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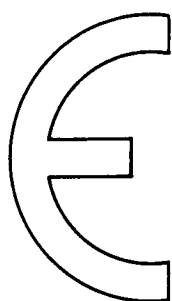
Radioactive effluents
from nuclear power stations
and nuclear fuel reprocessing plants
in the European Community

DISCHARGE DATA

1974 □ 1978

RADIOLOGICAL ASPECTS

SEPTEMBER 1980

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RADIOLOGICAL ASPECTS

F. LUYKX and G. FRASER

SEPTEMBER 1980

V/4116/80−EN

S U M M A R Y

The report covers operational nuclear power stations of capacity greater
than 50 MWe and nuclear fuel reprocessing plants in the European Community.
Radioactive gaseous and liquid effluent discharges from these installations
are given for the period 1974 to 1978, expressed both in absolute terms
and normalized to net electricity production from the fuel. An assessment
is then made of exposure of members of the public consequent to 1978
discharges.

Where environmental contamination levels were detectable the results have
been taken into account in the dose assessment; however, environmental
contamination was in general below the limit of detection. In these cir-
cumstances the dose assessment relied entirely on theoretical models
frequently incorporating conservative assumptions; hence these exposures
are likely to have been less than those derived.

In all cases the estimated exposures have been compared with the dose
limits corresponding to the ICRP 9 approach; an illustration of the
application of ICRP 26 is also given. It is concluded that the exposure
of members of the public always left an appreciable safety margin relative
to the limits and indeed lay within the variations in exposure which result
from natural background.

P R E F A C E

The Commission publishes periodically reports on releases to the environment of radioactive materials in airborne and liquid effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community.

The present report, the fifth in the series, deals with the years 1974-1978 and covers discharges from 39 power stations and 5 reprocessing plants.

It also presents conservative estimates of the maximum exposure of members of the population as a result of these discharges and compares them with the applicable radiation protection standards and exposure from natural radiation.

It is hoped that the report be of assistance to two categories of readership. Firstly for those professionaly concerned with nuclear power it should serve as a reference document of radioactive discharges from all major nuclear installations in the Community, demonstrating to what extent present day technology can restrict discharges, which radionuclides are most commonly present in effluents and, in general terms, which nuclides are from an environmental point of view of interest.

Secondly by inclusion of estimates of radiation exposure, it is hoped that the report will serve to put the radiological significance of these discharges in perspective for interested members of the public.

I would like to thank the national authorities for their cooperation in communicating the discharge data to the Commission.

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
MWa	Megawatt-year electrical
GWa	Gigawatt-year electrical

- 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 yet commissioned.

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

- 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 mainly uses the former units.

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

- In Table XI 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 or Ci/GWa. Where the thermal power is referred to this is shown explicitly by the use of MW(th)a or GW(th)a.

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TABLES

FIGURES

1. RADIOACTIVE EFFLUENTS

1.1 GENERAL

This report contains data on the discharge of gaseous and liquid radioactive effluents from 1974 to 1978 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 1974-76 occasionally differ from those given in the previous edition of this report 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 (2). 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.

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 XI includes the net electrical output of each station for the period 1974 to 1978.

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

The data on thermal and electrical capacity, date of connection to 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/PHWR/SGHWR) which may be
cooled by gas, heavy water or light water. The total net capacity in
1978 was 23 681 MW from the 39 (*) plants listed in the present report; the
actual output was 13 061 MWa.

The data in Tables II to IX were taken mainly from the information provided
by the respective national authorities.

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, radio-
active halogens and particulates, tritium and carbon-14.

Tables II to VI contain data on the discharges and limits for 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.

It should be noted that in the U.K. authorizations for gaseous discharges
from nuclear power stations in general place no limit on the quantities
but require that the best practicable means be used to minimize the amount
of radioactivity to be discharged. However, following the recommendation
of the Royal Commission on Environmental Pollution in its report on
Nuclear Power and the Environment (3), the British Government has agreed
that in the future each nuclear site should have clear standards for air-
borne emissions to which to work (4). Quantified limits are being prepared.

(*) Of these the Gundremmingen and Lingen plants in Germany
     have been shutdown since January 1977.

1.2.2.1 Noble gases

Noble gas discharge by NPSs and the corresponding authorized annual release limits are given in Table II. Table III shows the radionuclide composition of the noble gas releases during 1978.

In earlier GCRs the most significant source of noble gas release is the reactor shield-cooling air in which argon-41 is formed by neutron activation. In later GCR stations, Wylfa and Oldbury, and the AGRs, having water-cooled concrete pressure vessels, this source of argon-41 has been eliminated leaving only the primary CO_2 coolant leakage which also contains small amounts of argon-41. GCRs and AGRs effectively discharge no fission gases, as defective fuel elements can be discharged from the reactor on-load.

The discharges of argon-41 by the British magnox stations are not monitored systematically as they are proportional to power levels. However, the annual discharges given in Table II were obtained from a limited number of measurements with adjustments for average load factors.

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. The remainder consists effectively 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 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 (5).

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 <u>BWRs</u> 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.

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 discharges from the condenser off-gas system of Würgassen represented only 2.5 % of the total noble gas discharge (5). As with PWRs, therefore, 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.

From Table XI 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 0.18 to 48.4 Ci/MWa, with an average value of 7.3 Ci/MWa,

- for BWRs, equipped with a charcoal delay system, from 0.61 to 287 Ci/MWa with an average value of 26.0 Ci/MWa,

- for the Garigliano BWR from 1 321 to 4 315 Ci/MWa with an average value of 2 384 Ci/MWa,

- for the FBR, Phénix,from 0.96 to 3.77 Ci/MWa with an average value of 1.55 Ci/MWa.

Figure 1 shows how for PWRs and BWRs (equipped with a charcoal delay system) the normalized annual discharges have evolved from 1970 to 1978. It can be observed that for PWRs there has been a steady decrease since 1972 to less than 2 Ci/MWa in 1978.

For BWRs there is a similar trend overall, but, partly because there are only a limited number of stations of this type in operation, there are large statistical variations.

1.2.2.2 Tritium

Table IV shows the tritium discharges to atmosphere from NPSs. 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 few 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 leakage.

The normalized discharge of tritium to atmosphere, averaged over the stations and years for which data are available, amounts to 0.04 Ci/MWa for PWRs and 0.14 Ci/MWa for BWRs. For the FBR, Phénix, it was 0.07 Ci/MWa in 1975-1976 and for the AGR, Hunterston B, 0.33 Ci/MWa in 1978.

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).

Aerosol release levels were in general extremely low for all types of power plants. In 1978, for example, the annual discharge averaged over 41 power stations was only 14 mCi, the maximum being 180 mCi.

The normalized discharge, averaged over the 5 year-period 1974 to 1978 is 8.5×10^{-5} Ci/MWa for PWRs, 5.2×10^{-5} Ci/MWa for GCRs and 1.9×10^{-4} Ci/MWa for BWRs. Figure 2 gives the normalized annual discharges for each of these 3 reactor types for the period 1970 to 1978.

The normalized discharge from the FBR, Phénix, over the same period, was 2.8×10^{-8} Ci/MWa. The two AGRs, Hunterston B and Hinkley Point B, had from 1976 to 1978 a normalized discharge of 7.1×10^{-5} Ci/MWa.

The radioactivity of the aerosols may have two different origins, activation or fission.

The following table shows for 1978 the nuclide composition (% activity) measured at the German LWRs, the only reactors for which detailed data have been received.

Nuclide \ Facility	Gund-remmingen	Lingen	Obrigheim	Würgassen	Stade	Biblis A	Biblis B	Neckar-westheim	Brunsbüttel	Isar	Unterweser
Mn-54	1.4	2.0	-	0.2	1.1	-	-	1.8	3.9	8.6	2.6
Cr-51	18.4	16.5	-	22.0	2.8	-	-	14.6	13.8	35.0	20.5
Fe-59	3.7	3.2	-	≤ 0.07	2.8	-	-	2.8	1.3	7.4	4.1
Co-58	2.9	2.5	11	0.7	1.2	-	-	6.0	3.6	17.4	3.1
Co-60	10.0	17.3	89	3.0	8.5	71	100	5.4	16.7	6.7	4.6
Zn-65	-	-	-	0.9	3.3	-	-	-	19.5	23.2	-
Sr-89	0.01	0.4	-	0.9	0.06	-	-	0.01	2.0	0.1	0.03
Sr-90	0.02	0.4	-	0.02	0.04	-	-	0.004	0.01	0.03	0.003
Zr-95	4.1	3.6	-	≤ 0.07	2.3	-	-	2.2	1.4	-	4.6
Nb-95	2.9	2.4	-	0.07	1.2	-	-	2.2	1.6	-	3.1
Ru-103	1.9	1.6	-	0.03	0.9	-	-	1.4	0.5	-	2.1
Ru-106	-	16.7	-	≤ 0.07	-	-	-	14	-	-	-
Ag-110m	2.3	2.0	-	≤ 0.03	0.9	-	-	1.5	2.0	0.7	2.6
Sb-124	3.7	3.2	-	≤ 0.03	3.3	-	-	17.6	0.9	0.05	4.1
Sb-125	3.7	3.2	-	≤ 0.07	1.7	-	-	2.8	1.4	-	4.1
I-131	1.9	1.6	-	14.2	19.3	-	-	-	-	-	2.1
Cs-134	1.8	2.4	-	2.9	3.3	-	-	2.1	4.6	-	3.1
Cs-137	9.2	5.0	-	3.4	7.7	29	-	2.3	11.6	-	3.1
Ba-140	13.8	1.2	-	≤ 0.07	3.6	-	-	10.6	3.0	-	15.5
La-140	1.9	1.6	-	≤ 0.04	1.4	-	-	1.4	3.0	-	2.1
Ce-141	1.0	0.8	-	≤ 0.03	0.9	-	-	0.7	0.6	-	1.0
Ce-144	13.8	12.3	-	≤ 0.07	4.7	-	-	10.6	2.2	0.05	15.5
others	1.9	-	-	51.2	29	-	-	-	6.3	0.8	2.1
alpha	0.03	0.07	-	0.004	0.01	-	-	-	0.02	0.1	0.003

It appears that the nuclides most commonly found and at levels possibly exceeding 5 % are the activation products Mn-54, Cr-51, Fe-59, Co-58, Co-60 and the fission products Cs-134, Cs-137, Ba-140, Ce-144. Alpha activity is extremely low. Table V also shows 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 mainly in the graphite moderator.

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 1978 the average release for the 22 power stations considered was 15 mCi, with a maximum of 130 mCi. The normalized release, averaged over the 5-year period considered in the report is 2.5×10^{-5} Ci/MWa for PWRs and 6.2×10^{-4} Ci/MWa for BWRs. Figure 3 gives the normalized annual iodine-131 discharges from PWRs and BWRs from 1970 to 1978. Few data are available on iodine-131 discharges from GCRs; since failed fuel can be removed from GCRs on load, the British stations do not measure iodine-131 routinely; for the French stations the available data comprise aerosols and gaseous halogens. Thus the only data available are for Latina for which the normalized discharge is less than 2.1×10^{-7} Ci/MWa for the 5-year period.

Separate data on iodine-131 discharge from the fast breeder Phénix are also unavailable. However from those in Table V, giving the sum of aerosols and gaseous halogens, it can be concluded that over the 5-year period considered iodine-131 discharge must have been extremely low, i.e. less than 3×10^{-7} Ci/MWa.

At the AGR, Hinkley Point B, iodine-131 is measured routinely. The data available show that from 1977 to 1978 the normalized discharge was less than 7.8×10^{-5} Ci/MWa.

1.2.2.5 Carbon-14

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.

Few data on carbon-14 discharges from NPSs are available. In the Federal Republic of Germany the Federal Health Office (Bundesgesundheitsamt) instituted in 1976 a measuring programme in the German power plants. The results of some 700 individual measurements are summarized below (6).

Carbon-14 discharges from PWRs (1)			
Facility	Year	Ci/a	Ci/MWa
Obrigheim	1977	3.0	11.6×10^{-3}
	1978	0.9	3.0×10^{-3}
Stade (2)	1977	3.0	4.8×10^{-3}
	1978	1.5	3.0×10^{-3}
Biblis A	1977	4.8	6.4×10^{-3}
	1978	2.1	2.0×10^{-3}
Biblis B	1977	4.9	5.0×10^{-3}
	1978	4.8	7.2×10^{-3}
Neckarwestheim	1977	4.0	6.6×10^{-3}
	1978	3.9	6.3×10^{-3}

(1) 1978 data extrapolated from measurements over the
    first half-year only

(2) Only CO_2-bound C-14 measured

Carbon-14 discharges from BWRs (1)			
Facility	Year	Ci/a	Ci/MWa
Gundremmingen	1976	3.7	15.1×10^{-3}
Lingen	1976	1.4	9.2×10^{-3}
Würgassen	1977	6.2	14.3×10^{-3}
	1978	6.2	23.8×10^{-3}
Brunsbüttel	1977	4.3	10.9×10^{-3}
	1978	4.5	12.9×10^{-3}

(1) 1978 data extrapolated from measurements over the
    first half-year only

From the above data it appears that the normalized emission-rate of C-14
is 6 mCi/MWa for PWRs and 14 mCi/MWa for BWRs.

In PWRs the proportion of CO_2-bound, CO-bound and hydrocarbon-bound C-14
in gaseous effluents is found to vary considerably. The mean percentage
of CO_2-bound C-14, determined from several random samples (usually 9 per
plant and per year) of gaseous effluent from the above PWRs, ranges from
3 to 57 % of the total C-14 present. On the other hand in BWRs more than
95 % of the C-14 is found as CO_2-bound.

