 1	0.021	0	0	0.007	0	0	0	0.31
Vandellos 2	0.255	0.009	0.12	0.083	0.034	0.029	0.026	0.052
Sweden [N3]								
Ringhals 2-4	1.26	0.506	0.882	0.354	0.163	0.093	0.078	0.020
Switzerland [F3]								
Beznau 1-2	0.24	0.015	0.016	0.015	0.027	0.018	0.025	0.056
Gösgen	0.041	-	0.004	0.004	0.007	0.040	0.010	0.073
Ukraine [G3]								
Khmelnitski 1	0.44	0.45	1.37	0.57	0.13	0.30	0.57	0.32
Rovno 1-3	3.92	0.95	1.47	1.10	0.51	1.39	1.61	0.84
South Ukraine 1-3	0.012	0.021	0.012	0.0014	0.007	0.009	0.028	0.011
Zaporozhe 1-6	0.1	0.27	2.44	3.33	2.4	1.2	1.89	4.8
United Kingdom [M7]								
Sizewell B	-	-	-	-	-	-	0.049	0.034
United States [T3]								
Arkansas One 1-2	0.0074	0.081	0.036	0.0002	-	0.040	0.007	0.00008
Beaver Valley 1-2	0.0051	0.26	0.028	0.25	0.014	0.091	0.47	0.041
Braidwood 1-2	0.077	0.40	0.0014	0.12	0.14	0.031		
Byron 1-2	0.15	0.0063	0.016	0.016		0.024	0.017	
Callaway 1	0.0053	0.0006	0.017	0.023	0.00056	0.0016	0.0030	0.0007
Calvert Cliffs 1-2	0.054	0.49	0.62	0.52	0.16	0.067	0.020	0.037
Catawba 1-2	0.051	0.067	0.021	0.027	0.016	0.014	0	0
Comanche Peak 1-2	-	0.0007	0.031	0.0037	0	0	0.00005	0
Crystal River 3	0.028	0.0094	0.020	0.0007	0.00018		0.000009	
Davis-Besse 1	0.087	0.32	0.011	0.27	0.069	0.021	0.094	0.001
Diablo Canyon 1-2	0.0016	0.022	-	0.0002	0.15	0.23	0.074	0
Donald Cook 1-2	0.12	0.031	0.27	0.0028	0.35	0.33	0.23	0.076

Table 33 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*								
Farley 1-2	0.0001	0.060	0.0072	0	0.16	0.0046	0.0002	0.0049
Fort Calhoun 1	0.065	0.0075	0.011	0.0008	0.0015	0.11	1.02	
R. E. Ginna	0.19	0.059	0.052	0.027	0.0060	0.0027	0.0061	
Haddam Neck	0.094	0.62	0.0002	0.098				
Harris 1	-	-	0.023	0.0003	0.013	0.0016	0.00004	0.0020
Indian Point 1-3	0.17	0.014	0.48	0.18				
Kewaunee	0.00004	0.00001	-	-	0	-	0.14	0
Maine Yankee	0.16	0.24	0.14	0.15	0.028	0.011	0.0044	0.0004
McGuire 1-2	0.049	0.044	0.079	0.062	0.021	0.0023	0.00004	0
Millstone 2-3	1.25	0.93	0.31	0.052	0.030	0.67	0.0036	0
North Anna 1-2	0.23	0.094	0.50	0.090	0.015	0.009	0.004	0.007
Oconee 1-2-3	0.28	1.50	0.51	0.092	1.18	0.30	0.13	0.004
Palisades	0.069	0.0038	0.027	0.034	0.081	0.23	0.31	0.044
Palo Verde 1-3	0.20	1.22	0.46	0.42	0.22	0.36	0.23	
Point Beach 1-2	0.012	0.013	0.067	0.0045	0.0003	0.0041	0.0013	0
Prairie Island 1-2	0.053	0.0044	0.0070	0.025	0.001	0.019	0	0
Rancho Seco 1	-	-	-					
H. B. Robinson 2	0.000004	-	0.00004	0.054				
Salem 1-2	0.050	0.085	0.014	0.23	0.024	0.019	0	0
San Onofre 1-3	0.51	0.47	1.42	1.79	0.07	1.76	0.10	0.30
Seabrook 1	-	0.0007	0.0001	-				
Sequoyah 1-2	0.0073	0.0002	0.0002	0.00007	0.0003		0.00017	
South Texas 1-2	0.019	0.0068	0.082	0.0002	0.000001	0.0008	0.0014	0.064
St. Lucie 1-2	0.52	0.27	0.21	0.091	0.027	0.11		
Surry 1-2	0.049	0.019	0.018	0.023	0.15	0.081	0.010	0.14
Three Mile Island 1	0.057	0.037	0.18	0.27	0.049	0.20	0.00011	0.00008
Trojan	0.056	0.016	0.0084	0	0	0	0	0
Turkey Point 3-4	0.23	0.047	0.0080	0.084	0.18			
Virgil C. Summer 1	0.016	0.0087	0.0079	0.16	0.0078	0.00001	0.00006	0.00003
Vogtle 1-2	0.0010	0.074	0.050	0.017	0.030	0.030	0.22	0.076
Waterford 3	0.022	0.085	0.0007	0.00004	0.0040	0.029	0.00002	0.020
Watts Bar 1	-	-	-	-			0	
Wolf Creek	0.0031	0.089	0.0006	0.026			0.0033	
Yankee NPS	0.0050	0.0008	0.00008	0	0	0	0	0
Zion 1-2	0.048	0.28	1.77	0.41	0.0099	0.34	0.012	0
BWRs								
China [T2]								
Chin Shan 1-2	11.9	5.00	3.66	0.99	0.69	0.13	0.091	0.137
Kuosheng 1-2	0.102	0.0053	0.0011	0.0024	0.0034	0.052	0.0022	0.0030
Finland [F1]								
Olkiluoto 1-2	0.056	0.25	0.15	0.081	1.1	0.038	0.026	0.017
Germany [B3]								
Brunsbüttel	0.02	0.031	0.029	0	0	0.00094	0.017	0.0011
Gundremmingen B,C	0.015	0.00092	0.0021	0.00025	0.00036	0.00029	0.00014	0.00016
Isar 1	0.00055	0.00017	0.0016	0.023	0.035	0.013	0.023	0.057
Krümmel	0.06	0.077	0.32	0.15	0.036	0.38	0.22	0.14
Philippsburg 1	0.0014	0.0024	0.0033	0.12	0.59	0.05	0.047	0.075
Würgassen	0.019	0.16	0.098	0.036	0.045	0	0	0
India [B4]								
Tarapur 1-2	5.0	4.7	5.0	4.9	3.6			
Japan [J1, J5]								
Fukushima Daiichi 1-6	0.0083	0.0091	0.0072	0.0067	0.0028	0.0037	0.0032	0
Fukushima Daini 1-4	0	0	0	0	0	0	0	0.00002
Hamaoka 1-4	0.037	0	0	0	0	0	0	0
Kashiwazaki Kariwa 1-7	0	0	0	0	0	0	0	0
Onagawa 1-2	0	0	0	0	0	0	0	0
Shika 1	-	-	0	0	0	0	0	0
Shimane 1-2	0	0	0	0	0	0	0	0
Tokai 2	0	0	0	0	0	0	0	0
Tsuruga 1	0.0005	0.00006	0	0	0	0	0	0

Table 33 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico [C5]								
Laguna Verde 1-2	0.012	0.12	0.073	0.11	0.057	0.063	0.23	0.18
Netherlands [N7]								
Dodewaard	0.038	0.0035	0.0017	0.0014	0.0016	0.028	0.0024	0.0016
Spain [C2]								
Confrentes	0.032	3.05	1.48	0.604	0.38	0.128	0.052	0.24
S. Maria de Garona	0.015	0.031	0.012	0.105	0.083	0.091	0.031	0.011
Sweden [N3]								
Barsebeck 1-2	0.039	0.60	0.057	0.0062	0.0065	0.021	0.0027	0.0079
Forsmark 1-3	0.66	3.50	1.10	1.04	0.68	0.58	0.45	0.23
Oskarshamn 1-3	1.90	0.60	0.64	0.84	0.73	0.34	0.45	0.46
Ringhals 1	0.14	0.097	0.063	20.0	35.0	12.3	7.46	4.20
Switzerland [F3]								
Leibstadt	1.40	1.00	0.68	1.2	2.4	0.87	0.71	0.43
Mühleberg	0.15	0.018	0.021	0.012	0.013	0.0054	0.0053	0.02
United States [T3]								
Big Rock Point	0.077	0.049	0.16	0.095	0.12	0.04	0.17	0.02
Browns Ferry 1-3	-	0.36	0.51	0.19	0.50			
Brunswick 1-2	0.44	0.36	0.18	0.012	0.08	0.20	0.78	1.36
Clinton 1	0.0057	0.0011	0.0020	0.0047	0.0022	0.0036	0.016	0
Cooper	0.013	0.0037	0.0034	0.0010	0.0014	0.0016	0.71	0.65
Dresden 2-3	-	0.068	0.038	0.037	0.011	0.023	0.048	0.22
Duane Arnold 1	0.0096	0.0047	0.0034	0.0034	0.0034	0.0036	0.0029	0.0046
Enrico Fermi 2	0.13	0.090	0.15	0.23	0.0047	0.044	0.18	0.46
Fitzpatrick	0.073	0.096	0.0038	0.018	0.056	0.054	0.072	0.007
Grand Gulf 1	0.019	0.075	0.28	0.017	-	0.004	0.024	0.0003
Hatch 1-2	0.22	0.17	1.37	9.25	3.33	1.51	1.82	2.24
Hope Creek 1	0.044	-	-	-	0	0.024	0.015	0.020
Lasalle 1-2	0.080	0.065	0.052	1.10	0.12	0.17		
Limerick 1-2	0.0012	-	0.040	0.42	0.14	3.54		
Millstone 1	0.027	0.016	0.0083	0.052	0.012	0.056	0	0
Monticello	1.38	1.12	1.23	0.35	0.32	0.14	0.21	0.18
Nine Mile Point 1-2	0.053	0.19	0.090	0.17	0.015			
Oyster Creek	0.85	0.94	1.47	0.37	0.38	0.11	0.081	0.10
Peach Bottom 2-3	0.48	1.30	1.04	1.78	2.01	1.87	0.56	
Perry 1	0.36	0.51	5.62	1.47	0.48	1.01	0.30	
Pilgrim 1	0.34	1.42	1.19	1.14	0.50	0.23	0.26	0.21
Quad Cities 1-2	0.17	0.058	0.043	0.047	0.026	0.070	0.033	0.050
River Bend 1	1.79	1.45	0.30	0.81	1.78	1.40	0.51	0.90
Susquehanna 1-2	-	0.0005	0.0006	-	0.0004	0	0	0
Vermont Yankee	2.04	2.31	1.57	0.42	0.11	0.07	0.035	0.015
WPPSS 2	3.21	0.79	0.29	0.48	0.16	0.11	0.0023	
HWRs								
Argentina [C3]								
Atucha 1	0.078	1.3	0.0089	0.49	0.44	0.35	0.041	0.53
Embalse	1.4	1.6	0.07	0	0.26	1.7	0.27	0
Canada [A2]								
Bruce 1-4	0.063	0.055	0.040	0.033	0.030	0.027	0.019	0.014
Bruce 5-8	0.12	0.13	0.064	0.057	0.059	0.12	0.044	0.035
Darlington 1-4	0.012	0.016	0.018	0.031	0.036	0.034	0.022	0.020
Gentilly 2	0	0.019	0.0037	0.0037	0	0	0	0
Pickering 1-4	0.32	0.12	0.089	0.13	0.10	0.074	0.073	0.074
Pickering 5-8	0.089	0.063	0.052	0.048	0.085	0.10	0.098	0.099
Point Lepreau	0	0.016	0.0030	0.0002	0.0051	0	0.0015	0.021
India [B4]								
Kakrapar 1								
Kalpakkam 1-2	0.16	0.24	0.26	0.51	0.05			
Narora 1-2	0	0.02	1.55	2.30	2.97			
Rajasthan 1-2	1.43	1.00	0.46	0.78	0.31			

Table 33 (continued)

Country/reactor	Release (GBq)							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Fugen	0	0	0	0	0	0	0	0
Pakistan [P2]								
Karachi	0	0	0	0	0	0	0	0
Republic of Korea [K1]								
Wolsong 1-2	0	0.0012	0.00037	0	0	0.052	0.14	0
Romania								
Cernavoda	-	-	-	-	-	-	0	0.0071
United Kingdom [N5]								
Winfrith	0.22	0.38						
GCRs								
France [E1]								
Bugey 1	Amounts included with noble gases (Table 31)							
Chinon A2-3								
St. Laurent A1-2								
Japan [J1, J5]								
Tokai1	0.0020	0.0014	0.0006	0.00005	0	0.0016	0.0005	0
Spain [C2]								
Vandellos 1	0.0002	0.0001	0	0	0	0	0	
U. K. [M7, N4, N5]								
Berkeley	-	-	-					
Bradwell	-	-	-					
Calder Hall	0.58	0.57	1.05	0.61				
Chapelcross	-	-	-					
Dungeness A	-	-	-					
Dungeness B1-B2	1.9	2.0	3.0	6.0	0.4	0.3	0.004	0.004
Hartlepool A1-A2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.19
Heysham 1A-B, 2A-B	1.5	1.5	1.5	1.4	1.4	1.5	1.4	1.40
Hinkley Point A	-	-	-					
Hinkley Point B, A-B	0.4	0.41	0.14	0.1	0.1	0.1	0.02	0.02
Hunterston A1	-	-	-					
Hunterston B1-B2	-	-	-					
Oldbury A	-	-	-					
Sizewell A	-	-	-					
Torness A-B	-	-	-					
Trawsfynydd	-	-	-					
Wylfa	-	-	-					
LWGRs								
Lithuania [E2]								
Ignalina 1-2	4.25	10.0	1.2	0.5	2.9	6.2	11.5	6.3
Russian Federation [M6]								
Bilibino 1-4	0	0	0	0	0	0	0	0
Kursk 1-4	7.47	1.08	3.51	7.29	3.65	6.75	9.99	10.7
Leningrad 1-4	20.7	36.3	88.8	19.6	30.3	19.6	29.2	17.5
Smolensk 1-3	3.41	3.92	9.99	16.5	12.2	6.21	5.67	23.8
Ukraine [G3]								
Chernobyl 1-3	10.8	6.77	2.85	7.96	4.66	5.40	7.84	1.96
FBRs								
France [E1]								
Creys-Malville	Not reported							
Phenix								
Kazakhstan								
Bn-350								

