SOURCES AND EFFECTS OF IONIZING RADIATION

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NOTE

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ANNEX B

Exposures from man-made sources of radiation

CONTENTS

INTRODUCTION

1. Several practices and activities of man involving the production and use of radionuclides have resulted in releases of radioactive materials to the environment. Some of these activities have ceased, such as testing of nuclear weapons in the atmosphere, and some are continuing, such as electrical energy generation by nuclear reactors and radioisotope production and usage. In carrying out these activities, several accidents have occurred at nuclear installations and waste storage sites and in the transport of weapons or nuclear materials, causing in some cases significant contamination of the local environment. The purpose of this Annex is to evaluate and compare the collective doses to the local and global populations from these various man-made sources of radiation exposures.

2. Most of these subjects have been dealt with in the past by the Committee in separate assessments. Atmospheric nuclear testing and nuclear power production, in particular, have been extensively analysed. In this Annex, the evaluation procedures are summarized, and the dose calculations are extended. For nuclear power production, estimates of average releases per unit electrical energy generated are combined with data on energy generated by all reactors to evaluate the total releases of radionuclides worldwide and the collective dose from the beginning of this practice. For the first time since the Committee began its assessments of exposures from nuclear power production, there is complete reporting of radionuclides released from all reactors in operation in all countries for the latest evaluation period. The Committee acknowledges the cooperation of a great many scientists and officials who have made these data available for this evaluation.

3. A number of sources cannot be so systematically evaluated. These include releases from the use of radioisotopes in industries or hospitals, in which only trace contamination and very low doses result, and in the military fuel cycle, for which data have been restricted and the dose evaluations have therefore remained incomplete and uncertain. In this Annex the Committee considers these various sources to the extent possible to provide a comprehensive assessment of exposures from man-made sources.

4. Exposures from accidents of environmental significance are summarized here. Most of the doses resulting from these sources were evaluated in detail at the time of occurrence, in particular the doses

throughout the northern hemisphere from the Chernobyl accident, presented in the UNSCEAR 1988 Report [U1]. However, further data are becoming available on some accidents that occurred many years ago, when the full disclosure of details was not possible. This information is considered here to provide indications of the population doses that were received. Evaluations of doses to populations living near nuclear test sites have been undertaken, and some dose estimates have been provided in published reports. These results are also included in this Annex. For the various sources, the collective doses evaluated are those committed by the specific releases. If less than the complete dose commitments have been evaluated, the integration times are specified in the discussions for each type of source.

I. ATMOSPHERIC NUCLEAR TESTING

5. A very important concern of the Committee since its inception has been to evaluate the exposures caused by nuclear explosions in the atmosphere. The first atmospheric nuclear explosions took place in 1945. Subsequent testing of nuclear weapons in the atmosphere occurred until 1980, with periods of intensive testing in the years 1952-1954, 1957-1958 and 1961-1962. A limited nuclear test ban treaty (Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under the Water) was signed in August 1963, and much less frequent testing in the atmosphere occurred subsequently.

6. Exposures from nuclear weapons tests in the atmosphere have been reviewed by the Committee in all its previous reports until the cessation of the practice [U3-U10]. As there have been no tests in the atmosphere since October 1980, the most recent analysis prepared by the Committee, in the UNSCEAR 1982 Report [U3], remains complete and valid. These results and the generally applicable methodologies of exposure assessment are summarized here.

7. The basic quantity of radiation dose evaluations for radionuclides released to the environment is the dose commitment. Dose commitments are calculated from the input of radionuclides into the environment, using transfer coefficients relating appropriate time-integrated quantities in environmental compartments and in man. Schematic representation of the methodology used by the Committee for evaluating exposures from radionuclides released in nuclear testing is illustrated in Figure I. Transfer coefficients are used to relate input, integrated concentrations of radionuclides and dose in successive environmental compartments. For example, the transfer coefficient from diet to tissue is the ratio of the integrated concentration of the radionuclide in tissue to that in diet and is designated P_{34}. Transfers linking input to dose are determined by the sequential multiplication of transfer coefficients. Transfers by parallel pathways are assumed to be independent and are thus additive. For the transfers indicated in Figure I, the dose commitment for a specific radionuclide and a given tissue, D_c, due to an environmental input A_0 into the atmosphere is given by

$$D_c = P_{01}[P_{12}P_{23}P_{34}P_{45} + P_{14}P_{45} + P_{15} + P_{12}P_{25}]A_0 \quad (1)$$

8. In this formula the transfer coefficient P_{01} is the integrated concentration of a radionuclide in air at a specified location or averaged for a broader region, divided by the amount released. The first term in the brackets relates the subsequent transfer to deposition, diet, tissue and dose via ingestion. The second term (P_{14} P_{45}) is the transfer from the atmosphere to tissue and dose via inhalation. The third term (P_{15}) accounts for direct (cloud gamma) irradiation from the radionuclide in air. The fourth term is the component of external irradiation from radionuclides deposited on the ground. Some minor pathways (e.g., resuspension) have not been indicated in Figure I, but these are taken into account in determining the integrated concentrations in the compartments. To this extent, the model indicates compartment interrelationships rather than mechanical transfer pathways. Although the terminology was developed for evaluations of doses from radionuclides produced in atmospheric nuclear testing, the methodology is generally applicable to any source of release of radionuclides to the air or terrestrial environment.

A. ENVIRONMENTAL INPUT

9. A nuclear device derives its explosive energy, usually expressed in kilotonnes or megatonnes of TNT equivalent, from one or both of two nuclear processes: fission of the heavy nuclides ^{235}U and ^{239}Pu in a chain reaction and fusion of the hydrogen isotopes deuterium and tritium in a thermonuclear process. Fission produces a whole spectrum of different radioactive nuclides, while fusion in principle creates

only tritium. However, because a thermonuclear device needs high pressures and temperatures to ignite it, in practice a fission device is needed as a primary stage to provide these conditions. Also in practice, the nuclear reactions do not proceed to ultimate completion, so some residual amounts of tritium will also remain. Thus, the explosion of a fusion charge always implies that at least some residual radioactive material is released. Many thermonuclear devices also produce large amounts of radioactive debris in a second fission stage, where high energy neutrons from the fusion reactions are utilized to split the atoms of a ^{238}U blanket. In some fission charges a small thermonuclear stage is used primarily to make neutrons and boost the utilization of the fissile material.

10. The exact composition of products of the fission process depends on the mixture of fissioning nuclides (^{235}U, ^{239}Pu and ^{238}U) and on the neutron energies involved. However, for the purpose of estimating dose commitments, it is sufficient to use average production values per unit fission yield. These are dominated by the ^{238}U high-energy neutron fission mode, as this type of fission was the predominant one in past atmospheric testing.

11. Neutron activation products are produced in significant amounts in fusion explosions from reactions of neutrons with surrounding materials, such as nitrogen in the air and the construction materials of the device. One very important such product is ^{14}C, which is made in the $^{14}N(n,p)^{14}C$ reaction in the atmosphere. The fusion yields are thus of interest for estimating doses from certain radionuclides. Fusion yields are also important, as they are the second part of the total yield, which governs the altitude to which the nuclear cloud rises and, as a result, the time delay before the debris reaches man.

12. A total of 520 atmospheric nuclear explosions (including 8 underwater) have occurred at a number of locations [D2, D8, Z1]. Based on a survey of published estimates of nuclear yields of different tests and measurements of deposited amounts of radioactive materials, Bennett [B5] compiled a list of individual yields of atmospheric nuclear explosions and the partitioning of debris between different parts of the atmosphere. As accurate data on individual tests have not generally been available, this information is of course somewhat uncertain. Summed yields during certain periods of time, however, do agree with reported total yields for these time intervals, and the integrated depositions of long-lived fission products are reasonably consistent with the estimates. The estimates of fission, fusion and total yields exploded in the atmosphere for each year since 1945 are illustrated in Figure II.

13. There were two main periods when most of the radioactive debris produced in nuclear explosions was injected into the atmosphere, namely 1952-1958 and 1961-1962. About 42% of all fission yield in the atmosphere was exploded in the former period and 47% in the latter, adding up to 89% for the 11-year period from 1952 through 1962. The corresponding numbers for fusion yield are 25% and 72%, respectively, giving a total of 97% for the 1952-1962 period. Less than 0.5% of the total fission yield and completely insignificant amounts of fusion yield were exploded before 1952, leaving 11% and 3%, respectively, for the period since 1962. About 90% of the fission yield was due to explosions in the northern hemisphere.

14. The total explosive yield from past atmospheric nuclear weapons tests amounts to 545 Mt, consisting of 217 Mt from fission and 328 Mt from fusion. The contributions of local, tropospheric and stratospheric fallout to total fallout are 12, 10 and 78%, respectively. Local fallout, which is loosely defined as that part of the debris that deposits on the ground in the vicinity of the test site, has not previously been considered by the Committee in its dose assessments because nuclear weapons tests were conducted in isolated areas.

15. The major radionuclides produced in atmospheric nuclear testing from the standpoint of doses delivered are listed in Table 1, along with the basic data of radioactive half-life, mode of decay, fission yield and amounts released into the atmosphere (local fallout excluded).

B. DEPOSITS ON THE EARTH'S SURFACE

16. The Committee has traditionally estimated collective effective doses committed to the populations of the 40°-50° latitude bands in the northern and southern hemispheres (zones of maximum fallout), to the population of the whole northern hemisphere and the whole southern hemisphere, and to the entire world's population. Fission products, residual radionuclides of the weapons materials and activation products have been considered in the dose assessment.

17. The committed collective effective dose to those populations from past atmospheric testing arises mainly from external irradiation from the radionuclides deposited on the earth's surface and internal exposure from radionuclides incorporated into ingested foods. Since the doses from these pathways are strongly related to the amounts of radionuclides deposited on the ground, the first step in the dose assessment

consists in estimating the deposition densities in the latitude bands considered for the radionuclides of interest. For this purpose, the Committee has relied upon extensive measurements of ^{90}Sr, ^{89}Sr and ^{95}Zr for the assessment of the activities of all radionuclides present in the environment in a solid form. This is the case for all radionuclides considered in this Section, with the exception of ^{3}H and ^{14}C.

18. The deposition of ^{90}Sr has been monitored worldwide in a network of between 50 and 200 stations operated by and in cooperation with the Environmental Measurements Laboratory (EML), formerly the Health and Safety Laboratory (HASL) [H7]. The global deposition of ^{90}Sr has also been estimated by others, such as the United Kingdom Atomic Energy Authority [C2], with a network of 8 stations in the United Kingdom, and 18 stations elsewhere. When results of these two networks are compared, the annual values are found to differ by up to 50%, but the integrated and cumulative depositions agree to within 2% [L2]. Because the United States network has been the largest and most widely distributed, the data collected by it have been adopted by the Committee. The total hemispheric annual deposition values are calculated by averaging the deposition density over all collecting stations in each 10° latitude band, multiplying by the area of the respective band and then summing all nine bands of the hemisphere [L2].

19. Data on the time-integrated deposition of ^{90}Sr in each 10° latitude band of the globe are given in Table 2. Because the last atmospheric nuclear weapons test occurred in 1980, and deposition of radioactive aerosols takes place within a few years, it can be considered that the deposition of ^{90}Sr produced by past atmospheric tests is essentially complete. Also shown in Table 2 are the areas of the latitude bands and the population distribution in these regions. The latitudinal population distribution is used to calculate the population-weighted deposition densities, which are then used as the basis for estimating the per caput doses and dose commitments from ^{90}Sr. Owing to its rather well-known geographical distribution, ^{90}Sr is used as a fallout indicator for all long-lived radionuclides (defined here as those radionuclides with a radioactive half-life greater than 100 days) from past nuclear tests; ^{90}Sr deposition values are therefore the basic information for estimating dose commitments from a number of radionuclides. For long-lived nuclides that deposit over several years, the method of using ^{90}Sr as an indicator and applying a production ratio corrected for decay can be expected to yield adequate estimates of deposition densities. The uncertainties attached to the deposition estimates increase as the physical half-life of the radionuclide considered decreases.

20. Short-lived radionuclides (in this context, nuclides with half-lives from 8 to 100 days) show different fallout patterns. These vary not only with the half-life of the radionuclide but also with its decay chain and the chemical properties of the elements involved, because they determine the type of particles that the radionuclide will tend to be incorporated into and thus its subsequent dissemination pattern. As the deposition of all short-lived nuclides that might be of interest was not measured globally during the periods of atmospheric testing, a pattern drawn mainly from data on ^{95}Zr and ^{89}Sr has been used to infer deposition of all short-lived radionuclides [U3, U4].

21. The population-weighted deposition densities of ^{95}Zr in past tests are given in the last column of Table 2. Zirconium-95 has been chosen as the indicator for short-lived nuclides because it is a comparatively well-mapped radionuclide with a suitable half-life and it is commonly used in studies of fractionation (deviations of actual radionuclide ratios in fallout compared to what can be calculated from production yields and decay). The corresponding deposition densities of other short-lived nuclides are calculated by multiplying by an empirical factor that accounts for the difference in half-life and possible fractionation phenomena. However, the error introduced can be quite large, as the empirical factors in most cases are based on rather limited data and deposition patterns have varied among tests.

22. The ratios used to derive the population-weighted deposition densities of the radionuclides formed in atmospheric nuclear tests (based on ^{90}Sr for the long-lived radionuclides, with the exception of ^{3}H and ^{14}C, and on ^{95}Zr for the short-lived radionuclides) are presented in Table 3, along with the population-weighted average deposition densities obtained by this method for the 40°-50° latitude bands of each hemisphere, for each hemisphere and for the world.

23. This method has not been used for ^{3}H or ^{14}C, because these radionuclides are readily recycled in the biosphere and become homogeneously disseminated in the hemisphere in which they are released within a time that is short in comparison to their radioactive half-lives. The interhemispheric transfer of radionuclides other than isotopes of the inert noble gases is very limited because of tropospheric wind patterns and efficient scavenging by precipitation in the tropical latitudes. The dose commitments from ^{3}H and ^{14}C are based on a comparison with the doses and production rates of these radionuclides in their natural occurrence.

24. The quotient of the deposition density (integrated deposition density rate) to the production amount (integrated release rate) of the radionuclide forms the transfer coefficient P_{02}. These values may be

determined from the data in Tables 1 and 3. The relationship of P_{02} values to the half-lives of the radionuclides is illustrated in Figure III for the temperate zone of the northern hemisphere. Owing to the pattern of atmospheric testing, the deposition densities and thus the P_{02} values are higher by a factor of about 4 in the northern hemisphere than in the southern hemisphere. The values in the temperate zones are about 1.5 times higher than the hemispheric averages. Since the residence time of particulate debris injected into the stratosphere is of the order of one to a few years, most of the longer-lived radionuclides are deposited without appreciable decay. The P_{02} values in this case are approximately 5 kBq m^{-2} per EBq released. Radioactive decay before deposition appreciably lowers the values of P_{02} for radionuclides with half-lives of less than one year. The variations seen in Figure III of P_{02} values for a few radionuclides (^{125}Sb, ^{241}Pu) illustrate the uncertainties in production and deposition estimates.

C. TRANSFER FROM DEPOSITION TO DOSE

25. The assessments of doses from different radionuclides were presented in detail in the UNSCEAR 1977 Report [U4] and the UNSCEAR 1982 Report [U3]. Measurements reported in the scientific literature on which the estimates were based and the computational techniques applied to derive doses were listed and described. The results can be summarized in terms of the transfer coefficients P_{25}, which link the time-integrated deposition density on the earth's surface to the dose commitments in the relevant organs and tissues of man. Three principal pathways are considered: external irradiation, inhalation and ingestion.

26. The ingestion pathway is of significance for radionuclides that are efficiently transferred through the chain formed by deposition to plant uptake to grazing animals (in many cases)-dietary intake and are absorbed from the gastro-intestinal tract to blood. Some delay may be introduced in these transfers. One important exception to this, however, is the short-lived radionuclide ^{131}I, which can rather quickly be transferred via the pasture-cow-milk chain to man. For most radionuclides, the intake amounts by ingestion result primarily from the initial retention by crops and pasture during deposition and only secondarily from delayed root uptake.

27. To make reliable assessments of doses through the ingestion pathway, there is a need for extensive empirical data on the concentrations of the relevant radionuclides in different types of food and the various diets in different population groups. Analyses of this kind have been made in previous reports of the Committee, especially for ^{90}Sr and ^{137}Cs, which together with ^{14}C, are the primary contributors to the ingestion dose commitments [U3, U4]. To evaluate the P_{25} transfer coefficients, regression analysis has been applied to models relating measured radionuclide concentrations in diet to the annual deposition density rates and the measured concentrations in relevant organs.

28. The transfer of ^{90}Sr and ^{137}Cs from deposition to diet has been modelled by a three-component model:

$$C_i = b_1 \dot{F}_i + b_2 \dot{F}_{i-1} + b_3 \sum_{n=1}^{\infty} e^{-\lambda n} \dot{F}_{i-n} \qquad (2)$$

where C_i is the concentration of the radionuclide in a food component or in the total diet in the year i due to the deposition density rate in the year i, $\dot{F}_i$, in the previous year, $\dot{F}_{i-1}$, and 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.

29. The transfer coefficient from deposition to diet is given by

$$P_{23} = \int_0^{\infty} C(t)\,dt \,/\, \int_0^{\infty} \dot{F}(t)\,dt$$
$$or \quad \sum_{i=1}^{\infty} C_i / \sum_{i=1}^{\infty} \dot{F}_i \qquad (3)$$

From the above model, the transfer coefficient can be expressed as

$$P_{23} = b_1 + b_2 + b_3\, e^{-\lambda m}/(1 - e^{-\lambda m}) \qquad (4)$$

where b_i are the transfer components per unit annual deposition: b_1 is the transfer in the first year, primarily from direct deposition; b_2 is the transfer in the second year from lagged use of stored foods and uptake from the surface deposit; and b_3 is the transfer via root uptake from the accumulated deposit. The units of P_{23} and b_i are Bq $a\ kg^{-1}$ per Bq m^{-2}. In the exponential term, λ has units a^{-1} and m is a constant equal to one year.

30. Results of regression fitting of this fallout model to monitoring data have been presented in previous UNSCEAR Reports [U3, U4, U5]. Further analysis of the available data is presented in Table 4. The fits to the long-term monitoring results in Denmark are shown in Figure IV. Relatively minor adjustments in parameter values are needed in the fits to extended

monitoring data, indicating, in particular, that the projections of long-term transfers are confirmed.

31. Adequate representations of transfers to the total diet or to separate components of the diet are obtained for relatively uniform deposition during the year, as occurred for fallout from atmospheric weapons testing. For deposition occurring within a much shorter time period, such as following the Chernobyl accident, the transfer is dependent on the particular agricultural conditions at the time of deposition and on short-term restrictions on certain foods in the diet that may be imposed. Thus, the first-year and second-year lagged transfers of ^{137}Cs to diet in measured concentrations in 1986 and 1987 are much lower than would be expected from the fallout model. The discrepancy may have been less in other countries, depending on the agricultural conditions, than is shown for Denmark in Figure IV. In contrast to weapons fallout, the deposition of ^{90}Sr from the Chernobyl accident was much less significant than that of ^{137}Cs.

32. From the results of the transfer factor analysis given in Table 4, it is seen that transfers from widespread but relatively normal areas of transfer may vary by ±50% for total diet, with even greater variations for some specific food groups. The foods included in each major group differ in the various locations, as do the consumption amounts of these foods.

33. The transfer coefficients, P_{23}, for ^{90}Sr and ^{137}Cs are summarized in Table 5. These are the averaged results from Argentina, Denmark and the United States of the transfers to the five food categories weighted for consumption amounts. Because they come from only three locations, the average values with standard deviations are only general indications of the transfers and variations to be expected. The results are similar to the previously adopted values of P_{23}: 4 mBq a kg^{-1} per Bq m^{-2} for ^{90}Sr and 9 mBq a kg^{-1} per Bq m^{-2} for ^{137}Cs [U3].

34. Figure V shows the contributions to transfer in the various periods. For ^{90}Sr, the major component of P_{23} (50%) arises from transfer from the deposit. For ^{137}Cs, the major transfer is within the first year of deposition (45%), with diminishing transfer in the second and subsequent years following deposition. The contributions to transfers by the various food groups are indicated in Table 5. For ^{90}Sr, milk and grain products are the most significant foods. For ^{137}Cs, these categories, along with meat, account for the major part of the transfer. It is recognized that much wider variations in transfer occur in certain areas for particular soil conditions and foods. This includes the Arctic food chain (lichen-reindeer-man) and areas where the caesium-binding clay content of soils is low, thus allowing higher and more persistent uptake of ^{137}Cs to plants. In these cases, order of magnitude differences in transfer may result. More detailed evaluations of the extent of these conditions are necessary to determine the added contributions that may be made to the collective doses.

35. The transfer coefficients P_{34}, linking concentrations of radionuclides in diet to those in the body and P_{45}, linking concentrations in the body to dose, have been evaluated and the results published in the UNSCEAR 1982 Report [U3] and the UNSCEAR 1977 Report [U4]. For some radionuclides, the integrated dietary intake rates have been determined directly. Relating these values to the deposition of the radionuclide forms the transfer coefficient P_{24}. The units of this expression are Bq per Bq m^{-2}. Values of P_{23} may be transformed to this by multiplication by the consumption rate of foods, which is in effect the transfer coefficient P_{34}. As this is a convenient form for estimating dose, all radionuclides considered in the ingestion pathway evaluation are included in the listing of P_{24} values in Table 6.

36. The values of the dose per unit intake of radionuclides are, in fact, the transfer coefficients P_{45}. These have been or are being re-evaluated, based on the latest metabolic data, and compilations are available [I13, N1]. It is necessary to state the specific assumptions of absorption and retention of the radionuclides; therefore, the P_{45} values used in the evaluations given here are included in Table 7. The values of effective dose use the weighting factors defined by the ICRP in 1990 [I12].

37. The overall transfer coefficients P_{25}, linking the deposition to the dose from radionuclides produced in atmospheric nuclear testing, are compiled in Table 8. The results for the ingestion pathway have been obtained by multiplication of the transfer coefficients P_{24} in Table 6 and P_{45} in Table 7. The values of P_{25} are considered to apply as averages to large populations in the world. Adjustments are needed if applications are to be made to smaller groups for which diet or local conditions of transfer may be different.

38. For the inhalation pathway, the association is between atmospheric concentrations and dose, P_{15}, but because there is a direct relationship between atmospheric concentration and deposition, the association with dose from inhalation can also be made from the deposition amount. The expression used is

$$P_{25} = P_{14} P_{45} / P_{12} \qquad (5)$$

where P_{14} is the average breathing rate of the individual in the population, P_{45} is the dose per unit

intake factor for the organ or tissue considered and P_{12} is the deposition velocity averaged over all weather conditions, including precipitation. The value of P_{14} has been taken to be 20 m^3 d^{-1}, or 7,300 m^3 a^{-1} for all populations. The values of P_{45}, in nGy Bq^{-1}, are listed in Table 7. The transfer coefficient P_{12} varies with the precipitation rate at various locations and also with the physical and chemical nature of the radionuclide considered. The average value of P_{12} for particulate material has been estimated to be 1.76 cm s^{-1}, or 5.56 10^5 m a^{-1}. Although this value is based on observations in New York City over several years [B5], measurements in the United Kingdom [C3] and Sweden [B6, D1] are in reasonable agreement, after normalization to the same annual precipitation. Furthermore, since the yearly rainfall in New York City is fairly close to the population-weighted average for the whole world, the New York value is considered adequate for global average calculations. The transfer coefficients P_{25} evaluated for the inhalation pathway are listed in Table 8.

39. In addition to experiencing internal irradiation from inhaled or ingested radionuclides, people are also irradiated externally from gamma-emitting nuclides dispersed in the air and deposited on the ground. As the debris normally spends much more time deposited on the ground than dispersed in ground-level air, the external dose due to irradiation from the earth's surface is normally much higher than the dose due to irradiation while the debris is airborne. The average ratio of the absorbed dose from ground surface contamination to that from air immersion is proportional to the half-life of the radionuclide and is, for example, of the order of 100 for short-lived ^{140}Ba and 1,000,000 for long-lived ^{137}Cs.

40. The P_{25} transfer coefficients for external irradiation have been calculated by multiplying the dose rate conversion factors for radionuclides deposited on the ground, derived from Beck [B3], by the mean lifetime of the radionuclide (half-life ÷ ln 2) and by an average factor assuming 80% indoor occupancy in buildings with a shielding factor of 0.2. The latter factor is 0.7 Sv per Gy (equivalent dose rate in the body per unit absorbed dose rate in air) times 0.36 (0.2 outdoor occupancy plus 0.8 indoor occupancy times 0.2 building shielding). The Committee has in the past [U3, U4] rounded this product to 0.3; the procedure here, however, is to postpone the rounding to the final dose estimate. For short-lived radionuclides (all except ^{137}Cs), the dose-rate conversion factor applying to a plane source is used. For ^{137}Cs, the dose-rate conversion factor applying to an exponential concentration profile in the ground of mean depth 3 cm is used. The indoor occupancy, as well as the shielding factor, varies a great deal among different populations of the world, and this is a source of uncertainty in the dose assessments for external irradiation. Also, the different dynamic behaviours of radionuclides deposited in urban and in rural environments have not been taken into account for the dose estimates from radionuclides produced in atmospheric nuclear testing. The transfer coefficients P_{25} are given in Table 8 for the effective dose commitment. The same numerical values can be expected to apply more or less to the absorbed doses in individual organs in the body; however, since the absorbed doses per unit deposition density have not been specifically evaluated, there are no values given in Table 8.

D. DOSE ESTIMATES

1. Regional and global exposure

41. The effective dose commitments from individual radionuclides in past atmospheric testing (^3H and ^{14}C excepted) can be calculated by multiplying the population-weighted integrated deposition density of the radionuclide in the region of interest (Table 3) by the appropriate P_{25} transfer coefficient (Table 8). As an example, the effective dose commitment due to ingestion of ^{137}Cs in the population of the 40°-50° latitude band in the temperate zone of the northern hemisphere is 5,200 Bq m^{-2} times 54.6 nSv per Bq m^{-2} = 280 μSv. The results for each radionuclide and for all pathways are given in Table 9.

42. As indicated previously, the dose commitments from ^3H and ^{14}C are derived from comparisons with the natural doses and production rates by cosmic rays. The dose calculations make use of the fact that the dose commitment to production ratios for those radionuclides are equal to the annual natural dose to production ratios. The annual absorbed dose in tissue from natural tritium has been estimated to be 10 nGy, resulting from an annual production per hemisphere of 37 PBq [U3]. Assuming a total release from atmospheric nuclear testing of 190 EBq to the atmosphere of the northern hemisphere and 50 EBq to that of the southern hemisphere [U3], the absorbed dose commitments in tissue from fallout tritium are as follows: northern hemisphere, 1.9 10^{20} Bq × (10^{-8} Gy a^{-1}) ÷ (3.7 10^{16} Bq a^{-1}) = 51 μGy, and southern hemisphere, 0.5 10^{20} Bq × (10^{-8} Gy a^{-1}) ÷ (3.7 10^{16} Bq a^{-1}) = 14 μGy. It has not been possible to account for latitudinal variations in the tritium distribution. The simplification is made in assuming fairly rapid mixing of tritium throughout the hemisphere. The effective dose commitments from ^3H are 51 μSv (northern hemisphere), 14 μSv (southern hemisphere) and 47 μSv (world). The global value is the population-weighted estimate, taking into account that 89% of the world population resides in the northern

hemisphere and 11% in the southern hemisphere. On the basis of the intake rates of hydrogen in water [N8], the dose commitment can be apportioned as 7% arising from inhalation and absorption through the skin and 93% from ingestion [U3].

43. Carbon-14 is produced naturally by cosmic ray neutrons impinging on nitrogen in the upper atmosphere. This means that the dose commitment from ^{14}C injected into the atmosphere by nuclear tests can be calculated in the same way as the dose commitment from tritium produced in atmospheric tests. The annual natural production of ^{14}C of about 1 PBq and the resulting equilibrium specific activity in man yields an annual dose to the gonads of 5 μGy [U3]. Based on this, it can be concluded that the 220 PBq from nuclear explosions have given a dose commitment to the gonads of all populations of (5 μGy a^{-1}) ÷ (1 PBq a^{-1}) × 220 PBq = 1,100 μGy. In the same way, dose commitments to the lungs, bone lining cells, red bone marrow, thyroid and other tissues can be assessed as 1,300, 4,800, 5,300, 1,300 and 2,900 μGy, respectively [U3], yielding an effective dose commitment of 2,600 μSv. The corresponding collective effective dose per unit release is 120 man Sv per TBq, assuming an equilibrium world population of 10^{10} people reached in the next century and maintained over the next thousands of years. Other published estimates range between 67 and 159 man Sv per TBq [B10, I2, K2, K4, K5, M2, S1].

44. The ^{14}C doses are due to ingested and inhaled carbon. On the basis of the relative intake and retention of carbon in these pathways, the dose commitments from ingestion are estimated to be 10^4 times larger than those arising from inhalation [K4]. The dose commitments from ^{14}C are delivered over a very long time period. From calculations based on an environmental compartment model for ^{14}C that comprises 25 discrete carbon reservoirs (Figure VI) and takes into account the dilution of ^{14}C by stable carbon released during fossil fuel combustion, it is estimated that only 5% of the dose commitment is delivered in the first 100 years after the release of ^{14}C; about 71% of the dose commitment will have been delivered during 10^4 years after the release of ^{14}C [M2]. The deep ocean, divided into 18 compartments, accounts for the slow recycling of ^{14}C into the biosphere.

45. The effective dose commitments from atmospheric nuclear testing for all of the 22 radionuclides considered for the populations of the world and of the 40°-50° latitude bands of each hemisphere are presented in Table 9. The total effective dose commitments are 4.4 and 3.1 mSv in the 40°-50° latitude bands of the northern and southern hemispheres, respectively, and the global average is 3.7 mSv.

46. The summary listing in Table 10 for the world population shows that ^{14}C is the dominant contributor to the total effective dose commitment, accounting for 70% of the effective dose commitment to the world's population. However, if only 10% of the ^{14}C dose commitment is included in the comparison, that is, if the dose commitments are truncated approximately to the year 2200, at which time all other radionuclides will have delivered almost all of their dose, ^{14}C contributes only 19% to the truncated effective dose commitment to the world's population. Besides ^{14}C, the most important contributors to the effective dose commitment to the world population are ^{137}Cs, ^{95}Zr-^{95}Nb, ^{90}Sr, ^{106}Ru, ^{54}Mn, ^{144}Ce, ^{131}I and ^{3}H.

47. Including all of the ^{14}C dose, 16% of the total effective dose commitment to the world population is delivered through external irradiation, 4% through inhalation and 80% through ingestion. Including only 10% of the ^{14}C dose, the corresponding numbers are 44%, 10% and 46%, respectively. Thus, ingestion is the most important pathway, if ^{14}C is fully included, while ingestion and external irradiation are about equally important, if only 10% of effective dose commitment from ^{14}C is included. In both cases inhalation contributes substantially less.

48. As the explosive power in past atmospheric tests has been estimated to be 545 Mt, it may be concluded that the past tests have given an average complete effective dose commitment of about 7 μSv Mt^{-1} to the world population. Of this, about 5 μSv Mt^{-1} is due to ^{14}C and about 2 μSv Mt^{-1} to fission products. The transuranium elements have contributed about 0.1 μSv Mt^{-1}. Normalizing the fission product dose commitment to the total fission yield exploded of 217 Mt gives an estimate of about 5 μSv Mt^{-1} fission.

49. A summary of the global collective effective doses committed from past atmospheric nuclear tests is given in Table 11. For these calculations, some assumptions about the global population have been made. For inhalation exposure and other exposures from radionuclides with half-lives of less than a few years, the population of the world has been taken to be 3.2 10^9 persons, as it was in the early 1960s during maximum fallout. For ^{3}H, ^{90}Sr, ^{137}Cs and ^{241}Pu, a global population of 4 10^9 persons has been applied, and for the very long-lived ^{14}C, ^{239}Pu, ^{240}Pu and ^{241}Am, the projected global population has been assumed to be 1 10^{10} persons.

50. In Table 11 the radionuclides are listed in order of their decreasing contributions to the collective effective dose. The order is essentially the same as in Table 10, with ^{14}C being the dominant contributor and ^{137}Cs, ^{90}Sr, ^{95}Zr and ^{106}Ru following. The total global

impact of all atmospheric nuclear explosions carried out for test purposes in the past is 3 10^7 man Sv.

2. Local exposure

51. Populations living near the sites where nuclear weapons tests took place received relatively higher doses than the average values assessed above. In the United States, about 100 surface or near-surface tests were conducted at the Nevada test site between 1951 and 1962, with a total explosive fission yield of approximately 1 Mt. Dose reconstructions have been undertaken for the populations living in the vicinity of the Nevada test site during the period of atmospheric testing [C7, W1]. The local population size was 180,000 persons. Preliminary results indicate that thyroid doses of up to 1 Gy may have been received by children. The collective dose from external exposure has been estimated to be approximately 500 man Sv [A5]. Ninety per cent of the collective dose was received during the years 1953-1957.

52. Following the nuclear test Bravo at Bikini in the Pacific test site of the United States, residents of Rongelap and Utirik Atolls were exposed to unexpected fallout. The islands are 210 and 570 km, respectively, east of Bikini. Eighty-two individuals were evacuated from Rongelap 51 hours after the explosion and 159 persons were removed from Utirik within 78 hours. External exposures, mainly from short-lived radionuclides, ranged from 1.9 Sv on Rongelap (67 persons, including 3 in utero), 1.1 Sv on nearby Allingnae Atoll (19 persons, including 1 in utero) and 0.1 Sv on Utirik (167 persons, including 8 in utero) [L3]. The collective dose was thus of the order of 160 man Sv. Doses to the thyroid, caused by several isotopes of iodine, tellurium and by external gamma radiation, were estimated to be 12, 22 and 52 Gy on average and 42, 82 and 200 Gy maximum to adults and children of 9 years and 1 year, respectively, on Rongelap [L3].

53. At the Semipalatinsk test site in the Kazakh region of the former USSR, atmospheric tests were conducted from 1949 through 1962, and about 300 underground tests were conducted from 1964 until 1989 [T5]. In total, 10,000 people in settlements bordering the testing site were exposed to some extent. The collective dose due to external irradiation was estimated to be 2,600 man Sv, 80% of which resulting from testing in the period 1949-1953, due to external irradiation and 2,000 man Sv due to internal exposure from the ingestion intake of radionuclides [T5]. The collective absorbed dose to the thyroid was of the order of 10,000 man Gy.

54. The United Kingdom conducted a programme of nuclear warhead development tests between 1953 and 1963 in Australia, at the Monte Bello Islands and at Emu and Maralinga on the mainland. In all, twelve major nuclear tests involving atomic explosions with total yields of about 100 kt, 16 kt and 60 kt were performed at the three sites, respectively [D3]. The collective effective dose to the Australian population from these test series has been estimated to be 700 man Sv [W3]. In addition, several hundred smaller scale experiments were performed at Maralinga [D3] which resulted in the dispersal of about 24 kg of ^{239}Pu over some hundreds of square kilometres. This area remains contaminated and potential doses to future inhabitants of the Maralinga and Emu areas have been assessed with a view to rehabilitation of the two sites [D3, H3, W2]. Annual effective doses of several millisievert would be expected to result from continuous occupancy within the two areas, with maximums of several hundred millisievert in the immediate vicinity of the two sites.

II. UNDERGROUND NUCLEAR TESTS

55. About 1,400 nuclear test explosions have been carried out beneath the earth's surface. Particularly since 1963, when the limited nuclear test ban treaty banning atmospheric tests was agreed, the practice became more frequent. Prohibiting atmospheric tests was a crucial step in lessening the doses to the world's population from tests of weapons. In fact, a well-contained under-ground nuclear explosion delivers extremely low doses or dose commitments to any group of people. However, there have been occasions when, owing to venting or the diffusion of gases, radioactive materials leaked from underground tests, resulting in the dissemination of radioactive debris over at least regional distances.

A. WEAPONS TESTS

56. Estimates of annual yields and numbers of underground tests have been compiled from data collected by the National Defence Research Establishment in Sweden [N10]. The total annual yields are

presented in Table 12. The basis for these estimates are either announcements made by the testing nation or simple calculations employing a formula of the following form:

$$\text{yield (kt)} = 10^{(M-a)/b} \qquad (6)$$

where M stands for the seismic surface or body wave magnitude and a and b are constants that vary with wave type, explosion location and observing laboratory. The total yield of underground tests is estimated to be 90 Mt, or about one sixth of the total yield exploded in the atmosphere.

57. More than 500 tests were conducted underground at the Nevada test site in the United States, but only 32 are reported to have led to off-site contamination as a result of venting [H4]. Table 13 shows, as an example, the atmospheric releases of ^{131}I from these 32 underground tests. The total amount of ^{131}I released into the atmosphere was about 5 PBq, which is five orders of magnitude smaller than the amount produced by atmospheric testing (6.5 10^5 PBq, from Table 1). The amount of ^{131}I or of any other radionuclide released into the atmosphere by underground tests carried out at sites other than the Nevada test site is not available.

58. The collective effective dose per unit release of ^{131}I would be expected to be much greater for the venting of underground tests than for atmospheric tests, because the release from underground tests occurs at ground level instead of higher in the atmosphere. Estimates of collective effective dose per unit release to the lower layers of the atmosphere were made in the UNSCEAR 1988 Report [U1]; these estimates are 1 10^{-13} man Sv per Bq for ^{131}I released in the Chernobyl accident and 4 10^{-13} man Sv per Bq for ^{131}I released from nuclear power stations. In order to account for the low population densities in the vicinity of weapons tests sites, it is assumed that a lower figure, 1 10^{-14} man Sv per Bq, is appropriate for releases of ^{131}I from underground tests. This figure, combined with a release of 5 PBq, leads to a collective effective dose from ^{131}I releases from venting underground tests carried out at the Nevada test site of 50 man Sv. Extrapolating to the total number of underground tests (1,400) at all locations would indicate that 15 PBq, in total, of ^{131}I has been released, and the collective dose is of the order of 150 man Sv. In comparison, the corresponding collective effective dose from ^{131}I from past atmospheric tests is estimated to be 164,000 man Sv (Table 11).

59. Other than these rather unusual events, where amounts of radioactive materials have been collected on filters, it is reasonable to assume that a few high-yield underground tests have leaked radioactive gases such as tritium or noble gases such as ^{133}Xe. There have been suggestions that observed peak concentrations in atmospheric tritium (HT or HTO) and ^{37}Ar (produced in $^{40}Ca(n,\alpha)^{37}Ar$ reactions underground) could have been due to leakages from underground explosions [B7, L5, M1]. Traces of short-lived radionuclides resulting from tests in the USSR were observed in Finland and Sweden in 1966 [K1, P2] and in 1971 [E1, K6]. The collective dose to the population of Sweden was estimated to be 3 man Sv from the venting of an underground test at Semipalatinsk in 1966 and 0.1 man Sv or less on seven other occasions when radionuclides from underground tests were detected in that country [D10].

60. The total ^{131}I produced in the underground explosions could be estimated to be 90 Mt total yield times the normalized fission production of 4,200 PBq Mt^{-1} (Table 1), which is 380 EBq. The fractional release is thus 4 10^{-5} of the amount produced. This same estimate of the release fraction may be applied to the noble gases, of which ^{133}Xe is the predominant radionuclide. The normalized fission production of ^{133}Xe is 14.5 EBq Mt^{-1} (6.54% fission yield [R1], adjusted for the half-life and yield of ^{90}Sr production given in Table 1). Total production of ^{133}Xe in underground tests is then estimated to be 1,300 EBq, of which 50 PBq may have been released (90 Mt × 14.5 EBq Mt^{-1} × 4 10^{-5}). The normalized collective dose from noble gases estimated for surface releases (applied to releases from nuclear power reactors) is 0.1 man Sv PBq^{-1} [U1]. The collective dose due to noble gases released from underground tests is then 50 PBq × 0.1 man Sv PBq^{-1} = 5 man Sv. This estimate is very uncertain. The collective dose per unit release may be overestimated because of the remote locations of the test sites; however, there is even greater uncertainty in the release fraction.

61. The same estimation procedures applied to ^{3}H produced in underground testing would indicate a total release of 10^{-4} PBq and a collective dose of 0.001 man Sv. This is a negligible component of the collective dose under the assumptions made. The analysis indicates that releases of ^{131}I are of the most significance and that the total collective dose from released radioactive materials from the 1,400 underground tests conducted thus far is of the order of 200 man Sv. Evaluations have not yet been made of potential exposures resulting from residual debris underground at the sites of the explosions.

B. PEACEFUL NUCLEAR EXPLOSIONS

62. It is to be expected that shallow underground explosions conducted for excavation purposes or deeper underground explosions in mining operations

also involve releases of radioactive materials to the environment. Programmes to develop applications of peaceful nuclear explosions were carried out during the 1960s in the United States and USSR. About 100 test explosions were performed. The presumed advantages of nuclear explosions have, however, been outweighed by the residual contamination and other disadvantages.

63. Doses to local or global populations from peaceful nuclear explosions have resulted primarily from cratering experiments. There were 6 such tests at the Nevada Test Site between 1962 and 1968 and a reported 9 experiments worldwide [U5]. The collective dose to the local population (180,000 persons) living near the Nevada site has been estimated to be 3 man Sv from the Sedan 104 kt cratering experiment in 1962 [A5]. The total from all tests, peaceful and military, conducted at the Nevada site from 1961 to 1975 was 5.7 man Sv [A5]. Therefore the total local collective dose from peaceful nuclear explosions can be estimated to be no more than 5 man Sv at Nevada and perhaps 10 man Sv worldwide.

64. The long-range dose commitment from the Schooner cratering experiment in the United States in 1968 was estimated in the UNSCEAR 1972 Report [U5]. Tungsten-181, formed in the neutron shield used to minimize the formation of activation products, was detected in several locations in Europe after this event. The effective dose commitment was estimated to be 12 nSv from radionuclides other than ^{3}H in the population of the 40°-50° latitude band of the northern hemisphere (630 million persons at the time) [U5]. The estimated release of ^{3}H of 15 PBq [U5] would have resulted in a dose commitment of 4 nSv (0.27 nGy PBq^{-1} from comparison with natural ^{3}H dose and release in the northern hemisphere) in the population of the northern hemisphere (3,160 million persons at the time). The collective dose from this test is thus estimated to be 20 man Sv. If it may be considered that this result is representative of the other cratering experiments, the collective dose worldwide from cratering experiments is 180 man Sv. The collective dose from peaceful nuclear explosions is thus estimated to be the same order of magnitude as that from venting underground military tests.

III. NUCLEAR WEAPONS FABRICATION

65. The production of radioactive materials for military use and the fabrication of weapons has involved routine and accidental releases of radionuclides and exposures of local or regional populations. These dose commitments and collective doses have not been estimated before by the Committee because no data were available. Some of the secrecy of this industry is being reduced, however, and information on discharges and doses from recent (and, in some cases earlier) operations is being provided. With this information and some rough estimates of the total amounts of radioactive materials produced, the doses from the weapons industry can be estimated.

66. The radioactive components of nuclear weapons are the fissile nuclides ^{239}Pu and ^{235}U; the fertile nuclide ^{238}U, which fissions only if irradiated by high-energy neutrons; tritium; and in some presumably older constructions small amounts of materials such as ^{210}Po, which are used to initiate the chain reaction in the fission bomb. Tritium is used in boosted fission bombs, where the efficiency is increased by neutrons from a comparatively small thermonuclear reaction fuelled by tritium. Tritium is probably also used in the main thermonuclear stage of some types of hydrogen bombs.

67. Doses arise in several stages of the nuclear weapons production line. As in the nuclear energy fuel cycle, production starts with the mining and milling of uranium. After that there is the need to convert the uranium to uranium hexafluoride gas, which is the form of uranium used at the gas diffusion or centrifugation plant where the ^{235}U content is enriched. If this process is carried to enrichments of the order of 90%, weapons-grade uranium is produced, which can be used directly to fabricate nuclear weapons components. Alternatively, the enrichment can be omitted or carried to only a few per cent. The uranium is then used to fuel reactors, which coupled to reprocessing and purification yields plutonium and tritium for the weapons. Some doses also derive from the weapons fabrication and assembly, as well as from the maintenance, transportation and recycling of weapons. Doses resulting from routine releases are considered in this Chapter.

A. PRODUCTION AMOUNTS

68. The total amounts of radioactive materials produced for weapons use are not known from directly reported information. An assessment has been made of plutonium in present weapons stockpiles by consider-

ing the amounts of long-lived fission products in high-level waste in the United States and by analysing the global atmospheric inventory of ^{85}Kr [H5]. Krypton-85 is a noble gas and a long-lived fission product that is released to the atmosphere when reactor fuel is reprocessed, for example, to extract plutonium. Correcting the global inventory mainly for the hitherto modest civilian reprocessing yields a number that may be seen to be a measure of the global plutonium stockpile. The estimated stockpiles in the United States and the former USSR were estimated to be around 100 tonnes in each country.

69. According to United Nations studies in 1981 and 1990 on nuclear weapons, the nuclear arsenals comprise more than 40,000 weapons with a total explosive yield of 13,000 Mt [U11, U12]. If it is assumed that the first fission stage in all these weapons is based on plutonium, a total inventory of weapons plutonium of 200 tonnes implies that, on average, 5 kg is used in each device. This is a reasonable figure [E5], which thus lends some credibility to the estimated total production.

70. Tritium is also produced for weapons use. It decays with a half-life of 12.32 years, which means that tritium must be produced continually to preserve the weapons stockpile. It has been estimated for the United States that an annual production of 3 kg of tritium is just enough to balance the decay [C11], and from this the total amount of tritium in the United States stockpile can be easily calculated to be about 55 kg. The world tritium stockpile can then be assumed to be twice as much, or around 110 kg. If it is assumed that this tritium was first produced in the early 1960s and has been maintained since then, a total tritium production of 110 + 30 × 6 = 290 kg results. If a further reasonable assumption is made, that is, that tritium is produced at the same (atom)rate as plutonium in the reactor, these 0.29 tonnes of tritium are equivalent to a production of (239/3) 0.29 = 23 tonnes of plutonium.

B. RELEASES AND DOSE ESTIMATES

71. In the United States, weapons production activities have been centred at locations reporting mainly through four regional offices of the Department of Energy: Albuquerque, Oak Ridge, Richland and Savannah River. Doses reported from these centres between 1976 and 1982 are considered to contribute about 90% of the population dose from activities related to weapons research and production. Little information is available on doses or releases before 1976. Efforts are being made, however, to reconstruct doses to the public living near nuclear installations, and some data from earlier periods are becoming available.

72. The Hanford nuclear weapons facility in the United States released substantial quantities of radioactive materials into the atmosphere and the Columbia River from its plutonium production reactors and fuel reprocessing facilities. Two plutonium production reactors started operating at Hanford in December 1944. Two fuel reprocessing plants began extracting plutonium in the same month, and a third production reactor was added in 1945 [C5]. The atmospheric releases of ^{131}I from reprocessing facilities were estimated from the quantity of reactor fuel reprocessed and the time interval between removal from the reactors and reprocessing. Table 14 presents the estimated annual releases of ^{131}I into the atmosphere from 1944 to 1956 [C5]. The largest releases of ^{131}I occurred between 1944 and 1946 during the effort to develop and produce the first arsenal of nuclear weapons. At that time, fuel rods were reprocessed soon after their removal from the reactors in order to maximize plutonium production, and there was no filtering or chemical processing of ^{131}I before atmospheric release. About 18 PBq of ^{131}I was released into the atmosphere between 1944 and 1946, while the release from 1947 to 1956 amounted to about 2 PBq (Table 14). The total atmospheric release of ^{131}I was 20 PBq between 1944 and 1956. Preliminary calculations indicate that the maximum thyroid doses were of the order of 10 Gy in 1945 [C5]. The collective effective doses, based on a value of 4 10^{-13} man Sv per Bq of ^{131}I released from nuclear installations and a population density of 25 persons per km^2 [U1, W4], are roughly estimated to be 7,000 man Sv for 1944-1946 and 1,000 man Sv for 1947-1956. These figures do not include the contributions from other radionuclides in the airborne discharges, which have not yet been reported, or from the liquid releases to the Columbia River. The dose reconstruction effort, which is scheduled to be finished in 1994, will produce more complete and accurate dose estimates.

73. The Chelyabinsk-40 centre, located near the town of Kyshtym, was the first Soviet nuclear installation dedicated to the production of plutonium for military purposes. A uranium-graphite reactor with an open cooling water system was commissioned in June 1948, and a fuel reprocessing plant started operating in December 1948 [N5]. Liquid releases to the Techa River from 1949 to 1956 amounted to 100 PBq, with 95% of this release being discharged from March 1950 to November 1951 [K7]. The main contributors to the activity associated with the radioactive materials released were ^{89}Sr (8.8%), ^{90}Sr (11.6%), ^{137}Cs (12.2%), rare-earth isotopes (26.8%), ^{95}Zr-^{95}Nb (13.6%) and ruthenium isotopes (25.9%) [K7]. These

large releases appear to have resulted in large part from a lack of waste treatment capability and from the storage of radioactive wastes in open, unlined earthen reservoirs [T4]. A hydrological isolation system, including a small reservoir called Lake Karachay, was built after 1952 to contain the low- and intermediate-level wastes.

74. The population along the Techa River was exposed to both external and internal irradiation. External irradiation was caused by gamma radiation from ^{137}Cs, ^{106}Ru and ^{95}Zr in the flood-plain areas, in vegetable gardens near the houses, and inside the houses. Internal irradiation was mainly due to the consumption of water and of local foodstuffs contaminated with ^{89}Sr, ^{90}Sr, ^{137}Cs and some other radionuclides. Tissue and effective doses, presented in Table 15, have been estimated for the populations living along the 240-km-long Techa River [A4]. Average cumulative effective doses are estimated to have ranged up to 1,400 mSv in the village of Metlino, located 7 km downstream from the point of discharge. The evacuation of the population of that village started in 1953; from 1955 to 1960, inhabitants of another 19 settlements were moved away from the river. Altogether, 7,500 persons were evacuated [K7]. It appears from Table 15 that all villages along the Techa River within about 50 km of the plutonium production centre were evacuated. The collective effective dose can be assessed from the distribution of estimated cumulative effective doses to individuals, which are as follows [A4]: 0-50 mSv, 10% of population; 50-100 mSv, 44%; 100-200 mSv, 18%; 200-250 mSv, 15%; 250-500 mSv, 2%; 500-1,000 mSv, 3%; and >1,000 mSv, 8%. Assuming that the 11% of the exposed population who received cumulative effective doses greater than 500 mSv is identical with the 7,500 persons who were evacuated, the collective effective dose received by the population living along the Techa River is about 15,000 man Sv. This value does not include the contributions from the airborne discharges, which have not been reported, or from the contamination of the Iset River, into which the Techa River discharges its waters.

75. These data from Hanford and Chelyabinsk give some indications of doses from the earlier practice of nuclear weapons fabrication, but it is difficult to extrapolate this information to the total weapons industry. Another method of estimating dose is to relate the radioactive material production amounts to the doses involved in producing and utilizing nuclear fuels in the civilian fuel cycle. Plutonium production reactors, which are optimized for the purpose, produce about 1 g of ^{239}Pu per MW d (thermal power), which, if a thermal conversion of 0.33 is assumed, can be expressed, for comparison, as 1.1 tonne per GW a of electrical power. This means that the plutonium and tritium in present arsenals correspond to (200 + 23)/1.1 = about 200 GW a (electrical power) of reactor operation. According to the UNSCEAR 1988 Report [U1], 1 GW a of electrical power in the civilian fuel cycle yields a collective dose of 4 man Sv locally and regionally and 200 man Sv globally. The total collective effective dose committed from weapons plutonium and tritium production may thus be estimated to be 800 man Sv locally and regionally and 40,000 man Sv globally.

76. The estimated annual collective doses from weapons production activities in the United States, as reflected in reports of the Department of Energy for the four main locations between 1976 and 1982, were 5.8, 8.2, 5.2, 2.2, 2.4, 2.3 and 1.7 man Sv, respectively [D7]. The United States nuclear weapons stockpile grew by the mid-1960s to somewhat above 30,000 weapons [C12]. Since then, as older weapons have been retired, the stockpile has decreased, to some 25,000 weapons. However, some of the retired weapons have been replaced, and tritium has been produced continually to balance the radioactive decay. From the reported variation with time of the annual doses since 1976, it can be assumed that the collective dose per year of practice increases as one goes back in time. Assuming that the mean annual population dose commitment from 1965 to 1990 was 10 man Sv and that during this period, on average, 1,000 weapons were produced annually, an average population dose commitment of 0.01 man Sv for each weapon produced is estimated. With a total United States production of 30,000 + (20 × 1,000) = 50,000 weapons, the total estimate would be 500 man Sv. With similar doses from weapons production in the Soviet Union, the collective dose committed to the local and regional population from nuclear weapons production in the world would become 1,000 man Sv, in agreement with the estimate based on plutonium and tritium production in the previous paragraph.

77. This estimate of about 1,000 man Sv for the local and regional collective dose from the global nuclear weapons industry in more recent practice is admittedly uncertain, as it is based on many assumptions and few data. The global component of the collective effective dose is also rather uncertain, as it mainly arises from radon releases from mill tailings in the next 10^4 years. The amounts of enriched uranium produced for weapons purposes are not known, and this part of the military fuel cycle has not yet been assessed. However, even if the committed collective dose from nuclear weapons research, development and production is taken to be roughly 100,000 man Sv, this represents less than 1% of the committed collective dose from atmospheric testing, which according to Table 11 was about 3 10^7 man Sv.