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 1978. Table IX lists tritium discharges.

1.2.3.1 Activity other than tritium

Table VII shows that activity discharged annually from PWRs and BWRs has generally decreased over the period covered by the report. This tendency can also be seen from Figure 4, which gives the normalized discharges from 1970 to 1978.

Table XII gives for each station the normalized annual discharges over the 5-year period considered :

- for PWRs it varies from 5.3×10^{-5} to 1.5×10^{-1} Ci/MWa with an average value of 1.2×10^{-2} Ci/MWa;

- for BWRs from 7.9×10^{-4} to 8.1×10^{-2} Ci/MWa with an average value of 1.1×10^{-2} Ci/MWa;

- for GCRs from 6.1×10^{-4} to 7.1×10^{-1} Ci/MWa with an average value of 1.3×10^{-1} Ci/MWa (1.9×10^{-2} Ci/MWa for continental GCRs).

The higher activity discharges in liquid effluents from the British GCRs than from most continental stations frequently originate from the spent-fuel storage ponds as a result of corrosion damage to fuel stored for prolonged periods.

The normalized discharge from 1976 to 1978 from the AGRs Hunterston B and Hinkley Point B was 1.3×10^{-2} 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 (see Tables XVII to XXI).

Table VIII gives the radionuclide composition of liquid effluents (excluding tritium) discharged from NPSs in 1978. 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 table below summarises for PWRs, BWRs and British GCRs (*), the average of the percentages of the principal radionuclides present in the liquid effluent (excluding tritium) in 1978.

Radionuclide	PWR	BWR	GCR (UK)
S-35	-	-	13.2
Cr-51	6.2	11.6	-
Mn-54	4.2	5.9	-
Co-58	29.3	15.1	-
Co-60	22.0	18.8	0.3
Zn-65	-	6.4	-
Sr-89	0.1	0.4	0.2
Sr-90	0.2	0.1	8.4
I-131	1.9	5.5	-
Cs-134	4.2	10.2	8.9
Cs-137	13.3	21.2	47.9
Ce-144	1.4	0.7	2.4
Total	82.8	95.9	81.3

On average over 65 % of the activity from LWRs was radioactive cobalt and caesium. For the GCRs (UK) caesium gave over 55 %, sulphur and strontium some 10 % each.

1.2.3.2 Tritium

Annual tritium discharges and discharge limits are given in Table IX. They show relatively high releases for :
- the PWRs, Chooz and Trino
- the AGRs, Hunterston B and Hinkley Point B
- the heavy water moderated reactors MZFR and Winfrith.

The higher discharge from the PWRs, Chooz and Trino and from the AGRs 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 is because of the neutron reaction with the boric acid (chemical shim) used in PWRs.

(*) French GCRs are omitted since the S-35 data have not been communicated.

The tritium discharges from MZFR and Winfrith originate mainly by activation of deuterium in the heavy water.

Figure 5 gives the normalized annual tritium discharges for PWRs, BWRs and GCRs for the period 1970 to 1978. For the period 1974 to 1978 covered by this report the normalized values may be summarized as follows :

- for PWRs with zicaloy clad fuel from 2.4 x 10^{-3} to 1.0 Ci/MWa in any one year with an average of 0.58 Ci/MWa,

- for PWRs with stainless steel clad fuel, Chooz and Trino, from 4.3 to 19.7 Ci/MWa with an average of 8.0 Ci/MWa,

- for BWRs from 2.5 x 10^{-3} to 1 Ci/MWa with an average of 0.20 Ci/MWa,

- for GCRs from 6.7 x 10^{-3} to 3.7 Ci/MWa with an average of 0.41 Ci/MWa.

The normalized release from the AGRs was 6.4 Ci/MWa in 1978.

1.3 NUCLEAR FUEL REPROCESSING PLANTS

1.3.1 Plant Characteristics and Data Sources

Table XII gives general information on the five operational nuclear fuel reprocessing plants 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 XII in tonnes per annum serve to illustrate the overall scales of the individual plants; the capacities for commercial reactor fuel vary widely from 40 t per year for LWR fuel at WAK (Wiederaufarbeitungsanlage, Karlsruhe), to 2000 t per year for GCR fuel at Windscale. However, since the burn-up of spent LWR fuel is almost an order of magnitude greater than that of GCR fuel, the capacities lie closer together if expressed in terms of the electricity which has been produced from the fuel. Actual "throughputs", as opposed to design capacities have been estimated below in terms of GWa, from the

krypton-85 discharges. This allows all reprocessing plant discharges to be normalized to the equivalent electricity production.

The data presented have been drawn mainly from information supplied by the competent authorities of the Member States of the European Community. Additional references are cited individually in the text.

1.3.2 Gaseous Effluents

Tables XII to XVI 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 other facilities (fuel fabrication, hot cells, etc.) discharge to the same stack as the reprocessing facility and may contribute significantly to discharges on occasion.

1.3.2.1 Krypton-85

Krypton-85 is the only noble gas of sufficiently long half-life to be of interest. In the absence of data on the amount and burn-up of fuel reprocessed the discharges recorded may be used to calculate reprocessing plant throughputs, firstly in terms of equivalent thermal power produced in the reactors and subsequently in terms of the electricity produced. Since Dounreay, however, does not process either GCR or LWR fuel such a calculation in respect of this site would be meaningless.

All the krypton-85 is assumed to be released on reprocessing; the fuel content is taken to be :

0.11 MCi per GW (th)a for GCRs and
0.097 MCi per GW (th)a for LWRs.

Based on 1976 data from (1) the following overall efficiencies have been adopted :

25 % for GCRs and
32 % for LWRs

All krypton-85 discharged from Marcoule and Windscale can be ascribed to GCRs. However, since 1976 La Hague has processed both GCR and LWR fuel; a variety of supplementary data have been used to allocate the annual

krypton-85 discharges to the two types of fuel but the accuracy is uncertain; a small contribution from FBR fuel has been neglected. WAK discharges are attributed to LWR fuel.

The calculated throughputs in terms of electricity produced from the fuel processed are tabulated below together with the recorded annual EEC electricity production of GCRs and LWRs respectively (1), almost all the fuel having originated from EEC power stations.

Plant	Fuel Throughput - Net Electrical Equivalent (GWa)				
	1974	1975	1976	1977	1978
GCR fuel					
La Hague	1.6	1.5	0.66	1.2	1.1
Marcoule	0.25	0.23	0.21	0.27	0.70
Windscale	1.8	2.7	2.7	1.8	1.6
Total	3.7	4.4	3.6	3.3	3.4
Total recorded elec. output	4.6	4.6	4.8	4.8	4.5
LWR fuel					
La Hague	n.a.	n.a.	0.20	0.53	0.94
WAK	0.003	0.14	0.28	0.38	0.11
Total	0.003 (0.33)*	0.14	0.48	0.91	1.1
Total recorded elec. output	2.1	3.9	4.8	6.2	7.6

* Including Eurochemic prior to shutdown.

The table demonstrates the increasing backlog of fuel for reprocessing. Thus reprocessing plant discharges cannot be compared with reactor discharges on a year-by-year basis and the only method of comparison available is in terms of (equivalent) electricity production even although, as will be seen, this is not always straightforward.

1.3.2.2 Radioactive aerosols

Alpha-active aerosols, Table XIV, 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. U.S. experience of a particular plant (7) first showed that plutonium components dominated the alpha-activity released. This has now been confirmed at Windscale where 70 % of the 1978 gross alpha discharge, including that from the Plutonium Recovery Plant, was plutonium (americium-241 and curium-242 were also detected). Measured values of the plutonium isotopic composition of discharges have not been found but typical calculated values for the fuel are :

Fuel 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 annual discharges normalized to equivalent electricity output vary widely from plant to plant and in some cases from year to year at a given plant. Average values for the period 1974-1978 are :

$$\text{Windscale} \quad 3.5 \times 10^{-2} \text{ Ci/GWa}$$
$$\text{WAK} \quad 1.5 \times 10^{-2} \text{ Ci/GWa}$$
$$\text{Marcoule} \quad 1.3 \times 10^{-4} \text{ Ci/GWa}$$
$$\text{La Hague} \quad 5.2 \times 10^{-6} \text{ Ci/GWa}$$

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

Possibly significant nuclides contributing to measured beta discharges include strontium-90, zirconium/niobium-95, ruthenium-106, 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 will

not detect such emitters. Data on the radionuclide spectra of the discharges are sparse but the following information has been given :

Site	Nuclide	Discharge as a percentage of total beta activity (Table XV)				
		1974	1975	1976	1977	1978
Windscale	Cs-137		30	24	65	77
	Sr-90	5.3	13	7.8	11	15
WAK	Sr-90				6.7	8.3

The sharp rise in caesium-137 at Windscale in 1977 and 1978 in percentage terms is associated with an increase in total discharges from the solid waste silo used for storing magnox cladding. This component contributes both caesium-137 and strontium-90 and has served to increase **total beta activity by a factor of two and strontium-90 by a factor of four** since 1976, while caesium-137 has increased by a factor of **six.** Corrective action has been planned. Since these Windscale discharges represent a transient situation in respect of waste accumulated over many years it would be inappropriate to normalize them to the equivalent electrical output of fuel processed in the corresponding years. 1977 and 1978 have therefore been excluded in calculating the normalized Windscale discharges.

Over the four reprocessing plants there is again considerable variation in the normalized values, though less so than for alpha emitting nuclides. The average values are :

Windscale	**1.4**	Ci/GWa
WAK	0.78	Ci/GWa
Marcoule	5.1×10^{-2}	Ci/GWa
La Hague	5.6×10^{-3}	Ci/GWa

1.3.2.3 Tritium

The available tritium discharge data are given in Table XVI. Those for Windscale prior to 1977 have been stated to be "inferred by comparison with krypton-85" (8). The inferred values correspond to 1 % of the krypton-85 activity discharged which implies some 16 % of the theoretical tritium content of GCR fuel.

The data from the French plants show that measured annual tritium discharges, expressed as a percentage of krypton-85 discharges, have varied at Marcoule from 0.064 % to 0.56 % and at La Hague from 0.013 % to 0.075 %; the corresponding results from WAK are 0.12 % to 0.37 %. These values correspond to the order of 1 % to 10 % of the theoretical tritium content of the fuel with the majority of annual values lying towards the bottom of this range. However, more extreme values have been recorded previously from 0.1 % (Marcoule, 1973) to 26 % (Eurochemic, 1974) of the fuel content.

Normalized to equivalent electricity production individual annual discharges lie within a factor of two of the average over the period 1974-78 both at La Hague and WAK; the Marcoule results are more **variable. The** average results are :

$$
\begin{array}{lll}
\text{Windscale} & 4.5 \times 10^3 & \text{Ci/GWa} \\
\text{Marcoule} & 1.4 \times 10^3 & \text{Ci/GWa} \\
\text{WAK} & 5.6 \times 10^2 & \text{Ci/GWa} \\
\text{La Hague} & 1.0 \times 10^2 & \text{Ci/GWa}
\end{array}
$$

where the Windscale value includes the "inferred" discharges.

1.3.2.4 Radioactive iodine

The <u>iodine-131</u> content of fuel **depends on the rating** $\left[\text{MW(th)}/\text{t}\right]$ **and the** cooling time of the fuel rather than the burn-up $\left[\text{MW(th)d}/\text{t}\right]$. Thus processing fuel equivalent to one GWa (electricity output) in typical GCR or LWR conditions will correspond to a throughput of approximately

- 6 Ci of iodine-131 for a cooling time of 180 days
- 2.5 mCi for a cooling time of 270 d
- 0.7 μCi for a cooling time of one year.

In practice with the growing backlog of fuel for reprocessing a cooling time of one year is common but even a relatively small quantity of fuel with a short cooling time will dominate the total iodine-131 releases. The discharge data available are given in the following table :

Facility	Discharge of iodine-131 (Ci)				
	1974	1975	1976	1977	1978
La Hague	0.49	1.75	0.34	0.019	0.026
Marcoule	0.92	0.50	1.32	0.61	1.1
Windscale	0.012	0.009	0.076	0.07	0.4 *
Dounreay : organ.	< 0.11	< 0.27	< 0.058	< 0.036	< 0.036
inorgan.	< 0.057	< 0.040	< 0.052	< 0.036	< 0.036

* Processing of short-cooled fuel took place in May, 1978.

The data available for WAK (1976-78) combine all iodine isotopes and the total discharges can be accounted for by iodine-129 alone. It can be inferred that in each of these years iodine-131 discharges were less than 10^{-3} Ci.

Information on the chemical forms of iodine discharged is important for assessing the environmental effects. Unfortunately, Dounreay is the only site to distinguish between the organic and inorganic forms of iodine-131; the discharges recorded for this site may be influenced by work in hot cells with relatively fresh fuel.

Bearing in mind that the discharges are very sensitive to the fuel cooling times, the results normalized to equivalent electricity production are perhaps surprisingly consistent from year to year. The average normalized values are :

Marcoule	2.0	Ci/GWa
La Hague	0.3	Ci/GWa
Windscale	0.07	Ci/GWa
WAK	< 0.004	Ci/GWa

Discharges of iodine-129 are of particular interest because 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 one GWa will involve a throughput of 1 to 2 Ci of iodine-129. The available measurements of discharges of iodine-129 to atmosphere from operational reprocessing plants are as follows :

Facility	Discharges of Iodine-129 (Ci)				
	1974	1975	1976	1977	1978
WAK		4.3×10^{-2}	3.0×10^{-3}	2.2×10^{-3}	4.7×10^{-3}
Windscale			0.22	0.16	0.07

The reduction for WAK from 1976 onward 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 (9).