Table 33 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Russian Federation [M6]								
Beloyarsky 3	0	0	0	0	0	0	0	
United Kingdom [N5]								
Dounreay PFR								

Summary parameter	*Reactor*	*Release (GBq)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
All reactors									
Total release (GBq)	PWRs	32.3	28.2	60.7	44.1	15.3	19.7	19.4	20.1
	BWRs	33.4	30.7	29.1	49.1	55.6	25.8	15.6	12.6
	HWRs	3.90	4.96	2.62	4.39	4.35	2.41	0.71	0.80
	GCRs	4.68	4.68	5.99	8.41	2.20	2.20	1.72	1.62
	LWGRs	46.6	58.1	106	51.9	53.7	44.2	64.2	60.3
	FBRs	-	-	-	-	-	-	-	-
	All	121	127	205	158	131	94.2	102	95.4
Annual normalized release [GBq (GW a)$^{-1}$]	PWRs	0.31	0.26	0.54	0.40	0.14	0.18	0.16	0.19
	BWRs	0.74	0.62	0.60	0.98	1.1	0.45	0.30	0.26
	HWRs	0.39	0.44	0.25	0.35	0.32	0.20	0.06	0.07
	GCRs	1.8	1.4	1.5	1.8	0.49	0.56	0.37	0.35
	LWGRs	4.4	5.6	12	5.5	7.1	5.5	7.3	7.7
	FBRs								
	All	0.70	0.69	1.1	0.84	0.69	0.48	0.52	0.53
Average normalized release 1990-1994 and 1995-1997 [GBq (GW a)$^{-1}$]	PWRs			0.33				0.17	
	BWRs			0.81				0.33	
	HWRs			0.35				0.11	
	GCRs			1.4				0.42	
	LWGRs			6.8				6.9	
	FBRs								
	All			0.81				0.51	

Table 34
Particulates released from reactors in airborne effluents

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
PWRs								
Armenia [A5]								
Armenia 2							2.34	2.77
Belgium [M1]								
Doel 1-4	0.162	0.1	0.075	0.008	0.0006	0.0036	0.0028	0.0015
Tihange 1-3	0.136	0.077	0.017	0.020	0.032	0.051	0.033	0.015
Brazil [C7]								
Angra 1			0.000009	0.000007	0.0000001	0	0.01	0.044
Bulgaria [C6]								
Kozloduy 1-6	2.4	1.7	3.8	2.3	2.0	1.50	1.92	1.86
China [C8, T2]								
Guangdong 1-2	-	-	-					
Qinshan	-	-						
Maanshan 1-2	0	0	0.016	0.0044	0.0037	0.011	0.0019	0.011
Czech Republic [N2]								
Dukovany 1-4	0.099	0.10	0.21	0.21	0.15	0.13	0.080	0.24
Finland [F1]								
Loviisa 1-2	0.2	0.17	0.28	0.081	0.23	0.34	0.22	0.25
France [E1]								
Belleville 1-2	0.59	0.39	0.57	2.2	0.18	0.21	0.25	0.089
Blayais 1-4	0.52	0.33	0.53	0.31	0.44	0.80	0.33	0.11
Bugey 2-5	0.54	0.93	0.44	0.44	0.38	0.32	0.33	0.38
Cattenom 1-4	0.25	0.19	0.35	0.23	0.22	0.17	0.18	0.17
Chinon B1-B4	1.0	1.4	0.90	0.30	0.86	0.41	0.099	0.069
Chooz-A (Ardennes)	0.099	0.88	0.019	0.012	0.012	0.006	0.0004	0.0002
Chooz B1-B2							0.039	0.87
Cruas 1-4	0.21	0.14	0.11	0.25	0.52	0.17	0.14	0.059
Dampierre 1-4	0.55	0.37	0.37	0.84	0.69	1.1	0.099	0.10
Fessenheim 1-2	0.029	0.039	0.029	0.029	0.019	0.019	0.039	0.029
Flamanville 1-2	0.12	0.19	0.48	0.12	0.25	0.10	0.12	0.12
Golfech 1-2	0.049	0.029	0.019	0.028	0.019	0.039	0.19	0.80
Gravelines 1-6	1.4	1.1	0.75	1.1	2.1	4.3	0.55	0.35
Nogent 1-2	0.18	0.099	0.28	0.65	0.17	0.15	0.25	0.15
Paluel 1-4	0.26	0.39	0.24	0.18	1.3	0.54	0.33	0.13
Penly 1-2	0.019	0.019	0.049	0.087	0.31	0.039	0.096	0.12
St. Alban 1-2	0.089	0.29	0.11	0.12	0.089	0.59	0.13	0.11
St. Laurent B1-B	0.089	0.029	0.039	0.039	0.039	0.079	0.074	0.099
Tricastin 1-4	0.40	0.44	0.35	0.33	0.13	0.13	0.11	0.19
Germany [B3]								
Biblis A-B	0.011	0.024	0.014	0.01	0.03	0.0025	0.0020	0.0084
Brokdorf	0.00037	0.0012	0	0.0014	0.00045	0	0	0
Emsland	0.0006	0.00039	0.00037	0.000071	0.00068	0.000007	0.00066	0.00017
Grafenrheinfeld	0.0083	0.0033	0.0019	0.0015	0.0016	0.0027	0.0026	0.002
Greifswald	0.62	0.12	0.063	0.038	0.021	0.28	0.16	0.087
Grohnde	0.0001	0	0.00059	0.00029	0.0011	0.00025	0.00096	0.0012
Isar 2	0.000037	0.000013	0.00034	0.000036	0	0	0.0018	0.00007
Mülheim-Kärlich	0	0	0	0	0	0	0	0
Neckarwestheim 1-2	0.0063	0.0034	0.0026	0.0016	0.0071	0.0012	0.0029	0.00027
Obrigheim	0.004	0.0086	0.0049	0.012	0.012	0.018	0.0092	0.0074
Philippsburg 2	0.00045	0.00037	0.001	0.0018	0.0018	0.00099	0.00015	0.00053
Stade	0.046	0.021	0.0049	0.005	0.0042	0.079	0.0010	0.00024
Unterweser	0.0019	0.0021	0.001	0.00099	0.0014	0.0012	0.0015	0.00079
Hungary [F2]								
Paks 1-4	1.14	1.30	0.45	1.30	1.28	0.49	0.74	1.30

Table 34 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Genkai 1-4	0	0	0	0	0	0	0	0
Ikata 1-3	0	0	0	0	0	0	0	0
Mihama 1-3	0	0	0	0	0	0	0	0
Ohi 1-4	0	0	0	0	0	0	0	0
Sendai 1-2	0	0	0	0	0	0	0	0
Takahama 1-4	0	0	0	0	0	0	0	0
Tomari 1-2	0	0	0	0	0	0	0	0
Tsuruga 2	0	0	0	0	0	0	0	0
Netherlands [N7]								
Borssele	0	0	0	0	0.0011	0	0	0
Republic of Korea [K1]								
Kori 1-4	0.12	0.015	0.0014	0.95	0.00007	0.00007	0.0027	0
Ulchin 1-2	0.024	0.00004	0.0016	0.00002	0.0077	0.015	0.0020	0.021
Yonggwang 1-4	0.00078	0.0011	0.00015	0	2.7	0.013	0.023	0.00062
Russian Federation [M6]								
Balakovo 1-4	1.49	0.14	0.27	0.41	0.24	0.14	0.18	0.12
Kalinin 1-2	0.03	0.03	0.03	0.20	0.14	0.05	0.11	0.09
Kola 1-4	8.51	7.16	2.57	3.24	2.97	2.03	0.92	0.20
Novovoronezh 2-5	1.88	2.43	0.95	1.07	0.68	2.43	2.30	1.54
Slovakia [N2, S4]								
Bohunice 1-4	0.38	0.54	1.46	1.1	0.37	0.53	0.30	0.54
Slovenia [S1]								
Krsko	0	0	0	0.0034	0.0004	0.020	0.00017	0.0036
South Africa [C11]								
Koeberg 1-2	1.04	4.50	2.18	3.79	4.97	6.22	3.31	4.19
Spain [C2]								
Almaraz 1-2	0.071	0.033	0.006	0.04	0.037	0.011	0.043	0.0079
Asco 1-2	0.032	0.02	0.025	0.028	0.024	0.219	0.016	0.036
José Cabrera 1	0.063	0.25	0.668	0.344	0.007	0.004	0.017	0.0088
Trillo 1	0.01	0.017	0.006	0.006	0.005	0.006	0.002	0.0022
Vandellos 2	0.019	0.017	0.027	0.021	0.037	0.004	0.008	0.025
Sweden [N3]								
Ringhals 2-4	0.017	0.014	0.0038	0.016	0.014	0.0051	0.00088	0.050
Switzerland [F3]								
Beznau 1-2	0.0015	0.0018	0.0041	0.00087	0.002	0.006	0.006	0.006
Gösgen	0.0024	0.0013	0.00067	0.006	0.006	0.010	0.010	0.010
Ukraine [G3]								
Khmelnitski 1	0.035	0.16	0.10	0.12	0.076	0.080	0.10	0.076
Rovno 1-3	0.33	0.30	0.48	0.18	0.17	0.39	0.13	0.16
South Ukraine 1-3	0.012	0.021	0.012	0.0014	0.007	0.009	0.028	0.011
Zaporozhe 1-6	0.13	0.15	0.28	0.28	0.17	0.17	0.12	0.08
United Kingdom [M7]								
Sizewell B	-	-	-	-	-	-	0.0087	0.0051
United States [T3]								
Arkansas One 1-2	0.033	1.59	1.84	0.00022	0.0004	0.15	0.0004	0.0002
Beaver Valley 1-2	0.019	0.11	0.029	0.56	0.045	0.73	0.048	0.029
Braidwood 1-2	0.0014	0.012	0	0	0	0		
Byron 1-2	0.0015	0.0004	0	0.00022		0.00086	0.0039	
Callaway 1	0.0001	0.00004	0.0058	0.039	0.00051	0.057	0.0002	0.0001
Calvert Cliffs 1-2	0.0091	0.0001	0.0020	0.28	0.044	0.0019	0.00009	0.00021
Catawba 1-2	0.013	0.036	0.036	0.0073	0.0034	0.14	0.00056	0.036
Comanche Peak 1-2	0.0014	0	0	0.00014	0	0	0.00008	0
Crystal River 3	0.0002	0.0075	0.0003	0.00025	0.00035		0.00023	
Davis-Besse 1	0.0011	0.0022	0.024	0.016	0.0020	0.00009	0.0052	0.001
Diablo Canyon 1-2	0.0006	0.00026	0.095	0.0017	0.013	0.0038	0.0057	0.001
Donald Cook 1-2	2.60	0.058	0.074	0.016	0.078	0.22	1.10	0.46