IV. NUCLEAR POWER PRODUCTION

78. The generation of electrical energy by nuclear reactors has continually increased since the beginning of this practice in the 1950s. In 1989, the electrical energy generated by nuclear reactors amounted to 212 GW a, representing 17% of the world's electrical energy generated in that year and 5% of the world's energy consumption [I7].

79. The nuclear fuel cycle includes the mining and milling of uranium ore, its conversion to nuclear fuel material, which usually includes the enrichment of the isotopic content of ^{235}U, 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. Radioactive materials are transported between installations in the entire fuel cycle.

80. Radiation exposures of members of the public resulting from effluent discharges of radioactive materials from installations of the nuclear fuel cycle were assessed in previous UNSCEAR Reports [U1, U3, U4, U5], in which discharge data for 1970-1974, 1975-1979 and 1980-1984 were included. In this Annex, similar data are presented for the years 1985-1989, as well as the trend with time of the normalized annual releases since 1970. The doses are estimated using the same environmental and dosimetric models as in the UNSCEAR 1988 Report [U1]. In this Chapter doses to the public from routine effluent discharges are considered.

81. The doses to the exposed individuals vary widely from installation to installation and from one location to another, and the individual dose generally decreases rapidly with distance from a given source. In this Annex, an indication is given of the range of individual doses associated with each type of installation. To evaluate the total impact of radionuclides released at each stage of the nuclear fuel cycle, results are normalized in terms of the collective effective dose per unit quantity of electrical energy produced, expressed as man Sv per GW a. The estimated amounts of natural uranium, uranium oxide (U_3O_8), fuel, and units of enrichment required to generate 1 GW a of electrical energy are presented in Table 16 for several reactor types [O2, O3].

A. MINING AND MILLING

82. Uranium mining operations involve the removal from the ground of large quantities of ore containing uranium and its decay products at concentrations of between a tenth of a per cent and a few per cent. In comparison, the average concentrations of uranium in soils of normal natural background areas are of the order of 1 ppm. Uranium is mined using underground or open-pit techniques. The annual quantities of uranium produced in 1975-1989 are presented in Table 17 [O2]. The total amount of uranium produced worldwide remained fairly stable between 1985 and 1990, at about 50,000 tonnes, extracted from about 20 million tonnes of ore. Milling operations involve the processing of these large quantities of ore to extract the uranium in a partially refined form, known as yellow cake.

1. Effluents

83. Radon is the most important radionuclide released from uranium mines. Data on radon emissions from mines in Australia, Canada and the German Democratic Republic for the period 1985-1989 are collected in Table 18. Releases normalized to the production of uranium oxide (U_3O_8) ranged from 1 to 2,000 GBq t^{-1} and were, for most mines, much greater in Canada and in the German Democratic Republic than in Australia. The production-weighted average of the normalized radon release is 300 GBq t^{-1} of uranium oxide. Since about 250 t uranium oxide are required to produce 1 GW a of electrical energy (Table 16), the average radon release, normalized to the generation of electri-cal energy, is approximately 75 TBq $(GW\ a)^{-1}$. This is greater, by a factor of almost 4, than the value adopted in the UNSCEAR 1982 Report and the UNSCEAR 1988 Report. Previous data have been both limited and variable. The present database is somewhat more extensive, and a production-weighted average has been calculated.

84. Releases of natural radionuclides in uranium milling have been reported for mills in Australia and Canada. Results for airborne releases are shown in Table 19. The releases normalized to electrical energy generated are comparable to values adopted in the UNSCEAR 1982 Report and the UNSCEAR 1988 Report. Some variability is inherent, given the limited data available. Mill sites in dry areas give rise to effectively no liquid effluents. The run-off water of mills in wet climates, however, will contain radionuclides and may need treatment before release into watercourses. Liquid releases have been reported for two Canadian uranium mills and are presented in Table 20. There is no obvious explanation for the relatively large amounts of uranium in releases, compared to the other radionuclides of that decay series.

85. The extraction of uranium during milling is made as complete as possible but cannot reach 100%. Typically, the residual tailings from the mill will contain from 0.001% to 0.01% uranium, depending on the grade of ore and the extraction process. More importantly, mill tailings contain the totality of the decay products of ^{234}U that were present in the ore extracted from the mine. Because the two precursors of ^{222}Rn are present in the mill tailings, namely ^{226}Ra, with a half-life of 1,600 years, and ^{230}Th, with a half-life of 80,000 years, mill tailings constitute a long-term source of atmospheric ^{222}Rn. Tailings are discharged from mills into open, uncontained piles or behind engineered dams or dikes with solid or water cover. All tailings piles act as sources of airborne releases of ^{222}Rn, although the release rates can be low if the tailings are covered with water.

86. Measurements over bare tailings piles [A8, B8, C8, S8] show that the exhalation rate of ^{222}Rn is about 1 Bq m^{-2} s^{-1} per Bq g^{-1} of ^{226}Ra. Since the concentration of ^{226}Ra in uranium ore with 1% U_3O_8 is approximately equal to 100 Bq g^{-1}, the release rates of ^{222}Rn over bare tailings resulting from the treatment of uranium ore with 0.1%-3% U_3O_8 are expected to range between 10 and 300 Bq m^{-2} s^{-1}; taking the current average ore grade to be 0.2% U_3O_8, the average exhalation rate of ^{222}Rn is expected to be 20 Bq m^{-2} s^{-1}. Reported emission rates of ^{222}Rn for 1985-1989 from mill tailings in Argentina, Australia, Canada and the German Democratic Republic are presented in Table 21. The emission rates per unit area range from 0.1 to 43 Bq m^{-2} s^{-1}, with most of the values centred on 10 Bq m^{-2} s^{-1}, which is an improvement over the emission rates expected from bare tailings. Assuming, as in the UNSCEAR 1988 Report, that the production of a uranium mine generates tailings of about 1 ha $(GW\ a)^{-1}$ and that the release rates of ^{222}Rn remain unchanged during five years, a typical emission rate per unit area of 10 Bq m^{-2} s^{-1} corresponds to a normalized release of ^{222}Rn of about 20 TBq $(GW\ a)^{-1}$. This applies to mill tailings of an operating mill.

87. It is likely that further treatment will be carried out to minimize the releases of ^{222}Rn from abandoned tailings piles. As reported in the UNSCEAR 1988 Report, several techniques were analysed in a study by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD) [O1] for a number of sites. The radon exhalation rate varied by factors of more than 10^6, according to the treatment assumed, showing that this is clearly a crucial parameter in the assessment of the impact of tailings piles. In the UNSCEAR 1988 Report, it was assumed that some reasonably impermeable cover would be used and that the radon exhalation rate from abandoned tailings piles would be 3 Bq m^{-2} s^{-1}. Because of the assumed protection against erosion and of the long radioactive half-life of ^{230}Th, the radon exhalation rate would remain essentially unchanged over at least 10,000 years and would only decrease by a factor of 2 over the next 80,000 years. Further treatment of the abandoned tailings piles by future generations in the next millennium would probably cause a variation in the exhalation rate, which could be either a decrease or an increase. Two extreme options can be envisaged:

(a) to uncover the tailings piles so that the radon exhalation rate would be increased to its initial value of about 20 Bq m^{-2} s^{-1};

(b) to treat the tailings in such a way that the resulting exhalation rate is decreased to 0.02 Bq m^{-2} s^{-1}, which is the average value corresponding to soils in normal background areas.

88. In this Annex, it is assumed that the average ^{222}Rn exhalation rate from abandoned tailings piles is 3 Bq m^{-2} s^{-1} [corresponding to a normalized emission rate of 1 TBq a^{-1} $(GW\ a)^{-1}$] and that this value will remain unchanged over the next 10,000 years. These assumptions of the long-term release of radon are the same as in the UNSCEAR 1988 Report [U1]. It is, however, recognized that the ^{222}Rn exhalation rate could range between 0.02 and 20 Bq m^{-2} s^{-1} any time in the next 10,000 years and beyond. Normalized releases of radionuclides assumed for the mining and milling operations are summarized in Table 22.

2. Dose estimates

89. In the dose estimation procedure used in the UNSCEAR 1988 Report, a reference mine and mill site was considered with population densities of 3 km^{-2} at 0-100 km and 25 km^{-2} at 100-2,000 km. The collective doses resulting from airborne discharges were then calculated using an atmospheric dispersion model with the characteristics of a semi-arid area and an effective release height of 10 m. The resultant collective effective doses per unit release are shown in Table 22, along with the collective effective doses per unit electrical energy generated for the radionuclides released during the operation of the model mine and mill and from the abandoned tailings piles. The total collective effective dose per unit electrical energy generated is estimated to be 1.5 man Sv $(GW\ a)^{-1}$ during the operation of the mine and mill and to be essentially due to the radon releases. This is greater by a factor of 3 than the estimate given in the UNSCEAR 1988 Report, since additional data have indicated higher average normalized releases. The uncertainties exist not only from normalized releases but also from conditions of the model site and the population

distributions. There may be wide deviations from the above assumptions for actual sites. The doses from liquid effluents are negligible in comparison to the doses from airborne effluents.

90. The collective effective dose per unit electrical energy generated that is due to the releases of radon from abandoned tailings piles is estimated to be delivered at a rate of 0.015 man Sv (GW a)$^{-1}$ per year of release. The rate of release as a function of time is assumed to be constant, and given the very long radioactive half-lives of the radon precursors, the normalized collective effective dose committed is proportional to the assumed duration of the release. Taking this period to be 10,000 years for the sake of illustration, the result is an estimated 150 man Sv (GW a)$^{-1}$. This figure is highly dependent on future management practices; its estimated range is from 1 to 1,000 man Sv (GW a)$^{-1}$.

B. URANIUM FUEL FABRICATION

91. The uranium ore concentrate produced at the mills is further processed and purified and converted to uranium tetrafluoride (UF_4), and then to uranium hexafluoride (UF_6) if it is to be enriched in the isotope ^{235}U, before being converted into uranium oxide or metal and fabricated into fuel elements. Uranium enrichment is not needed for gas-cooled, graphite-moderated reactors (GCRs) or heavy-water-cooled, heavy-water-moderated reactors (HWRs). Enrichments of 2%-5% are required for light-water-moderated and cooled reactors (PWRs and BWRs) and for advanced gas-cooled, graphite-moderated reactors (AGRs).

1. Effluents

92. Available data on airborne and liquid discharges from installations of this stage of the fuel cycle are given in Table 23. Emissions of radionuclides from the conversion, enrichment, and fuel fabrication processes are generally small and consist essentially of the long-lived uranium isotopes, ^{234}U, ^{235}U, and ^{238}U, along with ^{234}Th and ^{234m}Pa, which are the short-lived decay products of ^{238}U. The long half-life of ^{230}Th prevents the activity build-up of any other radionuclide of the ^{238}U series. The solid wastes arising during uranium fuel fabrication are trivial in quantity by comparison with those from the uranium mines and mills.

93. The normalized effluent discharges from model fuel conversion, enrichment and fabrication facilities, which are taken to be the same as in the 1988 UNSCEAR Report, are presented in Table 24.

2. Dose estimates

94. Collective doses resulting from the airborne releases were estimated for the model facility specified in the UNSCEAR 1988 Report, with a constant population density of 25 km^{-2} out to 2,000 km. The normalized collective effective dose is estimated to be 2.8 10^{-3} man Sv (GW a)$^{-1}$, with inhalation the most important pathway of exposure. The collective doses due to liquid discharges are much less than those from airborne discharges, as was assessed in the UNSCEAR 1982 Report for the same relative releases.

C. REACTOR OPERATION

95. Nearly all the electrical energy generated by nuclear means is produced in thermal reactors. The fast neutrons produced by the fission process are slowed down to thermal energies by use of a moderator. The most common materials used as moderators are light water (in PWRs and in BWRs), heavy water (in HWRs) and graphite (in GCRs and light-water-cooled, graphite-moderated reactors [LWGRs]). The electrical energy generated by these various types of reactors from 1970 to the end of 1989 is illustrated in Figure VII. During this period the number of nuclear reactors increased from 77 to 426; the installed capacity, from 20 to 318 GW; and the energy generated, from 9 to 212 GW a [110]. Basic data on nuclear reactors in operation in 1985-1989 are presented in Table 25.

96. The uranium fuel for the nuclear reactors is contained in discrete pins, which prevent leakage of the radioactive fission products into the coolant circuit. The heat generated in the fuel pins by the slowing down of the fission fragments is removed by forced convection, the most usual coolants being light water (in PWRs, BWRs and LWGRs), heavy water (in HWRs), and carbon dioxide (in GCRs). The thermal energy carried by the coolant is then transformed into electrical energy by means of turbine generators.

97. In addition to the reactor types mentioned above, there are five fast breeder reactors (FBRs) in operation in the world. In that type of reactor, fission is induced by fast neutrons, there is no moderator and the coolant is a liquid metal. The main advantage of the FBR lies in its ability to produce more nuclear fuel than it consumes.

1. Effluents

98. During the production of power by a nuclear reactor, radioactive fission products are formed within the fuel and neutron activation products in structural

and cladding materials. Radioactive contamination of the coolant occurs because fission products diffuse into the coolant from the small fraction of fuel with defective cladding, and particles arising from the corrosion of structural and cladding materials are activated as they are carried through the core. All reactors have treatment systems for the removal of radionuclides from gaseous and liquid wastes.

99. The amounts of different radioactive materials released from the reactors depend on the reactor type, its design and the specific waste treatment plant installed. As in the previous UNSCEAR Reports, annual release data have been compiled for each type of reactor. Annual releases are reported in this Annex for the period 1985-1989. These include:

(a) noble gases (argon, krypton and xenon) released to atmosphere (Table 26); the radionuclide compositions of the noble gases discharged from PWRs and BWRs in the United States in 1988 are given in Tables 27 and 28, respectively;
(b) tritium in airborne effluents (Table 29);
(c) carbon-14 released to the atmosphere, available for a few reactors (Table 30);
(d) iodine-131 in airborne effluents (Table 31); releases of other radioactive isotopes of iodine from PWRs and BWRs in the United States in 1988 are presented in Table 32;
(e) particulates in airborne effluents (Table 33);
(f) tritium in liquid effluents (Table 34);
(g) radionuclides other than tritium in liquid effluents (Table 35); the radionuclide compositions of the activities released in liquid effluents from PWRs and BWRs in the United States in 1988 are given in Tables 36 and 37, respectively.

100. For each effluent category, the reported discharges from individual reactors in a given year vary over several orders of magnitude according to design, type of waste treatment, and level of irregular operations and maintenance. Even for reactors of the same type, the variations are enormous. As an example, the statistical distribution of the ^{131}I released from PWRs in the United States during 1988 is illustrated in Figure VIII. For the distribution assumed to be lognormal, a very large geometric standard deviation of 13 is obtained. Neither the amount of electrical energy generated nor the age of the reactor appears to have a clear effect on the quantities of radioactive materials released in a given year. The normalized releases of radionuclides in airborne effluents from PWRs in the United States in 1988 are illustrated in Figure IX. Both the total and normalized releases seem to be independent of the amount of electrical energy generated in that year or of the age of the reactor. This may indicate that effluent treatments in all reactors are maintained to current standards.

101. The trends in normalized releases from all reactors worldwide of the major components of radionuclides in airborne and liquid effluents are illustrated in Figures X to XVI. Deviations from the general patterns may reflect abnormal operation, special maintenance or the like in specific reactors. Some variability may also reflect data that are too incomplete to provide representative averages. The data become increasingly incomplete for years before 1985. For the period 1985-1989, although some components of discharges are not measured, the reporting of available data is nearly complete for all reactors in operation in the world.

102. Because of the variability in annual releases, normalized releases have been averaged over five-year periods in order to assess the collective doses. The normalized releases for the data available since 1970 are presented in Table 38. Data are available for all types of reactors and effluent categories for 1985 1989, except ^{131}I discharged from FBRs. A release equal to that from PWRs is assumed. Estimated values only are available for ^{3}H releases from LWGRs [I14]. For some earlier periods the data are less complete for some reactor types. In order to include estimates for those periods as well, the more recent data or the data for PWRs are used.

103. The trends in the principal components of releases from reactors, averaged over all reactor types and over five-year time periods from 1970 to 1989, are shown in Figure XVII. Atmospheric discharges of noble gases and iodines, as well as liquid discharges of radionuclides other than tritium, have been decreasing, and there have been less obvious changes for the other components. The downward trends no doubt reflect improvements in the quality of nuclear fuel as well as in the performance and standards of reactors in operation.

104. The estimates of normalized release of radionuclides from reactors may be combined with the electrical energy generated to obtain estimates of the total releases from all reactor operations in the world. A record of energy generation by reactors worldwide is compiled by the International Atomic Energy Agency (IAEA) [I10]. Since this record is not complete, especially for earlier years of operating experience in some countries, data provided separately to the Committee and a few estimated values have been added to provide the summary listing given in Table 39. The average normalized release values in Table 38 are assumed to be the most representative and are applied throughout each five-year period. The total releases from all reactors for the entire period of their usage, during which time 1,844 GW a of electrical energy was generated, and the average normalized releases are given in Table 40.

2. Local and regional dose estimates

105. National authorities usually require that environmental monitoring programmes be carried out in the vicinity of a nuclear reactor. In general, the activity concentrations of radionuclides in effluent discharges are too low to be measurable except close to the point of discharge. Dose estimates for the population therefore rely on modelling the environmental transfer and transport of radioactive materials.

106. In the UNSCEAR 1982 Report and the UNSCEAR 1988 Report, the Committee used a model site that is most representative of northern Europe and the north-eastern United States, since those areas contain a large proportion of all power-producing reactors. The cumulative population within 2,000 km of the model site is about 250 million, giving an average population density of 20 km^{-2}. Within 50 km of the site, the population density is taken to be 400 km^{-2} in order to reflect siting practices. This model site has also been used in this Annex, along with the environmental and dosimetric models of the UNSCEAR 1988 Report. With the exception of ^{3}H and ^{14}C, most of the collective doses are delivered to populations in local and regional areas surrounding the model site. The collective effective dose per unit release for the radionuclides or for the radionuclide compositions representative for each reactor type are presented in Table 41.

107. Estimates of collective effective dose per unit electrical energy generated resulting from effluent discharges from reactors in 1985-1989 are given in Table 42. These are obtained by multiplying the normalized releases (Table 38) by the collective effective dose per unit release (Table 41). The total for all reactor operation is 1.4 man Sv $(GW\ a)^{-1}$.

108. A similar procedure may be used to evaluate the collective dose from the entire period of reactor operation. The average normalized releases in five-year periods (Table 38) are multiplied by the annual energy generation of the different reactor types (Table 39) and by the factors of collective dose per unit release (Table 41). The results for each reactor type are combined in Table 43. The total collective effective dose from all reactor operations through 1989 is estimated to have been 3,700 man Sv. The contributions by each reactor type (not indicated, but determined from the calculation) are 45% from HWRs, 29% from BWRs, 14% from PWRs, 9% from LWGRs, 4% from GCRs and 0.3% from FBRs.

109. The estimated collective effective doses from effluent discharges from reactors have changed over the course of time, as the amounts of electrical energy generated and the released amounts per unit energy generated have changed. Figure XVIII shows the trends for the various effluent categories. The collective doses from atmospheric discharges of noble gases and of iodine and from liquid discharges of radionuclides other than tritium decreased or remained stable from before 1970 through 1985-1989. The other components of the local and regional collective dose increased with time as the quantity of electrical energy generated increased, also shown in Figure XVIII.

110. Individual doses resulting from routine releases of radioactive effluents from reactors are usually low. For the model site, the annual effective doses to most exposed individuals are estimated to be 1 μSv for PWRs, 7 μSv for BWRs, 10 μSv for HWRs, 10 μSv for GCRs, 20 μSv for LWGRs and 0.1 μSv for FBRs.

D. FUEL REPROCESSING

111. At the fuel reprocessing stage of the nuclear fuel cycle, the elements uranium and plutonium in the irradiated nuclear fuel are recovered to be used again in fission reactors. Spent fuel elements are preferably stored under water for a minimum of four to five months, in order to ensure that the short-lived ^{131}I decays to a very low level. Since one reprocessing plant can serve a large number of nuclear reactors, the quantities of radionuclides passing through the plant are high in absolute terms.

112. Reprocessing is, at present, carried out in only a few countries and is limited to a small portion of the irradiated fuel. Known reprocessing capacities, as summarized in Table 44, amount to about 3,300 t of uranium per annum. The annual throughputs of irradiated fuel from civilian power programmes to fuel reprocessing plants in France, Japan and the United Kingdom are illustrated in Figure XIX. In the 1980s the total throughput at these plants ranged from an equivalent of 5 to 8.5 GW a of electrical energy, representing 5% of the annual worldwide nuclear electrical energy production in that period. The fraction of irradiated fuel that is reprocessed has been decreasing slightly with time, as energy production has expanded somewhat more than the throughput of fuel at the reprocessing plants. The fractional amounts reprocessed in terms of energy production equivalent were 0.078, 0.066 and 0.04 during 1975-1979, 1980-1984 and 1985-1989, respectively. The data for years before 1975 are incomplete.

113. Several countries have taken decisions not to reprocess fuel. In these countries, the fuel will either be disposed of or stored retrievably; in the latter case the possibility of reprocessing at some later date

would not be precluded. The current strategy for the management of spent fuel in different countries is summarized in Table 45; in each case the amount of irradiated fuel produced in 1990 is indicated, based on the amount of nuclear energy generated in that year. For the countries included in Table 45, the generation of spent oxide fuel in 1990 was about 11,000 t of uranium.

1. Effluents

114. The radionuclides of principal concern in effluents from reprocessing plants are the long-lived nuclides: ^{3}H, ^{14}C, ^{85}Kr, ^{129}I, ^{134}Cs, ^{137}Cs and isotopes of transuranium elements. The reported releases of radionuclides to the atmosphere and to the sea from the Sellafield, Cap de La Hague and Tokai-Mura reprocessing plants for 1985-1989 are listed in Table 46. In this Table, the values for the electrical energy generated that correspond to the annual throughput of fuel were estimated from the ^{85}Kr discharges, using production rates of 14 PBq $(GW\ a)^{-1}$ for GCRs and 11.5 PBq $(GW\ a)^{-1}$ for PWRs. The variations with time of the normalized releases of ^{3}H and ^{137}Cs in liquid effluents from the Cap de La Hague and Sellafield reprocessing plants are illustrated in Figure XX. The annual total releases follow a similar pattern. Discharges of tritium have been increasing slightly, but ^{137}Cs releases have been decreasing. Stricter controls on releases from the Sellafield plant have, since the early 1980s, reduced the ^{137}Cs releases to levels comparable to those from the Cap de La Hague plant. The normalized releases from the Tokai-Mura plant have been comparable to those from the European plants for ^{3}H but several orders of magnitude less for ^{137}Cs.

115. The data in Table 46, along with those quoted in previous UNSCEAR Reports [U1, U3, U4] and additional data from Japan [N13], have been used to determine the average normalized releases of radionuclides during the five-year periods. The limited data prior to 1975 have been combined with later data to provide estimates for 1970-1979. The values are given in Table 47. The normalization is relevant to the equivalent energy production of the fuel reprocessed. Tritium releases in liquid effluents increased in the most recent five-year period, but there have been decreases for most other radionuclides, particularly for ^{137}Cs (by a factor of 80), for ^{90}Sr (by a factor of 13) and for ^{106}Ru (by a factor of 9).

116. The total amounts of radionuclides released from fuel reprocessing can be estimated by completing the record of amounts of fuel reprocessed prior to 1975. For this purpose the ratio of 0.078 times the annual electrical energy generated by reactors has been used. The energy generated by reactors was given in Table 39. The fuel reprocessed (energy equivalent) times the average normalized releases of Table 47 give estimates of the total annual releases, which are shown in Table 48. Whenever the measured results from all three reprocessing plants in France, Japan and the United Kingdom were available, those results, instead of estimated values, were used in Table 48. Measured results were available for ^{3}H and ^{85}Kr in airborne effluents and ^{3}H, ^{90}Sr, ^{106}Ru, ^{137}Cs in liquid effluents since 1975, for ^{129}I in airborne effluents in 1980-1984 and in liquid effluents in 1983-1986. The average normalized releases for the entire period of fuel reprocessing operations given in Table 48 correspond to 1,844 GW a of electrical energy generated and an amount of fuel reprocessed equivalent to 101 GW a.

2. Local and regional dose estimates

117. The collective doses from the reprocessing of nuclear fuel arise from local and regional exposures and from exposures to the globally dispersed radionuclides. Estimates of the local and regional dose commitments are given in this Section and the global contribution in Section E. The local and regional collective doses per unit release of radionuclides were evaluated in the UNSCEAR 1988 Report [U1]. These values are included in Table 49 along with the normalized release amounts derived in Table 46. The product of these two quantities gives the collective effective dose per unit energy equivalent of fuel reprocessed. Since the total fuel reprocessed in 1985-1990 was 4% of the total, the collective dose normalized to the total energy generated in the period is less by the factor 0.04. The total normalized collective effective dose (relative to total energy generated) is 0.05 man Sv $(GW\ a)^{-1}$ from airborne effluents and 0.2 man Sv $(GW\ a)^{-1}$ from liquid effluents.

118. The evaluation of the collective dose for the entire period of fuel reprocessing is straightforward from the estimates of annual releases of radionuclides presented in Table 48. The quantities in this table are multiplied by the factors of collective dose per unit release in Table 49. The results are presented in Table 50. The collective dose from the start of the reprocessing practice is estimated to be 4,600 man Sv. The main components (over 90%) of the dose are ^{137}Cs and ^{106}Ru in liquid effluents.

119. Annual individual doses to critical groups have been evaluated for the three reprocessing plants for which release data are available. Individual doses for Sellafield have been derived from environmental monitoring data, combined with information on the habits of local critical groups [C4]. The main path-

ways considered are the consumption of locally caught fish and shellfish, whole body external irradiation from intertidal areas and external irradiation of the skin of fishermen while handling nets and pots. Annual individual doses to critical groups by the ingestion pathway peaked at about 3.5 mSv in the early 1980s and later declined, to about 0.2 mSv in 1986. The estimated annual individual doses to the critical group for whole body exposure to external irradiation also peaked in the early 1980s at about 1 mSv and decreased to about 0.3 mSv in 1986. Finally, the measured beta dose rates from nets and pots have suggested that skin exposure to fishermen would be no more than 0.1 mSv a^{-1} [C4]. The exposure pathways for critical groups are similar for the fuel reprocessing plant at Cap de La Hague. The estimated annual individual doses for 1986 are 0.2 mSv for the consumption of fish and shellfish and 0.05 mSv for whole body external irradiation. The annual doses to critical groups near the Tokai-Mura reprocessing plant are of the order of 1 μSv [S3].

E. GLOBALLY DISPERSED RADIONUCLIDES

120. The radionuclides giving rise to global collective doses are those that are sufficiently long-lived and that migrate readily through the environment, achieving widespread distribution. The radionuclides of interest are ^{3}H, ^{14}C, ^{85}Kr and ^{129}I. The very long-lived ^{129}I poses a special problem because of the uncertainties involved in the prediction of population size, dietary habits and environmental pathways over periods of tens of millions of years. In this Annex, the global dose commitments are truncated at 10,000 years. By that time, ^{3}H and ^{85}Kr have decayed to insignificant levels and ^{14}C has decayed to about 30% of its initial value. Results for alternative integration periods were presented in the UNSCEAR 1988 Report [U1]. The limit of 10,000 years was chosen to correspond to the maximum period of integrity of tailings piles from which ^{230}Th continues to support ^{222}Rn emanation. Beyond 10,000 years either complete erosion or massive covering of the tailings would occur due to the expected intervention of an ice age. The uncertainties of dose calculations become exceedingly great as integration periods are extended over thousands of years.

121. The collective effective dose per unit electrical energy generated is evaluated in Table 51. The normalized release from reactors and reprocessing plants, the latter less by a factor of 0.04 when normalized for the total energy generated, representing the fraction of fuel reprocessed, is multiplied by the factors of collective dose per unit release. For tritium, the collective dose per unit release to air is taken to correspond to the quotient of the annual dose rate to the hemispheric production rate of natural tritium (10 nSv a^{-1} ÷ 37 PBq) times the world population of the northern hemisphere ($5\ 10^{9} \times 0.89$). The result is 0.0012 man Sv TBq^{-1}. For release to sea, calculations with a global circulation model have shown that the normalized collective dose is a factor of 10 less [N8]. For ^{14}C, the collective dose per unit release is taken to be 85 man Sv TBq^{-1}, which over the 10,000-year period is 71% of the normalized collective dose committed for all time (see paragraph 44). For ^{85}Kr and ^{129}I, the collective dose factors are taken to be as evaluated in the UNSCEAR 1988 Report [U1]. The normalized collective dose, truncated at 10,000 years, from globally dispersed radionuclides is 53 man Sv $(GW\ a)^{-1}$ and is due almost entirely to ^{14}C.

122. The total collective effective dose from globally dispersed radionuclides for the entire period of nuclear power production can be evaluated by multiplying the total release of these radionuclides by the collective dose per unit release. The results of this calculation are given in Table 52. The total is 123,000 man Sv, over 99% of which is due to ^{14}C.

F. SOLID WASTE DISPOSAL AND TRANSPORT

123. The solid wastes that arise from reactor operations as well as from the handling, processing and disposal of spent fuel are generally characterized as low-level wastes, intermediate-level wastes, and high-level wastes. Low-level wastes and intermediate-level wastes are generally disposed of by shallow burial. Burial facilities range from simple trenches or pits containing untreated wastes and capped with soil (typically used for low-level wastes) to concrete structures containing conditioned wastes and capped with soil (typically used for intermediate-level wastes). Some low-level wastes were disposed of at sea at more than 50 sites from 1946 to 1982 [I11]. Various solutions are envisaged for the disposal of high-level wastes, but none have yet been implemented. Decommissioned reactors will become part of solid waste management programmes in the future. Several reactors have been shut down, but none have yet been dismantled or transformed into a waste disposal site as yet.

124. Doses from solid waste disposal are usually assumed to result from the migration of radionuclides through the burial site into groundwater. The normalized collective effective dose attributable to wastes from reactor operation is almost entirely due to ^{14}C and roughly amounts to 0.5 man Sv $(GW\ a)^{-1}$; the corresponding value for wastes from the handling and processing of spent fuel is 0.05 man Sv $(GW\ a)^{-1}$.

These estimates are highly uncertain as they depend critically on the assumptions used for the containment of the solid wastes and for the site characteristics.

125. Materials of various types are transported between the installations involved in the nuclear fuel cycle. Members of the public in the vicinity of the trucks, boats or trains carrying the radioactive materials are exposed to small doses of external irradiation. On the basis of fragmentary data, the normalized collective effective dose was estimated to be 0.1 man Sv $(GW\ a)^{-1}$ in the UNSCEAR 1988 Report. The same value is used in this Annex.

G. SUMMARY OF DOSE ESTIMATES

126. A summary of the main contributions to the total collective effective dose, normalized per unit electrical energy generated, is shown in Table 53. The local and regional normalized collective effective doses, which are effectively received within one or two years of discharge, amount to 3 man Sv $(GW\ a)^{-1}$ and are principally due to routine atmospheric releases during reactor and mining operations. Even though the contributions from the various components of the nuclear fuel cycle are different from those reported in the UNSCEAR 1988 Report, the total remains the same, as the decreases in the dose estimates from reactor operation and fuel reprocessing have been compensated by increases in the dose estimates from mining and milling. Globally dispersed radionuclides in effluents from the nuclear fuel cycle and long-term releases from solid waste disposal result in small exposures to members of the public over a very long time (10,000 years or more). The normalized collective effective dose received within 10,000 years amounts to about 200 man Sv $(GW\ a)^{-1}$ and is mainly due to the release of radon from mill tailings and to the release of ^{14}C from fuel reprocessing plants and from reactors.

127. The assessment of the local and regional collective dose for the entire period of nuclear power production has been determined for reactor operation, 3,700 man Sv (Table 43), and for fuel reprocessing, 4,600 man Sv (Table 50). It can be assumed that the normalized collective effective dose from mining and milling, given as 1.5 man Sv $(GW\ a)^{-1}$ in Table 53, is also representative of earlier periods. The total collective dose from this portion of the fuel cycle is thus 1.5 man Sv $(GW\ a)^{-1} \times 1{,}844$ GW a = 2,700 man Sv. The total for the entire fuel cycle is 2,700 + 3,700 + 4,600 = 11,300 man Sv. The average normalized collective dose for the entire period of the practice is estimated to be 11,000 man Sv ÷ 1,844 GW a = 6 man Sv $(GW\ a)^{-1}$. This long-term average is higher than the value for present practice owing to the declining releases from reactors and fuel reprocessing operations.

128. The estimation of collective effective doses from globally dispersed radionuclides and from long-term releases from solid waste disposal is rather speculative, as it depends heavily on future waste management practices and on the evolution of the world's population over the next 10,000 years. Multiplying the figure of 200 man Sv $(GW\ a)^{-1}$ obtained in this Annex as well as in the UNSCEAR 1988 Report by 1,844 GW a yields a collective effective dose from these sources of about 400,000 man Sv. About 25% of the total is due to ^{14}C released from reactors and reprocessing plants (Table 52) and the remainder to radon released from mill tailings.

V. RADIOISOTOPE PRODUCTION AND USE

129. Radionuclides are used for a variety of purposes in industry, medicine and research [16], and both the number of uses and the quantities used have been continually increasing. For example, in Japan, the number of establishments using radionuclides and/or radiation generators has grown over the years, from about 100 in 1960 to about 5,000 in 1990 [J2]. Exposures of the public may result from activities associated with the production, use and waste disposal of the radioactive materials. The doses from the use of radioisotopes in consumer products were considered in the UNSCEAR 1982 Report [U3]. The doses evaluated in this Chapter are those resulting from releases to the environment, which may occur during production, use or disposal. Radionuclides produced for sealed sources are not considered, since they are not normally released. Radiopharmaceuticals, ^{14}C and ^{3}H are usually eventually released, and with some approximation the total production can give an estimate of the total release.

A. PRODUCTION AMOUNTS AND RELEASES

130. The amounts of radioisotopes produced for commercial or medical purposes are not well documented. Likewise, the releases during production

or use are not widely reported. The evaluation of doses must therefore remain rather approximate, with only preliminary, very uncertain results having been used. Statistics on radioisotope production and use are available only for Japan [J2]. Table 54 gives the annual uses of radioisotopes in 1989 in hospitals, schools, research institutions and industries. From the population of Japan (118.9 million) the usage per 10^6 population may be determined: for example, 5.2, 6.1, 14 and 34 GBq per 10^6 population for ^{14}C, ^{125}I, ^{3}H and ^{131}I, respectively.

131. The production of compounds labelled with ^{14}C has been estimated for the United States in 1978 to be about 7 TBq [N9], corresponding to 30 GBq per 10^6 population. This is six times the normalized usage in Japan. The production amount of ^{14}C in the United Kingdom is not available, but the reported releases in airborne and liquid effluents from the commercial production plant were reported to be 3.2 TBq in 1987 [H6]. This corresponds to 55 GBq per 10^6 population. The net production must be substantially greater. It is, however, supporting users in many other countries as well as in the United Kingdom. By assuming that 10% of the ^{14}C is lost at production and normalizing to the population of Europe (roughly 10 times that of the United Kingdom), the estimate of normalized production becomes 50 GBq per 10^6 population.

132. To obtain approximate figures of production, usage and ultimate release amounts, the ^{14}C estimate of the United States is assumed and applied at the rates of 100% to the population of developed countries ($1.2\ 10^9$ population) and 10% to the population of developing countries ($3.7\ 10^9$ population). The annual production and release of radioisotopes relative to ^{14}C are determined from the values given in Table 54 for Japan. Thus, for example, the production of ^{3}H and ^{131}I is three and six times greater, respectively, than the production of ^{14}C.

133. The annual global production and ultimate release of these radionuclides may be estimated to be 30 GBq per 10^6 population (^{14}C) times an equivalent world population of $1.6\ 10^9$ persons times the relative production fractions. The results for several radionuclides are given in Table 55. Other radionuclides not included in this Table, especially those in solid form, are unlikely to be released or widely dispersed from the end-uses.

134. Additional data on the production and release of radioisotopes are available for ^{131}I administered to patients in medical facilities. The total amount of ^{131}I produced for medical purposes in Sweden during 1986 was 0.9 TBq [N15]. Radioactive discharges of ^{131}I from hospitals in Australia in 1988-1989 have been reported as 2.9 TBq [A9]. These amounts, corresponding to 110 and 190 GBq per 10^6 population, give some corroboration to the value used in Table 55 (200 GBq per 10^6 population). About two thirds of orally administered ^{131}I is excreted via the urine of treated patients in the first day [E2]; however, only very low concentrations of ^{131}I have been measured in surface waters in Germany [A7] and in the sewage systems of cities in Sweden [E2] and in the United States [S5]. Waste treatment systems in hospitals with hold-up tanks may reduce the amounts of ^{131}I discharged in liquid effluents to $5\ 10^{-4}$ of amounts administered to patients [J3].

B. DOSE ESTIMATES

135. Since the environmental levels of radioisotopes used for medical, educational or industrial purposes are in general undetectable, only approximate, calculated estimates can be made of the collective doses. The results are given in Table 55. The estimates assume no partial retention of the radionuclides in end-products and no hold-up prior to wide dispersion and the exposure of local, regional or global populations. This could result in overestimated doses, significantly so for radioiodines that have short half-lives. The dose coefficients listed in Table 55 are those derived and used for radionuclides produced and released in nuclear power production. Tritium and the noble gases are assumed to be released to the atmosphere, ^{14}C to be released in both airborne and liquid effluents and ^{131}I and ^{125}I to be released to rivers. There could be occasional release of iodine in airborne effluents, for example from incineration of waste materials. This would be easily detected, but since it is so seldom reported, it can be assumed that this is not an important source of release. The dose coefficient for ^{125}I is based on age-weighted dose-per-unit-intake values [N1] and the ^{125}I half-life of 13 hours, with other model parameters the same as for ^{131}I.

136. The total local and regional collective effective dose from releases of radioisotopes used in one year in medical and industrial applications is of the order of 100 man Sv. If it can be assumed that the practice of these radioisotope uses has been building up over the past 40 years, the collective dose committed from all past releases would be 20 times the present annual value, or 2,000 man Sv in total. The global component of the collective effective dose, arising almost entirely from ^{14}C, is 4,000 man Sv from one year of radioisotope usage and 80,000 man Sv committed from the entire practice to date. The contribution of this source to man-made exposures in general is thus relatively unimportant on an annual basis. The doses from ^{14}C are at low dose rate but extend over a long period of time.

VI. ACCIDENTS

137. A number of accidents have occurred at both civilian and military nuclear installations and in the transport of nuclear materials. In some cases, there was substantial contamination of the environment. These accidents are discussed in this Chapter, and the magnitude of population doses incurred are estimated.

A. CIVILIAN NUCLEAR REACTORS

138. The two principal accidents involving installations of the civilian nuclear fuel cycle took place at the Three Mile Island reactor in the United States in March 1979 and at Chernobyl in the USSR in April 1986.

1. Three Mile Island

139. The accident at Three Mile Island has been the subject of many reports, particularly from the United States Nuclear Regulatory Commission and the President's Commission [K3]. The cause of the accident was the failure to close a pressure relief valve, which led to severe damage of uncooled fuel. The accident released large amounts of radioactive materials from failed fuel to the containment, but the environmental releases were relatively small (about 370 PBq of noble gases, mainly ^{133}Xe, and 550 GBq of ^{131}I into the atmosphere).

140. Individual doses averaged 15 μSv within 80 km of the plant, and the maximum effected dose that any member of the public could have received is estimated to have been 850 μSv from external gamma irradiation [K3]. The collective effective dose due to the release has been estimated to be 20 man Sv within 80 km of the plant [K3]. The contribution to the effective dose commitment due to ^{133}Xe dispersion beyond 80 km may have been equal to that within 80 km [U3], which gives a total of 40 man Sv.

2. Chernobyl

141. The worldwide exposures from the Chernobyl accident were evaluated in detail in the UNSCEAR 1988 Report [U1]. In the course of a low-power engineering test, uncontrollable instabilities developed and caused explosions and fire, which damaged the reactor and allowed radioactive gases and particles to be released into the environment. The fire was extinguished and the releases stopped by the tenth day after the accident. The death toll within three months of the accident was 30, all of them members of the operating staff of the reactor or of the fire-fighting crew.

142. The total release of radioactive materials is estimated to have been 1-2 EBq [I3], the principal radionuclides being ^{131}I (630 PBq), ^{134}Cs (35 PBq) and ^{137}Cs (70 PBq) [I15]. The proportional amounts dispersed beyond the USSR were determined to be 34% for ^{131}I and 56% for ^{137}Cs [I15].

143. About 115,000 residents were relocated from a 30 km exclusion zone surrounding the reactor. The external radiation doses to most of those evacuated was less than 0.25 Sv, although a few in the most contaminated areas might have received doses up to 0.3-0.4 Sv. The collective dose from external radiation to the evacuees is estimated to have been 16,000 man Sv. Individual thyroid doses to children may have been 2.5 Gy and higher in some cases, with an average thyroid dose of 0.3 Gy and a collective thyroid dose of 400,000 man Gy [C10].

144. The radiation situation beyond the 30 km zone surrounding the reactor was determined primarily by the wind directions. When rainfall occurred at the time that the radioactive cloud was passing, the deposition density of ^{137}Cs and other fission radionuclides was enhanced. In the USSR, an area of about 10,000 km^2 was contaminated with ^{137}Cs to levels in excess of 560 kBq m^{-2}, and an area of 21,000 km^2 received upwards of 190 kBq m^{-2} [I15]. A government commission determined that 786 settlements, located in Belarus, the Russian Federation, and Ukraine, with a population of 270,000, were to be considered as "strict control zones". Protective measures preventing the consumption of contaminated foodstuffs were applied in the strict control zones. The average effective dose received by the populations in the strict control zones is estimated to have been 37 mSv in the year following the accident and 23 mSv in 1987-1989 [I15]. An international review project was conducted in 1990 to investigate environmental levels, doses and the health of residents of unevacuated settlements [I1]. The project corroborated results of measurements and dose evaluations. Diet and body measurements showed that agricultural practices and protective measures were effective in limiting exposures. The doses determined by whole body counting were less than expected from calculation by environmental models. Estimation of thyroid doses requires interpretation of early direct measurements and calculation of presumed ^{131}I intakes; these doses are thus subject to considerable uncertainties.

145. Detailed information on environmental contamination levels and radiation doses received by populations in the northern hemisphere was made available to the Committee by many countries, either

directly to the UNSCEAR secretariat or in published reports. This information enabled the Committee, in the UNSCEAR 1988 Report [U1], to calculate first-year radiation doses in the USSR, all other European countries and a few other countries in the northern hemisphere. The projected doses beyond the first year were based on the environmental behaviour of ^{137}Cs determined in many years of measurements following atmospheric nuclear testing.

146. The collective effective dose from the Chernobyl accident was estimated to be approximately 600,000 man Sv [U1]. Of this amount, 40% is expected to be received in the territory of the former USSR, 57% in the rest of Europe and 3% in other countries of the northern hemisphere.

B. MILITARY INSTALLATIONS

147. There have been two accidents at military plants that are known to have caused measurable exposures of the public: an accident at Kyshtym in the southern Ural Mountains of the USSR in September 1957 and the Windscale reactor accident in the United Kingdom in October of the same year.

1. Kyshtym

148. In the early 1950s high-level radioactive wastes from the Chelyabinsk-40 plutonium production centre near Kyshtym were stored in water-cooled tanks encased in concrete. The corrosion and failure of process monitoring equipment led to a breakdown in the cooling system of a 300 m^3 tank, allowing the 70-80 tonnes of waste, stored mainly in the form of nitrate and acetate compounds and containing about 1 EBq of radioactive materials, to heat up. The water in the tank evaporated, and as the sediments dried out, they reached temperatures of 330-350°C. On 29 September 1957 the contents of the tank exploded with a power estimated to have been equivalent to 70-100 tonnes of TNT [R3]. About 90% of the radioactive materials contained in the tank deposited locally, while the remainder (about 100 PBq) was dispersed away from the site of the explosion [A4, B11, B12, N2, N3, R3, T1, T4]. The main contributors to the total activity associated with the radioactive materials released were ^{144}Ce + ^{144}Pr (66%), ^{95}Zr + ^{95}Nb (24.9%), ^{90}Sr + ^{90}Y (5.4%) and ^{106}Ru + ^{106}Rh (3.7%). In addition, ^{137}Cs (0.036%), ^{89}Sr (traces), ^{147}Pm (traces), ^{155}Eu (traces) and $^{239,240}Pu$ (traces) were also released [B11]. With the exception of caesium, the radionuclide composition is similar to that of fission products that had been cooled for about one year. Waste treatment at the reprocessing plant involved concentrating the radionuclides by means of precipitation with sodium hydroxide. Caesium was practically the only element with radionuclides that remained in the solution; it was later concentrated separately [R3].

149. The radioactive cloud reached a height of about 1 km. Wind conditions were relatively stable during the dispersion of the cloud over a relatively flat surface, and there was no precipitation. This resulted in an oblong fallout area, extending to about 300 km from the plant, with a clearly defined axis and monotonic decrease in the deposition density along the axis and perpendicular to it. Virtually all of the deposition occurred within 11 h. The boundaries of the contaminated area were taken to correspond to a ^{90}Sr deposition density of 4 kBq m^{-2}, twice the level of global fallout.

150. Redistribution of the deposited radionuclides occurred to some extent, most noticeably in the first few days after the accident. The main sources of the redistribution were the crowns of trees and the soil surfaces. On the whole, the delineation of the fallout area was practically complete by 1958, when wind migration was redistributing less than 1% of the original fallout. Over the next 30 years, wind transfer did not affect appreciably the distribution of the contamination [T1]. The contaminated area was estimated to comprise between 15,000 and 23,000 km^2, with a population of about 270,000, in the provinces Chelyabinsk, Sverdlovsk and Tyumen [B11, N3]. There were 1,154 people in areas with a ^{90}Sr deposition density greater than 40 MBq m^{-2}, 1,500 in areas with a deposition greater than 4 MBq m^{-2} and 10,000 in areas with a deposition greater than 70 kBq m^{-2} [B11, N3].

151. External irradiation was the main route of exposure during the first few months after the accident; subsequently, the ingestion of ^{90}Sr in foodstuffs became predominant. During the initial period, the dose rate in air was about 1.3 μGy h^{-1} from gamma emitting radionuclides in areas with a ^{90}Sr deposition density of 40 kBq m^{-2}, with maximum values of about 5 mGy h^{-1} near the plant, where the deposition density of ^{90}Sr reached 150 MBq m^{-2} [B11]. Within 10 days of the accident 1,154 persons [B11, B12, N3, R3] were evacuated from the settlements in the most severely affected area, which had a ^{90}Sr deposition density greater than 40 MBq m^{-2}. Subsequently, monitoring of the radioactive contamination levels in foodstuffs and agricultural produce was carried out to assure that an annual ^{90}Sr intake of 50 kBq a^{-1} would not be exceeded. A ban on foods was imposed with concentration limits of ^{90}Sr relative to the mass of calcium in foods of 7.4 Bq g^{-1} initially and 2.4 Bq g^{-1} at a subsequent period. This led to the destruction of more than 10,000 tonnes of agricultural produce in the first two years following the accident and to the

decision to carry out a further systematic evacuation of the population from areas with a ^{90}Sr deposition density greater than 150 kBq m^{-2} [R3]. The resettlement, which began 8 months after the accident, was completed 18 months after the accident. Altogether, 10,730 persons were evacuated [B11]. The collective dose is evaluated in Table 56. The average dose received by the population group evacuated within 10 days of the accident was 170 mSv from external irradiation and 1,500 mSv to the gastro-intestinal tract; the average effective dose was 520 mSv. The collective dose received by the evacuated individuals amounted to about 1,300 man Sv.

152. The doses received by the populations that were not evacuated are also presented in Table 56. About half of the effective dose had been delivered within one year, more than 90% within 10 years and nearly all within 30 years of the accident. The effective dose per unit deposition density was estimated to be 320 μSv per kBq m^{-2} over 30 years, with just over 20% due to external irradiation. The collective effective doses received by the non-evacuated population (about 260,000 persons) have been reported to be 1,100 man Sv [N3] and about 5,000 man Sv [B1]. It is difficult to judge the validity of these figures, as the information on the correspondence of ^{90}Sr deposition densities with populations is very coarse. However, it is indicated that average effective doses received over 30 years are estimated to have been 20 mSv for a group of about 10,000 people living in areas with a ^{90}Sr deposition density between 40 and 70 kBq m^{-2} and 4 mSv for a group of 2,000 people living in areas with a deposition density between 4 and 40 kBq m^{-2} [B11]. On the basis of the relationship between population and the deposition density of ^{90}Sr described above, it can be assumed that the number of people living in areas with deposition densities between 40 and 70 kBq m^{-2} was 10,000 and that the number of people living in areas with deposition densities between 4 and 40 kBq m^{-2} was 250,000, resulting in a collective effective dose over 30 years of 1,200 man Sv.

153. A less serious accident occurred in 1967, as a consequence of the disposal of radioactive wastes containing 4 EBq of ^{90}Sr and ^{137}Cs radioactive wastes in Lake Karachay [A3, N4, T4]. On that occasion, dust from the lake bed or the shore-line, containing about 20 TBq of ^{90}Sr and ^{137}Cs, was dispersed by the wind over an area of 1,800 km^2 and to a distance of up to 75 km. The contaminated territory included portions under the radioactive plume of the 1957 accident. The maximum deposition density of ^{90}Sr was 0.4 MBq m^{-2}, and the $^{137}Cs/^{90}Sr$ activity ratio was 3. Specific information on the doses resulting from that accident is not available; it is expected that they are included in the doses from the much more serious accident that occurred in 1957 at the same site. However, because the $^{137}Cs/^{90}Sr$ activity ratios were very different in the 1957 and 1967 accidents, it would be possible, as evidenced by recent measurements [A3], to separate the contributions from the two accidents by analysing soil samples.

2. Windscale

154. The accident at Windscale in October 1957 began during a routine release of the Wigner energy stored in the graphite of the gas-cooled reactor. Owing to errors in operation, the fuel became overheated and caught fire. The fire lasted for about three days. Major releases of radionuclides occurred mainly in two periods: when the air flow was re-started through the core soon after the accident started, in an attempt to cool it, and when water was pumped into the reactor to extinguish the fire on the second day of the accident [C13]. The release of ^{131}I is estimated to have been 740 TBq, accompanied by 22 TBq of ^{137}Cs, 3 TBq of ^{106}Ru and 1.2 PBq of ^{133}Xe [C10]. In addition to the fission products, other radionuclides were released, the most notable being ^{210}Po, which was being produced by neutron irradiation of bismuth ingots in the core. The release of ^{210}Po amounted to 8.8 TBq [C10, C14]. The Windscale reactor has not been used again since.

155. The contamination of pasture land was widespread, the majority of the released radioactive materials having passed south-south-east of Windscale, in the direction of London, and eventually over Belgium before having turned northwards, to Norway. At the time of accident, the radionuclide identified as being of principal concern was ^{131}I, and the main pathway to man was identified as the ingestion of cow's milk. The prompt imposition of a ban on milk supplies had the effect of reducing ^{131}I intakes via the pasture-cow-milk-pathway [C10]. Extensive environmental measurements were made in the United Kingdom at the time of the accident. Maximum doses to persons close to the site were estimated to have been of the order of 10 mGy to the thyroid of adults and perhaps 100 mGy to the thyroid of children [B2, C9]. Thyroid doses to adults in Leeds and London were estimated from measurements of ^{131}I in the thyroids to have been 1 mGy and 0.4 mGy, respectively [B2], with young children having received doses twice as great.

156. The collective effective dose received in the United Kingdom and in Europe from all radionuclides and pathways was estimated to have been 2,000 man Sv, of which about 900 man Sv was due to inhalation and 800 man Sv was due to the ingestion of milk and other foodstuffs. External irradiation from

ground deposits of radionuclides was estimated to have contributed 300 man Sv. The main contributors to the collective effective dose were ^{131}I (37%) and ^{210}Po (37%), followed by ^{137}Cs (15%) [C10].

C. TRANSPORT OF NUCLEAR WEAPONS

157. Fourteen accidents involving aircraft carrying nuclear weapons or components of nuclear weapons are known to have occurred, the two most publicized being the aircraft crash near Palomares, Spain, in January 1966 and the crash at Thule, Greenland, in January 1968. Appreciable amounts of ^{239}Pu were released locally to the environment. A number of nuclear weapons have also been lost at sea.

158. The accident at Palomares, on the Mediterranean coast, occurred on 17 January 1966, when two United States military planes collided in the process of a mid-air refuelling operation. The parachutes of two of the four thermonuclear weapons carried by one of the planes failed to deploy, resulting in the detonation of their conventional explosives and the release of their fissile material upon hitting the ground. Partial ignition of the fissile material formed a cloud that contaminated 2.26 km^2 of uncultivated farm land and urban land with ^{239}Pu and ^{240}Pu [I16-I20]. The other two bombs were recovered intact, one in a dry river bed near the mouth of the Almanzora River and the other in the sea.