A series of measurements, again at WAK, from November 1975 to August 1977 gave the following average values for the components of iodine-129 discharged :

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

However, these averages conceal wide variations in individual sample results.

Normalized to equivalent electrical output using the 1976-78 data the results are

$$\text{Windscale} \quad 7.3 \times 10^{-2} \text{ Ci/GWa}$$
$$\text{WAK} \quad \quad 1.3 \times 10^{-2} \text{ Ci/GWa}$$

about 4 % and 1 % respectively of the fuel content.

1.3.2.5 Carbon-14

Few routine discharge measurements at reprocessing plants are available for carbon-14 during the period under review.

As noted in the previous edition of this report, work at WAK (10) suggested discharges of about 13 Ci/GWa for LWR fuel compared with a theoretical fuel content of 6 Ci/GW(th)a (11), some 18 Ci/GWa. The release to atmosphere would thus correspond to some 70 % of the fuel content but the calculation of the carbon-14 contained is not well established because of uncertainties as to the nitrogen impurity levels in the manufactured fuel. Later work (5) has demonstrated that the dis-

charge is almost entirely as carbon dioxide, the monoxide and hydrocarbons contributing only some 0.1 % of the total.

For GCR fuel the fuel content has been given (11) as equivalent to about 100 Ci/GWa; for AGR fuel the value is not significantly different from that for LWR fuel.

The total throughput of carbon-14 calculated on the basis of the above values is 1.9 KCi for the period 1974-78 of which more than 95 % would be present in GCR fuel, but discharges are even more uncertain than the theoretical throughputs (the fraction going to atmosphere being dependent on the precise conditions of dissolution at the plant concerned). **The one measurement for GCR fuel in the period is 112 Ci for 1978 from Windscale (34); using the above data this was some 70 % of throughput.**

1.3.3 Liquid Effluents

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

As observed in footnote (c) to Table XII, liquid effluent from WAK is treated and discharged with the effluent from the Karlsruhe Nuclear Research Centre as a whole; likewise that from Dounreay and Marcoule includes discharges from other facilities on these sites.

For La Hague and Windscale 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. Thus at Windscale the use of delay tanks to reduce shorter lived nuclides means that the timing of discharges from these tanks can influence the year in which discharges are recorded.

1.3.3.1 **Alpha activity**

Table XVII gives the annual discharges of alpha activity in liquid effluent.

As regards nuclide compositions, these given for plutonium in Section 1.3.2.2 might again be expected to apply and the 1978 measurements of discharges and previous data on environmental levels (12) for Windscale do largely reflect the distribution suggested for GCR fuel. Americium-241 also contributes significantly to Windscale discharges as shown in the table below, although the contribution has fallen by an order of magnitude since 1975 when a further stage of effluent treatment was introduced.

Windscale Discharge (Ci)	1974	1975	1976	1977*	1978*
Pu-238	1 248	1 200	1 266	981	334
Pu-239/240					1 233
Am-241	3 192	984	323	99	214
Total	4 440	2 184	1 589	1 080	1 781
Total as % age of gross alpha	97.1	94.6	98.5	87.0	97.0

* The increase in 1978 relative to 1977 reflects the timing of discharges from delay tanks.

As can be seen from the table plutonium-238/239/240 has risen to over 80 % of the gross alpha result since the additional treatment stage was introduced.

WAK effluents are treated and discharged as part of the Karlsruhe site discharges and prior to 1978 the gross alpha levels for the latter were below the limit of detection. The following table gives the WAK _input_ to the liquid effluent treatment as a percentage of the total alpha activity and the results of nuclide specific measurements of the _discharge_ from Karlsruhe.

Karlsruhe	1974	1975	1976	1977	1978
WAK (% age of alpha activity treated)			64.5	35.8	28.4
Pu-238 discharge (Ci)	$1.4x10^{-4}$	$1x10^{-4}$	$5x10^{-4}$	$2x10^{-4}$	$5x10^{-5}$
Pu-239 discharge (Ci)	$2.9x10^{-4}$	$2x10^{-4}$	$4x10^{-4}$	$2x10^{-4*}$	$7x10^{-5*}$

* Pu-239/240

The Pu-238/239/240 total for 1978 corresponds to 80 % of the gross alpha discharge as given in Table XVII. However, the nuclide breakdown indicates, by comparison with that suggested in Section 1.3.2.2, that the discharges are not characterized by WAK even when, as in 1976, WAK provides over 60 % of the feed to the effluent treatment plant. By volume WAK provides only 3-4 %.

No information other than gross alpha results are available for La Hague Marcoule and Dounreay; even the gross results are of reduced significance for Marcoule and Dounreay in view of the unknown contributions from site facilities other than reprocessing plant.

Normalizing the La Hague 1974-78 and Windscale 1976-78 results to electrical equivalent gives the following results :

Windscale   730 Ci/GWa
La Hague   11 Ci/GWa

The site values for Marcoule and WAK (1974-78) are 1.2 Ci/GWa and $3.5x10^{-3}$ Ci/GWa respectively, which for WAK in particular must be regarded as an upper limit.

1.3.3.2   Beta activity other than tritium

Table XVIII gives the data on gross beta activity discharged (excluding tritium) and Tables XX and XXI 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.

The WAK, Marcoule and Dounreay discharges again include unknown contributions from other site facilities and these may influence the results. At WAK in particular it is known that in 1976-78 the reprocessing plant

provided only some 25 % of the input to the site effluent treatment plant in terms of beta-activity (3-4 % by volume). Thus for WAK the values are no more than upper limits to reprocessing effluent discharges and may be gross overestimates; individual nuclide data cannot be regarded as significant.

Nuclide specific analysis of the effluents although not as yet reported in detail for all sites is becoming more widely available. Those nuclides for which data are available are compared in the following table. The values correspond to the discharges of 1977 and 1978 combined and for simplicity are expressed as percentages of the recorded total beta discharges. (See also Tables XVIII, XX and XXI).

Facility	Discharges as a Percentage of the Gross Beta Activity (1977-78)		
	Sr-90	Ru-106 *	Cs-137
La Hague	11	72	4.8
Marcoule	1.9	80	8.1
Dounreay	22	2.7	26
Windscale	7.1	11	60

* The La Hague and Marcoule results include Ru-103 although this isotope is probably of minor importance.

The preponderance of ruthenium-106 at La Hague and Marcoule is borne out by data from earlier years. Windscale discharges are shown in the following table in greater detail :

Nuclide	Windscale Discharges (Percentage of Gross Beta)					
	Ann. Ave. 1970-73	1974	1975	1976	1977*	1978*
Sr-90	4.7	5.1	5.1	5.6	6.0	8.4
Ru-106	24	14	8.4	11.3	11.4	11.4
Cs-134	8.1	13	12	11.0	8.3	5.7
Cs-137	26	53	58	63	63	57
Ce-144	11.5	3.2	2.3	2.2	2.1	1.5
Gross Beta (kCi)	126	207	245	183	193	193

* The increase in strontium-90 and the corresponding decrease in caesium in 1978 relative to 1977 reflects the timing of discharges from delay tanks.

The sharp rise in the gross beta in 1974 was largely the result of increased release of caesium-137 into the fuel storage pond as a result of fuel cladding corrosion first evidenced in 1970. Interim measures have reduced the discharges of caesium but have not yet reduced them to the previous levels. However, the increasing average decay time of fuel prior to reprocessing has served to reduce the significance of the shorter-lived nuclides such as cerium-144.

A fully comprehensive nuclide analysis of Windscale liquid effluent was instituted in 1977-78 and the results for over twenty different fission products and other nuclides have been published (13). In addition to those listed above the following nuclides, expressed as a percentage of the gross beta, exceeded 0.1 %.

Sr-89	Zr-95	Nb-95	Te-99	Ru-103	Sb-125	Eu-154
0.14	1.15	2.07	2.54	0.12	0.41	0.54

Tritium (see below) and the nuclides iodine-129 and plutonium-241 are included in a group of low energy beta-emitters not detected by the gross beta measurements and hence not intended to be included in the authorised beta discharges. In 1977 3 Ci of iodine-129 and 26.5 KCi of plutonium-241* were discharged and in 1978 the corresponding figures were 2 Ci and 47.9 KCi. The increase in plutonium-241, in reasonable agreement with that for the alpha emitting isotopes, reflects the timing of discharges.

Normalizing total beta discharges to equivalent electricity production over the period 1974-78 gives the following results for the gross beta activity :

> Windscale   96 x 10^3 Ci/GWa
> La Hague   17 x 10^3 Ci/GWa
> Marcoule   2.5 x 10^3 Ci/GWa

The WAK value based on the total Karlsruhe discharges is 0.44 Ci/GWa.

The Windscale iodine-129 values average at 1.5 Ci/GWa which corresponds fairly well with the theoretical fuel content allowing for the accuracies involved.

1.3.3.3 Tritium

The available data are given in Table XIX and lead to the following over-all normalized values

Windscale	15	$x \ 10^3$ Ci/GWa
Marcoule	11	$x \ 10^3$ Ci/GWa
WAK	9.4	$x \ 10^3$ Ci/GWa
La Hague	7.7	$x \ 10^3$ Ci/GWa

On a year by year basis the Windscale and Marcoule values are reasonably consistent whereas the 1977 result for WAK is low compared to the others and in the case of La Hague the two years for which data are available differ by almost a factor of two.

Taking into account discharges to atmosphere approximately half of the theoretical fuel contents is unaccounted for in each case, the value being somewhat lower for La Hague.

2. RADIOLOGICAL ASPECTS

2.1 GENERAL

This part of the report gives generally conservative estimates of the exposure of members of the population as a result of the activities released as gaseous and liquid effluents during one year, namely 1978. 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 directly or indirectly by irrigation.

Since the levels of environmental contamination resulting from discharges are not usually readily detectable, dose evaluations mainly rely of necessity on generalised models used firstly to estimate environmental contamination and subsequently the resulting doses to man; the accuracy .of such models when applied to specific situations is open to question. Such considerations are examined in some detail and illustrated quantitatively in reference (28). In the models applied to obtain the dose estimates given below pessimistic values are often assigned to the parameters involved and hence, in most cases, the results cited can be regarded as indicating maximum hypothetical values for the exposure of members of the population.

In general the approach adopted in this section of the report is that of ICRP 2 (14) with the revisions introduced by ICRP 6 and 9 (15, 16) and taking into account the concept of committed dose and, on the basis of reference (17), the use of bone marrow as the critical organ for strontium-90. More recent developments on the approach to dose assessment and limitation will be discussed in Section 3.

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 X. 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, is a measure of 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. AGR/GCRs, for which the effective height was reduced to 30 m to take into account building entrainment; however, the model does not allow for the rapid dispersion in the building wake following entrainment;

- an individual remained out of doors throughout the year at the two points considered;

- long-term atmospheric dilution factors (18) were used supposing that the wind blew into the same 30° sector for 20 % of the time;

- where the radionuclide composition of noble gases was known (Table III) it was taken into account in the dose calculation. 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 external and internal doses, dose conversion factors were taken from a single reference (18) except for iodine-131 (19).

The assumption of a 100 % occupancy factor and the neglect of dilution in the building wake will serve to give pessimistically high results particularly at 0.5 km. The ratio of doses at 0.5 km and 5 km may vary by an order of magnitude depending on the particular stack height.

2.2.1.1 External gamma and beta doses

Table X gives the maximum external radiation doses in 1978 from the radio-active gases discharged by the NPSs. It shows that at 0.5 km from the discharge point of LWRs and continental GCRs whole body gamma doses and skin beta doses never exceeded 1 mrem except for one BWR of an older design. At 5 km the doses are an order of magnitude lower.

In the case of the British GCRs for which discharge data are available, the annual exposure at 0.5 km varied between 5 and 54 mrem due to argon-41 releases; at 5 km the maximum calculated dose was 2 mrem. Based on Groom's calculated maximum annual whole body exposures for 100 % occupancy of the nearest dwelling to each CEGB station (20), the 1978 discharges would imply doses in the range 2 to 11 mrem.

The doses from the FBR, Phénix, as shown in Table X, were respectively less than 0.01 and 0.001 mrem at 0.5 and 5 km. Hunterston B, the sole AGR for which the necessary data have been received, were calculated to have contributed 2 mrem and 0.1 mrem at 0.5 and 5 km respectively to the Hunterston A + B results.

As regards external irradiation from deposited activity, assuming a constant aerosol discharge rate of 180 mCi per year (the maximum observed in 1978) consisting of cobalt-60 alone (this being the most potent gamma emitter commonly observed in LWR aerosol discharges - see table on page 6) the gamma dose-rate at equilibrium would be 0.8 mrem per year at 0.5 km and 0.06 mrem at 5 km.

In practice, since colbalt-60 contributes only a small fraction of the discharges and since environmental losses into the soil have been neglected, the dose-rate would be lower, probably by an order of magnitude or more, even if the release rate remained constant over the succeeding years.

2.2.1.2 Internal irradiation by radioactive aerosols and sulphur-35

As for external radiation from aerosol deposition the assessment has been restricted to the doses resulting from the maximum ascertained discharge during 1978, i.e. 180 mCi.

Assuming in this case that the discharge was composed entirely of cerium-144, which has the highest inhalation dose factor of the nuclides most frequently observed in aerosol discharges from LWRs (see table on page 6) would imply a committed dose to the child's lung of 0.2 mrem at 0.5 km and 0.01 mrem at 5 km. All other 1978 annual discharges having been considerably less than 180 mCi, the corresponding doses will have been much lower than those derived above.