Table 34 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*								
Farley 1-2	0	0	0.0086	0.0011	0.50	0.00089	0.0004	0.00024
Fort Calhoun 1	0.0015	0.0044	0.01	0.00006	0.00011	0.00084	0.00026	
R. E. Ginna	0.0011	0.0019	0	0.00056	0.00023	0.00014	0.020	
Haddam Neck	0.080	0.34	0.20	0.36				
Harris 1	0.0029	0.0017	0.0070	0.0064	0.0041	0.34	0.0015	0.0089
Indian Point 1-3	0.036	0.064	0.0081	0.041				
Kewaunee	0.12	0.071	0.00006	0.0007	0.0017	0.00054	0.0013	0.00021
Maine Yankee	0.51	0.028	0.052	0.060	0.037	0.037	0.030	0.00095
McGuire 1-2	0.027	0.028	0.0067	0.0021	0.00024	0.0072	0.00006	0.0017
Millstone 2-3	0.0030	0.019	0.021	0.026	0.0054	0.0052	0.00028	0.0005
North Anna 1-2	0.022	0.0059	0.0037	0.017	0.0026	0.003	0.012	0.001
Oconee 1-2-3	0.052	0.041	0.011	0.031	0.11	0.015	0.01	0.014
Palisades	0.010	0.0073	0.0084	0.0077	0.0029	0.0035	0.0041	0.0032
Palo Verde 1-3	0.059	0.10	0.060	0.29	0.095	0.056	0.0095	
Point Beach 1-2	0.0083	0.12	0.41	0.54	0.08	0.16	0.0084	0.00008
Prairie Island 1-2	0.0026	0.014	0.0024	0.0026	0.0028	0.005	0.006	0.033
Rancho Seco 1	0	0	0	0				
H. B. Robinson 2	0.0050	0.0064	0.0051	0.0033	0.0001	0.0003	0.0013	0.0006
Salem 1-2	0.0021	0.0031	0.0025	0.00074	0.00073	0.00077	0.00098	0.00012
San Onofre 1-3	0.024	0.028	0.019	0.069	0.021	0.018	0.029	0.018
Seabrook 1	0	0.039	0.041	0.00002				
Sequoyah 1-2	0.0025	0.021	0.0032	0.00045	0		0.0016	
South Texas 1-2	0.045	0.084	0.013	0.020	0.0013	0.017	0.0057	0.0052
St. Lucie 1-2	0.0030	0.0070	0.0085	0.0046	0.020	0.0079		
Surry 1-2	0.059	0.022	0.011	0.0065	0.012	0.006	0.007	0.002
Three Mile Island 1	0.00014	0.0029	0.0012	0.00025	0.00046	0.00015	0.000001	0.0012
Trojan	0.0048	0.0054	0.0007	0	0	0	0	0
Turkey Point 3-4	0.0059	0.0013	0.0008	0	0.0016			
Virgil C. Summer 1	0.0043	0.0018	0	0.0048	0.014	0.00002	0.00025	0.0019
Vogtle 1-2	0.0020	0.0033	0.17	0.0021	0.0040	0.0091	0.012	0.00090
Waterford 3	0	0.0026	0.00037	0	0.0028	0.0027	0.00019	0.00080
Watts Bar	-	-	-	-			0	
Wolf Creek	0.0032	0	0.00005	0			0.00004	
Yankee NPS	0.0010	0.00035	0.00029	0.00003	0.00027	0.00091	0.00076	0.00003
Zion 1-2	0.0026	0.0070	0.12	0.87	0.035	0.14	0.060	0.032
BWRs								
China [T2]								
Chin Shan 1-2	0.71	0.22	0.080	0.039	0.11	0.038	0.020	0.012
Kuosheng 1-2	0.0039	0.075	0.015	0.0003	0.0003	0.0024	0	0.000007
Finland [F1]								
Olkilouto 1-2	0.22	0.74	0.3	0.11	0.13	0.033	0.014	0.045
Germany [B3]								
Brunsbüttel	0.054	0.023	0.075	0.041	0.034	0.034	0.034	0.026
Gundremmingen B,C	0	0	0	0	0	0	0.000074	0.000062
Isar 1	0.0063	0.0019	0.0087	0.011	0.018	0.010	0.016	0.013
Krümmel	0.0051	0.039	0.025	0.028	0.019	0.034	0.086	0.15
Philippsburg 1	0.073	0.023	0.022	0.08	0.054	0.032	0.021	0.025
Würgassen	0.045	0.17	0.058	0.077	0.053	0.013	0.012	0.041
India [B4]								
Tarapur 1-2	8.6	21.6	4.8	8.7	5.8			
Japan [J1, J5]								
Fukushima Daiichi 1-6	0.0081	0.0017	0.0010	0.0019	0.0034	0.0002	0.0006	0.0020
Fukushima Daini 1-4	0	0	0	0	0	0	0	0
Hamaoka 1-4	0	0	0	0	0	0	0	0
Kashiwazaki Kariwa 1-7	0	0	0	0	0	0	0	0
Onagawa 1-2	0	0	0	0	0	0	0	0
Shika 1	-	-	0	0	0	0	0	0
Shimane 1-2	0.0002	0.0004	0	0.0010	0.0003	0	0	0.0004
Tokai 2	0	0	0	0	0	0	0	0
Tsuruga 1	0	0.00005	0.0003	0.00004	0.00008	0	0.0001	0

Table 34 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico [C5]								
Laguna Verde 1-2	0.12	1.11	0.31	0.55	0.21	16.7	2.01	0.63
Netherlands [N7]								
Dodewaard	0.028	0.0086	0.0043	0.0045	0.0052	0.0049	0.0046	0.005
Spain [C2]								
Confrentes	0.153	0.545	0.415	0.077	0.066	0.049	0.005	0.46
S. Maria de Garona	0.071	0.032	0.046	0.139	0.216	0.077	0.127	0.015
Sweden [N3]								
Barsebeck 1-2	0.19	0.37	0.73	0.48	0.48	1.00	3.06	1.60
Forsmark 1-3	82.7	139	199	37.8	19.5	84.4	1.84	2.77
Oskarshamn 1-3	275	178	58.8	53.2	40.5	14.0	40.8	30.5
Ringhals 1	20.2	65.0	0.022	323	43 500	44 700	10 600	1 740
Switzerland [F3]								
Leibstadt	0.036	0.0071	0.0019	0.003	0.011	0.020	0.020	0.020
Mühleberg	0.049	0.078	0.013	0.01	0.007	0.020	0.020	0.020
United States [T3]								
Big Rock Point	0.13	0.065	0.026	0.046	0.12	0.09	0.13	0.14
Browns Ferry 1-3	0.0070	0.69	1.21	0.76	0.65			
Brunswick 1-2	1.35	0.35	0.097	0.28	0.78	0.83	0.24	0.36
Clinton 1	0.32	0.34	0.091	0.68	1.70	0.16	0.036	0.0025
Cooper	0.028	0.017	0.015	0.013	0.016	0.012	1.58	2.42
Dresden 2-3	5.45	1.45	0.84	1.38	0.58	0.52	0.079	0.30
Duane Arnold 1	0.16	0.093	0.11	0.077	0.030	0.11	0.064	0.014
Enrico Fermi 2	0.44	0.12	0.10	0.11	0.0052	0.052	0.056	0.12
Fitzpatrick	0.63	0.83	0.012	0.067	0.77	0.45	0.047	0.01
Grand Gulf 1	0.018	0.083	0.046	0.0031	0.0034	0.0032	0.0014	0.0059
Hatch 1-2	0.094	0.044	0.20	3.88	11.4	0.45	2.43	1.85
Hope Creek 1	0.16	0.016	0.099	0.072	0.0017	0.071	0.14	0.095
Lasalle 1-2	0.047	0.19	0.048	4.94	0.14	0.22		
Limerick 1-2	0.027	0.0042	0.015	0.63	17.8	0.17		
Millstone 1	0.070	0.076	0.047	0.14	0.23	0.42	0.021	0.016
Monticello	0.22	0.22	0.25	0.74	0.10	0.067	0.063	0.048
Nine Mile Point 1-2	0.23	0.59	0.32	0.37	0.13			
Oyster Creek	0.31	0.21	0.64	0.086	0.19	0.1	0.093	0.068
Peach Bottom 2-3	0.19	0.28	0.14	0.29	0.52	0.51	0.15	
Perry 1	0.052	0.011	0	0.085	2.62	0.21	0.75	
Pilgrim 1	0.036	0.32	0.52	0.47	0.25	0.87	0.089	0.087
Quad Cities 1-2	1.06	0.38	1.09	0.91	0.10	0.77	0.77	0.66
River Bend 1	0.13	0.19	0.044	0.052	0.13	0.14	0.13	0.24
Susquehanna 1-2	0.032	0.0085	0.17	0.048	0.07	0.06	0.029	0.054
Vermont Yankee	0.64	0.68	0.79	0.32	0.07	0.025	0.007	0.032
WPPSS 2	2.34	1.53	1.31	0.86	0.10	0.25	0.081	
HWRs								
Argentina [C3]								
Atucha 1	0.0011	0.015	0.015	0.18	0.049	0.013	0.038	0.006
Embalse	0	0.12	0.025	0	0.0036	0.077	0	0
Canada [A2]								
Bruce 1-4	0.081	0.063	0.072	0.079	0.11	0.12	0.072	0.070
Bruce 5-8	0.14	0.14	0.12	0.12	0.10	0.12	0.075	0.088
Darlington 1-4	0.012	0.046	0.046	0.11	0.10	0.085	0.058	0.065
Gentilly 2	0.00037	0.013	0.074	0.052	0.070	0.045	0.030	0.114
Pickering 1-4	0.29	0.087	0.089	0.085	0.070	0.070	0.051	0.355
Pickering 5-8	0.018	0.019	0.020	0.021	0.041	0.026	0.027	0.039
Point Lepreau	0	0	0.0040	0.0013	0.0005	0	0	0.00005
India [B4]								
Kakrapar 1								
Kalpakkam 1-2	0	0	0	0	0			
Narora 1-2	0	0	0	0	0			
Rajasthan 1-2	0.014	0.004	0.004	0.006	0.002			

Table 34 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Fugen	0	0	0	0	0	0	0	0
Pakistan [P2]								
Karachi	0	0	0	0	0	0	0	0
Republic of Korea [K1]								
Wolsong 1-2	0	0	0	0	0	0	0	0
Romania								
Cernavoda	-	-	-	-	-	-	0	0
United Kingdom [N5]								
Winfrith	0.19		0.021	0.00002	0.00002			
GCRs								
France [E1]								
Bugey 1	0.43	0.38	0.29	0.17	0.30	0.38	0.009	0.005
Chinon A2-3	0.025	0.018	0.011	0.006	0.008	0.019	0.005	0.009
St. Laurent A1-2	0.21	0.13	0.14	0.011	0.005	0.002	0.001	0.0007
Japan [J1, J5]								
Tokai 1	0.0021	0.011	0.0002	0.0002	0.0013	0.0001	0.0002	0
Spain [C2]								
Vandellos 1	0.02	0.004	0.003	0.002	0.0008	0	0.002	
U. K. [M7, N4, N5]								
Berkeley	0.01	0.01	0.01	0.01	0.01	0.01	0.004	0.004
Bradwell	0.07	0.07	0.03	0.05	0.26	0.16	0.21	0.20
Calder Hall	-	-	-					
Chapelcross	-	-	-					
Dungeness A	0.17	0.11	0.13	0.21	0.26	0.4	0.33	0.30
Dungeness B1-B2	0.07	0.06	0.07	0.07	0.04	0.01	0.049	0.035
Hartlepool A1-A2	0.04	0.04	0.04	0.04	0.04	0.04	0.035	0.025
Heysham 1A-B, 2A-B	0.05	0.05	0.012	0.07	0.07	0.08	0.069	0.099
Hinkley Point A	0.30	0.23	0.15	0.23	0.23	0.16	0.077	0.17
Hinkley Point B, A-B	0.57	0.46	0.32	0.40	0.31	0.08	0.077	0.075
Hunterston A1	0.008	0.0016	0.0011	0.0036	0.0025	0.0013	0.0002	0.0002
Hunterston B1-B2	0.13	0.049	0.12	0.18	0.13	0.074	0.036	0.034
Oldbury A	0.05	0.07	0.10	0.10	0.08	0.10	0.091	0.10
Sizewell A-B	0.33	0.37	0.41	0.55	0.53	0.36	0.022	0.073
Torness A-B	0.045	0.027	0.013	0.026	0.071	0.014	0.015	0.015
Trawsfynydd	0.28	0.04	0.02	0.01	0.01	0.01	0.0016	0.0023
Wylfa	0.11	0.10	0.16	0.13	0.11	0.10	0.0087	0.074
LWGRs								
Lithuania [E2]								
Ignalina 1-2	9.8	1.06	2.2	1.5	8.2	4.2	7.8	1.3
Russian Federation [M6]								
Bilibino 1-4	0	0	0	0	0	0	0	0
Kursk 1-4	25.9	11.6	11.2	9.18	8.51	13.1	13.5	19.2
Leningrad 1-4	62.2	96.2	98.7	28.1	76.4	42.6	64.6	22.9
Smolensk 1-3	9.55	12.4	24.0	8.64	2.70	1.76	2.97	3.78
Ukraine [G3]								
Chernobyl 1-3	51.2	43.2	13.7	13.5	6.85	3.66	4.00	1.89
FBRs								
France [E1]								
Creys-Malville	0.008	0.012	0.011	0.011	0.012	0.013	0.013	0.013
Phenix								
Kazakhstan [A6]								
Bn-350	0.84	0.97	1.25	23.4	0.69	0.67	0.53	0.46

Table 34 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Russian Federation [M6]								
Beloyarsky 3	0	0	0	0	0	0	0	0
United Kingdom								
Dounreay PFR								

Summary parameter	*Reactor*	*Release (GBq)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
All reactors									
Total release (GBq)	PWRs	29.2	29.6	22.9	26.3	25.2	26.5	17.7	18.2
	BWRs	402	416	273	442	43 610	44 820	10 660	1 783
	HWRs	0.75	0.51	0.49	0.65	0.55	0.56	0.35	0.74
	GCRs	2.92	2.33	2.14	2.27	2.47	2.00	1.04	1.22
	LWGRs	159	164	150	60.9	103	65.3	92.9	49.0
	FBRs	0.85	0.98	1.26	23.4	0.70	0.68	0.54	0.47
	All	595	614	450	555	43 740	44 920	10 770	1 852
Annual normalized release [GBq (GW a)$^{-1}$]	PWRs	0.21	0.20	0.15	0.17	0.17	0.17	0.11	0.12
	BWRs	8.4	8.0	5.5	8.6	826	781	204	36
	HWRs	0.076	0.044	0.046	0.053	0.040	0.046	0.030	0.070
	GCRs	0.43	0.32	0.27	0.25	0.27	0.24	0.14	0.13
	LWGRs	15	16	17	6.4	14	8.2	11	6.3
	FBRs	2.0	2.5	2.4	47	1.5	1.7	0.7	1.1
	All	2.8	2.7	2.0	2.4	187	188	45	8.2
Average normalized release 1990-1994 and 1995-1997 [GBq (GW a)$^{-1}$]	PWRs	0.18					0.13		
	BWRs	178					351		
	HWRs	0.051					0.048		
	GCRs	0.30					0.17		
	LWGRs	14					8.4		
	FBRs	12					1.0		
	All	40					81		