159. Where the deposition density of alpha emitters was greater than 1.2 MBq m^{-2} (an area of 22,000 m^2), the contaminated vegetation and a surface layer of soil, approximately 10 cm deep, were collected, separated and disposed of as radioactive waste. Arable land with levels below 1.2 MBq m^{-2} was irrigated, ploughed to a depth of 30 cm, harrowed and mixed. On rocky hillsides, where ploughing was not possible, soil with a plutonium level greater than 0.12 MBq m^{-2} was removed to some extent with hand tools [I17].

160. Estimates of the doses from inhalation and from ingestion have been derived from measured concentrations of ^{239}Pu and ^{240}Pu in ground-level air, in agricultural foodstuffs and in people. The urine and lungs of Palomares inhabitants have been sampled and measured for plutonium since 1966. Of the 714 people examined up to 1988, only 124 showed concentrations of plutonium in urine greater than the minimum detectable activity. Iranzo et al. [I18] estimated that the 70-year committed effective doses for 55 of these people ranged from 20 to 200 mSv owing to the acute inhalation of radioactive particles at the time of the accident or immediately afterwards. The highest estimated 70-year committed effective dose was 240 mSv to a one-year-old child [I18]. From data in this reference, the collective effective dose due to acute inhalation of radioactive particles immediately after the accident can be estimated to have been about 1 man Sv.

161. The resuspension of soil particles has been monitored since 1966 at four locations [I17]. The average annual concentrations of ^{239}Pu and ^{240}Pu during the period 1966-1980 were 5.5 μBq m^{-3} at the location representative of the urban centre and 52 μBq m^{-3} at the location representative of the most exposed farming area [I17]. The corresponding 50-year effective dose per year of intake by inhalation of radioactive particles resuspended from soil are 4 and 35 μSv per year of intake for people in the urban area and in the most exposed farming area, respectively. Assuming that (a) the total number of persons exposed is 714; (b) 90% of that exposed population resides in the urban area and the remainder in the most exposed farming area; and (c) the amount of ^{239}Pu and ^{240}Pu available for resuspension decreases exponentially with a half-time of 100 years, the collective effective dose due to the resuspension of radioactive particles is roughly estimated to be 1 man Sv.

162. The main crops in the cultivated area of the Palomares region are tomatoes, barley and alfalfa [I20]. From the plutonium concentrations in those products, it can be inferred that resuspension of the plutonium particles in soil plays a more important role than absorption through root uptake in the contamination of agricultural products cultivated in the area [I20]. Iranzo et al. [I20] estimated that the individual committed effective dose due to a yearly consumption of unwashed contaminated tomatoes would be 1.5 μSv and that the collective effective dose from a yearly consumption of tomatoes grown on one hectare of contaminated soils would be 10^{-4} man Sv. Assuming that (a) the cultivated area used for the production of tomatoes is 100 hectares (1 km^2) and (b) the amount of plutonium available for the contamination of agricultural crops decreases exponentially with a half-time of 100 years (reflecting the predominant role of resuspension), the collective effective dose due to the ingestion of tomatoes contaminated as a result of the accident is crudely estimated to be about 1 man Sv. The contamination of barley and alfalfa also results in the contamination of products used for human consumption (milk and meat), but the doses due to ingestion of those products are much lower than those due to the ingestion of tomatoes because of the filtering effect of the animals.

163. Some of the plutonium deposited on land was transferred to the Mediterranean Sea when the Almanzora River, which flows through the village of Palomares, flooded [G1]. This transfer, however, is not significant from a radiological point of view.

164. Near Thule, the high-explosive components of four weapons detonated in an airplane crash, contaminating about 0.2 km^2. About 10 TBq of plutonium was recovered in the surface layer of the snow pack, and about 1 TBq was estimated to be trapped in the ice [L1]. A radioecological investigation conducted during the summer of 1968, when the ice had broken up, showed that the accident had measurably raised the plutonium level in the marine environment as far as 20 km from the point of impact. The highest concentrations were found in bottom sediments, in bivalves and in crustacea. Larger animals such as birds, seals and walruses showed plutonium levels hardly different from the fallout background [A1, A2].

165. Accidents have also happened during the transport of nuclear weapons by sea. At least 48 nuclear weapons and 11 reactors have been reported to be lying on the ocean floor [E3]. The most serious losses were two nuclear-powered submarines, each carrying several nuclear weapons; one sank off the coast of Bermuda in October 1986 and the other in the Norwegian Sea in April 1989. Another loss occurred near the coast of Japan in 1965, when an airplane with a 1 Mt hydrogen bomb rolled off an aircraft carrier. No information has been reported on the number of deaths or on the extent of environmental contamination associated with those accidents that resulted in the loss of nuclear weapons. However, some information is available about an accident that took place aboard a missile-carrying nuclear submarine in July 1961 in the Atlantic Ocean [K8]. In that accident, a depressurization in the primary coolant of one of the two nuclear reactors led to substantial radioactive contamination in the submarine and to a reactor shutdown. To prevent reactor meltdown, a temporary emergency cooling system was fabricated; this required welding work to be carried out in the reactor compartment itself, which led to eight deaths within a few weeks of the accident [K8].

D. SATELLITE RE-ENTRY

166. In 1964, when a SNAP-9A satellite containing ^{238}Pu as a power source re-entered the atmosphere and then burned up, about 600 TBq of that radionuclide were injected into the stratosphere [H1]. A similar device re-entered the atmosphere intact, produced no releases and fell into the Pacific Ocean in April 1970. Another generator fell into waters off the coast of California in May 1968, when a weather satellite exploded during launch. It was recovered in October 1968. In January 1978, the Cosmos 954 satellite re-entered the atmosphere, partially burned and scattered debris in the Northwest Territories of Canada. Detailed information on the characteristics of the radioisotopes and reactor-powered devices used in satellites, as well as on the malfunctions that have occurred, has been gathered by OECD [O4].

167. The collective dose from the SNAP-9A re-entry may be evaluated by applying transfer coefficients to the released amount. The transfer coefficient P_{25} from deposition of ^{238}Pu to dose via the ingestion pathway has been estimated to be 0.6 nSv per Bq m^{-2} (Table 8). The transfer coefficient P_{02} for ^{238}Pu, which has a half-life 87.7 years, would be expected to be 5 kBq m^{-2} per EBq released (Figure III) for temperate latitudes. The dose commitment for these latitudes would then be estimated to be 0.6 PBq $\times$ P_{02} $\times$ P_{25} = 1.8 nSv. The hemisphere average is less by a factor of 1.5 and the opposite hemisphere average is less by a factor of 4. Since re-entry was in the southern hemi phere, the averages for the hemispheres are 1.2 nSv (south) and 0.3 nSv (north). The population-weighted world average is 0.4 nSv (89% of the population lives in the northern hemisphere). For the relatively long half-life of ^{238}Pu, a world population of 6 10^9 may be taken to apply to this exposure [U3]. The collective effective dose from the ingestion pathway due to the re-entry of the SNAP-9A is thus estimated to be 2.4 man Sv.

168. The transfer coefficient P_{25} for the inhalation pathway has an estimated value of 800 nSv per Bq m^{-2} (Table 8). The dose commitment for the southern hemisphere temperate region is thus 0.6 PBq $\times$ P_{02} $\times$ P_{25} = 2,400 nSv. The average values for the hemispheres are then 1,600 nSv (southern hemisphere), 400 nSv (northern hemisphere) and 530 nSv (world). The collective dose from the inhalation pathway, with a population of 4 10^9 applicable at the time of re-entry, is 2,100 man Sv. The inhalation pathway is the dominant contributor to the collective dose. This is comparable to the collective effective dose derived for ^{238}Pu produced in atmospheric nuclear testing, which released 0.33 PBq, about half the total of the satellite re-entry, but with injection mostly into the atmosphere of the northern hemisphere.

169. Similar procedures may be used to estimate the collective dose from the Cosmos 954 re-entry. The fuel core was estimated to contain 20 kg of enriched uranium [G3]. With a steady power output of 100 kW over the 128 day lifetime of the satellite, the burn-up of the fuel was estimated to be 2 10^{18} fissions per gram of uranium [G3]. The estimated radionuclide inventory in the core at re-entry is presented in Table 57 [T6]. From analysis of recovered debris, it has been assumed that 75% of the radionuclide amounts were dispersed in the high atmosphere on re-entry of the space craft and 25% was deposited on the ground in the uninhabited impact area. The absence of the volatile elements iodine and caesium in surface samples indicates that 100% of the radionuclides of

these elements were dispersed on burn-up of the fuel core in the atmosphere. The collective dose is estimated in Table 57 from the widely dispersed material using the transfer factors of Figure III and Table 8. The result is 16 man Sv, mainly to the population of the northern hemisphere from ^{137}Cs and ^{90}Sr and over a longer term from ^{239}Pu.

E. INDUSTRIAL AND MEDICAL SOURCES

170. Three notable accidents involving small sealed sources used for industrial or medical purposes have occurred since 1982 [U1]. In December 1983, at Ciudad Juarez, Mexico, a non-licensed teletherapy source containing 16.7 TBq of ^{60}Co was sold to a scrapyard [M4]. It is believed that the source was broken and that its 6,000 pellets began to be dispersed during transport [M4]. The consequences of this accident were the contamination of thousands of tonnes of metallic products that were sold in Mexico and the United States, as well as the contamination of several foundries and streets and hundreds of houses. About one thousand people were exposed to substantial levels of radiation. It is estimated that seven persons received between 3 and 7 Sv; 73 persons received between 0.25 and 3 Sv, and 700 persons received between 0.005 and 0.25 Sv [M4]. There were no deaths.

171. In 1984, at Mohammedia, Morocco, a source of ^{192}Ir used to make radiographs of welds at a construction site became detached from the take-up line to its shielded container. The source dropped to the ground and was noticed by a passer-by, who took it home. Eight persons, an entire family, died from the radiation over-exposure, having suffered doses of 8-25 Sv [I4, S10]. Estimates of doses to the individuals are unavailable, so only a rough approximation can be made of the collective dose. Assuming 10 Sv on average to each person, the collective dose to those who died would have been 80 man Sv.

172. In September 1987, at Goiania, Brazil, a 50.9 TBq ^{137}Cs source was inadvertently removed from a therapy unit and dismantled by junk dealers [C6, I5, R4, V1]. The therapy unit was located in the abandoned and partly demolished Goiania Radiotherapy Institute. The dismantling of the source resulted in localized contamination of an inhabited area of the city. As the result of the direct handling of the source or parts of it, either during its dismantling or subsequently, 129 people were exposed, either externally or internally. Some suffered very high external contamination owing to the way they had handled the caesium powder, such as having daubed their skin. Internal exposures resulted from eating with contaminated hands. The dose estimates varied from zero up to 5.3 Sv. Fifty-four persons were hospitalized and four died [I5]. The estimated collective doses were 56.3 man Sv from external exposures and 3.7 man Sv from internal exposures, including 14.9 man Sv (external) and 2.3 man Sv (internal) to the four persons who died [D9]. In the course of the decontamination programme, seven houses were demolished and large amounts of soil had to be removed. The total volume of waste removed was 3,100 m^3 [V1].

CONCLUSIONS

173. A number of events, activities or practices involving radiation sources have resulted in the release of radioactive materials to the environment. The consequent exposures of the population have been evaluated in this Annex. Estimates have been made of the total amounts of radioactive materials released in the event or since the beginning of the practice and of the collective doses that have been received or committed.

174. The most significant cause of exposure has been the testing of nuclear weapons in the atmosphere. A large number of tests were performed in the 1950s and to the end of 1962, with less frequent testing occurring until 1980, when the practice stopped altogether. The Committee has repeatedly evaluated the exposures from this source. The extensive measurements allow a rather systematic and complete assessment to be made. In this Annex the transfer coefficients that describe the movement of radionuclides in the environment to man and to the dose are summarized, extended and updated. The collective effective dose committed to the world population by atmospheric nuclear testing is estimated to be $3\ 10^7$ man Sv. Of this total, 86% is due to long-term, low-level exposure from ^{14}C. Over the next 10,000 years a collective dose of $2.2\ 10^7$ man Sv will have been received. This value is recorded in Table 58, which summarizes the estimated collective doses from all sources.

175. The underground testing of nuclear weapons does not generally cause the population to be exposed to radiation. It is only when there is some leakage or venting of gases or aerosols, as has occurred on some occasions, that relatively low exposures may result. The Committee estimates the collective effective dose

from underground testing to be of the order of 200 man Sv.

176. The Committee has not previously estimated the exposures of populations that result from the production of materials and the fabrication of nuclear weapons. Data are still not readily available, but initial estimates of collective doses have been made, namely of the order of 24,000 man Sv to local and regional populations and 40,000 man Sv from global, long-term exposure. Efforts are under way to reconstruct exposures that occurred in the early years of this activity, so some refinement and extension of the estimates can be anticipated.

177. A major activity utilizing radioactive materials is the generation of electrical energy with nuclear reactors. The release of radionuclides during routine operation of the nuclear fuel cycle is relatively low, however, and the doses can only be calculated using representative models for the sites and the dispersion processes through the environment. The releases and collective doses since the beginning of the practice in the 1950s have been at least two orders of magnitude less than those for atmospheric nuclear testing. The global, long-term collective effective dose to be received within 10,000 years is estimated to be 400,000 man Sv. Twenty-five per cent of this is due to ^{14}C released from reactors and reprocessing plants and 75% is due to ^{222}Rn released from uranium mill tailings piles.

178. A number of radioisotopes are used for industrial, educational and medical purposes. Those used in solid forms may not be released from end-uses; however, the gases, tritium, ^{14}C and radioiodines can be expected to be eventually released and dispersed. Data are generally unavailable on production amounts and release fractions of the radionuclides. Based on assumed values, the Committee estimates the global, long-term collective effective dose from this source to be 80,000 man Sv, with negligible contributions from all radionuclides except ^{14}C.

179. The accidents that have resulted in environmental contamination and exposures of population groups include those at civilian nuclear reactors (Three Mile Island and Chernobyl), at military installations (Windscale and Kyshtym), those that occurred in the transport of nuclear weapons (Thule and Palomares) and in satellite re-entry (SNAP-9A and Cosmos 954) and those that involved the loss or misuse of industrial and medical sources (Ciudad Juarez, Mohammedia and Goiania). With the exception of the Chernobyl accident and the re-entry of satellites, the environmental contamination has been localized, and for all except the Chernobyl accident the collective radiation doses have been relatively low. Nevertheless, injuries and deaths have resulted from some of these accidents.

180. The total collective dose from all sources of man-made environmental exposures is dominated by atmospheric nuclear testing. This source contributes 95% of the total collective dose indicated in Table 58. The annual collective effective dose to the world's population from natural sources of radiation exposure of 12,000,000 man Sv may help to put these estimates into perspective. Atmospheric nuclear testing was equivalent to three years of natural exposure of the world population at the time of the exposures. Other sources, of the order of a few tens or hundreds of thousands of man sievert, are comparable to hours or days of natural background exposure. The Committee has made the estimates in Table 58 with the objective of documenting each source of exposure and providing a perspective on the magnitudes of radionuclide releases and collective doses involved.

Table 1
Radionuclides produced and globally dispersed in atmospheric nuclear testing

Radio-nuclide	*Half-life* [E7]	*Decay mode*	*Fission yield* (%) [112]	*Estimates of amounts released into the atmosphere (excluding local fallout)* [a]		
				Total (EBq)	*Normalized release* (PBq Mt^{-1})	
					Fission	*Fusion*
H-3	12.32 a	β	-	240	0.026	740
C-14	5730 a	β	-	0.22	[b]	0.67
Mn-54	312.5 d	EC,γ	-	5.2	-	15.9
Fe-55	2.74 a	EC	-	2	-	6.1
Sr-89	50.55 d	β	2.56	91.4	590	-
Sr-90	28.6 a	β	3.50	0.604	3.90	-
Y-91	58.51 d	β	3.76	116	748	-
Zr-95	64.03 d	β,γ	5.07	143	922	-
Ru-103	39.25 d	β,γ	5.20	238	1540	-
Ru-106	371.6 d	β,γ	2.44	11.8	76.4	-
Sb-125	2.73 a	β,γ	0.29	0.524	3.38	-
I-131	8.02 d	β,γ	2.90	651	4200	-
Cs-137	30.14 a	β,γ	5.57	0.912	5.89	-
Ba-140	12.75 d	β,γ	5.18	732	4730	-
Ce-141	32.50 d	β,γ	4.58	254	1640	-
Ce-144	284.9 d	β,γ	4.69	29.6	191	-
Pu-239	24100 a	α,γ	-	0.00652	-	-
Pu-240	6560 a	α,γ	-	0.00435	-	-
Pu-241	14.4 a	β	-	0.142	-	-

[a] For the non-gaseous fission products a total non-local fission explosion yield of 155 Mt, obtained from measured ^{90}Sr deposition, was assumed in deriving the total amounts released.

[b] For simplicity it is assumed that all ^{14}C is due to fusion, as fusion produces up to 6 times more neutrons than fission for the same energy release. The production reaction is $^{14}N(n,p)^{14}C$.

Table 2
Latitudinal distribution of ^{90}Sr and ^{95}Zr deposition from atmospheric nuclear testing

Latitude band (degrees)	*Area of band* (10^{12} m^2)	*Population distribution* (%)	*Integrated deposition* (PBq)	*Integrated deposition density* (Bq m^{-2})	
			^{90}Sr	^{90}Sr	^{95}Zr
Northern hemisphere					
80-90	3.9	0	1.0	260	
70-80	11.6	0	7.9	680	
60-70	18.9	0.4	32.9	1740	
50-60	25.6	13.7	73.9	2890	
40-50	31.5	15.5	101.6	3230	38000
30-40	36.4	20.4	85.3	2340	
20-30	40.2	32.7	71.2	1770	
10-20	42.8	11.0	50.9	1190	
0-10	44.1	6.3	35.7	810	
Total	255	100	460	2140 [a]	25000 [a]
Southern hemisphere					
0-10	44.1	54.0	21.0	480	
10-20	42.8	26.7	17.8	420	
20-30	40.8	14.9	28.1	700	
30-40	36.4	13.0	27.6	760	
40-50	31.5	0.9	28.1	890	8300
50-60	25.6	0.5	12.1	470	
60-70	18.9	0	6.7	350	
70-80	11.6	0	2.5	220	
80-90	3.9	0	0.3	80	
Total	255	100	144	540 [a]	5000 [a]
Global	510	89 (northern) 11 (southern)	604	1960 [a]	23000 [a]

[a] Population-weighted values.

Table 3
Estimates of population-weighted deposition densities of the major radionuclides produced in atmospheric testing (^{3}H and ^{14}C not included)

Radio-nuclide	*Ratio to ^{90}Sr*	*Ratio to ^{95}Zr*	*Population-weighted deposition density (Bq m^{-2})*				
			Northern hemisphere		*Southern hemisphere*		*World*
			40°-50°	*Entire*	*40°-50°*	*Entire*	
Mn-54	2.9		9400	6200	2600	1600	5700
Fe-55	2.1		6800	4500	1900	1100	4100
Sr-89		0.52	20000	13000	4300	2600	12000
Sr-90	1.0		3230	2140	890	540	1960
Y-91		0.66	25000	17000	5000	3300	15000
Zr-95		1.0	38000	25000	8300	5000	23000
Nb-95		1.7	64000	43000	14000	8500	39000
Ru-103		0.75	28000	19000	6200	3800	17000
Ru-106	7.5		24000	16000	6700	4100	15000
Sb-125	0.89		2900	1900	790	480	1700
I-131		0.50	19000	13000	4200	2500	11000
Cs-137	1.6		5200	3400	1400	860	3100
Ba-140		0.62	23000	16000	5100	3100	14000
Ce-141		0.55	21000	14000	4600	2800	13000
Ce-144	15		48000	32000	13000	8100	29000
Pu-238	0.00046		1.5	0.98	0.41	0.25	0.90
Pu-239	0.011		35	23	10	6	22
Pu-240	0.0072		23	15	6	4	14
Pu-241	0.23		730	480	200	120	440
Am-241	0.0077 [a]		25	17	7	4	15

[a] Upon decay of ^{241}Pu.

Table 4
Components of the transfer coefficient P_{23} from deposition density to diet for ^{90}Sr and ^{137}Cs

Country	^{90}Sr					^{137}Cs				
	Transfer factor parameters [a] y					Transfer factor parameters [a]				
	b_1	b_2	b_3	λ	P_{23}	b_1	b_2	b_3	λ	P_{23}
Milk products										
Argentina	1.2	1.1	0.1	0.1	3.7	7.7	0	0.2	0.1	8.8
Denmark	1.5	0.9	0.3	0.1	4.9	3.0	2.1	0.06	0.08	5.9
United States	0.7	0.3	0.2	0.1	2.6	3.4	1.8	0.2	0.3	5.7
Average					3.7					6.8
Grain products										
Argentina	1.6	1.5	0.06	0.02	6	2.0	6.9	0		8.9
Denmark	3.1	9.8	0.1	0.02	17.2	3.4	23.2	0.0003	4.3	26.6
United States	0.7	1.5	0.2	0.08	4.1	2.1	8.0	0.3	0.2	11.7
Average					9.1					15.7
Vegetables										
Argentina	0.02	0	0.1	0.26	0.4	2.1	2.3	0		4.4
Denmark	0.4	0	0.1	0.05	3.1	2.4	0	0.02	0.02	3.3
United States	0.3	0.06	0.3	0.08	4.0	1.2	0	0.1	0.19	1.8
Average					2.5					3.2
Fruit										
Argentina	0.3	0.2	0.04	0.09	1.0	0.5	2.6	0		3.1
Denmark	0.9	0.005	0.05	0.05	2.0	1.8	1.2	0.1	0.3	3.5
United States	0.1	0	0.1	0.06	2.5	1.6	0.0	1.1	0.5	3.3
Average					1.8					3.3
Meat										
Argentina	0.7	0.8	0.03	0.02	3	22.1	0	3.7	0.7	26.2
Denmark	0.5	0.04	0.04	0.09	0.9	13.4	0	80.3	2.0	26.2
United States	0.002	0.1	0.04	0.1	0.4	1.5	0	17.7	1.3	7.9
Average					1.4					
Total diet										
Sum of weighted components [b]										
Argentina	0.8	0.7	0.07		2.7	4.9	2.5	0.3		8.0
Denmark	1.3	1.9	0.2		5.6	4.4	4.5	12.1		11.4
United States	0.4	0.3	0.2		2.6	2.2	1.7	3.3		5.8
Average					3.6					8.4
Fit on total diet										
Argentina	1.1	0.6	0.04	0 03	3.0	6.3	1.8	0		8.1
Denmark	1.3	2.0	0.1	0.06	5.5	4.1	6.5	0.02	0.02	11.4
United States	0.5	0.4	0.2	0 08	3.0	1.6	2.0	0.8	0.4	5.1
Average					3.8					8.2

[a] The transfer coefficients for the first year, b_1, second year, b_2, and subsequent years, b_3, and the total transfer factor, P_{23}, have the units mBq a kg^{-1} per Bq m^{-2}. The units of the exponential decay constant, λ, are a^{-1}. The regression fits are for the periods: Argentina 1964-1979, Denmark 1962-1985 and United States 1960-1983 (^{90}Sr, New York) and 1961-1977 (^{137}Cs, Chicago).

[b] Fractional amounts by weight of the five food groups, milk products, grain products, vegetables, fruit and meat, in the total diet are, respectively, [U3]:
Argentina: 0.26, 0.2, 0.24, 0.2, 0.08 (^{90}Sr); 0.26, 0.2,0.31, 0.16, 0.08 (^{137}Cs);
Denmark: 0.35, 0.16, 0.24, 0.1, 0.15 (^{90}Sr and ^{137}Cs)
United States: 0.31, 0.15, 0.19, 0.15, 0.19 (^{90}Sr) in New York; 0.33, 0.14, 0.19, 0.17, 0.17 (^{137}Cs) in Chicago.

Table 5
Transfer of fallout ^{90}Sr and ^{137}Cs from deposition to diet [a]

Component	*Transfer factor* [b]	*Contribution to total transfer*	*Contribution to component transfer from food categories (%)*				
			Milk	*Grain*	*Vegetables*	*Fruit*	*Meat*
^{90}Sr							
Direct deposition	0.8 ± 0.4	22%	43%	38%	6%	8%	5%
Lagged transfer	1.0 ± 0.8	27%	23%	72%	0.4%	2%	3%
Transfer from deposit	1.8 ± 0.6	51%	32%	28%	26%	10%	4%
Total transfer	3.6 ± 1.7	100%	32%	42%	15%	7%	4%
^{137}Cs							
Direct deposition	3.8 ± 1.4	45%	36%	11%	13%	5%	35%
Lagged transfer	2.9 ± 1.5	35%	15%	71%	8%	6%	0%
Transfer from deposit	1.7 ± 1.0	20%	15%	4%	7%	7%	67%
Total transfer	8.4 ± 2.8	100%	25%	30%	10%	6%	29%

[a] Average consumption-weighted results for Argentina, Denmark and the United States.
[b] The units are mBq a kg^{-1} per Bq m^{-2}.

Table 6
Transfer coefficients P_{24} from deposition to intake into the body by ingestion for fallout radionuclides derived from measurements in the temperate zone of the northern hemisphere

Radio-nuclide	*Deposition density* [a] *(Bq m^{-2})*	*Integrated intake rate (Bq)*	*Transfer coefficient (Bq per Bq m^{-2})*
Fe-55	4500	55000 [b]	10
Sr-89	20000	700 [c]	0.03
Sr-90	3230	6140 [d]	1.9
I-131	19000	1370 [e]	0.07 [f]
Cs-137	5200	21800 [d]	4.2
Ba-140	23000	120 [e]	0.005
Pu-238	1.5	0.075 [e]	0.05 [g]
Pu-239	35	24 [e]	0.7 [g]
Pu-240	23	16 [e]	0.7 [g]
Pu-241	730	29 [e]	0.04 [g]
Am-241	25	5 [e]	0.2 [g]

[a] Values from Table 3 (40°-50°) except for Fe-55 (entire) northern hemisphere.
[b] Inferred from estimated dose to red bone marrow in the northern hemisphere of 6 μGy [U3, U4] and dose to red bone marrow per unit intake by ingestion of 0.11 nGy Bq^{-1} [N1].
[c] Value from [U3]; measurements only for milk.
[d] Inferred from transfer coefficient value (Bq a kg^{-1} per Bq m^{-2}) in Table 4 times an average food consumption rate of 500 kg a^{-1}.
[e] Inferred from transfer coefficient value and deposition density.
[f] Derived from P_{23} value of 0.63 mBq a l^{-1} per Bq m^{-2} [U3] for transfer to milk times an average milk consumption rate of 0.3 l d^{-1}.
[g] Derived in [U3].

Table 7
Transfer coefficients P_{45} from intake to dose for radionuclides produced in atmospheric nuclear testing [a] [N1]

Radio-nuclide	Absorption fraction	Committed equivalent dose per unit intake ($nSv\ Bq^{-1}$)								
		Bone surfaces	Breast	Colon	Gonads	Liver	Lungs	Red bone marrow	Thyroid	Effective dose per unit intake ($nSv\ Bq^{-1}$)
Ingestion										
Fe-55	0.1	0.11	0.10	0.31	0.11	0.35	0.10	0.11	0.11	0.15
Sr-89	0.3	4.8	0.26	21	0.26	0.26	0.26	3.3	0.26	3.4
Sr-90	0.3	390	1.3	19	1.3	1.3	1.3	180	1.3	28
I-131 [b]	1.0	0.15	0.20	0.09	0.09	0.10	0.18	0.16	1218	61
Cs-137	1.0	12	12	14	13.5	14	13	13	13	13
Ba-140	0.1	0.53	0.16	26	0.565	0.12	0.069	0.42	0.056	3.7
Pu-238	0.00001	160	0.00018	57	2.3	29	0.00009	13	0.00008	12
Pu-239	0.00001	180	0.00012	53	2.6	31	0.00008	14	0.00008	12
Pu-240	0.00001	180	0.00018	53	2.6	31	0.00008	14	0.00007	13
Pu-241	0.00001	3.5	0.000003	0.27	0.056	0.53	0.000005	0.28	.000001	0.14
Am-241	0.0005	9000	0.016	59	130	1600	0.017	720	0.0066	290
Inhalation [c]										
Mn-54	0.1	1.3	0.85	1.3	0.49	2.4	6.4	1.1	0.74	1.7
Fe-55	0.1	0.18	0.17	0.28	0.18	0.58	1.0	0.18	0.19	0.33
Sr-89	0.01	0.16	0.0086	14	0.0086	0.0086	83	0.11	0.0086	12
Sr-90	0.01	65	0.24	20	0.24	0.24	2900	30	0.24	350
Y-91	0.0001	0.32	0.0089	15	0.0073	0.32	99	0.32	0.0084	14
Zr-95	0.002	2.3	1.2	3.9	0.33	2.1	40	1.3	1.2	6.3
Nb-95	0.01	0.51	0.4	1.9	0.24	0.66	8.3	0.44	0.36	1.6
Ru-103	0.05	0.24	0.31	3.1	0.19	0.50	16	0.32	0.26	2.5
Ru-106	0.05	1.6	1.8	37	1.2	2.3	1000	1.8	1.7	130
Sb-125	0.01	1.1	0.41	3.3	0.23	0.85	22	0.53	0.33	3.4
I-131	1.0	0.052	0.073	0.025	0.024	0.037	0.65	0.057	270	13
Cs-137	1.0	7.9	7.8	9	8.3	8.6	8.7	8.2	8.0	8.5
Ba-140	0.1	2.3	0.3	4.4	0.37	0.3	1.7	1.2	0.27	1.1
Ce-141	0.0003	0.26	0.044	4.1	0.031	0.26	17	0.085	0.025	2.6
Ce-144	0.0003	4.9	0.35	34	0.22	26	790	2.9	0.29	100
Pu-238	0.00001	720000	0.44	33	10000	130000	310000	58000	0.38	61000
Pu-239	0.00001	820000	0.39	31	12000	150000	320000	66000	0.37	64000
Pu-240	0.00001	820000	0.43	31	12000	150000	320000	66000	0.37	64000
Pu-241	0.00001	18000	0.023	0.18	270	3000	3100	1400	0.093	930
Am-241	0.0005	2200000	2.7	32	32000	380000	18000	170000	1.6	70000

[a] Values are for adults except for ingestion of ^{131}I; the absorption fractions correspond to values used in previous UNSCEAR assessments [U1, U3]; the committed equivalent doses (from [N1]) are for a period of 50 years after intake for adults and to age 70 years for children (for ingestion of ^{131}I).

[b] ^{131}I: age and milk consumption weighted values; 0-1 year, 1-9 years, 9-19 years, and adult age groups are 2, 16, 20, 62% of population with milk consumption 330, 180, 150, 90 l a^{-1}, respectively; the dose factors for the four age groups are the average for 3-month-old and 1-year-old children; for 5-year-old children; for 15-year-old children; and for adults.

[c] Absorption assumptions are Class D (days): ^{131}I, ^{137}Cs and ^{140}Ba; Class W (weeks): ^{54}Mn, ^{55}Fe, ^{125}Sb and ^{241}Am; and Class Y: (years) all other radionuclides.

Table 8
Transfer coefficients P_{25} from deposition to dose for radionuclides produced in atmospheric nuclear testing

Radio-nuclide	*Transfer coefficient to equivalent dose (nSv per Bq m^{-2})*								
	Bone surfaces	*Breast*	*Colon*	*Gonads*	*Liver*	*Lungs*	*Red bone marrow*	*Thyroid*	*Transfer coefficient for effective dose (nSv per Bq m^{-2})*
Ingestion									
Fe-55	1.5	1.3	4.1	1.5	4.7	1.3	1.5	1.5	2.0
Sr-89	0.17	0.0091	0.74	0.0091	0.0091	0.0091	0.12	0.0091	0.12
Sr-90	722	2.4	35	2.4	2.4	2.4	330	2.4	52
I-131	0.011	0.014	0.0063	0.0059	0.0069	0.012	0.011	84	4.2
Cs-137	50	50	59	57	59	55	55	55	55
Ba-140	0.0026	0.00077	0.13	0.0027	0.00058	0.00033	0.0020	0.00027	0.018
Pu-238	8.0	[a]	2.9	0.12	1.5	[a]	0.65	[a]	0.60
Pu-239	130	0.00008	37	1.8	22	0.00005	9.8	37	8.4
Pu-240	130	0.00013	37	1.8	22	0.00006	9.8	0.00005	9.1
Pu-241	0.14	[a]	0.011	0.0022	[a]	[a]	0.011	[a]	0.0056
Am-241	1800	0.0032	12	26	320	0.0034	140	0.00132	58
Inhalation									
Mn-54	0.017	0.011	0.017	0.0064	0.032	0.084	0.014	0.010	0.022
Fe-55	0.0024	0.0022	0.0037	0.0024	0.0076	0.013	0.0024	0.0025	0.0043
Sr-89	0.0021	0.0001	0.18	0.0001	0.0001	1.1	0.0014	0.0001	0.16
Sr-90	0.85	0.0032	0.26	0.0032	0.0032	38	0.39	0.0032	4.6
Y-91	0.0042	0.0001	0.20	0.0001	0.0042	1.3	0.0042	0.0001	0.18
Zr-95	0.030	0.016	0.051	0.0043	0.028	0.53	0.017	0.016	0.083
Nb-95	0.0067	0.0053	0.025	0.0032	0.0087	0.11	0.0058	0.0047	0.021
Ru-103	0.0032	0.0041	0.041	0.0025	0.0066	0.21	0.0042	0.0034	0.033
Ru-106	0.021	0.024	0.49	0.016	0.030	13	0.024	0.022	1.7
Sb-125	0.014	0.0054	0.043	0.0030	0.011	0.29	0.0070	0.0043	0.045
I-131	0.0007	0.0010	0.0003	0.0003	0.0005	0.0085	0.0008	3.5	0.17
Cs-137	0.10	0.10	0.12	0.11	0.11	0.11	0.11	0.11	0.11
Ba-140	0.030	0.0039	0.058	0.0049	0.0039	0.022	0.016	0.0035	0.014
Ce-141	0.003	0.0006	0.054	0.0004	0.0034	0.22	0.0011	0.0003	0.034
Ce-144	0.06	0.0046	0.45	0.0028	0.34	10	0.038	0.0038	1.3
Pu-238	9450	0.0058	0.43	130	1710	4100	760	0.0050	800
Pu-239	10800	0.0051	0.41	160	1970	4200	870	0.0049	840
Pu-240	10800	0.0056	0.41	160	1970	4200	870	0.0049	840
Pu-241	236	0.0003	0.0024	3.5	39	41	18	0.0012	12
Am-241	28900	0.035	0.42	420	4990	240	2230	0.021	920
External exposure									
Mn-54									9.9
Zr-95									3.7
Nb-95									1.0
Ru-103									0.72
Ru-106									2.9
Sb-125									16
I-131									0.12
Cs-137									97
Ba-140									1.1
Ce-141									0.081
Ce-144									0.47

[a] Less than 0.00001.

Table 9
Effective dose commitments from radionuclides produced in atmospheric nuclear testing

Radio-nuclide	Effective dose commitment (μSv)											
	North temperate zone (40°-50°)				South temperate zone (40°-50°)				World population			
	External	Ingestion	Inhalation	Total	External	Ingestion	Inhalation	Total	External	Ingestion	Inhalation	Total
H-3		48	3.6	51		13	0.95	14		44	3.3	47
C-14		2600	0.26	2600		2600	0.26	2600		2600	0.26	2600
Mn-54	93		0.21	94	26		0.06	26	57		0.13	57
Fe-55		14	0.03	14		3.8	0.01	3.8		8.2	0.02	8.2
Sr-89		2.3	3.1	5.5		0.51	0.68	1.2		1.4	1.9	3.3
Sr-90		170	15	180		46	4.1	50		102	9.0	111
Y-91			4.6	4.6			1.0	1.0			2.8	2.8
Zr-95	140		3.1	144	31		0.69	32	85		1.9	87
Nb-95	67		1.4	68	15		0.30	15	40		0.82	41
Ru-103	20		0.93	21	4.5		0.20	4.7	12		0.56	13
Ru-106	70		41	110	20		11	31	44		26	69
Sb-125	47		0.13	47	13		0.04	13	27		0.08	28
I-131	2.3	79	3.2	85	0.50	17	0.71	19	1.4	48	2.0	51
Cs-137	510	280	0.58	790	140	76	0.16	210	300	170	0.35	470
Ba-140	25	0.42	0.34	26	5.6	0.09	0.07	5.8	15	0.25	0.21	16
Ce-141	1.7		0.71	2.4	0.37		0.16	0.53	1.0		0.43	1.5
Ce-144	23		63	86	6.1		17	23	14		38	52
Pu-238		0.0009	1.2	1.2		0.0002	0.30	0.30		0.0005	0.72	0.72
Pu-239		0.29	29	30		0.08	8.4	8.5		0.18	18	18
Pu-240		0.21	19	20		0.05	5.0	5.1		0.13	12	12
Pu-241		0.004	8.9	8.9		0.001	2.4	2.4		0.003	5.4	5.4
Am-241		1.5	23	24		0.41	6.4	6.8		0.87	14	15
Total (rounded)	1000	3190	220	4400	260	2760	60	3100	600	2980	140	3700

Table 10
Contributions to the total effective dose commitment to the world population from atmospheric nuclear testing

Radio-nuclide	Effective dose commitment (μSv)	Contribution to total (%)		Radio-nuclide	Effective dose commitment (μSv)	Contribution to total (%)	
		Including 100% ^{14}C	Including 10% ^{14}C			Including 100% ^{14}C	Including 10% ^{14}C
C-14	2580	70	19	Pu-239	18	0.5	1.3
Cs-137	470	13	35	Ba-140	16	0.4	1.2
Sr-90	110	3.0	8.1	Am-241	15	0.4	1.1
Zr-95	87	2.4	6.4	Ru-103	13	0.3	0.9
Ru-106	69	1.9	5.1	Pu-240	12	0.3	0.9
Mn-54	57	1.5	4.2	Fe-55	8	0.2	0.6
Ce-144	52	1.4	3.8	Pu-241	5	0.1	0.4
I-131	51	1.4	3.8	Sr-89	3	0.09	0.2
H-3	47	1.3	3.5	Y-91	3	0.08	0.2
Nb-95	41	1.1	3.0	Ce-141	1	0.04	0.1
Sb-125	28	0.7	2.0	Pu-238	1	0.02	0.05
Total effective dose commitment				3700 μSv			

Table 11
Collective effective dose to the world population committed by atmospheric nuclear testing

Radio-nuclide	Collective effective dose (1000 man Sv)				Contribution to total (%)	
	External	Ingestion	Inhalation	Total	Including 100% ^{14}C	Including 10% ^{14}C [a]
C-14		25800	2.6	25800	86	39
Cs-137	1210	677	1.1	1890	6.3	28
Sr-90		406	29	435	1.5	6.6
Zr-95	272		6.1	278	0.93	4.2
Ru-106	140		82	222	0.74	3.3
H-3		176	13	189	0.63	2.8
Mn-54	181		0.4	181	0.61	2.7
Ce-144	44		122	165	0.55	2.5
I-131	4.4	154	6.3	164	0.55	2.5
Nb-95	129		2.6	131	0.44	2.0
Sb-125	88		0.2	88	0.30	1.3
Pu-239		1.8	56	58	0.20	0.88
Am-241		8.7	44	53	0.18	0.80
Ba-140	49	0.81	0.66	51	0.17	0.77
Ru-103	39		1.8	41	0.14	0.62
Pu-240		1.3	38	39	0.13	0.59
Fe-55		26	0.06	26	0.09	0.40
Pu-241		0.01	17	17	0.06	0.26
Sr-89		4.5	6.0	11	0.04	0.16
Y-91			8.9	8.9	0.03	0.13
Ce-141	3.3		1.4	4.7	0.02	0.07
Pu-238		0.003	2.3	2.3	0.01	0.03
Total (rounded)	2160	27200	440	30000	100	100

[a] Corresponds to dose delivered by ^{14}C before the year 2200.

Table 12
Estimated number and yields of underground nuclear explosions
[N10, S2]

Year	*Number of explosions*	*Yield (Mt)*	*Year*	*Number of explosions*	*Yield (Mt)*	*Year*	*Number of explosions*	*Yield (Mt)*
1957	5	0.002	1969	55	4.1	1981	51	1.8
1958	15	0.03	1970	52	6.6	1982	58	1.8
1959			1971	36	6.9	1983	56	1.2
1960			1972	40	2.5	1984	58	2.3
1961	12	0.1	1973	30	7.7	1985	35	1.2
1962	61	1.0	1974	34	4.2	1986	23	0.8
1963	43	1.0	1975	38	7.5	1987	47	2.2
1964	48	1.0	1976	42	5.4	1988	40	1.6
1965	51	1.8	1977	45	3.5	1989	27	0.7
1966	59	3.7	1978	55	2.7	1990	18	1.1
1967	51	2.2	1979	54	3.9	1991	14	0.3
1968	60	4.8	1980	51	2.9	1992	8	1.1
Total			1352 test explosions			Total yield 90 Mt		

Table 13
Atmospheric releases of iodine-131 to the atmosphere from underground tests carried out at the Nevada test site in the United States
[H4]

Name of test	*Year of test*	*Atmospheric release (TBq)*
Antler	1961	0.2
Feather	1961	0.04
Pampas	1962	0.0004
Platte	1962	0.4
Eel	1962	0.4
Des Moines	1962	1200
Bandicoot	1962	330
Yuba	1963	0.0008
Eagle	1963	0.08
Pike	1964	13
Alva	1964	0.001
Drill	1964	0.5
Parrot	1964	0.2
Alpaca	1965	0.0009
Tee	1965	0.06
Diluted Waters	1965	0.7
Red Hot	1966	7
Pin Stripe	1966	7
Double Play	1966	4
Derringer	1966	0.009
Nash	1967	0.5
Midi Mist	1967	0.01
Hupmobile	1968	4
Pod	1969	0.03
Scuttle	1969	0.0001
Snubber	1970	0.2
Mint Leaf	1970	3
Baneberry	1970	3000
Diagonal Line	1971	0.05
Riola	1980	0.02
Total (rounded)		5000

Table 14
Estimated annual releases of ^{131}I to the atmosphere from the Hanford plutonium production plant in the United States [C5]

Year	*Annual release (TBq)*	*Year*	*Annual release (TBq)*	*Year*	*Annual release (TBq)*
1944	1800	1947	900	1952	40
1945	13000	1948	40	1953	25
1946	2800	1949	230	1954	20
		1950	100	1955	30
		1951	630	1956	15
Total 1944-1946	17600	Total 1947-1956		2030	

Table 15
Estimated cumulative doses from radionuclides released into the Techa River from the Chelyabinsk plutonium production plant in the former USSR
[A4]

Village	*Distance downstream from the point of discharge (km)*	*Absorbed dose (mGy)*				*Effective dose (mSv)*
		Red bone marrow	*Bone lining cells*	*G.I. tract*	*Other*	
Metlino [a]	7	1640	2260	1400	1270	1400
Techa-Vrod [a]	18	1270	1480	1190	1150	1190
Asanovo [a]	27	1270	1900	1040	900	1000
Nadirovo [a]	49	950	1800	620	440	560
Muslyumovo	78	610	1430	290	120	240
Brodokalmak	109	140	310	70	33	58
Russkaya Techa	138	220	530	100	37	82
Novopetropavloskoe	152	280	680	130	43	100
Schutikha	202	80	180	26	22	36
Zatechenskoe	237	170	400	84	32	66

[a] Village was evacuated.

Table 16
Estimated uranium and fuel requirements to generate 1 GW a of electrical energy
[O2, O3]

Reactor type	*Amount required for 1 GW year*			
	Natural uranium (t)	*Uranium oxide [a] (t)*	*Enrichment (SWU) [b]*	*Fuel (t)*
LWR [c]	220	260	130000	37
HWR [d]	180	210	-	180
Magnox [e]	330	390	-	330
AGR [f]	220	260	130000	38

[a] Derived from the amounts of natural uranium using a U_3O_8: heavy metal ratio of 1:18.
[b] Separative work units.
[c] Assuming average fuel irradiation of 30 GWd/tU (thermal energy), thermal efficiency of 33% and an average fuel enrichment of 3% with 0.25% tails.
[d] Assuming a fuel irradiation of 7.3 GWd/tU (thermal energy) and a thermal efficiency of 30%.
[e] Assuming a fuel irradiation of 4.5 GWd/tU (thermal energy) and a thermal efficiency of 26%.
[f] Assuming an average fuel irradiation of 24 GWd/tU (thermal energy), a thermal efficiency of 40% and average enrichment of 2.7% and tails of 0.25%.

Table 17
Production of uranium
[02]

Country	Annual production of uranium (t) [a]														
	1975	*1976*	*1977*	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989* [b]
Argentina	22	40	100	126	134	187	123	155	172	129	126	173	95	142	150
Australia		359	356	516	705	1561	2922	4422	3211	4324	3206	4154	3780	3532	3600
Belgium						20	40	45	45	40	40	40	40	40	40
Brazil				35			4	242	189	117	115	115	0	0	0
Canada	3560	4850	5790	6800	6820	7150	7720	8080	7140	11170	10880	11720	12440	12400	11000
France	1731	1871	2097	2183	2362	2634	2552	2859	3271	3168	3189	3248	3376	3394	3190
Gabon	800	850	907	1022	1100	1033	1022	970	1006	918	940	900	800	930	950
Germany, Fed. Rep.of	57	38	15	35	25	35	36	34	47	32	30	26	53	38	30
India	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Japan	3	2	1	2	2	5	3	5	4	4	7	6	8	0	0
Namibia		654	2340	2697	3840	4042	3971	3776	3719	3700	3400	3300	3500	3600	3600
Niger	1306	1460	1609	2060	3620	4128	4363	4259	3426	3276	3181	3110	2970	2970	3000
Pakistan	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Portugal	115	88	95	98	114	82	102	113	104	115	119	110	141	144	150
South Africa	2488	2758	3360	3961	4797	6146	6131	5816	6060	5732	4880	4602	3963	3850	2900
Spain	136	170	177	191	190	190	178	150	170	196	201	215	223	228	216
United States	8900	9800	11500	14200	14400	16800	14800	10300	8200	5700	4300	5200	5000	5050	4600
Yugoslavia											30	59	72	80	85
Total	19348	23170	28577	34121	38339	44243	44197	41456	36994	38851	34874	37208	36691	36628	33941

[a] Data only include uranium produced in WOCA (World Outside Centrally planned economies Area). Estimate of uranium production in non-WOCA countries in 1990 is about 18,000 t uranium per year with a decreasing trend; the main producers are believed to be China, Czechoslovakia, the German Democratic Republic and the USSR [14].

[b] Data for 1989 are estimates.

Table 18
Radon emissions from uranium mines
[A6, A9, D4, N12, O5, R2, W5]

Mine	*Year*	*Ore grade* (% of U_3O_8)	*Production of* U_3O_8 [a] (t)	*Emission of* ^{222}Rn (TBq)	*Normalized emission of* ^{222}Rn (GBq t^{-1})
Australia					
Ranger	1985	0.32	4500	45 [b]	10 [c]
	1986	0.35	4700	73 [b]	16 [c]
	1987	0.38	5000	89 [b]	18 [c]
	1988	0.42	6400	120 [b]	19 [c]
	1989	0.41	6000	130	22
Olympic [d]	1988	0.11	600	16	27
	1989	0.11	1200	32	27
Nabarlek [e]	1985	1.42	1600	21	13
	1986	1.42	1600	21	13
	1987	1.42	1600	21	13
	1988	1.42	900	12	13
Canada [f]					
Amok	1985	0.37	860	1	1.2
	1986	0.40	850	1	1.2
	1987	0.42	870	1	1.2
	1988	0.49	900	1	1.1
	1989	0.57	740	1	1.4
Rabbit Lake	1985	0.22	890	1600	1800
	1986	0.46	1500	1600	1100
	1987	0.51	2300	1600	680
	1988	0.72	2800	1600	560
	1989	0.84	2011	1600	760
Denison Mine	1985	0.08	2600	1100	500
	1986	0.08	2040	1100	530
	1987	0.08	1900	1100	570
	1988	0.08	2060	1100	520
	1989	0.08	2000	1100	540
Panel Mine	1985	0.10	990	96	97
	1986	0.10	980	96	98
	1987	0.09	820	96	120
	1988	0.08	780	96	120
	1989	0.09	850	96	110
Stanleigh Mine	1985	0.07	810	120	150
	1986	0.07	750	120	160
	1987	0.07	500	120	240
	1988	0.07	460	120	270
	1989	0.09	570	120	210
German Democratic Republic					
Thuringian Mines	1985	0.092	3600	540	150
	1986	0.092	3500	610	170
	1987	0.091	3500	660	190
	1988	0.091	3400	730	210
	1989	0.090	3300	690	210
Aue	1985	0.483	840	1600	1900
	1986	0.466	750	1700	2300
	1987	0.475	710	1400	2000
	1988	0.463	710	1400	1950
	1989	0.481	690	650	2000
Königstein	1985	-	670	160	240
	1986	-	605	300	500
	1987	-	540	300	560
	1988	-	520	260	500
	1989	-	500	250	500

Table 18 (continued)

Mine	Year	Ore grade (% of U_3O_8)	Production of U_3O_8 [a] (t)	Emission of ^{222}Rn (TBq)	Normalized emission of ^{222}Rn (GBq t^{-1})
Freital	1985	0.097	160	10	61
	1986	0.100	180	8	45
	1987	0.116	190	7	36
	1988	0.112	170	6	36
	1989	0.111	130	5	40

[a] The mill throughput was used when the mine throughput was not available.
[b] Estimated from 1989 value.
[c] Estimated from 1989 value, normalized to U_3O_8 production.
[d] Metallurgical plant; production commenced in June 1988.
[e] Mining ceased in 1990. Mill feed was taken from stockpile, and tailings were returned to mine pit.
[f] Emission of radon estimated from annual average concentration in exhaust air.

Table 19
Radionuclides released in airborne effluents from uranium mills
[A6, N12, O5, R2]

Mine	Year	Ore grade (%)	Ore throughput (Mt)	U_3O_8 production (t)	Annual emission (GBq)					
					^{210}Pb	^{210}Po	^{222}Rn	^{226}Ra	^{230}Th	^{238}U
Australia										
Ranger	1985	0.32	1	3200			43000			1.2
	1986	0.35	0.97	3400			46000			1
	1987	0.38	0.87	3300			44000			0.8
	1988	0.42	0.78	3300			44000			0.8
	1989	0.41	0.98	4000			54000			2
Olympic [a]	1988	0.11	0.5	550	10	85	8000	0.05	0.05	0.1
	1989	0.11	1.1	1200	21	190	16000	0.1	0.1	0.2
Nabarlek [b]	1985	1.42	0.12	1700			21000			0.7
	1986	1.42	0.12	1700			21000			0.7
	1987	1.42	0.12	1700			21000			0.7
	1988	1.42	0.07	990			12000			0.4
Canada										
Key Lake	1985	0.28	0.19	530	0.0004				0.0004	0.02
	1986	0.23	0.25	580						
	1987	0.19	0.28	530	0.11			0.002	0.011	31.5
	1988	0.2	0.24	480						
	1989	0.24	0.24	580	0.009			0.024	0.041	0.85
Rabbit Lake	1985-1989	0.53	0.36	1900			9200			
Total release (GBq)					0.12 [c]	[c]	339200	0.18	0.20	41.0
U_3O_8 production (t)					1640		27000	2870	3400	26700
Normalized release (GBq t^{-1})					0.00007		13	0.00006	0.00006	0.0015
Normalized release [GBq (GW a)$^{-1}$]					0.02		3000	0.02	0.02	0.4

[a] Metallurgical plant; production commenced in June 1988, emissions of ^{210}Pb and ^{210}Po are for the particular process and are not representative of normal milling.
[b] Mill operations ceased in July 1988.
[c] Data for Olympic mill are not generally representative and are, therefore, not included in total.