From the data available the maximum discharge of alpha-activity to atmosphere in 1978 was 2.5×10^{-6} Ci (see table on page 6). Assuming this activity was wholely plutonium-239, the committed dose to bone for an adult by inhalation would be less than 0.01 mrem at 0.5 km.

Table V also shows sulphur-35 discharges for some of the British GCRs and AGRs. The highest reported value is 8.7 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 8.7 Ci would result in a milk concentration at 0.5 km of about 980 pCi/liter, which would lead to a committed dose to an infant, drinking only this milk, of 2.5 mrem (21). 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

Table XI shows, for the 1978 discharges of iodine-131 to atmosphere the calculated maximum doses 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. With one exception, the values at 0.5 km are less than 10 mrem, at 5 km 1 mrem.

The maximum iodine-131 discharge in one calendar year during the 5-year period considered was 1.3 Ci from Lingen in 1975. The corresponding maximum dose to the thyroid of an infant from milk consumption is 25 mrem at 0.5 km and 9 mrem at 5 km. The corresponding inhalation doses at these distances are respectively 0.15 and 0.05 mrem.

It should be noted that these calculated doses are maximum hypothetical values, based on very conservative assumptions, namely :

- all iodine discharges are in elemental form, whereas the limited information available indicate that in reality a substantial fraction is in organic form (22) which has a much lower deposition velocity and would therefore give much lower concentrations in the locally produced milk;

- the infant drinks only milk produced at one or other of the distances cited.

In reality doses from milk intake would have been considerably lower than those evaluated. Moreover, for older persons the values would be even lower; for an adult with the same milk consumption rate as an infant they would be less than 10 % of the above (17).

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, as given in Table IV, are calculated to have given committed doses to the whole body of less than 0.2 mrem at 0.5 km and less than 0.02 mrem at 5 km.

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

To estimate doses due to uptake of tritium through the food chain, reference has been made to a specific activity model (23) 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 km 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 LWR plant amounts to 10 Ci.

Use has again been made of a specific activity model (23), assuming the food intake pattern given in Section 2.2.1.4. This indicates that the food pathway is predominant; for a stack height of 100 m the committed dose to the critical organ (body fat) would not exceed 0.005 mrem 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.

The highest mean increase in the activity concentration in 1978 in the rivers receiving effluents from nuclear power stations was in the Rhône downstream of the Bugey site. Using the radionuclide composition of the effluents from the Bugey plant, as given in Table XVIII, the maximum committed doses from the above exposure paths have been assessed, taking account of local conditions,and the following results obtained :

Exposure path	Average consumption rates (kg/a) or exposure times (h/a)	Committed dose (mrem)	
		bone marrow	whole body
Internal exposure			
- drinking water	440	0.1	0.002
- river fish	1.3	0.01	0.005
- milk (infant)	250	0.1	0.002
- meat	75	0.003	0.002
- crops	280	2	0.04
External exposure			
- swimming + boating	8		3×10^{-5}
- exposure on river banks	2		0.001

These committed doses being based on average consumption rates and exposure times; members of critical groups could have received higher doses, especially by fish consumption and external exposure. However, these doses would probably never exceed 1 mrem. On the other hand, it is unlikely that the consumption of crops and meat consists only of local produce and hence the resulting committed doses will have been correspondingly lower than calculated.

As regards marine and estuarine sites, U.K. estimates, based on environmental monitoring results (24), show that in 1978 the highest dose to an individual came from the Bradwell discharges and was less than 1 mrem.

The dose to the critical group from the consumption of fish from Lake Trawsfynydd was less than 10 mrem.

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 represent the maxium 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, as regards liquid effluent.

2.3.1 Gaseous Effluents

Bryant (11) has presented estimates of the doses resulting from the
1976 Windscale discharges to atmosphere; separate estimates of the
doses from 1975 discharges were presented at the Windscale Inquiry (25).
Comparison of these two presentations is not strainghtforward but it
would appear that there are significant differences in the discharge/
dose relationships. No information is given as to the models (and
parameter values) and/or district survey results used to obtain the
values presented at the Inquiry; in the absence of such information
Bryant's results have been extrapolated to model the effects of the
1978 discharges and reference made to the corresponding district sur-
vey results where available.

Bryant distinguishes between discharges from high and low level stacks
but the 1978 data only indicate total discharges; it has been necessary,
therefore to assume the relative contributions from these stacks as be-
ing unchanged despite, for example, increased caesium activity being
associated with a single source (see Section 1.3.2.2). For iodine-129
tritium and carbon-14, Bryant uses Kelly's specific activity model (23)
which assumes half the food and water intake to have a specific ac-
tivity equivalent to the average value over a 50 km radius from the
point of intake and half to be uncontaminated. In all cases the re-
lease rates are assumed to be constant over the year with a uniform
wind rose and an atmospheric stability pattern typical of the United
Kingdom; wet deposition is taken into account.

Extrapolation to the 1978 discharges gives the following results :

Nuclide	Discharge 1978 (Ci)	Route	Critical organ	Committed Dose (mrem)		
				at 200 m	at 1 km	at 5 km
Krypton-85	7×10^5	Direct from plume External radiation	Skin	-	1.5	0.55
Total alpha (Pu-239 assumed)	0.036	Inhalation	Endosteal cells	-	1.1	0.35
Strontium-90	1.3	Wet + dry deposition Milk	Bone marrow	5.3	2.2	0.44
Caesium-137	6.5	External gamma from deposition	Whole body	-	10	1.9
		Milk	Whole body	13	5.8	1.1
Iodine-131	0.4	Milk	Thyroid	11	3.5	0.9
Iodine-129	0.07	Gnd. level airborne spec. activity model Inhalation plus ingestion	Thyroid	-	0.42	0.39
Tritium	6×10^3	Inhalation and skin absorption, plus ingestion	Whole body	-	0.02	0.01
Carbon-14	1.1×10^2	Inhalation plus ingestion	Body fat	-	0.06	0.05

It should be noted that the above refer to the committed doses from the 1978 discharges alone; district survey results on the other hand may reflect residual contributions from previous years' discharges to environmental concentrations.

The 1978 milk monitoring results are given in reference (13) for two categories of farm, those within 3.2 km of the site and those at between 3.2 and 6.4 km. Converting the published results (expressed as fractions of the ICRP 2 dose limits) to doses in mrem and correcting strontium-90 and caesium-137 levels by substracting the background from weapons tests

Distance from site (km)	Dose from milk pathway, 1978 (mrem)		
	Sr-90 (bone marrow)	Cs-137 (whole body)	I-131 (thyroid)
< 3.2	12.5	2.5	13.5
3.2 - 6.4	2.5	0.5	7.5

Bearing in mind the limited extent to which the results from the model can be directly compared with those from environmental monitoring, the agreement is reasonable.

The results of monitoring plutonium alpha activity in air at 0.8 km, 3 km and 6 km as given in the same reference, (13), appear to indicate higher doses than those which would be implied by the model but on the information available it is not possible to attribute the source(s) of the discrepancy.

Plutonium-241 is not accounted for in the discharges to atmosphere but the activity in liquid effluent was about thirty times that of the alpha-emitting plutonium isotopes in 1977-78. Assuming the same relationship for discharges to atmosphere would imply additional doses of about 60 % of those attributed to the alpha emitters.

2.3.2 Liquid Effluents

2.3.2.1 Windscale

For Windscale, environmental modelling need not be used to estimate external dose rates or radionuclide concentrations since in this case the levels in the environment are detectable and the results have been published e.g. (13, 26). Thus many, though not all, of the sources of uncertainty present in estimates of exposure around most sites have been eliminated. However, it must again be borne in mind that the environmental contamination levels measured in 1978 may reflect not only the effects of discharges in that year but also the cumulative influence of discharges in previous years. Two types of exposure pathway are considered : exposure to external radiation from sediments and internal exposure from the consumption of sea-foods.

Taking account of occupancy factors and dose rates the member of the public receiving the maximum annual exposure to external radiation

has been identified and his dose estimated at about 20 mrem in 1978, corrected for natural background.

For assessing doses received via the internal exposure pathway the sea-food consumption rates assumed have been recently updated (26). Two critical sub-groups have been identified and the consumption rates for fish, mollusca and crustacea assessed as :

Sea-food category	Critical Sub-group Consumption Rates (g/d)	
	Consumers of local produce	Consumers of landings at the nearest commercial ports
Fish	170	360
Crustacea	15	70
Mollusca	6	50

The sampling programme allows the concentrations of radioactive nuclides in each sea-food category to be assessed for each critical sub-group. Then, combining the above consumption rates with these concentrations, the results obtained (26)*, when expressed as committed doses are :

Nuclide	Whole body Committed Dose to Critical Sub-groups (mrem)	
	Local produce	Commercial landings
Sr-90	14	23
Ru-106	0.1	0.03
Cs-134	17	12
Cs-137	84	61
Pu-239/240	0.3	0.01
Am-241	0.5	0.04
All nuclides	1.2×10^2	0.95×10^2

For comparison the average consumer of fish from the nearest commercial ports would have received less than 7 mrem (almost all from caesium isotopes) from consuming 40 g/d of fish.

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* For Strontium the results are based on caesium measurements (27).

The caesium isotopes in fish gave easily the largest single contribution and it would appear from data for previous years that the concentrations in locally caught fish largely reflect the discharges in the preceding year.

Strontium-90 is the only other nuclide contributing in excess of 10 % of the totals reported. It is noteworthy that, with the higher consumption rates applicable to the critical sub-group which consumes commercially landed sea-foods, this sub-group receives a higher dose from strontium-90 than does its local counterpart; the committed doses to bone marrow for the 1978 intakes can be calculated, using reference (17), as 8 and 13 mrem for the "local" and "commercial" critical sub-groups respectively.

In addition, the committed doses to bone marrow from the transuranics, including plutonium-241, can be calculated as 43 mrem and 3.0 mrem to the critical sub-groups consuming local produce and commercial produce res-pectively. In this case the dose factors are taken from ICRP 30 (28).

The above results are all taken from or based on reference (26) and are independent of the results given in reference (13). However, the con-centrations cited, and used for the same purpose,differ. The principal effect of the latter reference would be to reduce the whole body doses quoted above by a factor of two from local produce for which a larger sampling zone is used (27). Whole body monitoring of a local consumer (25) indicated that the assumptions used in reference (26) can in practice overestimate the dose from caesium-137 by a factor of two to three.

Doses from tritium are not discussed in either reference but can be shown to be at most of the order of 10^{-2} mrem for the 1978 discharges.

2.3.2.2 Marcoule

In the table below, the committed doses calculated for the Marcoule 1978 discharges, taking account of local conditions, are presented together with the assumed consumption rates and exposure times, as appropriate, to the various pathways.

Exposure pathway	Average consumption rate (kg/a) or exposure time (h/a)	Committed Dose (mrem)	
		bone marrow	whole body
Internal exposure :			
Drinking water	440	0.1	0.05
Fish	1.3	0.01	0.1
Milk (child)	250	0.1	0.3
Meat	75	0.01	0.01
Crops	280	3	1
External exposure :			
Swimming and boating	8		2×10^{-4}
Exposure on river banks	2		4×10^{-3}

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
whole body dose could have been of the order of a mrem. On the other
hand, it is unlikely that the consumption of crops and meat will have
consisted entirely of local produce and hence the doses will have been
correspondingly reduced for these pathways.

3. DISCUSSION AND CONCLUSIONS

3.1 SIGNIFICANCE OF EXPOSURES FROM EFFLUENT RELEASES IN RELATION TO RADIOLOGICAL PROTECTION STANDARDS AND NATURAL RADIATION

Although in Section 2 various models have been used to evaluate radioactive discharges in terms of dose, all the results cited concerning internal exposure refer in effect to committed doses resulting from total intakes in 1978 and in later years solely from the 1978 discharges. The committed dose designates the total dose which would be incurred in the 50 year period following the intake.

Exceptionally, the results quoted for Windscale take account of environmental samples representing intakes in 1978 alone which often reflect discharges from previous years but not the effect of the 1978 discharges on future years. If, however, variations from year to year in Windscale discharges are neglected then, to a first approximation, the calculated doses are numerically equivalent to the committed doses from 1978 discharges.

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 and with exposure from natural radiation.

Application of annual dose limits to committed doses allows for the possible cumulative effects of similar committed doses being incurred in other years.

3.1.1 Significance in Relation to the Radiological Protection Standards

Since insufficient data are available to apply the concept of effective dose (29, 30, 31) in all cases (see below), the critical organ approach has been used in Section 2 to express the assessment of radiation exposure. The limits (32) corresponding to this approach are :

- 0.5 rem/year to the whole body,
- 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.

Comparison with the committed doses calculated in Section 2 then gives
the following results.

Nuclear Power Stations

For members of the population in the immediate vicinity of the nuclear
power stations, i.e. at 0.5 km, exposure resulting from discharges to
atmosphere were as follows :

- doses resulting from external irradiation by gaseous discharges did not
  exceed in general 0.2 % and 0.04 % of the respective dose limits to the
  whole body and to the skin. For British GCRs doses could have been up
  to 10 % of the whole body limit in one case on the basis of the model
  and assumptions adopted; in practice, an upper bound of 1 % is likely;

- doses resulting from inhalation of radioactive aerosols and iodine-131
  were less than 0.02 % and 0.01 % of the respective limits for the lung
  and for the child's thyroid;

- doses to the thyroid of an infant consuming milk produced near nuclear
  power stations were, with one exception (1.3%),less than 0.7 % of the
  dose limit; doses to the whole body from sulphur-35 in milk were less
  than 0.5 % of the limit;

- doses from the uptake of tritium and carbon-14 discharged to atmosphere
  were less than 0.05 % and 0.001 % of the respective dose limits for the
  whole body and body fat.

