COMMISSION OF THE EUROPEAN COMMUNITIES

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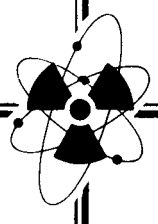
DISCHARGE DATA 1972-1976 RADIOLOGICAL ASPECTS

APRIL 1978



DIRECTORATE-GENERAL EMPLOYMENT AND SOCIAL AFFAIRS
Health and Safety Directorate

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prepared by F. LUYKX and G. FRASER

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COMMISSION
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Directorate General
Employment and Social Affairs

Health and Safety
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Luxembourg, 14th October 1978

C O R R I G E N D U M

to

Report EUR 6088 EN

"Radioactive effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community; Discharge Data - Radiological Aspects - April 1978"

- p. V, 5th dash, 3rd line, should read "MPCP corresponds to one tenth of the MPC for occupationally exposed".
- p. 18, 2nd paragr., 4th line, read "(45)" instead of "(24)".
- p. 19, 2nd line, read "Tables XVIII..." instead of "TABLES XVII ...".
- p. 20, 2nd paragr., 4th line, read "Table XVIII" instead of "Table XVII".
- p. 21, last paragr., 2nd line, read "(2, 21)" instead of "(21, 37)".
- p. 31, 3rd line, read " ... a few tenths of a mrem." instead of " .. a few mrem.".
- p. 35, 3rd line, read "(24)" instead of "(23)".
- p. 36, last line, read "(24)" instead of "(23)".
- p. 40, delete "bone marrow or gonads" after the first dash.
- Table VIII, Tihange 1 data apply to 1975.
- Table XI, United Kingdom, Calder; for the values 12, 12, 0.6, 0.5 substitute 6, 6, 0.3, 0.2 respectively.
- Table XIII, in the entry for Dounreay
  - add "(g)" after the 0.3 t capacity for MTR reprocessing
  - change date of "First Hot Run" to read 1961 for FBR reprocessing.

  add footnote "(g) Initial capacity 0.12 t per year."
- Tables XVIII, XIX, XX, XXI, change respective Eurochemic discharge limits to: 10.8, 54, 54000, 1.8 Ci/year.
- Table XVIII, footnote (a) should read "The monthly authorized discharge limit...".
- Table XXI, change discharge limit for Dounreay to "2 400 Ci/year".
- Table XXII, footnote (f) and all references thereto should be footnote (d); add "(d)" after "Eurochemic".

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SUMMARY

The report presents the available data on radioactive gaseous and liquid effluents discharged by nuclear power stations and nuclear fuel reprocessing plants in the European Community from 1972 to 1976. Discharges are expressed both in absolute terms and relative to the net production of electricity from the fuel.

On the basis of the discharges recorded for 1976 the resulting maximum exposure of members of the population is quantified and compared with the dose limits prescribed by Euratom radiological protection standards and with the exposure resulting from natural radioactivity.

It is concluded that there is no case in which a discharge could have given rise to an exposure exceeding the relevant prescribed limit. Not only did the possible maximum exposures incurred by individuals leave an appreciable safety margin relative to that limit but, for the vast majority of installations, they were comparable with or were considerably lower than the geographical and temporal variations in exposures resulting from natural radioactivity.

Where environmental levels have been detectable the measured results have of course been used but, with few exceptions, the levels have remained less than the very low limits of detection currently possible. In general, where theoretical models are used to evaluate exposure, they are designed to give conservative results and hence it is likely that the true exposures are even less than those calculated.

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PREFACE

The Commission has published periodically since 1972 reports on gaseous and liquid radioactive effluents discharged to the environment by nuclear power stations in the European Community.

The present report, the fourth in the series, dealing with the years 1972-1976, incorporates for the first time discharges not only from nuclear power stations but also from nuclear fuel reprocessing plants, thus covering two of the most important steps of the nuclear fuel cycle at which releases of radioactive material may occur.

Having such information available should be of use to those concerned with the protection of the population against ionizing radiation, to inspection bodies, plant designers, plant operators and not least to all interested members of the public. These data should, firstly, allow an insight to be gained into the extent to which discharges may be restricted using present-day technology and, secondly, enable an assessment to be made of the current radiological implications of nuclear power for the environment.

In fact the second part of the report presents such an assessment, giving the maximum doses received by members of the population from discharges in the period considered, and then compares the results with the Euratom radiation protection standards and the doses received from natural radiation.

We should like to thank the national authorities for making this report possible by communicating the data on the radioactive discharges.

Dr. P. RECHT

Notes to the text and the tables

- The following abbreviations apply :

NPS	Nuclear Power Station
AGR	Advanced Gas-cooled Reactor
BWR	Boiling Water Reactor
FBR	Fast Breeder Reactor
GCR	Gas-cooled Reactor
HWR	Heavy Water Reactor
LWR	Light Water Reactor
NFRP	Nuclear Fuel Reprocessing Plant
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor
SGHWR	Steam Generating Heavy Water Reactor

- Blanks appear in the tables where the relevant information was not available. In some cases measurements have not been carried out or no limit has been fixed.

- The abbreviation "n.a." (not applicable) is used in the tables to indicate that the facility in question was not operational.

- A dash "-" is used in the tables for values regarded in the source documents as negligible.

- The abbreviation MPCP, which appears in several places, stands for "Maximum Permissible Concentration for Members of the Public"; the MPCP corresponds to one-tenth of the MPCP for occupationally exposed personnel.

- The use of the units "rem" and "curie" instead of the new units "sievert" and "becquerel" respectively arises from the fact that the documentation to which this report refers uses the former units.

- The terms "dose" and "dose commitment" replace "dose equivalent" and "dose equivalent commitment" respectively throughout for brevity.

- In Table XII the units of net electricity production are expressed in GWh, in accordance with the units used in the EUROSTAT report (1); in the text, however, normalized discharges, i.e. the discharges per

unit net electrical energy produced are expressed in Ci/MWa (where 1 Ci/GWh = 8.76 Ci/MWa) to allow direct comparison with the data presented in the 1977 UNSCEAR report (2). For simplicity "MWa" implies "Megawatt-years electrical" throughout (similarly for GWa", ect.). Where thermal output is implied, the expression MW(th)a is used.

- In the tables, units are listed according to country. Where several power reactors are located on the same site, they are regarded as a single source.

CONTENTS

TABLES

FIGURES

1. RADIOACTIVE EFFLUENTS

1.1. GENERAL

This report contains data on the discharge of gaseous and liquid radioactive effluents from 1972 to 1976 by nuclear power stations (NPS) and nuclear fuel reprocessing plants (NFRP) in the Community.

The data were mainly supplied by the responsible national bodies, but in some cases have been drawn from other sources.

The discharges cited for nuclear power stations occasionally differ from those given for 1972-74 in the previous edition, as corrected values have been communicated in a few cases.

It should be borne in mind when comparing measurements of discharges from the various power stations and reprocessing plants that the values were frequently derived using different methods and equipment, which can lead to appreciably different results (3). Moreover, for reprocessing plants comparison is rendered still more difficult than for reactors since the former tend to be individual designs. Even although flow sheets may show basic similarities (dissolution in nitric acid and extraction with tributyl phosphate) at a more detailed level discrepancies appear; for example the extent to which process liquors are recycled and the nature of wastes and methods of treatment prior to discharge may differ. Further, fuel elements may be of high enriched, low enriched, or natural uranium, using uranium metal, uranium oxide or uranium alloy and may be clad in stainless steel, in alloys or in aluminium; irradiation histories and cooling times may also vary.

1.2. NUCLEAR POWER STATIONS

1.2.1. Plant Characteristics and Data Sources

Table I gives general characteristics of the nuclear power stations (*) which were in operation in the Community during the period covered by this report and to which the subsequent data on discharges relate. In addition, Table XII includes the net electrical output of each station for the period 1972 to 1976.

(*) Only stations with an output greater than 50 MWe are considered.

The data on thermal and electrical capacity, the first link-up with the grid and electricity produced were taken from the EUROSTAT report (1) of the Statistical Office of the European Communities. The types of reactor represented include the pressurized water reactor (PWR), the boiling-water reactor (BWR), the gas-cooled graphite moderated reactor (GCR), the advanced gas-cooled reactor (AGR), the fast breeder reactor (FBR) and the heavy water moderated reactor (HWR) which may be cooled by gas, heavy water or light water. The total net capacity in 1976 was 18 125 MW from 34 plants; the actual output was about 10 000 MWa.

The data in Tables II to XI were taken mainly from the following references :

- Belgian power stations (4)
- German power stations (5) (6) (7)
- French power stations (8) (9) (10) (11)
- Italian power stations (12)
- Dutch power stations (13)
- British power stations (14)

Any additional references are given in the text.

1.2.2. Gaseous Effluents

Gaseous effluents, discharged from nuclear power stations, may contain small amounts of fission and activation products produced in the reactor, i.e. noble gases such as krypton and xenon isotopes and argon-41, radioactive halogens and particulates, tritium and carbon-14.

Tables II-VI contain discharge data on noble gases, tritium, radioactive aerosols and iodine-131. For halogens, only iodine-131 discharges are given, this being the most important isotope from an environmental point of view.

1.2.2.1. Noble gases

Noble gas discharges by NPSs and the corresponding authorized annual release limits are given in Table II. It should be noted that in the U.K. authorizations for gaseous discharges from nuclear power stations place no limit on the quantities but require that the best practicable

means be used to minimize the amount of radioactivity to be discharged (*).

At most power stations the activity discharges did not vary very much over the period considered in the report; in all cases the discharge limits have been met. It can be observed that discharges at Chooz and Gundremmingen were considerably reduced in 1974 as compared with 1973; this is known to have resulted from the replacement of failed fuel in these reactors (8, 17).

The discharges of noble gases, mainly argon-41, by the British magnox stations are not monitored systematically. However, from a limited number of measurements made in 1976 on Central Electricity Generating Board (C.E.G.B.) stations (14), adjusted for average load factors, the annual discharges given in Table II were obtained.

Table II includes the argon-41 discharge from one of the AGRs which recently came on-line in the U.K., Hunterston B; the much lower discharge from Hunterston B in comparison with those from most GCRs reflects the absence of shield-cooling air from the AGR concept.

Table III shows the radionuclide composition of the noble gas releases during 1976. GCRs and AGRs effectively discharge no fission gases, as defective fuel elements are discharged from the reactor on-load. In the case of power stations equipped with light water reactors (LWRs), the nuclide composition of the discharge depends mainly on the hold-up time of the gases prior to discharge.

In PWRs radioactive gases come mainly from primary coolant degasification. Most of the remainder consists of gases which escape by leakage from the primary circuit.

To allow the short-lived radionuclides to decay before discharge, the gases resulting from degasification are either compressed into storage tanks and held for a period of 30 to 120 days, or passed over activated charcoal delay systems, which hold up the xenon isotopes for about 40 days and the krypton isotopes for about 2.5 days. Thus the main source of noble gases released is substantially reduced and direct leakage

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(*) Following the recommendation of the Royal Commission on Environmental Pollution in its recent report on Nuclear Power and the Environment (15), the British Government has now agreed that in the future each nuclear site should have clear standards for airborne emissions to which to work (16).

from the primary circuit may be more significant in practice. At Stade, for instance, 63 % of all noble gases discharged in 1976 resulted from leakage (18).

Those effluents which are discharged through the plant ventilation system do not necessarily have long hold-up times, so that short-lived nuclides can be present to a considerable extent as shown in Table III.

In BWRs the main source of noble gases is the air-ejector which maintains the vacuum in the main condenser and thus draws radioactive gases from the reactor's cooling circuit. Secondary sources are the turbine gland-seal leakage and other coolant leakage into the ventilation system.

In older BWRs (Garigliano) the gases extracted from the main condenser are delayed for about 20 to 30 minutes before discharge to reduce the activity of the very short-lived activation and fission gases. The activity released to atmosphere is, however, still relatively high (see Table XII).

For this reason, condenser off-gas treatment systems of later BWRs incorporate activated charcoal delay beds, which significantly reduce the activity discharged. Noble gas discharges from these stations result mainly, therefore, from leakage from the reactor coolant circuit. In 1976, for example, noble gas discharge from the condenser off-gas system of Würgassen represented only 2.5 % of the total noble gas discharge (18). As with PWRs, however, radionuclides of short half-life are still present in the emissions (see Table III), because of short hold-up times of leakage discharged via the ventilation system.

Phénix is the sole example of an FBR for which data are available. Activity discharged is comparable with that from the recent examples of other reactor types.

From Table XII it can be seen how the annual discharges of noble gases, normalized to net electrical output, varied over the 5-year period covered by this report :

- for PWRs from 0.53 to 135 Ci/MWa, with an average value of 14 Ci/MWa,
- for BWRs, equipped with a charcoal delay system, from 0.61 to 285 Ci/MWa with an average value of 54.5 Ci/MWa,

- for the Garigliano BWR from 1 832 to 6 367 Ci/MWa with an average value of 3 800 Ci/MWa,
- for the FBR, Phénix, 1.7 Ci/MWa averaged over 1975 and 1976.

Figure 1 shows how for PWRs and BWRs (excluding Garigliano) the normalized annual discharges have evolved from 1970 to 1976.

1.2.2.2. Tritium

Table IV shows the tritium discharges to atmosphere from NPSs, as far as available. Indeed, the tritium present in gaseous effluents is not measured systematically in all power stations, probably because of its low radiotoxicity and its limited presence in the discharge of many power stations. Presumably for the same reason only two stations have a specific discharge limit imposed. From the table it appears that the amount of tritium discharged by the light water reactors and the gas-cooled reactors amounts only to a few tens of curies per year. The discharge from the heavy water stations, namely MZFR, Monts d'Arrée and Winfrith, is higher, up to over a thousand curies per year. This tritium originates mainly by activation of deuterium in the heavy water and escapes from the primary circuit with D_2O leakages.

The normalized discharge of tritium to atmosphere, averaged over the years for which data are available, amounts to 0.04 Ci/MWa for PWRs, 0.2 Ci/MWa for BWRs and 18.6 Ci/MWa for HWRs. For the FBR, Phénix, it was 0.07 Ci/MWa in 1975-1976 and for the AGR, Hunterston B, 0.3 Ci/MWa in 1976.

1.2.2.3. Radioactive aerosols

Table V gives the discharges of radioactive aerosols from NPSs together with the annual discharge limits. The aerosols referred to generally approximate to those with longer half-lives (> 1 week), although this is not always specified in the references.

As in previous years, aerosol release levels for 1975-76 were in general extremely low. For the latter year, for example, the average aerosol discharge for 32 power stations for which results are available was only 19 mCi, the maximum being 210 mCi.

The normalized discharge, averaged over the 5 year-period 1972 to 1976 inclusive, is 6.8 x 10^{-5} Ci/MWa for PWRs, 7 x 10^{-4} Ci/MWa for BWRs and 8.9 x 10^{-5} Ci/MWa for GCRs (Table XII). Figure 2 gives the normalized annual discharges for each of these 3 reactor types for the period 1970 to 1976.

The normalized discharge from the FBR, Phénix, for 1975-1976 was 1.3 x 10^{-7} Ci/MWa and from the AGR, Hunterston B, 4.8 x 10^{-5} Ci/MWa in 1976.

The radioactivity of the aerosols may have two different origins, activation or fission. Discharges result mainly from leakage from the primary cooling circuits. In German LWRs (19), the following activation products have been identified : Cr-51, Mn-54, Co-57, Co-58, Co-60, Fe-59, Zn-65, Ag-110m, Sb-122, Sb-124, Sb-125. Fission products identified were : Zr-95, Nb-95, Ru-103, Ru-105, Ru-106, Te-123m, Cs-134, Cs-137, Ba-140, La-140, Ce-141, Ce-144. However, the radionuclide composition can vary greatly from one power station to another, and even in the same power station from year to year.

Table V also shows, for completeness, the sulphur-35 discharges, probably in the form of carbonyl sulphide (COS), from some GCRs and AGRs. This radionuclide originates from activation of sulphur and chlorine impurities present in the graphite moderator. Its release should thus decrease over the life of the plants with the progressive burn-up of the impurities.

1.2.2.4. Iodine-131

Table VI lists the iodine-131 releases to atmosphere and the annual discharge limits. It can be seen that the discharge levels were very low; in 1976, the average value for the 22 power stations with reported releases was 29 mCi, with a maximum of 350 mCi. The normalized release, averaged over the 5-year period considered in the report is 7.5 x 10^{-5} Ci/MWa for PWRs and 1.5 x 10^{-3} Ci/MWa for BWRs. The latter value, however, is not typical for BWRs as the result is strongly influenced by the high discharge from one or two stations.

Few data are available on iodine-131 discharges for GCRs. The normalized discharge from 4 continental stations corresponds to 5.6 x 10^{-5} Ci/MWa for the 5 year-period, which is comparable to the value for PWRs.

Figure 3 gives the normalized annual iodine-131 discharges from PWRs, BWRs and continental GCRs.

In 1976 the FBR, Phénix, discharged 2 x 10^{-6} Ci/MWa of I-131, which represents an extremely low value in comparison with other reactor types.

Analyses at the German power stations (19) show that only a very small fraction (usually less than 1 %) of the iodine released in gaseous effluent from LWRs, is bound to particulates, most of it being in gaseous form.

As regards the proportions of organic and inorganic forms there seem to be no regular measurements at any of the nuclear power stations.

1.2.2.5. Carbon-14

Discharges of carbon-14 have aroused interest in recent years, since its long half-life will lead to accumulation in the environment. Few measurements of carbon-14 discharges from NPSs have been made to date. However, in the Federal Republic of Germany the Federal Health Office (Bundesgesundheitsamt) instituted in 1976 a measuring programm in the German power plants, the results of which are summarized below (20).

Carbon-14 discharges from PWRs

Facility	Ci/a	Ci/MWa	% as CO_2
Obrigheim	1	3 x 10^{-3}	30
Stade	3 *)	4.5 x 10^{-3}	
Biblis A	1.4	1.2 x 10^{-3}	6.3
Biblis B	14	11 x 10^{-3}	1.4
Neckarwestheim	1.3	1.5 x 10^{-3}	7.5

*) only CO_2 form measured

Carbon-14 discharges as CO_2 from BWRs

Facility	Ci/a	Ci/MWa
Gundremmingen	3.7	14.5×10^{-3}
Lingen	1.4	8.5×10^{-3}
Würgassen	6.2	11.7×10^{-3}
Brunsbüttel	3.8	4.7×10^{-3}

In PWRs, only a small fraction of the carbon-14 is in CO_2 form; mostly it is present as methane and/or other hydrocarbons. In BWRs more than 95 % is discharged as CO_2.

It appears from the above tables that the normalized emission-rate for PWRs lies between 1 and 11 mCi/MWa, with a mean value of 5 mCi/MWa and that of BWRs between 5 and 15 mCi/MWa with a mean value of 10 mCi/MWa.

1.2.3. Liquid Effluents

Table VII gives the gross activities, exclusive of tritium, released in liquid effluent together with the corresponding annual discharge limits; Table VIII gives the nuclide analyses for 1976. Table IX lists tritium discharges.

1.2.3.1 Activity other than tritium

Discharges changed little over the period considered (see Table VII). Considering GCRs at Bugey, there was a sharp rise in 1974, most of the activity being sulphur-35 ($T_{\frac{1}{2}} = 87.1$ d) present in the water coming from the dryers serving to control humidity in the primary coolant. In the following years the discharge dropped considerably as action was then taken to store such water to reduce the sulphur-35 activity by decay (10). The activity discharges in liquid effluents from the British GCRs are higher than those from most continental stations and frequently originate from the spent-fuel storage ponds as a result of corrosion damage to fuel stored for prolonged periods.

Among LWRs, Doel had a high release in 1976, 49.75 Ci or 0.15 Ci/MWa, which is considerably more than for other PWRs.

From Table XII it can be seen how the normalized annual discharges varied over the 5-year period considered :

- for PWRs from 5.3×10^{-4} to 1.5×10^{-1} Ci/MWa with an average value of 1.3×10^{-2} Ci/MWa,
- for BWRs from 3.5×10^{-4} to 3.2×10^{-1} Ci/MWa with an average value of 1.8×10^{-2} Ci/MWa,
- for GCRs from 3.5×10^{-4} to 5.8×10^{-1} Ci/MWa with an average of 1.2×10^{-1} Ci/MWa (2.2×10^{-2} Ci/MWa for continental GCRs).