Table 20
Radionuclides released in liquid effluents from uranium mills
[A6]

Mine	*Year*	*Ore grade (%)*	*Ore throughput (Mt)*	*U_3O_8 production (t)*	*Annual emission (GBq)*			
					^{210}Pb	^{226}Ra	^{230}Th	^{238}U
Canada								
Amok	1987	0.42	0.206	865	0.3	0.13	0.25	16
	1988	0.49	0.183	897	0.1	0.02	0.035	6.5
	1988	0.57	0.13	741	0.05	0.01	0.029	7.6
Key Lake	1985	2.72	0.195	5304	0.34	0.23	0.61	1.7
	1986	2.31	0.249	5752	0.16	0.19	0.16	1.1
	1987	1.87	0.282	5273	0.15	0.19	0.06	1.3
	1988	1.94	0.242	4695	0.06	1.2	0.11	0.5
	1989	2.40	0.243	5832	0.07	0.17	0.07	0.7
Total release (GBq)					1.23	2.14	1.32	35.40
U_3O_8 production (t)					29400	29400	29400	29400
Normalized release (GBq t^{-1})					0.00004	0.00007	0.00005	0.0012
Normalized release [GBq (GW a)$^{-1}$]					0.01	0.02	0.01	0.3

Table 21
Radon emissions from uranium mill tailing piles

Mill	*Year*	*Tailings area (ha)*	*Emission rate ($Bq\ m^{-2}\ s^{-1}$)*	*^{222}Rn emission (TBq)*
Argentina [C18]				
San Rafael	1986	5.0	8.2	13
	1987	5.0	11.5	18
Los Adobes	1986	7.0	8.1	18
Don Otto	1986	7.5	43.1	100
Los Gigantes	1985	5.0	0.7	1
	1986	5.0	0.8	1
La Estela	1986	1.0	11.0	3
Malargue	1985	3.0	10.7	10
	1986	3.0	12.3	11
	1987	3.0	10.2	9.5
Australia [A9, C8, D4, L4, 05, R2]				
Ranger [a]	1985	0 / 360 [d]	0 / 0.1 [b]	11
	1986	0 / 360 [b]	0 / 0.1 [b]	11
	1987	0 / 360 [b]	0 / 0.1 [b]	11
	1988	110 / 250 [b]	0.9 / 0.1 [b]	40
	1989	120 / 240 [b]	0.9 / 0.1 [b]	45
Olympic [b]	1988	75	1.6	6
	1989	75	1.6	13
Nabarlek [c]	1985	6.2	0.1	0.2
	1986	6.2	0.1	0.2
	1987	6.2	2.1	4.2
	1988	6.2	2.1	4.2
	1989	6.2	2.1	4.2
Canada [A6]				
Key Lake	1985-1989	36	6	68
Rabbit Lake				
Tailings pond	1985-1989	53	3.7	62
Open pit	1985-1989	11.5	20	73
Panel mine	1985	55	10	173
	1986	60	10	189
	1987	67	10	211
	1988	74	10	233
	1989	80	10	252
Stanleigh mine	1985	35	10	110
	1986	38	10	120
	1987	43	10	136
	1988	47	10	148
	1989	50	10	158
Quirke mine	1985	107	10	337
	1986	111	10	350
	1987	115	10	363
	1988	121	10	382
	1989	127	10	400
German Democratic Republic [W5]				
Crossen	1989	230 [e]	12 [f]	450
Seelingsstädt	1989	250 [e]	12 [f]	500

[a] Subaqueous tailings deposition until 1988, then combination of subaqueous and subaerial tailings deposition.
[b] Subaerial tailings deposition, using a rotational cycle to produce layering of tailings.
[c] Subaqueous tailings deposition prior to 1987; subaerial tailings deposition thereafter.
[d] Subaerial/subaqueous values.
[e] About 50% of the tailing piles are covered with water.
[f] Subaerial value.

Table 22
Normalized releases of radionuclides in airborne effluents and collective doses from a model uranium mine and mill [a]

Radionuclide	Normalized release [GBq (GW a)$^{-1}$]				Collective dose per unit release	Normalized collective effective dose [man Sv (GW a)$^{-1}$]			
	Mine	Mill	Mill tailings		(man Sv TBq^{-1})	Mine	Mill	Mill tailings	
			In operation	Abandoned				In operation	Abandoned
Pb-210	75000	0.02	20000	1000 [b]	1	1.1	0.00002	0.3 [c]	150 [d]
Po-210		0.02			1		0.00002		
Rn-222		3000			0.015		0.045		
Ra-226		0.02			0.6		0.00001		
Th-230		0.02			30		0.0006		
U-234		0.4			8		0.003		
U-238		0.4			7		0.003		

[a] Normalized emissions in liquid effluents (0.01 for ^{210}Po, ^{210}Pb and ^{230}Th; 0.02 for ^{226}Ra; 0.3 for ^{234}U and ^{238}U) contribute negligibly to the collective dose.
[b] Annual activity released; the rate of activity is assumed to remain constant over more than 10,000 years.
[c] Dose commitment corresponding to a five-year release.
[d] Dose commitment corresponding to a 10,000-year release.

Table 23
Uranium-238 released in effluents from fuel conversion, enrichment and fabrication plants [a]
[A6, B13, M3]

Installation	Year	Airborne discharges (GBq)			Liquid discharges (GBq)	
		^{238}U			^{238}U	
Canada						
Blind River refinery Capacity: 18,000 t of uranium as UO_3	1985 1986 1987 1988 1989	0.9 1.0 1.1 1.0 0.9			0.2 0.08 0.1 0.2 0.1	
Port Hope UO_2 plant Capacity: 2,800 t of uranium as UO_2	1986 1987 1988 1989	0.4 0.6 0.4 0.2			0 0 0 0	
Port Hope UF_6 plant Capacity: 10,000 t of uranium as UF_6	1986 1987 1988 1989	3.1 2.6 2.5 0.7			5.3 2.6 3.7 2.6	
Toronto fuel fabrication plant Capacity: 1,050 t of uranium as UO_2	1987 1988 1989	< 0.001 < 0.001 < 0.001			0.02 0.02 0.02	
Port Hope fuel fabrication plant Capacity: 900 t of uranium as UO_2	1987 1988 1989	0.001 0.001 0.001			0.01 0.01 0.01	
		Airborne discharges (GBq)			Liquid discharges (GBq)	
		Uranium	Uranic α	Uranic β	Uranic α	Uranic β
Republic of Korea						
Korea Nuclear Fuel Company (fabrication)	1988 1989		0.07 0.3	0.3 0.1	0.009 0.03	0.013 0.013

Table 23 (continued)

Installation		Airborne discharges (GBq)			Liquid discharges (GBq)	
		Uranium	Uranic α	Uranic β	Uranic α	Uranic β
United Kingdom						
Capenhurst (enrichment)	1985	0.006			0.9	0.9
	1986	0.01			2	2
	1987	0.02			3	3
	1988	0.02			1.7	1.7
	1989				< 0.9	< 0.9
Springfields (conversion, fabrication)	1985		1	1	700	160000
	1986		1	1	600	115000
	1987		1	1	500	77000
	1988		1	1	400	110000
	1989		1	2	400	114000

Table 24
Normalized releases of radionuclides from model fuel conversion, enrichment and fabrication facility

Radionuclide	Atmospheric discharges [MBq (GW a)$^{-1}$] from			Aquatic discharges [MBq (GW a)$^{-1}$] from		
	Conversion	Enrichment	Fabrication	Conversion	Enrichment	Fabrication
Ra-226				0.11		
Th-228	0.022					
Th-230	0.4					
Th-232	0.022					
Th-234	130	1.3	0.34			170
U-234	130	1.3	0.34	94	10	170
U-235	6.1	0.06	0.0014	4.3	0.5	1.4
U-238	130	1.3	0.34	94	10	170

Table 25
Worldwide installed capacity and electrical energy generated
[19]

Country	*Reactor*	*Start-up year*	*Capacity (GW)*	*Electrical energy generated (GW a)*				
				1985	*1986*	*1987*	*1988*	*1989*
PWRs								
Belgium	Doel 1-4	1974/85	2.71	1.893	2.232	2.062	2.275	2.079
	Tihange 1-4	1975/85	2.791	1.440	2.026	2.483	2.386	2.388
Brazil	Angra 1	1982	0.626	0.362	0.015	0.104	0.065	0.194
Bulgaria	Kozloduy-1-2	1974/75	0.816	0.677	0.606	0.639	0.548	0.555
	Kozloduy-3-4	1980/82	0.816	0.712	0.669	0.659	0.687	0.601
	Kozloduy-5	1987	0.953	- [a]	-	0.016	0.449	0.383
China, Taiwan Province	Maanshan 1	1984	0.89	0.355	0.190	0.541	0.587	0.619
	Maanshan 2	1985	0.89	0.484	0.308	0.735	0.619	0.603
Czechoslovakia	Bohunice 1-4	1978/85	1.632	0.993	1.242	1.220	1.217	1.290
	Dukovany 1-4	1985/87	1.632	0.228	0.654	1.139	1.261	1.327
Finland	Loviisa 1-2	1977/80	0.89	0.816	0.765	0.819	0.794	0.814
France	Belleville 1-2	1987/88	2.62	-	-	0.071	0.955	1.559
	Blayais 1-4	1981/83	3.64	2.921	2.887	2.509	2.228	2.704
	Bugey 2-5	1978/79	3.64	2.605	2.658	2.140	1.952	2.273
	Cattenom 1-2	1986/87	2.6	-	0.025	0.998	1.532	0.978
	Chinon B1-B4	1982/87	3.55	1.257	1.499	1.674	2.125	2.340
	Chooz-A (Ardennes)	1967	0.305	0.193	0.156	0.094	0.198	0.186
	Cruas 1-4	1983/84	3.555	2.547	2.541	2.392	2.025	2.555
	Dampierre 1-4	1980/81	3.56	2.742	2.762	2.295	2.118	2.655
	Fessenheim 1-2	1977	1.76	1.366	1.277	1.276	1.168	1.016
	Flamanville 1-2	1985/86	2.66	0	0.792	1.631	1.630	1.552
	Gravelines 1-6	1980/85	5.46	3.952	4.098	3.617	3.694	3.882
	Nogent 1-2	1987/88	2.62	-	-	0.055	0.886	1.215
	Paluel 1-4	1984/86	5.32	1.586	4.577	5.537	4.836	5.667
	St. Alban 1-2	1985/86	2.67	0.147	0.891	1.490	1.113	1.473
	St. Laurent B1-2	1981	1.795	1.247	1.272	1.168	1.236	1.329
	Tricastin 1-4	1980/81	3.66	2.946	2.771	2.587	2.309	2.575
Germany, Fed. Rep. of	Biblis A-B	1974/76	2.386	1.752	1.563	1.494	1.322	1.324
	Brokdorf	1986	1.326	-	0.034	1.082	0.980	1.026
	Emsland	1988	1.242	-	-	-	0.650	1.125
	Grafenrheinfeld	1981	1.235	1.112	0.995	0.954	1.005	1.073
	Greifswald	1973/79	1.632	1.117	1.117	1.117	1.117	1.129
	Grohnde	1984	1.3	1.241	1.165	1.101	1.165	1.173
	Isar 2	1988	1.31	-	-	-	0.688	0.882
	Mülheim-Kärlich	1986	1.219	-	0.155	0.332	0.688	0
	Neckarwestheim 1-2	1976/89	2.02	0.703	0.474	0.616	0.602	1.449
	Obrigheim	1968	0.34	0.296	0.304	0.283	0.299	0.292
	Philippsburg 2	1984	1.268	1.068	1.168	1.098	1.109	1.105
	Stade	1972	0.64	0.555	0.573	0.506	0.507	0.478
	Unterweser	1978	1.23	1.134	0.831	0.990	1.040	1.055
Hungary	Paks 1-4	1982/87	1.66	0.696	0.797	1.179	1.441	1.490
Italy	Enrico Fermi	1964	0.26	0.148	0.230	0.018	0	0
Japan	Genkai 1-2	1975/80	1.058	0.793	0.856	0.872	0.665	0.619
	Ikata 1-2	1977/81	1.076	0.841	0.961	0.965	0.808	0.835
	Mihama 1-3	1970/76	1.57	1.154	1.468	1.124	1.091	1.178
	Ohi 1-2	1977/78	2.24	1.443	1.712	1.788	1.072	1.435
	Sendai 1-2	1983/85	1.692	0.994	1.379	1.392	1.495	1.413
	Takahama 1-4	1974/84	3.22	2.471	2.485	2.391	2.215	2.472
	Tomari-1	1988	0.55	-	-	-	0.006	0.412
	Tsuruga-2	1986	1.115	-	0.177	0.999	0.906	0.857
Netherlands	Borssele	1973	0.481	0.372	0.408	0.337	0.346	0.391
Republic of Korea	Kori 1	1977	0.556	0.361	0.374	0.520	0.254	0.312
	Kori 2	1983	0.605	0.426	0.450	0.487	0.514	0.578
	Kori 3-4	1985	1.79	0.201	1.218	1.332	1.373	1.458

Table 25 (continued)

Country	Reactor	Start-up year	Capacity (GW)	Electrical energy generated (GW a)				
				1985	1986	1987	1988	1989
Republic of Korea (continued)	Ulchin 1-2	1988/89	1.84	-	-	-	0.114	0.831
	Yonggwang 1-2	1986	1.8	-	0.282	1.172	1.425	1.388
South Africa	Koeberg 1-2	1984/85	1.844	0.616	1.008	0.710	1.201	1.269
Spain	Almaraz 1-2	1981/83	1.86	1.263	1.284	1.552	1.449	1.496
	Asco 1	1983	0.93	0.506	0.586	0.730	0.761	0.771
	Asco 2	1985	0.93	0.030	0.613	0.680	0.784	0.768
	José Cabrera 1	1968	0.153	0.032	0.120	0.125	0.130	0.129
	Trillo 1	1988	1.04	-	-	-	0.179	0.816
	Vandellos 2	1987	0.996	-	-	0.005	0.582	0.670
Sweden	Ringhals 2	1974	0.8	0.490	0.453	0.481	0.481	0.413
	Ringhals 3	1980	0.915	0.695	0.712	0.704	0.702	0.665
	Ringhals 4	1982	0.915	0.676	0.641	0.647	0.758	0.632
Switzerland	Beznau 1-2	1969/71	0.7	0.601	0.601	0.572	0.593	0.579
	Gösgen	1979	0.94	0.770	0.771	0.789	0.783	0.785
USSR	Armenia 1-2	1976/79	0.752	0.601	0.343	0.540	0.550	0.150
	Balakovo 1-3	1985/88	2.85	0.006	0.594	1.090	2.240	2.150
	Kalinin 1-2	1984/86	1.9	0.543	0.657	1.522	1.400	1.500
	Khmelnitski 1	1987	0.95	-	-	0.005	0.450	0.710
	Kola 1-4	1973/84	1.644	1.349	1.355	1.460	1.440	1.430
	Novovoronezh 3-5	1971/80	1.72	1.907	1.380	1.710	1.310	1.280
	Rovno 1-3	1980/86	1.695	1.210	0.696	1.302	1.380	1.440
	South Ukraine 1-3	1982/89	2.85	1.503	1.408	0.916	1.240	1.000
	Zaporozhe 1-5	1984/89	4.75	0.559	1.279	2.236	2.850	2.430
United States	Arkansas One-1	1974	0.836	0.593	0.410	0.544	0.452	0.386
	Arkansas One-2	1978	0.858	0.537	0.607	0.754	0.565	0.625
	Beaver Valley 1-2	1976/87	1.643	0.674	0.546	0.726	1.309	0.953
	Braidwood 1	1987	1.12	-	-	0.166	0.391	0.531
	Braidwood 2	1988	1.12	-	-	-	0.154	0.815
	Byron 1-2	1985/87	2.21	0.194	0.844	1.054	1.445	1.714
	Callaway 1	1984	1.118	0.918	0.822	0.722	0.930	0.953
	Calvert Cliffs 1-2	1975/76	1.65	1.138	1.465	1.153	1.343	0.319
	Catawba 1	1985	1.129	0.393	0.594	0.731	0.872	0.888
	Catawba 2	1986	1.129	-	0.151	0.818	0.620	0.745
	Crystal River 3	1977	0.821	0.327	0.303	0.413	0.658	0.334
	Davis-Besse 1	1977	0.86	0.222	0	0.578	0.133	0.836
	Diablo Canyon 1-2	1984/85	2.16	0.659	1.378	1.600	1.315	1.805
	Donald Cook 1-2	1975/78	2.08	0.890	1.254	1.148	1.118	1.381
	Farley 1	1977	0.824	0.670	0.655	0.736	0.674	0.688
	Farley 2	1981	0.83	0.625	0.680	0.561	0.748	0.642
	Fort Calhoun 1	1973	0.478	0.350	0.412	0.349	0.300	0.376
	H. B. Robinson 2	1970	0.665	0.598	0.548	0.484	0.363	0.319
	Haddam Neck	1967	0.565	0.529	0.244	0.290	0.378	0.338
	Indian Point 1-2	1962/73	0.864	0.761	0.437	0.588	0.692	0.511
	Indian Point 3	1976	0.965	0.540	0.631	0.554	0.766	0.567
	Kewaunee	1974	0.503	0.422	0.440	0.458	0.447	0.427
	Maine Yankee	1972	0.81	0.611	0.713	0.462	0.526	0.792
	McGuire 1	1981	1.129	0.774	0.591	0.839	0.845	0.891
	McGuire 2	1983	1.129	0.640	0.710	0.865	0.920	0.847
	Millstone 2	1975	0.863	0.401	0.590	0.787	0.655	0.544
	Millstone 3	1986	1.142	-	0.669	0.770	0.877	0.809
	North Anna 1-2	1978/80	1.83	1.440	1.408	1.053	1.687	1.164
	Oconee 1-2-3	1973/74	2.538	1.939	1.902	1.867	2.134	2.088
	Palisades	1971	0.73	0.605	0.096	0.301	0.392	0.415
	Palo Verde 1	1985	1.221	0.129	0.715	0.601	0.761	0.205
	Palo Verde 2	1986	1.221	-	0.303	0.935	0.770	0.536
	Palo Verde 3	1987	1.221	-	-	-	1.146	0.152
	Point Beach 1-2	1970/72	0.97	0.794	0.821	0.819	0.862	0.810
	Prairie Island 1-2	1973/74	1.003	0.832	0.876	0.919	0.880	0.945
	R. E. Ginna	1969	0.47	0.413	0.412	0.434	0.403	0.351
	Rancho Seco 1	1974	0.873	0.221	0	0	0.326	0.165
	Salem 1	1976	1.106	1.028	0.809	0.710	0.847	0.709
	Salem 2	1981	1.106	0.575	0.607	0.705	0.683	0.893
	San Onofre 1	1967	0.436	0.281	0.101	0.309	0.158	0.135
	San Onofre 2-3	1982/83	2.15	1.017	1.499	1.572	1.729	1.607
	Sequoyah 1-2	1980/81	2.296	1.107	0	0	0.464	1.783

Table 25 (continued)

Country	*Reactor*	*Start-up year*	*Capacity (GW)*	*Electrical energy generated (GW a)*				
				1985	*1986*	*1987*	*1988*	*1989*
United States (continued)	Shearon Harris 1	1987	0.86	-	-	0.386	0.610	0.644
	South Texas 1	1988	1.25	-	-	-	0.319	0.720
	South Texas 2	1989	1.25	-	-	-	-	0.346
	St. Lucie 1	1976	0.839	0.670	0.805	0.653	0.714	0.793
	St. Lucie 2	1983	0.839	0.697	0.702	0.679	0.846	0.621
	Surry 1-2	1972/73	1.562	1.106	1.026	1.076	0.714	0.464
	Three Mile Island 1	1974	0.808	0.093	0.550	0.575	0.624	0.824
	Three Mile Island 2	1978	0	0	0	0	0	0
	Trojan	1975	1.095	0.789	0.810	0.498	0.724	0.633
	Turkey Point 3	1972	0.666	0.391	0.515	0.101	0.396	0.412
	Turkey Point 4	1973	0.666	0.591	0.199	0.303	0.373	0.241
	Virgil C. Summer 1	1982	0.885	0.598	0.817	0.590	0.579	0.618
	Vogtle 1, 2	1987/89	2.166	-	-	0.447	0.776	0.994
	Waterford 3	1985	1.075	0.317	0.834	0.849	0.748	0.869
	Wolf Creek	1985	1.135	0.435	0.795	0.742	0.762	1.108
	Yankee NPS	1960	0.167	0.135	0.159	0.130	0.128	0.149
	Zion 1-2	1973	2.08	1.138	1.400	1.278	1.484	1.449
Yugoslavia	Krsko	1981	0.62	0.439	0.436	0.488	0.449	0.508
Total annual electrical energy generated (GW a)			199.54	95.01	106.94	119.15	130.10	137.79
BWRs								
China, Taiwan Province	Chin Shan 1	1977	0.604	0.431	0.469	0.456	0.401	0.318
	Chin Shan 2	1978	0.604	0.490	0.433	0.427	0.426	0.349
	Kuosheng 1	1981	0.951	0.677	0.833	0.729	0.638	0.608
	Kuosheng 2	1982	0.951	0.708	0.717	0.741	0.685	0.597
Finland	TVO 1-2	1978/80	0.71	1.236	1.290	1.297	1.312	1.242
Germany, Fed. Rep. of	Brunsbüttel	1976	0.771	0.642	0.643	0.597	0.581	0.468
	Gundremmingen B,C	1984	2.488	2.089	1.863	1.798	1.659	2.002
	Isar 1	1977	0.87	0.723	0.818	0.644	0.594	0.594
	Krümmel	1983	1.26	1.062	1.083	1.048	1.052	0.941
	Philippsburg 1	1979	0.864	0.699	0.596	0.741	0.708	0.703
	Würgassen	1971	0.64	0.530	0.551	0.540	0.531	0.432
India	Tarapur-1,2	1969	0.30	0.212	0.212	0.155	0.217	0.140
Italy	Caorso	1981	0.86	0.454	0.605	0	0	0
Japan	Fukushima Daiichi 1-6	1970/79	4.546	2.930	3.260	3.271	3.296	3.173
	Fukushima Daini 1-4	1981/86	4.286	2.426	2.474	3.067	3.309	2.718
	Hamaoka 1-3	1974/86	2.377	1.008	0.886	1.813	1.475	1.724
	Kashiwazaki Kariwa 1,5	1984/89	2.134	0.566	0.765	1.050	0.794	0.854
	Onagawa-1	1983	0.497	0.372	0.384	0.361	0.389	0.344
	Shimane 1-2	1973/88	1.23	0.433	0.243	0.344	0.419	0.967
	Tokai 2	1978	1.08	0.794	0.662	0.804	0.695	0.963
	Tsuruga 1	1969	0.341	0.194	0.261	0.268	0.254	0.281
Mexico	Laguna Verde (Mark)	1989	0.65	-	-	-	-	0.036
Netherlands	Dodewaard	1968	0.05	0.049	0.046	0.047	0.049	0.041
Spain	Confrentes	1984	0.939	0.701	0.761	0.786	0.815	0.805
	S. Maria de Garona	1971	0.46	0.198	0.390	0.293	0.307	0.401
Sweden	Barsebeck 1	1975	0.6	0.468	0.499	0.520	0.501	0.494
	Barsebeck 2	1976	0.6	0.492	0.471	0.508	0.501	0.480
	Forsmark 1	1980	0.97	0.638	0.835	0.741	0.782	0.701
	Forsmark 2	1981	0.97	0.655	0.798	0.748	0.796	0.678
	Forsmark 3	1985	1.068	0.474	0.921	0.804	0.852	0.841
	Oskarshamn 1	1971	0.442	0.314	0.358	0.369	0.327	0.363
	Oskarshamn 2	1974	0.605	0.455	0.488	0.483	0.504	0.452
	Oskarshamn 3	1985	1.16	0.439	0.957	0.806	0.835	0.889
	Ringhals 1	1974	0.75	0.590	0.510	0.556	0.536	0.554
Switzerland	Leibstadt	1984	0.99	0.773	0.773	0.823	0.842	0.799
	Mühleberg	1972	0.322	0.285	0.241	0.281	0.285	0.262

Table 25 (continued)

Country	Reactor	Start-up year	Capacity (GW)	Electrical energy generated (GW a)				
				1985	1986	1987	1988	1989
United States	Big Rock Point	1962	0.067	0.041	0.058	0.043	0.044	0.048
	Browns Ferry 1-3	1973/76	3.195	0.357	0	0	0	0
	Brunswick 1-2	1975/76	1.58	0.795	1.017	1.113	0.957	0.958
	Clinton 1	1987	0.946	-	-	0.186	0.669	0.327
	Cooper	1974	0.764	0.122	0.463	0.630	0.480	0.547
	Dresden 2-3	1970/71	1.545	0.857	0.703	0.886	0.970	1.127
	Duane Arnold-1	1974	0.538	0.222	0.364	0.291	0.402	0.359
	Enrico Fermi 2	1986	1.093	-	0	0.159	0.463	0.597
	Fitzpatrick	1975	0.757	0.476	0.687	0.479	0.497	0.703
	Grand Gulf 1	1984	1.142	0.493	0.468	0.882	1.095	0.896
	Hatch 1-2	1974/78	1.525	1.157	0.829	1.237	0.956	1.213
	Hope Creek 1	1986	1.031	-	0.118	0.834	0.739	0.755
	Humboldt Bay 3	1963						
	Lacrosse	1968	0.048	0.037	0.018	0.015		
	Lasalle 1-2	1982/84	2.072	0.948	0.894	0.991	1.269	1.448
	Limerick 1	1985	1.055	0.133	0.823	0.610	0.762	0.599
	Millstone 1	1970	0.654	0.524	0.599	0.500	0.632	0.530
	Monticello	1971	0.536	0.489	0.386	0.404	0.522	0.303
	Nine Mile Point 1	1969	0.61	0.563	0.359	0.527		
	Nine Mile Point 2	1987	1.072	-	-	0.030	0.290	0.490
	Oyster Creek	1969	0.62	0.428	0.150	0.355	0.405	0.275
	Peach Bottom 2-3	1974	2.086	0.651	1.342	0.355	0	0.471
	Perry 1	1986	1.141	-	-	0.095	0.826	0.612
	Pilgrim 1	1972	0.67	0.565	0.117	0	0	0.195
	Quad Cities 1-2	1972	1.538	1.214	1.045	1.074	1.123	1.144
	River Bend 1	1985	0.936	0.003	0.342	0.567	0.828	0.546
	Susquehanna 1-2	1982/84	2.07	1.439	1.290	1.682	1.635	1.514
	Vermont Yankee	1972	0.504	0.342	0.235	0.404	0.470	0.412
	WPPSS-2	1984	1.095	0.591	0.592	0.685	0.685	0.700
Total annual electrical energy generated (GW a)			73.58	37.65	40.00	42.95	44.09	43.98
HWRs								
Argentina	Atucha-1	1974	0.335	0.168	0.252	0.160	0.092	0
	Embalse	1983	0.6	0.431	0.350	0.522	0.521	0.532
Canada	Bruce 1-4	1977/78	3.394	2.558	2.447	2.167	2.008	1.830
	Bruce 5-8	1984/87	3.371	1.297	2.061	2.592	2.698	3.005
	Gentilly-2	1982	0.64	0.364	0.433	0.532	0.603	0.556
	Pickering 1-4	1971/73	2.06	0.710	0.783	0.919	0.872	1.205
	Pickering 5-8	1982/86	2.064	1.227	1.670	1.786	1.934	1.719
	Point Lepreau	1982	0.635	0.619	0.596	0.583	0.609	0.601
India	Kalpakkam 1-2	1983	0.44	0.094	0.176	0.247	0.217	0.096
	Rajasthan 1-2	1972/80	0.414	0.135	0.123	0.137	0.184	0.159
Pakistan	Karachi	1971	0.125	0.030	0.060	0.035	0.022	0.0080
Republic of Korea	Wolsong 1	1982	0.629	0.599	0.505	0.589	0.504	0.577
Total annual electrical energy generated (GW a)			14.58	8.20	9.40	10.24	10.24	10.28
GCRs								
France	Bugey 1	1972	0.54	0.317	0.179	0.211	0.289	0.203
	Chinon A2-3	1965/66	0.54	0.081	0	0.012	0.109	0.150
	St. Laurent A1-2	1969/71	0.84	0.461	0.514	0.492	0.628	0.316
Japan	Tokai-1	1965	0.159	0.098	0.099	0.092	0.116	0.053
Spain	Vandellos 1	1972	0.48	0.334	0.338	0.346	0.349	0.280
United Kingdom	Berkeley	1962	0.138	0.118	0.091	0.109	0.142	0.050
	Bradwell	1962	0.245	0.213	0.181	0.213	0.194	0.092
	Calder Hall	1956	0.198	0.164	0.161	0.153	0.149	0.159
	Chapelcross	1959	0.192	0.163	0.166	0.168	0.164	0.156
	Dungeness A	1965	0.424	0.381	0.300	0.349	0.238	0.251
	Dungeness B1-2	1983/85	0.72	0.278	0.277	0.111	0.260	0.100
	Hartlepool A1-A2	1983/84	0.84	0.156	0.319	0.241	0.221	0.464
	Heysham 1A-B, 2A-B	1983/86	2.07	0.254	0.272	0.467	0.665	1.322

Table 25 (continued)

Country	*Reactor*	*Start-up year*	*Capacity (GW)*	*Electrical energy generated (GW a)*				
				1985	*1986*	*1987*	*1988*	*1989*
United Kingdom (continued)	Hinkley Point A	1965	0.47	0.401	0.406	0.423	0.416	0.315
	Hinkley Point B, A-B	1976	1.12	0.855	0.764	0.549	0.819	0.763
	Hunterston A1	1964	0.3	0.256	0.261	0.259	0.227	0.231
	Hunterston B1-2	1976/77	1.15	0.931	0.935	0.901	0.868	0.878
	Oldbury-A	1967	0.434	0.379	0.378	0.368	0.385	0.333
	Sizewell-A	1966	0.42	0.307	0.227	0.315	0.305	0.296
	Torness A-B	1988/89	1.25	-	-	-	0.261	0.662
	Trawsfynydd	1965	0.39	0.368	0.334	0.353	0.230	0.297
	Wylfa	1971	0.84	0.763	0.468	0.514	0.705	0.755
Total annual electrical energy generated (GW a)			13.76	7.28	6.67	6.64	7.74	8.13
LWGRs								
USSR	Beloyarsky 2	1967	0.146	0.174		0.117	0.100	0.081
	Bilibino 1-4	1974/76	0.044	0.040	0.039	0.040	0.035	0.033
	Chernobyl 1-4	1977/81	2.775	3.335	0.240	1.549	2.240	2.310
	Ignalina 1-2	1983/87	2.76	1.082	1.128	1.540	1.460	1.900
	Kursk 1-4	1976/85	3.7	2.370	2.776	2.950	3.270	2.940
	Leningrad 1-4	1973/81	3.7	3.200	3.356	3.273	3.170	3.110
	Smolensk 1-3	1982/89	1.85	1.207	1.198	1.577	1.650	1.620
Total annual electrical energy generated (GW a)			14.98	11.41	8.74	11.05	11.93	11.994
FBRs								
France	Creys-Malville	1985	1.2	0	0.106	0.093	0	0.201
	Phenix	1973	0.233	0.132	0.173	0.178	0.168	0.069
USSR	Beloyarsky 3	1980	0.56	0.435	0.392	0.445	0.429	0.422
United Kingdom	Dounreay	1975	0.25	0.102	0.102	0.096	0.070	0.119
Total annual electrical energy generated (GW a)			2.243	0.669	0.773	0.811	0.668	0.810

[a] A dash indicates that the reactor is not yet in operation.

Table 26
Noble gases released from reactors in airborne effluents

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
PWRs						
Belgium [M6]	Doel 1-4	77900	17800	8000	24300	3400
	Tihange 1-4	15200	49700	30400	49500	13100
Brazil [C1]	Angra 1	300	80	800	200	9900
Bulgaria [C16]	Kozloduy-1-2	99000	47000	198000	84000	125000
	Kozloduy-3-4	80000	42000	61000	88000	114000
	Kozloduy-5	- [a]	-		433000	528000
China, Taiwan Province [T2]	Maanshan 1-2	73.4	537	3600	2150	1760
Czechoslovakia [N11]	Bohunice 1-4	66900	45700	37100	37200	36900
	Dukovany 1-4	1200	4100	5900	6400	3000
Finland [F2]	Loviisa 1-2	1100	1000.0	1100	1100	1100
France [E4]	Belleville 1-2	-	-	28000	85000	44000
	Blayais 1-4	430000	370000	110000	130000	140000
	Bugey 2-5	110000	93000	53000	45000	39000
	Cattenom 1-2	-	2600	40000	54000	59000
	Chinon B1-B4	170000	210000	49000	42000	48000
	Chooz-A (Ardennes)	160000	240000	15000	31000	69000
	Cruas 1-4	270000	150000	18000	16000	21000
	Dampierre 1-4	280000	270000	160000	140000	170000
	Fessenheim 1-2	94000	100000	44000	11000	10000
	Flamanville 1-2	36000	240000	24000	8600	7000
	Gravelines 1-6	330000	310000	110000	110000	81000
	Nogent 1-2	-	-	3200	18000	26000
	Paluel 1-4	340000	590000	220000	160000	150000
	St. Alban 1-2	7800	33000	15000	16000	9900
	St. Laurent B1-2	130000	100000	11000	8500	22000
	Tricastin 1-4	130000	130000	28000	27000	41000
Germany, Federal Republic of [B4, B9, S7]	Biblis A-B	14000	28100	40300	20700	3490
	Brokdorf	-	7.4	0	0.1	280
	Emsland	-	-	-	77	94
	Grafenrheinfeld	12	10	0.53	190	14000
	Greifswald	190000	160000	230000	280000	540000
	Grohnde	51	50	3800	10000	3800
	Isar 2	-	-	-	11	38
	Mülheim-Kärlich	-	0	0	0	0
	Neckarwestheim 1-2	11000	12000	11000	21000	18600
	Obrigheim	970	620	460	650	650
	Philippsburg 2	5300	500	830	2600	3100
	Stade	34000	190000	82000	38000	9900
	Unterweser	5600	8400	4700	3400	3700
Hungary [F3]	Paks 1-4	108000	194000	328000	133000	176000
Italy [C22]	Enrico Fermi (Trino)	28	18000	1590	0.03	0.07
Japan [J1]	Genkai 1-2	1300	1400	1000	1100	690
	Ikata 1-2	48	19	7.4	6.3	5.9
	Mihama 1-3	1400	1400	930	270	250
	Ohi 1-2	1300	3700	1500	930	1000
	Sendai 1-2	67	41	41	36	40
	Takahama 1-4	2000	630	480	1100	350
	Tomari-1	-	-	-	0	0.17
	Tsuruga-2	-	85	0.85	5.9	8.6
Netherlands [M5]	Borssele	600	4000	200	1200	2300
Republic of Korea [M3]	Kori 1	6660	8670	2440	0000	2380
	Kori 2	1430	1520	527	121	0
	Kori 3-4	24800	34800	28900	18500	22600
	Ulchin 1-2	-	-	-	6	405
	Yonggwang 1-2	-	1781	11730	12356	5030

Table 26 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
South Africa [C20]	Koeberg 1-2		207000	33700	55000	50800
Spain [C21]	Almaraz 1-2	169000	270000	6590	29800	3950
	Asco 1	4760	10800	9650	57100	84900
	Asco 2	1590	18500	14400	62100	60600
	José Cabrera 1	41500	141000	142000	99400	96900
	Trillo 1	-	-	-	300	2990
	Vandellos 2	-	-	0	17600	26300
Sweden [N14]	Ringhals 2	3600	10100	14000	15000	5400
	Ringhals 3	9100	63200	31000	620	6800
	Ringhals 4	490	26400	76000	57300	6000
Switzerland [D5, D6]	Beznau 1-2	14500	32000	18000	18000	44000
	Gösgen	15000	7000	4200	6800	12000
USSR [G2, I14]	Armenia 1-2	66000	55400	577000	57700	62200
	Balakovo 1-3	0	66200	173000	173000	60500
	Kalinin 1-2	270000	270000	248000	56700	51300
	Khmelnitski 1	-	-	-	119000	96200
	Kola 1-4	1040000	544000	564000	415000	423000
	Novovoronezh 3-5	43000	41000	27200	29700	32400
	Rovno 1-3	88100	99900	55500	241000	136000
	South Ukraine 1-3	200000	123000		41400	47100
	Zaporozhe 1-5	110000	407000	275000	110000	78700
United States [T3]	Arkansas One-1	300000	63300	12100	45900	86200
	Arkansas One-2	330000	128000	7620	79900	102000
	Beaver Valley 1-2	1450	2800	8330	3480	5800
	Braidwood 1	-	-	10.4	1550	43300
	Braidwood 2	-	-	-	1410	18800
	Byron 1-2	10320	23500	48100	65900	30200
	Callaway 1	61800	192000	107000	25500	26700
	Calvert Cliffs 1-2	147000	283000	168000	211000	121000
	Catawba 1	10200	50300	89200	57700	11700
	Catawba 2	-	50300	89200	57700	11700
	Crystal River 3	38900	102000	40700	126000	167000
	Davis-Besse 1	4370	0.02	14100	4030	14000
	Diablo Canyon 1-2	21200	85900	26400	12100	12400
	Donald Cook 1-2	183000	12200	32400	9550	4300
	Farley 1	62900	47400	48100	35500	3700
	Farley 2	24500	68100	26700	21900	5900
	Fort Calhoun 1	54800	21000	15700	29000	6100
	H. B. Robinson 2	79200	24400	28500	38500	1000
	Haddam Neck	102000	86200	132000	94400	633000
	Indian Point 1-2	69600	75900	173000	8400	3200
	Indian Point 3	57000	71400	67300	11500	11600
	Kewaunee	1840	2420	1180	1080	2400
	Maine Yankee	16300	39600	28900	2660	750
	McGuire 1	71400	38900	75500	72200	26600
	McGuire 2	71400	38900	75500	72200	26600
	Millstone 2	14800	3700	14700	23500	9100
	Millstone 3	-	884	3890	3120	11000
	North Anna 1-2	298000	211000	38900	17900	53300
	Oconee 1-2-3	870000	899000	389000	958000	332000
	Palisades	136000	64000	64800	89900	5600
	Palo Verde 1	9360	98800	47000	68100	23700
	Palo Verde 2	-	72900	202000	110000	15900
	Palo Verde 3	-	-	0.93	5030	30900
	Point Beach 1-2	4290	1030	1780	2990	560
	Prairie Island 1-2	1700	1120	32.4	5.25	6400
	R. E. Ginna	15000	7730	6550	1910	18900
	Rancho Seco 1	173000	3440	0.80	56200	74000
	Salem 1	62200	51400	135000	19600	51400
	Salem 2	42600	31700	39200	43700	2700
	San Onofre 1	142000	15200	36300	111000	33500
	San Onofre 2-3	936000	305000	807000	189000	91000
	Sequoyah 1-2	169000	44.8	0	8330	142000
	Shearon Harris 1	-	-		83300	42600
	South Texas 1	-	-	-	31700	16500
	South Texas 2	-	-	-	-	4300

Table 26 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	St. Lucie 1	1880000	1230000	230000	52500	168000
	St. Lucie 2	353000	369000	318000	339000	82100
	Surry 1-2	76600	73600	11400	13500	5100
	Three Mile Island 1	4000	141000	29200	69200	77700
	Three Mile Island 2	0	10.4	0	16.3	0
	Trojan	40700	34900	9440	15700	22000
	Turkey Point 3	48800	135000	34700	46300	62900
	Turkey Point 4	66600	37400	29100	48500	63300
	Virgil C. Summer 1	5180	514	23500	12300	67300
	Vogtle 1-2	-	-	3960	4260	20200
	Waterford 3	304000	414000	208000	196000	20700
	Wolf Creek	6360	1170	6400	29300	23700
	Yankee NPS	54400	18900	14200	7620	4500
	Zion 1-2	144000	118000	4370	48500	41400
Yugoslavia [F1]	Krsko	0	0	0	0	0
Total release (GBq)		12900000	12000000	8320000	7640000	6970000
Normalized release [GBq (GW a)$^{-1}$]		137000	112000	70600	58700	50600
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		81000				
BWRs						
China, Taiwan Province [T2]	Chin Shan 1-2	499000	254000	84000	62200	46900
	Kuosheng 1-2	407	136	4510	7840	5330
Finland [F2]	TVO 1-2	0	5800	6000	180	19000
Germany, Federal Republic of [B4, B9]	Brunsbüttel	19000	820	6600	23000	7900
	Gundremmingen B,C	21	4800	19000	3900	15000
	Isar 1	27000	1900	860	860	360
	Krümmel	950	210	14000	9700	1000
	Philippsburg 1	35	29	760	480	10
	Würgassen	11000	9300	2900	3100	1400
India	Tarapur-1,2					
Italy [C22]	Caorso	420	1360	3470	5550	1060
Japan [J1]	Fukushima Daiichi 1-6	740	290	190	4.1	0
	Fukushima Daini 1-4	0	0	0.0034	0	0
	Hamaoka 1-3	0	0	0	0	0
	Kashiwazaki Kariwa 1,5	0	0	0	0	0
	Onagawa-1	0	0	0	0	0
	Shimane 1-2	0	0	0	0	0
	Tokai 2	0	0	150	0	0
	Tsuruga 1	1.6	3.1	1.7	0	0.26
Mexico [C19]	Laguna Verde (Mark II)	-	-	-	-	0
Netherlands [M5]	Dodewaard	9800	11000	4300	3200	5400
Spain [C21]	Confrentes	49500	59200	113000	97500	49500
	S. Maria de Garona	70500	76400	58600	68200	74700
Sweden [N14]	Barsebeck 1	160	640	630	530	5800
	Barsebeck 2	290	80700	980	528000	1560000
	Forsmark 1	70800	81	330	740	304000
	Forsmark 2	232000	265000	199000	278000	721000
	Forsmark 3	660	24600	4850	11500	10300
	Oskarshamn 1	533000	508000	301000	305000	201000
	Oskarshamn 2	30400	25000	14500	15900000	2410000
	Oskarshamn 3	17200	265000	49000	106000	131000
	Ringhals 1	1280000	1240000	482000	490000	132000
Switzerland [D5, D6]	Leibstadt	12	1800	160	13000	63000
	Mühleberg	83000	620000	1400	200000	120000
United States [T3]	Big Rock Point	2320000	2320000	309000	287000	262000
	Browns Ferry 1-3	977000	83600	11.9	0	0

Table 26 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	Brunswick 1-2	648000	1670000	977000	58500	50300
	Clinton 1	-	-	253	161	480
	Cooper	51400	63600	44400	67000	12700
	Dresden 2-3	109000	16200	10200	6220	1360
	Duane Arnold-1	9290	11500	8100	26100	1620
	Enrico Fermi 2	-	0	0	41.1	6070
	Fitzpatrick	540000	98100	175000	144000	20700
	Grand Gulf 1	5590	4960	7700	3490	5330
	Hatch 1-2	466000	733000	781000	128000	18600
	Hope Creek 1	-	1410	44000	6510	12400
	Humboldt Bay 3	0	0	0	2400	240
	Lacrosse	317000	131000	86200	0	0
	Lasalle 1-2	7220	110000	241000	140000	40000
	Limerick 1	0	13.7	892	6250	9550
	Millstone 1	41100	122000	216000	32400	6700
	Monticello	138000	131000	146000	218000	147000
	Nine Mile Point 1	36400	18200	7300	666	0.006
	Nine Mile Point 2	-	-	222	1490	3120
	Oyster Creek	1540000	2840000	125000	187000	12000
	Peach Bottom 2-3	4770000	1030000	426000	44000	97700
	Perry 1	-	45.5	392	46300	7100
	Pilgrim 1	121000	4660	0	0	25100
	Quad Cities 1-2	109000	54800	13800	139	10600
	River Bend 1		62900	51.4	75.9	3070
	Susquehanna 1-2	19100	8700	4550	2680	4400
	Vermont Yankee	127000	57720	0	0	38100
	WPPSS-2	7840	6140	19800	33400	202000
Total release (GBq)		15300000	13000000	5020000	19600000	6880000
Normalized release [GBq (GW a)$^{-1}$]		409000	328000	117000	446000	157000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		290000				
HWRs						
Argentina [C15, C18]	Atucha-1	5500	6200	1400	3500	600
	Embalse	150000	420000	310000	96000	130000
Canada [A6]	Bruce 1-4	789000	558000	519000	1500000	491000
	Bruce 5-8	106000	127000	139000	154000	106000
	Gentilly-2	120000	50000	49000	83000	0
	Pickering 1-4	192000	183000	289000	233000	340000
	Pickering 5-8	176000	269000	231000	215000	218000
	Point Lepreau	800	5000	100	300	0
India	Kalpakkam 1-2	*Not reported*				
	Rajasthan 1-2					
Pakistan	Karachi	*Not reported*				
Republic of Korea [M3]	Wolsong 1	137900	125400	151300	171800	91000
Total release (GBq)		1680000	1740000	1690000	2460000	1380000
Normalized release [GBq (GW a)$^{-1}$]		210000	192000	172000	250000	137000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		191000				
GCRs						
France [E4]	Bugey 1	130000	122000	37000	53000	96000
	Chinon A2-3	25000	0	5000	36000	63000
	St. Laurent A1-2	244000	256000	118000	179000	140000
Japan [J1]	Tokai-1	280000	260000	230000	260000	210000
Spain [C21]	Vandellos 1	45200	18600	29500	27600	12000
United Kingdom [N6, P1, S4]	Berkeley	340000	240000	290000	380000	70000
	Bradwell	740000	630000	730000	680000	320000

Table 26 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United Kingdom (continued)	Calder Hall					2530000
	Chapelcross	3000000	3000000	3100000	3000000	3000000
	Dungeness A	1200000	1000000	1100000	760000	830000
	Dungeness B1-2	20000	50000	10000	20000	7200
	Hartlepool A1-A2	10000	20000	10000	10000	20000
	Heysham 1A-B, 2A-B	10000	10000	10000	10000	7600
	Hinkley Point A	3100000	3100000	3700000	3200000	2400000
	Hinkley Point B, AB	70000	140000	120000	110000	69000
	Hunterston A1	725000	735000	730000	640000	650000
	Hunterston B1-2	56000	32000	46000	59000	37000
	Oldbury-A	130000	70000	160000	180000	150000
	Sizewell-A	1700000	1400000	1900000	1800000	1800000
	Torness A-B	-	-	-	4300	4600
	Trawsfynydd	5000000	5000000	5000000	900000	1600000
	Wylfa	70000	70000	5000	70000	70000
Total release (GBq)		16900000	16200000	17300000	12400000	14100000
Normalized release [GBq (GW a)$^{-1}$]		2370000	2480000	2670000	1630000	1730000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		2150000				
LWGRs						
USSR [G2, 114]	Beloyarsky 2					12700000
	Bilibino 1-4					307000
	Chernobyl 1-4	2550000				3120000
	Ignalina 1-2	4900000	3170000	1170000	2460000	2260000
	Kursk 1-4	2330000	8510000	6970000	6200000	7030000
	Leningrad 1-4	7830000	4700000	4440000	3510000	2930000
	Smolensk 1-3	2910000	3490000	3940000	2130000	3250000
Total release (GBq)		20500000	19900000	16500000	14300000	31600000
Normalized release [GBq (GW a)$^{-1}$]		1800000	2300000	1800000	1500000	2600000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		2000000				
FBRs						
France [S6]	Creys-Malville	5000	38000	29000	31000	36000
	Phenix	5200	6300	6100	5100	4600
USSR	Beloyarsky 3					
United Kingdom	Dounreay					
Total release (GBq)		10200	44300	35100	36100	40600
Normalized release [GBq (GW a)$^{-1}$]		77000	160000	130000	210000	150000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		150000				

[a] A dash indicates that the reactor was not yet in operation.

Table 27
Isotopic composition of noble gases released from PWRs in the United States, 1988 [T3]

Reactor	Release (TBq)										
	^{41}Ar [a]	^{85}Kr	^{85m}Kr	^{87}Kr	^{88}Kr	^{131m}Xe	^{133}Xe	^{133m}Xe	^{135}Xe	^{135m}Xe	^{138}Xe [b]
Arkansas One 1	. [c]	0.119	0.137	-	-	0.0618	42.9	0.0374	2.96	-	-
Arkansas One 2	0.00073	0.00066	0.00907	0.00043	0.00321	1.42	66.2	0.0833	12.2	-	-
Beaver Valley 1-2	0.0112	2.35	0	-	-	0.139	0.858	0.00107	0.125	0.00087	-
Braidwood 1	0.0123	0.0066	0.00069	0.00002	0.0006	0.0197	1.49	0.00999	0.0141	-	-
Braidwood 2	0.0290	0.00054	0.00044	0	0.00002	0.0327	1.35	0.00403	0.00138	-	-
Byron 1-2	0.0243	0.392	0.0147	0.00021	0.00936	0.249	64.0	0.463	0.633	-	-
Callaway 1	0.0226	3.03	0.0925	-	0.0269	0.0888	20.7	0.0947	1.38	-	-
Calvert Cliffs 1-2	0.00225	11.6	1.65	0.336	0.165	0.944	181	1.44	13.8	0.00012	-
Catawba 1	0.222	0.0770	0.0342	0.00485	0.0381	0.451	55.9	0.574	0.666	0.00021	0.00013
Catawba 2	0.222	0.0770	0.0342	0.00485	0.0381	0.451	55.9	0.574	0.666	0.00021	0.00013
Crystal River 3	-	0.907	0.255	-	-	1.59	121	0.150	2.67	-	-
Davis-Besse 1	-	0.183	-	-	0.0369	0.00071	3.77	0.00588	0.0414	-	-
Diablo Canyon 1-2	0.0766	0.333	0.00381	0.00006	0.00429	0.577	10.7	0.0339	0.433	0.00016	0.00004
Donald C. Cook 1-2	0.0144	0.0562	0.00537	0.0047	0.0261	0.0299	9.07	0.0463	0.300	0.005	0.00385
Fort Calhoun	0.0640	0.225	0.00027	-	-	0.633	27.9	0.126	0.0599	-	-
H.B. Robinson 2	0.176	4.26	0.172	0.00577	0.0102	0.166	31.0	0.244	2.23	0.00287	-
Haddam Neck	0.0264	7.18	0.125	0.114	0.168	0.150	84.0	0.285	2.01	0.0202	0.0503
Harris 1	0.0131	-	1.80	0.599	3.00	-	71.8	1.20	4.18	-	0.599
Indian Point 1-2	0.0274	-	0.00799	0.00169	0.0106	-	7.59	0.0161	0.418	0.0185	0.00013
Indian Point 3	0.0133	0.121	0.0054	0.00219	0.0077	0.308	10.6	0.0747	0.305	0.00049	0.00012
Joseph M. Farley 1	0.973	25.4	0.0226	0.00232	0.00747	0.0426	6.77	0.0807	2.23	0	0.00304
Joseph M. Farley 2	1.32	16.9	-	-	-	-	2.74	0.00703	0.881	-	0.00197
Kewaunee	0.0028	0.00696	0.00007	-	-	0.00005	0.238	0.00053	0.00184	-	-
Maine Yankee	-	0.0577	0.00013	-	0	0.00334	2.48	0.0183	0.101	-	-
McGuire 1	0.324	1.37	0.182	0.0261	0.172	0.396	66.2	0.903	2.62	0.00051	0.00004
McGuire 2	0.324	1.37	0.182	0.0261	0.172	0.396	66.2	0.903	2.62	0.00051	0.00004
Millstone 2	-	0.157	0	-	-	0.0907	27.1	0.0633	4.77	-	-
Millstone 3	-	-	0.00008	-	-	0.00751	2.87	0.0186	0.221	-	-
North Anna 1-2	0.00003	0.135	0.0011	0.00001	0.00002	0.0722	17.5	0.0216	0.0962	-	-
Oconee 1-3	0.189	62.5	0.357	0.0566	0.325	13.8	866	6.92	6.92	0.0466	-
Palisades	0.0337	0.0981	0.0298	0.0662	0.0766	0.0257	88.8	0.0264	0.179	0.242	0.164

Table 27 (continued)

Reactor	Release (TBq)										
	^{41}Ar [a]	^{85}Kr	^{85m}Kr	^{87}Kr	^{88}Kr	^{131m}Xe	^{133}Xe	^{133m}Xe	^{135}Xe	^{135m}Xe	^{138}Xe [b]
Palo Verde 1	0.0208	0.955	0.0158	0.00003	0.00129	0.259	58.1	0.230	2.54	-	5.88
Palo Verde 2	0.0640	1.62	0.037	0.00067	0.0925	2.04	104	0.411	1.54	-	0.00149
Palo Verde 3	0.291	0.00244	0.00403	-	0.00114	0.00899	4.55	0.00411	0.154	-	0.00001
Point Beach 1-2	0.0725	0.0364	0.0271	0.0548	0.0625	-	2.23	0.0124	0.131	0.0940	0.266
Prairie Island 1-2	-	0.00455	-	-	-	-	0.0007	0	0.00002	-	-
R.E. Ginna	0.0440	-	0.00364	0.00592	0.00795	0.00729	1.28	0.00104	0.466	0.0655	0.0240
Rancho Seco 1	0.00088	0.0744	0.109	0.00018	0.0881	0.566	54.0	0.357	0.936	0.00001	-
Salem 1	0.00028	0.0407	0.0133	-	-	0.290	18.5	0.0366	0.703	0.00001	-
Salem 2	0.00057	0.0673	0.114	0.0209	0.154	0.0981	41.4	0.225	1.27	0.185	-
San Onofre 1	0.00021	0.426	0.137	0.0094	0.0426	0.145	105	0.988	3.27	0.00004	-
San Onofre 2-3	0.640	0.592	1.21	0.223	0.316	0.570	174	0.235	11.8	0.120	0.0346
Sequoyah 1-2	0.00921	0.0744	0.00648	-	0.00055	0.0403	7.99	0.0788	0.136	-	-
South Texas 1	28.1	-	0.00633	0.00814	0.0119	-	3.54	0.00218	0.0474	0.00173	-
St. Lucie 1	0.112	-	0.195	0.00618	0.248	0.00043	44.4	0.202	7.51	-	-
St. Lucie 2	0.0696	0.0355	2.76	0.0137	1.18	0.128	296	3.22	35.2	-	-
Summer 1	0.0138	0.151	0.0751	0.00019	0.108	0.0562	11.0	0.0392	0.840	-	-
Surry 1-2	0.0451	0.153	0	0.00034	0.00055	0.0729	13.1	0.0223	0.169	0.00024	-
Three Mile Island 1	0.120	0.320	0.0496	0.00002	0.00407	0.437	66.2	0.533	1.33	0.00001	-
Three Mile Island 2	-	0.0163	-	-	-	-	-	-	-	-	-
Trojan	0.0313	0.101	0.0131	0.0036	0.00433	0.0929	14.2	0.0503	0.239	0.0264	0.0094
Turkey Point 3	0.0312	0.0511	0.0221	0.00031	0.00148	0.577	44.4	0.257	0.692	-	-
Turkey Point 4	1.08	0.0559	0.0235	0.00027	0.00284	0.511	45.5	0.278	0.718	-	-
Vogtle 1	1.17	0	0	-	0.00001	-	2.87	0.00201	0.232	-	-
Waterford 3	0.0195	0.477	0.0133	-	0.00581	0.648	188	0.189	6.96	-	-
Wolf Creek 1	0.0360	0.0433	0.0283	0.00001	0.0407	0.151	28.0	0.283	0.696	-	-
Yankee Rowe 1	0.0320	0.152	0.0718	0.0625	0.131	0.0407	3.77	0.0766	1.44	1.76	0.0303
Zion 1-2	0.00385	0.126	0.00042	-	0.00048	0.0238	51.4	0.0132	2.05	-	-
Total release (TBq)	36.1	145	10.1	1.66	6.80	28.9	3400	22.2	147	2.59	7.07
Normalized activity [TBq (GW a)$^{-1}$]	0.87	3.5	0.24	0.040	0.16	0.69	82	0.53	3.5	0.062	0.17

[a] Discharge of ^{37}Ar from one reactor (Yankee Rowe 1): 0.0263 TBq, resulting in a normalized activity of 0.00063 TBq (GW a)$^{-1}$.