At 5 km from the power stations, 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 never greater than 2 % of the dose limits and in almost
all cases will have been very much less.

Nuclear Fuel Reprocessing Plants

Discharges to atmosphere from Windscale, on the basis of the model used, implied the following committed doses in relation to the limits for members of the population at 1 km :

- 3   % of the limit to the whole body (caesium-137)
- 0.1   % of the limit to bone marrow (strontium-90)
- 0.05 % of the limit to skin (krypton-85)
- 0.3   % of the limit to the infant thyroid (iodine-129/131)
- 0.1   % of the limit to the endosteal cells (plutonium-239)
- 0.004% of the limit to body fat (carbon-14).

Caesium-137 is clearly the most significant individual nuclide, giving rise by deposition to direct external radiation and, via the ingestion of milk, to internal radiation. In any year measured values of caesium in milk are influenced by earlier discharges, particularly those in the preceding year. However, the 1977 and 1978 discharges were little different and thus the results obtained by milk monitoring in 1978, as given in Section 2.3.1, should give a reasonable indication of total committed doses to be attributed to caesium discharges in 1978. On this basis the monitoring results would imply that the model is pessimistic in respect of this nuclide, possibly by a factor of four.

For liquid effluent discharges from Windscale the results are based on environmental monitoring. Again previous years' discharges influence the results but annual caesium discharges changed little in the period 1976-78. Reference (26) indicates that members of the critical group consuming local sea-food produce incurred

- 23 % of the whole body limit

and that members of the group consuming commercial produce incurred

- 19 % of the same limit.

In both cases some 70 % of the committed dose is attributable to caesium-137. Whole body monitoring of local consumers (25) suggests that the whole body dose may be overestimated by a factor of two to three.

Extension of the dose calculations for strontium-90 and the transuranics further suggests that, in 1978, the critical group consuming local produce incurred

- 10 % of the committed dose limit to bone marrow

and the critical group consuming commercial products

- 3 % of the same limit.

For the other NFRPs doses to members of the population will have been substantially less in view of the generally much lower quantities of radioactivity in liquid and gaseous effluents even although Marcoule and WAK liquid effluents are discharged to rivers and hence are not so rapidly dispersed.

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The effective dose approach was first quantified in ICRP 26 (30) and has now been taken up in a Directive of the European Community (31). It is "based on the principle that the risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation", and provides for the weighting of the average dose to any single tissue in order to equate the "risk from that tissue to the total risk when the whole body is irradiated uniformly" (30). Thus on summing the weighted doses to individual tissues the effective dose obtained is a measure of the risk to the whole body; a common limit, 0.5 rem per year for a member of the public, is given for the committed effective dose and for uniform whole body irradiation. Additionally, for members of the public, a limit of 5 rem per year is applied to the unweighted committed dose to any single tissue other than the lens of the eye, for which the limit is 3 rem (31).

To apply the limits on committed effective dose in the case of ingested or inhaled radioactive material it is necessary to have a knowledge of the subsequent distribution of the material throughout the body and the committed dose to each organ and this will vary with, in particular, the age group concerned. The necessary data have been published collectively, in respect of all the most important nuclides for intakes by adults (29, 33) but not for children. Hence where children are involved, for example in the milk pathway, any calculation of the committed effective dose would have to rely on data which have not received general recognition.

However, in the case of liquid effluent discharges from Windscale this problem does not arise and hence this case can be used to illustrate the consequences of applying the ICRP 26 approach and the associated dosimetry

data. Reference 26 reports the results thus obtained using the Windscale 1978 intake data; these results are given in the table below together with, for comparison, those given in the same reference using the earlier ICRP 2/ICRP 9 approach as reported in Section 2.3.2.1 above

Nuclide	Committed Dose to Critical Group as a Percentage of the Limit			
	Consumers of Local Produce		Consumers of Commercial Produce	
	ICRP 9	ICRP 26	ICRP 9	ICRP 26
Sr-90	2.8	0.6	4.5	0.9
Ru-106	0.02	1.5	0.005	0.4
Cs-134	3.4	2.0	2.4	1.4
Cs-137	16.8	16.8	12.1	12.1
Pu-239/240	0.05	0.9	0.002	0.04
Am-241	0.1	3.7	0.008	0.2
Total	23	26	19	15

It will be observed that the overall effect is little different since the result for caesium-137, the most important nuclide in both cases, is the same. As regards the other individual nuclides, however, appreciable differences are evident.

In the presence of the transuranics and strontium the dose to bone surfaces in relation to the limit of 5 rem to any individual organ as adopted in the new approach could be of greater importance than the effective dose. However, using the intake data in reference (26) in conjunction with ICRP 30 (29) and allowing for Pu-241 on the basis of 1978 plutonium discharges, it can be calculated that the dose to bone surfaces was, for the critical group consuming local produce, some 10 % of the limit and much less for the critical group consuming commercial produce. Hence the effective dose is of greater significance in this case. The principal contribution to the dose to bone surfaces is that from americium-241 and the principle pathway component is mollusca.

3.1.2 Significance in Relation to the Exposure from Natural Radiation

In areas of average radiation background, the annual absorbed dose from natural sources is estimated to be of the order of 100 mrem. In total, some 90 % of this dose is accounted for by the ionizing component of cosmic radiation, terrestrial radiation (gamma) and potassium-40 incorporated in the body (35).

Comparison with the maximum exposure levels resulting from radioactive effluents discharged by the nuclear installations covered in this report shows that the latter generally account for less than 5 % of the average exposure from natural sources. Thus the radiological burden imposed by these installations lies well within the margin of regional and temporal variations in natural radiation exposure levels.

Of particular interest in the present context is the enhanced exposure from natural radiation arising from the production of electricity by coal-fired power stations insofar as such stations release to the atmosphere some fraction of the naturally radioactive material present in coal. Actual discharges will depend on the nature of the coal and on the effluent treatment system in use but published estimates (e.g. 36, 37) tend to indicate that the radiological significance of discharges to atmosphere lies in the same range for the two types of power station.

3.2 CONCLUSIONS

As regards nuclear power stations, a steady overall downward trend both in authorisations to discharge and in actual discharges can be observed; particularly in the case of light water reactors. For PWRs, figure 1 shows how releases of noble gases have fallen from an average of 25 Ci/MWa in 1970 to 2 Ci/MWa in 1978; from Figure 4 liquid effluents can be seen to have fallen from 2.2×10^{-2} to 6×10^{-3} Ci/MWa over the same period. This downward trend is even more pronounced when discharges from older light water reactors are compared with those from the corresponding reactors of more recent design.

Consequently there will have been a corresponding reduction in the exposure of members of the population, although this is less obvious from the Commission reports in the present series since the dose estimates given

are based on a combination of the maximum recorded individual discharges and the least favourable receiving environment. Nevertheless, the present report shows that exposure of the public in 1978 was extremely low; the most exposed individuals seldom received more than 1 % of the dose limit i.e. some 5 % of the average exposure from natural radiation.

Compared with nuclear power stations, nuclear fuel reprocessing plants are few in number and hence general trends in discharge levels and doses are not present. Discharges from and throughput at Windscale being as high as or higher than those for other plants, the radiological consequences are of special interest; correspondingly the relevant data are particularly well documented. Taking account of measurements it appears that for Windscale discharges the exposure of members of some critical groups in 1978 was some 10 % of the limit. Although this leaves a considerable margin of safety and the exposure incurred still lies within the range of variations in exposure from natural radioactivity, improvements are in hand to significantly reduce the discharges.

Hence the doses received by members of the public as a result of effluents from nuclear power stations and fuel reprocessing plants in the Community have been kept to a fraction, often a minute fraction, of the admissible limits and are comparable with the differences in exposure from natural radiation background which are experienced in everyday life.

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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
Doel 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	183 (c)	20.05.68	Ems
Lower Saxony					
Obrigheim	PWR	1 050	345	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	3 515	1 089	25.08.74	} Rhine
Biblis B	PWR	3 733	1 178	25.04.76	
Hesse					
Neckarwestheim	PWR	2 497	810	03.06.76	Neckar
Baden-Wurtemberg					
Brunsbüttel	BWR	2 292	770	13.07.76	Elbe
Schleswig-Holstein					
Isar	BWR	2 575	870	03.12.77	Isar
Bavaria					
Unterweser	PWR	3 733	1 230 (d)	29.09.78	Weser
Lower Saxony					

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-2	GCR	848	210	24.02.65	⎰ Loire
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	⎰
Tr-2	PWR	2 785	925	10.05.78	⎬ Rhône
Tr-3	PWR	2 785	925	21.09.78	⎭
St-Vulbas, Ain					
Phénix	FBR	563	233	13.12.73	Rhône
Marcoule, Gard					
Fessenheim					
Tr-1	PWR	2 660	890	06.04.77	⎰ Rhine
Tr-2	PWR	2 660	890	07.10.77	⎱
Haut-Rhin					
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	260	22.10.64	Po
Trino Vercellese, Vercelli					
Caorso	BWR	2 651	548 (d)	23.05.78	Po
Plaisance					
NETHERLANDS					
Dodewaard	BWR	163	51.5	25.10.68	Waal
Gelderland					
Borssele	PWR	1 365	445	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	Solvay Firth
Bradwell Essex	GCR	2 x 531	250	06.62	Blackwater Estuary
Berkeley Gloucestershire	GCR	2 x 555	276	06.62	Severn Estuary
Hunterston A Hunterston B Ayrshire	GCR AGR	2 x 535 2 x 1 270	300 1 000 (d)	02.64 06.02.76	} Firth of Clyde
Trawsfynydd Gwynedd	GCR	2 x 860	390	12.64	Lake Trawsfynydd
Hinkley Point A Hinkley Point B Somerset	GCR AGR	2 x 971 2 x 1 493	430 800	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 1 500	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) Interim rating.

TABLE II

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

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
BELGIUM						
Doel 1 + 2	4×10^4	-	208	822	759	469
Tihange 1	4×10^4	n.a.	466	4 606	1 480	1 577
GERMANY						
HZFR	3×10^3	949	1 116	985	316	411
Gundremmingen	4×10^4	4 145	7 440	5 280	250	230
Lingen	$< 10\ 500$	35 000	6 400	133	6	
Obrigheim	2×10^4	13 456	8 010	328	370	455
Würgassen	3.2×10^4	52	121	482	785	3 268
Stade	3×10^4	890	1 260	10 500	3 320	490
Biblis A	9×10^4	61.5	1 680	1 200	106	362
Biblis B	9×10^4	n.a.	n.a.	304	4 100	1 768
Neckarwestheim	2.4×10^4	n.a.	n.a.	634	1 880	117
Brunsbüttel	7×10^4	n.a.	n.a.	970	3 130	7 568
Isar	9×10^4	n.a.	n.a.	n.a.	23	1 070
Unterweser	2.4×10^4	n.a.	n.a.	n.a.	n.a.	53
FRANCE						
Chinon	(6×10^3) (1)	2 082	6 050	4 924	3 920	2 530
Chooz	(7×10^3) (1)	1 462	2 700	4 945	2 800	3 230
Monts d'Arrée		164 460	196 000	242 978	200 000	196 240
St-Laurent-des-Eaux	(8×10^3) (1)	4 338	3 480	2 893	4 200	6 750
Bugey 1	(4×10^4) (a)	4 475	5 280	3 080	2 400	2 890
Bugey 2 + 3		n.a.	n.a.	n.a.	n.a.	110.5
Phénix (b)	8.4×10^4	-	170	234	128,5	136
Fessenheim 1 + 2	4×10^4	n.a.	n.a.	n.a.	1 900	1 972
ITALY						
Latina	5×10^3 (c)	3 011	2 591	2 478	2 413	2 613
Garigliano	6.3×10^5 (d)	250 000	228 541	239 486	89 946	68 158
Trino (e)	5×10^4	7 000	457	179	59	532
Caorso	5×10^3 (f)	n.a.	n.a.	n.a.	n.a.	91

TABLE II (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
NETHERLANDS						
Dodewaard	7×10^5 (g)	4 160	2 109	6 230	13 013	4 302
Borssele	1.2×10^4	5 830	2 609	3 897	999	416
UNITED KINGDOM (h)	(i)					
Calder (m)		40 000	30 000	30 000	26 000	29 000
Chapelcross			32 000	32 000	32 000	32 000
Bradwell				18 000	18 000	16 000
Berkeley				16 000	15 000	12 000
Hunterston A (k)				15 000	15 000	20 000
Hunterston B		n.a.	n.a.	2 000	6 000	4 400
Trawsfynydd				150 000	150 000	130 000
Hinkley Point A				80 000	80 000	80 000
Dungeness A				30 000	30 000	30 000
Sizewell A				60 000	60 000	60 000
Winfrith (j)	3.24×10^5			17 900	16 670	25 280

(a) Overall limit for Bugey site, instituted in 1978.

(b) Activity expressed in Xe-135 equivalent.

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

$$\frac{Q \ (A\text{-}41)}{5\times10^3} + \frac{Q \ (H\text{-}3) + Q(\text{other noble gases expressed in Xe-133 equivalent})}{10^2} \leqslant 1 \ Ci/a$$

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

(d) Equivalent to 0.02 Ci/s, the actual authorised limit.

(e) Limit and discharges expressed in Xe-133 equivalent; for comparison the sum of the activities of the nuclides present in the 1978 discharge (see Table III) is only 109 Ci.

(f) The complete discharge formula which applies is :

$$Q_0' + 0.2 \ Q_{60} + 0.1 \ Q_{75} \leqslant 5 \ 000 \ Ci/a$$

in which Q_0 is the activity (Ci/a) discharged at ground level, Q_{60} at a height of 60 m and Q_{75} at 75 m.