The normalized annual discharges from 1970 to 1976 for these 3 types of power plants are presented in Figure 4.

The normalized discharge in 1976 from the AGR, Hunterston B, was 3.8×10^{-3} Ci/MWa. Phénix liquid effluent discharge data are not available as the effluent from this plant is transferred to the Nuclear Centre of Marcoule for decontamination and discharged to the Rhône together with the other effluents from the Centre.

In 1976, about 40 different radionuclides have been identified in the liquid effluents from NPSs - see Table VIII. It can be seen that not only the amounts but also the composition of the liquid releases vary considerably, even among stations of the same type. The most prevalent fission products, however, are Cs-134, Cs-137, Sr-89 and Sr-90; the predominant activation products are Co-58, Co-60, Sb-124, Cr-51 and Mn-54. GCR effluents also contain large quantities of sulphur-35 - see Section 1.2.2.3.

For some NPSs alpha discharges have been communicated. The largest reported value for 1976 was for Hinkley Point A, namely 0.28 Ci or 7.7×10^{-4} Ci/MWa.

1.2.3.2. Tritium

Tritium discharges listed in Table IX show that the PWRs Chooz and Trino had the highest discharges over the period considered. This is mainly due to the fact that these plants utilize fuel with stainless steel cladding through which tritium, formed by ternary fission, diffuses easily. Tritium releases from the other PWRs, all with zircaloy clad fuel, are much

lower but tend to remain higher than those from BWRs; this difference arises from neutron reactions with boric acid used as a chemical shim in PWRs. In the case of GCRs the tritium discharged is generated from lithium present as an impurity in the moderator graphite. Since AGR fuel uses stainless steel cladding, tritium from ternary fission adds to that from the lithium impurity in the moderator and fuel sleeves.

Figure 5 gives the normalized annual tritium discharges for PWRs, BWRs and GCRs for the period 1970 to 1976.

For the period 1972 to 1976 the normalized values may be summarized as follows :

- for PWRs with zircaloy clad fuel from 2.2×10^{-2} to 1.2 Ci/MWa in any one year with an overall average of 0.35 Ci/MWa,
- for PWRs with stainless steel clad fuel (Chooz and Trino) from 2.9 to 20 Ci/MWa with an average of 8.0 Ci/MWa,
- for BWRs from 2.5×10^{-3} to 1 Ci/MWa with an average of 0.27 Ci/MWa,
- for GCRs from 4.1×10^{-2} to 3.7 Ci/MWa with an average of 0.3 Ci/MWa.

The normalized tritium release in liquid effluent from the AGR, Hunterston B, was 0.29 Ci/MWa in 1976, which is no higher than those from GCRs, although appreciably larger releases were allowed for in the discharge limits (see Table IX).

1.3. NUCLEAR FUEL REPROCESSING PLANTS

1.3.1. Plant Characteristics and Data Sources

Table XIII gives general information on the seven nuclear fuel reprocessing plants constructed within the Member States of the European Community, the most significant being Windscale on the north-west coast of England and La Hague, situated on the north coast of France. These two plants have been primarily concerned with GCR fuel (as has Marcoule); with Dounreay, they constitute the only coastal sites. Eurochemic, in Belgium, and Eurex, in Italy, have not reprocessed fuel since 1974.

The nominal reprocessing capacities quoted in Table XIII in tonnes per annum serve to illustrate the overall scales of the individual plants, from pilot plants to large-scale commercial installations. The capacities for commercial reactor fuel vary widely from 40 t per year for LWR fuel at WAK (Wiederaufarbeitungsanlage, Karlsruhe), to 2 000 t per year for GCR fuel at Windscale. However, since the burn-up of spent LWR fuel is an order of magnitude greater than that of GCR fuel, the capacities would lie much closer together if expressed in terms of the electricity which has been produced from the fuel. Actual "throughputs" as opposed to design capacities, can be estimated, in terms of MWa, from the krypton-85 discharges in Table XIV; this approach is discussed further below. The data presented have been mainly drawn from the following references :

- Belgium (Eurochemic) : (4)
- Germany (WAK) : (5)
- France (La Hague and Marcoule) : (21)
- Italy (Eurex) : (12)
- United Kingdom (Dounreay and Windscale) : (14)

In addition reference is made to numerous papers presented at the 1977 Karlsruhe Seminar on "Fuel Reprocessing Plant Effluents"; these are cited individually with other specific references in the text.

1.3.2. Gaseous Effluents

As in the case of reactors, gaseous effluents from reprocessing plants can contain both fission and, to a lesser extent, activation products. Moreover, the composition of the activity entrained in the gaseous discharges will vary from one step of the process to another; the table below illustrates the kind of variation which may occur (22).

Tables XIV to XVII give discharge data on krypton-85, radioactive aerosols and tritium. Where available, additional data on specific nuclides and sites are given in the text below. At Dounreay, in particular, other facilities (fuel fabrication, hot cells, etc.) discharge to the same stack as the reprocessing facility and may contribute significantly to discharges on occasion.

Source / Nuclide	Dismantling and De-cladding	Dissolution and Processing	Fission Product Treatment and Storage	Treatment and Storage of Residues
Kr-85	x	x		
I-129/131	x	x		x
Sb-125			x	x
Ru-106			x	
Cs-137	x		x	
Hg-203		x		
H-3		x		x
Aerosols	x	x	x	x

1.3.2.1. Krypton-85

Table XIV gives discharges of krypton-85, the only noble gas of interest in reprocessing plants. In the absence of data on the amount of fuel reprocessed, these discharge values may be used to calculate the throughputs, firstly in terms of the burn-up of fuel in MW(th)a and subsequently, taking account of the efficiencies of GCRs and LWRs, in terms of electricity produced.

The assumed rates of production of krypton-85 in fuel are 1.1×10^2 Ci per MW(th)a for GCRs and 0.97×10^2 Ci per MW(th)a for LWRs (23). A 100 % release of krypton at the reprocessing plant is assumed. Estimates based on 1973 data (taken as typical of fuel processed in 1972-76) suggest the following overall efficiencies weighted for net electrical output (1) :- for German LWRs 31.6 %
- for French GCRs 26.5 %
- for British GCRs 24.0 %

For Eurochemic the fuel reprocessed in the period of interest was essentially from LWRs; the krypton-85 discharges are therefore treated as coming entirely from LWR fuel and the corresponding reactor efficiency is taken as that given above for the FRG (Federal Republic of Germany) reactors.

WAK has processed HWR fuel in addition to LWR fuel; however, the krypton-85 yield can be taken as the same for both fuel types (24) and the above reactor efficiency for LWRs has been adopted.

At La Hague the first hot run with LWR fuel took place in 1976; in the absence of further information GCR fuel has been assumed throughout.

Fuel from other than commercial GCRs has also been processed at Marcoule. Its influence on krypton-85 discharges is not known and has been necessarily neglected.

At Eurex, and to a large extent at Dounreay, fuel has come from MTRs and calculations of the type proposed would not be valid. The results of calculations for the other plants are given in the table below :

Throughput	Reprocessing Plant	1972	1973	1974	1975	1976
Kr-85 [Ci]	Eurochemic	2.0×10^{5}	2.2×10^{5}	1.0×10^{5}	-	-
	WAK	6.7×10^{4}	2.5×10^{4}	$< 8.5\times10^{2}$	4.3×10^{4}	8.6×10^{4}
	La Hague	2.4×10^{5}	2.3×10^{5}	7.2×10^{5}	6.5×10^{5}	3.5×10^{5}
	Marcoule	4.7×10^{4}	1.3×10^{5}	1.1×10^{5}	1.0×10^{5}	9.2×10^{4}
	Windscale	1.2×10^{6}	8×10^{5}	8×10^{5}	1.2×10^{6}	1.2×10^{6}
Equivalent net electrical output [MWa]	Eurochemic	6.5×10^{2}	7.2×10^{2}	3.2×10^{2}	-	-
	WAK	2.1×10^{2}	8.1×10^{1}	$< 2.7\times10^{0}$	1.4×10^{2}	2.8×10^{2}
	La Hague	5.8×10^{2}	5.5×10^{2}	1.7×10^{3}	1.6×10^{3}	8.4×10^{2}
	Marcoule	1.1×10^{2}	3.1×10^{2}	2.7×10^{2}	2.4×10^{2}	2.2×10^{2}
	Windscale	2.6×10^{3}	1.7×10^{3}	1.7×10^{3}	2.6×10^{3}	2.6×10^{3}
	LWR total	8.6×10^{2}	8.0×10^{2}	3.2×10^{2}	1.4×10^{2}	2.8×10^{2}
	GCR total	3.3×10^{3}	2.6×10^{3}	3.7×10^{3}	4.4×10^{3}	3.7×10^{3}
Recorded EEC net electrical output [MWa]	LWR total	1.6×10^{3}	2.0×10^{3}	2.3×10^{3}	4.2×10^{3}	4.9×10^{3}
	GCR total	4.3×10^{3}	4.1×10^{3}	4.7×10^{3}	4.7×10^{3}	4.8×10^{3}

These values allow discharges of other radioactive materials to be related to net electricity production as in the case of nuclear power stations. However, the dwell time of fuel in the reactor and the cooling time prior to reprocessing imply a time lag between electricity production and discharges from reprocessing the corresponding fuel. Nevertheless, a growing backlog of fuel committed for reprocessing is indicated

by comparison of the recorded electrical ouput (1), as included in the table above, with the electrical value of the fuel reprocessed.

1.3.2.2. Radioactive aerosols

Alpha-active aerosols, Table XV, can contain a variety of uranic and transuranic nuclides, but more detailed information on the nuclide composition of the discharges is not generally available. Nor can it be supposed that the releases of uranium and transuranic elements will necessarily be in the same proportions as were present in the irradiated fuel. However, U.S. experience of a particular plant (25) showed that plutonium components dominated the alpha-activity released. While the relative proportions of the various plutonium isotopes will remain constant throughout reprocessing they will initially depend on the type of fuel and irradiation conditions; typical GCR and LWR fuel conditions would respectively result in the following values at the reprocessing plant expressed as percentages of the total plutonium alpha activity :

Reactor type	Activity as a percentage of total plutonium alpha activity			
	Pu-238	Pu-239	Pu-240	Pu-242
GCR	16	44	40	0.1
LWR	78	9	13	0.04

The toxicities of these alpha-emitting plutonium isotopes, however, are not significantly different when used to calculate doses from direct inhalation or ingestion.

Annual alpha discharges normalized to net electrical output vary widely from a maximum of around 1×10^{-4} Ci/MWa at Windscale in 1973 down to 2×10^{-11} Ci/MWa at La Hague in 1976. In 1976 the maximum normalized discharge recorded was 1×10^{-5} Ci/MWa for discharges from WAK.

Beta-active aerosol discharges are given in Table XVI. Exceptionally, the Dounreay results included are based on total gamma measurements and not on beta measurements.

Possibly significant nuclides contributing to measured beta discharges include strontium-90, zirconium/niobium-95, ruthenium-106, antimony-125, caesium-134 and -137 and cerium-144. The soft beta emitters plutonium-241 and technetium-99 will be present but the beta detectors normally

used are insensitive to such nuclides. Quantitative information on the contributions of individual nuclides to the total beta discharges is sparse but the following data are available for Windscale :

Activity discharged \ Year		1972	1973	1974	1975	1976
Total beta	(Ci)	3.1	19	2.8	1.9	3.4
Sr-90	(Ci)	0.11	0.72	0.15	0.20	0.19
Cs-137	(Ci)				0.17	0.25

The above discharges for 1975-76 from Windscale are from high stacks. Comparable discharges of caesium-137 and strontium-90 took place from stacks with a height of less than 46 metres (26). Such discharges may be associated with caesium activity in the storage pond water and strontium from the high active waste silo gaseous discharges (27). The latter reference also identifies the site discharges of alpha activity to atmosphere as being mainly from the Plutonium Recovery Plant.

At Dounreay occasional gamma-spectrometry has suggested that for discharged aerosols there is a roughly equal division of gamma activity between cerium-144 and zirconium/niobium-95.

Annual discharges normalized to equivalent net electrical output range from 1×10^{-2} Ci/MWa at Windscale in 1973 down to 1×10^{-6} Ci/MWa at Marcoule in 1973. In 1976 the maximum value observed was 1×10^{-3} Ci/MWa for discharges from Windscale.

1.3.2.3. Tritium

The available tritium discharge data are given in Table XVII. Those for Windscale are stated to be "inferred by comparison with krypton-85" (14). The values correspond to 1 % of the krypton-85 activity discharged which implies some 16 % of the tritium content of GCR fuel.

The data from the French plants for similar fuel show that measured annual tritium discharges, expressed as a percentage of krypton-85 discharges, have varied at Marcoule from 0.005 % to 0.31 % and at La Hague from 0.013 % to 0.034 %. The implied overall range expressed in terms of the tritium inventory of the fuel is thus around 0.1 % to 5 %.

For WAK the data have been calculated retrospectively on the basis of recent experimental work (28). The activity discharged corresponds to

0.11 % to 0.16 % of the annual krypton-85 discharges and hence to some 2 % of the tritium present in LWR fuel.

At Eurochemic for the three years of operation during the period of interest tritium to atmosphere rose from 0.36 % to 1.6 % of krypton activity discharged annually, i.e. from some 6 % to some 26 % of the tritium inventory.

Normalized to the equivalent electrical production, the maximum annual measured discharge of tritium to atmosphere was 4.8 Ci/MWa from Eurochemic in 1974, and the minimum 0.02 Ci/MWa from Marcoule in 1973. In 1976 the maximum recorded value was 0.55 Ci/MWa and was for discharges from Marcoule. The assumption used at Windscale corresponds to 4.5 Ci/MWa.

1.3.2.4. Radioactive iodine

The iodine-131 content of fuel is sensitive to the rating (MW/t) and cooling time of the fuel rather than the burn-up (MWd/t). Thus reprocessing irradiated GCR fuel equivalent to 10^3 MWa and with a fuel rating of 2.2 MW/t will involve a throughput of around :

- 5 Ci iodine-131 for a cooling time of 180 days,
- 2.5 mCi for a cooling time of 270 days,
- 1 µCi for a cooling time of one year.

In practice a cooling time of up to one year before reprocessing can be considered as common but a relatively small quantity of fuel with a short cooling time will control the amount of iodine-131 released. Discharge data available are as follows :

Facility	Discharge of iodine-131 (Ci)				
	1972	1973	1974	1975	1976
La Hague	3	0.76	0.49	1.75	0.34
Marcoule	0.144	0.013	0.917	0.503	1.319
Windscale	22 (1)	1.2	0.012	0.0092	0.076
Dounreay (2) : organ.	2.6	1.3	< 0.11	< 0.27	< 0.058
inorgan.	1.4	0.41	< 0.057	< 0.040	< 0.052

Notes : (1) this includes an exceptional discharge of 20 Ci caused by inadvertent feeding of short-cooled fuel (14).

(2) these results may be particularly influenced by discharges to the same stack from hot cell operations involving fuel with a relatively short cooling time.

Discharges of iodine-129 have become a focus of interest in recent years. This nuclide is characterized by a relatively low fission yield but a very long radioactive half-life, 1.6×10^7 years, which will allow the nuclide to accumulate in the environment. Fuel equivalent to 10^3 MWa will involve a throughput of 1 to 2 Ci of iodine-129 depending on the type of fuel. Measurements of discharges of iodine-129 from operational reprocessing plants are as yet relatively few.

Exceptionally, discharge data are available for WAK for 1975 and 1976 and are given in the table below together with the implied discharges in terms of equivalent electrical production and iodine-129 throughput.

I-129 discharged to atmosphere	1975	1976
Ci	4.3×10^{-2}	3.0×10^{-3}
Ci/MWa	3.1×10^{-4}	1.1×10^{-5}
% of total iodine-129 throughput	$\sim$ 25 %	$\sim$ 1 %

The reduction in 1976, resulted from the installation of a new filtration system for the dissolver off-gases which has reduced discharges of iodine-129 from this source to negligible amounts (29).

A series of measurements from November 1975 to August 1977 gave the following average value for the components of I-129 as discharged :

- inorganic forms, 74 %,
- organic forms, 23 %,
- aerosol forms, 2 %.

However, these averages conceal wide variations in individual sample results. Overall iodine-129 discharged is stated to have been 0.5 % of the throughput in period of measurements.

1.3.2.5. Carbon-14

As noted previously, interest in carbon-14 discharges has arisen in recent years from the fact that its long half-life, some 5 700 years, will lead to accumulation in the environment. No routine discharge measurements at reprocessing plants are available for the period under review.

Work carried out in 1976-77 at WAK (30) for PWR and BWR fuel resulted in mean discharge values of 1.24×10^{-2} and 1.37×10^{-2} Ci per MWa for the respective fuel types, discharges being in the form of carbon dioxide. The carbon-14 content of such fuels may be taken (24) as 6 Ci per GW(th)a, i.e. 1.8×10^{-2} Ci per MWa assuming a reactor efficiency of 33 % as was done in the WAK evaluation; such estimates are noted, however, to be sensitive to the nitrogen impurity levels in the fuel, published estimates of which have varied widely for all fuel types.

Assuming a production rate of 26 Ci/GW(th)a for GCR fuel (24) and taking a reactor efficiency of around 25 % gives a production rate of approximately 0.1 Ci/MWa. The potential discharges of carbon-14 from GCR fuel are, therefore, greater than from those handling LWR fuel for equivalent throughputs when considered in terms of the electricity produced from the fuel. The calculated carbon-14 throughputs for Windscale, which handles GCR fuel and also has the largest throughput expressed in MWa, are given below together with the combined results for reprocessing plants in the Community.

Plant	Carbon-14 throughput (Ci)				
	1972	1973	1974	1975	1976
Windscale	260	171	171	260	260
Total of EEC reprocessing plants	340	270	380	450	370

These estimated throughputs indicate possible upper limits to possible discharges from an individual reprocessing plant in the Community and from the Community as a whole for the period in question.

1.3.3. Liquid Effluents

Tables XVII to XXII give in turn liquid effluent discharges of alpha activity, beta activity (excluding tritium) and the individual nuclides tritium, strontium-90 and ruthenium-106.

As observed in footnote (c) to Table XIII, liquid effluent from Eurochemic is treated and discharged with that from the CEN/SCK site at Mol and that from WAK with the effluent from the Karslruhe Nuclear Research Centre as a whole; likewise that from Dounreay and Marcoule includes discharges from other facilities on these sites.

Thus, although there has been no reprocessing at Eurochemic since 1974, the Mol discharges for 1975 and 1976 are of the same order of magnitude (except for tritium) as in the preceeding years; the relative contributions from Eurochemic plant decontamination work or from processing stored liquid wastes is not known.

For La Hague, Windscale and Eurex it can be assumed that the discharges arise from or are related to fuel reprocessing.

The larger discharges have taken place from coastal sites (La Hague, Dounreay and Windscale) where environmental capacities for liquid effluents are greater than at riverain sites.

Finally, unlike gaseous discharges in general, discharges of liquid effluent can sometimes be delayed sufficiently beyond the reprocessing run which gave rise to the effluent to change the reported year of discharge.

1.3.3.1. Alpha activity

Table XVIII gives the annual discharges of alpha activity in liquid effluent. As regards nuclide compositions, those given for plutonium in Section 1.3.2.2. might again be expected to apply and measurement relating to discharges from Windscale do largely reflect the distribution suggested for GCR fuel, e.g. (31). Americium-241 has also contributed significantly to Windscale discharges as shown in the table below.

Discharge (Ci)	1972	1973	1974	1975	1976
Gross α	3 860	4 896	4 572	2 309	1 614
Plutonium α	1 548	1 776	1 248	1 200	1 272
Americium-241	2 172	2 952	2 192	984	324

It can be observed that the reduction in discharges since 1973-74 has been mainly associated with a reduction in the americium-241 content, reflecting more efficient removal of this nuclide prior to discharge (32). The plutonium contribution to the alpha activity has remained at over 90 % of gross alpha discharges not attributable to americium.