Table 35
Tritium released from reactors in liquid effluents

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
PWRs								
Armenia								
Armenia 2								
Belgium [M1]								
Doel 1-4	63 000	38 100	43 900	32 800	32 800	47 000	31 300	38 400
Tihange 1-3	56 400	34 500	34 900	35 200	33 100	41 200	44 700	47 300
Brazil [C7]								
Angra 1	12 200	11 400	49 300	6 560	587	5 130	4 640	19 500
Bulgaria [C6]								
Kozloduy 1-6	Not reported							11 690
China [C8, T2]								
Guangdong 1-2	-	-	-		22 200	10 100	22 100	38 500
Qinshan	-	-	1 690	1 450	6 320	4 820	3 580	2 950
Maanshan 1-2	4 630	6 030	9 140	16 900	20 500	11 700	15 300	6 790
Czech Republic [N2]								
Dukovany 1-4	20 100	18 300	19 300	18 600	15 600	14 500	17 200	14 600
Finland [F1]								
Loviisa 1-2	12 000	14 000	10 000	12 000	11 000	12 000	9 400	12 000
France [E1]								
Belleville 1-2	31 000	39 000	37 000	38 000	22 000	30 000	36 000	33 000
Blayais 1-4	58 000	54 000	39 000	36 000	32 000	46 000	53 000	40 000
Bugey 2-5	42 000	30 000	15 000	46 000	35 000	33 000	33 000	38 000
Cattenom 1-4	35 000	47 000	86 000	66 000	69 000	80 000	72 000	74 000
Chinon B1-B4	62 000	49 000	52 000	33 000	33 000	44 000	44 000	59 000
Chooz-A (Ardennes)	108 000	95 000	26 000	800	1 000	600	1600	100
Chooz B1-B2							200	13 000
Cruas 1-4	51 000	37 000	34 000	46 000	55 000	43 000	50 000	37 000
Dampierre 1-4	52 000	52 000	73 000	50 000	43 000	44 000	44 000	38 000
Fessenheim 1-2	20 000	26 000	16 000	17 000	20 000	21 000	20 000	22 000
Flamanville 1-2	48 000	37 000	34 000	35 000	30 000	31 000	35 000	25 000
Golfech 1-2	500	8 000	9 000	8 400	30 000	27 000	22 000	33 000
Gravelines 1-6	87 000	80 000	70 000	43 000	60 000	39 000	51 000	58 000
Nogent 1-2	23 000	18 000	18 000	26 000	22 000	25 000	32 000	22 000
Paluel 1-4	100 000	82 000	73 000	77 000	67 000	75 000	70 000	81 000
Penly 1-2	4 000	16 000	20 000	33 000	23 000	24 000	29 000	24 000
St. Alban 1-2	30 000	24 000	9 000	13 000	16 000	22 000	43 000	23 000
St. Laurent B1-B2	34 000	36 000	41 000	33 000	24 000	16 000	20 000	17 000
Tricastin 1-4	49 000	33 000	32 000	34 000	38 000	25 000	46 000	32 000
Germany [B3]								
Biblis A-B	23 000	18 300	25 000	30 000	26 000	21 000	15 000	25 000
Brokdorf	9 400	15 000	19 000	14 000	14 000	12 000	14 000	17 000
Emsland	8 700	8 300	13 000	9 500	13 000	10 000	12 000	15 000
Grafenrheinfeld	12 000	14 000	14 000	13 000	13 000	13 000	16 000	16 000
Greifswald	6 400	200	83	31	69	45	26	24
Grohnde	14 000	16 000	14 000	15 000	18 000	12 000	10 000	7 400
Isar 2	7 200	8 600	16 000	19 000	22 000	19 000	20 000	17 000
Mülheim-Kärlich	2 000	490	420	460	320	250	49	180
Neckarwestheim 1-2	27 000	32 000	24 000	30 000	38 000	35 000	34 000	33 000
Obrigheim	3 500	890	3 300	5 400	4 400	4 600	5 700	5 100
Philippsburg 2	19 000	17 000	15 000	13 000	13 000	17 000	15 000	16 000
Stade	3 400	2 900	4 800	4 800	3 600	2 700	2 900	2 700
Unterweser	11 000	11 000	9 000	8 500	7 700	6 000	12 000	15 000
Hungary [F2]								
Paks 1-4	14 000	16 000	16 000	18 000	18 000	20 000	20 000	15 600

Table 35 (continued)

Country/reactor	Release (GBq)							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Genkai 1-4	34 000	26 000	24 000	36 000	50 000	58 000	46 000	61 000
Ikata 1-3	33 000	29 000	25 000	33 000	38 000	53 000	40 000	45 000
Mihama 1-3	20 000	13 000	12 000	18 000	11 000	17 000	17 000	16 000
Ohi 1-4	16 000	20 000	29 000	42 000	63 000	61 000	59 000	46 000
Sendai 1-2	37 000	36 000	48 000	39 000	31 000	42 000	50 000	36 000
Takahama 1-4	35 000	30 000	55 000	69 000	33 000	37 000	57 000	64 000
Tomari 1-2	16 000	11 000	21 000	24 000	21 000	19 000	26 000	30 000
Tsuruga 2	23 000	30 000	7 500	16 000	12 000	18 000	14 000	21 000
Netherlands [N7]								
Borssele	5 540	2 900	4 370	5 980	5 870	6 161	6 020	4 330
Republic of Korea [K1]								
Kori 1-4	76 100	85 900	48 700	66 100	58 000	31 800	32 900	36 700
Ulchin 1-2	13 100	14 300	35 300	29 900	28 000	21 300	20 800	21 900
Yonggwang 1-4	42 600	29 600	28 600	46 600	26 000	27 900	42 200	55 800
Russian Federation								
Balakovo 1-4								
Kalinin 1-2	Average normalized release estimated to be 30,000 GBq (GW a)$^{-1}$							
Kola 1-4								
Novovoronezh 2-5								
Slovakia [N2, S4]								
Bohunice 1-4	13 000	15 600	12 800	14 000	12 600	12 400	12 700	9 580
Slovenia [S1]								
Krsko	13 500	13 500	14 600	10 900	10 500	8 500	9 300	7 800
South Africa [C11]								
Koeberg 1-2	60 700	91 000	83 700	13 500	17 900	11 300	31 800	17 200
Spain [C2]								
Almaraz 1-2	47 200	48 600	53 700	70 600	51 300	42 800	49 300	54 100
Asco 1-2	42 300	53 400	59 300	55 500	35 800	85 800	50 700	58 000
José Cabrera 1	1 740	1 340	2 940	943	511	1 020	2 590	2 160
Trillo 1	10 900	20 000	11 900	19 800	19 000	14 000	19 400	28 800
Vandellos 2	14 600	17 200	10 400	15 700	14 700	13 400	16 600	20 700
Sweden [N3]								
Ringhals	48 800	45 400	53 100	43 400	34 300	21 000	24 600	22 500
Switzerland [F3]								
Beznau 1-2	9 300	8 900	7 200	12 000	11 000	12 000	12 000	12 000
Gösgen	11 000	12 000	12 000	13 000	11 000	14 000	13 000	14 000
Ukraine [G3]								
Khmelnitski 1				1 600	2 050	1 810	663	1 380
Rovno 1-3								
South Ukraine 1-3	15	13	12	25	28	28	39	23
Zaporozhe 1-5								
United Kingdom [M7]								
Sizewell B	-	-	-	-	-	-	37 600	44 200
United States [T3]								
Arkansas One 1-2	29 600	53 900	29 700	28 100	35 400	34 100	42 400	26 500
Beaver Valley 1-2	18 200	17 900	17 200	20 500	13 600	19 200	72 900	20 100
Braidwood 1-2	48 100	25 400	70 900	59 600	45 700	69 600		
Byron 1-2	36 900	52 900	58 500	76 200		50 000	52 100	
Callaway 1	37 700	45 400	21 900	52 000	38 100	29 300	43 300	25 300
Calvert Cliffs 1-2	2 700	37 600	65 600	23 500	24 200	28 200	28 000	33 600
Catawba 1-2	22 000	23 900	28 600	30 600	21 700	18 100	23 700	23 900
Comanche Peak 1-2	6 920	17 000	22 600	18 600	32 900	31 100	36 500	53 800
Crystal River 3	18 900	16 600	13 500	21 800	12 200		9 700	
Davis-Besse 1	4 700	12 100	14 100	6 700	16 400	6 200	19 400	25 100
Diablo Canyon 1-2	35 800	38 900	45 100	38 100	102 000	58 090	35 500	49 600
Donald Cook 1-2	57 700	57 400	16 000	22 200	212	300	75 200	111 000

Table 35 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*								
Farley 1-2	52 100	30 500	59 500	67 300	50 100	46 700	56 400	35 800
Fort Calhoun 1	6 440	6 500	3 920	8 840	8 820	9 500	18 100	
R. E. Ginna	11 900	13 900	7 880	6 550	5 100	3 610	4 400	
Haddam Neck	36 600	171 000	31 900	148 000				
Harris 1	26 900	10 800	33 400	20 500	37 400	11 800	16 900	11 000
Indian Point 1-3	36 100	40 100	42 400	21 600				
Kewaunee	14 000	16 100	10 700	8 730	6 070	8 730	11 600	15
Maine Yankee	8 990	14 400	8 030	10 100	14 600	1 650	11 000	4 710
McGuire 1-2	33 900	32 500	32 000	28 700	17 800	23 900	23 800	21 800
Millstone 2-3	48 100	21 100	26 000	31 300	37 700	31 600	14 800	10 700
North Anna 1-2	61 900	42 900	34 400	25 600	45 800	36 100	41 500	37 300
Oconee 1-2-3	36 700	41 800	36 900	40 700	33 600	30 900	32 500	22 900
Palisades	5 510	2 040	29 90	7 770	674	4 660	7 590	5 100
Palo Verde 1-3	0	0	0	0				
Point Beach 1-2	32 300	29 100	15 400	17 200	17 200	19 600	15 500	6 360
Prairie Island 1-2	14 700	20 600	17 500	17 800	13 800	28 900	23 200	20 900
Rancho Seco 1	507	36.4	895	275				
H. B. Robinson 2	13 100	6 960	14 600	31 300	7 990	36 700	36 600	33 300
Salem 1-2	24 300	38 800	17 400	33 300	40 600	14 300	1 720	2 320
San Onofre 1-3	87 000	86 300	144 000	52 700	33 000	36 200	53 700	11 400
Seabrook 1	4 180	14 280	18 500	20 800				
Sequoyah 1-2	31 600	61 100	53 300	20 700	18 200		46 700	
South Texas 1-2	30 200	40 300	50 400	8 360	27 900	137 000	59 800	60 600
St. Lucie 1-2	21 000	30 000	29 600	18 800	19 200	27 800		
Surry 1-2	41 000	33 800	36 000	48 700	36 200	30 800	36 700	41 100
Three Mile Island 1	7 810	13 300	20 700	13 900	13 200	19 500	6 180	27 600
Trojan	8 100	6 250	7 250	45 100	336	106	138	150
Turkey Point 3-4	23 800	7 550	16 400	19 000	27 800	11 700		
Virgil C. Summer 1	15 600	30 100	22 500	17 700	27 800	11 300	21 400	34 100
Vogtle 1-2	43 400	40 500	54 800	28 200	38 900	35 800	60 500	54 400
Waterford 3	26 300	12 700	18 300	18 100	24 700	43 700	19 200	12 500
Watts Bar	-	-	-	-			8 260	
Wolf Creek	21 800	26 500	16 700	37 000			20 000	
Yankee NPS	7 110	7 510	2 330	18.5	22.6	7.03	5.42	2.96
Zion 1-2	25 200	34 400	19 300	45 900	25 100	46 300	46 800	8 550
BWRs								
China [T2]								
Chin Shan 1-2	1 890	1 390	1 530	1 090	973	1 260	1 480	350
Kuosheng 1-2	1 020	2 670	3 960	2 800	4 850	729	367	160
Finland [F1]								
Olkiluoto 1-2	1 300	1 900	1 800	3 600	2 800	1 500	2 400	1 300
Germany [B3]								
Brunsbüttel	170	290	240	74	23	120	350	240
Gundremmingen B,C	2 200	3 000	2 800	4 800	4 500	6 400	11 000	13 000
Isar 1	460	400	460	640	1 100	1 300	1 000	1 200
Krümmel	960	950	650	610	130	580	680	470
Philippsburg 1	460	630	620	760	470	570	540	490
Würgassen	330	460	410	440	330	35	38	14
India								
Tarapur 1-2								
Japan [J1, J5]								
Fukushima Daiichi 1-6	2 700	2 400	2 100	1 900	1 400	1 100	1 100	1 400
Fukushima Daini 1-4	1 100	870	460	580	580	490	570	1 000
Hamaoka 1-4	2 100	1 300	1 000	1 400	1 300	1 000	680	600
Kashiwazaki Kariwa 1-7	150	42	390	160	160	130	170	80
Onagawa 1-2	68	58	38	90	15	8.5	21	44
Shika 1	-	-	3	16	57	140	170	200
Shimane 1-2	430	510	430	570	1 000	730	1 200	720
Tokai 2	980	1 600	1 400	1 300	830	1 500	1 700	1 200
Tsuruga 1	160	470	380	210	97	110	170	190