(g) Under revision.

(h) The quantities of discharged radioactive gases from GCRs are not measured routinely. A limited number of measurements, adjusted for average load factors, indicate the A-41 annual discharges given in the table.

(i) Authorisations 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. Quantified limits are being prepared.

(j) Limit and discharges given in Curie-MeV.

TABLE II (continued 2)

(k) Estimated values.

(1) Limit instituted subsequent to 1978.

(m) Discharges include a contribution from the adjacent Windscale AGR (24 MW).

TABLE III

RADIONUCLIDE COMPOSITION (%) OF NOBLE GAS DISCHARGES IN 1978 (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
BELGIUM												
Tihange 1 (b)		0.03	0.1	-	0.04		95.2	1.3	3.3			
GERMANY												
Lingen (e)		x										
Obrigheim	x						x					
Würgassen (d)	<0.03	6.1	0.7	2.2	1.7	5.0	23.5	0.6	17.3	12	12.8	4.0
Stade	0.4	11.3	8.4	0.4	7.8	0.4	35.5	8.0	26.6	0.4	0.4	0.4
Biblis A	0.06	-	0.03	-	0.03	0.03	94.0	0.6	4.8	0.03	0.06	0.03
Biblis B	0.02	-	0.07	6×10^{-3}	0.05	6×10^{-3}	84.7	11.6	3.3	0.02	0.01	6×10^{-3}
Neckarwestheim	29.4	-	1.6	0.3	1.2	0.6	42.8	-	20.9	2.1	0.6	0.5
Brunsbüttel	0.1	23.4	2.7	3.0	2.7	8.4	32.1	1.2	12.5	7.5	4.1	2.4
Unterweser							x					
FRANCE												
Chinon	x											
Chooz												
Monts d'Arrée	x											
St-Laurent-des-Eaux	x											
Bugey 1	x											
ITALY												
Latina	99.7	2×10^{-2}	3×10^{-3}	1×10^{-2}	3×10^{-3}	-	0.2	-	8×10^{-2}	-	-	-
Garigliano (c)			6.9	12.2	11.7		17		27.5	6		18.7
Trino	53.1	6.5	13.6				20.9	1.4×10^{-3}	5.9			
NETHERLANDS												
Dodewaard		-	9.0	4.6	15.5	-	29.1	0.3	41.5	-	-	-
Borssele		1					74		25			
UNITED KINGDOM												
GCR and AGR Power stations	x											

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

(b) Concerns discontinuous discharges only (from reactor building and gas storage tanks), i.e. 45 % of total.

(c) Data for 1976.

(d) + 14 % unspecified nuclides.

(e) Shutdown since January, 1977.

TABLE IV

ANNUAL DISCHARGE OF TRITIUM TO ATMOSPHERE (a)
FROM NPSs

Facility	Discharge Limit (Ci/a) (a)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
GERMANY						
MZFR	4 000	1 099	765	703	1 019	1 038
Gundremmingen		∿ 200	∿ 100	27.2	7	∿ 1
Lingen			∿ 30	6	5.3	-
Obrigheim		11.5	27	62.3	23	26
Würgassen			∿ 2		6	-
Stade		11.1	15	21	16	27
Biblis A			13	9.5	16	51
Biblis B		n.a.	n.a.	3.5	18	11
Neckarwestheim		n.a.	n.a.	2	25	28
Brunsbüttel		n.a.	n.a.	0.5	4.8	6.4
Isar	500	n.a.	n.a.	n.a.	-	1.5
Unterweser		n.a.	n.a.	n.a.	n.a.	-
FRANCE						
Monts d'Arrée		1 756	2 860	1 395		
Phénix		-	8.2	10.8		
Bugey 1						0.5
Bugey 2 + 3		n.a.	n.a.	n.a.	n.a.	1
ITALY						
Latina	100(b)		2.8	2.7	3.1	0.3
Garigliano	100(c)		0.74	14.7	13.3	6.4
Trino		7.3	3.7	16.3		48.8
NETHERLANDS						
Borssele	50	9	12	9	10	25
UNITED KINGDOM						
Hunterston A						72.3
Hunterston B		n.a.	n.a.	45.6		81.8
Oldbury (d)		12	10	7	8	5
Winfrith	1.8×10^4	283	268	775	602	386

(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 few stations have a specific discharge limit imposed.

TABLE IV (continued 1)

(b) See foot-note (c) to Table II.

(c) See foot-note (f) to Table V.

(d) Discharges cited are specific to conditioning of the reactor gas circuit after shutdown.

TABLE V

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (BETA) FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
BELGIUM						
Doel 1 + 2	2	-	1.8×10^{-1}	2.1×10^{-1}	1.7×10^{-1}	1.8×10^{-1}
Tihange 1	2	n.a.	-	4.8×10^{-5}	3.0×10^{-2}	8.6×10^{-2}
GERMANY	(a)					
MZFR		1.3×10^{-3}	-		6.6×10^{-4}	9.2×10^{-4}
Gundremmingen	2	2.0×10^{-3}	8×10^{-3}	5×10^{-3}	7.4×10^{-3}	4.0×10^{-3}
Lingen		6×10^{-3}	1×10^{-2}	5×10^{-4}	1.9×10^{-3}	1.5×10^{-3}
Obrigheim	0.5	2.3×10^{-2}	2.5×10^{-2}	8.0×10^{-3}	6.6×10^{-3}	4.2×10^{-3}
Würgassen	10.5	1.3×10^{-2}	1.1×10^{-2}	1.7×10^{-2}	3.8×10^{-2}	$\leqslant 5.6 \times 10^{-2}$
Stade	8.75	1.4×10^{-2}	3×10^{-2}	7×10^{-3}	8.9×10^{-3}	1.9×10^{-2}
Biblis A	3.25	8×10^{-4}	6×10^{-3}	2.8×10^{-2}	1.5×10^{-3}	1.2×10^{-5}
Biblis B	3.25	n.a.	n.a.	2×10^{-3}	4.0×10^{-3}	2.2×10^{-5}
Neckarwestheim	0.5	n.a.	n.a.	5.0×10^{-4}	1.6×10^{-2}	5.0×10^{-3}
Brunsbüttel	17.5	n.a.	n.a.	7×10^{-3}	7.3×10^{-2}	3.7×10^{-2}
Isar	1.5	n.a.	n.a.	n.a.	3.0×10^{-5}	4.2×10^{-3}
Unterweser	0.125	n.a.	n.a.	n.a.	n.a.	3.2×10^{-4}
FRANCE (b)						
Chinon	(0.1) (c)	5.2×10^{-3}	1.0×10^{-2}	1.8×10^{-2}	1.3×10^{-2}	1.3×10^{-2}
Chooz	(0.2) (c)	5.8×10^{-3}	2.4×10^{-3}	1.7×10^{-3}	9.3×10^{-2}	1.2×10^{-2}
Monts d'Arrée		5.4×10^{-2}	3.8×10^{-2}	4.9×10^{-3}	2.7×10^{-2}	7.6×10^{-3}
St-Laurent-des-Eaux	(0.2) (c)	3.1×10^{-3}	1.3×10^{-3}	1.9×10^{-3}	6.3×10^{-3}	4.3×10^{-3}
Bugey 1	} 2 (d)	1.4×10^{-2}	1.7×10^{-3}	8×10^{-3}	7.5×10^{-3}	1.8×10^{-2}
Bugey 2 + 3		n.a.	n.a.	n.a.	n.a.	1.6×10^{-3}
Phénix		-	1.8×10^{-5}	1.6×10^{-5}	3.9×10^{-5}	7.6×10^{-5}
Fessenheim 1 + 2	3	n.a.	n.a.	n.a.	-	1.8×10^{-2}
ITALY						
Latina (e)	0.1	4.8×10^{-4}	1.1×10^{-3}	1.2×10^{-4}	1.8×10^{-4}	1.6×10^{-5}
Garigliano (f)		$< 1 \times 10^{-3}$	3.6×10^{-1}	3.2×10^{-2}	2.0×10^{-2}	1.4×10^{-2}
Trino (e)	0.2	7.6×10^{-5}	7×10^{-7}	-	3.1×10^{-5}	2.8×10^{-5}
Caorso (g)	0.008	n.a.	n.a.	n.a.	n.a.	1.4×10^{-6}

TABLE V (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1974	1975	1976	1977	1978
NETHERLANDS						
Dodewaard	0.2 (h)	4.8×10^{-3}	5.9×10^{-3}	3.6×10^{-3}	3.1×10^{-3}	9.4×10^{-4}
Borssele	1	6.6×10^{-4}	1.8×10^{-3}	1.3×10^{-4}	6.7×10^{-4}	1.4×10^{-5}
UNITED KINGDOM	(i)					
Calder (j)						
Chapelcross (j)						
Bradwell		4×10^{-3}	3×10^{-3}	3×10^{-3}	3×10^{-3}	4×10^{-3}
Berkeley		4×10^{-3}	4×10^{-3}	3×10^{-3}	3×10^{-3}	2×10^{-3}
Hunterston A				1×10^{-2} (j)	1×10^{-2} (j)	1×10^{-2} plus 1.96 S-35
Hunterston B		n.a.	n.a.	7×10^{-3} (j)	7×10^{-3} (j)	5×10^{-4} plus 8.7 S-35
Trawsfynydd		2.6×10^{-2} (k)	1.1×10^{-2}	1.3×10^{-2}	1.8×10^{-2}	1.0×10^{-2}
Hinkley Point A		4.2×10^{-2} (k)	1.1×10^{-2}	1.3×10^{-2}	1.0×10^{-2}	1.1×10^{-2}
Hinkley Point B		n.a.	n.a.	1.9×10^{-2} plus 5.7 S-35	1.8×10^{-2} plus 5.7 S-35	3.0×10^{-2} plus 5.5 S-35
Dungeness A		9.0×10^{-2} (k)	5.4×10^{-2} (k)	1.9×10^{-2}	1.1×10^{-2}	1.4×10^{-2}
Sizewell A		8×10^{-3}	1.0×10^{-2}	1.1×10^{-2}	1.5×10^{-2}	1.3×10^{-2}
Oldbury (1)		1.5×10^{-1} (k) plus 0.67 S-35	3.5×10^{-2} (k) plus 1.6 S-35	2×10^{-3} plus 1.4 S-35	3×10^{-3} plus 0.46 S-35	2×10^{-3} plus 0.76 S-35
Winfrith		1.5×10^{-1}	3.8×10^{-2}	1.4×10^{-1}	-	-
Wylfa (1)		4×10^{-3}	4×10^{-3} plus 2.0 S-35	8×10^{-3} plus 2.4 S-35	1.0×10^{-2} plus 5.5 S-35	1.0×10^{-2} plus 4.7 S-35

(a) Limits for nuclides with $T1/2 > 8$ d.

(b) Limits and discharges comprise aerosols and gaseous halogens.

(c) Limit instituted subsequent to 1978.

(d) Overall site limit, instituted in 1978.

(e) Limits and discharges for Latina and Trino are expressed as Sr-90 equivalent.

(f) The limiting overall discharge formula applied is :

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

in which Q is the activity discharged in Ci/a, Q(alpha) is expressed in Pu-239 equivalent, and

TABLE V (continued 2)

Q(other particulates) in Cs-137 equivalent. The discharges are,however, the sum of the individually measured radionuclides.

(g) The limiting discharge formula is :

$$Q_0 + 0.2 \, Q_{60} + 0.1 \, Q_{75} \leqslant 0.008 \text{ Ci/a}$$

in which Q_0 is the activity (Ci/a) discharged at ground level, Q_{60} at a height of 60 m and Q_{75} at 75 m. The limit and discharges are expressed as Sr-90 equivalent.

(h) Under revision.

(i) 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. Quantified limits are being prepared.

(j) Estimated discharges.

(k) Early results are based on samples collected using charcoal impregnated papers and can therefore include a contribution from S-35 etc. in vapour form. This practice ceased early in 1975.

(1) Oldbury and Wylfa S-35 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)				
		1974	1975	1976	1977	1978
BELGIUM						
Doel 1 + 2	0.2	-	2.6×10^{-4}	5.0×10^{-3}	2.4×10^{-3}	-
Tihange 1	0.2	n.a.	5.7×10^{-4}	2.0×10^{-2}	2.2×10^{-3}	1.0×10^{-2}
GERMANY						
MZFR					5×10^{-5}	-
Gundremmingen	0.5	0.12	0.25	0.35	5×10^{-3}	7.6×10^{-5}
Lingen		2×10^{-3}	1.3	5×10^{-2}	1.4×10^{-3}	2×10^{-5}
Obrigheim	0.5	4.9×10^{-3}	1.1×10^{-2}	2×10^{-3}	6.0×10^{-4}	7.0×10^{-4}
Würgassen	0.26	$< 7 \times 10^{-4}$	1.4×10^{-3}	4.6×10^{-2}	2.8×10^{-2}	0.11
Stade	2.6×10^{-2}	1.1×10^{-2}	1×10^{-2}	2×10^{-2}	2.6×10^{-2}	3.7×10^{-3}
Biblis A	0.7	6.3×10^{-5}	5×10^{-3}	1.3×10^{-2}	5.0×10^{-4}	9.0×10^{-3}
Biblis B	0.7	n.a.	n.a.	9.7×10^{-3}	3.5×10^{-3}	7.0×10^{-3}
Neckarwestheim	0.25 (a)	n.a.	n.a.	2×10^{-3}	4.6×10^{-2}	7.0×10^{-3}
Brunsbüttel	0.26	n.a.	n.a.	2×10^{-5}	1.5×10^{-2}	6.9×10^{-3}
Isar	0.5	n.a.	n.a.	n.a.	-	-
Unterweser	0.125	n.a.	n.a.	n.a.	n.a.	2×10^{-5}
FRANCE (b)						
ITALY (c)						
Latina	1×10^{-3}	$< 5.5 \times 10^{-5}$	2.3×10^{-5}	2.5×10^{-5}	-	1.8×10^{-5}
Garigliano	1.0	2.4×10^{-2}	1.6×10^{-2}	3.5×10^{-2}	1.5×10^{-2}	2.5×10^{-2}
Trino	0.05	6.4×10^{-7}	4.7×10^{-5}	7.3×10^{-7}	9×10^{-5}	4.2×10^{-5}
Caorso	0.1 (d)	n.a.	n.a.	n.a.	n.a.	1.3×10^{-3}
NETHERLANDS						
Dodewaard (e)	(f)	9.5×10^{-3}	5.2×10^{-3}	4.5×10^{-3}	6.2×10^{-3}	4.4×10^{-3}
Borssele	0.24	3.4×10^{-2}	1.4×10^{-2}	8.3×10^{-3}	3.5×10^{-3}	2.1×10^{-4}
UNITED KINGDOM (g)						
Hinkley Point B		n.a.	n.a.	$< 1.4 \times 10^{-2}$	$< 1.6 \times 10^{-2}$	$< 1.8 \times 10^{-2}$
Winfrith	2.16			0.13	0.15	0.13

(a) 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).