At Karlsruhe, although it is known that in 1974 (33) and 1975 (34) over 85 % of alpha activity fed to the site effluent treatment plant came from WAK (65 % in 1976 (35)), the plutonium-238/plutonium-239 ratios of the discharges noted in footnote (b) to Table XVII are in fact very different from those given by the calculated results for LWR fuel in Section 1.3.2.2.

Detailed nuclide information on alpha activity discharged from sites other than WAK and Windscale is unavailable.

Averaged over the period 1972-76 and normalized to equivalent electrical throughput the following discharges took place from Windscale :

- gross alpha activity, 1.54 Ci/MWa;
- plutonium alpha activity,0.63 Ci/MWa;
- americium alpha activity,0.86 Ci/MWa.

The trend towards the end of the period, however, indicates lower values particularly, as noted above, for americium.

For La Hague the corresponding value for gross alpha activity is 0.01 Ci/MWa and for the other sites is even lower.

1.3.3.2. Beta activity other than tritium

Table XIX gives the data on gross beta activity discharged (excluding tritium) and Tables XXI and XXII the data available on discharges of strontium-90 and ruthenium-106 respectively. Data on other specific nuclides are available in a limited number of cases and are considered below.

From Table XIX the coastal site discharges (La Hague, Dounreay, and Windscale) are clearly the highest, particularly Windscale. Marcoule discharges are appreciably greater than those from other riverain sites. La Hague discharges approximate to the pattern of krypton-85 discharged to atmosphere as do those from Eurex.

Normalized discharges averaged over 1972-76 for major sites were :

80 Ci/MWa for Windscale,
20 Ci/MWa for La Hague,
3 Ci/MWa for Marcoule.

The minimum average value is that for WAK - less than 10^{-3} Ci/MWa.

Available specific nuclide data additional to that in Tables XXI and XXII is summarized below for Windscale (14, 36) La Hague (21, 37) and WAK (33). For convenience the average contributions of these nuclides over the period 1972-76 are expressed below as percentages of the recorded gross beta discharges; if discharges of all nuclides were known in absolute terms the activity obtained by summation would not correspond, unless by chance, to the recorded gross beta discharges. The nuclides strontium-90 and ruthenium-106 from Tables XXI and XXII are included for completeness.

Site	Discharges as a Percentage of the Gross Beta 1972-76				
	Sr-90	Ru-106	Cs-134	Cs-137	Ce-144
WAK [1]	4.8 [2]	4.3	14	62	0.03
La Hague	7.6 [2]	65		13 [3]	12 [3]
Windscale	6.2	15	9.6	47	4.9

1) WAK data are based on discharges from Karlsruhe in 1974 when WAK provided 63 % of beta activity treated. Modifications to the effluent

treatment subsequently reduced the total discharges. In 1975-76 Sr-89/90 contributed about 25 % of the gross beta activity and Cs-137 about 20 % (34, 35) : however, the WAK contribution to the beta activity treated was less than 30 % of the total.

2) Including Sr-89.

3) Averaged over 1972-73 the years for which data have been published

For Windscale the data are given in full in the table below :

Nuclide	Expressed as a Percentage of the Gross Beta Discharge					
	1972	1973	1974	1975	1976	Ann.Ave. 1970-73
Sr-90	11	5.9	5.1	5.1	5.6	4.7
Ru-106	22	30	14	8.4	11.3	24
Cs-134	4.2	3.5	13	12	11	8.1
Cs-137	25	16	53	58	63	26
Ce-144	9.7	12	3.2	2.3	2.2	11.5
Gross beta (kCi)	140	127	207	245	183	126

This show a sharp increase in the significance of caesium-134 and 137 starting in 1974. The effect comes not from reprocessing per se, but from the onset of damage to fuel-cladding by corrosion in the fuel storage pond following extended storage (27). Short-term corrective measures succeded in reducing the caesium discharges in absolute terms in 1976. The average values over the period 1970-73 have been added to the table as being possibly more typical of normal operational conditions.

1.3.3.3. Tritium

The data available are given in Table XX, and the following normalized discharge values have been calculated :

- for Eurochemic 10 Ci/MWa (based on 1973 and 1974 alone and assuming that effectively all tritium discharged from Mol came from Eurochemic),
- for WAK 12 Ci/MWa (based on 1974 to 1976, the years for which tritium data specific to WAK have been received),
- for Windscale 14 Ci/MWa (averaged over 1972-76).

10 Ci/MWa would correspond to 44 % of the tritium generated in LWR fuel (Eurochemic and WAK). Similarly 14 Ci/MWa would correspond to 50 % for GCR fuel (Windscale).

Taking the sum total of tritium discharges in liquid effluent with that in gaseous effluent (Section 1.3.2.3.) insofar as data are available for both forms of discharge gives the following results :

- Eurochemic discharges (1973 and 1974) were 13 Ci/MWa of which 26 % was to atmosphere. 13 Ci/MWa corresponds to 59 % of the throughput calculated from krypton-85 discharges;
- WAK discharges (1973 to 1976) amounted to 12 Ci/MWa only 3 % of this being discharged to atmosphere. The total corresponds to 55 % of the calculated throughput;
- Windscale discharges (1972 to 1976) were 16 Ci/MWa of which 21 % was to atmosphere. Total discharges were 61 % of the calculated throughput.

The differences between total discharges and theoretical throughputs presumably indicate inaccurate theoretical values, inaccurate discharge assessments, unaccounted waste forms or some combination of the three. Losses from fuel prior to the reprocessing plant should not be significant in this context, since only two LWRs, Chooz and Trino use stainless-steel clad fuel which permits tritium diffusion to the reactor coolant.

2. RADIOLOGICAL ASPECTS

2.1. GENERAL

In this part of the report an attempt will be made to assess the maximum exposure of members of the population as a result of the activities released as gaseous and liquid effluents during 1976. Where significantly higher discharges have occurred in other years, they are also taken into consideration.

The exposure of man to radioactive gaseous effluents may occur in several ways :

- external irradiation by the plume or deposited activity,
- internal irradiation by direct uptake of airborne radioactivity;
- internal irradiation by ingestion of contaminated foodstuffs.

For liquid radioactive effluents the principal pathways are :

- external irradiation by water and sediments,
- internal irradiation by consumption of contaminated drinking water,
- internal irradiation by consumption of fish or shellfish, or farm produce contaminated by irrigation.

Since the levels of environmental contamination resulting from discharges are not usually readily detectable, dose evaluations mainly rely of necessity on models representing environmental transfer. The contamination levels calculated with such models are often quoted, for reasons of consistency in the calculations, to two significant figures but in reality indicate only approximate levels. When such results are introduced into biological models to estimate exposure levels the uncertainties are further increased. However, the assumptions adopted in the calculations are usually pessimistic and the results cited below can, therefore, be regarded in general as indicating maximum hypothetical values for the exposure of members of the population.

2.2. NUCLEAR POWER STATIONS

External whole body and skin doses from noble gases and thyroid doses from iodine-131 in milk have been calculated for each station - see Table XI. For other effluents and exposure pathways the evaluations

have been limited to those plants giving the highest discharges to atmosphere or those rivers with the highest resulting increases in activity concentrations.

2.2.1. Gaseous Effluents

The doses from gaseous effluents have been calculated at two positions, 0.5 km and 5 km respectively from the point of discharge. The first of these roughly corresponds to the site surroundings immediately beyond the site boundary and hence to a position where members of the general public are hardly ever present; the second position, at 5 km, corresponds to the distance at which the group of dwellings and/or dairy herd closest to the discharge point of a nuclear installation is often to be found.

The following were the main hypotheses used in these calculations :

- effluent releases were presumed to be continuous and constant in time;
- the effective height of release was taken as the height of the discharge point except for :
  - Tihange and Neckarwestheim, where a correction was made to take account of local topography,
  - U.K. stations, for which the effective height was reduced to 30 m to take into account building entrainment (37);
- an individual remained out of doors throughout the year at the two points considered;
- long-term atmospheric dilution factors were used supposing that the wind blew into the same 30° sector for 20 % of the time (38);
- where the radionuclide composition of noble gases was known (Table III) it was taken into account in the dose calculation (38). For those PWRs and BWRs, for which the composition was unknown, average dose conversion factors were used based respectively on those for PWRs and BWRs with known effluent compositions;
- in assessing internal doses, dose conversion factors were taken from a single reference (38) except for iodine-131 (39).

2.2.1.1. External gamma and beta doses from the radioactive plume

Table XI shows that in 1976 whole body gamma doses and skin beta doses from LWRs and continental GCRs did not exceed 1 mrem at 0.5 km from the discharge point and 0.1 mrem at 5 km except for one BWR of an older design.

In the case of the British GCRs, for which discharge data are available, the annual exposure at 0.5 km varied between 6 and 60 mrem due to the relatively high argon-41 releases.

The AGR, Hunterston B, gave doses similar to those encountered with LWRs as did the FBR, Phénix.

2.2.1.2. Internal irradiation by radioactive aerosols and sulphur-35

The amounts of aerosols released being very small, assessment has been restricted to the doses resulting from the maximum ascertained discharge during the five years under review.

As can be seen from Table V, the maximum discharge in one calendar year was 1.5 Ci by Lingen. On the pessimistic assumption that the MPCP of this discharge was equal to that of the most toxic radionuclide found in the effluent of other power stations of this type, i.e. 2×10^{-10} Ci/m^3 for insoluble cerium-144, doses to the lungs of 0.04 mrem at 0.5 km and less than 0.02 mrem at 5 km are obtained. All other annual discharges having been considerably less than in the above case, the corresponding doses will have been much lower than those derived above.

Table V also shows for convenience sulphur-35 discharges by some of the British GCRs and AGRs. The highest reported value is 2.4 Ci. The critical pathway for uptake of this radionuclide is via milk produced by cows grazing contaminated pastures; the critical organ is the whole body. An annual discharge of 2.4 Ci would result in a milk concentration at 0.5 km of about 270 pCi/liter, which would lead to an annual dose to an infant, drinking only this milk, of 0.7 mrem (40). At 5 km the milk contamination and hence the dose would be more than an order of magnitude lower.

2.2.1.3. Internal irradiation by iodine-131

The maximum iodine-131 discharge in one calendar year during the period considered was from Gundremmingen, 1.96 Ci in 1973. The corresponding maximum dose to the thyroid of a child from inhalation would have been 0.7 mrem at 0.5 km and 0.1 mrem at 5 km.

As regards the grass-cow-milk pathway, the bulk of this discharge took place outwith the grazing season and hence there was no significant exposure via this pathway (17).

Table XI shows for 1976 the calculated maximum doses,from iodine-131 releases into the atmosphere,to the thyroid of an infant drinking milk produced at each of the two distances under consideration, viz. 0.5 and 5 km from the discharge points.

For Gundremmingen the dose was calculated as 22 mrem at 0.5 km and 3 mrem at 5 km; at all other stations doses were considerably less, mostly smaller than 5 mrem at 0.5 km and 1 mrem at 5 km.

It must be underlined again that these calculated doses are maximum hypothetical values, based on very conservative assumptions, namely :

- the infant drinks only milk produced at one or other of the distances cited;
- all iodine discharges are assumed to be in elemental form, whereas the limited information available indicate that in reality a substantial fraction is in organic form (41) which has a much lower deposition velocity and would therefore give much lower concentrations in the locally produced milk.

In reality the doses would thus have been considerably lower than those evaluated. Moreover, for older persons the values would be still lower; for an adult with the same milk consumption rate as an infant it would be less than 10 % of the above (42).

2.2.1.4. Exposure to tritium

Tritium discharged to the atmosphere can be taken up direct by man via inhalation and absorption through the skin.

Discharges from the three heavy water power stations, MZFR, Monts d'Arrée and Winfrith, given in Table IV, are calculated to have given doses to the whole body of less than 0.1 mrem/year at 0.5 km and less than 0.01 mrem/year at 5 km.

For the other types of power station doses were less than 10^{-2} mrem/year at 0.5 km and less than 10^{-3} mrem/year at 5 km.

To estimate doses due to uptake of tritium through the food chain, reference has been made to a specific activity model (24) which assumes 50 % of the food intake to be contaminated at the mean level for the area within 50 km of the point of intake and the remainder to be uncontaminated. This indicates that at 0.5 and 5 km the food chain contribution is less than that from direct uptake.

2.2.1.5. Exposure to carbon-14

Carbon-14 discharged to atmosphere can reach man by inhalation of contaminated air or ingestion of contaminated foodstuffs.

Based on German experience - see Section 1.2.2.5. - it is assumed that the annual release of carbon-14 from a 1 000 MW_e LWR plant amounts to 10 Ci.

Use has again been made of a specific activity model (24), assuming a food intake pattern as in Section 2.2.1.4. This indicates that the food pathway is predominant; for a stack height of 100 m the dose to the critical organ (body fat) would be less than 0.01 mrem/year at all distances from the discharge point.

2.2.2. Liquid Effluents

Radioactive liquid effluents may give rise to doses to man through several exposure pathways :

- internal irradiation by drinking water,
- internal irradiation following ingestion of fish, irrigated crops, and milk and meat from cattle drinking river water,
- external irradiation by water and sediments.

Table X gives the mean increases in activity concentration of the rivers receiving liquid effluents from nuclear power stations, for other than estuarine sites, resulting from the 1976 discharges. Starting from these concentrations and using the nuclide composition of the effluents given in Table VIII, maximum doses from the above exposure paths can be assessed. Using the model given (43) by the German Strahlenschutzkommission (Radiological Protection Commission), the following whole body doserates* were calculated for those rivers with the highest concentration increases (Ellez, Meuse, Garigliano) :

Exposure path	Average consumption rates (kg/a) or exposure times (h/a)	Whole body doserate* (mrem/a)
Internal exposure		
- drinking water	440	
- gross beta activity (excl. H-3)		< 0.1
- tritium		< 0.03
- river fish	1.3	< 0.1
- milk	110	< 0.03
- meat	75	< 0.01
- crops	231	< 0.2
External exposure		
- swimming + boating	8	$< 2 \times 10^{-5}$
- exposure on river banks	2	< 0.001

The model used is not necessarily directly applicable to the rivers considered, more particularly in respect of the pathways defined and the transfer factors incorporated. Nevertheless, the table serves to indicate the doserates which might result from liquid effluent discharges into these rivers. It appears, therefore, that, even for the highest increases of activity concentrations in rivers, the annual whole body dose for an average member of the population would be a fraction of a mrem. Members of critical groups could, however, receive higher doses which, in the case of river fish consumption, could amount to a few mrem per year.

See Section 3.1

As regards marine and estuarine sites, U.K. estimates of the maximum exposure of an individual (44) show that the highest value was for Bradwell where the exposure in 1976 was a few mrem.

Trawsfynydd is situated on a lake. In the period 1972-75 the dose to the critical group, consuming 100 g per day of fish from the lake, was less than 40 mrem. In 1976, an exceptionally dry year giving a low water turnover rate, this maximum estimate approximately doubled (44).

2.3. NUCLEAR FUEL REPROCESSING PLANTS

Consideration of the effects of discharges from individual reprocessing plants has been limited to those from two sites, viz. Windscale and Marcoule. Discharges from the former currently represent the maximum for an individual plant but, in the case of liquid effluent, discharges are to a marine environment. Hence Marcoule, which has recorded the highest discharges to a river, is also discussed.

2.3.1. Gaseous Effluents

Detailed estimates of the environmental effects of the discharges to atmosphere from Windscale in 1976 have recently been published (45) and the table below is a synopsis of the results obtained. For details of the environmental models used reference should be made to the original paper but a number of salient features are listed here for convenience.

- The discharges of carbon-14 and iodine-129 are estimates based on the fuel inventory and assume for carbon-14 a conservative value of 100 % released to atmosphere and for iodine-129 a 1 % release.
- The atmospheric dispersion model (46) corresponds to a steady release rate over a prolonged period. The average frequency of Pasquill stability categories in U.K. conditions is assumed. There is no weighting for prevailing winds.
- For particulates both wet and dry deposition are taken into account; based on the U.K. average, this results in higher deposition levels at 200 m than at 1 km, even for a 100 m stack height (47).
- The results are expressed as dose commitment (in contrast to the results in the previous part of the present report - see also Section 3.1.).

- For tritium, carbon-14 and iodine-129 specific activity models are used (24). It is assumed that 50 % of the food and water intake is contaminated at the mean level within a 50 km radius of the point of intake, the other 50 % being uncontaminated.
- All alpha activity is assumed to be plutonium-239 and no allowance is made for re-entrainment in the atmosphere of deposited activity. The dose results quoted are for adults; for children they will be at most a factor of two higher.

Nuclide	Discharge 1976 (Ci)	Route	Critical organ	Dose at 200 m	Commitment (mrem)	
					at 1 km	at 5 km
		Direct from plume				
Krypton-85	1.2×10^6	External radiation	Skin	-	2.5	0.94
Total alpha (Pu-239 assumed)	0.052	Inhalation	Endosteal cells	-	1.4	0.47
		Wet + dry deposition				
Strontium-90	0.19	Milk	Bone marrow	0.46	0.15	0.038
	0.17 *			1.0	0.47	0.085
Caesium-137	0.25	External gamma from deposition	Whole body	- **	0.13	0.032
	0.88 *			- **	1.6	0.29
	0.25	Milk	Whole body	0.22	0.072	0.018
	0.88 *			2.0	0.88	0.17
Iodine-131	0.076	Milk	Thyroid	2.1	0.66	0.17
		Gnd. level airborne spec. activity model				
Iodine-129	0.02	Milk	Thyroid	-	0.12	0.11
Tritium	1.2×10^4	Inhalation and skin absorption, plus ingestion	Whole body	-	0.040	0.020
Carbon-14	250	Inhalation plus ingestion	Body fat	-	0.13	0.11

* Low-level stacks (assumed effective height of release 30 m) - see Section 1.3.2.2.

** The very small occupancy factor applicable at this distance would reduce the values to a small fraction of those at 1 km.

[After Reference (45)]

The models used in deriving the above results are based on average U.K. conditions. The latter are not strongly atypical of the continental situation in the present context and hence scaling the calculated dose values in respect of the discharges should serve to give an indication of the environmental effects of gaseous effluents from the other NFRPs.

2.3.2. Liquid Effluents

2.3.2.1. Windscale

Exceptionally, environmental modelling need not be used to estimate the effects of liquid effluent discharges from Windscale since contamination levels in the environment are detectable and the results have been widely published e.g. (26, 31, 36). Additionally, surveys of the consumption of contaminated foodstuffs and the occupancy factors of beaches with measurable contamination have been carried out. Thus many of the sources of uncertainty present in estimates of exposure around other sites have been eliminated in this case. However, it must be borne in mind that the environmental contamination levels as measured for 1976 will reflect not only the effects of discharges in that year but also the cumulative influence of discharges in previous years.

A well known exposure pathway to man for liquid effluents from Windscale has been laverbread manufactured from the seaweed porphyra. Harvesting of this seaweed from the Windscale area was, however, discontinued in 1972 (48) and although monitoring continued the pathway was still of little actual importance in 1976 (49).

The environmental effects of alpha discharges to the marine environment have been reviewed elsewhere to 1974 (31). The discharges in fact reached a peak in 1973 - see Section 1.3.3.1 - and the limited environmental data for 1976 available for comparison with that for 1974 indicate a consequent reduction in contamination levels (49, 50). Based on the 1974 review, therefore, for an average member of the public consuming 20 g per day of fish from the Irish Sea, the doserate to the critical organ, bone, will have been of the order of 10^{-2} mrem per year.

For the critical group consuming almost 300 g per day of fish taken close to the discharge point the result is of the order of mrem per year.

Work on resuspension in the atmosphere of alpha activity in mudflats has been reported for one area where its possible significance had been questioned. The measured airborne concentrations (51) indicate an eventual doserate of less than 1 mrem per year to the lung on the basis of I.C.R.P. Publication 2 (52).

For beta-gamma activity other than tritium the two critical pathways considered are :

- internal exposure from consumption of fish and shellfish,
- external exposure via sediments.

Caesium-134 and -137 are the nuclides of interest in the former case. It is believed that the 1976 results reflect a maximum following the sharply increased discharges of 1974-75 and the subsequent steps taken to reduce them (49). For an average member of the public consuming 20 g per day of Irish Sea commercial fish landings the resulting doserate in 1976 was of the order of mrem per year. For the maximum consumption rate of almost 300 g per day of fish taken within 5 km of the discharge point the calculated doserate is some 220 mrem per year. However, whole body monitoring of a local consumer of 130 g per day led to an estimate of some 40 mrem per year (51) a factor of three less than the theoretical model would suggest; this may well reflect the conservative assumption that all fish were taken within 5 km of the discharge point.