[b] Discharges of ^{137}Xe from two reactors (Haddam Neck: 0.0135 TBq; Trojan: 0.00762 TBq), resulting in a normalized activity of 0.00051 TBq (GW a)$^{-1}$.

[c] A dash indicates no value reported.

Table 28
Isotopic composition of noble gases released from BWRs in the United States, 1988 [T3]

Reactor	Release (TBq)													
	^{41}Ar	^{83m}Kr	^{85}Kr	^{85m}Kr	^{87}Kr	^{88}Kr	^{89}Kr [a]	^{131m}Xe	^{133}Xe	^{133m}Xe	^{135}Xe	^{135m}Xe	^{137}Xe	^{138}Xe [b]
Big Rock Point	- [c]	-	-	4.18	20.8	13.1	-	-	1.58	-	19.7	33.9	-	140
Browns Ferry 1-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brunswick 1-2	0.803	-	-	2.62	0.396	2.26	-	-	16.1	0.0418	22.6	3.13	8.51	1.87
Clinton 1	-	-	-	-	-	-	-	-	-	-	0.161	-	-	-
Cooper	-	0.511	2.83	0.999	3.17	3.27	14.1	-	4.85	0.0426	4.85	1.75	17.0	13.8
Dresden 1-3	-	-	0.00048	0.0320	0	0.0607	-	-	0.833	-	4.14	0.272	-	0.866
Duane Arnold	-	-	0.00028	0.581	0.781	1.19	-	-	8.47	0.0270	13.4	0.647	-	0.762
Edwin I. Hatch 1-2	0.496	-	3.26	6.77	3.09	6.66	-	2.52	87.3	0.0925	9.99	4.44	0.0121	3.37
Fermi 2	-	-	-	0.0158	-	-	-	-	-	-	0.0253	-	-	-
Grand Gulf 1	0.0747	-	-	0.023	0.0422	0.0251	3.16	-	0.00105	-	0.0400	0.0341	-	0.0947
Hope Creek 1	-	0.0651	-	0.0651	0.261	0.261	1.76	-	0.130	-	0.329	0.392	2.02	1.24
Humboldt Bay 3	-	-	2.40	-	-	-	-	-	-	-	-	-	-	-
James A. Fitzpatrick	0.496	-	-	15.4	6.14	20.7	-	0.466	52.2	2.19	38.9	1.91	-	5.55
Lacrosse	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lasalle 1-2	0.307	-	0.0017	19.4	0.0103	24.3	-	-	89.5	-	6.73	-	-	-
Limerick 1	-	-	0	-	-	-	-	-	3.96	0.00365	1.57	0.751	-	-
Millstone 1	-	-	7.36	0.178	1.17	0.0929	-	-	15.0	-	1.97	1.33	-	5.40
Monticello	-	0.470	6.25	0.470	2.37	1.54	41.1	0.304	59.9	0.295	2.29	3.19	53.7	40.0
Nine Mile Point 1	-	-	0.00001	-	-	-	-	-	0.544	-	0.122	-	-	-
Nine Mile Point 2	0.221	-	0.00001	0.0122	0.0280	0.0176	-	-	0	-	0.0314	0.110	0.310	0.759
Oyster Creek 1	-	-	-	12.6	28.6	32.8	-	-	33.3	-	66.2	5.96	-	7.55
Peach Bottom 2-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Perry 1	0.0381	-	-	1.95	0.105	0.655	-	0.0984	29.2	0.540	9.21	4.07	0.0295	0.247
Pilgrim 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quad-Cities 1-2	-	-	-	-	-	0.0625	-	-	0.0636	-	0.0132	-	-	-
River Bend 1	-	-	-	-	-	-	-	-	-	-	0.0759	-	-	-
Susquehanna 1-2	-	-	-	-	-	-	-	-	2.68	-	-	-	-	-
Vermont Yankee	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WNP-2	0.0229	-	0.00126	1.62	0.614	1.92	-	0.231	20.9	1.48	4.26	1.67	-	0.611
Total release (TBq)	2.46	1.05	22.1	66.9	67.5	109	60.1	3.61	427	4.71	207	63.7	81.5	221
Normalized activity [TBq (GW a)$^{-1}$]	0.15	0.063	1.3	4.0	4.0	6.5	3.6	0.22	26	0.28	12	3.8	4.9	13

[a] Discharge of ^{90}Kr from one reactor (Monticello): 1.3875 TBq, resulting in a normalized activity of 0.08299 TBq (GW a)$^{-1}$.
[b] Discharge of ^{130}Xe from one reactor (Monticello): 4.107 TBq, resulting in a normalized activity of 0.24566 TBq (GW a)$^{-1}$.
[c] A dash indicates no value reported.

Table 29
Tritium released from reactors in airborne effluents

Country	Reactor	Release (GBq)				
		1985	*1986*	*1987*	*1988*	*1989*
PWRs						
Belgium [M6]	Doel 1-4	540	580	630	1580	1410
	Tihange 1-4	0	0	0	0	0
Brazil [C1]	Angra 1	8.4	47.9	29.9	82	160
Bulgaria [C16]	Kozloduy-1-5	*Not reported*				
China, Taiwan Province [T2]	Maanshan 1-2	22.4	184	422	740	947
Czechoslovakia [N11]	Bohunice 1-4	370	3400	2400	1600	1480
	Dukovany 1-4	37	190	404	404	409
Finland [F2]	Loviisa 1-2	2900	1800	1800	1700	1100
France [E4]	Belleville 1-2 Blayais 1-4 Bugey 2-5 Cattenom 1-2 Chinon B1-B4 Chooz-A (Ardennes) Cruas 1-4 Dampierre 1-4 Fessenheim 1-2 Flamanville 1-2 Gravelines 1-6 Nogent 1-2 Paluel 1-4 St. Alban 1-2 St. Laurent B1-2 Tricastin 1-4	*Included with noble gases*				
Germany, Federal Republic of [B4, B9, S7]	Biblis A-B	3640	1800	720	670	1000
	Brokdorf	- [a]	4	89	180	100
	Emsland	-	-	-	230	500
	Grafenrheinfeld	640	700	710	500	500
	Greifswald					
	Grohnde	45	200	440	580	500
	Isar 2	-	-	-	220	400
	Mülheim-Kärlich	-	3	48	520	300
	Neckarwestheim 1-2	420	1200	980	610	1000
	Obrigheim	340	200	170	160	200
	Philippsburg 2	140	400	1000	1100	1100
	Stade	830	1100	1600	760	800
	Unterweser	1700	1800	1300	1300	800
Hungary [F3]	Paks 1-4	760	570	1000	610	680
Italy [C22]	Enrico Fermi (Trino)	370	300	180	43	31
Japan [J1]	Genkai 1-2 Ikata 1-2 Mihama 1-3 Ohi 1-2 Sendai 1-2 Takahama 1-4 Tomari-1 Tsuruga-2	*Not measured*				
Netherlands [M5]	Borssele	330	500	390	480	340
Republic of Korea [M3]	Kori 1				5	2
	Kori 2	65		167	10	357
	Kori 3-4					3260
	Ulchin 1-2	-	-	-	2	98
	Yonggwang 1-2	-	48	593	1260	650
South Africa [C20]	Koeberg 1-2				1190	2330

Table 29 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
Spain [C21]	Almaraz 1-2	100	160	1050	1360	2070
	Asco 1	280	350	480	1370	1680
	Asco 2	4	230	250	200	270
	José Cabrera 1	510	270	580	260	1530
	Trillo 1	-	-	-	20	0
	Vandellos 2	-	-	0	20	70
Sweden [N14]	Ringhals 2 Ringhals 3 Ringhals 4	*Not measured*				
Switzerland [D5, D6]	Beznau 1-2 Gösgen	*Not measured*				
USSR [G2, I14]	Armenia 1-2 Balakovo 1-3 Kalinin 1-2 Khmelnitski 1 Kola 1-4 Novovoronezh 3-5 Rovno 1-3 South Ukraine 1-3 Zaporozhe 1-5	*Reported to be = 0*				
United States [T3]	Arkansas One-1	355	223	250	128	600
	Arkansas One-2	127	81.4	177	185	460
	Beaver Valley 1-2	570	733	2630	1600	2980
	Braidwood 1	-	-	1.64	101	320
	Braidwood 2	-	-	-	98.4	140
	Byron 1-2	34.5	19.8	36.3	59.9	6810
	Callaway 1	190	759	825	566	1440
	Calvert Cliffs 1-2	121	137	35.5	1160	750
	Catawba 1	5.74	105	551	1120	880
	Catawba 2	-	105	551	1120	880
	Crystal River 3	762	614	544	367	1270
	Davis-Besse 1	607	381	344	1850	700
	Diablo Canyon 1-2	366	574	788	2420	1410
	Donald Cook 1-2	803	247	426	223	650
	Farley 1	4292	3411	1469	4290	4260
	Farley 2	12210	4551	4107	2210	3450
	Fort Calhoun 1	35.3	51.1	113	142	140
	H. B. Robinson 2	3275	127	514	283	620
	Haddam Neck	3286	357	2327	3400	5070
	Indian Point 1-2	64.8	114	31.4	62.5	11
	Indian Point 3	67.0	137	121	169	82
	Kewaunee	315	1939	1340	265	370
	Maine Yankee	101	224	113	238	470
	McGuire 1	932	1130	925	888	980
	McGuire 2	932	1130	925	888	980
	Millstone 2	4630	4290	4920	3850	2420
	Millstone 3	-	30600	2340	2650	680
	North Anna 1-2	330	2710	640	3490	4510
	Oconee 1-2-3	1580	1600	3960	1700	4370
	Palisades	158	116	118	154	410
	Palo Verde 1	151	16900	9880	15700	5770
	Palo Verde 2	-	3620	13800	10400	13300
	Palo Verde 3	-	-	115	14100	6770
	Point Beach 1-2	2480	4440	4370	4660	5250
	Prairie Island 1-2	2700	4180	2280	5590	4370
	R. E. Ginna	3200	2850	6730	6220	3200
	Rancho Seco 1	1230	910	485	648	1390
	Salem 1	947	2360	7360	14800	7360
	Salem 2	1110	5770	18200	13700	8070
	San Onofre 1	1070	63	559	759	1250
	San Onofre 2-3	295	559	3120	699	1500
	Sequoyah 1-2	3620	1040	544	507	2080
	Shearon Harris 1	-	-	0	0	0
	South Texas 1	-	-	-	636	230
	South Texas 2	-	-	-	-	440
	St. Lucie 1	14800	1510	2830	5400	11500
	St. Lucie 2	5990	1490	2530	3160	2880

Table 29 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	Surry 1-2	1210	1070	1130	1030	1020
	Three Mile Island 1	0.87	910	36.1	223	180
	Three Mile Island 2	733	1480	1310	422	530
	Trojan	884	1090	1040	2380	2700
	Turkey Point 3	8440	11000	15100	7440	160
	Turkey Point 4	5810	11000	15100	7440	160
	Virgil C. Summer 1	10.2	0.06	20.1	55.9	3.9
	Vogtle 1-2	-	-	2090	3080	33700
	Waterford 3	0	4480	22800	9100	4660
	Wolf Creek	1530	1950	2770	5400	4550
	Yankee NPS	195	381	3130	169	250
	Zion 1-2	688	2600	3070	13700	2560
Yugoslavia [F1]	Krsko	2200	1530	2470	345	590
Total release (GBq)		110000	156000	191000	203000	201000
Normalized release [GBq (GW a)$^{-1}$]		2230	2920	3140	2850	2620
Average normalized release 1985-1989[GBq (GW a)$^{-1}$]		2800				
BWRs						
China, Taiwan Province [T2]	Chin Shan 1-2	1280	1650	1260	237	334
	Kuosheng 1-2	35.7	259	323	5110	1100
Finland [F2]	TVO 1-2	140	200	150	150	110
Germany, Federal Republic of [B4, B9]	Brunsbüttel	470	240	230	150	140
	Gundremmingen B,C	76	120	140	140	220
	Isar 1	520	520	230	320	410
	Krümmel	510	730	260	230	100
	Philippsburg 1	120	16	31	51	69
	Würgissen	1000	410	450	660	920
India	Tarapur-1,2					
Italy [C22]	Caorso	545	40	20	8	2
Japan [J1]	Fukushima Daiichi 1-6 Fukushima Daini 1-4 Hamaoka 1-3 Kashiwazaki Kariwa 1,5 Onagawa-1 Shimane 1-2 Tokai 2 Tsuruga 1	*Not measured*				
Mexico [C19]	Laguna Verde (Mark II)	-	-	-	-	1120
Netherlands [M5]	Dodewaard	130	180	100	140	140
Spain [C21]	Confrentes	41	70	190	170	80
	S. Maria de Garona	250	190	210	320	620
Sweden [N14]	Barsebeck 1 Barsebeck 2 Forsmark 1 Forsmark 2 Forsmark 3 Oskarshamn 1 Oskarshamn 2 Oskarshamn 3 Ringhals 1	*Not measured*				
Switzerland [D5, D6]	Leibstadt Mühleberg	*Not measured*				
United States [T3]	Big Rock Point	932	352	256	196	190
	Browns Ferry 1-3	277	108	43.7	21.9	7.4
	Brunswick 1-2	141	262	224	205	340
	Clinton 1	-	-	9.69	326	32

Table 29 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
United States (continued)	Cooper	18.6	14.4	0	0	0
	Dresden 2-3	1800	344	696	962	540
	Duane Arnold-1	729	533	562	881	610
	Enrico Fermi 2	-	0	0	0	0
	Fitzpatrick	87.0	350	396	411	470
	Grand Gulf 1	78.1	103	121	138	120
	Hatch 1-2	984	1230	2620	1810	2000
	Hope Creek 1	-	170	170000	6030	1020
	Humboldt Bay 3	1.47	1.47	1.46	1.47	1.50
	Lacrosse	1290	448	529	47.4	39
	Lasalle 1-2	85.1	396	1240	0.12	22
	Limerick 1	0	0	5660	2370	660
	Millstone 1	3070	2420	6920	2670	4260
	Monticello	2710	2170	4480	3020	3420
	Nine Mile Point 1	1220	2950	1720	147	290
	Nine Mile Point 2	-	-	0.91	320	370
	Oyster Creek	451	714	291	463	380
-	Peach Bottom 2-3	1420	973	1100	260	210
	Perry 1	-	55.1	710	174	0
	Pilgrim 1	240	175	21.3	5.92	180
	Quad Cities 1-2	1930	2510	2510	1670	2890
	River Bend 1		22.6	157	107	220
	Susquehanna 1-2	2880	1580	1730	759	2130
	Vermont Yankee	327	105	418	1624	2050
	WPPSS-2	286	192	810	318	620
Total release (GBq)		26100	22800	207000	32600	28400
Normalized release [GBq (GW a)$^{-1}$]		1130	950	8200	1230	1080
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		2500				
HWRs						
Argentina [C15, C18]	Atucha-1	250000	320000	460000	810000	700000
	Embalse	30000	27000	33000	49000	86000
Canada [A6]	Bruce 1-4	1481000	1809000	2116000	2120000	2324000
	Bruce 5-8	98000	164000	462000	480000	760000
	Gentilly-2	49000	137000	123000	117000	137000
	Pickering 1-4	385000	346000	654000	962000	1184000
	Pickering 5-8	144000	187000	231000	196000	278000
	Point Lepreau	110000	200000	220000	220000	210000
India [B14]	Kalpakkam 1-2	167000	653000	727000	1338000	1148000
	Rajasthan 1-2	637000	667000	1123000	1032000	1476000
Pakistan [P3]	Karachi	235000	183000	199000	117000	1430000
Republic of Korea [M3]	Wolsong 1	89720	241600	313300	299000	225600
Total release (GBq)		3680000	4930000	6660000	7740000	9960000
Normalized release [GBq (GW a)$^{-1}$]		446000	522000	649000	754000	968000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		480000				
GCRs						
France [E4]	Bugey 1 Chinon A2-3 St. Laurent A1-2	*Included with noble gases*				
Japan [J1]	Tokai-1	*Not measured*				
Spain [C21]	Vandellos 1	25000	7310	9	16	18
United Kingdom [N6, P1, S4]	Berkeley Bradwell Calder Hall Chapelcross					2500

Table 29 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United Kingdom (continued)	Dungeness A					
	Dungeness B1-2					
	Hartlepool A1-A2					
	Heysham 1A-B, 2A-B					
	Hinkley Point A					
	Hinkley Point B, A,B					
	Hunterston A1	1200	1500	2000	4100	1000
	Hunterston B1-2	5500	8200	6000	5500	5400
	Oldbury-A	400				
	Sizewell-A					
	Torness A-B	-	-	-	1000	3200
	Trawsfynydd					
	Wylfa					
Total release (GBq)		32100	17000	8010	10600	12100
Normalized release [GBq (GW a)$^{-1}$]		16900	11100	5320	6230	5480
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		9020				
LWGRs						
USSR [G2, 114]	Beloyarsky 2	*Only average normalized release reported*				
	Bilibino 1-4					
	Chernobyl 1-4					
	Ignalina 1-2					
	Kursk 1-4					
	Leningrad 1-4					
	Smolensk 1-3					
Total release (GBq)						
Normalized release [GBq (GW a)$^{-1}$]						
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		26000				
FBRs						
France	Creys-Malville					
	Phenix					
USSR	Beloyarsky 3					
United Kingdom [N6]	Dounreay		13600	190	23000	350
Total release (GBq)			13600	190	23000	350
Normalized release [GBq (GW a)$^{-1}$]			130000	2000	330000	2900
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		96000				

[a] A dash indicates that the reactor was not yet in operation.

Table 30
Carbon-14 discharged as CO_2 from reactors into the atmosphere

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
PWRs						
Finland [F2]	Loviisa 1,2	320	300	320	83	300
Germany, Federal Republic of [B4, B9]	Biblis A-B	28	53	44	45	46
	Brokdorf	-	-	12	86	180
	Emsland	-	-	-	29	100
	Grafenrheinfeld	91	95	92	75	230
	Grohnde	17	-	58	61	88
	Isar 2	-	-	-	370	380
	Mülheim-Kärlich	-	10	20	26	7.4
	Neckarwestheim 1-2	30	32	49	63	93
	Obrigheim	13	20	13	9.9	9.1
	Philippsburg 2	5.6	69	54	48	71
	Stade	49	55	12	46	19
	Unterweser	75	26	28	46	33
Hungary [F3]	Paks 1, 2, 3, 4				65	59
Yugoslavia [F1]	Krsko	529	270	454	208	356
Total release (GBq)		1160	930	1160	1260	1960
Normalized release [GBq (GW a)$^{-1}$]		130	130	120	99	140
Average normalized release [GBq (GW a)$^{-1}$]		120				
BWRs						
Germany, Federal Republic of [B4, B9]	Brunsbüttel	260	720	420	590	280
	Gundremmingen	770	750	810	740	940
	Isar	320	350	330	390	400
	Kahl			0	0	0
	Krümmel	190	410	440	320	77
	Lingen			0	0	0
	Philippsburg 1	250	270	320	350	69
	Würgassen	360	340	180	190	170
Total release (GBq)		2150	2840	2500	2580	1940
Normalized release [GBq (GW a)$^{-1}$]		370	510	470	500	380
Average normalized release [GBq (GW a)$^{-1}$]		450				
HWRs						
Argentina [C15, C18]	Atucha	370	381	268	146	0
	Embalse	385	318	472	458	467
Canada [A6]	Pickering A		13300	13000	11800	4400
	Pt. Lepreau	234	443	333	36	43
Total release (GBq)		990	14400	14100	12400	4910
Normalized release [GBq (GW a)$^{-1}$]		810	7300	6400	5900	2100
Average normalized release [GBq (GW a)$^{-1}$]		4800				
GCRs						
United Kingdom [N6, S4]	Heysham 1A-B, 2A-B				76	528
	Hunterston A1					77
	Hunterston B1-2					1000
Total release (GBq)					76	1610
Normalized release [GBq (GW a)$^{-1}$]					110	660
Average normalized release [GBq (GW a)$^{-1}$]		540				

Table 31
Iodine-131 released from reactors in airborne effluents

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
PWRs						
Belgium [M6]	Doel 1-4	0.56	0.22	0.042	0.15	0.18
	Tihange 1-4	0.16	0.6	0.14	1.36	0.31
Brazil [C1]	Angra 1	0	0	0	0	0
Bulgaria [C16]	Kozloduy-1-2	5.08	3.08	13.7	4.58	1.07
	Kozloduy-3-4	3.73	2.73	4.92	2.32	1.67
	Kozloduy-5	- [a]	-		0.60	1.38
China, Taiwan Province [T2]	Maanshan 1-2	0.0057	0.00004	0	0.024	0
Czechoslovakia [N11]	Bohunice 1-4	2.2	2.4	1.8	1.4	1.48
	Dukovany 1-4	0.09	1.7	1.7	0.93	2.11
Finland [F2]	Loviisa 1-2	0.0067	0	0.038	0.08	0.24
France [E4]	Belleville 1-2 Blayais 1-4 Bugey 2-5 Cattenom 1-2 Chinon B1-B4 Chooz-A (Ardennes) Cruas 1-4 Dampierre 1-4 Fessenheim 1-2 Flamanville 1-2 Gravelines 1-6 Nogent 1-2 Paluel 1-4 St. Alban 1-2 St. Laurent B1-2 Tricastin 1-4	*Included with particulates*				
Germany, Federal Republic of [B4, B9, S7]	Biblis A-B [a]	0.1	0.037	0.055	0.078	0.021
	Brokdorf	-		0	0	0
	Emsland	-	-	-	0	0
	Grafenrheinfeld	0.00007	0.13	0.00002	0	0.011
	Greifswald	3.9	5.7	8.6	10.3	6.7
	Grohnde		0.0042	0.0029	0.00091	0.0082
	Isar 2	-	-	-	0	0
	Mülheim-Kärlich	-	0.084	0.00012	0.00091	0
	Neckarwestheim 1-2	0.018	0.16	0.00014	0.00013	0.012
	Obrigheim	0.005	0.00044	0.00004	0.00019	0
	Philippsburg 2	0.003	0.00035	0.00092	0.00047	0.00065
	Stade	0.039	0.095	0.072	0.01	0.033
	Unterweser	0.0005	0.011	0.0041	0.0056	0.003
Hungary [F3]	Paks 1-4	0.1	0.12	0.22	0.22	0.22
Italy [C22]	Enrico Fermi (Trino)	0.00019	0.0015	0.00099		
Japan [J1]	Genkai 1-2	0	0.0085	0	0	0
	Ikata 1-2	0.00005	0.034	0	0	0
	Mihama 1-3	0.027	0.067	0.0037	0.0013	0.0025
	Ohi 1-2	0.0059	0.23	0.0016	0.056	0.0012
	Sendai 1-2	0	0.011	0	0	0
	Takahama 1-4	0.021	0.11	0.0027	0.02	0.00022
	Tomari-1	-	-	-	0	0
	Tsuruga-2	-	0.033	0.001	0	0
Netherlands [M5]	Borssele	0.0025	0.011	0.002	0	0.0085
Republic of Korea [M3]	Kori 1	1.51	0.54		0	0.013
	Kori 2		0.004	0.002	0.013	
	Kori 3-4	0.028	0.052	0.2	0.174	0.096
	Ulchin 1-2	-	-	-		0.0007
	Yonggwang 1-2	-		0.00004	0.013	0.0004

Table 31 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
South Africa [C20]	Koeberg 1-2		0.18	0.38	1.5	1.183
Spain [C21]	Almaraz 1-2	0.295	0.315	0	0.004	0.002
	Asco 1	0.114	0.04	0.015	0.1	0.183
	Asco 2	0.006	0.003	0.003	0.013	0.019
	José Cabrera 1	1.18	0.199	0.393	0.234	0.848
	Trillo 1	-	-	-	0.015	0.027
	Vandellos 2	-	-	0	0.2	0.09
Sweden [N14]	Ringhals 2	0.053	0.097	0.29	0.48	0.09
	Ringhals 3	0.0024	0.53	0.57	0.063	0.01
	Ringhals 4	0.0036	0.1	1.1	1.6	0.03
Switzerland [D5, D6]	Beznau 1-2	0.0093	0.021	0.024	0.07	0.6
	Gösgen	0.078	0.0093	0.0034	0.007	0.029
USSR [G2, I14]	Armenia 1-2	7.5	4.05	1.11	5.81	5.55
	Balakovo 1-3	0	0.44	1.89	2.03	0.22
	Kalinin 1-2	0.13	0.95	3.38	0.27	1.35
	Khmelnitski 1	-	-	0	0.078	0.30
	Kola 1-4	0.54	0.77	1.60	1.13	6.35
	Novovoronezh 3-5	0.67	12.2	0.068	0.14	0.027
	Rovno 1-3	0.085	0.20	3.11	4.18	1.23
	South Ukraine 1-3	0.047	0.17		0.021	
	Zaporozhe 1-5	0.141	0.052	4.07		0.23
United States [T3]	Arkansas One-1	0.12	0.14	0.0088	0.030	0.02
	Arkansas One-2	0.11	0.0060	0.0009	0.0098	0.017
	Beaver Valley 1-2	0.016	0.18	0.45	0.046	0.0014
	Braidwood 1	-	-	0.0003	0.012	0.0085
	Braidwood 2	-	-	-	0.0028	0.0081
	Byron 1-2	0.078	2.01	0.34	0.47	0.028
	Callaway 1	0.011	0.043	0.015	0.0007	0.0057
	Calvert Cliffs 1-2	1.92	3.22	3.39	4.63	1.776
	Catawba 1	0.021	0.095	0.047	0.028	0.025
	Catawba 2	-	0.095	0.047	0.028	0.025
	Crystal River 3	0.015	0.025	0.081	0.037	0.075
	Davis-Besse 1	0.019		0.040	0.018	0.11
	Diablo Canyon 1-2	0.0089	0.051	0.068	0.026	0.034
	Donald Cook 1-2	3.81	0.60	1.97	0.25	0.024
	Farley 1	0.21	0.027	0.0098	0.044	0.0013
	Farley 2	0.011	0.050	0.0054	0.00009	0.00002
	Fort Calhoun 1	0.26	0.052	0.19	0.011	0.0047
	H. B. Robinson 2	0.50	0.36	0.77	0.040	0.00011
	Haddam Neck	0.028	0.29	0.021	1.35	0.53
	Indian Point 1-2	0.047	0.069	0.065	0.0015	0.046
	Indian Point 3	0.067	0.15	0.076	0.13	0.05
	Kewaunee	0.0014	0.0013	0.0023	0.013	0.46
	Maine Yankee	0.011	0.080	0.048	0.016	0.007
	McGuire 1	0.30	0.17	0.30	0.21	0.13
	McGuire 2	0.30	0.17	0.30	0.21	0.13
	Millstone 2	0.22	0.20	0.24	1.88	1.4
	Millstone 3	-	0.0093	0.071	0.35	0.45
	North Anna 1-2	0.90	0.79	0.47	0.058	0.14
	Oconee 1-2-3	0.14	0.86	0.51	3.07	0.83
	Palisades	0.76	0.032	0.77	0.75	0.47
	Palo Verde 1	0.053	0.29	2.09	0.058	0.022
	Palo Verde 2	-	0.11	0.50	1.68	0.11
	Palo Verde 3	-	-		0.0046	0.22
	Point Beach 1-2	0.13	0.041	0.11	0.020	0.012
	Prairie Island 1-2	0.27	0.081	0	0.00004	0.00017
	R. E. Ginna	0.036	0.010	0.084	0.0016	0.017
	Rancho Seco 1	0.24	0.055	0	0.0073	0.0098
	Salem 1	0.20	0.043	0.061	0.025	0.13
	Salem 2	0.017	0.12	0.058	0.033	0.003
	San Onofre 1	0.042	0.0074	0.015	0.38	0.077
	San Onofre 2-3	16.4	5.88	15.1	2.77	17.5
	Sequoyah 1-2	0.095	0	0	0.0013	0.011
	Shearon Harris 1	-	-	0		0.00003
	South Texas 1	-	-	-	0.030	0.13
	South Texas 2	-	-	-	-	

Table 31 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	St. Lucie 1	6.70	9.95	1.46	0.24	0.21
	St. Lucie 2	3.96	1.55	2.04	1.05	0.31
	Surry 1-2	0.94	0.65	0.67	0.35	0.014
	Three Mile Island 1	0	0.0012	0.0047	0.047	0.3
	Three Mile Island 2	0	0.0002	0		
	Trojan	0.19	0.24	0.068	0.11	0.1576
	Turkey Point 3	0.26	0.64	0.42	0.14	0.011
	Turkey Point 4	0.26	0.072	0.47	0.14	0.01055
	Virgil C. Summer 1	0.0007	0.0011	0.017	0.084	0.06
	Vogtle 1-2	-	-	0.0005	0.0004	0.003
	Waterford 3	0.13	0.19	0.031	0.032	0.024
	Wolf Creek	0.00006	0.0078	0.0008	0.0021	0.00065
	Yankee NPS	0.026	0.0070	0.0010	0.0019	0.0033
	Zion 1-2	0.070	0.11	0.0082	0.043	0.075
Yugoslavia [F1]	Krsko	10.9	13	10.5	16.3	12
Total release (GBq)		79.2	81.3	93.5	77.5	72.2
Normalized release [GBq (GW a)$^{-1}$]		1.1	1.0	1.1	0.80	0.71
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		0.93				
BWRs						
China, Taiwan Province [T2]	Chin Shan 1-2	30.1	20.9	5.74	7.14	3.96
	Kuosheng 1-2	0.0044	0.00033	0.0047	0.33	0.26
Finland [F2]	TVO 1-2	0.0030	0.078	0.036	0.0025	0.12
Germany, Federal Republic of [B4, B9]	Brunsbüttel	0.2	0.044	0.04	0.088	0.076
	Gundremmingen B,C	0.093	0.46	0.11	0.018	0.012
	Isar 1	0.011	0.54	0.12	0.15	0.0083
	Krümmel	0.011	0.0057	0.092	0.13	0.08
	Philippsburg 1	0.019	0.011	0.00092	0.12	0.0063
	Würgassen	0.8	0.4	0.25	0.16	0.3
India	Tarapur 1-2	Not reported				
Italy [C22]	Caorso	0.20	0.50	0.02	0.03	0.007
Japan [J1]	Fukushima Daiichi 1-6	0.13	0.37	0.035	0.041	0.0096
	Fukushima Daini 1-4	0	0.089	0.00001	0	0.00001
	Hamaoka 1-3	0.0029	0.093	0.00067	0.00048	0
	Kashiwazaki Kariwa 1,5	0	0.063	0	0	0
	Onagawa-1	0	0.015	0	0.00037	0
	Shimane 1-2	0	0.035	0	0	0
	Tokai 2	0	0.018	0.07	0	0
	Tsuruga 1	0.0002	0.011	0.00026	0	0
Mexico [C19]	Laguna Verde (Mark II)	-	-	-	-	0.0001
Netherlands [M5]	Dodewaard	0.05	0.04	0.03	0.04	0.04
Spain [C21]	Confrentes	0.118	0.17	1.61	1.83	0.14
	S. Maria de Garona	0.013	0.14	0.12	0.16	0.03
Sweden [N14]	Barsebeck 1	0.03	0.030	0.012	0.034	0.05
	Barsebeck 2	0.01	0.067	0.008	0.037	0.2
	Forsmark 1	0.01	0.18	0.023	0.017	0.03
	Forsmark 2	0.66	0.21	0.053	0.081	0.16
	Forsmark 3	0.03	2.40	0.64	0.86	1.1
	Oskarshamn 1	0.20	0.24	0.082	0.14	0.1
	Oskarshamn 2	0.05	0.45	0.055	5.60	1.6
	Oskarshamn 3	0.002	2.80	0.13	32.00	0.88
	Ringhals 1	5.70	0.86	0.31	0.41	0.47
Switzerland [D5, D6]	Leibstadt	0.00	0.70	0.00	0.52	2
	Mühleberg	0.06	5.40	0.04	0.57	0.46
United States [T3]	Big Rock Point	2.56	1.00	0.16	0.08	0.096
	Browns Ferry 1-3	0.44	0.06	0		

Table 31 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	Brunswick 1-2	1.48	0.56	1.85	0.84	0.56
	Clinton 1	-	-	0.00	0.01	0.0062
	Cooper	0.09	0.28	0.19	0.36	0.19
	Dresden 2-3	2.29	0.47	0.67	4.03	0.17
	Duane Arnold-1	0.03	0.26	1.67	0.25	0.0068
	Enrico Fermi 2	-	0.00	0.00	0.01	
	Fitzpatrick	1.73	0.44	1.09	0.62	0.023
	Grand Gulf 1	0.01	0.00	0.11	0.00	0.023
	Hatch 1-2	0.22	0.87	13.10	0.35	0.12
	Hope Creek 1	-				
	Humboldt Bay 3	0.00	0.00	0.00		
	Lacrosse	0.18	0.20	0.07		
	Lasalle 1-2	0.31	2.42	0.58	0.29	0.21
	Limerick 1		0.00	0.00	0.21	0.13
	Millstone 1	0.43	0.40	0.69	0.11	0.067
	Monticello	2.49	2.13	5.85	1.59	3.36
	Nine Mile Point 1	0.83	0.28	0.25		
	Nine Mile Point 2	-	-	0.00	0.00	0.017
	Oyster Creek	109	24.3	3.24	1.95	1.49
	Peach Bottom 2-3	2.20	3.20	0.56		0.032
	Perry 1	-	-	0.00	1.67	0.31
	Pilgrim 1	1.78	0.30	0.01		0.19
	Quad Cities 1-2	1.78	0.76	0.76	0.22	0.096
	River Bend 1		0.00	0.00	0.02	0.001
	Susquehanna 1-2	0.04	0.00	0.00	0.03	0.019
	Vermont Yankee	0.01	0.00	0.37	0.13	0.2
	WPPSS-2	0.07	0.15	0.24	3.33	1.43
Total release (GBq)		167	75.4	41.1	66.6	20.9
Normalized release [GBq (GW a)$^{-1}$]		4.5	1.9	0.98	1.5	0.49
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		1.8				
HWRs						
Argentina [C15, C18]	Atucha-1	0.59	0.59	0.065	0.23	0.0013
	Embalse	0.23	2.5	0.0019	0.37	0
Canada [A6]	Bruce 1-4	0	0.1	0.1	0.1	0
	Bruce 5-8	0.1	0.1	0.1	0.1	0.1
	Gentilly-2	0	0.2	0	0	0
	Pickering 1-4	0.1	0.1	0.1	0.9	1.1
	Pickering 5-8	0	0.1	0.1	0.1	0.1
	Point Lepreau	0	0	0	0.1	0
India	Kalpakkam 1-2 Rajasthan 1-2	*Not reported*				
Pakistan [P3]	Karachi	0.015	0.041			
Republic of Korea [M3]	Wolsong 1					0.00004
Total release (GBq)		1.04	3.73	0.47	1.90	1.30
Normalized release [GBq (GW a)$^{-1}$]		0.14	0.43	0.050	0.20	0.13
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		0.19				
GCRs						
France [E4]	Bugey 1 Chinon A2-3 St. Laurent A1-2	*Included with particulates*				
Japan [J1]	Tokai-1	0.0017	0.016	0.0031	0.00081	0
Spain [C21]	Vandellos 1	0.002	0.017	0.011	0.047	0.099
United Kingdom [N6, P1, S4]	Berkeley Bradwell					

Table 31 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
United Kingdom (continued)	Calder Hall					0.63
	Chapelcross					
	Dungeness A					
	Dungeness B1-2	1.9	1.9	1.9	1.9	1.9
	Hartlepool A1-A2	0.2	0.3	0.3	0.3	0.3
	Heysham 1A-B, 2A-B	0.9	1.2	1.2	1.2	1.2
	Hinkley Point A					
	Hinkley Point B, A,B	0.4	0.4	0.4	0.4	0.4
	Hunterston A1					
	Hunterston B1-2	2.3	0.1	0.1	0.1	
	Oldbury-A					
	Sizewell-A					
	Torness A-B	-	-	-		
	Trawsfynydd					
	Wylfa					
Total release (GBq)		5.70	3.93	3.91	3.95	4.53
Normalized release [GBq (GW a)$^{-1}$]		2.0	1.3	1.4	1.2	1.1
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		1.4				
LWGRs						
USSR [G2, 114]	Beloyarsky 2					17.2
	Bilibino 1-4					0
	Chernobyl 1-4	8.10				13.4
	Ignalina 1-2	80.0	149	11.9	77.3	2.63
	Kursk 1-4	64.8	35.1	39.2	16.2	5.4
	Leningrad 1-4	45.9	29.7	27.0	13.5	2.7
	Smolensk 1-3	4.3	13.5	18.9	8.17	4.2
Total release (GBq)		203	227	97.0	115	45.5
Normalized release [GBq (GW a)$^{-1}$]		18	27	10	12	3.8
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		14				
FBRs						
France [S6]	Creys-Malville	*Not reported*				
	Phenix					
USSR [114]	Beloyarsky 3	*Not reported*				
United Kingdom [N6]	Dounreay	*Not reported*				
Total release (GBq)						
Normalized release [GBq (GW a)$^{-1}$]						
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]						

[a] A dash indicates that the reactor was not yet in operation.

Table 32
Isotopic composition of Iodine released from reactors in the United States, 1988
[T3]

Reactor	Release (GBq)				
	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I
PWRs					
Arkansas One 1	0.030	0.00016	0.00111	-	-
Arkansas One 2	0.00981	0.00008	0.00142	-	-
Beaver Valley 1-2	0.0459	.[a]	0.00659	-	0.00079
Braidwood 1	0.0119	-	0.0047	0.888	-
Braidwood 2	0.00282	-	0.00058	-	0.00012
Byron 1-2	0.474	0.0165	0.138	0.00093	0.0414
Callaway 1	0.00069	-	-	-	-
Calvert Cliffs 1-2	4.63	-	4.33	-	0.00332
Catawba 1	0.0282	0.00009	0.0167	0.00005	0.00007
Catawba 2	0.0282	0.00009	0.0167	0.00005	0.00007
Crystal River 3	0.0365	-	0.00269	-	-
Davis-Besse 1	0.0176	-	0.00607	-	-
Diablo Canyon 1-2	0.0259	-	0.0134	-	-
Donald C. Cook 1-2	0.251	-	0.0301	-	0.00246
Fort Calhoun	0.0114	-	0.0847	-	-
H.B. Robinson 2	0.0396	-	0.0252	-	-
Haddam Neck	1.35	-	0.0944	-	1.44
Harris 1	-	0.00013	-	-	-
Indian Point 1-2	0.00149	-	0.110	-	-
Indian Point 3	0.126	-	0.0202	-	-
Joseph M. Farley 1	0.0437	-	0.00005	-	-
Joseph M. Farley 2	0.00009	-	0	-	-
Kewaunee	0.0128	0.196	0.00093	-	-
Maine Yankee	0.0164	-	0.004	-	-
McGuire 1	0.206	0.0444	0.0677	0	0.00003
McGuire 2	0.206	0.0444	0.0677	0	0.00003
Millstone 2	1.88	-	0.966	-	-
Millstone 3	0.350	-	0.1647	-	-
North Anna 1-2	0.0577	0.00025	0.448	-	0.00044
Oconee 1-3	3.07	0.0540	0.707	0.00692	0.174
Palisades	0.747	0.0263	0.172	-	0.0187
Palo Verde 1	0.0577	-	0.0188	-	0.0258
Palo Verde 2	1.68	0.0001	0.0247	-	0.00042
Palo Verde 3	0.00455	0.00025	0.00474	-	0.00041
Point Beach 1-2	0.0201	0.0177	0.0566	-	0.0034
Prairie Island 1-2	0.00004	-	0.00074	-	-
R.E. Ginna	0.0016	-	0.104	-	-
Rancho Seco 1	0.00733	-	0.00155	-	-
Salem 1	0.0249	-	-	-	-
Salem 2	0.0326	-	-	-	-
San Onofre 1	0.381	0.144	0.0396	-	0.0198
San Onofre 2-3	2.77	0.0167	0.599	-	0.0692
Sequoyah 1-2	0.00134	-	-	-	-
South Texas 1	0.0303	-	0.00947	-	-
St. Lucie 1	0.237	1.584	1.58	-	-
St. Lucie 2	1.055	-	1.44	-	-
Summer 1	0.0844	0.00851	0.0418	0.00008	0.00389
Surry 1-2	0.354	0.0403	0.174	0.00034	0.0154
Three Mile Island 1	0.0466	0.00012	0.0285	-	0.0414
Three Mile Island 2	-	-	-	-	-
Trojan	0.107	0.00001	0.0377	-	0.00026
Turkey Point 3	0.144	-	0.157	-	0.0729
Turkey Point 4	0.142	-	0.156	-	0.0729
Vogtle 1	0.00035	-	0.00179	-	-
Waterford 3	0.0322	-	0.0002	-	-
Wolf Creek 1	0.00209	-	-	-	-
Yankee Rowe 1	0.00186	-	0.0006	-	0.00006
Zion 1-2	0.0426	0.0611	0.0151	0.00973	0.00673
Total release (GBq)	20.1	2.25	11.1	0.91	2.01
Normalized activity [GBq (GW a)$^{-1}$]	0.50	0.054	0.29	0.022	0.048

Table 32 (continued)

Reactor	Release (GBq)				
	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I
BWRs					
Big Rock Point	0.0796	-	0.759	-	0.929
Browns Ferry 1-3	-	-	-	-	-
Brunswick 1-2	0.840	1.41	1.61	0.840	1.69
Clinton 1	0.00907	-	0.0177	0.00285	-
Cooper	0.365	0.00342	0.0747	-	0.0414
Dresden 1-3	4.03	-	1.447	-	2.49
Duane Arnold	0.246	-	0.0725	-	0.0117
Edwin I. Hatch 1 -2	0.347	-	0.995	-	0.910
Fermi 2	0.015	0.00037	0.236	-	0.00312
Grand Gulf 1	0.00225	-	0.0109	-	-
Hope Creek 1	-	-	-	-	-
Humboldt Bay 3	-	-	-	-	-
James A. Fitzpatrick	0.622	-	1.77	-	-
Lacrosse	-	-	-	-	-
Lasalle 1-2	0.289	0.888	14.9	0.115	1.43
Limerick 1	0.208	-	0.136	-	-
Millstone 1	0.110	-	0.537	-	-
Monticello	1.59	-	7.84	-	7.14
Nine Mile Point 1	-	-	-	-	-
Nine Mile Point 2	0.00094	-	0.00858	-	-
Oyster Creek 1	1.95	-	8.66	-	7.4
Peach Bottom 2-3	-	-	-	-	-
Perry 1	1.67	0.00246	1.24	-	0.0182
Pilgrim 1	-	-	-	-	-
Quad-Cities 1-2	0.225	-	1.32	-	3.38
River Bend 1	0.0177	-	0.176	-	-
Susquehanna 1-2	0.0262	-	-	-	-
Vermont Yankee	0.128	-	0.184	-	-
WNP-2	3.33	0.249	1.49	-	0.0503
Total release (GBq)	16.1	2.54	43.5	0.95	25.5
Normalized activity [GBq (GW a)$^{-1}$]	0.96	0.15	2.6	0.057	1.5

[a] A dash indicates no value reported.

Table 33
Particulates released from reactors in airborne effluents

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
PWRs						
Belgium [M6]	Doel 1-4	0.33	0.53	0.18	0.12	0.03
	Tihange 1-4	0.025	0.073	0.062	0.095	0.071
Brazil [C1]	Angra 1	0.0007	0	0	0	0
Bulgaria [C16]	Kozloduy-1-2	1.56	1.21	5.28	1.96	1.32
	Kozloduy-2					
	Kozloduy-3-4	1.74	3.16	0.90	0.74	0.74
	Kozloduy-4					
	Kozloduy-5	- [a]	-		0.41	1.19
China, Taiwan Province [T2]	Maanshan 1-2	0.038	0.0030	0	0.018	0.033
Czechoslovakia [N11]	Bohunice 1-4	1.73	0.44	0.16	0.2	0.38
	Dukovany 1-4	0.031	0.06	0.08	0.04	0.172
Finland [F2]	Loviisa 1-2	0.043	0.091	0.068	0.058	1.8
France [E4]	Belleville 1-2	-	-	0.013	0.082	0.13
	Blayais 1-4	2.5	2.6	0.33	0.41	0.72
	Bugey 2-5	0.7	1.5	0.84	0.85	0.69
	Cattenom 1-2	-	0.0041	0.3	0.19	0.18
	Chinon B1-B4	0.3	1.1	1.5	0.36	0.56
	Chooz-A (Ardennes)	0.07	0.26	0.096	0.1	0.19
	Cruas 1-4	0.07	0.28	0.093	0.069	0.09
	Dampierre 1-4	1.5	7.1	0.59	0.41	0.75
	Fessenheim 1-2	0.12	0.17	0.11	0.026	0.025
	Flamanville 1-2		0.089	0.097	0.29	0.1
	Gravelines 1-6	1.9	2.1	1.7	0.69	1.1
	Nogent 1-2	-	-	0.0047	0.084	0.096
	Paluel 1-4	0.26	0.48	0.59	0.43	0.51
	St. Alban 1-2	0.033	0.18	0.11	0.083	0.11
	St. Laurent B1-2	0.7	1.5	0.6	0.52	0.44
	Tricastin 1-4	0.6	0.7	0.22	0.18	0.23
Germany, Federal Republic of [B4, B9, S7]	Biblis A-B	0.31	0.1	0.17	0.32	0.077
	Brokdorf	-	0	0.00003	0.00023	0
	Emsland	-	-	-	0	0.00032
	Grafenrheinfeld	0.002	0	0.0017	0.0014	0.00096
	Greifswald	0.5	0.5	0.5	0.6	0.6
	Grohnde		0.00054	0.00069	0.00065	0.00088
	Isar 2	-	-	-	0.00014	0.00005
	Mülheim-Kärlich	-	0	0	0	0
	Neckarwestheim 1-2	0.014	0.022	0.012	0.0063	0.0044
	Obrigheim	0.024	0.032	0.012	0.014	0.013
	Philippsburg 2		0.00005	90.0001	0.00013	0.0011
	Stade	0.028	0.026	0.013	0.031	0.052
	Unterweser	0.008	0.0056	0.0076	0.0028	0.0014
Hungary [F3]	Paks 1-4	0.12	1.02	2.21	1.57	4.12
Italy [C22]	Enrico Fermi (Trino)	0.00067	0.0045	0.0017	0.0009	0.0006
Japan [J1]	Genkai 1-2 Ikata 1-2 Mihama 1-3 Ohi 1-2 Sendai 1-2 Takahama 1-4 Tomari-1 Tsuruga-2	*Not measured*				
Netherlands [M5]	Borssele	0	0.004	0	0	0
Republic of Korea [M3]	Kori 1	0.13	0.14	0.015	0.009	0.034
	Kori 2	0.002	0.003	0.003	0.001	0.0002
	Kori 3-4		0.002	0.016	0.0001	0.001

Table 33 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
Republic of Korea (continued)	Ulchin 1-2	-	-	-	0	0.139
	Yonggwang 1-2	-	0.00007	0.001	0.007	0.002
South Africa [C20]	Koeberg 1-2		0 005	0.0007	0	0.0002
Spain [C21]	Almaraz 1-2	2.47	0.67	0.003	0.04	0.05
	Asco 1	0.06	2.24	4.45	0.04	0.04
	Asco 2	0.007	0.01	0.02	0.03	0.03
	José Cabrera 1	0.23	0.1	0.08	0.12	0.18
	Trillo 1	-	-	-	0.005	0.005
	Vandellos 2	-	-	0	0.0002	0.01
Sweden [N14]	Ringhals 2	0.008	0.006	0.005	0.012	0.0045
	Ringhals 3	0.004	0.002	0.011	0.006	0.0034
	Ringhals 4	0.001	0.002	0.012	0.008	0.0058
Switzerland [D5, D6]	Beznau 1-2	0.0009	0.0007	0.00085	0.011	0.00065
	Gösgen	0.01	0.0057	0.00078	0.0023	0.0014
USSR [G2, I14]	Armenia 1-2	7.50	7.48	24.3	32.4	31.9
	Balakovo 1-3	0	104	0.43	0.49	0.15
	Kalinin 1-2	0.009	0.088	0.059	0.19	0.05
	Khmelnitski 1	-	-			0.063
	Kola 1-4	0.22	0.43	0.91	0.89	11.3
	Novovoronezh 3-5	27.8	28.1	3.10	5.31	1.32
	Rovno 1-3		0.74	0.84	0.14	0.20
	South Ukraine 1-3	0.19	2.43		0.16	
	Zaporozhe 1-5	0.00072	0.041	0.044	0.067	0.19
United States [T3]	Arkansas One-1	0.012	0.0067	0.0024	0.0080	0.01
	Arkansas One-2	0.010	0.0027	0.0010	0.0058	0.005
	Beaver Valley 1-2	0.043	0.11	0.052	0.085	0.4086
	Braidwood 1	-	-	0.0002	0.89089	0.0009
	Braidwood 2	-	-	-	0.0007	0.0029
	Byron 1-2	0.0026	0.011	0.0048	0	0.001
	Callaway 1	0.0006	0.0011	0.0014	0.012	0.0004
	Calvert Cliffs 1-2	0.059	0.0074	0.0037	0.41	0.004
	Catawba 1	0	0.15	0.23	0.12	0.003
	Catawba 2	-	0.15	0.23	0.12	0.003
	Crystal River 3	0.012	0.013	0.048	0.0097	0
	Davis-Besse 1	0		0.0059	0	0.003
	Diablo Canyon 1-2	0	0.0026	0.019	0.022	0.002
	Donald Cook 1-2	2.78	0.25	0.41	0.079	1.246
	Farley 1	0.0004	0.0029	0.0043	0.016	0
	Farley 2	0.0003	0	0.0002	0.00001	0.00001
	Fort Calhoun 1	0.0081	0.0026	0	0.0001	0
	H. B. Robinson 2	0.0074	0.0078	0	0.0011	0.00509
	Haddam Neck	0.014	0.056	0.029	0.019	0.03
	Indian Point 1-2	210	309	0.52	0.34	0.094
	Indian Point 3	0.0033	0.0033	0.0007	0.0004	0.0003
	Kewaunee	0.0089	0.21	0.45	0.38	0.19
	Maine Yankee	0.0042	0.020	0.044	0.0010	0.0018
	McGuire 1	0.18	0.96	1.95	0.021	0.01
	McGuire 2	0.18	0.96	1.95	0.021	0.01
	Millstone 2	0.020	0.0026	0.0004	0.019	0
	Millstone 3	-	0.0044	0.12	0.016	0.02
	North Anna 1-2	2.27	0.052	0.17	0.027	0.02
	Oconee 1-2-3	0.044	0.75	4.89	2.96	0.49
	Palisades	1.06	0.080	0.25	0.23	0.17
	Palo Verde 1	0.0004	0.0022	0.056	0.0096	0.006
	Palo Verde 2	-	0.015	0	0.048	0.002
	Palo Verde 3	-	-		0.00004	0.02
	Point Beach 1-2	0.21	0.021	0	0.062	0.108
	Prairie Island 1-2	0.0011	0.0007	0.0086	0.0028	0.00061
	R. E. Ginna	0.0003	0.0046	0.24	0.0005	0.014
	Rancho Seco 1	0.053	0.0004	0.00006	0.010	0.0002
	Salem 1	1.44	0	0	0.054	0.004
	Salem 2	3.29	0	0.0019	0.0041	0.029
	San Onofre 1	0.0011	0.0004	0.0003	0.019	0.005
	San Onofre 2-3	0.19	0.11	0.41	0.096	0.001
	Sequoyah 1-2	0.022	0.058	0.019	0.0057	0.005