Table 35 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico [C5]								
Laguna Verde 1-2	498	82	158	0.00005	1 970	1 960	531	781
Netherlands [N7]								
Dodewaard	147	152	245	163	90	26	19	18
Spain [C2]								
Confrentes	64.7	235	310	516	385	99.4	160	511
S. Maria de Garona	157	73.7	427	177	371	121	165	231
Sweden [N3]								
Barsebeck 1-2	1 100	1 000	1 500	580	530	554	1 100	760
Forsmark 1-3	1 900	3 500	2 600	2 920	2 370	2 340	1 990	2 000
Oskarshamn 1-3	2 600	2 500	1 700	740	1 130	1 190	1 380	1 360
Ringhals 1	711	882	1 270	500	860	832	790	490
Switzerland [F3]								
Leibstadt	930	810	950	620	570	470	710	1 100
Mühleberg	330	380	200	300	200	340	290	320
United States [T3]								
Big Rock Point	21.8	9.29	40.0	5.85	1.55	3.99	8.79	5.03
Browns Ferry 1-3	7.66	221	1 050	459	1 630			
Brunswick 1-2	1 830	2 960	1 570	1 750	2 580	2 040	1 750	962
Clinton 1	96.2	165	87.3	0	0	0	0	0
Cooper	188	335	541	400	129	2 780	198	218
Dresden 2-3	755	474	158	862	551	96.1	425	462
Duane Arnold 1	-	-	-	0	0	0	0	0
Enrico Fermi 2	27.6	74.7	13.0	13.8	90.0	0	0	0
Fitzpatrick	114	282	105	53.3	23.9	13.5	168	0
Grand Gulf 1	699	799	851	2 330	5 980	4 850	7 990	6 360
Hatch 1-2	836	1 080	1 650	1 880	1 700	1 700	1 180	890
Hope Creek 1	437	907	4 630	2 280	6 070	1 710	418	457
Lasalle 1-2	13.8	0	0.0011	0	5.37	0		
Limerick 1-2	1 120	507	389	951	2 100	1 650		
Millstone 1	749	311	272	907	747	485	271	30
Monticello	0	0	0	0.0007	0	0	0	0
Nine Mile Point 1-2	229	288	331	877	654	707		
Oyster Creek	-	22.3	-	0	0	-	226	0.37
Peach Bottom 2-3	870	540	655	267	95.2	1 480	3 420	
Perry 1	325	392	343	346	343			
Pilgrim 1	136	377	0.54	139	34.7	650	542	875
Quad Cities 1-2	966	164	463	1 360	1 740	834	818	1 040
River Bend 1	3 090	1 130	866	1 120	2 400	758	202	296
Susquehanna 1-2	2 150	1 710	2 850	2 510	3 760	2 940	1 240	1 280
Vermont Yankee	0	0	0.0015	0	0	0	0	0
WPPSS 2	27.9	67.0	400	1 260	307	192	152	
HWRs								
Argentina [C3]								
Atucha 1	530 000	550 000	770 000	920 000	2 200 000	500 000	550 000	1 200 000
Embalse	220 000	520 000	160 000	200 000	140 000	230 000	320 000	160 000
Canada [A2]								
Bruce 1-4	1 221 000	3 241 000	1 700 000	1 480 000	1 440 000	1 900 000	1 200 000	310 000
Bruce 5-8	481 000	488 000	410 000	658 000	555 000	380 000	230 000	680 000
Darlington 1-4	12 600	71 000	46 000	57 700	130 000	140 000	120 000	112 000
Gentilly 2	163 000	248 000	263 000	241 000	134 000	200 000	120 000	140 000
Pickering 1-4	407 000	395 000	3 034 000	518 000	555 000	440 000	430 000	350 000
Pickering 5-8	30 000	32 000	44 000	12 600	118 000	110 000	160 000	50 000
Point Lepreau	160 000	110 000	320 000	470 000	260 000	170 000	480 000	500 000
India [B4]								
Kakrapar 1-2	-	-	-					
Kalpakkam 1-2	142 800	211 500	366 000	428 600	266 400			
Narora 1-2	9 950	15 380	34 200	58 680	49 020			
Rajasthan 1-2	23 690	31 170	30 190	65 450	19 010			

Table 35 (continued)

Country/reactor	Release (GBq)							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Fugen	3 100	1 600	3 400	3 200	4 200	3 800	5 500	5 100
Pakistan [P2]								
Karachi	127 000	94 300	46 300	56 200	118 000	168 000	105 000	39 100
Republic of Korea [K1]								
Wolsong 1-2	51 800	93 200	42 000	46 300	180 000	170 000	50 000	94 700
Romania								
Cernavoda	-	-	-	-	-	-	8 210	11 600
United Kingdom [M7, N5]								
Winfrith	39 330	13 280	13 790	74 010	59 980		1 610	3 900
GCRs								
France [E1]								
Bugey 1	0	0	0	0	9 600	100	2 800	8 200
Chinon A2-3	2 000	0	0	0	0	0	0	0
St. Laurent A1-2	-	-	-	-	-	-	-	-
Japan [J1, J5]								
Tokai 1	0.037	1.4	0.83	24	5.1	9.2	16	20
Spain [C2]								
Vandellos 1	141	74.3	18 300	105	114	45.6	206	
U. K. [M7, N4, N5]								
Berkeley	1 350	272	157	265	29.1	39.5	37.2	55.2
Bradwell	1 380	1 370	3 920	3 030	2 170	2 080	1 360	1 460
Calder Hall	-	-	-					
Chapelcross	280	1 870	690	500	490	500	368	198
Dungeness A	713	492	451	4 430	547	296	1 380	135
Dungeness B1-B2	7 200	76 100	93 300	268 900	236 200	15 080	252 000	247 000
Hartlepool A1-A2	166 100	140 900	276 900	349 800	289 400	239 000	353 000	367 000
Heysham 1A-B, 2A-B	202 100	416 000	525 000	854 700	732 600	584 800	710 000	816 000
Hinkley Point A	913	780	706	779	713	757	670	810
Hinkley Point B, A-B	295 600	277 000	317 000	390 000	336 000	431 000	319 000	385 000
Hunterston A1	520	250	170	360	200	41.0	22.9	9.9
Hunterston B1-B2	353 000	257 000	245 000	362 000	423 000	449 000	399 000	413 000
Oldbury A	1 750	271	215	229	263	233	186	178
Sizewell A	5 010	5 610	5 080	2 790	3 570	17 400	1 130	5 060
Torness A-B	82 000	132 000	250 000	235 000	220 000	270 000	298 000	324 000
Trawsfynydd	2 520	360	222	74.7	122	232	103	298
Wylfa	5 380	5 680	2 750	5 920	6 980	7 560	9 880	7 020
LWGRs								
Lithuania								
Ignalina 1-2								
Russian Federation [M6]								
Bilibino 1-4	Only average normalized release reported							
Kursk 1-4								
Leningrad 1-4								
Smolensk 1-3								
Ukraine [G3]								
Chernobyl 1-3	Only average normalized release reported							
FBRs								
France [E1]								
Creys-Malville	70	20	10	1	22	28	630	1
Phenix								
Kazakhstan								
Bn-350								

Table 35 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Russian Federation Beloyarsky 3								
United Kingdom Dounreay PFR								

Summary parameter	*Reactor*	*Release (TBq)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
All reactors									
Total release (TBq)	PWRs	2 935	3 084	2 995	2 954	2 560	2 677	2 814	2 551
	BWRs	39.6	41.4	45.3	47.3	60.0	48.5	49.8	43.1
	HWRs	3 622	6 115	7 283	5 290	6 225	4 412	3 780	3 656
	GCRs	1 128	1 316	1 740	2 479	2 262	2 018	2 349	2 575
	LWGRs	0	0	0	0	0	0	0	0
	FBRs	0.070	0.020	0.010	0.001	0.022	0.028	0.63	0.001
	All	7 725	10 560	12 060	10 770	11 110	9 155	8 994	8 814
Annual normalized release [TBq (GW a)$^{-1}$]	PWRs	23	24	22	21	18	19	19	18
	BWRs	0.85	0.81	0.95	0.93	1.14	0.85	0.95	0.82
	HWRs	367	536	682	426	452	361	321	316
	GCRs	163	183	215	271	247	236	314	284
	LWGRs	-	-	-	-	-	-	-	-
	FBRs	1.0	-	-	-	26	-	1.6	-
	All	41	53	60	51	52	42	41	41
Average normalized release 1990-1994 and 1995-1997 [TBq (GW a)$^{-1}$]	PWRs	22					19		
	BWRs	0.94					0.87		
	HWRs	490					330		
	GCRs	220					280		
	LWGRs	-					-		
	FBRs	1.8					1.7		
	All	51					41		

Table 36
Other radionuclides released from reactors in liquid effluents

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
PWRs								
Armenia [A5]								
Armenia 2							22.9	15.4
Belgium [M1]								
Doel 1-4	15.5	22.3	4.4	23.6	8.6	37.8	18.9	26.4
Tihange 1-3	41.5	43.7	53.6	40.9	23.8	22.5	52.3	24.3
Brazil [C7]								
Angra 1	0.430	0.197	0.167	0.548	0.182	0.214	0.19	1.08
Bulgaria [C6]								
Kozloduy 1-6	2.07	2.46	2.03	2.07	1.63	3.61	2.53	2.38
China [C8, T2]								
Guangdong 1-2	-	-	-		89.2	28.9	9.32	11.3
Qinshan	-	-	0.732	0.650	0.45	0.412	0.500	0.336
Maanshan 1-2	0.313	0.736	2.75	4.11	0.433	0.336	0.168	0.522
Czech Republic [N2]								
Dukovany 1-4	0.19	0.34	0.094	0.41	0.31	0.17	0.095	0.077
Finland [F1]								
Loviisa 1-2	18	5.2	3.5	1.9	0.41	0.073	0.056	0.012
France [E1]								
Belleville 1-2	25	10	11	16	7.9	4.0	6.1	3.3
Blayais 1-4	73	40	25	11	10	14	4.9	2.2
Bugey 2-5	255	104	51	26	18	9.6	12	9.6
Cattenom 1-4	12	13	15	9.0	16	7.0	3.8	2.3
Chinon B1-B4	107	96	20	9.5	7.3	10	10	3.2
Chooz-A (Ardennes)	18	13	10	5.5	7.5	20	4.4	1.8
Chooz B1-B2							0.2	1.9
Cruas 1-4	17	13	9.0	5.9	6.1	3.9	4.4	2.8
Dampierre 1-4	46	20	10	7.6	9.6	9.0	7.0	7.8
Fessenheim 1-2	34	18	13	6.8	5.9	2.2	2.7	6.1
Flamanville 1-2	32	40	11	6.9	7.9	3.4	2.0	2.8
Golfech 1-2	0.28	0.07	0.7	1.1	2.3	4.8	1.7	2.8
Gravelines 1-6	173	73	23	12	9.5	18	14	5.8
Nogent 1-2	28	6.0	3.0	3.0	1.7	3.0	3.0	3.2
Paluel 1-4	180	62	24	9.9	8.5	9.2	4.6	6.5
Penly 1-2	26	2.0	4.0	3.8	3.3	1.8	1.6	1.7
St. Alban 1-2	61	30	6.0	3.4	2.8	3.0	3.0	5.4
St. Laurent B1-B2	23	20	6.0	8.6	5.4	2.3	2.0	3.0
Tricastin 1-4	83	40	24	8.9	6.7	6.4	5.2	8.6
Germany [B3]								
Biblis A-B	0.52	0.56	0.46	0.48	0.83	0.73	0.52	0.34
Brokdorf	0	0	0	0	0	0.11	0.026	0.022
Emsland	0.0087	0.0033	0.00065	0.0006	0.0007	0.00021	0.00001	0
Grafenrheinfeld	0.044	0.047	0.012	0.032	0.017	0.017	0.011	0.03
Greifswald	3.7	0.62	0.32	0.17	0.16	0.038	0.16	0.16
Grohnde	0.03	0.093	0.013	0.04	0.049	0.13	0.11	0.046
Isar 2	0.06	0.0039	0.0095	0.0083	0.0004	-	0.00029	0.012
Mülheim-Kärlich	0.32	0.066	0.24	0.14	0.15	0.036	0.0089	0.0084
Neckarwestheim 1-2	0.091	0.098	0.045	0.021	0.016	0.028	0.104	0.026
Obrigheim	0.23	0.15	0.21	0.11	0.24	0.52	0.36	0.23
Philippsburg 2	0.39	0.18	0.49	0.61	0.92	0.44	0.29	0.43
Stade	0.52	0.49	0.45	0.32	0.049	0.37	0.18	0.13
Unterweser	0.15	0.36	0.21	0.23	0.11	0.16	0.20	0.12
Hungary [F2]								
Paks 1-4	2.03	3.51	2.24	1.82	2.40	1.20	0.81	0.67