For external exposure the nuclides zirconium/niobium-95, ruthenium-106 and caesium-134 and -137 are all significant. The mudbank area in which the highest doserates are encountered were found to give a maximum annual dose of 40 mrem to an individual who frequents the area concerned (49).

To evaluate the dose from tritium an analogy has been drawn with caesium. The latter nuclide effectively remains in solution after discharge and the sea water concentrations close to the discharge point largely reflect the current year's discharges (36). Then taking account of tritium discharges relative to those of caesium it can be inferred that, for a consumption rate of 300 g per day of locally caught fish, the annual (1976) dose is less than 10^{-2} mrem. Other pathways exist e.g. via airborne

humidity from the sea. However, even if body water were in equilibrium with the corresponding average sea water specific activity (0.4 pCi/gm) the annual dose would still only be of the order of 10^{-2} mrem (23).

2.3.2.2. Marcoule

Discharges of alpha activity in liquid effluent from Marcoule in 1976 amounted to 0.3 Ci. Taking an average flowrate of 1 500 m^3/s, the resulting average increase in the concentration of alpha activity in the River Rhône was 6 x 10^{-3} pCi/l neglecting removal by sediments. Taking the consumption of drinking water as 440 l/a the corresponding annual intake by an individual is therefore 2.6 pCi. The corresponding dose commitment to the critical organ, bone, is some 10^{-3} mrem assuming the activity to be plutonium-239.

The gross beta activity (excluding tritium) discharged from Marcoule in 1976 was 624 Ci (Table XIX). Assuming that discharges of ruthenium-106 (541 Ci - Table XXII) and strontium-90 (11 Ci - Table XXI) are adequately reflected in the gross beta results, the residual activity of 72 Ci has been assigned to caesium-137.

As insufficient data on environmental transfer factors etc., specific to the Rhône,were available, the data used in Section 2.2.2. were applied.

In the table below, the doserates thus calculated for the Marcoule 1976 discharges are presented together with the assumed consumption rates and exposure times as appropriate to the various pathways.

Exposure pathway	Ave. consumption rate (kg/a) or exposure time (h/a)	Whole body dose (mrem/a)
Internal exposure :		
Drinking water	440	< 0.25
Fish	1.3	< 0.2
Milk	110	< 0.1
Meat	75	< 0.1
Crops	231	0.4
External exposure :		
Swimming and boating	8	< 1 x 10^{-4}
Exposure on river banks	2	< 2 x 10^{-2}

Members of critical groups will have received higher doses than those stated especially in respect of fish consumption and external exposure. For the more significant of these two pathways, fish consumption, the doserate may have been a few mrem per year.

In the absence of tritium discharge data it is for present purposes assumed that liquid effluent contained 50 % of the fuel content as calculated from the krypton discharges to atmosphere. Then the average increase in the specific activity of the river water would be 0.1 pCi/g. Even assuming that the specific activity of the body water of members of the public attained the same level the doserate would not exceed 10^{-2} mrem per year (23).

3. DISCUSSION AND CONCLUSIONS

3.1. METHODS USED TO EXPRESS THE RESULTS

The use in Section 2 of various models to evaluate radioactive discharges in terms of dose has led to different methods of expressing the results. Thus, in discussing discharges to atmosphere, the results for NPSs are given in terms of doserate whereas for NFRPs the form dose commitment is used. The latter (more correctly referred to as "dose equivalent commitment") is defined (53) as the infinite time integral of the per caput doserate (dose equivalent rate) in a given organ or tissue resulting from a given decision or practice; in the present context the "practice" is that of discharging in 1976 the amounts of radioactivity cited in the tables.

Should the time integral approach its infinite time value soon after a prolonged release is complete, the committed dose is largely received in the period of the release (in the present case, 1976) and hence is approximated by the dose for that period (i.e. the 1976 doserate for one year).

Hence for external radiation by discharges to atmosphere the doserates quoted for 1976 received direct from the plume are numerically equal to the dose commitments for the 1976 discharges. External radiation following deposition, however, requires that the dose commitment takes account of any exposure experienced in subsequent years as a result of activity persisting in the soil; the same is true for deposition from liquid effluents onto sediments. Thus, the dose commitment in these cases will be effectively equal to the 1976 annual doserate only for nuclides which have a half-life in the ground appreciably less than the one year period of discharge.

For internal irradiation, persistence in the environment and in the body must be considered. Uptake by the body may be effectively complete during the period of discharge as in the case of ingestion of drinking water from rivers and inhalation of airborne effluents. Alternatively, uptake may be extended, e.g. strontium-90 in milk following root uptake from the soil of contamination derived from the air or from irrigation water. Following uptake, should the nuclide persist in the body, the dose

commitment must include doses imparted in subsequent years, again e.g. by strontium-90. The dose received in the period of discharge will effectively equal the dose commitment only if the effective half-lifes in the environment and in the body are small in relation to the discharge period.

Specific activity models constitute another approach to evaluation of internal irradiation; those used in Section 2 assume that the specific activity in air and in food produced at any point is in both cases equal to the value obtained from the concentration of the radioactive nuclide in air at that point relative to that of its stable isotopes. Hence the uptake is that at equilibrium and it is further assumed that the specific activity in the critical organ is also at a corresponding specific activity equilibrium.

The concept of equilibrium introduces another approach to the comparison of dose commitment and doserate. For all models the dose commitment from one year's discharges is numerically equal to the annual doserate at equilibrium for that annual discharge rate*. In terms of the previous discussion, the time taken to reach effective equilibrium will depend on how quickly the dose commitment integral approaches its infinite time value.

The implications of the above generalisations for the results given in Section 2 can now be considered in respect of the models used and the nuclides cited; it is recalled that the discharge model already assumes a uniform discharge rate throughout a given calendar year.

Discharges to atmosphere from NPSs of the nuclides considered will rapidly give rise to equilibrium doserates via the pathways specified.

For liquid effluents to rivers, the model as here applied indicates an equilibrium situation. Thus the doserates quoted for 1976 are valid only insofar as equilibrium is effectively reached. In practice the only pathway for which the results may be significantly different, bearing in mind the limited accuracy of all such models, is that of

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* This neglects any changes in intake pattern and dose commitment per unit intake with age.

external radiation from sediments, itself a minor pathway. For the United Kingdom liquid effluent discharges,the doses cited are based largely on environmental samples and hence already include any contributions from previous years, i.e. insofar as annual discharges have remained relatively constant the doses reflect an equilibrium condition.

Thus all the results in Section 2 for both liquid and gaseous effluents from NPSs may be regarded as the equilibrium doserates.

As regards NFRPs, the model used for discharges to atmosphere from Windscale gives dose commitments specific to 1976 discharges. For strontium-90, caesium-137 and alpha activity (plutonium-239) the results allow for intakes in years subsequent to the discharges and/or doses received in the years following intake as appropriate. However, annual doses at equilibrium* will be of the same order as the corresponding dose commitments for one year's discharges.

The consequences of liquid effluent discharges from Windscale are again based on environmental measurements and reflect previous years discharges where applicable. Discharges have tended to reduce since 1973-74 and hence the 1976 dose estimates will if anything tend to overestimate the equilibrium situation for the 1976 rate of discharge. The model use for Marcoule liquid effluent is that used for NPSs.

Hence for NFRPs as a whole, taking the dose commitments from gaseous discharges by Windscale to be numerically equal to annual doserates at equilibrium,all the results may be regarded as representing the equilibrium situation.

3.2. SIGNIFICANCE OF EXPOSURES RESULTING FROM EFFLUENT RELEASES

To assess the relative importance of exposure of members of the public to radioactive effluents from NPSs and NFRPs, the results evaluated in Section 2 have been compared with the radiological protection standards in force in the Community and with natural radiation exposure.

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* More correctly for plutonium equilibrium in the body is not attained. The doses quoted in Section 2 will correspond to the annual doserate after 50 years uptake at the 1976 rate.

3.2.1. Significance in Relation to the Euratom Radiological Protection Standards

The dose limits currently in force in the European Community for members of the public are as follows (54) :

- 0.5 rem/year to the whole body, bone marrow or gonads,
- 0.5 rem/year to bone marrow or gonads,
- 3 rem/year to skin or bone,
- 3 rem/year to the thyroid of persons aged 16 years or over,
- 1.5 rem/year to the thyroid of persons aged less than 16 years,
- 7.5 rem/year to the extremities,
- 1.5 rem/year to other organs or tissues.

It should be noted that the ICRP Recommendations, from which the Euratom Standards are derived, were revised in 1977 (53). However, these changes have yet to be taken into consideration in the Standards and have not, therefore, been considered in this report.

Comparison of the above limits with the doses resulting from the radioactive effluents and presented in Section 2 allows the following conclusions.

Nuclear Power Stations

In the immediate vicinity of nuclear power stations, as typified by the results at 0.5 km from the point of release, discharges to atmosphere in 1976 were such that :

- external doses to the whole body and to the skin from gaseous radioactive discharges did not generally exceed 0.2 % and 0.04 % of the respective dose limits, although for some U.K. GCRs the whole body dose may have amounted to several % of the limit;
- doses resulting from inhalation of radioactive aerosols (to lung) and iodine-131 (to thyroid) were respectively less than 0.003 % and 0.05 % of the corresponding limits;
- for an infant consuming milk produced near nuclear power stations doses to the thyroid (from iodine-131) were usually less than 1 % of the dose limit and to the whole body (from sulphur-35) less than 0.2 %;

- doses resulting from the uptake of tritium (to whole body) and carbon-14 (to body fat) discharged to atmosphere were less than 0.1 % and 0.001 % of the respective dose limits.

At 5 km from NPSs doses were generally an order of magnitude less than those mentioned above.

Doses to critical groups of the population exposed to liquid radioactive effluents were generally lower than 1 % of the dose limits.

Nuclear Fuel Reprocessing Plants

Equilibrium doserates in the vicinity of the Windscale plant, based on the dose commitments at 1 km resulting from the 1976 discharges to atmosphere, would compare as follows with the dose limits :

- the doserate to the skin from krypton-85 discharges would be less than 0.1 % of the dose limit. The external whole body doserate from caesium-137 deposition on the ground would be less than 0.4 % of the limit;
- the doserates, via milk, from iodine-131, strontium-90 and caesium-137 would be respectively some 0.05 %, 0.1 % and 0.2 % of the corresponding limits for the critical organs concerned (thyroid, bone marrow, whole body);
- the doserates resulting from the uptake of tritium, carbon-14 and iodine-129 would be less than 0.01 % of the corresponding limits;
- for alpha discharges the doserate would be less than 0.3 % of the limit.

The doserates in the vicinity of other reprocessing plants would be substantially lower than those above, in accordance with their lower levels of discharge.

The liquid effluent discharges from Windscale to the Irish Sea resulted, by fish consumption, in a calculated maximum doserate for 1976 to members of the critical group equal to 44 % of the dose limit; whole body monitoring of local fish consumers suggests, however, a maximum value of about 20 %. The whole body dose to the critical group through external irradiation by sediments amounted to 8 % of the dose limit. The doses to the critical groups for the two other marine sites, La Hague and Dounreay, should have been appreciably lower.

The 1976 liquid effluent discharges from Marcoule to the River Rhône gave maximum doses, to the critical group of the population, of less than 1 % of the dose limits. As the discharges from the other riparian plants were considerably lower, the doses should also have been correspondingly lower.

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Apart from the Euratom Standards more restrictive dose limits have been introduced in several European countries to control the exposure arising from discharges of radioactive substances from nuclear installations (55). These limits have been imposed in furtherance of the fundamental principle of ICRP (53), to maintain "exposures as low as reasonably achievable", although they differ from country to country and are for the most part not amenable to direct comparison.

The doses given in Section 2 above confirm that, in those countries where such specific dose limits exist, they have been respected in the period covered in this report.

3.2.2. Significance in Relation to Exposure from Natural Radiation Sources

The environmental impact of discharges from nuclear installations can also be put into perspective by comparison with exposure from natural radiation. It is recalled that the various natural radiation sources include external sources, such as cosmic rays and radioactive substances in the ground and in building materials, and internal sources in the form of naturally occurring radioactive substances in the human body, particularly potassium-40.

Exposure to natural sources can vary substantially from place to place, but the average annual dose to the gonads is estimated to be 78 mrad (2) which allows a corresponding average whole body dose of the order of 100 mrem to be presumed.

The maximum doses to members of the public via radioactive discharges from the nuclear installations covered in this report are seen to account, in general, for less than 5 % of man's average exposure to

natural radiation sources and hence to lie within the margin of regional and temporal fluctuations of natural exposure. Exceptionally, where such levels are exceeded, even although the doses received still leave a considerable safety margin in relation to the applicable limits, they are not regarded with equanimity. For example, plans have been made (27) to refurbish the Windscale plant and construct a new plant such that, even with an appreciably increased total plant capacity, overall environmental exposure should be much reduced in comparison with the period covered in this report.

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TABLE I

GENERAL CHARACTERISTICS OF NUCLEAR POWER STATIONS (NPSs) (a)

Facility/Location	Reactor type (b)	Thermal capacity MW(th)	Maximum output capacity MW(e)	First Grid Connection	Water body receiving liquid effluents
BELGIUM					
Doel 1	PWR	1 192	395	28.08.74	Scheldt
-"- 2	PWR	1 192	395	24.08.75	
Oost Vlaanderen					
Tihange 1	PWR	2 652	870	07.03.75	Meuse
Liège					
GERMANY					
MZFR (Karlsruhe)	PHWR	200	51	09.03.66	Rhine
Baden-Wurtemberg					
Gundremmingen	BWR	801	237	12.11.66	Danube
Bavaria					
Lingen	BWR	520	182 (c)	20.05.68	Ems
Lower Saxony					
Obrigheim	PWR	1 050	328	29.10.68	Neckar
Baden-Wurtemberg					
Würgassen	BWR	1 912	640	18.12.71	Weser
N.Rhine-Westphalia					
Stade	PWR	1 900	630	29.01.72	Elbe
Lower Saxony					
Biblis A	PWR	3 517	1 146	25.08.74	Rhine
-"- B	PWR	3 733	1 178	25.04.76	
Hesse					
Neckarwestheim	PWR	2 360	791	03.06.76	Neckar
Baden-Wurtemberg					
Brunsbüttel	BWR	2 292	770	13.07.76	Elbe
Schleswig-Holstein					

TABLE I (continued 1)

Facility/Location	Reactor type (b)	Thermal capacity MW(th)	Maximum output capacity MW(e)	First Grid Connection	Water body receiving liquid effluents
FRANCE					
Chinon Tr-1 (d)	GCR	300	70	14.06.63	Loire
Tr-2	GCR	848	210	24.02.65	
Tr-3	GCR	1 560	400	04.08.66	
Indre-et-Loire					
Chooz	PWR	905	305	03.04.67	Meuse
Ardennes					
Monts d'Arrée	HWR	240	70	09.07.67	Ellez
Finistère					
St-Laurent-des-Eaux Tr-1	GCR	1 652	460	14.03.69	Loire
Tr-2	GCR	1 700	515	09.08.71	
Loir-et-Cher					
Bugey Tr-1	GCR	1 950	540	15.04.72	Rhône
St-Vulbas, Ain					
Phénix	FBR	563	233	13.12.73	Rhône
Marcoule, Gard					
ITALY					
Latina	GCR	575	153	12.05.63	Thyrrhenian Sea
Latina					
Garigliano	BWR	506	151.5	23.01.64	Garigliano
Sessa, Casserta					
Trino	PWR	825	247	22.10.64	Po
Trino Vercellese, Vercelli					
NETHERLANDS					
Dodewaard	BWR	163	51.5	25.10.68	Waal
Gelderland					
Borssele	PWR	1 365	450	04.07.73	Scheldt Estuary
Zeeland					

TABLE I (continued 2)

Facility/Location	Reactor type (b)	Thermal capacity MW(th)	Maximum output capacity MW(e)	First Grid Connection	Water body receiving liquid effluents
UNITED KINGDOM					
Calder Cumbria	GCR	4 x 268	200	10.56	Irish Sea
Chapelcross Dumfries and Galloway	GCR	4 x 248	192	02.59	Solway Firth
Bradwell Essex	GCR	2 x 531	250	06.62	Blackwater Estuary
Berkeley Gloucester	GCR	2 x 555	276	06.62	Severn Estuary
Hunterston A -"- B Strathclyde	GCR AGR	2 x 535 2 x 1516	300 1 240	02.64 06.02.76	Firth of Clyde
Trawsfynydd Gwynedd	GCR	2 x 860	390	12.64	Lake Trawsfynydd
Hinkley Point A -"- B Somerset	GCR AGR	2 x 971 2 x 1516	460 1 240	02.65 05.02.76	Severn Estuary
Dungeness A Kent	GCR	2 x 840	410	09.65	English Channel
Sizewell A Suffolk	GCR	2 x 948	420	12.65	North Sea
Oldbury Avon	GCR	2 x 892	416	11.67	Severn Estuary
Winfrith Devon	SGHWR	300	92	12.67	English Channel
Wylfa Gwynedd	GCR	2 x 1500	840	11.71	Irish Sea

(a) Technical data and terminology are taken from Ref. 1.

(b) Type of reactor : AGR - Advanced Gas-cooled Reactor
BWR - Boiling Water Reactor
FBR - Fast Breeder Reactor
GCR - Gas-cooled Reactor
HWR - Heavy Water Reactor
PHWR - Pressurized Heavy Water Reactor
PWR - Pressurized Water Reactor
SGHWR - Steam Generating Heavy Water Reactor

(c) Plus 74 MW(e) by natural gas-fired superheating

(d) Decommissioned - 16.04.1973

TABLE II

ANNUAL DISCHARGE OF GASEOUS RADIOACTIVE WASTE (NOBLE GASES) FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1972	1973	1974	1975	1976
BELGIUM						
Doel	4×10^4	n.a.	n.a.	-	208	822
Tihange 1	4×10^4	n.a.	n.a.	n.a.	466	4 606
GERMANY						
MZFR	3×10^3	955	< 218	949	1 116	985
Gundremmingen	1.9×10^6	11 105	42 700	4 145	7 440	5 280
Lingen	3.1×10^6	< 5 800	< 3 400	< 10 500	35 000	6 400
Obrigheim	8×10^4	3 202	2 927	13 456	8 010	328
Würgassen	3.2×10^4	594	559	52	121	482
Stade	6.1×10^4	2 445	2 613	890	1 260	10 500
Biblis A	9×10^4	n.a.	n.a.	61.5	1 680	1 200
Biblis B		n.a.	n.a.	n.a.	n.a.	304
Neckarwestheim	2.5×10^4	n.a.	n.a.	n.a.	n.a.	634
Brunsbüttel	7×10^4	n.a.	n.a.	n.a.	n.a.	970
FRANCE						
Chinon	4×10^5 (b)	11 515	2 808	2 082	6 050	4 924
Chooz	2.5×10^6 (b)	31 342	19 914	1 462	2 700	4 945
Monts d'Arrée	4×10^5 (b)	144 450	130 051	164 460	196 000	242 978
St-Laurent-des-Eaux	4×10^5 (b)	3 863	4 967	4 338	3 480	2 893
Bugey	4×10^5 (b)	841	3 097	4 475	5 280	3 080
Phénix (a)	8.4×10^4	n.a.	n.a.	-	170	234
ITALY						
Latina	5×10^3 (c)	3 600	2 050	3 011	2 591	2 478
Garigliano	6.3×10^5 (c)	290 000	380 000	250 000	228 541	239 486
Trino	5×10^4	1 031	6 100	7 000	457	179

TABLE II (continued)

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
NETHERLANDS						
Dodewaard	3×10^5	8 400	6 703	4 160	2 109	6 230
Borssele	1.2×10^4	n.a.	307	5 830	2 609	3 897
UNITED KINGDOM (d)	(e)					
Calder		30 000	30 000	30 000	22 000	14 800
Chapelcross					32 000	32 000
Bradwell						15 000
Berkeley						16 000
Hunterston B		n.a.	n.a.	n.a.	n.a.	2 000
Trawsfynydd						150 000
Hinkley Point A						80 000
Dungeness A						30 000
Sizewell A						60 000

(a) Activity expressed in Xe-135 equivalent.