Table 33 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
United States (continued)	Shearon Harris 1	-	-	0.0002	1.00	0.00003
	South Texas 1	-	-	-	0	0.02
	South Texas 2	-	-	-	-	0.053
	St. Lucie 1	22.6	0	0	0	0.003
	St. Lucie 2	3.15	0.0074	0.0037	0.0037	0
	Surry 1-2	0.044	0.13	0.10	0.39	0.046
	Three Mile Island 1	0.0011	0.013	0	0	0
	Three Mile Island 2	0.0017	0.0060	0.0027	1.00	0.00013
	Trojan	0.016	0.017	0.028	0.040	0.0014
	Turkey Point 3	0.030	0.074	0.041	0.034	0.099
	Turkey Point 4	0.030	0.019	0.041	0.034	0.00051
	Virgil C. Summer 1	0.0002	0	0.0095	0.0019	0
	Vogtle 1-2	-	-	0.0003	0.0003	0.043
	Waterford 3	0	0.0059	0.0068	0.014	0.004
	Wolf Creek	0	0	0.0072	0.001	0.0002
	Yankee NPS	0.0020	0.0005	0.0005	0.0003	0.0034
	Zion 1-2	0.87	1.54	0.14	0.48	0.013
Yugoslavia [F1]	Krsko	0.535	0.102	0.396	0.1	0.073
Total release (GBq)		303	487	154	60	65
Normalized release [GBq (GW a)$^{-1}$]		3.6	5.0	1.4	0.50	0.51
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		2.0				
		BWRs				
China, Taiwan Province [T2]	Chin Shan 1-2	7.51	8.21	0.63	0.60	0.37
	Kuosheng 1-2	0.036	0.0056	0.0027	0.027	0.021
Finland [F2]	TVO 1-2	1.1	0.95	0.2	0.2	0.18
Germany, Federal Republic of [B4, B9]	Brunsbüttel	0.021	0.008	0.03	0.023	0.052
	Gundremmingen B,C	0	0.031	0.0034	0.0031	0
	Isar 1	0.15	0.23	0.019	0.028	0.0085
	Krümmel	0.052	0.035	0.022	0.0025	0.0054
	Philippsburg 1	0.11	0.029	0.02	0.017	0.013
	Würgassen	0.22	0.22	0.21	0.24	0.28
India	Tarapur-1					
	Tarapur-2					
Italy [C22]	Caorso	0.68	0.33	0.069	0.03	0.036
Japan [J1]	Fukushima Daiichi 1-6 Fukushima Daini 1-4 Hamaoka 1-3 Kashiwazaki Kariwa 1,5 Onagawa-1 Shimane 1-2 Tokai 2 Tsuruga 1	*Not measured*				
Mexico [C19]	Laguna Verde (Mark II)	-	-	-	-	0.0122
Netherlands [M5]	Dodewaard	0.062	0.028	0.019	0.038	0.041
Spain [C21]	Confrentes	0.16	0.13	0.07	0.15	0.1
	S. Maria de Garona	0.27	0.15	0.23	0.14	0.05
Sweden [N14]						
	Barsebeck 1	3.96	0.45	0.3	0.066	0.2
	Barsebeck 2	0.2	0.22	0.087	0.124	48
	Forsmark 1	15.4	1.4	0.54	0.25	0.2
	Forsmark 2	5.21	7.7	2.3	0.94	0.6
	Forsmark 3	0.45	103	156	112	61
	Oskarshamn 1	6.15	7.9	2.5	4.5	7.3
	Oskarshamn 2	1.5	0.32	1	179	64
	Oskarshamn 3	0.013	1.7	0.026	79	14
	Ringhals 1	0.93	4.19	0.35	1.95	87

Table 33 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
Switzerland [D5, D6]	Leibstadt	0.0012	0.00038	0.037	0.012	0.056
	Mühleberg	0.07	12	0.19	0.13	0.078
United States [T3]	Big Rock Point	0.49	1.80	0.93	1.80	0.084
	Browns Ferry 1-3	0.48	0.039	0.066	1.07	0.0069
	Brunswick 1-2	0.85	1.17	4.88	5.71	1.23
	Clinton 1	-	-	0.0080	2.19	0.34
	Cooper	0.76	0.15	0.80	0.39	0.0046
	Dresden 2-3	3.48	2.16	4.70	4.66	42.4
	Duane Arnold-1	0.30	2.45	3.40	0.33	0.11
	Enrico Fermi 2	-	0.00001	0.32	0.068	0.62
	Fitzpatrick	4.45	2.76	3.94	1.97	2.61
	Grand Gulf 1	0.020	0.013	0.048	0.016	0.017
	Hatch 1-2	2.50	0.35	0.59	1.24	0.09
	Hope Creek 1	-				0
	Humboldt Bay 3	0.0028	0.0061	0.0025	1.01	0.0014
	Lacrosse	0.096	0.020	0.016	1.00	0.00048
	Lasalle 1-2	0.55	0.20	1.26	0.21	0.09
	Limerick 1		0.28	0.043	0.038	0.15
	Millstone 1	1.49	1.35	0.23	0.17	0.26
	Monticello	1.19	0.40	0.56	1.33	0.86
	Nine Mile Point 1	0.45	0.37	0.35	1.07	0.11
	Nine Mile Point 2	-	-	191	0.025	0.17
	Oyster Creek	3.33	1.55	0.60	0.40	0.39
	Peach Bottom 2-3	0.34	0.21	0.185	1.06	0.098
	Perry 1	-	0.00004	0.0003	0.041	0.01
	Pilgrim 1	0.32	0.16	0.0175	1.01	0.02
	Quad Cities 1-2	20.6	3.35	2.72	0.69	1.4
	River Bend 1		0.0009	0.011	0.018	0.014
	Susquehanna 1-2	0.94	0.12	0.22	0.041	0.022
	Vermont Yankee	0.20	0.47	0.10	0.12	0.13
	WPPSS-2	8.92	2.44	2.61	15.02	2.9
Total release (GBq)		96.1	171	385	422	338
Normalized release [GBq (GW a)$^{-1}$]		3.3	5.6	12.4	13.0	10.3
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		9.1				
HWRs						
Argentina [C15, C18]	Atucha-1	0.022	0.0044	0.014	0.0023	0.00075
	Embalse	0.22	0.039	0.95	0.089	0
Canada [A6]	Bruce 1-4	0.3	0.4	0.8	1	0.1
	Bruce 5-8	0.2	0.3	0.3	0.2	0.2
	Gentilly-2	0	0	0	0	0
	Pickering 1-4	0	1.1	1.1	0.8	1
	Pickering 5-8	0	0	0	0	0
	Point Lepreau	0	0	0	0	0
India [B14]	Kalpakkam 1-2					
	Rajasthan 1-2	0.22	0.20	0.35	0.35	0.15
Pakistan	Karachi	*Not reported*				
Republic of Korea [M3]	Wolsong 1	0.006				0.006
Total release (GBq)		0.97	2.04	3.51	2.44	1.46
Normalized release [GBq (GW a)$^{-1}$]		0.12	0.23	0.37	0.26	0.14
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		0.23				
GCRs						
France [E4]	Bugey 1	0.2	0.15	0.13	0.12	0.33
	Chinon A2-3	0.1	0.5	1.3	0.25	0.21
	St. Laurent A1-2	1.2	1.3	0.5	0.4	0.26
Japan [J1]	Tokai-1					

Table 33 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
Spain [C21]	Vandellos 1	0.05	0.07	0.08	0.19	0.27
United Kingdom [N6, P1, S4]	Berkeley	0	0	0	0.03	0.006
	Bradwell	0.1	0.1	0.1	0.08	0.06
	Calder Hall					0.6
	Chapelcross					
	Dungeness A	0.2	0.2	0.2	0.2	0.2
	Dungeness B1-2	0.1	0.3	0.1	0.1	0.1
	Hartlepool A1-A2	0	0	0	0.04	0.04
	Heysham 1A-B, 2A-B	0	0	0.1	0.05	0.05
	Hinkley Point A	0.3	0.3	0.3	0.3	0.3
	Hinkley Point B, A,B	0.5	0.6	0.6	0.5	0.5
	Hunterston A1	0	0.065	0.084	0.098	0.11
	Hunterston B1-2	0.2	0.22	0.27	0.14	0.083
	Oldbury-A	0.2	0.2	0.3	0.1	0.1
	Sizewell-A	0.5	1.4	0.4	0.6	0.5
	Torness A-B	-	-	-	0.17	0.023
	Trawsfynydd	0.5	0.5	0.6	0.3	0.2
	Wylfa	0.1	0.1	0.1	0.2	0.1
Total release (GBq)		4.25	6.01	5.16	3.87	4.04
Normalized release [GBq (GW a)$^{-1}$]		0.62	0.96	0.83	0.53	0.51
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		0.68				
LWGRs						
USSR [G2, 114]	Beloyarsky 2					28.5
	Bilibino 1-4					0
	Chernobyl 1-4	14.8				49.7
	Ignalina 1-2	38.0	8.78	3.33	3.55	1.74
	Kursk 1-4	153	48.6	91.8	43.2	20.3
	Leningrad 1-4	9.45	7.29	5.40	4.05	9.45
	Smolensk 1-3	4.40	12.2	8.64	11.2	4.86
Total release (GBq)		220	76.9	109	62.0	115
Normalized release [GBq (GW a)$^{-1}$]		20	9.1	12	6.5	9.6
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		12				
FBRs						
France [S6]	Creys-Malville	0.002	0.04	0.007	0.007	0.008
	Phenix	0.03	0.02	0.02	0.02	0.02
USSR	Beloyarsky 3					
United Kingdom [N6]	Dounreay		0.013	0.010	0.032	0.056
Total release (GBq)		0.032	0.073	0.037	0.059	0.084
Normalized release [GBq (GW a)$^{-1}$]		0.24	0.19	0.10	0.25	0.22
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		0.19				

[a] A dash indicates that the reactor was not yet in operation.

Table 34
Tritium released from reactors in liquid effluents

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
PWRs						
Belgium [M6]	Doel 1-4	46700	44300	49400	72800	56800
	Tihange 1-4	46200	54500	58000	69200	49600
Brazil [C1]	Angra 1	*Not reported*				
Bulgaria [C16]	Kozloduy 1-5	*Not reported*				
China, Taiwan Province [T2]	Maanshan 1-2	6600	4120	15400	14600	17400
Czechoslovakia [N11]	Bohunice 1-4	12560	14590	13650	8280	10440
	Dukovany 1-4	6900	2800	13700	14600	18000
Finland [F2]	Loviisa 1-2	9300	13000	13000	16000	15000
France [E4]	Belleville 1-2	- [a]	-	200	19000	29000
	Blayais 1-4	80000	87000	78000	63000	60000
	Bugey 2-5	79000	87000	64000	62000	51000
	Cattenom 1-2	-	100	12000	23000	24000
	Chinon B1-B4	22000	40000	48000	50000	47000
	Chooz-A (Ardennes)	98000	111000	107000	71000	110000
	Cruas 1-4	57000	48000	50000	49000	36000
	Dampierre 1-4	67000	77000	57000	54000	64000
	Fessenheim 1-2	30000	38000	36000	33000	24000
	Flamanville 1-2	100	7000	42000	36000	33000
	Gravelines 1-6	95000	114000	97000	82000	91000
	Nogent 1-2	-	-	1000	15000	22000
	Paluel 1-4	31000	68000	86000	100000	100000
	St. Alban 1-2	3000	16000	29000	21000	37000
	St. Laurent B1-2	30000	40000	43000	31000	43000
	Tricastin 1-4	72000	61000	54000	55000	54000
Germany, Federal Republic of [B4, B9, S7]	Biblis A-B	33000	29000	24000	24000	25000
	Brokdorf	-	100	25000	940	13000
	Emsland	-	-	-	1700	13000
	Grafenrheinfeld	22000	14000	16000	14000	14000
	Greifswald					
	Grohnde	7200	8000	16000	13000	13000
	Isar 2	-	-	-	1800	7100
	Mülheim-Kärlich	-	1900	4900	10000	1700
	Neckarwestheim 1-2	13000	11000	12000	7400	17800
	Obrigheim	5300	4100	5700	3800	4400
	Philippsburg 2	13000	22000	13000	13000	21000
	Stade	6200	7100	6100	6000	4600
	Unterweser	27000	14000	14000	12000	15000
Hungary [F3]	Paks 1-4	8600	7200	11800	16400	14900
Italy [C22]	Enrico Fermi (Trino)	23800	69	5350	63	67
Japan [J1]	Genkai 1-2	21000	32000	29000	17000	26000
	Ikata 1-2	31000	33000	33000	21000	34000
	Mihama 1-3	16000	22000	24000	21000	13000
	Ohi 1-2	29000	41000	33000	30000	26000
	Sendai 1-2	20000	27000	34000	41000	38000
	Takahama 1-4	37000	44000	48000	70000	40000
	Tomari-1	-	-	-	440	2100
	Tsuruga-2	-	5600	23300	4070	12000
Netherlands [M5]	Borssele	5700	8400	4600	6900	5700
Republic of Korea [M3]	Kori 1	18900	10900		7810	16000
	Kori 2	10800	14000	18300	12100	25700
	Kori 3-4	12200	24800	26600	30300	32600
	Ulchin 1-2	-	-	-	2430	6900
	Yonggwang 1-2	-	3970	17700	7740	35100
South Africa [C20]	Koeberg 1-2		15100	10800	32400	37300

Table 34 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
Spain [C21]	Almaraz 1-2	36100	15000	31100	47000	49000
	Asco 1	9130	11000	13000	18400	16100
	Asco 2	3180	20000	16200	18300	23500
	José Cabrera 1	2540	1180	20	10	2150
	Trillo 1	-	-	-	677	10200
	Vandellos 2	-	-	0.4	4680	10600
Sweden [N14]	Ringhals 2	19500	13400	30500	13100	12600
	Ringhals 3	10800	19600	19200	20000	23000
	Ringhals 4	14600	13500	14600	19100	21700
Switzerland [D5, D6]	Beznau 1-2	34000	41000	37000	22000	10000
	Gösgen	23000	15000	12000	14000	12000
USSR [G2, I14]	Armenia 1-2 Balakovo 1-3 Kalinin 1-2 Khmelnitski 1 Kola 1-4 Novovoronezh 3-5 Rovno 1-3 South Ukraine 1-3 Zaporozhe 1-5	*Average normalized release estimated to be 30000 GBq (GW a)$^{-1}$*				
United States [T3]	Arkansas One-1	12100	7840	5550	9250	14097
	Arkansas One-2	8920	8510	13000	9030	16280
	Beaver Valley 1-2	5550	7620	21200	15100	22977
	Braidwood 1	-	-	1520	10100	20646
	Braidwood 2	-	-	-	9030	20646
	Byron 1-2	9660	2480	15200	37400	47730
	Callaway 1	21800	16100	16600	33000	22533
	Calvert Cliffs 1-2	17900	27200	27300	23100	8732
	Catawba 1	6480	4370	13500	13100	16465
	Catawba 2	-	4370	13500	13100	16465
	Crystal River 3	6510	6400	13200	18900	12728
	Davis-Besse 1	2490	773	9100	1300	8843
	Diablo Canyon 1-2	15800	25800	25600	15900	34595
	Donald Cook 1-2	42200	25700	72900	40700	32338
	Farley 1	22300	26400	23600	19100	25863
	Farley 2	18600	23000	18700	27900	22496
	Fort Calhoun 1	6180	6810	8440	8580	8436
	H. B. Robinson 2	11400	12700	10100	19800	6068
	Haddam Neck	213000	95500	117000	43700	178000
	Indian Point 1-2	13000	12400	20800	16200	20720
	Indian Point 3	12600	21000	12600	21200	12897
	Kewaunee	14000	10900	13000	12300	12617
	Maine Yankee	6810	13000	4370	10800	15614
	McGuire 1	14900	16900	18200	19600	15651
	McGuire 2	14900	16900	18200	19600	15651
	Millstone 2	6140	10400	10600	9580	13542
	Millstone 3	-	20000	21800	20200	25789
	North Anna 1-2	54800	57700	30900	71800	51800
	Oconee 1-2-3	45900	49600	35100	26300	37740
	Palisades	15900	2340	4400	10500	2982
	Palo Verde 1	0	0	0	0	0
	Palo Verde 2	-	0	0	0	0
	Palo Verde 3	-	-	0	0	0
	Point Beach 1-2	29800	30000	26200	13200	20683
	Prairie Island 1-2	25800	24800	16500	15000	17168
	R. E. Ginna	18500	13200	20900	12900	21904
	Rancho Seco 1	3330	2410	677	3740	2697
	Salem 1	34200	15200	14000	23500	22533
	Salem 2	21300	16200	24500	13600	18907
	San Onofre 1	88100	16800	84000	56600	35594
	San Onofre 2-3	17600	27400	30300	23800	48100
	Sequoyah 1-2	23400	9100	4400	7440	42550
	Shearon Harris 1	-	-	9180	14800	16946
	South Texas 1	-	-	-	7360	11729
	South Texas 2	-	-	-	-	10064
	St. Lucie 1	10600	10300	12500	10200	14985
	St. Lucie 2	13500	10300	12500	10200	14985

Table 34 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	Surry 1-2	28800	32300	30200	18300	15873
	Three Mile Island 1	335	6250	7290	11200	13801
	Three Mile Island 2	0.08	0.06	0.05	0.2	0.036
	Trojan	9810	5290	6480	13900	11800
	Turkey Point 3	16000	13500	9950	11100	8473
	Turkey Point 4	16000	13500	9950	11100	8473
	Virgil C. Summer 1	11500	13900	27200	27900	25345
	Vogtle 1-2	-	-	11900	14400	33966
	Waterford 3	940	15900	19400	18600	13256
	Wolf Creek	6770	13900	11700	15000	21756
	Yankee NPS	8440	6510	8100	7250	6216
	Zion 1-2	24300	26400	24300	35900	38739
Yugoslavia [F1]	Krsko	10900	13000	10500	16300	12000
Total release (GBq)		2350000	2350000	2650000	2580000	2970000
Normalized release [GBq (GW a)$^{-1}$]		28000	24200	25100	22600	24200
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		25000				
BWRs						
China, Taiwan Province [T2]	Chin Shan 1-2	174	233	673	205	1720
	Kuosheng 1-2	95.1	112	944	529	1150
Finland [F2]	TVO 1-2	1200	1600	1900	1300	1300
Germany, Federal Republic of [B4, B9]	Brunsbüttel	870	500	500	510	270
	Gundremmingen B,C	1200	1200	1600	1200	1500
	Isar 1	470	650	750	810	510
	Krümmel	760	1000	950	880	690
	Philippsburg 1	900	770	620	550	480
	Würgassen	710	490	390	410	960
India	Tarapur-1					
	Tarapur-2					
Italy [C22]	Caorso	1120	1200	97	29	6.3
Japan [J1]	Fukushima Daiichi 1-6	4100	3400	2300	2600	2600
	Fukushima Daini 1-4	410	440	700	960	1500
	Hamaoka 1-3	2400	1700	1700	1500	1300
	Kashiwazaki Kariwa 1,5	44	16	36	0	170
	Onagawa-1	24	41	63	110	75
	Shimane 1-2	310	120	280	130	280
	Tokai 2	590	740	520	480	1100
	Tsuruga 1	350	410	350	440	240
Mexico [C19]	Laguna Verde (Mark II)	-	-	-	-	1120
Netherlands [M5]	Dodewaard	170	270	170	150	200
Spain [C21]	Confrentes	540	120	70	30	70
	S. Maria de Garona	250	100	160	490	60
Sweden [N14]	Barsebeck 1	290	950	490	280	400
	Barsebeck 2	290	950	490	280	400
	Forsmark 1	580	441	630	705	760
	Forsmark 2	580	441	630	705	760
	Forsmark 3	150	1060	330	390	550
	Oskarshamn 1	260	386	610	735	490
	Oskarshamn 2	260	386	610	735	490
	Oskarshamn 3	110	330	335	430	220
	Ringhals 1	525	527	533	639	665
Switzerland [D5, D6]	Leibstadt	270	400	320	300	440
	Mühleberg	260	520	440	410	540
United States [T3]	Big Rock Point	47.0	13.0	21.7	12.8	23.6
	Browns Ferry 1-3	1230	293	75.1	54.0	0.7
	Brunswick 1-2	366	214	714	1150	25.9

Table 34 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	Clinton 1	-	-	69.2	107	55.1
	Cooper	187	206	186	154	202
	Dresden 2-3	276	470	825	636	677
	Duane Arnold-1	1.32	0	0	0	0
	Enrico Fermi 2	-	11.1	38.9	34.5	48.1
	Fitzpatrick	155	185	91.8	328	27.1
	Grand Gulf 1	191	544	677	496	488
	Hatch 1-2	2120	1060	1040	1630	1690
	Hope Creek 1	-	0.26	353	346	870
	Humboldt Bay 3	40.0	2.47	0.03	0.03	0.042
	Lacrosse	4740	2130	1720	170	103
	Lasalle 1-2	14.4	5.07	40.7	64.8	39.6
	Limerick 1	42.6	76.2	223	0	999
	Millstone 1	662	197	659	1400	1690
	Monticello	0	0	0	0	0
	Nine Mile Point 1	0	81.0	0	0	0
	Nine Mile Point 2	-	-	17.1	293	300
	Oyster Creek	0	39.6	72.5	599	147
	Peach Bottom 2-3	1870	1650	1720	359	740
	Perry 1	-	0.1	108	272	258
	Pilgrim 1	289	370	119	21.2	87.7
	Quad Cities 1-2	126	238	256	269	1077
	River Bend 1		169	256	357	592
	Susquehanna 1-2	338	570	692	537	1014
	Vermont Yankee	0	0	0	0	0
	WPPSS-2	555	4700	2080	51.1	75.1
Total release (GBq)		33500	34700	32200	28300	34200
Normalized release [GBq (GW a)$^{-1}$]		900	870	750	640	780
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		790				
HWRs						
Argentina [C15, C18]	Atucha-1	320000	280000	360000	590000	300000
	Embalse	16000	79000	160000	170000	220000
Canada [A6]	Bruce 1-4	1066000	1376000	1110000	1550000	1639000
	Bruce 5-8	31000	42000	520000	58000	48000
	Gentilly-2	31000	42000	520000	58000	48000
	Pickering 1-4	333000	84000	444000	592000	592000
	Pickering 5-8	377000	844000	1687000	1073000	85000
	Point Lepreau	24000	110000	96000	120000	320000
India [B14]	Kalpakkam 1-2	16870	30450	30410	63200	90690
	Rajasthan 1-2	6470	15380	4950	28670	23550
Pakistan [P3]	Karachi	36800	49000	39600	25400	10000
Republic of Korea [M3]	Wolsong 1	12000	36810	50780	74520	60440
Total release (GBq)		2270000	2990000	5020000	4400000	3440000
Normalized release [GBq (GW a)$^{-1}$]		276000	316000	489000	429000	334000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		374000				
GCRs						
France [E4]	Bugey 1	17000	2000	100	9000	0
	Chinon A2-3	500	300	0	3000	1000
	St. Laurent A1-2	5000				
Japan [J1]	Tokai-1	31	0.2	22	0.05	5.2
Spain [C21]	Vandellos 1	6210	283	3530	7480	83.4
United Kingdom [N6, P1, S4]	Berkeley	500	100	1200	270	3530
	Bradwell	1300	6200	1600	790	960
	Calder Hall					

Table 34 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United Kingdom (continued)	Chapelcross	900	200	700	550	630
	Dungeness A	800	2400	200	340	200
	Dungeness B1-2	46400	29700	6800	22900	16200
	Hartlepool A1-A2	22400	45800	31900	33800	112000
	Heysham 1A-B, 2A-B	24700	58200	82900	112000	195000
	Hinkley Point A	22600	2100	5400	2760	1140
	Hinkley Point B, A,B	336000	257000	169000	272000	266000
	Hunterston A1	1900	1100	1300	2200	760
	Hunterston B1-2	342000	366000	269000	292000	333000
	Oldbury-A	800	900	900	890	720
	Sizewell-A	9900	3100	2300	760	2100
	Torness A-B	-	-	-		
	Trawsfynydd	2400	600	3800	550	490
	Wylfa	7000	8700	6200	7300	3000
Total release (GBq)		848000	785000	567000	769000	937000
Normalized release [GBq (GW a)$^{-1}$]		119000	131000	97800	115000	134000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		120000				
LWGRs						
USSR [G2, 114]	Beloyarsky 2 Bilibino 1-4 Chernobyl 1-4 Ignalina 1-2 Kursk 1-4 Leningrad 1-4 Smolensk 1-3	*Only average normalized release reported*				
Total release (GBq)						
Normalized release [GBq (GW a)$^{-1}$]						
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		11000				
FBRs						
France [S6]	Creys-Malville Phenix	0 0	300 0	100 0	0 0	2900 0
USSR	Beloyarsky 3					
United Kingdom	Dounreay					
Total release (GBq)		0	300	100	0	2900
Normalized release [GBq (GW a)$^{-1}$]		0	1100	370	0	11000
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		3000				

[a] A dash indicates that the reactor was not yet in operation.

Table 35
Radionuclides excluding tritium released from reactors in liquid effluents

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
PWRs						
Belgium [M6]	Doel 1-4	14.0	21.3	3.7	11.0	22.5
	Tihange 1-4	52.4	57.3	62.2	57.4	77.3
Brazil [C1]	Angra 1	*Not reported*				
Bulgaria [C16]	Kozloduy-1-2	0.81	0.83	0.71	0.88	0.83
	Kozloduy-3-4	0.78	0.65	0.76	0.80	0.60
	Kozloduy-5	- [a]	-		1.24	1.09
China, Taiwan Province [T2]	Maanshan 1-2	3.3	2.95	1.01	0.23	1.61
Czechoslovakia [N11]	Bohunice 1-4	0.64	0.33	0.81	0.22	0.08
	Dukovany 1-4	0.012	0.036	0.021	0.30	0.30
Finland [F2]	Loviisa 1-2	18	17	13	15	21
France [E4]	Belleville 1-2	-	-	1	3	24
	Blayais 1-4	87	104	75	75	56
	Bugey 2-5	177	176	168	117	160
	Cattenom 1-2	-	0.4	8	3	10
	Chinon B1-B4	61	89	56	63	56
	Chooz-A (Ardennes)	8	9	10	7	17
	Cruas 1-4	26	19	12	11	11
	Dampierre 1-4	222	138	212	75	35
	Fessenheim 1-2	37	42	27	28	23
	Flamanville 1-2	0.5	39	62	111	23
	Gravelines 1-6	120	153	109	96	130
	Nogent 1-2	-	-	1	6	22
	Paluel 1-4	98	175	160	54	57
	St. Alban 1-2	6	73	88	30	23
	St. Laurent B1-2	369	58	17	10	18
	Tricastin 1-4	140	62	53	35	36
Germany, Federal Republic of [B4, B9, S7]	Biblis A-B	2.4	2.3	3.8	0.12	1.26
	Brokdorf	-	0	0	0	0
	Emsland	-	-	-	0.023	0.013
	Grafenrheinfeld	0.035	0.15	0.071	0.054	0.068
	Greifswald					
	Grohnde	0.11	0.011	0.084	0.082	0.25
	Isar 2	-	-	-	0.0039	0.02
	Mülheim-Kärlich	-	0.25	0.13	0.019	0.38
	Neckarwestheim 1-2	0.3	0.16	0.1	0.033	0.07
	Obrigheim	0.77	0.58	0.41	0.38	0.41
	Philippsburg 2	0.047	0.25	0.32	0.69	0.29
	Stade	1.2	1.5	1.3	1	0.56
	Unterweser	0.72	0.23	0.23	0.1	0.23
Hungary [F3]	Paks 1-4	1.31	1.09	3.19	2.04	2.91
Italy [C22]	Enrico Fermi (Trino)	61	42	54	3.6	2.2
Japan [J1]	Genkai 1-2	0	0	0	0	0
	Ikata 1-2	0	0	0	0	0
	Mihama 1-3	0.022	0.015	0.017	0.021	0.0065
	Ohi 1-2	0.021	0.016	0.0044	0.00021	0
	Sendai 1-2	0	0	0	0	0
	Takahama 1-4	0.0081	0.013	0.0027	0	0
	Tomari-1	-	-	-	0	0
	Tsuruga-2	-	0.00013	0.0017	0.00014	0.00059
Netherlands [M5]	Borssele	5.7	2.7	1.9	3.0	3.7
Republic of Korea [M3]	Kori 1	0.33	0.85	0.71	3.09	2.09
	Kori 2	0.80	0.63	0.33	0.23	0.14
	Kori 3-4	0.60	3.35	4.31	0.40	0.26
	Ulchin 1-2	-	-	-	2.15	1.73
	Yonggwang 1-2	-	0.214	1.69	2.09	1.34

Table 35 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
South Africa [C20]	Koeberg 1-2		3.36	7.8	1.47	1.69
Spain [C21]	Almaraz 1-2	75.4	30.1	7.7	18.9	18.7
	Asco 1	70.6	97.7	89.1	264	103
	Asco 2	1.88	84.1	217	316	75.6
	José Cabrera 1	9.76	173	11	20	44.9
	Trillo 1	-	-	-	3.59	1.1
	Vandellos 2	-	-	0.03	8.34	24.6
Sweden [N14]	Ringhals 2	47.5	102	102	48.8	52.5
	Ringhals 3	20.9	57.8	26.7	82.0	37.7
	Ringhals 4	58.7	26.9	46.1	46.8	41.4
Switzerland [D5, D6]	Beznau 1-2	8.9	0.00001	8	5.9	21
	Gösgen	0.16	0.089	0.0026	0.0081	0.0096
USSR [G2, I14]	Armenia 1-2 Balakovo 1-3 Kalinin 1-2 Khmelnitski 1 Kola 1-4 Novovoronezh 3-5 Rovno 1-3 South Ukraine 1-3 Zaporozhe 1-5	-	-			
United States [T3]	Arkansas One-1	131	188	90.7	138	75.5
	Arkansas One-2	161	127	68.5	165	98.1
	Beaver Valley 1-2	4.18	4.40	24.8	3.77	20.2
	Braidwood 1	-	-	1.85	317	92.5
	Braidwood 2	-	-	-	112	93.2
	Byron 1-2	603	150	91.8	51.8	23.5
	Callaway 1	0.18	1.42	18.2	2.86	0.37
	Calvert Cliffs 1-2	88.1	66.2	192	97.7	76.6
	Catawba 1	46.6	14.1	24.2	20.1	12.7
	Catawba 2	-	14.1	24.2	20.1	12.7
	Crystal River 3	55.9	30.0	35.3	8.55	8.73
	Davis-Besse 1	6.85	2.28	2.41	6.22	6.81
	Diablo Canyon 1-2	118	411	106	74	59.6
	Donald Cook 1-2	83.6	12.4	74	16.4	29.8
	Farley 1	2.49	3.77	1.88	2.95	2.7
	Farley 2	1.39	3.06	1.71	3.16	2.72
	Fort Calhoun 1	10.6	3.10	7.51	11.4	20.8
	H. B. Robinson 2	34.8	9.657	27.2	35.7	10.4
	Haddam Neck	3.12	11.47	15.8	25.4	14.4
	Indian Point 1-2	68.5	134	223	105	23.6
	Indian Point 3	15.5	7.22	12.8	11.9	21.9
	Kewaunee	50.0	19.7	47.7	18.5	45.1
	Maine Yankee	1.15	11.1	32.6	12.9	6.77
	McGuire 1	23.0	28.6	58.1	95.1	57
	McGuire 2	23.0	28.6	58.1	95.1	57
	Millstone 2	170	166	151	329	392
	Millstone 3	-	111	200	117	220
	North Anna 1-2	188	34.8	49.2	16.0	42.9
	Oconee 1-2-3	154	112	107	115	141
	Palisades	2.16	5.18	3.42	1.27	0.14
	Palo Verde 1	0	0	0	0	0
	Palo Verde 2	-	0	0	0	0
	Palo Verde 3	-	-	0	0	0
	Point Beach 1-2	70.3	592	27.9	3.54	2.06
	Prairie Island 1-2	1.02	22.2	2.23	9.44	6.4
	R. E. Ginna	19.3	2.39	2.18	1.27	3
	Rancho Seco 1	0.27	0.054	0.021	0.21	0.08
	Salem 1	107	161	123	119	115
	Salem 2	104	226	151	120	132
	San Onofre 1	288	31.5	31.2	26.3	25.4
	San Onofre 2-3	414	30.3	19.9	42.9	34
	Sequoyah 1-2	53.7	6.11	17.2	16.6	13.1
	Shearon Harris 1	-	-	33.6	2.97	8.95
	South Texas 1	-	-	-	8.29	112
	South Texas 2	-	-	-	-	0.43

Table 35 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United States (continued)	St. Lucie 1	101	93.6	22.0	9.77	9.47
	St. Lucie 2	102	89.9	20.1	9.58	9.36
	Surry 1-2	316	324	191	89.2	143
	Three Mile Island 1	0.23	0.52	1.63	1.72	0.6
	Three Mile Island 2	0.0066	0.0069	0.0043	0.041	0.012
	Trojan	17.2	9.77	7.73	7.44	5.96
	Turkey Point 3	16.6	9.36	13.8	12.1	5.85
	Turkey Point 4	16.6	9.36	13.8	12.1	5.85
	Virgil C. Summer 1	26.2	12.1	18.1	27.9	50.7
	Vogtle 1-2	-	-	21.3	61.4	14.9
	Waterford 3	10.7	149	47.4	52.2	47.4
	Wolf Creek	23.5	83.6	10.7	14.0	26.8
	Yankee NPS	0.63	0.50	0.58	2.63	0.18
	Zion 1-2	87.7	59.2	58.1	132	127
Yugoslavia [F1]	Krsko	13.4	4.54	1.88	1.71	0.63
Total release (GBq)		5650	5500	4320	4460	3840
Normalized release [GBq (GW a)$^{-1}$]		66	56	40	38	31
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		45				
BWRs						
China, Taiwan Province [T2]	Chin Shan 1-2	10.1	10.1	12.0	8.77	14.6
	Kuosheng 1-2	8.84	3.81	115	41.4	91.8
Finland [F2]	TVO 1-2	14	35	36	17	33
Germany, Federal Republic of [B4, B9]	Brunsbüttel	0.81	0.49	0.4	1.1	0.35
	Gundremmingen B,C	2.7	4.8	0.84	0.54	0.22
	Isar 1	0.54	0.87	0.56	1.6	0.27
	Krümmel	0.36	0.042	0.013	0.062	0.022
	Philippsburg 1	0.78	0.97	0.56	0.5	0.44
	Würgassen	1.9	1.2	0.55	1.1	0.96
India	Tarapur-1					
	Tarapur-2					
Italy [C22]	Caorso	20	58	16	15	12
Japan [J1]	Fukushima Daiichi 1-6	0.037	0.01	0.0067	0	0
	Fukushima Daini 1-4	0	0	0	0	0
	Hamaoka 1-3	0.056	0.03	0.014	0.012	0.011
	Kashiwazaki Kariwa 1,5	0	0	0	0	0.00073
	Onagawa-1	0	0	0	0	0
	Shimane 1-2	0.007	0.0089	0.0081	0.0059	0.0034
	Tokai 2	0.13	0.12	0	0	0
	Tsuruga 1	0.019	0.012	0.0093	0.011	0.0036
Mexico [C19]	Laguna Verde (Mark II)	-	-	-	-	15.03
Netherlands [M5]	Dodewaard	15	9.6	14	11	11
Spain [C21]	Confrentes	0.96	0.63	0.38	1.26	0.24
	S. Maria de Garona	8	1.13	1.19	2.09	0.32
Sweden [N14]	Barsebeck 1	32.4	80	33.4	12.8	14.4
	Barsebeck 2	32.4	80	33.4	12.8	14.4
	Forsmark 1	180	233	122	163	185
	Forsmark 2	180	233	122	163	185
	Forsmark 3	20	174	14	4	4
	Oskarshamn 1	30	41	29	49	149
	Oskarshamn 2	30	41	29	49	149
	Oskarshamn 3	2	3	2	7	13
	Ringhals 1	54.8	63.4	42.9	30.4	56.5
Switzerland [D5, D6]	Leibstadt	0.6	0.0004	0.026	0.41	0.48
	Mühleberg	2.4	13	6.6	14	4.6

Table 35 (continued)

Country	*Reactor*	*Release (GBq)*				
		1985	*1986*	*1987*	*1988*	*1989*
United States [T3]	Big Rock Point	5.66	2.62	10.1	8.07	8.58
	Browns Ferry 1-3	49.6	19.9	12.0	8.95	6.33
	Brunswick 1-2	4.26	4.66	26.5	30.8	57.7
	Clinton 1	-	-	0.57	4.07	0.64
	Cooper	481	273.8	83.3	86.2	81
	Dresden 2-3	75.1	7.92	14.0	4.29	24.2
	Duane Arnold-1	0.030	0	0	0	0
	Enrico Fermi 2	-	0.14	0.78	2.74	6.22
	Fitzpatrick	6.66	0.71	2.90	1.80	2.02
	Grand Gulf 1	7.88	11.1	13.5	14.7	11.8
	Hatch 1-2	27.5	29.2	30.2	36.4	9.18
	Hope Creek 1	-	28.0	59.9	26.8	38.9
	Humboldt Bay 3	4.63	1.74	0.44	0.28	0.31
	Lacrosse	67.7	185	42.9	16.5	6.25
	Lasalle 1-2	142	0.66	32.9	407	14.8
	Limerick 1	0.81	0.21	2.76	0	4.14
	Millstone 1	17.2	28.6	42.2	40.0	33.5
	Monticello	0	0	0	0	0
	Nine Mile Point 1	0	0.025	0	0	0
	Nine Mile Point 2	-	-	48.1	114	8.14
	Oyster Creek	0	0	0.25	0.99	1.85
	Peach Bottom 2-3	79.9	17.0	12.2	7.47	4.18
	Perry 1	-	0.14	0.54	9.25	42.9
	Pilgrim 1	39.2	7.81	54.4	1.32	0.92
	Quad Cities 1-2	54.0	8.73	2.63	2.07	17.9
	River Bend 1		3.92	2.95	20.6	41.1
	Susquehanna 1-2	23.5	29.3	11.5	3.51	3.77
	Vermont Yankee	0	0	0	0	0
	WPPSS-2	0.40	0.86	0.45	0.23	1.86
Total release (GBq)		1740	1750	1140	1460	1380
Normalized release [GBq (GW a)$^{-1}$]		46	44	27	33	32
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		36				
HWRs						
Argentina [C15, C16]	Atucha-1	51	42	100	96	59
	Embalse	1.9	7.1	4.5	2.7	5.8
Canada [A6]	Bruce 1-4	90	120	50	130	20
	Bruce 5-8	7	13	3	8	9
	Gentilly-2	9.7	3.5	12	2.8	1.1
	Pickering 1-4	32	20	23	23	44
	Pickering 5-8	10	20	20	60	10
	Point Lepreau	1.6	1.1	0.4	1.9	1.1
India [B14]	Kalpakkam 1-2	13.4	23.2	46.0	48.1	27.6
	Rajasthan 1-2	2.81	3.50	0.39	3.05	4.53
Pakistan [P3]	Karachi	38.1	20.0	40.0	44.0	13.0
Republic of Korea [M3]	Wolsong 1	0.72	2.56	1.54	1.23	0.16
Total release (GBq)		258	276	301	421	195
Normalized release [GBq (GW a)$^{-1}$]		31	29	29	41	19
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		30				
GCRs						
France [E4]	Bugey 1	43	76	35	15	4
	Chinon A2-3	5	11	5	2	3
	St. Laurent A1-2	57				
Japan [J1]	Tokai-1	0.1	0.059	0.067	0.031	0.015
Spain [C21]	Vandellos 1	154	133	129	97.6	12.6

Table 35 (continued)

Country	Reactor	Release (GBq)				
		1985	1986	1987	1988	1989
United Kingdom [N6, P1, S4]	Berkeley	290	320	240	330	230
	Bradwell	1510	720	710	440	395
	Calder Hall					
	Chapelcross	2000	86	500	170	220
	Dungeness A	2190	3100	570	410	230
	Dungeness B1-2	38	76	18	51	2.5
	Hartlepool A1-A2	18	65	34	24	22
	Heysham 1A-B, 2A-B	9	15	24	33	57
	Hinkley Point A	3720	450	960	500	900
	Hinkley Point B, A,B	50	39	19	26	32
	Hunterston A1	3.6	1.6	1.1	1	0.62
	Hunterston B1-2	90	40	30	30	40
	Oldbury-A	1120	690	560	830	410
	Sizewell-A	1010	760	710	460	360
	Torness A-B	-	-	-		
	Trawsfynydd	430	200	180	380	280
	Wylfa	48	61	58	75	64
Total release (GBq)		12800	6840	4780	3870	3260
Normalized release [GBq (GW a)$^{-1}$]		1800	1140	800	580	470
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		960				
LWGRs						
USSR [G2, I14]	Beloyarsky 2 Bilibino 1-4 Chernobyl 1-4 Ignalina 1-2 Kursk 1-4 Leningrad 1-4 Smolensk 1-3	*Not reported*				
Total release (GBq)						
Normalized release [GBq (GW a)$^{-1}$]						
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]						
FBRs						
France [S6]	Creys-Malville	0	31	0.1	0.1	0.1
	Phenix	0	0	0	0	0
USSR	Beloyarsky 3					
United Kingdom	Dounreay					
Total release (GBq)		0	31	0.1	0.1	0.1
Normalized release [GBq (GW a)$^{-1}$]		0	110	0.4	0.6	0.4
Average normalized release 1985-1989 [GBq (GW a)$^{-1}$]		30				

[a] A dash indicates that the reactor was not yet in operation.

Table 36
Composition of radionuclides, excluding tritium, released in liquid effluents from PWRs in the United States, 1988 [T3]

PART A

Reactor	*Release (GBq)*														
	^{24}Na	^{51}Cr	^{54}Mn	^{55}Fe	^{56}Mn	^{57}Co	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{89}Sr	^{90}Sr	^{92}Sr	^{95}Nb	^{95}Zr
Arkansas One 1	0.0366	1.17	10.8	16.0	- [a]	0.0659	30.3	0.151	3.34	0.118	0.699	0.0155	0.123	0.291	0.164
Arkansas One 2	0.588	6.18	5.96	1.72	-	0.00337	25.7	0.280	2.49	-	0.0511	0.00163	0.340	2.36	1.68
Beaver Valley 1-2	0.00053	0.00102	0.0216	0.562	-	0.0077	1.65	-	0.784	0.00086	-	-	-	0.00039	-
Braidwood 1	0.102	0.206	7.92	-	-	0.250	297	0.213	5.18	-	0.0247	-	-	0.0648	0.0355
Braidwood 2	0.0944	0.206	5.99	-	-	0.130	96.9	0.0951	3.22	-	-	-	-	0.0629	0.0338
Byron 1-2	0.00048	6.99	1.08	-	-	0.0385	22.1	1.02	11.1	0.0301	-	-	-	1.44	0.899
Callaway 1	-	-	0.0696	0.555	-	0.00152	0.139	0.00053	0.389	-	0.174	0.0688	-	0.0211	0.00633
Calvert Cliffs 1-2	0.0455	3.16	0.326	-	-	0.00981	17.7	0.00799	1.22	-	0.136	0.0182	-	1.17	0.614
Catawba 1	0.0124	1.94	0.792	6.73	-	0.0176	4.33	0.377	2.00	0.0149	0.00225	0.0005	0.00205	0.241	0.152
Catawba 2	0.0124	1.94	0.792	6.73	-	0.0176	4.33	0.377	2.00	0.0149	0.00225	0.0005	0.00205	0.241	0.152
Crystal River 3	-	0.0214	0.118	0.525	-	-	1.62	-	1.47	-	0.156	0.00773	0.321	0.0311	0.00633
Davis-Besse 1	-	0.00507	0.0336	1.428	-	0.0115	1.21	0.00028	2.09	0.00017	0.00426	0.00131	-	-	0.0107
Diablo Canyon 1-2	0.0277	0.692	1.33	13.0	0	0.108	31.6	0.210	7.4	0.00334	0.0725	0.00514	0	-	0.360
Donald C.Cook 1-2	0.0150	0.263	0.884	1.37	-	0.0183	2.70	-	2.49	0.0659	0.0136	0.00607	-	0.0054	0.0054
Fort Calhoun	-	0.0121	0.644	-	-	0.00128	1.59	-	0.302	-	0.1125	0.0157	-	0.0108	0.00161
H.B. Robinson 2	0.00351	0.707	0.37	18.3	-	0.0228	5.96	0.0367	5.25	0.00158	-	0.0011	0.00004	0.0344	0.00585
Haddam Neck	-	-	0.107	2.00	-	0.00507	0.696	-	3.81	-	0.00333	0.0411	-	0.00107	0.00107
Harris 1	-	1.61	0.186	0.0781	-	0.00288	2.27	0.0276	0.241	-	-	0.00009	-	0.0142	0.0142
Indian Point 1-2	-	7.81	0.353	24.8	-	0.0137	17.9	0.257	16.9	0.00239	0.00714	0.00083	-	0.592	0.0936
Indian Point 3	0.00268	0.662	0.0566	4.33	-	0.00045	1.47	0.167	0.562	-	0.00018	-	-	0.0345	0.00795
Joseph M. Farley 1	0.00037	0.264	0.0187	0.364	-	0.00071	0.264	0.00551	0.511	0.00025	-	0.00064	-	0.107	0.0288
Joseph M. Farley 2	0.00286	0.199	0.0253	0.755	-	0.00024	0.240	0.0100	0.522	0.00038	-	-	-	0.104	0.0214
Kewaunee	0.0114	0.309	0.186	2.93	-	0.0134	9.92	0.0718	2.32	-	0.0474	0.00052	-	0.0503	0.0353
Maine Yankee	-	0.548	0.0216	1.61	-	0.00309	2.32	0.00903	1.84	-	0.257	0.00455	-	0.0186	0.0186
McGuire 1	0.074	11.1	3.05	15.4	0.00011	0.135	38.1	0.662	13.7	0.110	0.00287	0.00035	0.0426	2.24	1.35
McGuire 2	0.074	11.1	3.05	15.4	0.00011	0.135	38.1	0.662	13.7	0.110	0.00287	0.00035	0.0426	2.24	1.35
Millstone 2	0.0488	12.6	2.92	9.92	-	0.381	154	0.37	71.0	-	0.255	0.0829	0.492	1.02	0.474
Millstone 3	0.688	1.32	14.5	8.95	-	0.221	29.6	0.773	22.8	0.0747	0.0229	0.00466	0.525	2.11	0.784
North Anna 1-2	0.2446	-	0.0829	-	-	-	0.618	-	4.96	-	-	-	0.00681	0.129	0.0158
Oconee 1-3	0.0788	8.84	0.310	3.12	-	0.0429	23.2	0.112	4.48	-	0.0225	0.00588	0.340	1.81	1.12
Palisades	-	0.0212	0.0181	-	-	-	0.253	-	0.302	-	0.0951	0.0258	-	0.0014	-

Table 36 (continued)

Reactor	Release (GBq)															
	^{24}Na	^{51}Cr	^{54}Mn	^{55}Fe	^{56}Mn	^{57}Co	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{89}Sr	^{90}Sr	^{92}Sr	^{95}Nb	^{95}Zr
Palo Verde 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palo Verde 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palo Verde 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Point Beach 1-2	1.41	0.00196	0.0057	-	-	0.00188	0.252	-	0.755	-	0.0992	0.0130	-	0.00596	-
Prairie Island 1-2	0.00068	0.0607	0.0148	8.33	-	0.00008	0.313	0.114	0.148	0.00127	0.0844	0.00237	0.00041	0.0112	0.00168
R.E. Ginna	-	0.00999	0.00496	0.00091	-	-	0.0318	-	0.0596	-	0.00418	0.00167	-	0.00171	0.00171
Rancho Seco 1	-	-	0.00095	-	-	-	0.0003	-	0.0451	-	-	0.00069	-	-	-
Salem 1	0.511	0.881	3.74	11.0	-	0.148	47.0	0.00984	10.2	0.0203	0.463	0.0873	0.00073	0.566	0.455
Salem 2	0.385	0.117	6.44	13.0	0.11914	0.168	48.8	0.00108	11.0	-	0.625	0.152	0.0130	0.242	0.117
San Onofre 1	-	0.157	0.0194	0.153	-	0.00145	1.91	0.0067	0.829	0.00152	0.0013	0.00374	-	0.00696	0.0115
San Onofre 2-3	0.0144	0.518	0.796	1.02	-	0.0248	8.73	0.0309	0.810	0.00051	0.400	0.00303	-	0.403	0.211
Sequoyah 1-2	-	0.00106	0.0607	2.71	-	0.0022	0.00296	-	9.07	-	0.0170	0.0122	-	0.00013	-
South Texas 1	0.00157	0.718	0.122	-	-	-	5.37	0.0414	0.123	-	-	-	-	0.134	0.137
St. Lucie 1	0.00455	0.655	0.0481	1.22	-	0.00018	2.27	0.00121	1.82	-	-	0.0303	-	0.275	0.144
St. Lucie 2	0.00455	0.655	0.0481	1.22	-	0.00018	2.27	0.00121	1.82	-	-	0.00099	-	0.275	0.144
Summer 1	0.00984	1.02	0.636	2.26	-	0.0332	8.66	0.0677	2.65	0.0240	-	-	-	0.315	0.315
Surry 1-2	0.0246	5.96	0.411	10.5	-	0.0259	12.5	0.245	16.4	0.00329	-	-	0.00022	0.448	0.229
Three Mile Island 1	-	0.0714	0.00287	0.282	-	-	0.847	0.00065	0.0231	-	0.00083	0.00013	-	0.0111	0.00422
Three Mile Island 2	-	-	-	-	-	-	-	-	-	-	-	0.0224	-	-	-
Trojan	-	0.755	0.0470	2.78	-	0.00186	0.936	0.0250	1.30	-	0.0814	0.0140	-	0.223	0.121
Turkey Point 3	0.00092	0.289	0.555	1.72	-	0.00012	0.966	0.0186	6.81	0.00063	0.00722	0.00194	-	0.00825	0.0023
Turkey Point 4	0.00092	0.289	0.555	1.72	-	0.00012	0.966	0.0186	6.81	0.00063	0.00722	0.00194	-	0.00825	0.0023
Vogtle 1	0.144	9.69	1.75	7.29	-	0.0836	35.1	1.18	1.92	0.0522	-	-	-	1.15	0.736
Waterford 3	0.0522	2.38	0.278	4.70	-	0.0266	18.9	0.303	1.47	0.00622	0.0163	0.00042	0.0121	1.03	0.599
Wolf Creek 1	0.00016	0.729	0.448	2.83	-	0.0261	5.44	0.322	2.34	0.0128	0.103	0.00117	0.00647	0.196	0.0681
Yankee Rowe 1	-	0.0374	0.00307	0.151	-	-	0.00433	0.00869	0.00544	0.00932	0.0295	0.0131	-	0.00374	0.00374
Zion 1-2	0.0966	9.81	0.659	2.72	-	0.0659	47.0	1.06	29.7	-	-	-	-	1.74	1.10
Total release (GBq)	4.83	115	78.7	232	0.12	2.27	1110	9.36	315	0.68	4.10	0.67	2.27	23.5	13.9
Normalized activity [GBq (GW a)$^{-1}$]	0.12	2.8	1.9	5.6	0.0029	0.054	26.7	0.22	7.6	0.016	0.099	0.016	0.055	0.56	0.33

Table 36 (continued)

PART B

Reactor	Release (GBq)														
	^{97}Nb	^{97}Zr	^{99}Mo	^{99m}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{113}Sn	^{122}Sb	^{124}Sb	^{125}Sb	^{131}I	^{132}I	^{132}Te	^{133}I
Arkansas One 1	0.0129	0.0134	0.230	0.159	0.00729	0.0275	29.3	0.0283	0.0123	1.01	12.2	7.4	0.0150	-	0.103
Arkansas One 2	0.0137	0.0168	1.51	1.57	0.0799	0.0143	34.2	0.249	0.366	2.87	24.5	4.96	0.0855	0.0710	1.08
Beaver Valley 1-2	0.0105	-	0.00072	0.00071	0.0002	-	0.0662	-	-	0.0366	0.466	0.0134	-	-	0.00331
Braidwood 1	-	0.555	0.00377	-	-	-	0.00166	0.00095	-	1.67	0.0455	0.692	2.43	-	0.0477
Braidwood 2	-	0.555	0.00377	-	-	-	-	0.00095	-	0.209	0.0455	0.644	2.42	-	0.0474
Byron 1-2	-	-	0.00747	0.00085	0.0310	-	0.00118	0.0198	-	0.0356	0.529	0.999	0.0374	-	0.0357
Callaway 1	-	-	-	-	-	0.0356	0.00015	0.00028	-	0.00052	-	0.0122	-	-	0.00012
Calvert Cliffs 1-2	0.648	-	0.00355	0.134	0.111	-	2.67	0.0803	-	0.759	6.29	10.3	0.0633	0.0250	0.940
Catawba 1	0.0300	-	0.00198	0.0125	0.0114	0.0189	0.0117	0.0361	0.0540	0.271	0.847	0.362	0.0057	-	0.0810
Catawba 2	0.0300	-	0.00198	0.0125	0.0114	0.0189	0.0117	0.0361	0.0540	0.271	0.847	0.362	0.0057	-	0.0810
Crystal River 3	-	0.0400	0.00257	0.0338	-	0.144	0.914	-	-	-	-	0.117	-	-	0.0161
Davis-Besse 1	-	-	-	0.00023	-	-	1.28	0.0081	-	-	0.109	0.00925	-	-	-
Diablo Canyon 1-2	-	-	0.0588	-	0.00488	-	0.0115	0.0120	0.0109	0.234	2.82	2.35	0.00082	0.0130	0.629
Donald C. Cook 1-2	-	0.0253	-	0.00327	-	-	0.995	0.00995	-	0.0733	1.72	1.46	-	-	0.0422
Fort Calhoun	-	-	0.00488	0.0248	0.00385	-	0.0414	-	-	0.0309	2.58	0.855	-	-	0.0392
H.B. Robinson 2	0.0574	-	-	0.00559	-	0.0044	0.463	0.00168	-	1.45	2.42	0.0156	-	-	0.00205
Haddam Neck	-	-	-	-	-	-	0.00067	-	-	0.0147	0.0323	1.39	2.82	-	3.69
Harris 1	-	-	-	0.00059	0.00021	-	-	0.00329	0.00043	0.0109	0.0244	0.0109	-	-	0.00097
Indian Point 1-2	-	-	-	-	0.00692	0.0150	0.323	-	-	1.65	10.9	1.14	1.02	-	5.77
Indian Point 3	-	-	-	0.00574	-	-	0.511	0.00352	-	0.138	1.22	1.10	0.00046	-	0.0150
Joseph M. Farley 1	-	0.00032	0.00032	0.00152	0.0341	0.0511	0.177	-	-	0.0206	0.818	0.0107	0.0796	0.00356	0.00016
Joseph M. Farley 2	-	0.00043	-	0.00083	0.0267	0.0477	0.210	-	-	0.0278	0.855	0.00226	0.0231	0.00451	0.00075
Kewaunee	-	-	-	-	-	-	0.858	0.0292	0.0233	0.562	0.426	0.0500	0.00215	-	0.0120
Maine Yankee	-	-	0.00067	0.00096	0.0217	-	0.283	0.00932	-	3.40	1.18	0.0821	-	-	0.00053
McGuire 1	0.180	0.00131	0.0302	0.120	0.122	0.146	0.511	0.267	0.00958	0.277	2.48	2.35	0.0147	-	0.283
McGuire 2	0.180	0.00131	0.0302	0.120	0.122	0.146	0.511	0.267	0.00958	0.277	2.48	2.35	0.0147	-	0.283
Millstone 2	2.13	-	-	0.00122	0.100	0.381	1.30	-	-	3.16	3.92	3.92	0.0363	-	0.814
Millstone 3	2.68	-	0.327	0.190	-	0.101	1.23	-	-	0.146	0.744	9.84	0.500	-	1.82
North Anna 1-2	-	0.107	-	0.0733	-	0.525	4.11	-	0.00329	0.0114	2.31	0.448	0.00677	-	0.870