Table 36 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Genkai 1-4	0	0	0	0	0	0	0	0
Ikata 1-3	0	0	0	0	0	0	0	0
Mihama 1-3	0.016	0.0005	0.0030	0.0003	0.0001	0.0005	0	0
Ohi 1-4	0.0007	0	0.00008	0.0001	0	0	0	0
Sendai 1-2	0	0	0	0	0	0	0	0
Takahama 1-4	0	0	0	0	0	0	0	0
Tomari 1-2	0	0	0	0	0	0	0	0
Tsuruga 2	0.0043	0.00004	0	0.0002	0	0.00009	0	0
Netherlands [N7]								
Borssele	1.9	1.3	0.83	0.58	0.73	0.62	0.38	1.3
Republic of Korea [K1]								
Kori 1-4	48.7	0.61	4.94	1.03	1.80	0.86	0.43	0.11
Ulchin 1-2	1.48	1.67	0.54	0.93	1.40	0.57	0.26	0
Yonggwang 1-4	1.18	0.41	0.24	0.13	0.23	0.21	0.22	0.016
Russian Federation [M6]								
Balakovo 1-4	0.17	0.21	0.25	0.13	0.74	0.33	0.19	0.65
Kalinin 1-2	0.25	0.46	1.60	1.68	1.64	1.53	1.46	1.18
Kola 1-4	0.15	0.09	0.17	0.16	0.07	0.01	0.12	0.15
Novovoronezh 2-5	0.16	0.19	0.37	0.34	0.34	0.16	0.10	0.70
Slovakia [N2, S4]								
Bohunice 1-4	0.15	0.97	0.29	0.2	0.14	0.15	0.085	0.078
Slovenia [S1]								
Krsko	1.54	1.53	2.50	2.90	1.60	0.70	7.90	1.20
South Africa [C11]								
Koeberg 1-2	1.56	1.16	2.49	21.3	59.8	59.7	57.5	47.4
Spain [C2]								
Almaraz 1-2	28.7	17.6	12.4	7.87	17.4	24.4	14.4	12.7
Asco 1-2	33.2	33.3	24.68	28.4	31.9	52.1	12.4	19.8
José Cabrera 1	12.6	7.53	4.66	1.69	3.84	0.231	0.194	0.202
Trillo 1	0.74	0.25	0.43	1.05	0.97	0.685	0.761	1.34
Vandellos 2	15.6	8.95	14.6	10	30.9	17.3	11.2	19.3
Sweden [N3]								
Ringhals 2-4	235	75.9	102	91.4	98.1	81.1	48.2	47.3
Switzerland [F3]								
Beznau 1-2	6.2	4.3	12	8.5	3	2.1	3.0	1.8
Gösgen	0.011	0.0014	0.0034	0.13	0.005	0.20	0.20	0.20
Ukraine [G3]								
Khmelnitski 1	0.0096	0.0093	0.0078	0.0071	0.0067	0.0033	0.0062	0.0016
Rovno 1-3	0.48	0.55	0.48	0.99	3.05	8.10	2.61	1.94
South Ukraine 1-3	0.023	0.024	0.018	0.014	0.0067	0.0083	0.01	0.0086
Zaporozhe 1-6			0.13	0.42	0.17	0.81	0.20	0.47
United Kingdom [M7]								
Sizewell B	-	-	-	-	-	-	19.9	21.3
United States [T3]								
Arkansas One 1-2	96.6	142	201	82.4	52.4	82.9	49.1	24.6
Beaver Valley 1-2	94.1	11.6	12.6	14.7	7.62	14.8	41.4	13.7
Braidwood 1-2	158	747	38.7	35.3	38.2	29.7		
Byron 1-2	43.7	24.8	152	46.6		66.8		
Callaway 1	1.43	0.59	0.17	1.48	0.36	0.38	29.5	7.19
Calvert Cliffs 1-2	52.3	58.8	53.1	57.0	38.9	20.6	12.7	17.8
Catawba 1-2	72.4	28.2	34.4	33.1	22.2	23.2	11.4	4.9
Comanche Peak 1-2	0.44	1.80	14.8	15.5	9.2	4.6	5.5	4.2
Crystal River 3	22.9	6.66	60.3	19.6	43.3		23.0	
Davis-Besse 1	5.22	6.81	4.07	1.93	59.9	2.90	91.2	9.94
Diablo Canyon 1-2	104	31.3	27.5	36.4	84.7	40.5	14.3	8.6
Donald Cook 1-2	59.6	38.1	41.4	19.9	2.46	10.9	79.4	49.3

Table 36 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
United States *(continued)*								
Farley 1-2	6.18	17.4	13.9	13.3	11.3	11.0	5.03	7.37
Fort Calhoun 1	29.8	77.0	21.8	19.2	13.3	52.1	114	
R. E. Ginna	5.55	5.62	12.7	5.07	3.38	1.46	4.79	
Haddam Neck	99.5	27.5	6.40	30.9				
Harris 1	27.0	24.5	11.6	2.88	5.9	6.0	2.7	2.4
Indian Point 1-3	50.7	58.7	64.5	30.7				
Kewaunee	7.62	8.70	2.38	4.44	3.32	3.04	2.15	0.58
Maine Yankee	6.92	15.3	9.29	5.99	6.27	9.12	5.91	3.29
McGuire 1-2	148	77.0	24.2	21.1	32.2	2.98	3.52	2.85
Millstone 2-3	416	187	168	127	47.9	61.6	26.5	10.8
North Anna 1-2	25.0	11.8	18.4	17.9	19.8	13.0	24.4	4.6
Oconee 1-2-3	115	51.8	95.5	17.4	13.5	14.4	12.7	12.6
Palisades	0.29	0.42	0.14	0.52	0.52	0.55	0.10	0.40
Palo Verde 1-3	0	0	0	0				
Point Beach 1-2	0.43	2.18	15.9	8.58	5.56	5.59	1.78	8.95
Prairie Island 1-2	4.81	6.85	24.6	7.22	19.5	16.5	20.7	32.3
Rancho Seco 1	0.0077	0.0075	0.018	0.015				
H. B. Robinson 2	13.3	8.73	8.14	2.02	1.97	3.25	2.95	0.99
Salem 1-2	227	209	255	254	185	126	18.4	21.5
San Onofre 1-3	22.4	19.6	17.3	53.0	10.5	12.1	6.9	12.2
Seabrook 1	0.082	4.51	4.40	3.40				
Sequoyah 1-2	45.1	54.8	53.7	56.2	74.1		88.1	
South Texas 1-2	485	370	143	32.1	18.0	32.7	38.9	23.5
St. Lucie 1-2	59.0	26.2	37.9	53.1	120	76.3		
Surry 1-2	170	105	14.6	0.77	2.4	2.1	7.2	15.0
Three Mile Island 1	0.88	1.30	0.96	3.28	1.92	2.55	0.16	0.26
Trojan	5.33	2.15	3.31	3.92	0.48	4.08	1.82	0.73
Turkey Point 3-4	10.4	27.2	22.1	17.6	22.5	2.76		
Virgil C. Summer 1	13.2	22.5	8.25	7.14	17.3	4.23	5.83	2.34
Vogtle 1-2	47.3	11.3	7.12	56.3	28.3	15.0	37.6	21.3
Waterford 3	27.0	33.7	48.5	22.3	389	140	30.2	50.0
Watts Bar	-	-	-	-			1.81	
Wolf Creek	11.7	78.4	10.8	26.1			406	
Yankee NPS	2.20	0.49	0.23	0.027	0.011	0.014	0.016	0.008
Zion 1-2	132	62.2	67.0	38.2	41.6	40.1	33.1	6.22
BWRs								
China [T2]								
Chin Shan 1-2	20.3	6.15	3.39	2.13	2.97	2.29	2.08	2.25
Kuosheng 1-2	9.06	42.2	17.3	8.70	25.8	5.39	2.34	3.52
Finland [F1]								
Olkiluoto 1-2	31	22	17	9.5	11	24	16	9.5
Germany [B3]								
Brunsbüttel	0.17	0.46	0.17	0.088	0.023	0.058	0.11	0.037
Gundremmingen B,C	0.49	0.5	0.51	0.55	0.99	0.48	0.64	1.1
Isar 1	0.28	0.069	0.16	0.25	0.25	0.15	0.16	0.14
Krümmel	0.016	0.015	0.012	0.012	0.009	0.016	0.014	0.0028
Philippsburg 1	0.65	0.25	0.18	0.52	0.42	0.25	0.84	0.92
Würgassen	0.4	0.52	0.61	0.42	1	0.12	0.11	0.098
India [B4]								
Tarapur 1-2	1 430	1 420	1 120	1 210	762			
Japan [J1, J5]								
Fukushima Daiichi 1-6	0	0	0	0	0	0	0	0
Fukushima Daini 1-4	0	0	0	0	0	0	0	0
Hamaoka 1-4	0.0091	0.0052	0.0024	0.0006	0	0	0	0
Kashiwazaki Kariwa 1-7	0	0	0	0	0	0	0	0
Onagawa 1-2	0	0	0	0	0	0	0	0
Shika 1	-	-	0	0	0	0	0	0
Shimane 1-2	0.0006	0.0015	0.0024	0.0022	0.0005	0.00007	0	0
Tokai 2	0	0	0	0	0	0	0	0
Tsuruga 1	0.0013	0.0065	0.0025	0	0	0	0	0

Table 36 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Mexico [C5]								
Laguna Verde 1-2	18.8	9.5	11.2	5.66	23.5	20.1	1.14	0.88
Netherlands [N7]								
Dodewaard	9.12	9.24	8.35	6.68	8.89	12.9	13.3	5.5
Spain [C2]								
Confrentes	0.1	0.18	0.15	0.13	0.11	0.063	0.119	0.392
S. Maria de Garona	0.57	0.24	3.58	0.58	1.64	0.591	0.765	0.650
Sweden [N3]								
Barsebeck 1-2	45.4	104	105	26.1	26.6	57.8	194	58.3
Forsmark 1-3	230	245	118	156	118	60.5	72.4	115
Oskarshamn 1-3	140	167	129	102	68.3	97.6	130	51.1
Ringhals 1	70.0	54.0	111	118	247	69.5	47.9	155
Switzerland [F3]								
Leibstadt	0.49	0.24	0.17	0.18	0.5	0.4	0.4	0.4
Mühleberg	4.7	2	1.8	3.7	1.9	1.7	2.0	3.7
United States [T3]								
Big Rock Point	1.35	4.51	5.55	3.59	5.30	3.83	8.98	0.90
Browns Ferry 1-3	11.2	31.0	89.2	178	41.5			
Brunswick 1-2	16.9	16.1	1.83	3.85	1.67	15.4	1.48	0.54
Clinton 1	0.92	1.26	0.67	0	0.00004	0	0.00003	0
Cooper	75.4	84.8	147	85.7	12.5	49.3	41.8	48.1
Dresden 2-3	26.3	28.2	0.82	5.99	1.48	2.30	0.98	0.53
Duane Arnold 1	0	0	0	0	0	0	0	0
Enrico Fermi 2	8.07	7.96	0.0056	0.055	0.40	0	0	0
Fitzpatrick	1.01	1.14	0.43	0.070	0.028	0.002	0.33	0
Grand Gulf 1	23.9	32.4	4.44	6.14	8.87	13.1	14.2	4.81
Hatch 1-2	12.6	28.2	34.2	31.3	36.8	14.3	14.5	10.8
Hope Creek 1	55.1	29.2	11.3	13.4	3.32	52.0	28.9	10.1
Lasalle 1-2	0.91	0	0.011	0	0.16	0		
Limerick 1-2	12.7	1.24	1.09	5.37	18.3	16.5		
Millstone 1	5.22	50.3	17.1	4.74	2.20	0.95	1.06	0.88
Monticello	0	0	0	0	0	0	0	0
Nine Mile Point 1-2	2.42	6.22	9.62	4.33	3.96			
Oyster Creek	0.0025	0.89	-	0	0	-	0.10	0
Peach Bottom 2-3	0.50	1.38	0.97	2.09	5.95	1.80	1.25	
Perry 1	22.6	4.37	2.21	5.74	425	1.78	1.45	
Pilgrim 1	0.59	1.48	0.12	0.85	0.10	2.83	0.34	4.89
Quad Cities 1-2	4.18	27.1	1.45	2.27	2.22	2.32	0.93	1.08
River Bend 1	27.3	13.4	61.4	36.0	168	109	16.9	19.6
Susquehanna 1-2	6.29	2.30	1.79	1.82	4.44	21.5	2.07	0.36
Vermont Yankee	0	0	0.001	0	0	0	0	0
WPPSS 2	0.57	1.28	3.51	7.62	1.05	0.96	0.41	
HWRs								
Argentina [C3]								
Atucha 1	130	93	93	60	660	330	680	230
Embalse	3.5	20	2	2	1.6	4.3	4.6	2.0
Canada [A2]								
Bruce 1-4	20	20	30	26.5	44.4	29	20	21
Bruce 5-8	4.0	3.0	5.0	5.15	5.9	9.6	4.5	14.8
Darlington 1-4	330	710	27	11	16	12	20	9.8
Gentilly 2	4.2	3.0	14	9.0	6.9	42	6.5	5.0
Pickering 1-4	52	44	48	34.8	37	17	13	7.3
Pickering 5-8	10	10	2.2	5.55	6.7	6.7	0	5.2
Point Lepreau	2.0	4.0	2.0	5.24	7.3	5.9	3.2	2.7
India [B4]								
Kakrapar 1-2	-	-	-					
Kalpakkam 1-2	26.4	23.6	26.3	35.3	25.5			
Narora 1-2	0.04	0.94	14.5	11.3	3.14			
Rajasthan 1-2	3.63	2.93	2.09	2.40	1.77			

Table 36 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Japan [J1, J5]								
Fugen	0.014	0.0047	0.011	0.0016	0	0	0	0
Pakistan [P2]								
Karachi	8.5	13.3	13.0	22.2	8.9	5.2	4.8	5.3
Republic of Korea [K1]								
Wolsong 1-2	0.20	0.20	0.30	0.55	0.43	0.17	0	0
Romania								
Cernavoda 1	-	-	-	-	-	-	0.04	7.15
United Kingdom [N5]								
Winfrith	3 994	665	115	55	63		29	
GCRs								
France [E1]								
Bugey 1	0.2	2	1	0.9	3.7	0.6	2.5	6.9
Chinon A2-3	0.9	1	2	1.4	3.3	4.0	0.6	0.4
St. Laurent A1-2	-	-	-	-	-	-	-	-
Japan [J1, J5]								
Tokai 1	0.034	0.016	0.016	0.0067	0.0015	0.0089	0.0064	0.0029
Spain [C2]								
Vandellos 1	8.77	9.29	30.7	17.9	30.4	19.8	58.3	
U. K. [M7, N4, N5]								
Berkeley	329	496	156	378	144	134	49	72
Bradwell	324	453	1 380	603	725	809	756	849
Calder Hall	-	-	-					
Chapelcross	110	110	70	270	310	160	111	40
Dungeness A	395	374	507	1 720	996	802	836	792
Dungeness B1-B2	8.9	10.3	8.0	19	51	27	18	27
Hartlepool A1-A2	20	36	49	52	11	8.1	20	11
Heysham 1A-B, 2A-B	73	34	55	48	53	18	6 910	19.7
Hinkley Point A	751	729	610	686	724	981	570	707
Hinkley Point B, A-B	38	27	16	15	21	17	9.0	15
Hunterston A1	320	280	210	290	210	150	141	165
Hunterston B1-B2	50	40	20	34	31	23	5.9	4.1
Oldbury A	429	372	397	505	394	363	186	273
Sizewell A-B	428	467	383	274	292	411	589	233
Torness A-B	1.8	7.0	15	9.8	1.5	2.3	1.8	3.8
Trawsfynydd	334	259	167	41	24	25	21	10
Wylfa	72	88	44	68	54	53	61	46
LWGRs								
Lithuania [E2]								
Ignalina 1-2	25.8	3.1	22.6	4.2	7.7	16.6	5.9	6.1
Russian Federation [M6]								
Bilibino 1-4	0.10	0.10	0.11	0.06	0.07	0.06	0.08	0.04
Kursk 1-4	0.03	0.0004	0.002	0.001	0.007	0.03	0.007	0.004
Leningrad 1-4	0.003	0.0004	0.003	0.003	0.008	0.001	0.003	0.003
Smolensk 1-3	0.09	0.08	0.04	0.02	0.03	0.02	0.03	0.03
Ukraine [G3]								
Chernobyl 1-3	61.8	36.3	24.8	17.0	18.9	28.1	45.1	40.0
FBRs								
France [E1]								
Creys-Malville	0.10	0.11	0.083	0.013	0.017	0.010	0.021	0.017
Phenix								
Kazakhstan [A6]								
Bn-350	22.6	21.5	17.4	15.2	14.1	7.8	7.4	7.4