(b) For these discharge limits, assuming an atmospheric dilution factor of 1.5×10^{-5} s/m^3 and a 20 % probability of the wind blowing in one direction, the maximum concentration in air at ground level would correspond to the MPCP for the nuclides concerned.

(c) The stated limit for Latina assumes the presence of A-41 alone; the overall discharge formula for noble gases and tritium is :

$$\frac{Q\ (A\text{-}41)}{5 \times 10^3} + \frac{Q\ (H\text{-}3) + Q\ (\text{other noble gases expressed in Xe-133 equivalent})}{10^2} \leqslant 1\ \text{Ci/a}$$

in which Q is the activity discharged in Ci/a.
Prior to 1974 the limits for Latina and Garigliano were 5×10^5 Ci/a and 3×10^6 Ci/a respectively.

(d) The quantities of discharged radioactive gases from GCRs are not measured routinely. A limited number of measurements, made during 1976 on CEGB stations, when adjusted for average load factors, indicate the A-41 annual discharges given in the table.

(e) Authorizations for discharge of radioactive gases and aerosols from British power stations place no limit on the quantities but require that the best practicable means be used to minimize the amount of radioactivity to be discharged.

TABLE III

RADIONUCLIDE COMPOSITION (%) OF NOBLE GAS DISCHARGES IN 1976 (a)
FROM NPSs

Facility	A-41	Kr-85	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-133	Xe-133m	Xe-135	Xe-135m	Xe-137	Xe-138
GERMANY												
MZFR							x					
Gundremmingen (b)		1	11	3	7	6	47		5	3	8	9
Lingen	0.3	0.3	7.5	1.5	7.5	0.3	42.5	0.3	39.0	0.3	0.3	0.3
Obrigheim							x					
Würgassen	0.2	1	1.7	2.3	1.2	15.1	1.1	0.2	6.7	14.3	43.8	12.4
Stade	$1x10^{-2}$	20	8	$1x10^{-2}$	3.6	$1x10^{-2}$	45.6	5.4	17.3	$1x10^{-2}$	$1x10^{-2}$	$1x10^{-2}$
Biblis A	0.6		1.7	0.7	0.7		80.4	2.6	12.8	0.4		
FRANCE												
Chinon	x											
Chooz							x					
Monts d'Arrée	x											
St-Laurent-des-Eaux	x											
Bugey	x											
ITALY												
Latina	99.2	$2x10^{-2}$	$3x10^{-3}$	$1x10^{-2}$	$1x10^{-2}$		0.4		0.2			
Garigliano			6.9	12.2	11.7		17		27.5	6		18.7
Trino	10.5	1	0.5				77		11			
NETHERLANDS												
Borssele	1						74		25			
UNITED-KINGDOM												
GCR and AGR Power stations	x											

(a) In the table a cross indicates the predominant nuclide.

(b) Data for 1974

TABLE IV

ANNUAL DISCHARGE OF TRITIUM TO ATMOSPHERE (a)
FROM NPSs

Facility	Discharge Limit (Ci/a) (a)	Activity released (Ci/year) 1972	1973	1974	1975	1976
GERMANY						
MZFR	4 000	542	1 091	1 099	765	703
Gundremmingen		~ 50	~ 50	~ 200	~ 100	27.2
Lingen					~ 30	6
Obrigheim		11.5	20.3	11.5	27	62.3
Würgassen					~ 2	
Stade		< 20	< 20	11.1	15	21
Biblis A		n.a.	n.a.		13	9.5
-"- B		n.a.	n.a.	n.a.	n.a.	3.5
Neckarwestheim		n.a.	n.a.	n.a.	n.a.	2
Brunsbüttel		n.a.	n.a.	n.a.	n.a.	0.5
FRANCE						
Monts d'Arrée		83	696	1 756	2 860	1 395
Phénix		n.a.	n.a.	-	8.2	10.8
ITALY						
Latina					2.8	2.7
Garigliano					0.74	14.7
Trino				7.3	3.7	16.3
NETHERLANDS						
Borssele	50	n.a.	n.a.	9	12	9
UNITED KINGDOM						
Hunterston B		n.a.	n.a.	n.a.	n.a.	45.6
Oldbury (b)			30	12	10	7
Winfrith		232	300	283	268	780
Wylfa (b)		194	200			

(a) The tritium present in gaseous effluent is not measured systematically in all power stations, probably because of its low radiotoxicity and its limited presence in the effluent. Presumably for the same reasons only one station has a specific discharge limit imposed.

(b) See foot-note (i) to Table V.

TABLE V

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (BETA) FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1972	1973	1974	1975	1976
BELGIUM						
Doel	2	n.a.	n.a.	-	1.8×10^{-1}	2.1×10^{-1}
Tihange 1	2	n.a.	n.a.	n.a.	-	4.8×10^{-5}
GERMANY						
MZFR		1.2×10^{-3}	0.8×10^{-3}	1.3×10^{-3}	-	-
Gundremmingen	2 850	1.5×10^{-2}	1.8×10^{-2}	2.0×10^{-3}	8×10^{-3}	5×10^{-3}
Lingen	15 800	$< 1.4\times10^{-2}$	1.5	6×10^{-3}	1×10^{-2}	5×10^{-4}
Obrigheim	(a)	8.9×10^{-2}	3.3×10^{-2}	2.3×10^{-2}	2.5×10^{-2}	8.0×10^{-3}
Würgassen	10.5	$< 10^{-3}$	$< 10^{-3}$	1.3×10^{-2}	1.1×10^{-2}	1.7×10^{-2}
Stade	17.5	1.2×10^{-2}	2.2×10^{-2}	1.4×10^{-2}	3×10^{-2}	7×10^{-3}
Biblis A	3.25 (h)	n.a.	n.a.	8×10^{-4}	6×10^{-3}	2.8×10^{-2}
-"- B	3.25 (h)	n.a.	n.a.	n.a.	n.a.	2×10^{-3}
Neckarwestheim	0.5 (b)	n.a.	n.a.	n.a.	n.a.	5.0×10^{-4}
Brunsbüttel	17.5	n.a.	n.a.	n.a.	n.a.	7×10^{-3}
FRANCE						
Chinon	30 (c)	7.5×10^{-2}	9.8×10^{-3}	5.2×10^{-3}	1.0×10^{-2}	1.8×10^{-2}
Chooz	30 (c)	5×10^{-4}	5.9×10^{-3}	5.8×10^{-3}	2.4×10^{-3}	1.7×10^{-3}
Monts d'Arrée (d)	30 (c)	8.2×10^{-2}	2.8×10^{-2}	5.4×10^{-2}	3.8×10^{-2}	4.9×10^{-3}
St-Laurent-des-Eaux	30 (c)	7×10^{-3}	7.7×10^{-3}	3.1×10^{-3}	1.3×10^{-3}	1.9×10^{-3}
Bugey	30 (c)	4×10^{-4}	3.3×10^{-3}	1.4×10^{-2}	1.7×10^{-3}	8×10^{-3}
Phénix		n.a.	n.a.	-	1.8×10^{-5}	1.6×10^{-5}
ITALY						
Latina	0.1 (f)	-	4.8×10^{-4}	4.8×10^{-4}	1.1×10^{-3}	1.2×10^{-4}
Garigliano (é)	1 (f)	6×10^{-2}	6×10^{-2}	$< 1\times10^{-3}$	3.6×10^{-1}	3.2×10^{-2}
Trino	0.2 (f)	$< 1\times10^{-5}$	7×10^{-8}	7.6×10^{-5}	7×10^{-7}	-
NETHERLANDS						
Dodewaard	(a)	2×10^{-2}	8×10^{-3}	4.8×10^{-3}	5.9×10^{-3}	3.6×10^{-3}
Borssele	1	n.a.	-	6.6×10^{-4}	1.8×10^{-3}	1.3×10^{-4}

TABLE V (continued 1)

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year) 1972	1973	1974	1975	1976
UNITED KINGDOM	(g)					
Calder (h)						
Chapelcross (h)						
Bradwell		3.0×10^{-3}	2.8×10^{-3}	4.0×10^{-3}	2.8×10^{-3}	2.6×10^{-3}
Berkeley		5.7×10^{-3}	5.3×10^{-3}	4.4×10^{-3}	4.2×10^{-3}	3.0×10^{-3}
Hunterston A (h)						
-"- B		n.a.	n.a.	n.a.	n.a.	7.4×10^{-3}
Trawsfynydd (i)		3.4×10^{-2}	1.4×10^{-2}	2.6×10^{-2}	1.1×10^{-2}	1.3×10^{-2}
Hinkley Point A (i)		4.3×10^{-2}	5.9×10^{-2}	4.2×10^{-2}	1.1×10^{-2}	1.3×10^{-2}
-"- B		n.a.	n.a.	n.a.	n.a.	1.9×10^{-2} plus 2.2 S-35
Dungeness A (i)		9.4×10^{-2}	6.6×10^{-2}	9.0×10^{-2}	5.4×10^{-2}	1.9×10^{-2}
Sizewell A		8.4×10^{-3}	1.2×10^{-2}	8.1×10^{-3}	9.7×10^{-3}	1.1×10^{-2}
Oldbury (i)		3.2×10^{-2} plus 0.3 S-35	9.7×10^{-2} plus 0.57 S-35 30 H-3 0.14 As-76	1.5×10^{-1} plus 0.67 S-35 12 H-3	3.5×10^{-2} plus 1.6 S-35 10 H-3	1.8×10^{-3} plus 1.4 S-35 7 H-3
Winfrith		6.1×10^{-2}	2.0×10^{-1}	1.5×10^{-1}	3.8×10^{-2}	1.4×10^{-1}
Wylfa (i)		3.2×10^{-3} plus 5.6×10^{-2} S-35 194 H-3	4.2×10^{-3} plus 1.3 S-35 200 H-3	4.1×10^{-3}	4.0×10^{-3} plus 2.0 S-35	8.4×10^{-3} plus 2.4 S-35

(a) No limit laid down in the operating licence.

(b) Limit for nuclides with $T_{\frac{1}{2}} > 8$ d.

(c) Expressed in Cs-137 equivalent and based on the milk pathway to the infant.

(d) Discharges comprise aerosols and volatiles.

(e) 1972-73 results are estimated; the 1974-75-76 results are based on measurements.

(f) The limits for Latina and Trino are expressed as Sr-90 equivalent. The limit in the table for Garigliano is in Cs-137 equivalent units, but a limiting overall discharge formula is applied :

$$\frac{Q(H\text{-}3)}{100} + \frac{Q(I\text{-}131)}{1} + \frac{Q(Sr\text{-}90)}{10^{-3}} + \frac{Q(alpha)}{10^{-3}} + \frac{Q(other\ particulates)}{1} \leq 1 \text{ Ci/year}$$

in which Q is the activity discharged in Ci/a, Q(alpha) is expressed in Pu-239 equivalent, and Q(other particulates) in Cs-137 equivalent. Prior to 1974 the limits for Latina and Garigliano were 5×10^2 Ci/year and 3×10^3 Ci/year respectively.

TABLE V (continued 2)

(g) Authorizations for discharge of radioactive gases and aerosols from British power stations place no limit on the quantities but require that the best practicable means be used to minimize the amount of radioactivity to be discharged.

(h) A continuous measurement programme is not undertaken; for Hunterston A it is estimated that about 3×10^{-2} Ci/year is discharged and for Calder and Chapelcross 2×10^{-2} to 3×10^{-2} Ci/year.

(i) The Dungeness, Hinkley Point A, Trawsfynydd and Oldbury results are based on samples collected using charcoal impregnated papers and can therefore include a contribution from S-35 etc. in vapour form. Oldbury and Wylfa S-35 and H-3 discharges cited are specific to conditioning of the reactor gas circuit after shutdown.

TABLE VI

ANNUAL DISCHARGE OF IODINE-131 TO ATMOSPHERE FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1972	1973	1974	1975	1976
BELGIUM						
Doel	0.2	n.a.	n.a.	-	2.6×10^{-4}	5.0×10^{-3}
Tihange 1	0.2	n.a.	n.a.	n.a.	5.7×10^{-4}	2.0×10^{-2}
GERMANY						
MZFR						
Gundremmingen	22	0.19	1.96	0.12	0.25	0.35
Lingen	16	0.15	1.6×10^{-2}	2×10^{-3}	1.3	5×10^{-2}
Obrigheim	15 (a)	6.2×10^{-3}	4.9×10^{-3}	4.9×10^{-3}	1.1×10^{-2}	2×10^{-3}
Würgassen	0.26	$< 10^{-4}$	$< 10^{-4}$	$< 7\times10^{-4}$	1.4×10^{-3}	4.6×10^{-2}
Stade	0.21	4.7×10^{-2}	4.3×10^{-2}	1.1×10^{-2}	1×10^{-2}	2×10^{-2}
Biblis A	0.7	n.a.	n.a.	6.3×10^{-5}	5×10^{-3}	1.3×10^{-2}
-"- B		n.a.	n.a.	n.a.	n.a.	9.7×10^{-3}
Neckarwestheim	0.25 (b)	n.a.	n.a.	n.a.	n.a.	2×10^{-3}
Brunsbüttel	0.26	n.a.	n.a.	n.a.	n.a.	2×10^{-5}
FRANCE (h)						
Chinon	1.5	2.7×10^{-2}	3.2×10^{-2}	3.87×10^{-3}	2.1×10^{-2}	2.2×10^{-3}
Chooz	1.5	2.3×10^{-2}	2.9×10^{-2}	5.76×10^{-3}	0.41	4.5×10^{-2}
Monts d'Arrée (c)	1.5					
St-Laurent-des-Eaux	1.5	6.5×10^{-2}	6.2×10^{-3}	1.68×10^{-2}	1.6×10^{-2}	1.1×10^{-2}
Bugey	1.5	1×10^{-4}	1.6×10^{-1}	5.99×10^{-3}	2.2×10^{-2}	1.9×10^{-3}
Phénix		n.a.	n.a.	-	-	2.2×10^{-4}
ITALY						
Latina	1×10^{-3} (e)	$< 5.5\times10^{-5}$	$< 5.5\times10^{-5}$	$< 5.5\times10^{-5}$	2.3×10^{-5}	2.5×10^{-5}
Garigliano	1.0 (e)	6×10^{-2}	3.4×10^{-2}	2.4×10^{-2}	1.6×10^{-2}	3.5×10^{-2}
Trino	0.05 (e)	1×10^{-6}	5×10^{-7}	6.4×10^{-7}	4.7×10^{-5}	7.3×10^{-7}
NETHERLANDS						
Dodewaard (d)	(f)	6×10^{-3}	1.1×10^{-2}	9.5×10^{-3}	5.2×10^{-3}	4.5×10^{-3}
Borssele	0.24	n.a.	2.5×10^{-3}	3.4×10^{-2}	1.4×10^{-2}	8.3×10^{-3}
UNITED KINGDOM (g)						
Hinkley Point B		n.a.	n.a.	n.a.	n.a.	$< 1.4\times10^{-2}$

TABLE VI (continued)

(a) 1 mCi/d and 2.5 mCi/week limits are imposed during grazing season.

(b) Limit quoted is for stack discharges; a different limit, 5×10^{-4} Ci/a I-131, is applied to ground level discharges (turbine hall + valves).

(c) See Table V.

(d) "Halogen" results.

(e) The limits given for Latina and Trino apply to halogens in I-131 equivalent. For Garigliano, see foot-note (f) of Table V. Prior to 1974 the I-131 limits for Latina and Garigliano were 3×10^{3} Ci/a and 1×10^{4} Ci/a respectively.

(f) No official limits laid down.

(g) Since defective fuel can be removed on-load from the UK Magnox reactors as soon as it is detected routine measurements of the iodine discharges are not made, being negligible.

(h) For the French stations 1975 and 1976 discharges comprise all volatiles.

TABLE VII

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (EXCLUDING TRITIUM) FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1972	1973	1974	1975	1976
BELGIUM						
Doel (a)	24	n.a.	n.a.	6.2×10^{-2}	0.54	4.98
Tihange 1 (a)	8	n.a.	n.a.	n.a.	0.51	0.93
GERMANY						
MZFR, (b)						
Gundremmingen	14.6	1.55	1.55	0.93	1.26	1.16
Lingen	5.4	0.11	< 0.04	0.03	0.04	0.26
Obrigheim	18	3.33	2.30	3.05	1.72	0.98
Würgassen	6.7	1.81	1.59	1.45	1.86	1.12
Stade	5	0.63	1.19	0.39	0.27	0.33
Biblis A	10	n.a.	n.a.	0.6	0.74	0.22
B		n.a.	n.a.	n.a.	n.a.	0.29
Neckarwestheim	1 (j)	n.a.	n.a.	n.a.	n.a.	0.24
Brunsbüttel	5	n.a.	n.a.	n.a.	n.a.	2.23
FRANCE						
Chinon	900 (c)	3.0	3.28	0.40	0.65	0.57
Chooz	100 (c)	12.4	8.18	8.64	8.6	2.56
Monts d'Arrée	5 (c)	0.22	0.04	0.05	0.05	0.03
St-Laurent-des-Eaux	850 (c)	9.4	7.28	4.24	4.7	2.97
Bugey	680 (c)	0.04	1.60	60.24	13.8	3.59
Phénix (d)		n.a.	n.a.			
ITALY						
Latina	(e)	16.5	10.5	6.1	4.9	5.17
Garigliano	(e)	14.4	3.7	4.2	3.13	3.77
Trino	(e)	6.0	6.4	3.3	1.46	2.71
NETHERLANDS						
Dodewaard	2.6	2.03	1.56	2.16	1.25	0.34
Borssele	15	n.a.	0.16	0.52	1.61	0.85

TABLE VII (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1972	1973	1974	1975	1976
UNITED KINGDOM	(f)					
Calder (g)						
Chapelcross	700	9.5	8.6	1.2	17.3	32.4
Bradwell	200 (incl. Zn-65)	119	53.5	90	115	65.4
	5 Zn-65	0.033	0.047	0.10	0.10	0.20
Berkeley	200	23.3	20.7	23.1	54.0	112
Hunterston A (i)	200	18.3	38.7	58.7	114.7	158.8
-"- B	100	n.a.	n.a.	n.a.	n.a.	$\leq$ 0.58
	plus 700 S-35	n.a.	n.a.	n.a.	n.a.	
Trawsfynydd	40 (incl. Cs-137)	31.4	16.0	19.0	17.0	20.0
	7 Cs-137		1.92	2.30	4.70	4.30
Hinkley Point A	200	147	114	125	159	138
-"- B	100	n.a.	n.a.	n.a.	n.a.	1.1
	plus 700 S-35	n.a.	n.a.	n.a.	n.a.	1.1
Dungeness A	200	29.0	22.2	69.0	79.5	46.3
Sizewell A	200	14.6	13.1	15.9	20.0	29.5
Oldbury	100	5.2	4.0	32.6	27.2	50.4
Winfrith (h)						
Wylfa	65	0.30	0.18	0.46	3.4	6.5

(a) Limits and discharges are expressed in Curie equivalent. The Curie equivalent is obtained for each radionuclide by multiplying the true curies of each by a risk coefficient defined as the ratio between the MPC_w (occupational) of 3×10^{-5} Ci/m^3 of a fictitious nuclide and the MPC_w of the nuclide in question. The discharges in real curies are :

- for Doel : 2.0 Ci in 1974, 10.25 Ci in 1975, 49.75 Ci in 1976
- for Tihange : 0.38 Ci in 1975, 0.83 Ci in 1976

(b) MZFR liquid effluent is transferred to the decontamination centre at Karlsruhe and is not separately discharged into the Rhine (see Table XIX).

(c) Values inferred from an MPCP in drinking water of 10^{-7} Ci/m^3 (any mixture of alpha, beta and/or gamma emitters excluding Ra-226 and Ra-228) and the annual flow of the receiving watercourse, except for SENA where the following discharge formula is applied with the exclusion of tritium :

$$10\,Q(\text{Sr-90}) + Q(\text{other } \beta\gamma \text{ emitters}) + 1.5\,Q(\alpha\text{-emitters}) \leq 100 \text{ Ci/year}$$

in which Q is the activity discharged in Ci/a.