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

TABLE VI (continued 1)

(c) Limits and discharges given for Latina, Trino and Caorso apply to halogens in I-131 equivalent. For Gargliano, see foot-note (f) to Table V.

(d) The following discharge formula is applied :

$$Q_0 + 0.2 \, Q_{60} + 0.1 \, Q_{75} \leqslant 0.1 \, Ci/a$$

in which Q_0 is the activity (Ci/a) discharged at ground level, Q_{60} at a height of 60 m and Q_{75} at 75 m.

(e) "Halogen" results.

(f) No official limit laid down.

(g) Since defective fuel can be removed on-load from UK Magnox and AGR reactors as soon as it is detected routine measurements of the iodine discharges are in general negligible as illustrated by the results for Hinkley "B" for which no sample was above the limit of detection. Again, for such reactors, quantified limits, although in preparation, are not yet applied; the present criterion is to use the best practicable means to minimize discharges.

TABLE VII

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

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
BELGIUM (a)						
Doel 1 + 2	(24)	2.0	10.3	49.8	16.9	18.8
Tihange 1	(8)	n.a.	0.38	0.83	3.58	1.95
GERMANY						
MZFR (b)						
Gundremmingen	14.6	0.93	1.26	1.16	1.72	0.53
Lingen	5.4	0.03	0.04	0.26	0.01	0.01
Obrigheim	5	3.05	1.72	0.98	0.26	0.17
Würgassen	6.7	1.45	1.86	1.12	1.56	0.53
Stade	5	0.39	0.27	0.33	0.37	0.10
Biblis A	10	0.6	0.74	0.22	0.10	0.13
Biblis B	10	n.a.	n.a.	0.29	0.03	0.12
Neckarwestheim	1	n.a.	n.a.	0.24	0.15	0.03
Brunsbüttel	5	n.a.	n.a.	2.23	1.64	1.41
Isar	5	n.a.	n.a.	n.a.	0.04	0.21
Unterweser	2	n.a.	n.a.	n.a.	n.a.	-
FRANCE						
Chinon	(4) (c)	0.40	0.65	0.57	0.23	0.34
Chooz	(5) (d)	8.64	8.6	2.56	2.25	0.81
Monts d'Arrée		0.05	0.05	0.03	0.04	0.03
St-Laurent-des-Eaux	(8) (c)	4.24	4.7	2.97	4.9	8.1
Bugey 1	(35) (e)	60.24	13.8	3.59	3.9	10.83
Bugey 2 + 3		n.a.	n.a.	n.a.	n.a.	9.85
Phénix (f)						
Fessenheim 2 + 3	25	n.a.	n.a.	n.a.	6.93	4.71
ITALY						
Latina	(g)	6.1	4.9	5.17	4.3	3.3
Garigliano	(h)	4.2	3.13	3.77	4.1	2.7
Trino	(i)	3.3	1.46	2.71	1.4	1.3
Caorso	(j)	n.a.	n.a.	n.a.	n.a.	0.49

TABLE VII (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
NETHERLANDS						
Dodewaard	2.6	2.16	1.25	0.34	1.1	0.42
Borssele	5	0.52	1.61	0.85	0.43	0.29
UNITED KINGDOM						
Calder (k)						
Chapelcross	700	1.2	17.3	32.4	9.7	76.5
Bradwell	200 (incl. Zn-65)	90.0	119.0	65.4	66.3	54.2
	5 Zn-65	0.1	0.1	0.2	0.3	0.2
Berkeley	200	23.1	54.0	112.0	148.0	32.0
Hunterston A	200	58.7	114.7	158.8	147.0	60.0
Hunterston B	100	n.a.	n.a.	0.6	1.2	6.0
	plus 700 S-35	n.a.	n.a.	< 0.6	< 1.2	1.2
Trawsfynydd	40 (incl. Cs-137)	19.0	17.0	20.0	13.5	17.5
	7 Cs-137	2.3	4.7	4.3	2.9	3.7
Hinkley Point A	200 (l)	125.0	159.0	138.0	120.0	110.0
Hinkley Point B	100 (l)	n.a.	n.a.	1.1	1.2	5.1
	plus 700 S-35	n.a.	n.a.	1.1	1.1	1.3
Dungeness A	200	69.0	79.5	46.3	45.3	38.1
Sizewell A	200	15.9	20.0	29.5	43.0	24.6
Oldbury	100	32.6	27.2	50.4	66.0	30.4
Winfrith (m)	3×10^{4} (n)	222	320	336	379	272
Wylfa	65	0.5	3.4	6.5	18.6	26.4

(a) Limits 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. Discharges are given in real curies; in Curie equivalent the values are :

Doel : 0.06 Ci-eq in 1974, 0.5 Ci-eq in 1975, 5 Ci-eq in 1976, 0.55 Ci-eq in 1977 and 0.67 Ci-eq in 1978.

Tihange : 0.5 Ci-eq in 1975, 0.9 Ci-eq in 1976, 3.7 Ci-eq in 1977 and 2.4 Ci-eq in 1978.

(b) MZFR liquid effluent is transferred to the decontamination centre at Karlsruhe and is not separately discharged into the Rhine (see Tables XVII to XXI - WAK discharges).

(c) Limit instituted subsequent to 1978.

(d) Limit instituted subsequent to 1978. The following discharge formula was applied previously :

$$10 \, Q(Sr-90) + Q(other \, \beta\gamma \, emitters) + 1.5 \, Q(\alpha-emitters) \leqslant 100 \, Ci/a$$

in which Q is the activity discharged in Ci/a and tritium is excluded.

(e) Overall site limit, instituted in 1978.

TABLE VII (continued 2)

(f) Phénix liquid effluent is transferred to Marcoule and is not separately discharged into the Rhône (see Tables XVII to XXI).

(g) Discharge authorization is :

$$\frac{H\text{-}3}{10^4} + \frac{P\text{-}32}{0.5} + \frac{Sr\text{-}90}{10} + \frac{Cs\text{-}134 + Cs\text{-}137}{20} + \frac{\beta\gamma}{3} + \frac{\beta}{100} + \frac{\alpha}{0.1} \leqslant 1 \text{ Ci/a}$$

where "$\beta\gamma$" is in Mn-54 curie-equivalent, "β" in Ca-45 equivalent, "α" in Pu-239 equivalent.

(h) Discharge authorization is :

$$\frac{H\text{-}3}{5\times10^3} + \frac{\beta}{1} + \frac{0.5Cs\text{-}137 + Cs\text{-}134 + 0.1Co\text{-}58 + 0.3Co\text{-}60 + 2I\text{-}131}{25} + \frac{\beta\gamma}{2} + \frac{\alpha}{1} \leqslant 1 \text{ Ci/a}$$

where "$\beta\gamma$" is in Fe-59 curie-equivalent, "β" in Sr-90 equivalent and "α" in Pu-239 equivalent.

(i) Discharge authorization is :

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

where "γ" is in Co-60 curie-equivalent.

(j) Discharge authorization is :

$$\frac{H\text{-}3}{10^3} + 10\beta + 10\alpha + \beta\gamma \leqslant 5 \text{ Ci/a}$$

where "β" is in P-32 curie-equivalent, "$\beta\gamma$" in Cs-134 equivalent, and "α" in Pu-239 equivalent.

(k) Calder liquid effluent is transferred to Windscale and is not separately discharged to the Irish Sea (see Tables XVII to XXI).

(l) There is a single site authorization for the A and B stations. The presentation above represents the subdivision in practice between the two stations.

(m) Site discharges.

(n) The limit quoted is derived from the authorized limit of 2 500 Ci per month, including tritium.

TABLE VIII

RADIONUCLIDE COMPOSITION (%) OF LIQUID EFFLUENT (EXCLUDING TRITIUM) IN 1978 FROM NPSs

Facility / Isotope	BELGIUM		GERMANY				
	Doel 1 + 2	Tihange 1 (a)	Gund-remmingen	Lingen	Obrigheim (b)	Würgassen (c)	Stade
C-14							
P-32							
S-35							
Ca-45							
Cr-51	2.3	3.9	7.8		1.9	7.09	5.8
Mn-54	3.2	4.8	9.2		1.3	0.63	1.38
Fe-55							
Co-57	0.05	0.15	0.47		0.04		0.04
Co-58	78.5	52.4	0.54		4.7	1.38	5.58
Fe-59	0.17	1.0	1.1				0.14
Co-60	15.5	13.9	42.0	8.9	50.0	12.6	24.6
Ni-63							
Zn-65		0.03	2.6			2.62	0.05
Sr-89			0.56		0.43	1.15	
Sr-90	0.02		8.8		0.08	0.09	0.27
Y-90							
Y-91							
Zr-95			1.1				1.78
Nb-95	0.12	0.26	0.78		0.14	4×10^{-3}	3.45
Ru-103			0.78		0.06		1.64
Ru-106							
Rh-106							
Ag-110m			0.47		0.84	0.17	15.7
Te-123m							
Sb-124	0.11		0.47			0.01	5.23
Sb-125			1.6				1.47
I-131		10.4	1.1		1.1	20.7	3.0
Cs-134		4.3	3.9	20.3	6.7	18.2	7.33
Cs-137	0.02	8.8	10.5	70.8	25.5	23.1	12.1
Ba-140			3.1		0.02	0.87	0.17
La-140			0.94			2.90	0.60
Ce-141			0.47			0.14	0.03
Ce-144		0.02	1.6		0.28		4.20
Pr-144							
Pm-147							
Eu-154							
Eu-155							
Alpha							

(a) Plus 0.03 % Cs-136

(b) Plus 7 % Xe-133

(c) Plus 4.6 % Xe-133

TABLE VIII (continued 1)

Facility / Isotope	GERMANY					FRANCE (d)	
	Biblis A	Biblis B	Neckar-westheim	Bruns-büttel	Isar	Chinon	Chooz (e)
C-14							
P-32							
S-35							
Ca-45							
Cr-51	0.23	0.85	8.7	7.8	22.0		46.8
Mn-54	1.91	0.15	4.6	1.8	7.9	18.2	
Fe-55							
Co-57	0.02	3×10^{-3}		0.20			
Co-58	10.1	2.6	17.1	2.6	51.0	1.13	3.08
Fe-59		0.08	0.42	0.40	1.2	1.05	0.25
Co-60	37.2	1.6	12.8	5.7	5.1		19.7
Ni-63							
Zn-65				9.6	10.6	0.92	
Sr-89	0.53	0.62	0.12	0.07	0.05		
Sr-90	0.04	0.11	0.10	0.01	2×10^{-3}	39.4	1.72
Y-90							
Y-91							
Zr-95	0.90	2.3	0.29	0.47			
Nb-95	3.48	5.5	2.0	0.38			0.12
Ru-103	1.02	2.2		0.31			
Ru-106							
Rh-106							
Ag-110m	0.40	0.39	0.56	1.7	1.6		
Te-123m	2.46	2.3	3.3				
Sb-124	19.3	23.3	43.9	0.82	0.48		
Sb-125	0.14	0.02	0.04	0.91	6×10^{-3}		
I-131	3.62	2.2	0.12	11.1			0.74
Cs-134	4.12	15.3	1.2	16.6			
Cs-137	13.5	37.3	4.6	35.4		39.4	18.5
Ba-140				1.4			
La-140	0.02			1.0			
Ce-141	0.36	0.69		0.44			
Ce-144	0.64	2.5		1.4			7.02
Pr-144							
Pm-147							
Eu-154							
Eu-155							
Alpha							

(d) The sum (S) of the activities of the radionuclides given in this table is significantly different from the beta activity (β) given in Table VII :

	Chinon	St-Laurent	Bugey 1	Chooz	Bugey 2+3	Fessenheim
S(Ci)	3.8×10^{-2}	5.54	1.73	0.81	9.85	4.71
β(Ci)	3.4×10^{-1}	8.1	10.83	0.53	4.89	2.42

For the GCRs the difference is due essentially to S-35, for the PWRs to Co-58

(e) Plus 1.60 % Na-24 and 0.49 % Tc-99

TABLE VIII (continued 2)

Facility / Isotope	FRANCE (d)				ITALY		
	St-Laurent	Bugey 1 (f)	Bugey 2 + 3 (g)	Fessenheim 1 + 2 (h)	Latina	Garigliano	Trino (i)
C-14							
P-32					0.22		0.03
S-35					1.3		
Ca-45					2.0		
Cr-51		11.0	0.10	1.89	0.29	1.1	1.1
Mn-54	0.14		0.50	6.58	0.03	2.6	24.4
Fe-55							
Co-57							
Co-58		0.52	86.8	75.4		4.1	10.6
Fe-59		0.09	0.87		0.03		1.1
Co-60	18.8	1.56	10.3	8.07	0.28	36.4	24.7
Ni-63							
Zn-65	0.61	0.17			0.12		
Sr-89					4.8	1.1	
Sr-90	16.4	52.7			45.0	0.33	0.01
Y-90							
Y-91					0.19		
Zr-95	0.61			0.13	⎰ 0.16	0.01	0.4
Nb-95	3.79	21.4			⎱	0.01	
Ru-103							
Ru-106					1.6		
Rh-106	21.9						
Ag-110m					0.12	0.01	3.5
Te-123m							
Sb-124		1.27		3×10^{-3}	0.08		20.7
Sb-125					4.7		
I-131				1.30	0.03	0.42	0.01
Cs-134					5.2	17.6	3.2
Cs-137	9.93	10.4		0.06	27.5	35.8	9.8
Ba-140					0.09	⎰ 0.48	
La-140						⎱	
Ce-141						0.09	
Ce-144	27.8		0.09		6.3	0.005	
Pr-144							
Pm-147							
Eu-154							
Eu-155							
Alpha							

(f) Plus 0.93 % Na-24

(g) Plus 1.73 % Na-24, 0.06 % Tc-99 and 0.42 % W-187

(h) Plus 0.04 % F-18, 5.73 % Na-24 and 0.01 % Tc-99

(i) Plus 0.01 % Na-24, 0.03 % Se-75, 0.1 % As-76, 0.08 % Mo-99, 0.2 % Sb-122 and 0.01 % W-187.