Table 36 (continued)

Country/reactor	*Release (GBq)*							
	1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Russian Federation [M6]								
Beloyarsky 3	3.47	5.46	8.79	3.51	1.89	1.59	1.23	2.67
United Kingdom								
Dounreay PFR								

Summary parameter	*Reactor*	*Release (GBq)*							
		1990	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
All reactors									
Total release (GBq)	PWRs	4 609	3 546	2 356	1 718	1 980	1 454	1 605	685
	BWRs	2 329	2 461	2 040	2 055	2 044	662	620	511
	HWRs	4 588	1 613	394	286	888	462	786	310
	GCRs	3 693	3 794	4 125	5 030	4 079	4 008	10 350	3 275
	LWGRs	87.8	39.6	47.6	21.3	26.7	44.8	51.1	46.2
	FBRs	26.2	27.1	26.3	18.7	16.0	9.4	8.7	10.1
	All	15 330	11 480	8 989	9 130	9 034	6 640	13 420	4 837
Annual normalized release [GBq $(GW\ a)^{-1}$]	PWRs	34	25	16	11	13	10	10	4.5
	BWRs	48	47	41	40	39	12	12	10
	HWRs	465	141	37	23	65	38	67	27
	GCRs	533	526	511	550	445	470	1 380	361
	LWGRs	8.2	3.8	5.4	2.2	3.5	5.6	5.8	5.9
	FBRs	61	70	50	38	33	24	22	23
	All	72	51	39	39	39	28	56	21
Average normalized release 1990-1994 and 1995-1997 [GBq $(GW\ a)^{-1}$]	PWRs			19				8.1	
	BWRs			43				11	
	HWRs			130				44	
	GCRs			510				700	
	LWGRs			4.8				5.8	
	FBRs			49				23	
	All			48				35	

Table 37
Normalized releases of radionuclides from nuclear reactors

Release	*Year*	*Normalized release [TBq (GW a)⁻¹]*						
		PWR	*BWR*	*GCR*	*HWR*	*LWGR*	*FBR*	*Total* [a]
Noble gases	1970-1974	530	44 000	580	4 800	5 000 [b]	150 [b]	13 000
	1975-1979	430	8 800	3 200	460	5 000 [b]	150 [b]	3 300
	1980-1984	220	2 200	2 300	210	5 500	150 [b]	1 200
	1985-1989	81	290	2 100	170	2 000	820	330
	1990-1994	27	350	1 600	2 100	1 700	380	330
	1995-1997	13	180	1 200	250	460	210	130
Tritium	1970-1974	5.4	1.8	9.9	680	26 [b]	96 [b]	48
	1975-1979	7.8	3.4	7.6 [b]	540	26 [b]	96 [b]	38
	1980-1984	5.9	3.4	5.4	670	26 [b]	96 [b]	44
	1985-1989	2.7	2.1	8.1	690	26 [b]	44	40
	1990-1994	2.3	0.94	4.7	650	26 [b]	49	36
	1995-1997	2.4	0.86	3.9	330	26	49 [b]	16
Carbon-14	1970-1974	0.22 [b]	0.52 [b]	0.22 [b]	6.3 [b]	1.3 [b]	0.12 [b]	0.71
	1975-1979	0.22	0.52 [c]	0.22 [b]	6.3 [b]	1.3 [b]	0.12 [b]	0.70
	1980-1984	0.35	0.33	0.35 [b]	6.3	1.3 [b]	0.12 [b]	0.74
	1985-1989	0.12	0.45	0.54	4.8	1.3	0.12 [b]	0.53
	1990-1994	0.22	0.51	1.4	1.6	1.3 [b]	0.12 [b]	0.44
Iodine-131	1970-1974	0.0033	0.15	0.0014 [b]	0.0014	0.080 [b]	0.0033 [b]	0.047
	1975-1979	0.0050	0.41	0.0014 [b]	0.0031	0.080 [b]	0.0050 [b]	0.12
	1980-1984	0.0018	0.093	0.0014	0.0002	0.080	0.0018 [b]	0.030
	1985-1989	0.0009	0.0018	0.0014	0.0002	0.014	0.0009 [b]	0.002
	1990-1994	0.0003	0.0008	0.0014	0.0004	0.007	0.0003 [b]	0.0007
	1995-1997	0.0002	0.0003	0.0004	0.0001	0.007	0.0002	0.0004
Particulates	1970-1974	0.018 [c]	0.040 [c]	0.0010 [b]	0.00004 [b]	0.015 [b]	0.0002 [b]	0.019
	1975-1979	0.0022	0.053	0.0010	0.00004	0.015 [b]	0.0002 [b]	0.017
	1980-1984	0.0045	0.043	0.0014	0.00004	0.016	0.0002 [b]	0.014
	1985-1989	0.0020	0.0091	0.0007	0.0002	0.012	0.0002	0.004
	1990-1994	0.0002	0.18	0.0003	0.00005	0.014	0.012	0.040
	1995-1997	0.0001	0.35	0.0002	0.00005	0.008	0.001	0.085
Tritium (liquid)	1970-1974	11	3.9	9.9	180	11 [b]	2.9 [b]	19
	1975-1979	38	1.4	25	350	11 [b]	2.9 [b]	42
	1980-1984	27	2.1	96	290	11 [b]	2.9 [b]	38
	1985-1989	25	0.78	120	380	11 [b]	0.4	41
	1990-1994	22	0.94	220	490	11 [b]	1.8	48
	1995-1997	19	0.87	280	340	11 [b]	1.7	38
Other (liquid)	1970-1974	0.20 [b]	2.0 [c]	5.5 [c]	0.60	0.20 [b]	0.20 [b]	2.1
	1975-1979	0.18	0.29	4.8	0.47	0.18 [b]	0.18 [b]	0.70
	1980-1984	0.13	0.12	4.5	0.026	0.13 [b]	0.13 [b]	0.38
	1985-1989	0.056	0.036	1.2	0.030	0.045 [b]	0.004	0.095
	1990-1994	0.019	0.043	0.51	0.13	0.005	0.049	0.047
	1995-1997	0.008	0.011	0.70	0.044	0.006	0.023	0.040

a Weighted by the fraction of energy generated by the reactor types.
b Estimated value.
c Data available for one year only.

Table 38
Collective effective dose per unit release of radionuclides from reactors

Type of release	*Radionuclide*	*Pathway*	*Collective dose per unit release [a] (man Sv PBq⁻¹)*
Airborne	Noble gases		
	PWR	Immersion	0.11 [b c] (0.12)
	BWR	Immersion	0.43 (0.26)
	GCR	Immersion	0.90 (0.011)
	Tritium	Ingestion	2.1 (11)
	Carbon-14	Ingestion	270 [d] (1 800)
	Iodine [e]	External	4.5
		Ingestion	250
		Inhalation	49
		All pathways	300 (340-510)
	Particulates	External	1 080
		Ingestion	830
		Inhalation	33
		All pathways	2 000 (5 400)
Liquid	Tritium	Ingestion	0.65 (0.81)
	Particulates	Ingestion	330 (20-170)

a Previously assessed values [U3] indicated in parentheses unless unchanged.
b Also assumed for LWGRs and FBRs.
c Also assumed for HWRs.
d Local and regional.
e Expressed in terms of ^{131}I.

Table 39
Normalized collective effective doses from radionuclides released from reactors, 1990-1994

Reactor type	*Electrical energy generated (%)*	*Collective effective dose per unit electrical energy generated [man Sv (GW a)⁻¹]*						
		Airborne effluents					*Liquid effluents*	
		Noble gases	^{3}H	^{14}C [a]	^{131}I	*Particulates*	^{3}H	*Other*
PWR	65.04	0.003	0.005	0.059	0.0001	0.0004	0.014	0.006
BWR	21.95	0.15	0.002	0.14	0.0002	0.36	0.0006	0.014
GCR	3.65	1.44	0.010	0.38	0.0004	0.0006	0.14	0.17
HWR	5.04	0.23	1.4	0.43	0.0001	0.0001	0.32	0.043
LWGR	4.09	0.19	0.05	0.35	0.002	0.028	0.007	0.002
FBR	0.24	0.042	0.10	0.032	0.00009	0.024	0.0012	0.016
Weighted average		0.11	0.075	0.12	0.0002	0.080	0.031	0.016
Total		0.43						

a Local and regional components only.

Table 40
Radionuclides released from fuel reprocessing plants

Year	Fuel reprocessed (GW a)	Release in airborne effluents (TBq)						Release in liquid effluents (TBq)					
		^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
France (Cap de La Hague) [C4]													
1970				2 300		0.00026		61		2	100		89
1971		0.9		4 400		0.0074	0.00081	78		8.3	143		243
1972		3.1		8 900		0.1		84		16	140		33
1973		2.6		8 500		0.026		110		19	132		69
1974		7.1		27 000		0.019	<0.00001	281		52	269		56
1975		3.3		24 000		0.067		411		37.6	415		34
1976		1.8		13 000	0.00021	0.011		264		20	278		35
1977	1.4	2.3		25 000	0.0022	0.00007	<0.00001	331		36.4	270		51
1978	1.6	4.4		29 000	0.01	0.0001	<0.00001	729		70	401		39
1979	2.9	7.1		24 000	0.0074	0.028		539		56	374		23
1980	2.8	9.2		30 000	0.017	0.00033	<0.00001	539		29.4	387		27
1981	3.3	10		36 000	0.0098	0.00031	<0.00001	710		27.1	331		39
1982	3.7	6.3		51 000	0.015	0.00018		810		86.3	469		51
1983	5.2	8.3		50 000	0.021	0.0005	<0.00001	1 170		141.8	337	0.1	23
1984	4.8	8.5		27 000	0.027	0.00051	<0.00001	1 460		109.6	351	0.1	30
1985	9.3	33		71 000	0.021	0.00057	0.00008	2 600		47	437	0.13	29
1986	7.2	6.1		29 000	0.011	0.00041	<0.00001	2 310		68.5	403	0.13	10
1987	9.1	15		35 000	0.014	0.00054	<0.00001	2 960		57	525		7.6
1988	7.1	21		27 000	0.021	0.00059		2 540		39.5	259	0.20	8.5
1989	10.8	25		42 000	0.027	0.00077	<0.00001	3 720		28.5	275	0.26	13
1990	12.3	25	2.6	63 000	0.018	0.00053	<0.00001	3 260		15.8	150	0.33	13
1991	18.5	28	2.3	100 000	0.023	0.00074	<0.00001	4 710		29.8	18	0.46	5.6
1992	16.4	30	2	95 000	0.011	0.00038	<0.00001	3 770		17.5	11	0.48	3.0
1993	21.5	42	3.8	120 000	0.010	0.00058	<0.00001	5 150		24.6	8	0.65	4.4
1994	34.3	55	5.4	180 000	0.021	0.00049	<0.00001	8 090		15.6	14	1.1	11
1995	43.4	84	8.5	230 000	0.032	0.00078	<0.00001	9 610		29.6	15.2	1.5	4.6
1996	43.0	75	12	260 000	0.038	0.0015	<0.00001	10 500	9.94	10.6	16.9	1.7	2.4
1997	49.8 [a]	76	17	300 000	0.017	0.0012	<0.00001	11 900	9.65	3.7	19.6	1.6	2.5
Japan (Tokai) [J1, J5]													
1977	0.04	0.25		810	0.00016	0		4.8		0.00014	0	0	0.00093
1978	0.11	0.93		1 800	0.00081	0		30		0.00004	0.0044	0.0011	0.0010
1979	0.18	0.85		1 800	0.00032	0		59		0.00009	0.0025	0.0018	0.00028
1980	0.61	3.5		7 400	0.0007	0		160		0.00002	0.00044	0.00017	0.00022
1981	0.60	3.6		7 800	0.00041	0		140		0	0.00033	0.00004	0.00017
1982	0.54	4.1		7 800	0.00056	0		200		0.00001	0.00023	0.00001	0.00014
1983	0.01	1.5		180	0.00009	0		5.6		<0.00001	0	<0.0001	0.00002
1984	0.12	0.67		1 300	0.00004	0		32		0.00006	0	<0.00001	0
1985	1.2	2.8		10 000	0.001	0		260		<0.00001	0	0.00009	0.00008

Table 40 (continued)