(d) Phénix liquid effluent is transferred to Marcoule and is not separately discharged into the Rhône.

TABLE VII (continued 2)

(e) Liquid effluent discharge authorizations in Italy are now expressed as formulae. In all cases alpha activity is expressed in terms of the Pu-239 equivalent. For Latina the limits were 1.6×10^3 Ci/year excluding tritium, and 2.5×10^5 Ci/year of tritium prior to 19.3.1973 when the following formula was applied :

$$\frac{\text{H-3}}{10^4} + \frac{\text{P-32}}{0.5} + \frac{\text{Sr-90}}{10} + \frac{\text{Cs-134} + \text{Cs-137}}{20} + \frac{\beta\gamma}{3} + \frac{\beta}{100} + \frac{\alpha}{1} < 1 \text{ Ci/year}$$

For Garigliano prior to 1974 the limits were 5×10^3 Ci/year excluding tritium and 5×10^5 Ci/year of tritium. The current formula is :

$$\frac{\text{H-3}}{5 \times 10^3} + \frac{\beta}{1} + \frac{0.5\text{Cs-137} + \text{Cs-134} + 0.1\text{Co-58} + 0.3\text{Co-60} + 2\text{I-131}}{25} + \frac{\beta\gamma}{2} + \frac{\alpha}{1} < 1 \text{ Ci/year}$$

For Trino the limits were 21 Ci/year excluding tritium, and 5×10^3 Ci/year of tritium until 1973 when the formula was applied :

$$\frac{\text{H-3}}{10^4} + \frac{\text{I-131}}{15} + \frac{\text{Cs-137}}{15} + \frac{\text{Sr-90}}{0.1} + \frac{\gamma}{50} < 1 \text{ Ci/year}$$

For Latina "$\beta\gamma$" is expressed in terms of Mn-54 equivalent and "β" in terms of Ca-45 equivalent ; for Garigliano "$\beta\gamma$" is the Fe-59 equivalent value and "β" the Sr-90 equivalent value; for Trino "γ" is the Co-60 equivalent.

(f) Discharge limits are based on actual requirements of each station within the maximum permissible discharge as estimated by the "critical path" approach. The limit on Cs-137 at Trawsfynydd was introduced in November 1972.

(g) Calder liquid effluent is transferred to Windscale and is not separately discharged to the Irish Sea.

(h) SGHWR, Winfrith liquid effluent is mixed with other liquid effluent from the site and is not separately discharged to the English Channel.

(i) Annual alpha activity discharge is ≤ 0.13 Ci.

(j) Provisional limit.

TABLE VIII

RADIONUCLIDE COMPOSITION (%) OF LIQUID EFFLUENT (EXCLUDING TRITIUM) IN 1976 FROM NPSs (a)

Facility / Isotope	BELGIUM		GERMANY					
	Doel (b)	Tihange 1	Gund-remmingen	Lingen	Obrigheim	Würgassen	Stade	Biblis A
C-14								
P-32								
S-35								
Ca-45								
Cr-51	9.7				1.6	13.7	10.9	
Mn-54	2.1	2.3	4.4	0.1	1.2	0.9	2.5	0.9
Fe-55								
Co-57	0.2				0.0			
Co-58	71.3	43.5	4.8	0.0	6.1	7.3	9.1	8.9
Fe-59	0.9							
Co-60	7	6.0	17.1	34.6	24.6	27.5	20.2	17.4
Ni-63								
Zn-65			0.0			5.9		
Sr-89			10.6	2.5	0.1	0.5	0.0	0.1
Sr-90	0.0		18.7	0.3	0.0	0.0	0.0	0.0
Y-90								
Y-91								
Zr-95	0.2		0.1	0.2	0.0		0.0	
Nb-95	0.5	2.7	0.3	0.9	0.1	0.0	0.8	
Ru-103			0.1	0.2		0.0		
Ru-106								
Rh-106								
Ag-110m	0.0				2.3	0.1	15.4	
Sb-124	0.2		0.4		0.1	0.1	33.8	46.9
Sb-125			0.6					
Te-125m								
I-131	2.4	44	15.5	0.8		21.5	0.1	0.7
Cs-134	0.0		8.7	15.0	27.7	7.4	2.9	11.8
Cs-137	0.2	1.5	18.0	45.2	36.2	15.1	4.3	13.3
Ba-140								
La-140			0.0	0.1		0.0		
Ce-141			0.0	0.1				
Ce-144			0.7					
Pr-144								
Pm-147								
Eu-154								
Eu-155								
Alpha								

(a) 0.0 indicates a value smaller than 0.1 %.

(b) Plus 4.5 % noble gases, 0.4 % Na-24, 0.03 % Co-56, 0.02 % Nb-97, 0.1 % Tc-99m, 0.2 % Mo-99 and 0.1 % I-133.

TABLE VIII (continued 1)

Facility / Isotope	GERMANY			FRANCE				
	Biblis B	Neckar-westheim	Bruns-büttel	Chinon	Chooz	Monts d'Arrée	St-Laurent	Bugey
C-14								
P-32								
S-35				36.2			79.4	99.2
Ca-45								
Cr-51	0.5		13.8			2.4	0.1	0.1
Mn-54			8.2		32.4	0.6	0.1	0.0
Fe-55								
Co-57			0.0					
Co-58	15.1	5.0	72.2		4.5	0.5		
Fe-59								
Co-60	1.5	0.0	2.0	12.5	10.5	21.6	1.6	0.3
Ni-63								
Zn-65			2.6				0.2	0.1
Sr-89	0.0		0.1					
Sr-90				7.3	2.3	9.2	0.7	0.1
Y-90								
Y-91								
Zr-95							1.1	
Nb-95					0.4		2	0.0
Ru-103								
Ru-106								
Rh-106				6.7				
Ag-110m								0.0
Sb-124	75.2	92.6	1.1				0.7	0.0
Sb-125								
Te-125m								
I-131	6.1	2.3			5.5			
Cs-134				3.4	17.2	23.9	3.6	0.1
Cs-137	1.6	0.1		34	25	41.8	9.5	0.1
Ba-140								
La-140					1.8			
Ce-141					0.1			
Ce-144					0.3		1	
Pr-144								
Pm-147								
Eu-154								
Eu-155								
Alpha								

TABLE VIII (continued 2)

Facility / Isotope	ITALY			NETHERLANDS		UNITED-KINGDOM		
	Latina	Garigliano	Trino	Dodewaard (c)	Borssele	Chapelcross	Bradwell	Berkeley
C-14							0.0	0.0
P-32	0.6						1.3	0.4
S-35	2.2					7.2	8.5	6.3
Ca-45	9.5						0.8	0.9
Cr-51	1.3	5.3	3.7				0.3	0.5
Mn-54	0.0	1.1	18.1	+	2.3		0.2	0.0
Fe-55							2.3	0.1
Co-57								
Co-58		2.6	12.5		4.4		0.0	0.0
Fe-59	0.0	0.2	0.8	+			0.1	0.0
Co-60	0.2	26.5	36.8	+	36.0		0.5	0.0
Ni-63							0.0	0.0
Zn-65	0.1				0.1	0.1	0.3	0.0
Sr-89	1.3	2.7					0.1	0.2
Sr-90	31.4	0.3	0.0	+		13.6	11.3	1.0
Y-90							11.3	1.0
Y-91	0.2						0.1	0.1
Zr-95	0.4		0.7		1.1		0.1	0.0
Nb-95							0.3	0.2
Ru-103								
Ru-106	1.1						0.6	0.3
Rh-106							0.6	0.3
Ag-110m	0.1	0.3	1.3				0.0	0.0
Sb-124	0.7		3.7		2.8		0.1	0.1
Sb-125	1.3						0.3	0.1
Te-125m							0.1	0.0
I-131	0.0	5.3	0.2		0.3			
Cs-134	8.2	10.6	8.5	+	14.5	9.2	11.3	21.1
Cs-137	37.4	29.2	13.7	+	32.7	66.3	45.6	66.7
Ba-140	0.1	15.9						
La-140								
Ce-141					0.4			
Ce-144	3.7				5.4	3.2	1.0	0.2
Pr-144							1.0	0.2
Pm-147							1.7	0.3
Eu-154							0.1	0.0
Eu-155							0.0	0.0
Alpha	0.0					0.3	0.0	0.0

(c) "+" indicates that the nuclide has been identified as being present. The contributions of individual nuclides are not quantified but Sr-90 is stated to be present only in trace quantities.

TABLE VIII (continued 3)

Facility / Isotope	UNITED KINGDOM						
	Hunterston A (d)	Trawsfynydd	Hinkley Point A	Dungeness	Sizewell	Oldbury (e)	Wylfa (e)
C-14		0.0	0.0	0.0	0.0	0.2	0.1
P-32		0.2	0.2	0.3	0.3	0.1	1.7
S-35	1.6	16.1	2.3	17.7	18.8	16.8	12.4
Ca-45		0.0	0.5	0.7	1.0	1.3	1.0
Cr-51		0.0	0.9	0.4	0.5	0.8	1.5
Mn-54		0.0	0.0	0.0	0.0	0.0	0.4
Fe-55		0.8	0.1	0.9	0.2	1.2	15.8
Co-57							
Co-58		0.0	0.0	0.0	0.0	0.0	0.0
Fe-59		0.0	0.0	0.0	0.0	0.0	0.1
Co-60	-	0.1	0.0	0.1	0.0	0.2	1.3
Ni-63		0.0	0.0	0.0	0.0	0.1	0.1
Zn-65		0.0	0.0	0.0	0.0	0.1	0.1
Sr-89		0.0	5.2	1.0	0.4	0.8	0.1
Sr-90	9.9	6.9	22.5	6.6	7.0	15.2	3.4
Y-90		6.9	22.5	6.6	7.0	15.2	3.4
Y-91		0.0	0.6	0.1	0.1	0.2	0.3
Zr-95		0.2	0.1	0.0	0.0	0.1	0.1
Nb-95		0.4	0.4	0.0	0.0	0.3	0.1
Ru-103							
Ru-106	-	3.7	1.6	0.1	0.3	0.3	0.4
Rh-106		3.7	1.6	0.1	0.3	0.3	0.4
Ag-110m		0.0	0.0	0.0	0.0	0.0	0.1
Sb-124		0.2	0.0	0.7	0.3	0.1	0.0
Sb-125		25.5	3.0	0.4	0.3	0.6	0.1
Te-125m		6.2	0.7	0.1	0.1	0.1	0.0
I-131							
Cs-134	20.6	3.8	6.6	10.9	8.5	8.3	8.0
Cs-137	62.9	15.4	27.6	53.0	54.6	36.5	47.6
Ba-140							
La-140							
Ce-141							
Ce-144	-	3.0	0.8	0.1	0.1	0.3	0.2
Pr-144		3.0	0.8	0.1	0.1	0.3	0.2
Pm-147		3.7	1.8	0.1	0.1	0.5	0.9
Eu-154		0.2	0.0	0.0	0.0	0.0	0.1
Eu-155		0.0	0.0	0.0	0.0	0.0	0.0
Alpha			0.2	0.0	0.0	0.1	0.1

(d) nuclides marked "-" are stated to contribute altogether not more than 5 % of the total activity.

(e) Values based on discharges summed over three calendar quarters for Oldbury and one calendar quarter for Wylfa.

TABLE IX

ANNUAL TRITIUM DISCHARGE IN LIQUID EFFLUENT FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1972	1973	1974	1975	1976
BELGIUM						
Doel	3 600	n.a.	n.a.	-	369	280
Tihange 1	4 000	n.a.	n.a.	n.a.	60.2	162.3
GERMANY						
MZFR (a)				370	880	880
Gundremmingen	438 (b)	90.2	142.2	213.4	127	50
Lingen	(c)	24.0	14.6	9.0	16.5	15
Obrigheim	(c)	319.8	273.1	161.0	168	126
Würgassen	300	4.6	6.3	3.1	3.9	29
Stade	1 300	101.4	115.4	31.4	106	43
Biblis A	1 600	n.a.	n.a.	8.3	110	319
B		n.a.	n.a.	n.a.	n.a.	22
Neckarwestheim	500	n.a.	n.a.	n.a.	n.a.	5
Brunsbüttel	1 000	n.a.	n.a.	n.a.	n.a.	0.3
FRANCE						
Chinon						106
Chooz		1 762	1 850	3 300	2 490	1 929
Monts d'Arrée	150 000 (d)	5	41.7	116	13.8	27
St-Laurent-des-Eaux						509
Bugey				824	243	195
Phénix (f)		n.a.	n.a.			
ITALY						
Latina	(e)	16.9	33	6.6	403	5
Garigliano	(e)	3.0	5	3	5	18
Trino	(e)	1 078	442	1 018	1 202	743
NETHERLANDS						
Dodewaard		2.5		9.2	17	23
Borssele	(c)	n.a.		171.2	56	41

TABLE IX (continued)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1972	1973	1974	1975	1976
UNITED KINGDOM						
Calder (g)						
Chapelcross	150	9.3	11.7	1.2	7.1	8.8
Bradwell	1 500	251	198	117	88	309
Berkeley	1 500	44.2	200	56.7	70.7	30.5
Hunterston A	1 200	37.5	86.7	67.0	54.9	66.3
-"- B	40 000	n.a.	n.a.	n.a.	n.a.	44.3
Trawsfynydd	2 000	46.0	116	60	89	16
Hinkley Point A	2 000	38.6	30.0	39	53	23.7
-"- B	18 000	n.a.	n.a.	n.a.	n.a.	2.5
Dungeness A	2 000	28.9	30.5	20.0	24.5	34.2
Sizewell A	3 000	53.2	208	253	49	62
Oldbury	2 000	15.0	13.6	37.4	14.1	19.4
Winfrith (h)						
Wylfa	4 000	82.7	275	134	129	198

(a) MZFR liquid effluent is discharged to Karlsruhe decontamination centre. Separate values for 1972 and 1973 are not available. See Table XX for site discharges.

(b) Based on a daily discharge limit of 1.2 Ci.

(c) No annual limit is applied per se, only a concentration limit on cooling water discharges.

(d) Inferred from an MPCP of 3×10^{-3} Ci/m^3 and from the annual flow of the watercourse.

(e) See foot-note (e) to Table VII.

(f) See foot-note (d) to Table VII.

(g) Calder liquid effluent is transferred to Winscale and is not separately discharged to the Irish Sea.

(h) SGHWR, Winfrith liquid effluent is mixed with other liquid effluent from the site and is not separately discharged to the English Channel.

TABLE X

MEAN INCREASES IN SPECIFIC ACTIVITY OF RECEIVING WATERCOURSES, 1976
(OTHER THAN ESTUARINE AND MARINE SITES)
ARISING FROM NPS DISCHARGES

Facility	Watercourse	Mean Annual Flowrate (a) (m^3/sec)	Activity without H-3 Increase in specific activity (Ci/m^3)	Tritium alone Increase in specific activity (Ci/m^3)
BELGIUM				
Tihange 1	Meuse	77	3.4×10^{-10}	6.7×10^{-8}
GERMANY				
Gundremmingen	Danube	116	3.2×10^{-10}	1.4×10^{-8}
Lingen	Ems	36.7	2.2×10^{-10}	1.3×10^{-8}
Obrigheim	Neckar	124	2.5×10^{-10}	3.2×10^{-8}
Würgassen	Weser	138	2.6×10^{-10}	6.7×10^{-9}
Stade	Elbe	700 (b)	1.5×10^{-11}	1.9×10^{-9}
Biblis A + B	Rhine	1 380	1.2×10^{-11}	7.8×10^{-9}
Brunsbüttel	Elbe	87.3	8.1×10^{-10}	1.1×10^{-10}
FRANCE				
Chinon	Loire	447	4.0×10^{-11}	7.5×10^{-9}
Chooz	Meuse	73	1.1×10^{-9}	8.4×10^{-7}
Monts d'Arrée	Ellez	0.7	1.2×10^{-9}	1.2×10^{-6}
St-Laurent-des-Eaux	Loire	332	2.8×10^{-10}	4.9×10^{-8}
Bugey	Rhône	275	4.1×10^{-10}	2.2×10^{-8}
ITALY				
Garigliano	Garigliano	138	8.7×10^{-10}	2.6×10^{-9}
Trino	Po	223	3.9×10^{-10}	1.1×10^{-7}
NETHERLANDS				
Dodewaard	Waal	1 300	8.3×10^{-12}	5.6×10^{-10}

(a) Values quoted for Belgium, France and Italy are for 1976 specifically; the other values are long term averages.

(b) The value quoted represents the net average downstream water movement and does not take account of the effects of tidal flow which provides additional dilution.

TABLE XI

MAXIMUM HYPOTHETICAL EXPOSURE IN 1976 FROM GASEOUS EFFLUENTS (NOBLE GASES AND IODINE-131) AT 0.5 KM AND 5 KM FROM NPSs (a)

Facility	Height (b) of release (m)	Dose (mrem) at 0.5 km			at 5 km		
		Whole body (gamma)	Skin (beta only)	Thyroid (c)	Whole body (gamma)	Skin (beta only)	Thyroid (c)
BELGIUM							
Doel 1 + 2	48	0.04	0.04	1.3	0.002	0.003	0.1
Tihange 1	160	0.1	0.06	1	0.02	0.02	0.5
GERMANY							
MZFR	100	0.03	0.01		0.002	0.002	
Gundremmingen	109	0.4	0.2	22	0.03	0.03	3
Lingen	150	0.2	0.04	1	0.02	0.01	0.4
Obrigheim	60	0.01	0.01	0.4	< 0.001	0.001	0.04
Würgassen	67	0.06	0.1	7	0.003	0.01	1
Stade	80	0.3	0.3	3	0.02	0.03	0.3
Biblis A + B	100	0.03	0.002	2	0.002	< 0.001	0.2
Neckarwestheim	150	0.02	0.008	0.1	0.001	< 0.001	0.02
Brunsbüttel	100	0.03	0.01	0.001	0.002	0.002	< 0.001
FRANCE							
Chinon	50	1	0.8	0.6	0.07	0.06	0.04
Chooz	18	0.4	1	5	0.02	0.03	1
Monts d'Arrée	70	57	24		3	0.2	
St-Laurent-des-Eaux	78	0.6	0.2	1	0.03	0.03	0.2
Bugey	85	0.6	0.2	0.2	0.03	0.03	0.03
Phenix	70	0.01	0.01	0.04	< 0.001	0.001	0.004
ITALY							
Latina	52	0.7	0.4	0.006	0.04	0.03	< 0.001
Garigliano	92	20	13	3	1	2	0.4
Trino	100	0.005	0.003	< 0.001	< 0.001	< 0.001	< 0.001
NETHERLANDS							
Dodewaard	100	0.6	0.4	0.3	0.04	0.05	0.04
Borssele	57	0.1	0.1	2	0.006	0.01	0.1

TABLE XI (continued)

Facility	Height (b) of release (m)	Dose (mrem) at 0.5 km			at 5 km		
		Whole body (gamma)	Skin (beta only)	Thyroid (c)	Whole body (gamma)	Skin (beta only)	Thyroid (c)
UNITED KINGDOM							
Calder		12	12		0.6	0.5	
Chapelcross		13	13		0.6	0.5	
Bradwell		6	6		0.3	0.2	
Berkeley		7	6		0.3	0.3	
Hunterston B		0.8	0.8	< 10	0.04	0.03	
Trawsfynydd		62	60		3	2	
Hinkley Point A		33	32		1	1	
Dungeness A		12	12		0.5	0.5	
Sizewell A		25	24		1	1	

(a) Calculations based on pessimistic assumptions as indicated in Section 2.

(b) The effective height of release is taken as the height of the discharge point except for :

- Tihange and Neckarwestheim where the latter height was modified to take account of local topography;
- U.K. stations for which the effective height was reduced to 30 m to take into account building entrainment (37).

For sites with two or more stations a single discharge point is assumed, the lowest height being taken as applying to the site.

(c) Dose to the thyroid of an infant drinking only milk from cattle grazing at this distance.