Table 36 (continued)

Reactor	Release (GBq)														
	^{97}Nb	^{97}Zr	^{99}Mo	^{99m}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{113}Sn	^{122}Sb	^{124}Sb	^{125}Sb	^{131}I	^{132}I	^{132}Te	^{133}I
Oconee 1-3	1.99	-	0.0807	0.227	0.999	0.422	12.0	-	0.111	4.18	36.8	4.70	0.0651	-	1.09
Palisades	-	-	-	-	-	-	-	-	-	-	-	0.0169	-	-	-
Palo Verde 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palo Verde 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palo Verde 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Point Beach 1-2	0.00039	0.00064	0.00137	0.00122	0.00217	0.00385	0.0365	0.0119	-	0.00866	0.037	0.0518	0.0377	0.00027	0.448
Prairie Island 1-2	0.00257	0.00153	-	-	-	-	0.0747	0.0459	0.00327	0.0718	0.129	-	-	-	-
R.E. Ginna	-	-	0.00411	-	-	-	0.00551	-	-	-	-	0.369	0.00221	-	0.243
Rancho Seco 1	-	-	0.0111	-	-	0.00079	-	-	-	-	-	0.0335	-	-	0.00258
Salem 1	0.903	0.507	0.0581	0.176	0.0596	0.0140	0.184	0.00163	0.202	2.33	3.46	2.05	0.360	0.0006	1.04
Salem 2	0.256	-	0.0044	0.121	0.0507	-	0.385	0.00381	0.137	2.03	3.42	5.00	1.73	0.00548	3.27
San Onofre 1	-	-	0.0385	0.0186	0.0184	0.0228	0.00892	0.00058	-	0.0305	0.0143	6.36	0.00164	0.00202	2.74
San Onofre 2-3	0.00296	-	0.433	0.440	0.0155	0.0290	0.0884	0.0236	-	0.130	0.777	15.0	0.00048	0.00574	4.26
Sequoyah 1-2	0.00007	0.00253	-	0.00396	-	-	0.00696	-	-	-	0.810	0.0599	-	0.00008	0.00228
South Texas 1	-	0.00023	0.00296	0.00367	-	-	-	-	-	-	-	0.186	-	-	0.00289
St. Lucie 1	0.0884	-	-	0.00098	0.0234	-	0.0548	0.0129	0.0323	0.525	1.10	0.288	0.00222	0.00418	0.0320
St. Lucie 2	0.0884	-	-	0.00098	0.0234	-	0.0548	0.0129	0.0323	0.525	1.10	0.269	0.00222	0.00418	0.0320
Summer 1	-	0.00006	0.0181	0.0407	0.0429	0.0362	0.00651	0.0135	-	0.211	0.662	1.72	0.437	-	0.914
Surry 1-2	-	-	0.00548	0.00707	0.137	-	0.270	-	-	1.48	13.6	3.09	0.0285	0.0295	0.0581
Three Mile Island 1	-	-	-	-	0.00024	-	0.0570	-	-	-	0.00807	0.0714	-	-	-
Three Mile Island 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trojan	-	-	0.00054	0.00057	0.0973	0.670	0.0707	0.0113	-	-	0.119	0.00977	-	-	-
Turkey Point 3	0.00012	-	0.0179	0.0179	0.00258	-	0.0792	-	-	0.0955	0.673	0.0851	-	-	0.00943
Turkey Point 4	0.00012	-	0.0179	0.0179	0.00258	-	0.0792	-	-	0.0955	0.673	0.0537	-	-	0.00232
Vogtle 1	0.0004	0.00056	0.0381	0.0459	0.00124	-	-	-	0.0440	0.844	0.592	0.102	-	0.0017	0.176
Waterford 3	0.0651	0.0122	0.0385	0.0392	0.0810	0.0714	0.381	0.403	0.629	1.93	4.44	3.7	0.0145	0.0319	0.161
Wolf Creek 1	0.0599	-	0.0744	0.00134	-	-	0.128	0.0607	-	0.0755	0.662	0.0522	-	-	0.00016
Yankee Rowe 1	-	-	0.0316	0.00175	0.0047	-	0.0044	-	-	0.00463	0.013 3	0.0194	-	-	0.00396
Zion 1-2	-	-	0.00403	0.0107	0.126	-	7.73	0.366	-	2.42	11.1	0.862	0.729	0.0666	0.178
Total (GBq)	9.43	1.84	3.10	3.64	2.38	2.94	102	2.03	1.73	35.6	163	97.4	13.0	0.27	31.4
Normalized activity [GBq (GW a)$^{-1}$]	0.23	0.044	0.074	0.087	0.057	0.071	2.4	0.049	0.042	0.85	3.9	2.3	0.31	0.0065	0.75

Table 36 (continued)

PART C

Reactor	Release (GBq)													
	^{134}Cs	^{134}I	^{135}I	^{136}Cs	^{137}Cs	^{138}Cs	^{139}Ba	^{140}Ba	^{140}La	^{141}Ce	^{143}Ce	^{144}Ce	^{187}W	^{239}Np
Arkansas One 1	2.53	-	0.00189	0.00115	5.92	0.0559	-	0.00433	0.232	-	-	-	-	-
Arkansas One 2	4.37	-	0.0895	-	16.2	0.0692	-	-	0.107	-	-	0.0448	0.0500	-
Beaver Valley 1-2	0.0407	-	-	-	0.0899	-	-	0.00013	0.00013	-	-	0.00083	-	-
Braidwood 1	0.0710	0.0533	0.00121	0.00474	0.326	-	-	0.0350	0.0350	-	-	-	0.00135	-
Braidwood 2	0.0710	0.0455	0.00051	0.00474	0.326	-	-	0.0252	0.0252	-	-	-	0.00135	-
Byron 1-2	1.65	-	0.0134	0.0301	2.02	-	-	0.161	0.161	-	-	-	-	-
Callaway 1	0.477	-	-	-	0.747	-	-	0.00054	-	-	-	0.164	-	-
Calvert Cliffs 1-2	16.6	-	0.0247	0.171	34.4	-	-	0.00064	0.0121	0.0212	-	0.0818	-	-
Catawba 1	0.219	-	0.0035	0.00158	0.342	0.247	0.00046	0.00233	0.0533	0.00033	0.0001	-	0.00138	0.00084
Catawba 2	0.219	-	0.0035	0.00158	0.342	0.247	0.00046	0.00233	0.0533	0.00033	0.0001	-	0.00138	0.00084
Crystal River 3	0.217	-	-	-	0.485	-	0.0102	-	0.0362	-	-	-	-	-
Davis-Besse 1	0.0229	-	-	-	0.0622	-	-	-	0.00178	-	-	0.0252	-	-
Diablo Canyon 1-2	6.03	0	0.0414	0.0718	7.03	0	0	-	0.0762	0.00009	-	0.00199	0.00006	-
Donald C. Cook 1-2	1.08	-	-	0.122	1.40	-	-	0.0105	0.0105	-	-	-	-	-
Fort Calhoun	1.34	-	-	0.0022	3.66	-	-	0.00966	0.124	-	-	-	-	-
H.B. Robinson 2	0.0766	-	-	-	0.187	0.0101	0.0135	-	-	-	-	0	-	-
Haddam Neck	0.279	4.92	4.66	-	0.899	-	-	0.00015	0.00015	-	-	-	-	-
Harris 1	-	-	-	-	0.0077	-	-	0.00086	0.00086	-	-	-	-	-
Indian Point 1-2	0.451	0.318	3.59	-	2.11	-	-	0.0529	0.269	-	-	0.00488	-	-
Indian Point 3	0.722	-	-	0.00533	0.692	-	-	-	0.0197	-	-	-	-	-
Joseph M. Farley 1	0.0331	-	0.00007	0.00211	0.121	-	-	-	0.0081	0.00518	-	0.00914	-	0.00029
Joseph M. Farley 2	0.00369	-	0.00008	0.00315	0.0369	-	-	0.00054	0.00529	0.00358	-	0.00821	-	0.00086
Kewaunee	0.228	-	0.00096	0.0071	0.293	-	-	-	0.00273	-	-	-	-	-
Maine Yankee	0.172	-	-	-	1.07	-	-	0.0237	0.0237	0.00249	-	0.00172	-	-
McGuire 1	0.259	0.00866	0.747	0.00655	0.459	0.258	0.00258	0.0115	0.109	0.0522	0.0130	0.129	0.00003	0.0929
McGuire 2	0.259	0.00866	0.747	0.00655	0.459	0.258	0.00258	0.0115	0.109	0.0522	0.0130	0.129	0.00003	0.0929
Millstone 2	13.3	-	0.0611	0.184	42.2	-	0.0507	0.429	0.400	-	-	0.00548	-	-
Millstone 3	5.85	0.0659	0.0396	0.296	8.47	-	-	-	-	-	-	-	-	-
North Anna 1-2	0.303	-	0.463	-	0.714	-	0.00707	-	-	-	0.00243	-	-	-

Table 36 (continued)

Reactor	Release (GBq)													
	^{134}Cs	^{134}I	^{135}I	^{136}Cs	^{137}Cs	^{138}Cs	^{139}Ba	^{140}Ba	^{140}La	^{141}Ce	^{143}Ce	^{144}Ce	^{187}W	^{239}Np
Oconee 1-3	1.49	-	-	0.0559	3.26	0.0670	1.79	0.0209	0.611	0.239	-	0.759	0.00736	0.149
Palisades	0.0225	-	-	-	0.773	-	-	-	-	-	-	-	-	-
Palo Verde 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palo Verde 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palo Verde 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Point Beach 1-2	0.0184	0.00844	0.0166	-	0.319	-	0.00914	0.00227	-	-	-	0.0176	0.00126	-
Prairie Island 1-2	-	-	-	-	0.00008	0.00053	-	-	-	-	-	-	-	-
R.E. Ginna	0.132	0.0018	0.0918	-	0.300	-	-	-	-	-	-	-	-	-
Rancho Seco 1	0.0163	-	-	0.0144	0.103	-	-	-	-	-	-	-	-	-
Salem 1	4.85	0.407	0.622	0.00344	4.96	2.84	-	0.0104	0.0144	0.0492	-	0.699	0.463	-
Salem 2	3.53	1.29	0.703	0.0814	4.00	0.703	-	0.0581	0.0381	0.0644	-	0.0829	0.0236	0.144
San Onofre 1	5.88	-	1.34	0.151	6.62	0.0077	-	0.0209	0.00529	0.00288	-	0.0177	-	0.0255
San Onofre 2-3	2.06	-	-	0.192	4.40	-	0.00396	0.170	0.144	0.00238	0.00071	0.0529	-	-
Sequoyah 1-2	1.01	-	-	-	2.78	-	0.00006	-	-	-	0.00015	0.00071	-	-
South Texas 1	-	-	-	-	-	-	-	-	-	-	-	-	0.00081	-
St. Lucie 1	0.407	0.00161	-	-	0.644	-	-	-	0.0422	0.00205	-	-	0.00202	-
St. Lucie 2	0.374	0.00161	-	-	0.592	-	-	-	0.0422	0.00205	-	-	0.00202	-
Summer 1	3.74	0.168	0.607	0.119	2.66	0.0261	-	0.0411	-	0.0116	-	0.0588	-	0.00023
Surry 1-2	5.03	0.00154	0.00215	0.020	18.4	0.00067	-	0.328	0.115	0.00171	-	0.00448	-	0.00141
Three Mile Island 1	0.112	-	-	0.00244	0.231	-	-	-	0.00101	-	-	-	-	-
Three Mile Island 2	0.00014	-	-	-	0.0192	-	-	-	-	-	-	-	-	-
Trojan	0.0115	-	-	-	0.0293	-	-	-	0.00881	0.00744	-	0.108	-	-
Turkey Point 3	0.169	-	-	0.270	0.385	-	0.0105	-	0.0796	-	-	-	-	-
Turkey Point 4	0.169	-	-	0.270	0.385	-	0.0105	-	0.0796	-	-	-	-	-
Vogtle 1	-	-	0.0514	-	0.00574	-	0.00133	-	0.0217	-	-	-	0.0958	-
Waterford 3	2.47	-	-	0.0139	3.89	0.115	0.172	0.00088	0.239	0.0130	-	0.0522	0.0292	0.180
Wolf Creek 1	0.0440	0.00014	-	-	0.0725	0.0120	0.00108	-	0.0025	0.00377	-	0.0540	-	-
Yankee Rowe 1	0.0666	-	-	0.00403	0.0788	-	-	0.00814	0.00814	0.00662	-	0.0300	-	-
Zion 1-2	5.40	0.0836	0.0110	0.323	7.51	-	-	0.00044	0.110	-	-	-	-	-
Total release (GBq)	93.9	7.39	13.9	2.44	194	4.92	2.08	1.44	3.43	0.54	0.03	2.54	0.68	0.68
Normalized activity [GBq (GW a)$^{-1}$]	2.3	0.18	0.33	0.059	4.6	0.12	0.050	0.035	0.082	0.013	0.00071	0.061	0.016	0.017

[a] A dash indicates no value reported.

Table 37
Composition of radionuclides, excluding tritium, released in liquid effluents from BWRs in the United States, 1988 [T3]

PART A

Reactor	Release (GBq)														
	^{24}Na	^{51}Cr	^{54}Mn	^{55}Fe	^{56}Mn	^{57}Co	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{89}Sr	^{90}Sr	^{92}Sr	^{95}Nb	^{95}Zr
Big Rock Point	-[a]	0.0392	1.68	-	-	-	0.0366	0.223	2.11	0.0921	0.0260	0.139	0.00027	-	-
Browns Ferry 1-3	-	0.00095	0.00781	-	-	0.00026	-	-	1.69	0.256	-	-	-	-	-
Brunswick 1-2	533	5.29	5.96	1.21	0.00181	0.0003	1.44	0.400	8.55	-	0.0907	0.00235	0.00903	0.00087	-
Clinton 1	0.0305	2.92	0.455	0.0666	-	-	0.270	0.0185	0.225	0.00075	0.0455	0.00141	-	0.00012	0.00012
Cooper	0.588	5.33	10.4	2.76	-	-	3.27	0.037	40.3	-	3.06	0.259	-	-	-
Dresden 1-3	-	0.0252	0.260	0.444	-	-	0.0133	0.0287	2.93	-	0.00008	0.00633	-	0	0
Duane Arnold	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Edwin I. Hatch 1-2	0.496	0.284	0.488	-	0.0141	-	0.124	0.0287	1.60	5.07	0.0277	-	0.0293	0.0196	0.00525
Fermi 2	0.120	1.07	0.155	-	-	-	0.241	0.0777	0.0818	0.0892	0.00918	0.0004	-	0.00821	0.00659
Grand Gulf 1	0.0463	11.5	1.06	0.180	0.0008	-	0.239	0.107	0.999	-	0.0414	-	0.0064	0.00533	0.00533
Hope Creek 1	4.63	3.42	1.19	8.66	-	-	0.280	0.411	0.562	7.10	-	-	0.00097	0.00128	-
Humboldt Bay 3	-	-	-	-	-	-	-	-	0.0347	-	-	0.00562	-	-	-
James A. Fitzpatrick	0.0188	0.0105	0.396	-	-	-	0.0407	0.00403	0.659	0.0130	-	-	-	-	-
Lacrosse	-	-	0.877	3.89	-	0.00181	0.0022	-	9.07	0.0361	0.0159	0.0581	-	0.00135	0.00135
Lasalle 1-2	0.918	261	42.9	9.84	-	-	12.3	19.5	55.5	2.20	0.0176	0.00118	-	0.234	0.0389
Limerick 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Millstone 1	0.0781	0.0599	1.35	2.32	-	-	0.0318	0.00136	32.8	0.316	0.0224	0.0670	-	-	-
Monticello	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nine Mile Point 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nine Mile Point 2	2.30	40.0	13.6	0	-	-	28.3	6.73	15.7	7.03	-	-	-	-	-
Oyster Creek 1	-	0.181	0.0245	-	-	-	0.0437	-	0.507	-	0.0311	0.00077	-	-	-
Peach Bottom 2-3	-	-	0.00063	-	-	-	-	-	-	-	0.00999	0.0211	-	-	-
Perry 1	0.00662	6.07	0.936	0.173	0.0175	-	0.392	0.265	1.04	-	0.0511	0.00225	-	-	-
Pilgrim 1	-	-	0.00507	0.0836	-	-	-	-	0.326	-	-	0.00054	-	-	-
Quad-Cities 1-2	0.0132	0.659	0.0670	0.119	-	-	0.0562	-	0.655	0.00895	0.0269	0.00784	-	-	-
River Bend 1	-	17.7	0.736	0.625	-	-	0.252	0.0836	1.22	0.0881	-	-	-	0.00013	0.00013
Susquehanna 1-2	0.186	1.64	0.714	0.507	-	-	0.0064	0.0137	0.342	0.0255	-	-	-	-	-
Vermont Yankee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WNP-2	-	0.0381	0.00237	0.00178	-	-	0.00555	-	0.0369	0.074	0.00155	0.00007	-	0.00122	0.00122
Total release (GBq)	5340	357	83.2	30.9	0.03	0.002	47.4	27.9	177	22.4	3.4	0.57	0.046	0.272	0.059
Normalized activity [GBq (GW a)$^{-1}$]	320	21	5.0	1.9	0.0021	0.00014	2.8	1.7	11	1.3	0.21	0.034	0.0028	0.016	0.0035

Table 37 (continued)

PART B

Reactor	Release (GBq)													
	^{97}Nb	^{97}Zr	^{99}Mo	^{99m}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{122}Sb	^{124}Sb	^{125}Sb	^{131}I	^{132}I	^{132}Te	^{133}I
Big Rock Point	-	-	0.0003	-	-	-	0.0327	-	0.0184	-	0.00799	-	-	0.0197
Browns Ferry 1-3	-	-	0.0125	0.0125	-	-	-	-	-	0.0426	-	-	-	-
Brunswick 1-2	-	-	0.0577	0.179	-	-	0.0162	-	0.00133	0.00459	0.485	0.00999	0.0389	0.221
Clinton 1	-	-	0.0057	0.0174	-	-	-	0.00089	0.00133	-	-	-	-	-
Cooper	-	-	0.0176	0.437	-	-	0.365	-	-	0.0636	2.55	-	-	0.125
Dresden 1-3	-	-	-	-	-	-	-	-	0.00001	-	0.00092	-	-	-
Duane Arnold	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Edwin I. Hatch 1-2	0.131	-	0.0171	0.106	-	-	-	-	-	0.194	0.836	0.0158	-	0.341
Fermi 2	-	-	0.0570	0.0910	0.127	-	0.00044	-	-	-	-	-	-	0.00455
Grand Gulf 1	-	0.00047	0.00574	0.0167	-	0.00873	0.0403	-	-	-	0.00067	-	-	0.00082
Hope Creek 1	0.0107	0.0105	0.0141	0.0437	0.00057	-	-	0.00032	-	-	0.00081	-	0.00059	0.0129
Humboldt Bay 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
James A. Fitzpatrick	-	-	-	-	-	-	-	-	0.00144	-	0.0218	-	-	0.0107
Lacrosse	-	-	-	-	-	-	0.0208	-	-	-	-	-	-	-
Lasalle 1-2	-	-	-	0.0007	-	-	0.265	-	-	-	1.23	-	-	-
Limerick 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Millstone 1	-	-	-	0.0177	0.00017	-	-	-	-	-	0.0474	-	-	0.0411
Monticello	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nine Mile Point 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nine Mile Point 2	-	-	0.0206	0.0194	-	-	-	-	-	-	-	-	-	-
Oyster Creek 1	-	-	-	0.0153	-	-	-	-	-	-	0.00199	-	-	-
Peach Bottom 2-3	-	-	-	-	-	-	0.00629	-	-	-	-	-	-	-
Perry 1	-	-	-	0.00566	-	-	0.116	-	0.00105	-	0.101	-	-	0.00503
Pilgim 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quad-Cities 1-2	-	-	0.00115	-	-	-	0.0596	-	-	-	0.00078	-	-	0.00066
River Bend 1	0.0751	-	0.0329	0.0340	-	-	0.0170	0.00138	0.273	-	-	-	-	-
Susquehanna 1-2	-	-	-	-	-	-	0.0403	-	-	-	-	-	-	-
Vermont Yankee	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WNP-2	-	-	-	-	-	-	0.0289	-	-	-	0.00777	-	-	-
Total release (GBq)	0.216	0.0110	0.242	0.995	0.127	0.0087	1.01	0.00259	0.297	0.304	5.29	0.025	0.039	0.782
Normalized activity [GBq (GW a)$^{-1}$]	0.013	0.00066	0.015	0.060	0.0076	0.00052	0.060	0.00015	0.018	0.018	0.32	0.0015	0.0024	0.047

Table 37 (continued)

PART C

Reactor	Release (GBq)													
	^{134}Cs	^{134}I	^{135}I	^{136}Cs	^{137}Cs	^{138}Cs	^{139}Ba	^{140}Ba	^{140}La	^{141}Ce	^{143}Ce	^{144}Ce	^{187}W	^{239}Np
Big Rock Point	0.145	-	0.0102	-	1.37	-	-	-	-	-	-	-	-	-
Browns Ferry 1-3	1.36	-	-	-	5.59	-	-	-	-	-	-	-	-	-
Brunswick 1-2	1.27	0.00126	0.107	0.0105	4.48	-	-	0.0025	0.0025	-	-	0.0318	0.00825	0.294
Clinton 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cooper	5.96	-	-	0.0074	10.2	-	-	0.0777	0.0825	-	-	-	-	-
Dresden 1-3	-	-	-	-	0.592	0.0125	-	-	0.00004	-	-	-	-	-
Duane Arnold	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Edwin I. Hatch 1-2	9.88	0.253	0.134	0.116	14.9	0.0107	0.0134	0.0131	0.00603	0.00364	-	0.0094	-	0.252
Fermi 2	-	-	-	-	-	-	-	-	-	-	-	0.0662	-	-
Grand Gulf 1	0.0147	-	0.0007	-	0.0138	0.00056	-	-	-	0.00079	-	-	0.00396	-
Hope Creek 1	-	-	-	-	0.00005	-	0.00304	-	-	0.00045	0.00013	-	-	0.00163
Humboldt Bay 3	0.00081	-	-	-	0.240	-	-	-	-	-	-	-	-	-
James A. Fitzpatrick	0.171	-	0.0022	-	0.418	-	-	-	-	-	-	-	-	0.0124
Lacrosse	0.0566	-	-	-	2.52	-	-	-	-	-	-	0.00463	-	-
Lasalle 1-2	0.681	-	-	0.0722	1.82	0.0777	-	0.00017	0.00017	0.0281	-	-	-	-
Limerick 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Millstone 1	0.0426	-	-	-	2.85	-	-	-	-	-	-	0.00025	-	-
Monticello	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nine Mile Point 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nine Mile Point 2	-	-	-	-	-	-	-	-	-	-	-	-	0.0074	-
Oyster Creek 1	0.0140	-	-	-	0.147	-	-	-	0.0244	-	-	-	-	-
Peach Bottom 2-3	1.62	-	-	-	2.81	-	-	-	-	-	-	-	-	-
Perry 1	-	-	-	-	0.00411	-	-	-	0.0204	-	-	-	-	-
Pilgrim 1	0.0140	-	-	-	0.588	-	-	-	-	-	-	-	-	-
Quad-Cities 1-2	0.00677	-	-	-	0.348	-	-	-	0.0018	-	-	-	-	-
River Bend 1	-	-	-	-	-	-	-	-	-	-	-	0.00625	0.0114	-
Susquehanna 1-2	0.0155	-	-	-	0.0148	-	-	-	-	-	-	-	-	-
Vermont Yankee	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WNP-2	0.0107	-	-	-	0.0138	-	-	-	-	-	-	-	-	-
Total release (GBq)	21.3	0.254	0.254	0.206	49.0	0.101	0.0164	0.093	0.138	0.033	0.00013	0.119	0.0310	0.560
Normalized activity [GBq (GW a)$^{-1}$]	1.3	0.015	0.015	0.012	2.9	0.0061	0.00098	0.0056	0.0082	0.0020	0.00001	0.0071	0.0019	0.034

[a] A dash indicates no value reported.

Table 38
Average releases of radionuclides from reactors per unit electrical energy generated

Years	Normalized release [TBq (GW a)$^{-1}$]						
	PWRs	BWRs	GCRs	HWRs	LWGRs	FBRs	Total [a]
Noble gases							
1970-1974	530	44000	580	4800	5000 [b]	150 [b]	13000
1975-1979	430	8800	3200	460	5000 [b]	150 [b]	3300
1980-1984	220	2200	2300	210	5500	150 [b]	1200
1985-1989	81	290	2100	190	2000	150	330
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	2.8	2.5	9.0	480	26 [b]	96	30
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]	0.75
1985-1989	0.12	0.45	0.54	4.8	1.3	0.12 [b]	0.52
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	0.0093	0.0014	0.0002	0.080	0.0018 [b]	0.0089
1985-1989	0.0009	0.0018	0.0014	0.0002	0.014	0.0009 [b]	0.0018
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	0.0040
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	0.79	120	370	11 [b]	2.9	41
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	0.045	0.036	0.96	0.030	0.045 [b]	0.028	0.079

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

Table 39
Electrical energy generated by nuclear reactors worldwide

Year	Electrical energy generated (GW a)						
	PWRs	BWRs	GCRs	HWRs	LWGRs	FBRs	Total
Before 1970	5.53	3.18	18.92	0.41	0.74	0	28.8
1970	2.54	1.53	3.67	0.18	0.17	0	8.1
1971	4.07	3.47	4.16	0.57	0.17	0.008	12.5
1972	5.52	5.30	5.15	0.85	0.17	0.006	17.0
1973	7.90	6.63	4.44	1.82	0.82	0.005	21.6
1974	12.12	8.20	5.28	2.02	0.84	0.11	28.6
1975	20.34	10.16	5.19	1.93	1.49	0.15	39.3
1976	22.70	13.38	5.55	2.45	2.15	0.11	46.3
1977	29.84	14.14	5.88	2.74	2.79	0.036	55.4
1978	34.00	18.86	5.68	3.81	3.44	0.17	66.0
1979	33.37	20.89	5.79	4.60	4.74	0.22	69.6
1980	40.08	21.18	5.56	4.81	4.74	0.55	76.9
1981	50.94	22.93	5.38	5.19	6.03	0.58	91.0
1982	56.06	25.20	6.00	5.03	6.68	0.52	99.5
1983	63.92	26.04	6.48	6.52	8.94	0.54	112.4
1984	78.80	31.27	7.00	7.29	8.87	0.61	133.8
1985	94.82	37.76	7.46	8.29	11.41	0.67	160.4
1986	105.3	40.07	6.89	9.53	8.74	0.77	171.3
1987	117.3	43.15	6.86	10.33	11.05	0.81	189.5
1988	128.6	44.21	7.93	10.77	11.93	0.67	204.1
1989	135.9	44.23	8.13	10.33	11.99	0.81	211.4
Total	1050	442	137	99.5	108	7.4	1844

Table 40
Estimated releases of radionuclides from reactors worldwide

Year	Release (TBq)						
	Noble gases	^{3}H	^{14}C	^{131}I	Particulates	Tritium (liquid)	Other (liquid)
Before 1970	160000	519	10.6	0.59	0.26	341	112
1970	72500	179	3.5	0.26	0.11	104	23.9
1971	161000	462	7.5	0.56	0.22	203	31.0
1972	244000	670	10.7	0.85	0.32	285	40.6
1973	312000	1360	18.8	1.11	0.42	490	40.5
1974	385000	1540	22.0	1.36	0.56	567	49.3
1975	123000	1330	25.1	4.40	0.61	1610	32.6
1976	157000	1650	31.5	5.79	0.79	1900	36.1
1977	172000	1880	36.2	6.19	0.86	2290	39.5
1978	218000	2540	47.2	8.20	1.12	2830	41.3
1979	243000	3000	54.8	9.13	1.25	3110	42.9
1980	94200	3740	59.7	0.66	1.18	3110	33.7
1981	107000	4100	68.1	0.79	1.32	3510	34.7
1982	118000	4040	70.7	0.88	1.46	3680	38.5
1983	135000	5160	86.3	1.08	1.56	4390	42.1
1984	151000	5780	98.1	1.15	1.86	5080	47.1
1985	59600	4700	86.8	0.32	0.68	6520	13.6
1986	54700	5330	91.3	0.30	0.69	7150	13.5
1987	61300	5820	101	0.35	0.77	7780	14.2
1988	66700	6080	107	0.38	0.81	8360	15.9
1989	67800	5910	106	0.38	0.83	8410	16.4
Total release (TBq)	3160000	65800	1140	44.7	17.7	71700	759
Average normalized release [TBq (GW a)$^{-1}$]	1720	36	0.62	0.024	0.010	39	0.41

Table 41
Collective dose per unit release of radionuclides from reactors

Type of release	*Radionuclide*	*Composition for reactor type*	*Collective dose per unit release (man Sv PBq^{-1})*
Airborne	Noble gases	PWR	0.12 [a] [b]
		BWR	0.26
		GCR	0.011
	Tritium		11
	Carbon-14		1800 [c]
	Iodines [d]	PWR	340
		BWR	520 [a]
		GCR	510 [b]
	Particulates		5400
Liquid	Tritium		0.81
	Other than tritium	PWR	20 [a] [b]
		BWR	170
		GCR	40

[a] Also assumed for LWGRs and FBRs.
[b] Also assumed for HWRs.
[c] Local and regional.
[d] Expressed in terms of ^{131}I released.

Table 42
Normalized collective effective doses from radionuclides released from reactors, 1985-1989

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	62.13	0.010	0.030	0.22	0.0003	0.011	0.020	0.0009
BWR	22.35	0.075	0.028	0.81	0.0009	0.049	0.0006	0.0061
GCR	3.98	0.024	0.099	0.97	0.0007	0.0038	0.097	0.038
HWR	5.26	0.023	5.3	8.6	0.0001	0.0011	0.30	0.0006
LWGR	5.88	0.24	0.29	2.3	0.0069	0.065	0.0089	0.0009
FBR	0.40	0.018	1.1	0.22	0.0005	0.0010	0.0023	0.0006
Weighted average		0.039	0.33	0.94	0.0008	0.022	0.033	0.004
Total		1.4						

[a] Local and regional components only.

Table 43
Collective effective dose from radionuclides released from reactors worldwide

Year	Collective effective dose (man Sv)							
	Noble gases	Tritium	^{14}C	^{131}I	Particulates	Tritium (liquid)	Other (liquid)	Total
Before 1970	38	5.7	19	0.30	1.4	0.28	5.3	70
1970	18	2.0	6.3	0.13	0.61	0.08	1.3	28
1971	41	5.1	13	0.29	1.2	0.16	2.1	63
1972	62	7.4	19	0.44	1.7	0.23	3.0	94
1973	78	15	34	0.57	2.3	0.40	3.3	133
1974	96	17	40	0.70	3.0	0.48	4.0	161
1975	25	15	45	2.3	3.3	1.3	1.6	94
1976	33	18	57	3.0	4.3	1.5	1.8	119
1977	36	21	65	3.2	4.6	1.9	2.0	133
1978	47	28	85	4.2	6.1	2.3	2.2	175
1979	53	33	99	4.7	6.7	2.5	2.3	201
1980	16	41	107	0.32	6.4	2.5	1.5	176
1981	18	45	123	0.39	7.2	2.8	1.6	198
1982	20	44	127	0.43	7.9	3.0	1.7	205
1983	22	57	155	0.53	8.5	3.6	1.9	249
1984	26	64	177	0.57	10	4.1	2.1	283
1985	6.9	52	156	0.15	3.7	5.3	0.62	225
1986	6.6	59	164	0.14	3.7	5.8	0.62	240
1987	7.5	64	182	0.16	4.1	6.3	0.65	264
1988	7.9	67	192	0.17	4.4	6.8	0.71	279
1989	8.0	65	190	0.17	4.5	6.8	0.72	275
Total	668	724	2055	23	95	58	41	3665

Table 44
Fuel reprocessing capacities in 1989
[18]

Fuel reprocessing plant	Reprocessing capacity (t a^{-1})		
	Metal	Oxide	FBR
France			
Marcoule UP1 (GCR fuel)	600		
Cap de La Hague UP2 (LWR fuel)		400	
Marcoule APM			5
Germany, Federal Republic of			
Karlsruhe		35	
Japan			
Tokai-Mura		210	
India			
Tarapur (HWR and LWR fuel)		100	
Trombay (Reseach reactor fuel)	50		
USSR			
Kyshtym		400	
United Kingdom			
Sellafield (Magnox reactor fuel)	1500		
Dounreay			1
Total	2150	1145	6

Table 45
Management strategies for spent fuel [a]
[18]

Country	*Interim storage*	*Final storage*	*Reprocessing*	*Indicative amounts of spent fuel generated in 1990 (t a^{-1})*			
				All countries		*Countries with an intent to reprocess*	
				Metal	*Oxide* [b]	*Metal*	*Oxide* [b]
Argentina [c]	×		×		170		170
Belgium			×		170		170
Brazil	×				9		
Bulgaria			×		57		57
Canada [c]		×			2500		
China			×				
Czechoslovakia			×		10		10
Finland	×		×		8		8
France			×	150	1200	150	1200
Germany	×		×		670		670
Hungary			×		54		54
India [d]			×		200		200
Japan			×	33	1000	33	1000
Mexico	×				24		
Netherlands			×		14		14
Pakistan [c]	×				23		
Republic of Korea [d]	×				300		
South Africa	×				36		
Spain	×				230		
Sweden	×	×			340		
Switzerland			×		100		100
USSR			×		420		420
United Kingdom			×	1300	140	1300	140
United States		×			2900		
Yugoslavia	×				19		
Total (rounded)				1500	11000	1500	4900

[a] Based on energy generated in 1990 and the data in Table 16.
[b] LWR oxide fuel unless otherwise indicated.
[c] HWR fuel.
[d] In the case of India, about 190 t, in the case of the Republic of Korea, about 100 t is HWR fuel.

Table 46
Radionuclides released in effluents from fuel reprocessing plants, 1985-1989
[B13, C17, N7, N13, S3, S9]

Reprocessing plant	*Year*	*Electrical energy generated (GW)*	*Release (TBq)*											
			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
France	1985	6.11	32		70300				2600	0.7	76	440	0.13	29
Cap de La Hague	1986	2.52	6		29000				2300	0.7	78	470	0.13	29
	1987	3.04	15		35000				3000		65			7.6
	1988	2.35	21		27000				2500		48			8.5
	1989	3.65	25		42000				3700		41			13
United Kingdom	1985	1.70	268	7.0	23800	0.007	0.002	0.002	1062	1.3	52	81	< 0.1	325
Sellafield	1986	3.81	171	5.4	53300	0.03	0.003	0.007	2150	2.6	18.3	28	0.12	17.9
	1987	2.43	78.3	9.5	34000	0.019	0.004	0.004	1375	2.1	15.0	22.1	0.1	11.8
	1988	2.84	185.6	3.6	39800	0.024	0.002	0.005	1724	3.0	10.1	23.6	0.13	13.3
	1989	3.69	677	3.9	51700	0.024	0.002	0.004	2144	2.0	9.2	25.0	0.17	28.6
Japan	1985	1.2	2.8		10000	0.0010	[a]		260		0.000002	[a]	[a]	0.00008
Tokai-Mura	1986	1.2	2.7		13000	0.0023	[a]		240		0.000025	[a]	[a]	0.00017
	1987	0.93	3.7		12000	0.00014	[a]		260		0.000009	[a]	[a]	0.00015
	1988	0.17	2.5		2700	0.00009	[a]		74		[a]	[a]	[a]	0.00009
	1989	1.1	3.7		9800	0.00024			240					0.00004
Total release (TBq)			1494	29.4	453400	0.108	0.013	0.022	23630	12.4	412.6	1090	0.880	483.7
Electrical energy generated (GW a)			36.74	14.47	36.74	19.07	19.07	14.47	36.74	23.1	36.74	27.70	27.70	36.74
Normalized release [TBq (GW a)$^{-1}$]			41	2.0	12300	0.0057	0.0007	0.0015	643	0.54	11	39	0.032	13

[a] Less than detection limit.

Table 47
Normalized releases of radionuclides from fuel reprocessing plants

Years	Normalized release [TBq (GW a)$^{-1}$] [a]					
	Airborne effluents					
	^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs
1970-1979	88	1.8	14200	0.002	0.098	0.11
1980-1984	52	3.4	12700	0.004	0.019	0.038
1985-1989	41	2.0	12300	0.006	0.0007	0.002
	Liquid effluents					
	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
1970-1979	400	0.54 [b]	140	340	0.046	1000
1980-1984	405	0.54 [b]	48	120	0.040	270
1985-1989	643	0.54	11	39	0.032	13

[a] Normalization is for energy equivalent of fuel reprocessed.
[b] Estimated value.

Table 48
Estimated releases of radionuclides from fuel reprocessing plants worldwide

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
Before 1970	2.2	198	4.0	32000	0.004	0.22	0.25	898	1.2	306	753	0.10	2250
1970	0.6	56	1.1	8990	0.001	0.06	0.07	252	0.34	86	212	0.03	633
1971	1.0	86	1.7	13800	0.002	0.10	0.11	389	0.52	133	326	0.04	975
1972	1.3	117	2.3	18900	0.002	0.13	0.15	530	0.71	181	444	0.06	1330
1973	1.7	149	3.0	24000	0.003	0.17	0.19	674	0.90	230	565	0.08	1690
1974	2.2	197	3.9	31800	0.004	0.22	0.25	891	1.2	304	747	0.10	2240
1975	4.8	447	8.5	68000	0.008	0.47	0.53	1810	2.6	541	1590	0.22	5260
1976	4.0	446	7.1	57000	0.007	0.40	0.45	1460	2.2	421	1320	0.18	4320
1977	3.9	307	7.0	58800	0.007	0.39	0.44	1250	2.1	500	1360	0.18	4530
1978	4.0	227	7.1	56800	0.007	0.39	0.44	1810	2.2	737	1610	0.18	4130
1979	4.8	422	8.4	68100	0.008	0.47	0.53	1840	2.6	367	1140	0.22	2620
1980	5.5	265	19	68900	0.03	0.10	0.21	1980	2.9	381	727	0.22	3000
1981	7.4	473	25	95600	0.02	0.14	0.28	2810	4.0	304	861	0.29	2400
1982	8.2	370	28	103600	0.03	0.16	0.31	2760	4.4	405	890	0.33	2050
1983	7.5	278	25	93800	0.03	0.14	0.28	3000	4.0	346	890	0.30	1220
1984	5.1	358	17	65400	0.04	0.10	0.19	3080	2.7	182	699	0.20	464
1985	9.0	303	18	104100	0.05	0.006	0.014	3920	4.8	128	521	0.23	354
1986	7.5	180	15	95300	0.04	0.005	0.011	4690	4.0	96	498	0.25	47
1987	6.4	97	13	81000	0.04	0.004	0.010	4640	3.4	80	252	0.20	19
1988	5.4	209	11	68700	0.03	0.004	0.008	4300	2.9	58	211	0.17	22
1989	8.4	706	17	103500	0.05	0.004	0.013	6080	4.5	50	332	0.27	42
Total	101	5890	243	1318000	0.41	3.7	4.7	49100	54	5840	15900	3.9	39600
Average normalized release for fuel reprocessed [TBq (GW a)$^{-1}$]		58	2.4	13000	0.0040	0.036	0.047	490	0.54	58	160	0.038	390
Average normalized release for energy generated [TBq (GW a)$^{-1}$]		3.2	0.13	720	0.0002	0.002	0.003	27	0.029	3.2	8.6	0.002	21

Table 49
Normalized local and regional collective effective dose from fuel reprocessing, 1985-1989

Radio-nuclide	*Normalized release* [a] *[TBq (GW a)$^{-1}$]*	*Collective dose per unit release (man Sv TBq^{-1})*	*Normalized collective dose [man Sv (GW a)$^{-1}$]*	
			For fuel reprocessed	*For energy generated* [b]
Airborne effluents				
H-3	41	0.0027	0.11	0.004
C-14	2.0	0.4	0.81	0.033
Kr-85	12300	0.0000074	0.091	0.004
I-129	0.0057	44	0.25	0.010
I-131	0.0007	0.4	0.0003	0.00001
Cs-137	0.0015	11	0.017	0.0007
Total				0.05
Liquid effluents				
H-3	643	0.0000018	0.0012	0.00005
C-14	0.54	0.4	0.21	0.009
Sr-90	11	0.012	0.13	0.005
Ru-106	39	0.07	2.8	0.11
I-129	0.032	-	-	-
Cs-137	13	0.08	1.1	0.042
Total				0.17

[a] Normalized for the energy equivalent of fuel reprocessed.
[b] The fraction of fuel reprocessed during 1985-1989 was 0.04.

Table 50
Estimated local and regional collective dose from radionuclides released from fuel reprocessing plants worldwide

Year	Collective effective dose (man Sv)											
	Airborne						Liquid					
	^{3}H	^{14}C	^{85}Kr	^{129}I	^{131}I	^{137}Cs	^{3}H	^{14}C	^{90}Sr	^{106}Ru	^{129}I	^{137}Cs
Before 1970	0.5	1.6	0.24	0.17	0.088	2.7	0.002	0.5	3.7	53	0	180
1970	0.2	0.4	0.07	0.05	0.025	0.8	0.0005	0.1	1.0	15	0	51
1971	0.2	0.7	0.10	0.07	0.038	1.2	0.0007	0.2	1.6	23	0	78
1972	0.3	0.9	0.14	0.10	0.052	1.6	0.001	0.3	2.2	31	0	106
1973	0.4	1.2	0.18	0.13	0.066	2.1	0.001	0.4	2.8	40	0	135
1974	0.5	1.6	0.23	0.17	0.088	2.7	0.002	0.5	3.6	52	0	179
1975	1.2	3.4	0.50	0.36	0.19	5.9	0.003	1.0	6.5	111	0	421
1976	1.2	2.9	0.42	0.30	0.16	4.9	0.003	0.9	5.1	92	0	346
1977	0.8	2.8	0.44	0.30	0.15	4.8	0.002	0.8	6.0	95	0	362
1978	0.6	2.8	0.42	0.30	0.16	4.9	0.003	0.9	8.8	113	0	330
1979	1.1	3.4	0.50	0.36	0.19	5.8	0.003	1.0	4.4	80	0	210
1980	0.7	7.4	0.51	1.47	0.042	2.3	0.004	1.2	4.6	51	0	240
1981	1.3	10.1	0.71	0.93	0.056	3.1	0.005	1.6	3.6	60	0	192
1982	1.0	11.1	0.77	1.16	0.062	3.4	0.005	1.8	4.9	62	0	164
1983	0.7	10.1	0.69	1.31	0.057	3.1	0.005	1.6	4.1	62	0	98
1984	1.0	7.0	0.48	1.63	0.039	2.1	0.006	1.1	2.2	49	0	37
1985	0.8	7.3	0.77	2.24	0.002	0.2	0.007	1.9	1.5	36	0	28
1986	0.5	6.1	0.71	1.87	0.002	0.1	0.008	1.6	1.2	35	0	3.8
1987	0.3	5.2	0.60	1.59	0.002	0.1	0.008	1.4	1.0	18	0	1.6
1988	0.6	4.4	0.51	1.33	0.001	0.1	0.008	1.2	0.7	15	0	1.7
1989	1.9	6.9	0.77	2.10	0.002	0.1	0.011	1.8	0.6	23	0	3.3
Total	16	97	9.8	18	1.5	52	0.09	22	70	1110	0	3200
Total	4600											

Table 51
Normalized collective effective dose from globally dispersed radionuclides for a time period of 10,000 years

Radio-nuclide	*Normalized activity released [TBq (GW a)$^{-1}$]*			*Collective dose per unit release (man Sv TBq^{-1})*	*Normalized collective dose [man Sv (GW a)$^{-1}$]*
	Reactors [a]	*Reprocessing plants* [b]	*Total* [c]		
H-3	71	684 [d]	98	0.0012 [e f]	0.09
C-14	0.52	2.54	0.62	85 [g]	53
Kr-85		12300	490	0.0002 [f]	0.1
I-129		0.038	0.0015	4 [g]	0.006
Total					53

[a] Normalization for total energy generated.
[b] Normalization for fuel reprocessed.
[c] Normalization for total energy generated; the contribution from reprocessing plants is weighted according to the fraction of fuel reprocessed (0.04).
[d] Release to sea: 643 TBq (GW a)$^{-1}$; remainder released to air.
[e] For release to air or fresh water; less by a factor of 10 for release to sea.
[f] For world population of $5\ 10^9$ at time of release.
[g] For world population of 10^{10}.

Table 52
Estimated releases of globally dispersed radionuclides and collective effective dose for a time period of 10,000 years

Year	*Release (TBq)*			
	^{3}H	^{14}C	^{85}Kr	^{129}I
Before 1970	1960	15.8	32000	0.11
1970	592	5.0	8990	0.030
1971	1140	9.7	13800	0.046
1972	1600	13.8	18900	0.063
1973	2670	22.6	24000	0.080
1974	3210	27.1	31800	0.11
1975	5200	36.2	68000	0.23
1976	5460	40.8	57000	0.19
1977	5720	45.3	58800	0.19
1978	7400	56.4	56800	0.19
1979	8370	65.8	68100	0.23
1980	9090	81.2	68900	0.25
1981	10900	97.3	95600	0.32
1982	10900	103	103600	0.35
1983	12800	116	93800	0.33
1984	14300	118	65400	0.24
1985	15500	110	104100	0.28
1986	17400	111	95300	0.29
1987	18300	117	81000	0.24
1988	19000	120	68700	0.20
1989	21100	127	103500	0.32
Total release (TBq)	193000	1440	1318000	4.3
Dose commitment per unit release (nGy TBq^{-1})	0.00027 [a]	8.5	0.000043	0.4
Population	[b]	10^{10}	[b]	10^{10}
Collective effective dose (man Sv)	180	122000	260	17
Total collective effective dose (man Sv)	123000			

[a] Release to atmosphere or fresh water; factor of 10 less for release to sea surface.
[b] Global population in year of release (1970 $3.7\ 10^9$, 1975 $4.1\ 10^9$, 1980 $4.5\ 10^9$, 1985 $4.9\ 10^9$, 1989 $5.2\ 10^9$); assuming $3.6\ 10^9$ persons for releases before 1970.

Table 53
Normalized collective effective dose to members of the public from radionuclides released in effluents from the nuclear fuel cycle

Source	*Normalized collective effective dose [man Sv (GW a)$^{-1}$]*
Local and regional component	
Mining	1.1
Milling	0.05
Mine and mill tailings (releases over 5 years)	0.3
Fuel fabrication	0.003
Reactor operation	
Atmospheric	1.3
Aquatic	0.04
Reprocessing	
Atmospheric	0.05
Aquatic	0.2
Transportation	0.1
Total (rounded)	3
Solid waste disposal and global component	
Mine and mill tailings (releases of radon over 10,000 years)	150
Reactor operation	
Low-level waste disposal	0.00005
Intermediate-level waste disposal	0.5
Reprocessing solid waste disposal	0.05
Globally dispersed radionuclides (truncated to 10,000 years)	50
Total (rounded)	200

Table 54
Unsealed radioisotopes used in Japan in 1989
[J2]

Radio-nuclide	*Quantities of radioisotopes used (GBq)*				
	Hospitals and clinics	*Educational organizations*	*Research institutions*	*Industry and other*	*Total*
H-3	25	334	1168	123	1650
C-14	13	16	469	118	616
P-32	24	407	543	21	995
S-35	10	111	134	8	263
Ca-45	2	11	6	1	20
Cr-51	25	114	79	8	236
Fe-59	6	0.7	1	0.3	8
Ga-67	16660	0.6	0.2	1.2	16660
Se-75	10	(0.05)	(0.1)	-	10
Kr-81m [a]	813	-	-	-	813
Kr-85	-	-	14	202	216
Tc-99m [a]	163200	22	12	265	163500
Tc-99m [b]	63770	1	(0.4)	75	63840
In-111	344	0.2)	(0.07)	(0.07)	344
I-123	8353	4	(0.5)	2	8359
I-125	273	133	174	149	729
I-131	3964	12	32	3	4011
Xe-133	32060	33	3	3	32100
Pm-147	-	-	-	75850	75850
Tl-201	15200	(0.4)	1	2	15200

[a] Generator.
[b] Solution.

Table 55
Production and dose estimates for radioisotopes used in medical, educational and industrial applications

Radio-nuclide	*Annual normalized production [a] (GBq per 10^6 population)*	*Annual global production [b] and release (PBq)*	*Collective dose coefficient (man Sv PBq^{-1})*	*Annual collective effective dose (man Sv)*
H-3	80	0.13	11	1.4
C-14	30	0.05	1800 [c]	86 [c]
Kr-85	10	0.02	0.18	0.004
I-123	400	0.7	0.022	0.01
I-125	40	0.06	120	7
I-131	200	0.3	30	9
Xe-133	1600	2.6	0.14	0.4
Total				100

[a] Developed countries only.
[b] Equivalent to 1.6 10^9 population (1.2 10^9 times 100% usage in developed countries plus 3.7 10^9 times 10% usage in developing countries).
[c] Local and regional (short-term) dose. Long-term collective dose coefficient is 85,000 man Sv PBq^{-1} and annual collective effective dose is 4,000 man Sv.

Table 56
Collective effective dose from the Kyshtym accident

Number of individuals	Deposition density of ^{90}Sr in regions ($kBq\ m^{-2}$)	Average effective dose (mSv)		Collective dose (man Sv)
		External	Total	
Evacuated population				
1150 [a]	20000	170	520	600
280 [b]	2400	140	440	120
2000 [b]	670	39	120	240
4200 [c]	330	19	56	235
3100 [d]	120	6.8	23	70
Total				1300
Non-evacuated population				
10000	40-70		20	200
250000	4-40		4	1000
Total				1200

[a] Evacuated 7-10 days after the accident.
[b] Evacuated 250 days after the accident.
[c] Evacuated 350 days after the accident.
[d] Evacuated 670 days after the accident.

Table 57
Estimates of collective effective dose from re-entry to the atmosphere and burn-up of the Cosmos 954 satellite

Radionuclide	Core inventory at re-entry [T6] (TBq)	Transfer coefficient P_{02} [a] ($Bq\ m^{-2}$ per EBq)	Deposition [a b] ($Bq\ m^{-2}$)	Transfer coefficient P_{25} [c] ($nSv\ per\ Bq\ m^{-2}$)	Dose commitment [d] (nSv)	Collective effective dose [e] (man Sv)
Sr-90	3.1	5300	0.012	56.6	0.70	2.0
Zr-95	310	270	0.063	3.78	0.24	0.62
Nb-95	220	270	0.045	1.02	0.045	0.12
Ru-103	120	120	0.011	0.75	0.008	0.02
Ru-106	5.4	2000	0.008	4.6	0.04	0.10
I-131	180	29	0.005	4.5	0.02	0.06
Cs-137	3.2	5400	0.017	143	2.5	7.1
Ba-140	400	31	0.009	1.13	0.01	0.03
Ce-141	340	83	0.021	0.12	0.002	0.01
Ce-144	93	1600	0.11	1.8	0.20	0.52
Pu-239	0.27	5400	0.001	848	0.93	5.7
Total						16

[a] For temperate latitudes of the northern hemisphere.
[b] Assuming 100% of ^{131}I and ^{137}Cs and 75% of other radionuclides in core inventory at the time of re-entry were released to the atmosphere.
[c] From Table 8, all pathways combined.
[d] Average value for temperate latitudes of northern hemisphere; divide by 1.5 to obtain average for northern hemisphere; divide northern hemisphere average value by 4 to obtain average value for southern hemisphere.
[e] Assuming global population of $4.3\ 10^9$ distributed 89% in northern hemisphere and 11% in southern hemisphere; for ^{239}Pu, the global population is assumed to be 10^{10}.