Year	Fuel reprocessed (GW a)	Release in airborne effluents (TBq)						Release in liquid effluents (TBq)					
		^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
1986	1.2	2.7		13 000	0.0023	0		240		0.00003	0	<0.00001	0.00017
1987	0.93	3.7		12 000	0.00014	0		260		<0.00001	0	<0.00001	0.00015
1988	0.17	2.5		2 700	0.00009	0		74		0	0	0	0.00009
1989	1.1	3.7		9 800	0.00024	0		240		0	0	0.00001	0.00004
1990	1.5	4.2		13 000	0.000024	0	–	360	–	0	0	0.00004	0
1991	1.5	3.2	0.34	15 000	0.00030	0	–	330	–	0	0	0.00003	0.00003
1992	1.5	2.8	0.78	9 800	0.00030	0	–	380	–	0	0	0.00007	0.00007
1993	0.8	2.2	0.31	5 300	0.00024	0	–	160	–	0	0	0.00005	0.00005
1994	1.5	5.4	0.80	18 000	0.00033	0	–	490	–	0	0	0.00007	0.00007
1995	1.0	3.8	0.44	8 600	0.00016	0	–	220	–	0	0	0.00008	0
1996	1.5	3.7	0.48	12 000	0.00016	0	0.001	240	–	0	0	0.00005	0
1997	0	1.5	0.0047	1.6	0	0	–	3.6	–	0	0	0.00001	0
United Kingdom (Sellafield) [B5, J2]													
1970		443	9.0		0.022	0.027	0.066	6 200	1.0	230	1 000	0.10	1 200
1971		443	10.0		0.022	0.069	0.13	1 200	1.0	460	1 400	0.10	1 300
1972	2.6	303	17.3	37 000	0.022	2.4	0.015	1 240	1.0	562	1 130	0.10	1 289
1973		443	24.3		0.022	0.13	0.068	740	1.0	280	1 400	0.10	770
1974		443	17.3		0.022	0.0013	0.038	1 200	1.0	390	1 100	0.10	4 100
1975	3.2	444	20.3	44 000	0.022	0.0011	0.096	1 400	1.0	466	762	0.10	5 230
1976	3.2	444	32.3	44 000	0.024	0.009	0.11	1 200	1.0	381	766	0.13	4 289
1977	2.1	296	26.3	33 000	0.018	0.0078	0.49	910	1.0	427	816	0.096	4 480
1978	1.8	222	8.6	26 000	0.0078	0.045	0.51	1 000	1.0	597	810	0.074	4 090
1979	2.5	290	7.3	35 000	0.017	0.091	0.51	1 200	1.0	250	390	0.12	2 600
1980	2.2	252	8.5	31 000	0.045	0.0033	0.93	1 280	1.0	352	340	0.14	2 970
1981	3.7	459	19.3	52 000	0.027	0.90	0.19	1 966	1.0	277	530	0.19	2 360
1982	3.1	360	9.5	44 000	0.033	0.017	0.054	1 750	1.0	319	420	0.10	2 000
1983	3.0	268	7.3	41 800	0.027	0.015	0.046	1 831	1.0	204	553	0.20	1 200
1984	2.7	349	7.3	37 100	0.030	0.006	0.040	1 586	1.0	72	348	0.10	434
1985	1.7	268	7.3	23 800	0.021	0.006	0.036	1 062	1.3	52	81	0.10	325
1986	3.8	171	5.7	53 300	0.030	0.003	0.038	2 150	2.6	18.3	28	0.12	17.9
1987	2.4	78.3	9.8	34 000	0.019	0.0035	0.0071	1 375	2.1	15	22.1	0.10	11.8
1988	2.8	186	3.6	39 700	0.024	0.0022	0.0038	1 724	3	10.1	23.6	0.13	13.3
1989	3.7	677	4.2	51 700	0.024	0.0021	0.0026	2 144	2	9.2	25	0.17	28.6
1990	3.8	593	4.1	37 600	0.012	0.0012	0.0028	1 699	2.0	4.2	16.5	0.11	23.5
1991	4.5	619	5.8	44 600	0.012	0.0019	0.0036	1 803	2.4	4.1	18.7	0.16	15.6
1992	2.7	324	2.5	27 400	0.019	0.0016	0.0020	1 199	0.8	4.2	12.6	0.07	15.3
1993	5.7	860	11.4	57 000	0.039	0.0020	0.0007	2 309	2.0	17.1	17.1	0.16	21.9
1994	3.8	550	4.2	38 000	0.024	0.0017	0.0007	1 680	8.2	28.9	6.7	0.16	13.8
1995	6.9	580	4.2	97 000	0.020	0.0011	0.0006	2 700	12	28	7.3	0.25	12
1996	7.1	530	3.8	100 000	0.025	0.0023	0.0009	3 000	11	16	9.0	0.41	10
1997	6.8	170	1.8	95 000	0.025	0.0026	0.0006	2 600	4.4	37	9.8	0.52	7.9

a Estimated based on normalized ^{85}Kr release of 6,020 TBq $(GW\ a)^{-1}$.

Table 41
Normalized releases and collective doses in fuel reprocessing

Year	*Fuel reprocessed (GWa)*	*Normalized release [TBq (GW a)$^{-1}$]*											
		Airborne effluents						*Liquid effluents*					
		^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
1970-1979	29.2	93	7.3	13 920	0.006	0.12	0.09	399	0.4	131	264	0.04	1 020
1980-1984	36.3	48	3.5	11 690	0.007	0.03	0.04	376	0.3	45	112	0.04	252
1985-1989	62.5	24	2.1	7 263	0.003	0.0003	0.002	378	0.8	7.5	33	0.03	7.4
1990-1994	131	24	0.4	6 300	0.001	0.00009	0.00008	270	0.8	2.0	2.1	0.03	1.0
1995-1997	160	9.6	0.3	6 900	0.001	0.00005	0.00001	255	0.4	0.8	0.5	0.04	0.2

Year	*Fuel reprocessed (GWa)*	*Collective effective dose per unit release (man Sv TBq^{-1})*											
		Airborne effluents						*Liquid effluents*					
		^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
		0.0021	0.27	0.0000074	44	0.3	7.4	0.0000014	1.0	0.0047	0.0033	0.099	0.098

Year	*Fuel reprocessed (GWa)*	*Collective effective dose (man Sv) [a]*											
		Airborne effluents						*Liquid effluents*					
		^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
Pre-1970	2.3 [b]	0.5	4.5	0.2	0.6	0.08	1.6	0.001	0.9	1.4	2.0	0.009	230
1970-1974	7.0	1.4	14	0.7	1.9	0.25	4.9	0.004	2.7	4.3	6.1	0.03	704
1975-1979	22.2	4.3	44	2.3	5.9	0.79	15	0.01	8.7	14	19	0.09	2 220
1980-1984	36.3	3.7	35	3.1	11	0.28	11	0.02	12	7.6	13	0.1	895
1985-1989	62.5	3.1	36	3.4	9.5	0.006	0.80	0.03	48	2.2	6.9	0.2	46
1990-1994	131	6.6	13	6.1	8.4	0.003	0.08	0.05	98	1.2	0.9	0.4	12
1995-1997	160	3.2	13	8.2	6.9	0.002	0.02	0.06	66	0.6	0.3	0.6	3.9
Total	420	23	158	24	44	1.4	34	0.18	236	31	49	1.4	4 110
		280						4 430					
		4 710											

a Collective doses prior to 1970 and in 1970-1974 and 1975-1979 are estimated using the normalized release estimates of 1970-1979.
b Estimated to be 8% of electrical energy generated.

Table 42
Normalized activity releases of globally dispersed radionuclides from reactors and reprocessing plants

Years	*Normalized release [TBq (GW a)$^{-1}$]*						
	From reactors		*From reprocessing plants*				
	^{3}H	*^{14}C*	*^{3}H*	*^{3}H (to sea)*	*^{14}C*	*^{85}Kr*	*^{129}I*
Pre-1970	67	0.71	93	399	7.7	13 920	0.046
1970-1974	67	0.71	93	399	7.7	13 920	0.046
1975-1979	80	0.70	93	399	7.7	13 920	0.046
1980-1984	83	0.74	48	376	3.9	11 690	0.042
1985-1989	82	0.53	24	378	2.9	7 260	0.029
1990-1994	84	0.44	24	272	1.1	6 330	0.030
1995-1997	54	0.44 [a]	9.6	255	0.7	6 900	0.038

a Estimated value.

Table 43
Activity releases of globally dispersed radionuclides from reactors and reprocessing plants

Years	*Electrical energy generated (GW a)*	*Fuel reprocessed (GW a)*	*Release (TBq)*				
			^{3}H	*^{3}H (to sea)*	*^{14}C*	*^{85}Kr*	*^{129}I*
Pre-1970	28.8	2.30	2 146	919	38	32 060	0.11
1970-1974	87.7	7.04	6 543	2 809	116	97 970	0.32
1975-1979	277	22.2	24 200	8 858	364	308 900	1.01
1980-1984	514	36.3	44 330	13 640	523	424 400	1.53
1985-1989	937	62.5	77 960	23 660	672	454 000	1.79
1990-1994	1 147	130	98 900	35 390	650	823 700	3.87
1995-1997	767	160	42 830	40 770	442	1 102 000	6.14
Total	3 757	420	296 900	126 000	2 805	3 243 000	14.8

Table 44
Collective dose commitment (10,000 years) from globally dispersed radionuclides released from reactors and reprocessing plants

Years	*Collective effective dose (man Sv)* [a b]						*Normalized collective effective dose [man Sv (GW a)$^{-1}$]*
	^{3}H	*^{3}H (to sea)*	*^{14}C*	*^{85}Kr*	*^{129}I*	*Total*	
Pre-1970	4.3	0.2	2 670	64	2.1	2 740	95
1970-1974	13	0.6	8 140	196	6.4	8 350	95
1975-1979	48	1.8	25 510	618	20	26 200	95
1980-1984	89	2.7	36 580	849	31	37 550	73
1985-1989	156	4.7	47 070	908	36	48 180	51
1990-1994	198	7.1	45 470	1 650	77	47 400	41
1995-1997	86	8.1	30 930	2 200	123	33 350	43
Total	594	25	196 400	6 490	295	203 800	54

a Collective dose per unit release (man Sv TBq^{-1}): ^{3}H, 0.002; ^{3}H (to sea), 0.0002; ^{14}C: 70; ^{85}Kr, 0.002; ^{129}I, 20.
b Assumes world population at time of release: 5 10^{9} (for ^{3}H and ^{85}Kr); 10^{10} (for ^{14}C and ^{129}I).

Table 45
Normalized collective effective dose to members of the public from radionuclides released in effluents from the nuclear fuel cycle [a]

Source	*Normalized collective effective dose [man Sv (GW a)$^{-1}$]*				
	1970-1979	*1980-1984*	*1985-1989*	*1990-1994*	*1995-1997*
Local and regional component					
Mining	0.19	0.19	0.19	0.19	0.19
Milling	0.008	0.008	0.008	0.008	0.008
Mine and mill tailings (releases over five years)	0.04	0.04	0.04	0.04	0.04
Fuel fabrication	0.003	0.003	0.003	0.003	0.003
Reactor operation					
Atmospheric	2.8	0.7	0.4	0.4	0.4
Aquatic	0.4	0.2	0.06	0.05	0.04
Reprocessing					
Atmospheric	0.3	0.1	0.06	0.03	0.04
Aquatic	8.2	1.8	0.11	0.10	0.09
Transportation	<0.1	<0.1	<0.1	<0.1	<0.1
Total (rounded)	12	3.1	0.97	0.92	0.91
Solid waste disposal and global component					
Mine and mill tailings (releases of radon over 10,000 years)	7.5	7.5	7.5	7.5	7.5
Reactor operation					
Low-level waste disposal	0.00005	0.00005	0.00005	0.00005	0.00005
Intermediate-level waste disposal	0.5	0.5	0.5	0.5	0.5
Reprocessing solid waste disposal	0.05	0.05	0.05	0.05	0.05
Globally dispersed radionuclides (truncated to 10,000 years)	95	70	50	40	40
Total (rounded)	100	80	60	50	50

a Analysis is based on reported releases per unit electrical energy generated and presently adopted dose coefficients. These results may, therefore, differ somewhat from earlier evaluations by the Committee.

Table 46
Local and regional component of the collective effective dose to members of the public from radionuclides released in effluents from the nuclear fuel cycle

Years	*Electrical energy generated (GW a)*	*Normalized collective effective dose [man Sv (GW a)$^{-1}$]*			*Collective effective dose (man Sv)*		
		Mining, milling, fuel fabrication, transportation	*Reactor operation*	*Fuel reprocessing*	*Mining, milling, fuel fabrication, transportation*	*Reactor operation*	*Fuel reprocessing*
Pre-1970	28.8	0.24	3.9	8.4	7	110	240
1970-1974	87.7	0.24	6.7	8.4	21	590	740
1975-1979	276.6	0.24	2.0	8.4	66	550	2 330
1980-1984	513.7	0.24	0.9	1.9	120	460	990
1985-1989	936.0	0.24	0.4	0.2	220	390	150
1990-1994	1146.7	0.24	0.4	0.1	280	490	150
1995-1997	767.2	0.24	0.4	0.1	180	320	100
Total					900	2 900	4 700

Table 47
Estimated amount of ^{131}I used in medical radiation therapy

Health care level	*Fraction of world population*	*Treatments per 1,000 population*		*Total activity administered [a] (TBq)*
		Thyroid cancer	*Hyperthyroidism*	
I	0.26	0.038	0.15	410
II	0.53	0.01	0.02	190
III	0.11	0.0027	0.017	15
IV	0.10	0	0.0004	-
Total (rounded)				600

a Assumes total world population of 6 10^9 and average amounts administered per treatment of 5 GBq (thyroid cancer) and 0.5 GBq (hyperthyroidism).

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