TABLE XII

RADIOACTIVE WASTE DISCHARGE FROM NPSs PER UNIT NET ELECTRICAL ENERGY PRODUCED

Facility	Net electricity production		Activity released per GWh		
			Gaseous effluent	Liquid effluent	
	Year	(GWh)	(noble gases) (Ci/GWh)	Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
BELGIUM					
Doel 1 + 2	1974	114	-	17.54	-
	1975	3 269	0.06	3.13	112.88
	1976	5 068	0.16	9.82	55.25
Tihange 1	1975	3 091	0.15	0.12	19.48
	1976	4 405	1.05	0.19	36.84
GERMANY					
MZFR	1972	387	2.47		
	1973	87	2.62		
	1974	324	2.94		
	1975	328	3.40		
	1976	394	2.50		
Gundremmingen	1972	1 724	6.44	0.90	52.32
	1973	1 634	26.13	0.95	87.03
	1974	1 819	2.28	0.51	117.32
	1975	1 796	4.14	0.70	70.71
	1976	1 207	4.37	0.96	41.43
Lingen	1972	502	11.55	0.22	47.81
	1973	880	3.86	0.04	16.59
	1974	321	32.71	0.08	28.04
	1975	1 139	30.73	0.04	14.49
	1976	1 196	5.35	0.22	12.54
Obrigheim	1972	2 287	1.40	1.46	139.83
	1973	2 500	1.17	0.92	109.24
	1974	2 436	5.52	1.25	66.09
	1975	2 588	3.10	0.66	64.91
	1976	2 210	0.15	0.44	57.01
Würgassen	1972	538	1.10	3.36	8.55
	1973	1 967	0.28	0.81	3.20
	1974	466	0.11	3.11	6.65
	1975	1 748	0.07	1.06	2.23
	1976	3 679	0.13	0.30	7.88
Stade	1972	3 106	0.79	0.20	32.65
	1973	3 917	0.67	0.30	29.46
	1974	5 065	0.18	0.08	6.20
	1975	4 534	0.28	0.06	23.38
	1976	5 187	2.02	0.06	8.29
Biblis A + B	1974	769	0.08	0.78	10.79
	1975	7 917	0.21	0.09	13.89
	1976	5 722	0.26	0.09	59.59
Neckarwestheim	1976	1 958	0.32	0.12	2.55
Brunsbüttel	1976	1 032	0.94	2.16	0.29

TABLE XII (continued 1)

Facility	Net electricity production		Activity released per GWh		
			Gaseous effluent (noble gases)	Liquid effluent	
	Year	(GWh)	(Ci/GWh)	Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
FRANCE					
Chinon	1972	4 001	2.88	0.75	
	1973	2 554	1.10	1.28	
	1974	1 475	1.41	0.27	
	1975	3 570	1.69	0.18	
	1976	2 452	2.01	0.23	43.23
Chooz	1972	2 032	15.42	6.10	867.13
	1973	2 028	9.82	4.03	912.23
	1974	1 470	0.99	5.88	2 244.90
	1975	2 016	1.34	4.27	1 235.12
	1976	1 362	3.63	1.88	1 416.30
Monts d'Arrée	1972	476	303.47	0.46	10.50
	1973	427	304.57	0.09	97.66
	1974	551	299.02	0.09	210.91
	1975	505	388.12	0.10	27.33
	1976	518	469.07	0.06	52.12
St-Laurent-des-Eaux	1972	5 547	0.70	1.69	
	1973	5 951	0.83	1.22	
	1974	5 965	0.73	0.71	
	1975	6 751	0.52	0.70	
	1976	5 771	0.50	0.51	88.20
Bugey	1972	1 079	0.78	0.04	
	1973	2 468	1.25	0.65	
	1974	3 007	1.49	20.03	274.03
	1975	2 768	1.91	4.99	87.79
	1976	3 405	0.90	1.05	57.27
Phenix	1975	1 298	0.13		
	1976	948	0.25		
ITALY					
Latina	1972	1 147	3.14	14.39	14.73
	1973	651	3.15	16.13	50.69
	1974	954	2.15	6.39	6.92
	1975	943	2.75	6.59	427.36
	1976	947	2.62	5.46	5.28
Garigliano	1972	399	726.82	36.09	7.52
	1973	969	392.16	3.82	5.16
	1974	715	349.65	5.87	4.20
	1975	464	492.55	6.75	10.78
	1976	1 145	209.16	3.29	15.72
Trino	1972	1 898	0.54	3.16	567.97
	1973	1 354	4.51	4.73	326.44
	1974	1 559	4.49	2.12	652.98
	1975	2 207	0.21	0.66	544.63
	1976	1 512	0.12	1.79	491.40

TABLE XII (continued 2)

Facility	Net electricity production		Activity released per GWh		
			Gaseous effluent	Liquid effluent	
	Year	(GWh)	(noble gases) (Ci/GWh)	Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
NETHERLANDS					
Dodewaard	1972	307	27.63	6.61	8.14
	1973	353	18.99	4.42	
	1974	268	15.52	8.06	34.33
	1975	389	5.42	3.21	43.70
	1976	407	15.31	0.84	56.51
Borssele	1973	665	0.46	0.24	
	1974	2 824	2.06	0.18	60.62
	1975	2 768	0.94	0.58	20.23
	1976	3 274	1.19	0.26	12.52
UNITED KINGDOM (a)					
Chapelcross	1972	1 573		6.04	5.91
	1973	1 567		5.49	7.47
	1974	1 561		0.77	0.77
	1975	1 503	21.3	11.5	4.72
	1976	1 527	21	21.2	5.76
Bradwell	1972	1 811		65.71	138.60
	1973	1 653		32.37	119.78
	1974	1 723		52.23	67.90
	1975	1 749		65.75	50.31
	1976	1 736	8.7	37.67	178.0
Berkeley	1972	1 954		11.92	22.62
	1973	2 094		9.89	95.51
	1974	1 968		11.74	28.81
	1975	1 974		27.36	35.82
	1976	1 979	8.1	56.59	15.41
Hunterston A	1972	(b) 1 979		9.25	18.95
	1973	1 938		19.97	44.74
	974	2 128		27.58	31.48
	1975	2 223		51.60	24.70
	1976	2 214		71.73	29.95
Hunterston B	1976	1 342	1.49	0.43	33.01
Trawsfynydd	1972	2 371		13.24	19.40
	1973	1 704		9.39	68.08
	1974	3 168		6.00	18.94
	1975	3 080		5.52	28.90
	1976	3 024	49.6	6.61	5.29
Hinkley Point A	1972	2 975		49.41	12.97
	1973	2 315		49.24	12.96
	1974	3 044		41.06	12.81
	1975	2 991		53.16	17.72
	1976	3 199	25	43.14	7.41
Hinkley Point B	1976	5		220 (c)	500 (c)

TABLE XII (continued 3)

Facility	Net electricity production		Activity released per GWh		
			Gaseous effluent (noble gases)	Liquid effluent	
	Year	(GWh)	(Ci/GWh)	Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
Dungeness A	1972	3 230		8.98	8.95
	1973	3 211		6.91	9.50
	1974	3 384		20.39	5.91
	1975	3 297		24.11	7.43
	1976	2 732	11	16.95	12.52
Sizewell A	1972	2 708		5.39	19.65
	1973	2 903		4.51	71.65
	1974	3 116		5.10	81.19
	1975	3 424		5.84	14.31
	1976	3 403	176	8.67	18.22
Oldbury	1972	2 650		1.96	5.66
	1973	2 525		1.58	5.39
	1974	2 710		12.03	13.80
	1975	2 873		9.47	4.91
	1976	3 017		16.71	6.43
Wylfa	1972	2 305		0.13	35.88
	1973	2 233		0.08	123.15
	1974	4 364		0.11	30.71
	1975	1 562		2.18	82.59
	1976	4 818		1.35	41.10

(a) Electricity production figures quoted for 1972 are based on the financial year fig.; from 1973 onwards figures refer to the calendar year except for Chapelcross and Hunterston.

(b) Figure obtained in multiplying gross value by 0.863, value derived from 1973 onwards figures quoted in Ref. 1.

(c) Hinkley Point B operated only for a few days in 1976; therefore, the normalized releases cannot be considered as representative.

TABLE XIII

GENERAL CHARACTERISTICS OF NUCLEAR FUEL REPROCESSING PLANTS (NFRPs)

Facility/Location	Types of fuel reprocessed	Nominal annual capacity (t)	First "Hot Run"	Water body receiving liquid effluents
BELGIUM				
Eurochemic (Mol) Antwerp Province	1 LWR 2 GCR 3 MTR	60 (a)	1966 (b)	Mol-Neet (c) (and thence to the Scheldt)
GERMANY				
WAK (Karlsruhe) Baden-Wurtemberg	1 LWR 2 HWR	40	1971	Rhine (c)
FRANCE				
La Hague Manche	1 GCR 2 LWR 3 FBR	900 } 400 } (d) 4 }	1966 1976	English Channel
Marcoule Gard	GCR		1958	Rhône (c)
ITALY				
Eurex (Saluggia) Vercelli	MTR	(e)	1970 (b)	Dora Baltea (tributary of the Po)
UNITED KINGDOM				
Dounreay Caithness	1 MTR 2 FBR	0.3 3	1958 1958	Atlantic Ocean (c)
Windscale Cumbria	GCR	2 000	1952 (f)	Irish Sea

(a) Based on a capacity of 0.3 t per day and 200 days of operation per year. In practice the total throughput since commissioning amounts to some 200 t of fuel of less than 5 % enrichment and some 1.5 t of high enrichment fuel. In 1972-74 reprocessed fuel was largely from LWRs.

(b) No reprocessing since 1974.

(c) The liquid effluent from this installation is treated and discharged with that from other installations which may contribute significantly to the discharges recorded in the tables which follow : thus the "Eurochemic" liquid effluent quoted is that from CEN/SCK site at Mol, that for WAK is from the Karlsruhe Nuclear Research Centre as a whole and that for Dounreay and Marcoule includes the effluent from all installations on their respective sites.

(d) The capacity for LWR will rise to 800 t per year by 1983-84 and reprocessing of GCR fuel will be progressively transferred to Marcoule. A residual capacity for GCR fuel, 150 t per year, will be retained this fuel being used to dilute FBR fuel to be processed.

(e) The plant has a stated capacity of 6 MTR elements per day; in practice a total of 110 kg of highly enriched uranium has been recovered to date from in excess of 500 elements in total.

(f) Present plant started operation in 1964 (i.e. using the Purex process).

TABLE XIV

ANNUAL DISCHARGE OF KRYPTON-85 FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic	6.3×10^6 (a)	2.0×10^5	2.2×10^5	1.0×10^5	-	-
WAK	3.5×10^5 (b,c)	6.8×10^4	2.5×10^4	$< 8.5 \times 10^2$	4.3×10^4	8.6×10^4
La Hague		2.4×10^5	2.3×10^5	7.2×10^5	6.6×10^5	3.5×10^5
Marcoule		4.7×10^4	1.3×10^5	1.1×10^5	1.0×10^5	9.2×10^4
Eurex	4.5×10^4	-	4.7×10^3	4.3×10^3	-	-
Dounreay	(d)					
Windscale	(d)	1.2×10^6	8×10^5	8×10^5	1.2×10^6	1.2×10^6

(a) The annual limit quoted is derived from a maximum authorized discharge rate of 0.2 Ci/sec.

(b) All limits are reviewed annually as part of Karlsruhe site effluent coordination plan.

(c) 2.5×10^5 Ci in 1974 and 1975.

(d) Authorizations for British NFRPs place no limits on the quantities but require that the best practicable means be used to minimize the amount of radioactive material discharges.

TABLE XV

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (ALPHA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year) 1972	1973	1974	1975	1976
Eurochemic	1.25 (a)	$< 1.2\times10^{-2}$		$< 5\times10^{-4}$	$< 3\times10^{-4}$	$< 5\times10^{-5}$
WAK	1×10^{-2} (b)	3.8×10^{-3}	2.1×10^{-3}	1.5×10^{-4}	3.0×10^{-3}	3.1×10^{-3}
La Hague		3.8×10^{-5}	5.2×10^{-6}	6.8×10^{-6}	1.6×10^{-8}	2×10^{-8}
Marcoule		1.7×10^{-5}	3×10^{-5}	3.8×10^{-5}	2.2×10^{-5}	1.8×10^{-5}
Eurex	1×10^{-2}	5.7×10^{-5}	-	-		
Dounreay	(c)		5.5×10^{-3}	1.2×10^{-2}	1.4×10^{-2}	2.1×10^{-2}
Windscale	(c)	0.13	0.18	0.18	7.6×10^{-2}	5.2×10^{-2}

(a) The annual limit quoted is derived from a maximum authorised discharge rate of 4×10^{-8} Ci/sec for Pu-239.

(b) See footnote (b) to Table XIV.

(c) See footnote (c) to Table XIV.

TABLE XVI

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (BETA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic	220 (a)	< 0.12		< 8.7×10^{-3}	< 2.4×10^{-3}	< 1.2×10^{-4}
WAK	20 (b)	0.13	0.31	1.4×10^{-2}	0.17	0.14
La Hague		1.3×10^{-2}	0.11	1.3×10^{-2}	1.4×10^{-2}	8.9×10^{-3}
Marcoule		2.4×10^{-4}	3.7×10^{-4}	5.9×10^{-4}	3.4×10^{-2}	3.6×10^{-2}
Eurex	0.2	4.1×10^{-5}	-	-		
Dounreay (d)	(c)			< 6.2	< 4.0	< 5.8
Windscale	(c)	3.1	19	2.8	1.9	3.4

(a) The annual limit quoted is derived from a maximum authorized discharge rate of 7×10^{-6} Ci/sec for "non-volatile fission products". The same value is separately quoted for Sr-90; that for Sr-89 is two orders of magnitude greater and that for I-131 a factor of 17 down.

(b) See foot-note (b) to Table XIV.

(c) See foot-note (c) to Table XIV.

(d) Results correspond to total gamma measurements.

TABLE XVII

ANNUAL DISCHARGE OF TRITIUM TO ATMOSPHERE FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic	(4.4×10^6)(a)	7.1×10^2	1.9×10^3	1.6×10^3	-	-
WAK (b)				$\leq$ 30	68	102
La Hague		82	71	190	88	49
Marcoule		36	6.6	340	120	120
Eurex (c)						
Dounreay	(d)					
Windscale (e)	(d)	1.2×10^4	8×10^3	8×10^3	1.2×10^4	1.2×10^4

(a) The annual limit quoted is based on a maximum continuous discharge rate of 0.4 Ci/sec for tritiated water, as derived in Ref. (56). The discharges quoted correspond, however, to total tritium.

(b) Calculated results based on later experimental work.

(c) No limit has been fixed and no measurements carried out.

(d) See footnote (c) to Table XIV.

(e) The values quoted "are inferred by comparison with krypton-85".

TABLE XVIII

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (ALPHA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic (f)	0.9(a)		0.10	0.18	0.29	0.43
WAK (f)		1.3×10^{-3}	2×10^{-4}	- (b)	- (b)	- (b)
La Hague		3.1	3.6	27	13.3	9.9
Marcoule (f)		0.2	0.2	0.4	0.5	0.3
Eurex	10 (c)	-	-	-		
Dounreay (f)	240 (d)	35	19	12	23	11
Windscale	6 000 (e)	3 860	4 896	4 572	2 309	1 614

(a) The annual authorized discharge limit for the Mol site is expressed by the following formula :

$$300\ (\text{Ra-226}) + 5\ (\text{alpha}) + 30\ (\text{Sr-90}) + 3\ (\text{I-131}) + 10^{-3}\ (\text{H-3}) + (\text{beta}) \leq 4\ 500\ \text{mCi}$$

where "(X)" means "multiplied by the number of mCi of nuclide X discharged." Thus, if it is assumed that each form of activity is alone present a hypothetical maximum individual value for each form can be derived. The alpha "limit" quoted above necessarily excludes Ra-226, as do the discharges shown.

(b) Gross alpha-activity was below the detection limit; nuclide specific measurement gave the following discharge results for Pu-238 and Pu-239 (33, 34, 35)

Pu-238 : 1.4×10^{-4} Ci in 1974, 1×10^{-4} Ci in 1975, 5×10^{-4} Ci in 1976
Pu-239 : 2.9×10^{-4} Ci in 1974, 2×10^{-4} Ci in 1975, 4×10^{-4} Ci in 1976.

(c) In 1972-74 the annual authorized discharge limit has been expressed by the following discharge formula :

$$\frac{\text{H-3}}{10^3} + \text{I-131} + \frac{\text{Sr-90}}{10} + (\text{Cs-134} + \text{Cs-137}) + \frac{\beta\gamma}{10^2} + \frac{\alpha}{10} \leq 1\ \text{Ci/a}$$

This limit only applied to the reprocessing period; subsequently during the decontamination of the plant it was reduced to 10 % or less of its initial value.

(d) The stated limit is derived from that in the liquid effluent authorization which requires that, "In any period of three consecutive calendar months the discharge of alpha activity shall not exceed ... 60 curies".

(e) The limit applies to any period of twelve consecutive calendar months. An additional limitation is that the discharge shall not exceed 2 000 Ci in any period of three consecutive calendar months.

(f) See footnote (c) to Table XIII.

TABLE XIX

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (BETA - EXCLUDING TRITIUM) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic (g)	4.5(a)		15.6	12.9	13.2	10.4
WAK (g)		0.17	0.17	0.24	0.09	0.04
La Hague		11 600	13 700	25 300	31 900	19 300
Marcoule (g)		331	577	575	1 126	624
Eurex (b)	1 (c)	0.09	0.58	0.21	0.01	0.02
Dounreay (g)	24 000(d,e)	18 000	17 000	5 440	5 520	1 370
Windscale	300 000(e,f)	140 000	127 000	207 000	245 000	183 000

(a) See foot-note (a) to Table XVIII.

(b) Discharge of Cs-134, Cs-137 and other beta-gamma emitters.

(c) Discharge limit for Cs-134 + Cs-137; see foot-note (c) to Table XVIII.

(d) This is a derived maximum limit based on the requirement given in the liquid effluent authorization that the total discharge of alpha and beta activity shall not exceed 6 000 Ci in any period of three consecutive calendar months. The limit on alpha activity alone is 60 Ci in the same three months period; see Table XVIII, foot-note (d).

(e) The limit does not specifically exclude tritium but in practice the method of measurement, approved by the competent authorities, for beta activity does not detect tritium. Hence tritium is not considered as contributing to the authorized discharge of beta-activity and indeed was not intended to be so considered.

(f) The annual limit quoted is derived from the authorized limit of 75 000 Ci in any period of three consecutive months.

(g) See footnote (c) to Table XIII.

TABLE XX

ANNUAL DISCHARGE OF TRITIUM IN LIQUID EFFLUENT FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic (f)	4 500 (a)		7 560	2 510	523	555
WAK (f)		2 230	1 580	770(b)	2 800(b)	4 100(b)
La Hague						
Marcoule (f)						
Eurex	1 000 (c)	-	-	-	-	-
Dounreay (d) (f)	(e)	< 600	< 900	< 600	< 600	< 104
Windscale	(e)	33 569	20 123	32 396	37 952	32 460

(a) See foot-note (a) to Table XVIII.

(b) Estimated WAK contributions (33, 34, 35) : 1974 - $3x10^2$ Ci; 1975 - $1.5x10^3$ Ci; 1976 - $3.1x10^3$ Ci.

(c) See foot-note (c) to Table XVIII.

(d) The limit of detection up until the end of 1975 corresponded to discharges totalling 600 Ci/year, but was reduced in 1976.

(e) No specific tritium limit is cited in the authorization; see foot-note (e) to Table XIX.

(f) See footnote (c) to Table XIII.

TABLE XXI

ANNUAL DISCHARGE OF STRONTIUM-90 IN LIQUID EFFLUENT FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released (Ci/year)				
		1972	1973	1974	1975	1976
Eurochemic (f)	0.15(a)		0.19	0.47	0.19	0.30
WAK (b) (f)				1.1×10^{-2}	2.4×10^{-2}	8.7×10^{-3}
La Hague (b)		868	1 020	2 820	2 030	1 080
Marcoule (f)		8.3	14.2	21.4	24.9	11
Eurex	10 (c)	2×10^{-3}	1.5×10^{-2}	3×10^{-3}	1.5×10^{-2} (e)	1.8×10^{-2} (e)
Dounreay (f)	240 (d)	566	1 810	1 170	541	183
Windscale	30 000 (d)	15 200	7 440	10 600	12 600	10 300

(a) See foot-note (a) to Table XVIII.