Table 58
Estimates of radionuclide released and collective effective dose from man-made environmental sources of radiation

Source	Release (PBq)						Collective effective dose [a] (man Sv)	
	^{3}H	^{14}C	Noble gases	^{90}Sr	^{131}I	^{137}Cs	Local and regional	Global
Atmospheric nuclear testing								
Global	240000	220		604	650000	910		22300000
Local								
Semipalatinsk							4600	
Nevada							500 [b]	
Australia							700	
Pacific test site							160 [b]	
Underground nuclear testing			50		15		200	
Nuclear weapons fabrication								
Early practice								
Hanford							8000 [c]	
Chelyabinsk							15000 [d]	
Later practice							1000	10000
							30000 [e]	
Nuclear power production								
Milling and mining							2700	
Reactor operation	140	1.1	3200		0.04		3700	
Fuel reprocessing	57	0.3	1200	6.9	0.004	40	4600	
Fuel cycle							300000 [e]	100000
Radioisotope production and use	2.6	1.0	52		6.0		2000	80000
Accidents								
Three Mile Island			370		0.0006		40	
Chernobyl					630	70		600000
Kyshtym				5.4		0.04	2500	
Windscale			1.2		0.7	0.02	2000	
Palomares							3	
Thule							0	
SNAP 9A								2100
Cosmos 954				0.003	0.2	0.003		20
Ciudad Juarez							150	
Mohammedia							80	
Goiania						0.05	60	
Total							380000	23100000
Total collective effective dose (man Sv)							23500000	

[a] Truncated at 10,000 years.
[b] External dose only.
[c] From release of ^{131}I to the atmosphere.
[d] From releases of radionuclides into the Techa River.
[e] Long-term collective dose from release of ^{222}Rn from tailings.

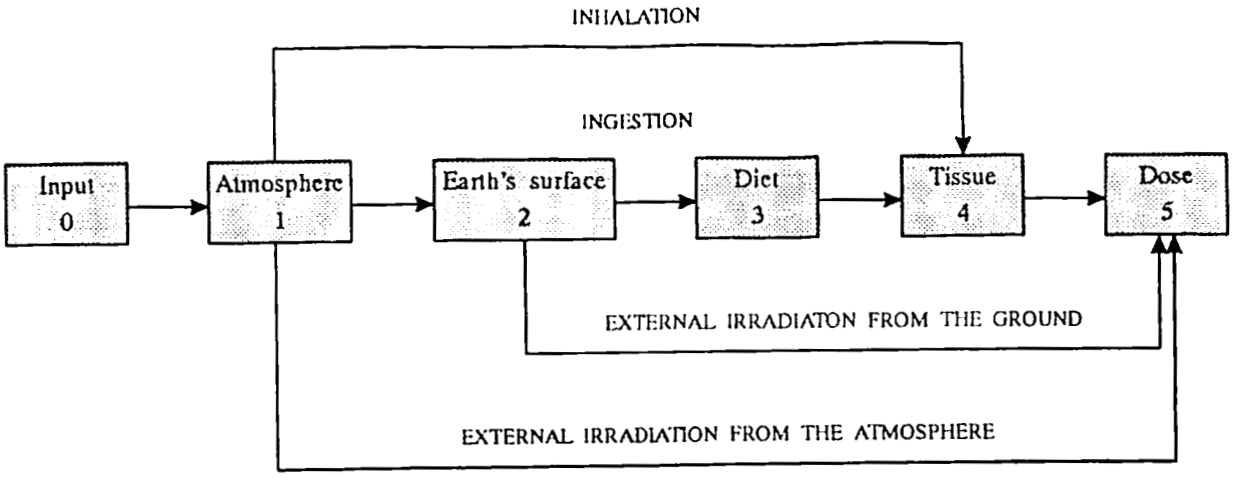

Figure I.
Compartment model used to assess doses from releases of radioactive materials to the atmosphere from nuclear testing.

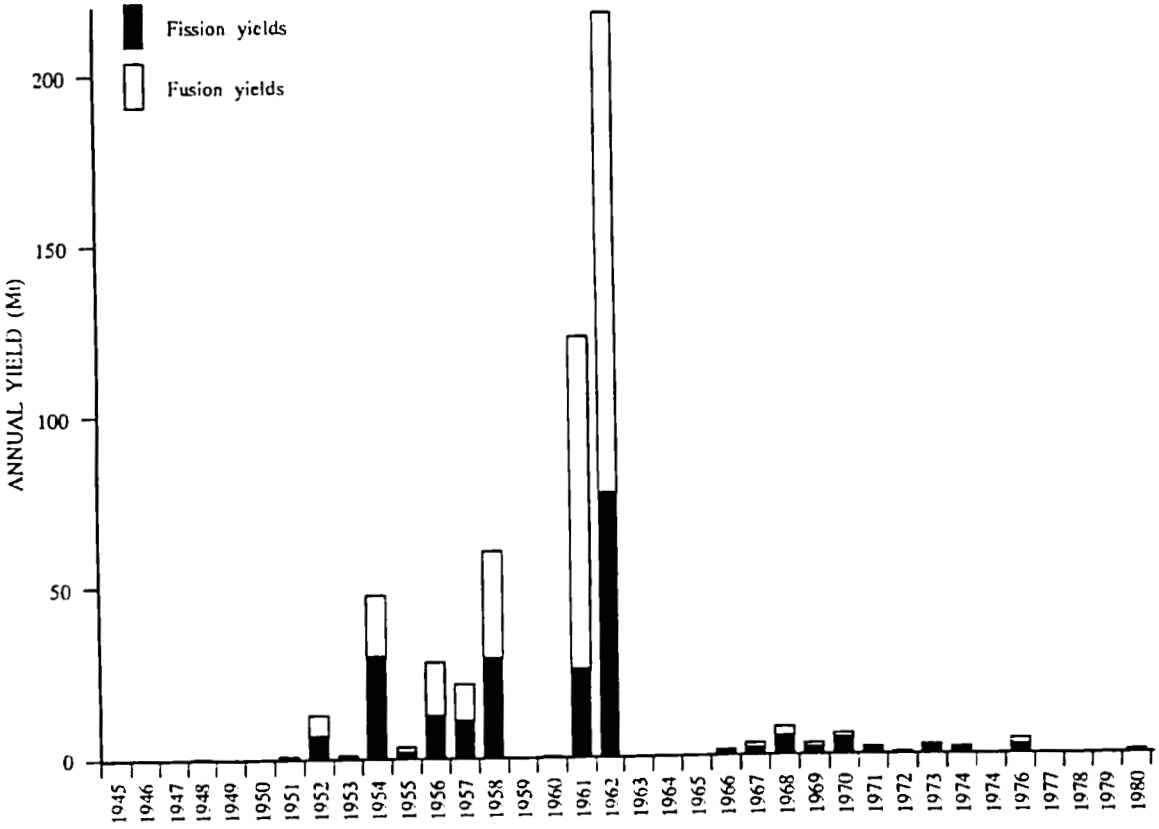

Figure II.
Fission and fusion yields of atmospheric nuclear explosions.
[B5]

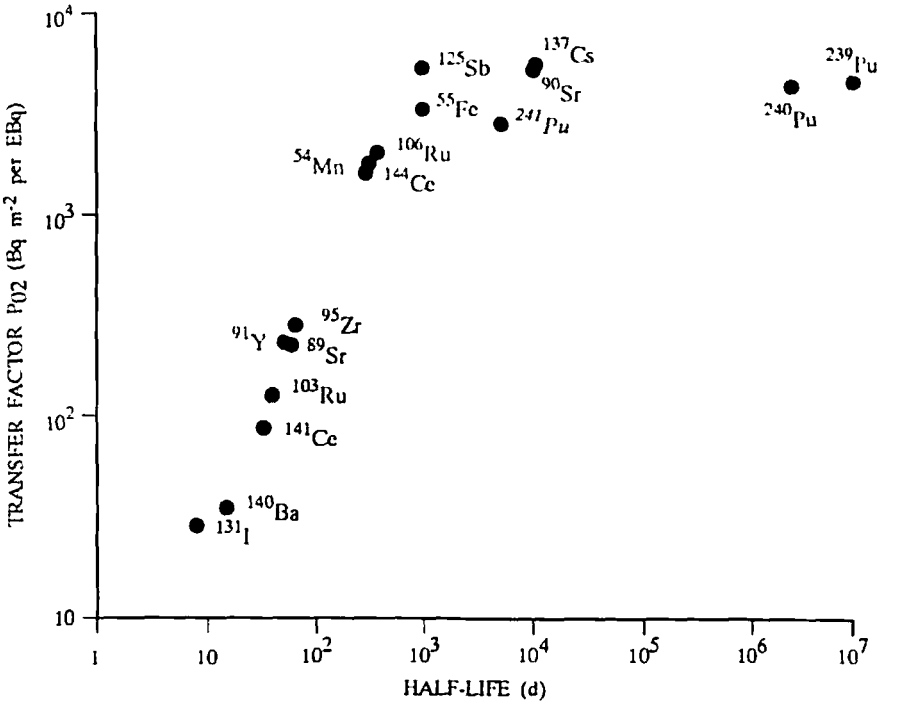

Figure III.
Transfer factor P_{02} from production of radionuclides in atmospheric nuclear testing to deposition on the earth's surface in the temperate zone of the northern hemisphere.

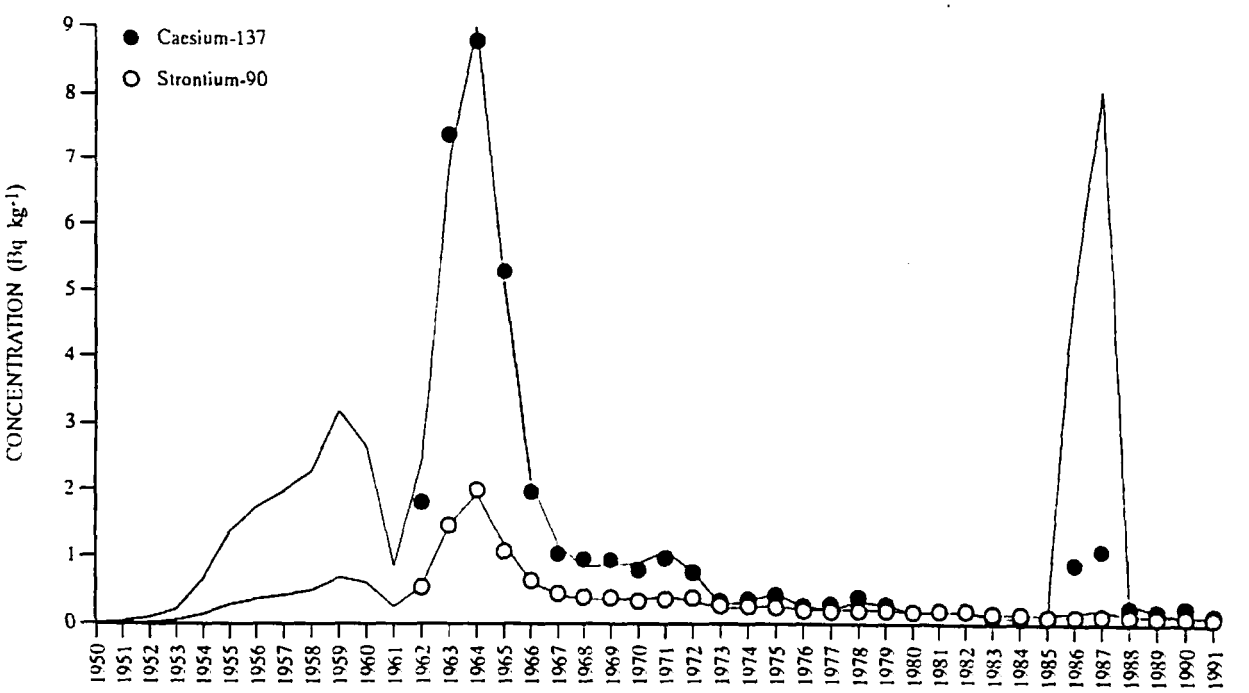

Figure IV.
Strontium-90 and caesium-137 in the total diet of Denmark.
Points: measured values; lines: results of application of regression models to the annual deposition densities.

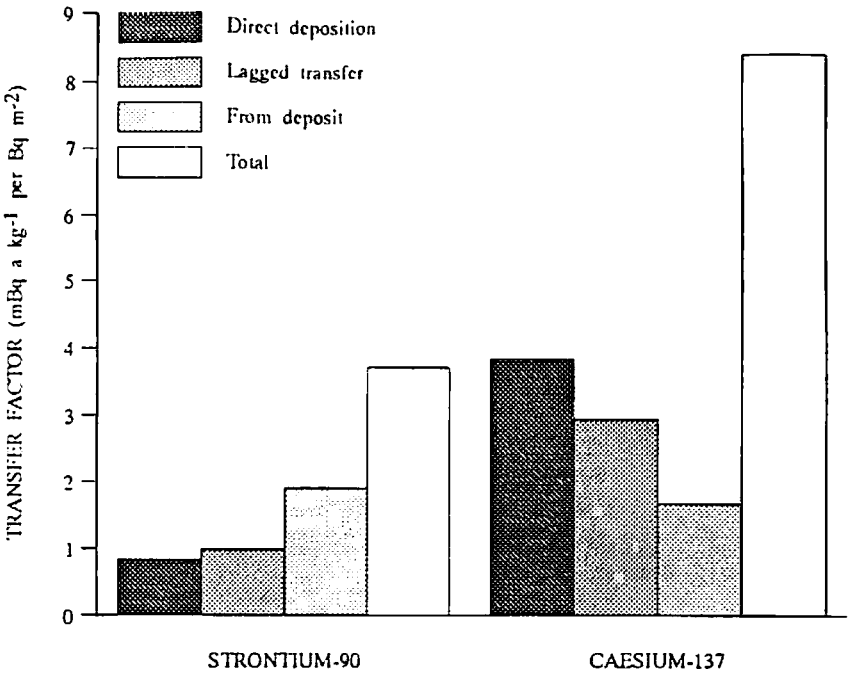

Figure V.
Contributions to strontium-90 and caesium-137 in total diet per unit deposition density derived from regression model results of measurements in Argentina, Denmark and the United States.

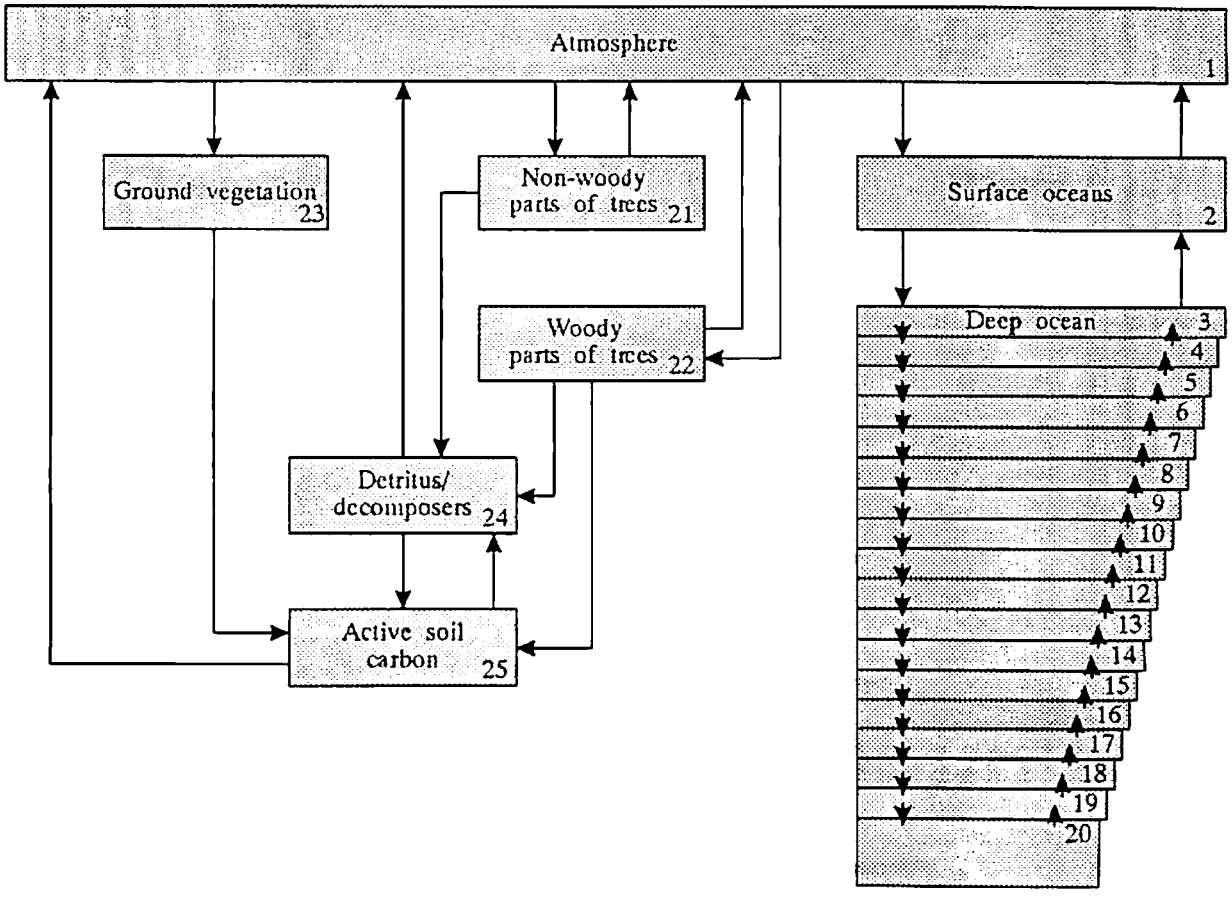

Figure VI.
Environmental compartment model of the carbon cycle.
[E6]

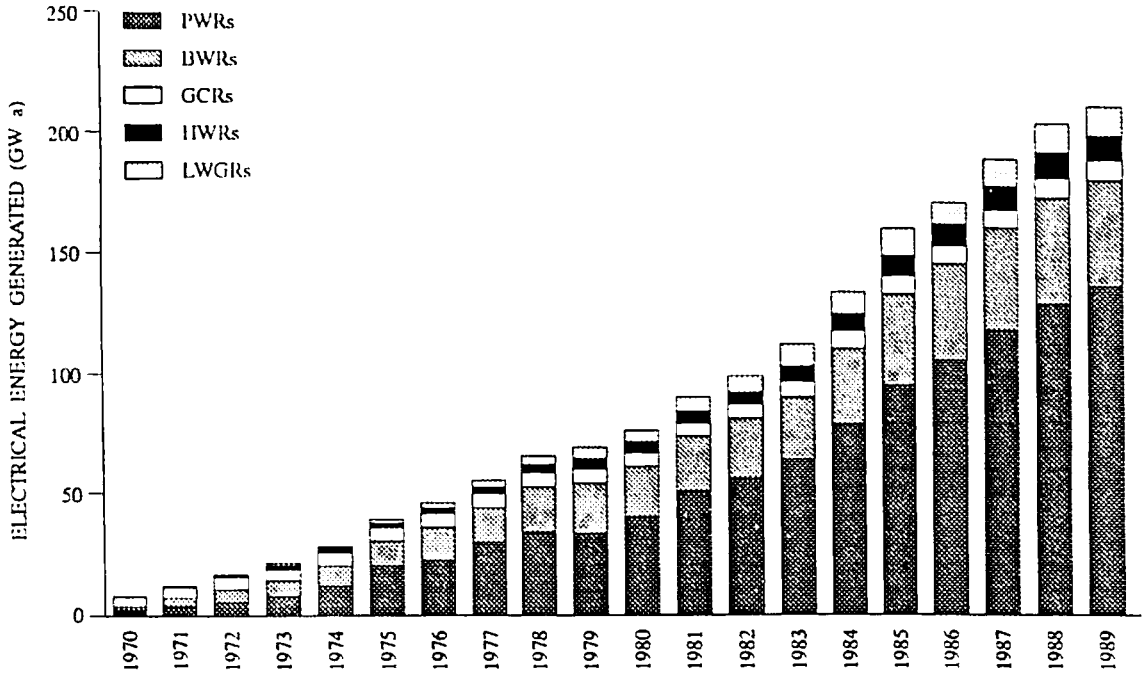

Figure VII.
Contributions by reactor types to total electrical energy generated worldwide by nuclear means.

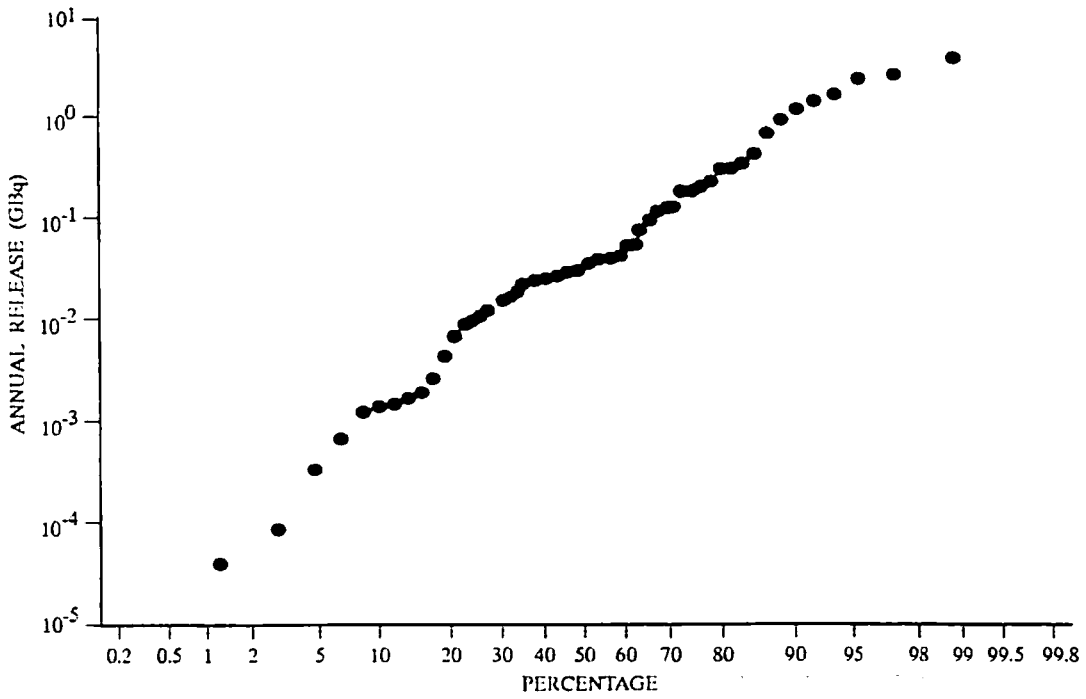

Figure VIII.
Distribution of annual releases of iodine-131 in airborne effluents from PWRs in the United States, 1988.
(Number of values: 56; geometric mean: 0.038 GBq; geometric SD: 13.)
[T3]

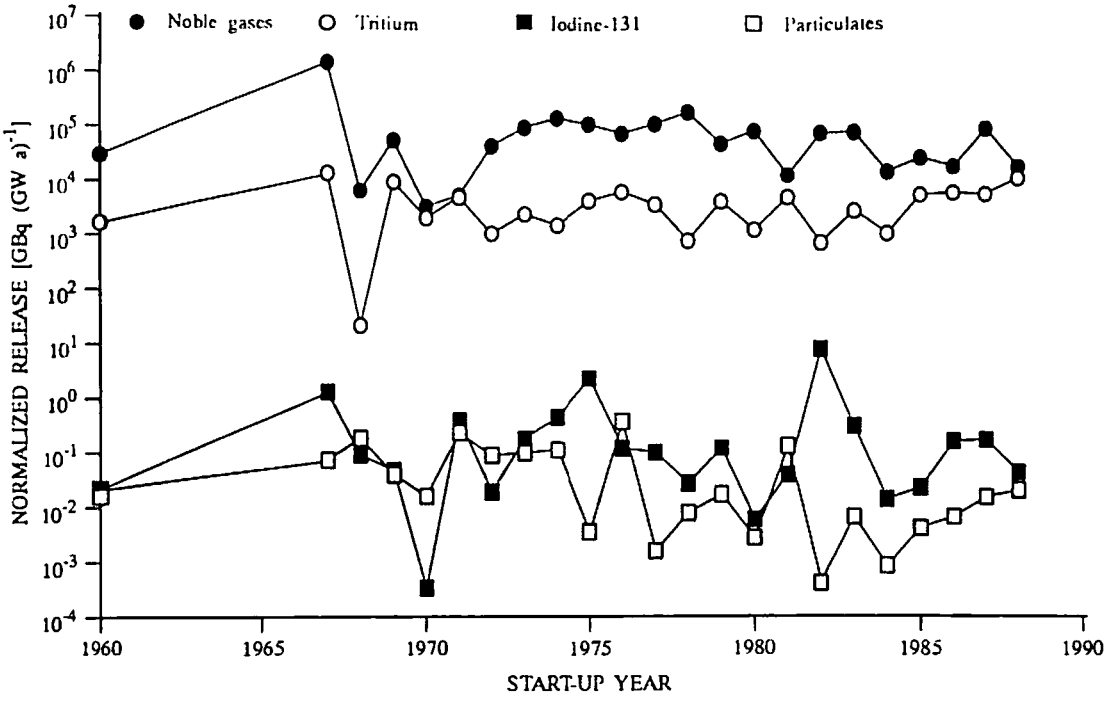

Figure IX.
Normalized release of radionuclides from PWRs in the United States during 1988, averaged for reactors of the same age (start-up year).

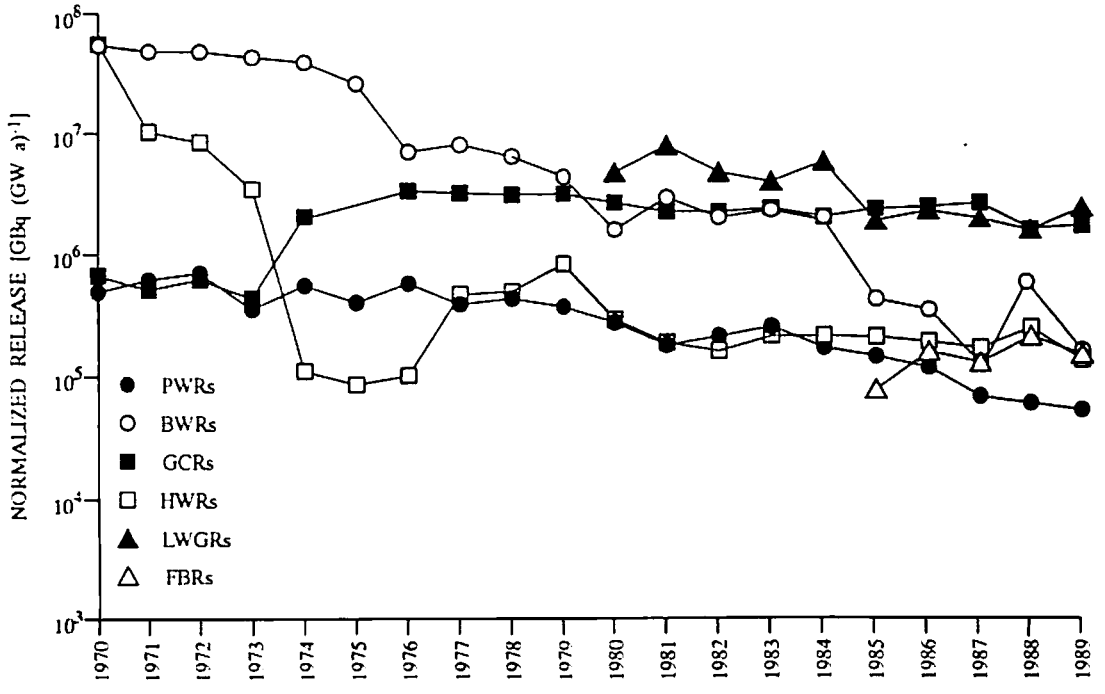

Figure X.
Trends in release of noble gases in airborne effluents from reactors.

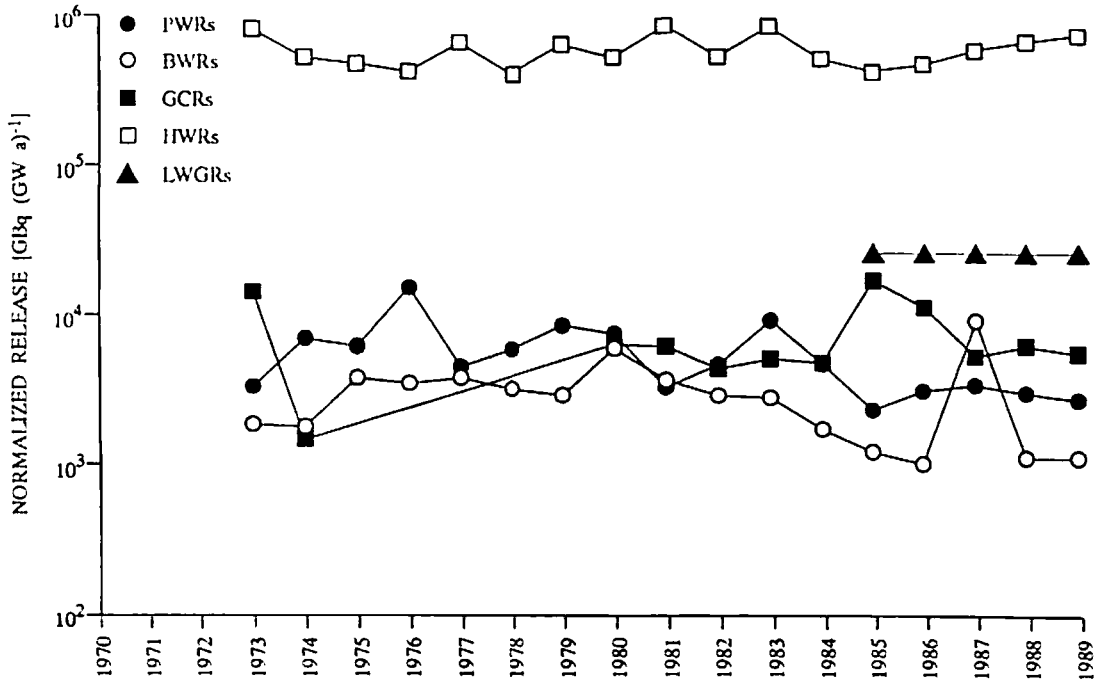

Figure XI.
Trends in release of tritium in airborne effluents from reactors.
For LWGRs, only estimated average value is available.

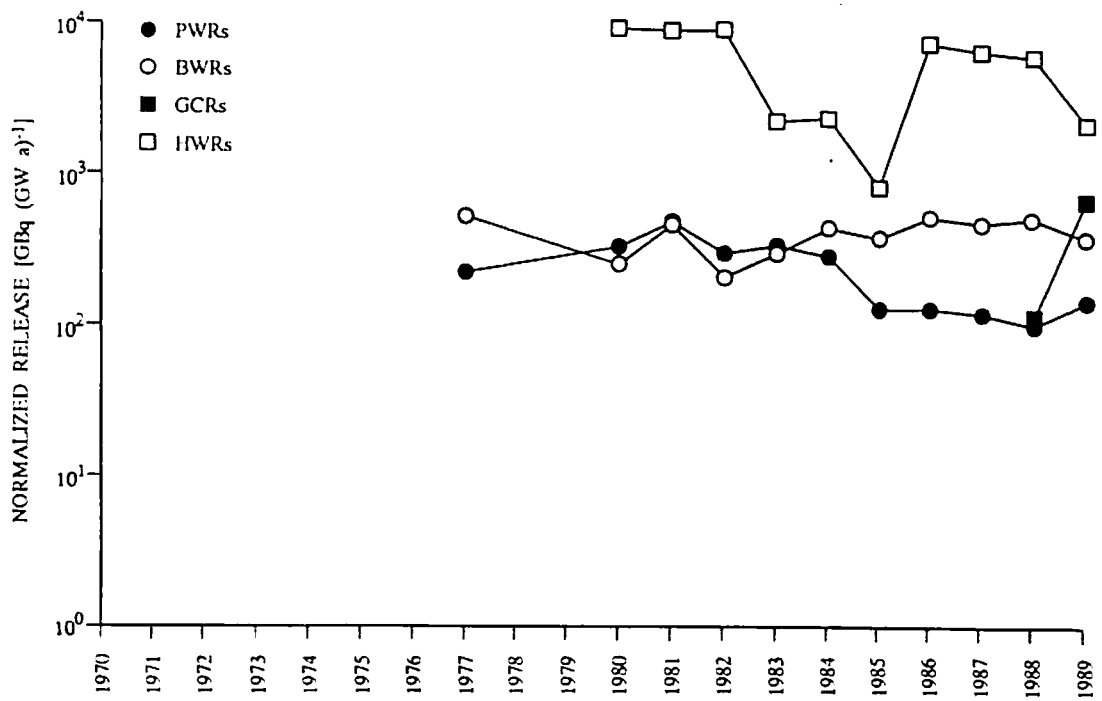

Figure XII.
Trends in release of carbon-14 in airborne effluents from reactors.

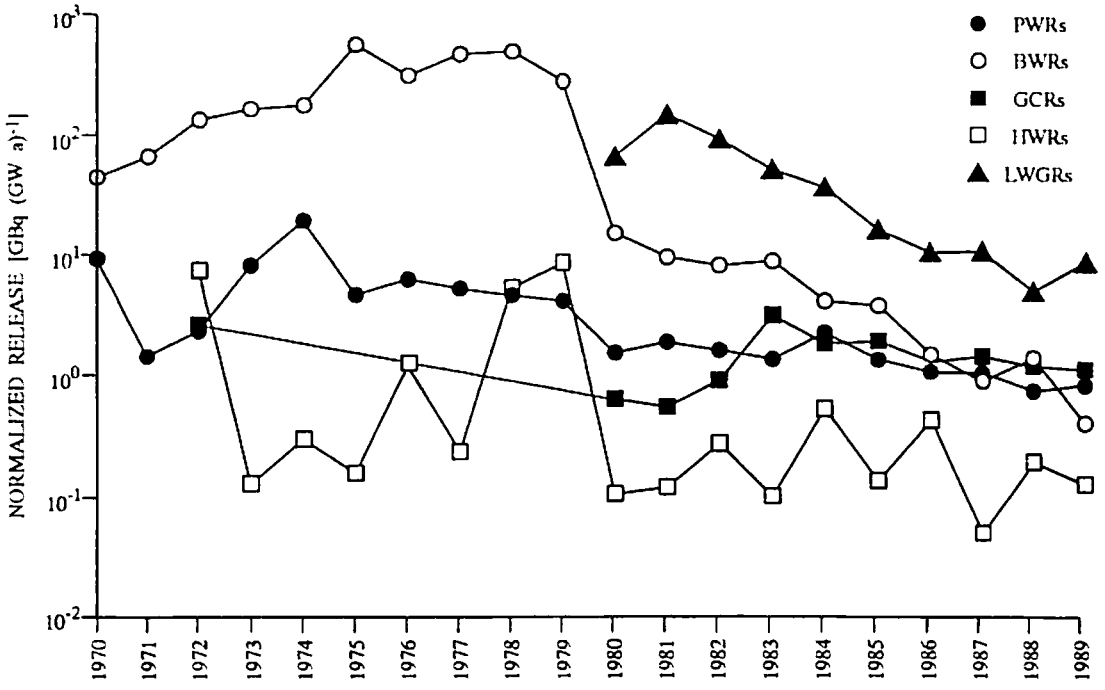

Figure XIII.
Trends in release of Iodine-131 in airborne effluents from reactors.

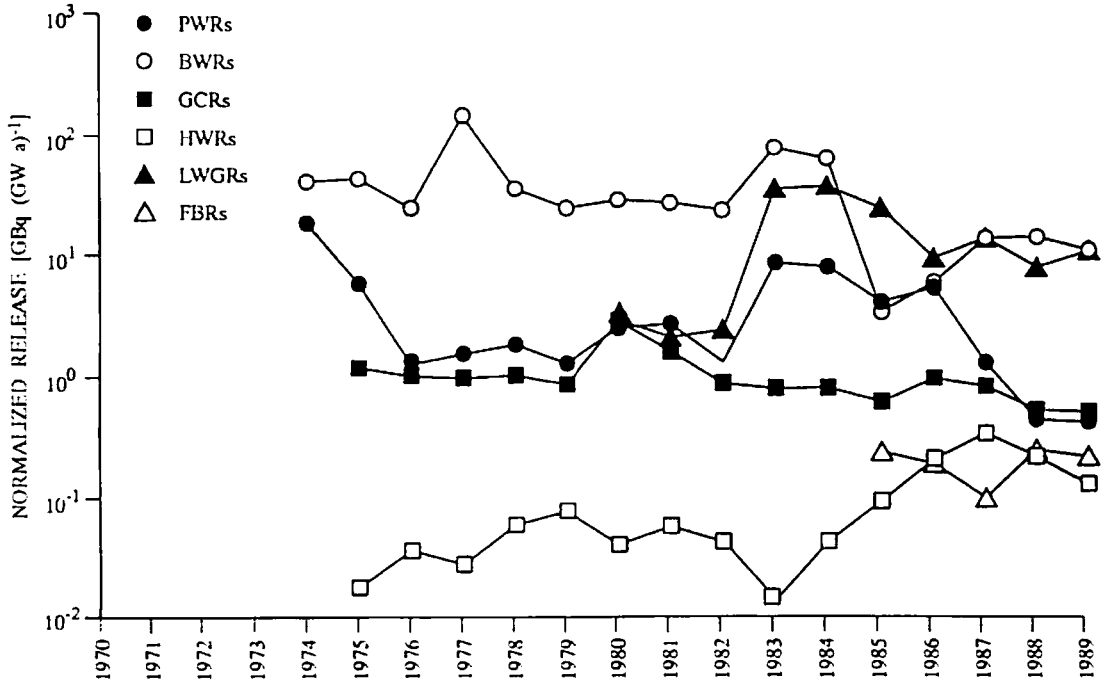

Figure XIV.
Trends in release of particulates in airborne effluents from reactors.

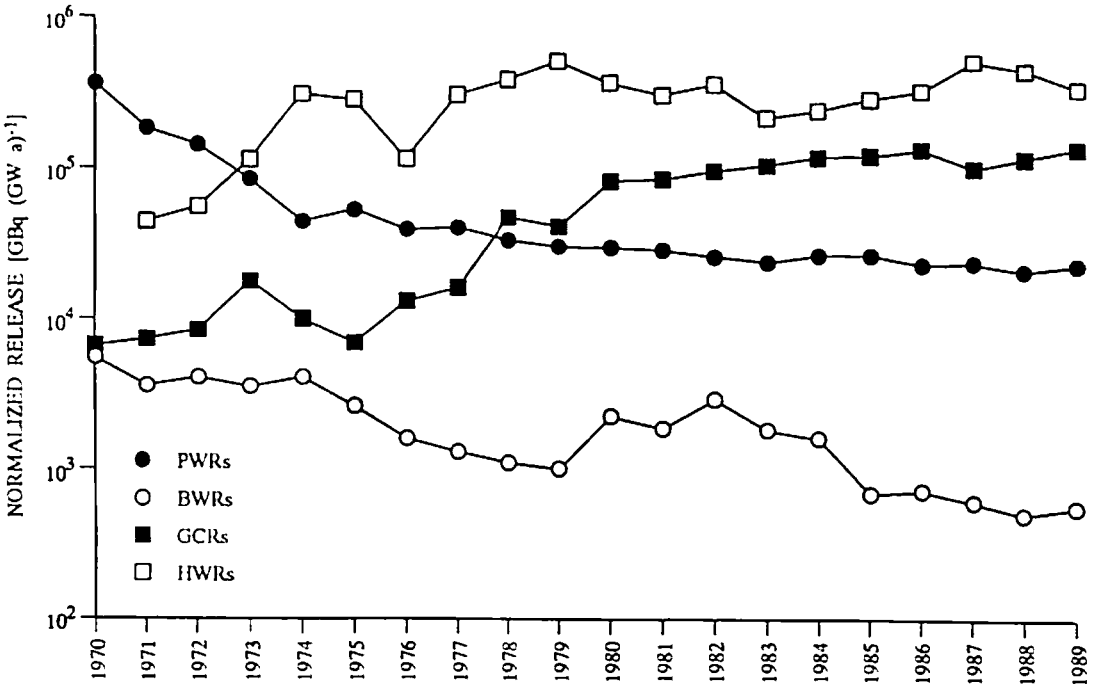

Figure XV.
Trends in release of tritium in liquid effluents from reactors.

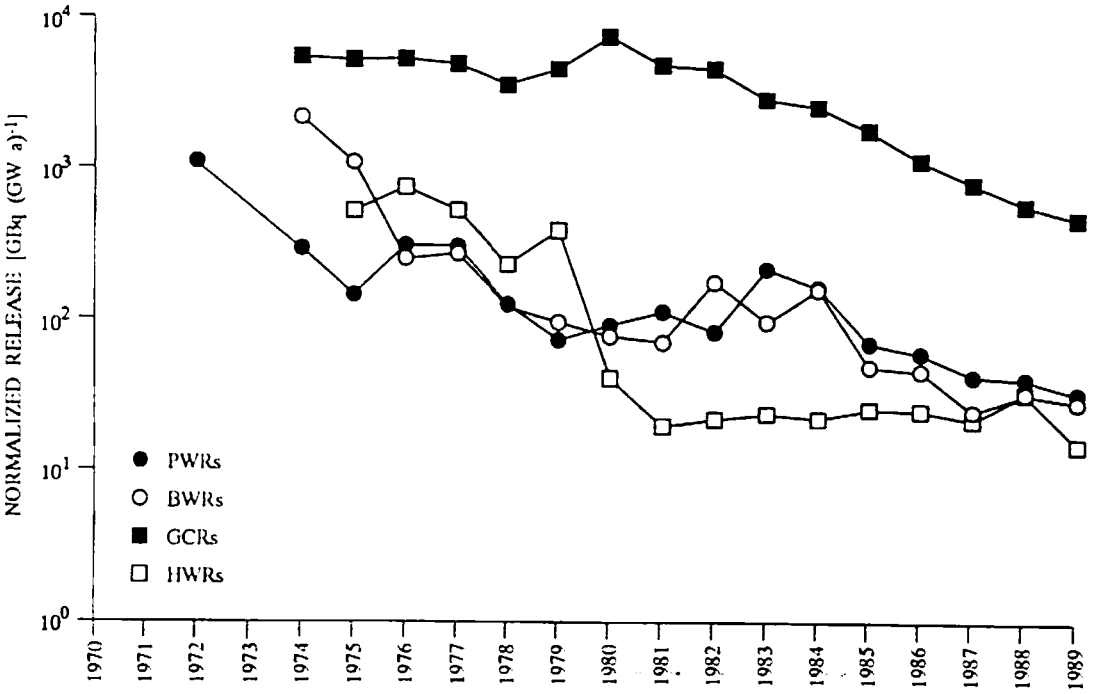

Figure XVI.
Trends in release of radionuclides excluding tritium in liquid effluents from reactors.

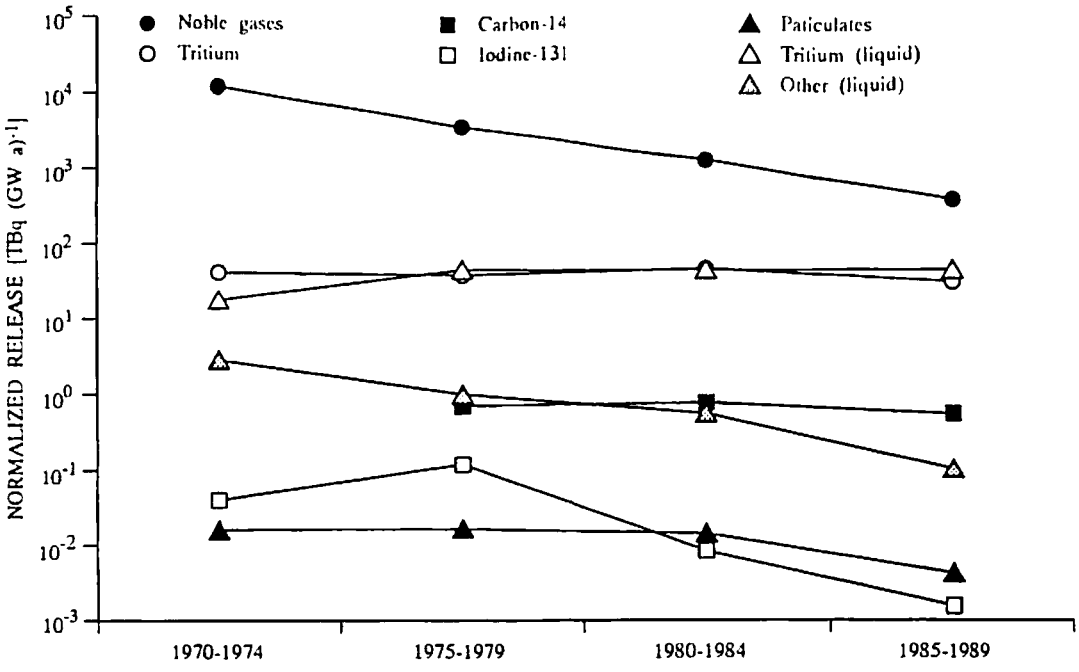

Figure XVII.
Normalized release of radionuclides averaged over five-year periods for all reactors.

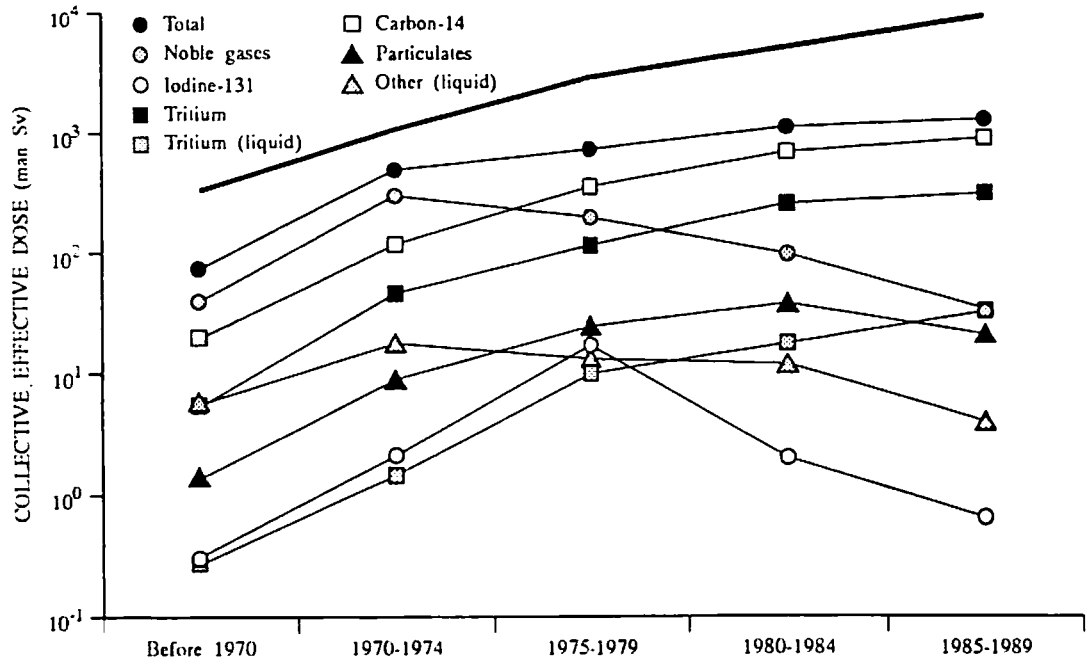

Figure XVIII.
Local and regional collective effective dose from release of radionuclides from reactors. The trend in the total electrical energy generated by nuclear means is indicated by the heavy line (numerical values on left axis apply with units 0.1 GW a).

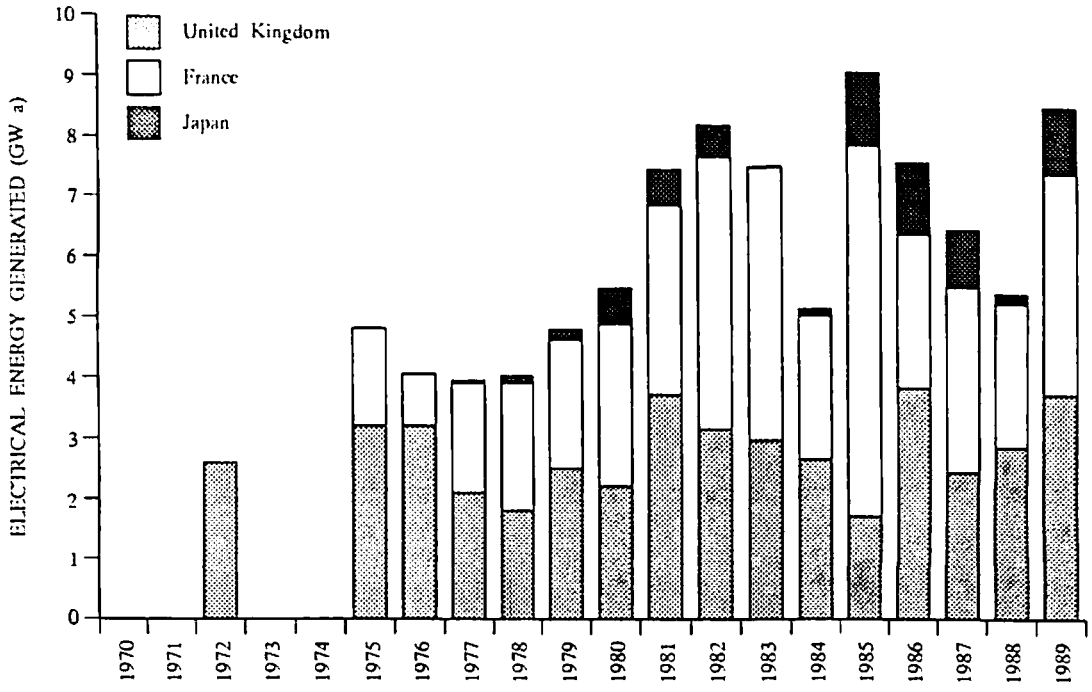

Figure XIX.
Nuclear fuel reprocessed wordwide.
Data before 1975 are incomplete.

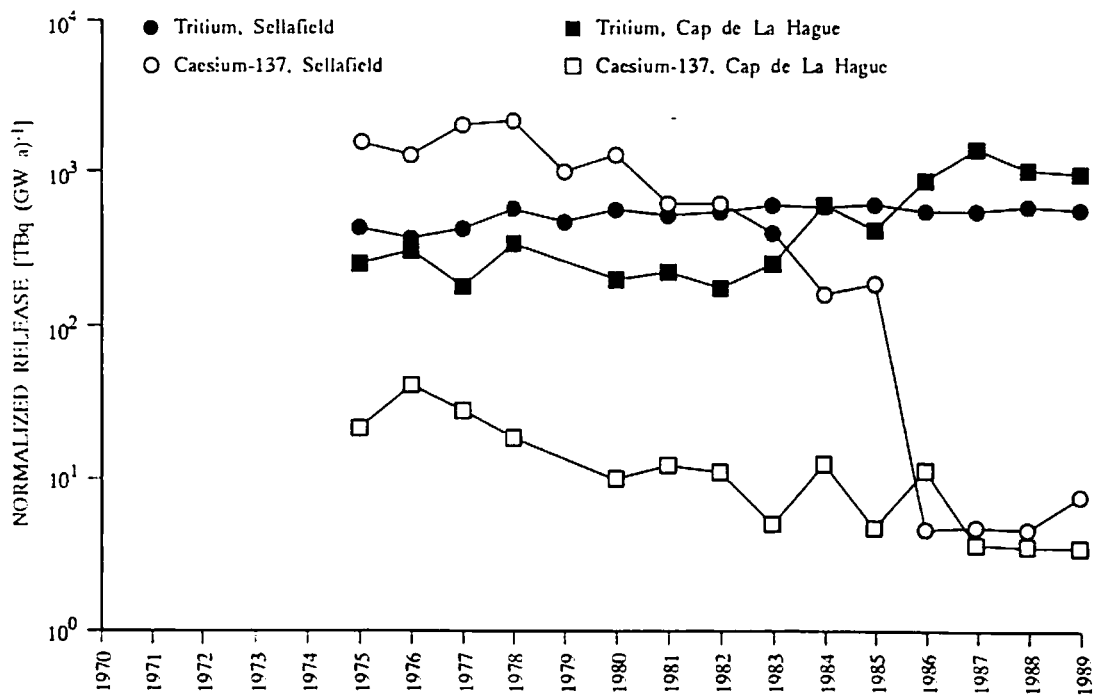

Figure XX.
Trends in normalized releases of tritium and caesium-137 in liquid effluents
from fuel reprocessing plants at Cap de La Hague in France
and Sellafield in the United Kingdom.

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