(b) Sr-89 + Sr-90 discharges.

(c) See foot-note (c) to Table XVIII.

(d) The annual limit quoted is derived from the authorized limit for any period of three consecutive calendar months.

(e) Possibly from plant decontamination (57).

(f) See footnote (c) to Table XIII.

TABLE XXII

ANNUAL DISCHARGE OF RUTHENIUM-106 IN LIQUID EFFLUENT FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity released Ci/year				
		1972	1973	1974	1975	1976
Eurochemic	(a)					
WAK (b) (f)				1.0×10^{-2}	2.1×10^{-3}	-
La Hague		7 570	7 100	14 500	22 400	15 000
Marcoule (f)		243	455	435	879	541
Eurex						
Dounreay (f)	(a)	604	567	155	146	36
Windscale	60 000 (c)	30 500	37 800	29 200	20 600	20 700

(a) There is no discharge limit specific to Ru-106.

(b) Ru-106 + Rh-106 discharges.

(c) This is a derived maximum limit based on the requirement given in the liquid effluent authorization that :

"... If a is the sum total of curies of ruthenium 106 in all the waste discharged in any one period of three consecutive calendar months, b the sum total of curies of cerium 144 in all that waste and c the sum total of curies of all beta-emitters, taken together, in all that waste, then

$$\frac{a}{15\,000} + \frac{b}{90\,000} + \frac{c}{300\,000}$$ shall not exceed 1".

(f) See footnote (c) to Table XIII.

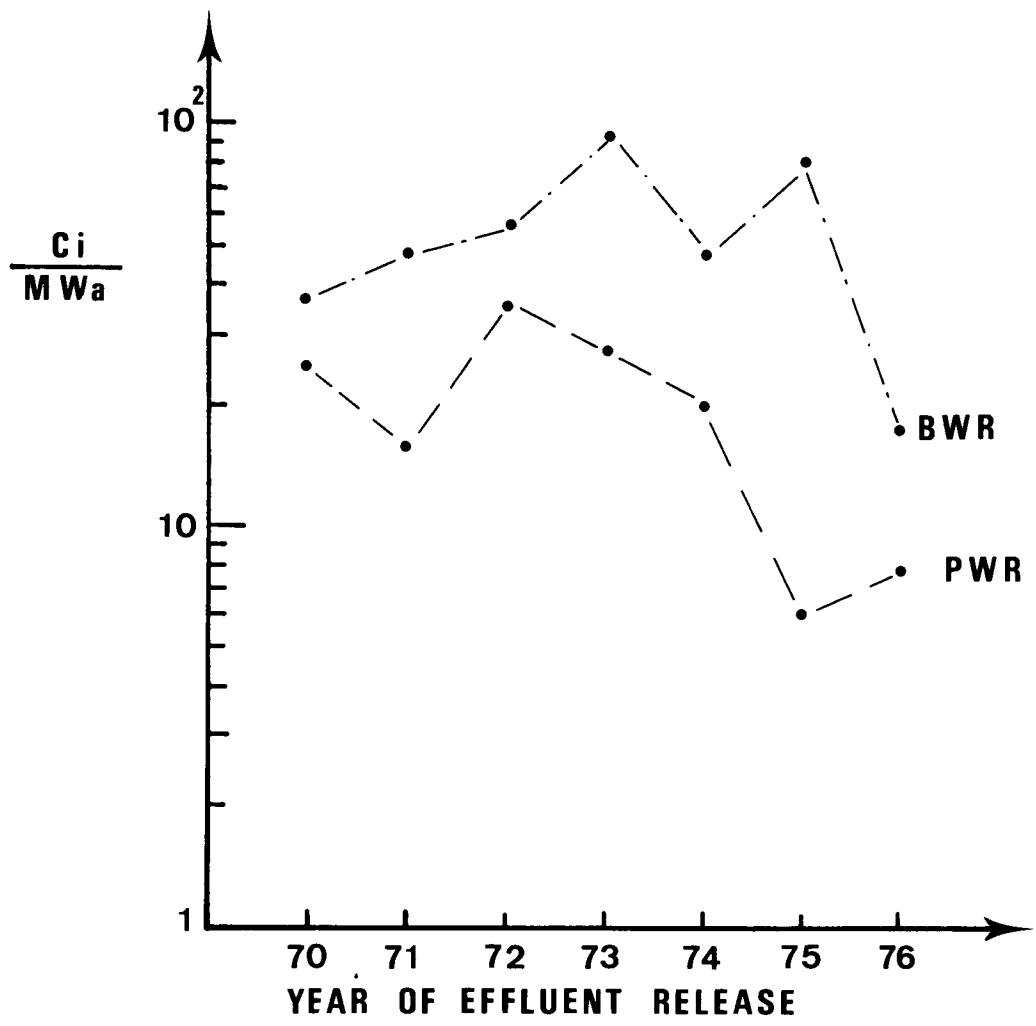

FIG. 1 — Normalized annual discharges (Ci/MWa) of noble gases from E.C. PWRs and BWRs

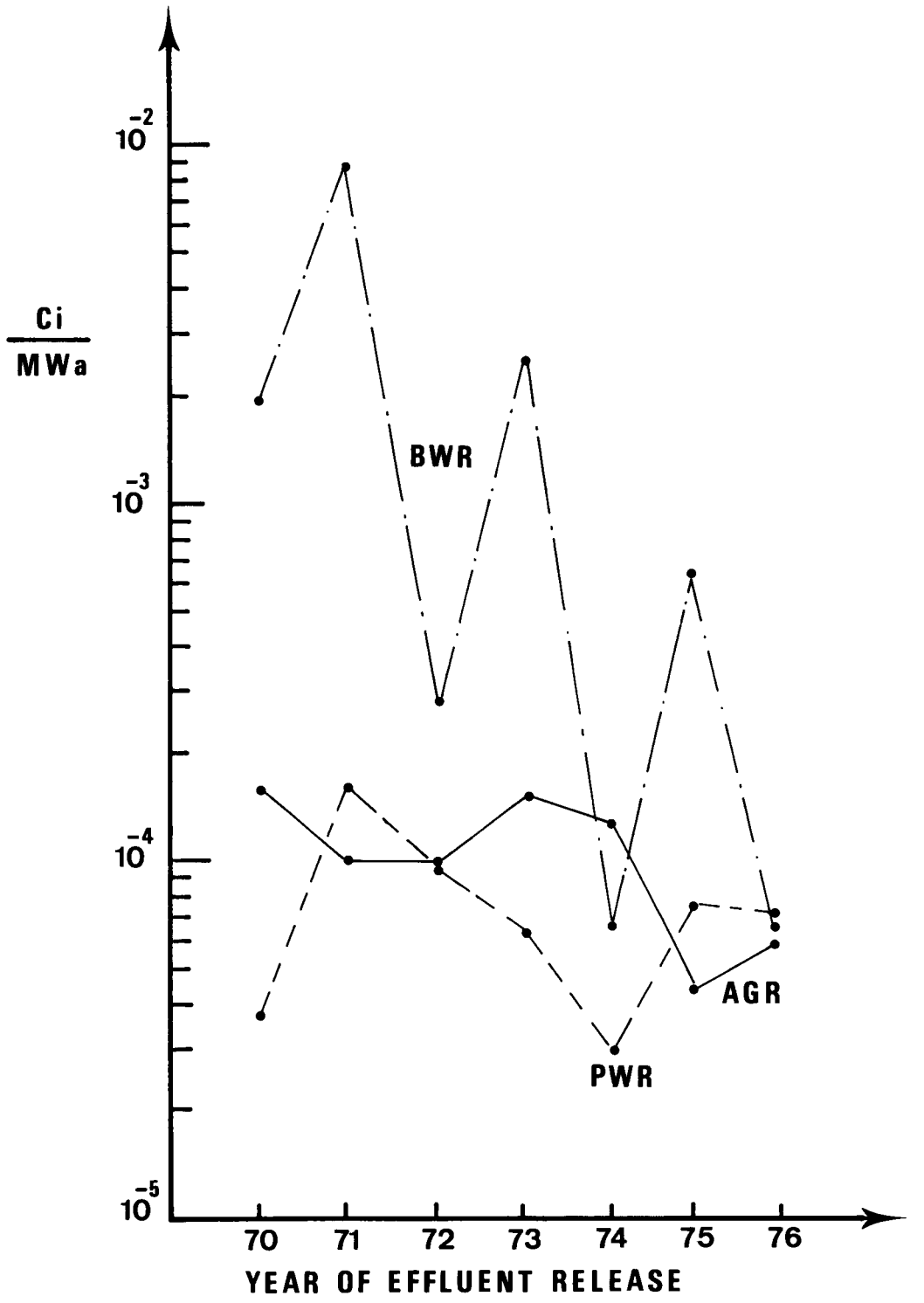

FIG. 2 — Normalized annual discharges (Ci/MWa) of radioactive aerosols (beta) from E.C. PWRs, BWRs and GCRs

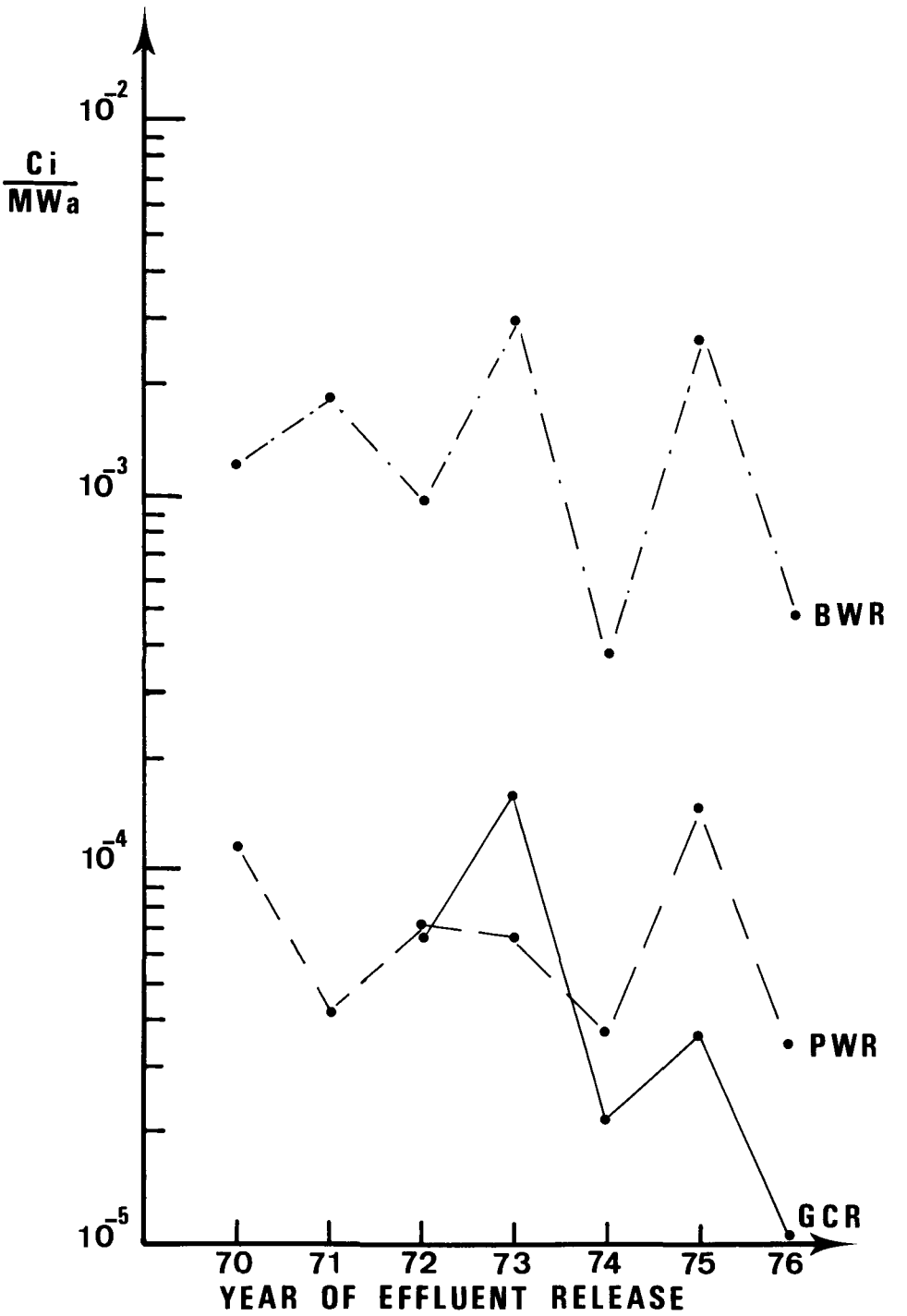

FIG. 3 — Normalized annual discharges (Ci/MWa) of iodine-131 to atmosphere from E.C. PWRs, BWRs and GCRs

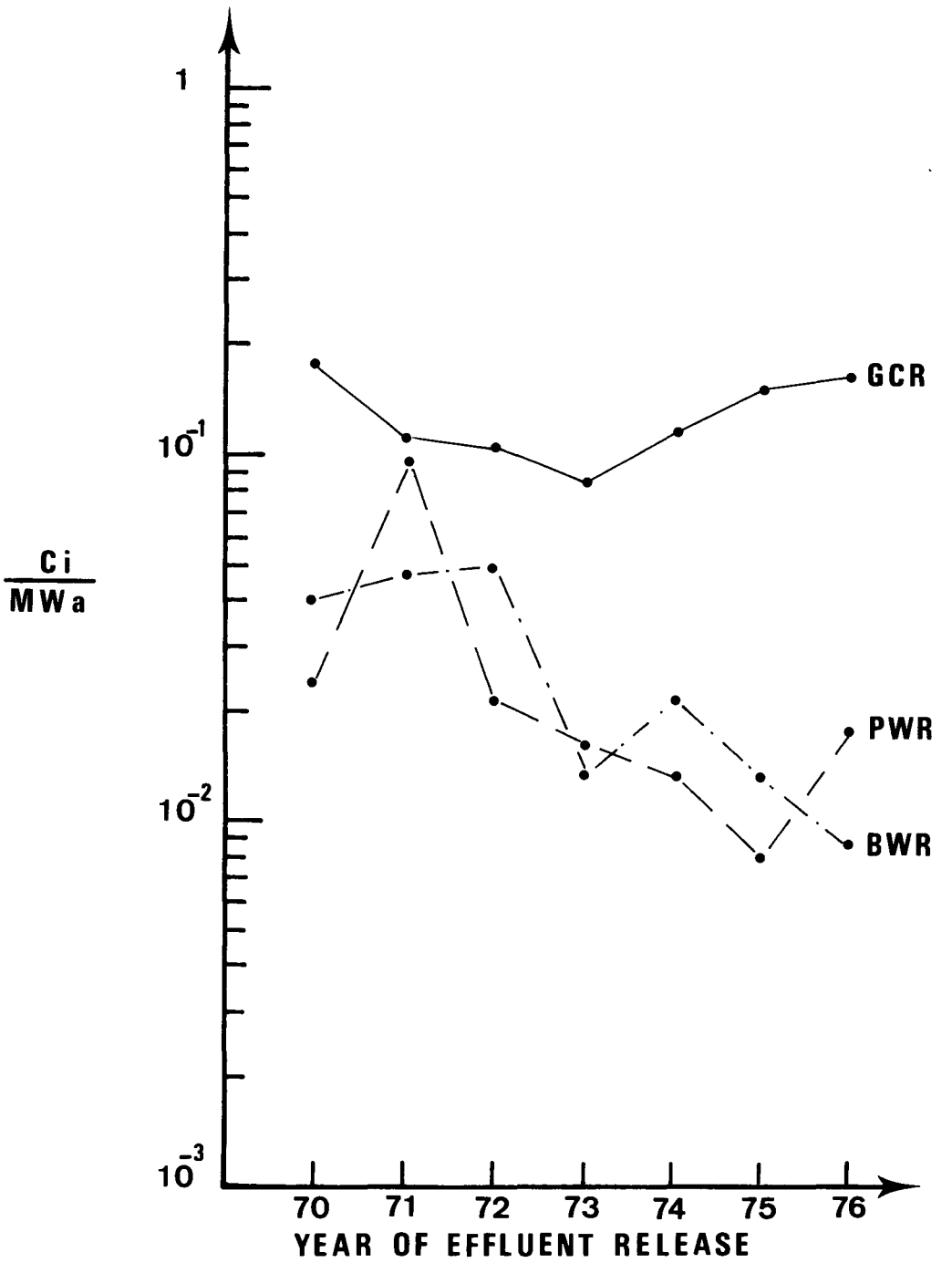

FIG. 4 — Normalized annual discharges (Ci/MWa) of liquid radioactive effluents (excluding tritium) from E.C. PWRs, BWRs and GCRs

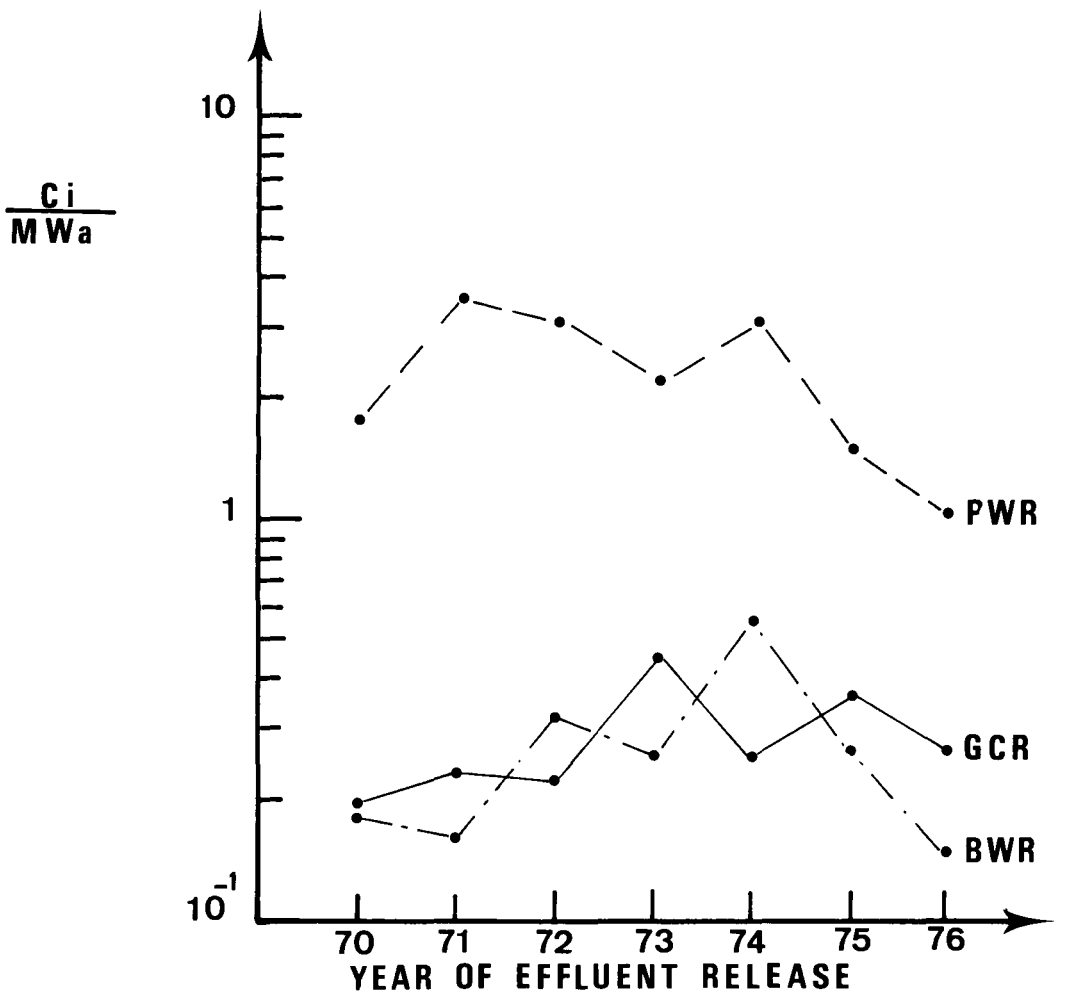

FIG. 5 — Normalized annual discharges (Ci/MWa) of tritium in liquid effluents from E.C. PWRs, BWRs and GCRs