TABLE VIII (continued 3)

Isotope	ITALY Caorso	NETHERLANDS Dodevaard	NETHERLANDS Borssele	UNITED-KINGDOM Chapelcross	UNITED-KINGDOM Bradwell	UNITED-KINGDOM Berkeley	UNITED-KINGDOM Hunterston A (j)
C-14					< 0.05	< 0.05	
P-32	< 0.1				< 0.05	< 0.05	
S-35				6.8	11.1	11.8	10
Ca-45					1.4	0.5	
Cr-51	31.6	0.1	1.0		< 0.05	< 0.05	
Mn-54	5.2	17.2	1.4		0.1	< 0.05	
Fe-55					3.2	0.2	
Co-57			0.1				
Co-58	31.2	0.5	4.7		< 0.05	< 0.05	
Fe-59	3.0	3.4			0.1	< 0.05	
Co-60	7.0	37.1	45.7		0.9	0.1	
Ni-63					< 0.05	< 0.05	
Zn-65	15.6	0.1		0.4	0.3	< 0.05	
Sr-89	< 0.1				0.4	0.1	
Sr-90	< 0.1	0.03	{ 0.4	10.6	10.6	1.4	{ 12
Y-90					10.6	1.4	
Y-91					0.1	0.2	
Zr-95	< 0.5		0.1		0.1	0.1	
Nb-95			0.6		0.1	1.3	
Ru-103							
Ru-106			{ 0.3		0.4	0.5	
Rh-106					0.4	0.5	
Ag-110m	< 0.4		1.8		< 0.05	< 0.05	
Sb-124	0.6	0.1	4.7		0.3	< 0.05	
Sb-125			0.1		0.3	0.5	
Te-125m					0.1	0.1	
I-131	< 0.3	0.5					
Cs-134	< 0.3	8.6	7.8	13.5	9.6	14.8	10
Cs-137	< 0.3	32.5	29.6	66.2	45.7	59.3	57
Ba-140	< 0.8						
La-140							
Ce-141							
Ce-144	< 2.6		1.8	2.5	1.1	2.8	
Pr-144					1.1	2.8	
Pm-147					1.7	1.6	
Eu-154					0.1	< 0.05	
Eu-155					< 0.05	< 0.05	
Alpha	0.3			0.4	0.2	< 0.05	

(j) Plus 11 % total of Fe-55, Co-60, Zn-65, Zr-95/Nb-95, Ru-106 and Ce-144

TABLE VIII (continued 4)

Facility / Isotope	UNITED-KINGDOM						
	Hunterston B	Trawsfynydd	Hinkley Point A	Dungeness	Sizewell	Oldbury	Wylfa (k)
C-14		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
P-32		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
S-35	16	28.7	6.8	6.6	13.2	24.6	11.9
Ca-45	42	0.6	0.1	1.6	0.9	1.1	0.1
Cr-51		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Mn-54		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.1
Fe-55		0.3	0.2	0.8	0.5	10.7	1.8
Co-57							
Co-58		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Fe-59		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Co-60	42	0.1	< 0.05	0.1	0.1	1.4	0.2
Ni-63		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Zn-65		< 0.05	< 0.05	< 0.05	< 0.05	0.5	< 0.05
Sr-89		< 0.05	0.1	0.4	0.3	0.1	0.1
Sr-90		18.1	7.6	7.1	6.6	6.1	3.6
Y-90		18.1	7.6	7.1	6.6	6.1	3.6
Y-91		< 0.05	0.2	0.1	0.9	2.8	< 0.05
Zr-95		0.1	0.1	< 0.05	0.1	0.1	< 0.05
Nb-95		0.2	0.5	< 0.05	< 0.05	0.1	< 0.05
Ru-103							
Ru-106		0.8	3.5	0.1	0.1	4.1	0.3
Rh-106		0.8	3.5	0.1	0.1	4.1	0.3
Ag-110m		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Sb-124		0.2	< 0.05	0.1	0.2	0.2	< 0.05
Sb-125		6.7	8.1	0.1	0.5	0.3	0.1
Te-125m		1.6	2.0	< 0.05	0.1	0.1	< 0.05
I-131							
Cs-134		3.3	5.8	12.7	10.4	1.7	7.2
Cs-137		17.1	31.7	62.1	57.9	12.4	69.3
Ba-140							
La-140							
Ce-141							
Ce-144		0.7	9.3	0.1	0.4	6.8	0.4
Pr-144		0.7	9.3	0.1	0.4	6.8	0.4
Pm-147		1.5	3.3	0.8	0.7	8.9	0.6
Eu-154		0.1	0.1	< 0.05	< 0.05	0.3	< 0.05
Eu-155		< 0.05	< 0.05	< 0.05	< 0.05	0.2	< 0.05
Alpha		0.3	0.2	< 0.05	< 0.05	0.5	< 0.05

(k) Values based on discharges summed over three calendar quarters.

TABLE IX

ANNUAL TRITIUM DISCHARGE IN LIQUID EFFLUENT
FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
BELGIUM						
Doel 1 + 2	3 600	-	369	280	475	632
Tihange 1	4 000	n.a.	60.2	162.3	320	356.1
GERMANY						
MZFR (a)		370	880	880	1 200	1 000
Gundremmingen	438 (b)	213.4	127	50	1.9	2.5
Lingen	(c)	9.0	16.5	15	3×10^{-3}	1.9
Obrigheim	500	161.0	168	126	150	130
Würgassen	300	3.1	3.9	29	36	53
Stade	1 300	31.4	106	43	130	133
Biblis A	1 600	8.3	110	319	190	346
Biblis B	1 600	n.a.	n.a.	22	150	400
Neckarwestheim	500	n.a.	n.a.	5	83	134
Brunsbüttel	1 000	n.a.	n.a.	0.3	9.1	19
Isar	500	n.a.	n.a.	n.a.	0.04	4.6
Unterweser	950	n.a.	n.a.	n.a.	n.a.	0.22
FRANCE						
Chinon	(500)(d)			106	110	131
Chooz	(3 000)(d)	3 300	2 490	1 929	2 600	1 748
Monts d'Arrée		116	13.8	27	41	28
St-Laurent-des-Eaux	(1 000)(d)			509	350	684
Bugey 1	(3 500)(e)	824	243	195	240	384
Bugey 2 + 3		n.a.	n.a.	n.a.	n.a.	89.8
Phénix (f)						
Fessenheim 1 + 2	2 000	n.a.	n.a.	n.a.	83	832
ITALY	(g)					
Latina		6.6	403	5	9.9	7.6
Garigliano		3	5	18	15.0	10.3
Trino		1 018	1 202	743	1 736	2 082
Caorso		n.a.	n.a.	n.a.	n.a.	1

TABLE IX (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
NETHERLANDS						
Dodewaard	100	9.2	17	23	21.1	46.2
Borssele	(c)	171.2	56	41	39.7	226
UNITED KINGDOM						
Calder (h)						
Chapelcross	150	1.2	7.1	8.8	1.8	30.8
Bradwell	1 500	117.0	88.0	309.0	199.0	103.0
Berkeley	1 500	56.7	70.7	30.5	51.2	15.9
Hunterston A	1 200	67.0	54.9	66.3	56.0	53.0
Hunterston B	40 000	n.a.	n.a.	44.3	55.0	2 289
Trawsfynydd	2 000	60.0	89.0	16.0	13.0	15.0
Hinkley Point A	2 000 (i)	39.0	53.0	23.7	33.1	53.1
Hinkley Point B	18 000 (i)	n.a.	n.a.	2.5	739.0	1 590.0
Dungeness A	2 000	20.0	24.5	34.2	25.8	31.6
Sizewell A	3 000	253.0	49.0	62.0	43.7	29.5
Oldbury	2 000	37.4	14.1	19.4	14.6	7.4
Winfrith (j)	30 000 (k)	561	1 114	5 119	2 075	1 181
Wylfa	4 000	134.0	129.0	198.0	288.0	1 052.0

(a) MZFR liquid effluent is discharged to Karlsruhe decontamination centre (see Table XIX -WAK).

(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) Limit instituted subsequent to 1978.

(e) Overall site limit, instituted in 1978.

(f) Phénix liquid effluent is discharged with Marcoule site effluent (see Table XIX).

(g) See foot-notes (g) to (j) to Table VII.

(h) Calder liquid effluent is transferred to Windscale and is not separately discharged to the Irish Sea (see Table XIX).

(i) See foot-note (1) to Table VII.

(j) Site discharges.

(k) See foot-note (n) to Table VII.

TABLE X

MAXIMUM HYPOTHETICAL EXPOSURE IN 1978 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			Dose (mrem) at 5 km		
		Whole body (gamma)	Skin (beta only)	Thyroid (c)	Whole body (gamma)	Skin (beta only)	Thyroid (c)
BELGIUM							
Doel 1 + 2	48	0.02	0.03	-	0.001	0.003	-
Tihange 1	160	0.04	0.03	0.4	0.005	0.01	0.2
GERMANY							
MZFR	100	0.01	0.007	-	< 0.001	0.001	-
Gundremmingen	109	0.02	0.01	3×10^{-3}	0.001	0.001	< 0.001
Obrigheim	60	0.06	0.03	0.05	0.003	0.003	0.005
Würgassen	67	0.2	0.4	9	0.01	0.04	1
Stade	80	0.02	0.02	0.3	0.002	0.002	0.03
Biblis A + B	100	0.03	0.01	0.5	0.002	0.002	0.1
Neckarwestheim	150	0.01	0.003	0.3	< 0.001	< 0.001	0.04
Brunsbüttel	100	0.4	0.3	0.3	0.02	0.05	0.04
Isar	130	0.06	0.02	-	0.005	0.005	-
Unterweser	100	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
FRANCE							
Chinon	50	0.7	0.4	2	0.04	0.03	0.2
Chooz	18	0.3	0.9	7	0.01	0.02	0.2
Monts d'Arrée	70	46	19	1	2	0.2	0.1
St-Laurent-des-Eaux	78	1	0.5	0.3	0.08	0.06	0.03
Bugey 1 / Bugey 2 + 3	85 / 62	0.6	0.2	1.2	0.03	0.02	0.1
Phénix	70	0.007	0.008	0.01	< 0.001	< 0.001	0.001
Fessenheim	56	0.2	0.1	2	0.01	0.009	0.2
ITALY							
Latina	52	0.7	0.4	0.003	0.04	0.03	< 0.001
Garigliano	92	7	4	1	0.4	0.6	0.2
Trino	100	0.05	0.02	0.003	0.003	0.002	< 0.001
Caorso	57	0.01	0.01	0.2	< 0.001	0.001	0.01

TABLE X (continued 1)

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)
NETHERLANDS							
Dodewaard	100	0.3	0.2	0.2	0.02	0.02	0.02
Borssele	57	0.01	0.01	0.02	< 0.001	0.001	0.002
UNITED KINGDOM (d)							
Calder		12	12		0.5	0.5	
Chapelcross		13	13		0.6	0.5	
Bradwell		7	6		0.3	0.3	
Berkeley		5	5		0.2	0.2	
Hunterston A + B		8	8		0.4	0.3	
Trawsfynydd		54	52		2	2	
Hinkley Point A		33	32		1.5	1	
Dungeness A		12	12		0.5	0.5	
Sizewell A		25	24		1	1	
Winfrith		8	8	20	0.3	0.3	1

(a) Calculations based on pessimistic assumptions.

(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. AGR/GCRs for which the effective height was reduced to 30 m to take into account building entrainment.

For sites with two or more stations a single discharge point is assumed.

(c) Dose to the thyroid of an infant drinking only milk from cattle grazing at this distance. Moreover, for the French stations in this Table it is conservatively assumed that the entire discharge termed "radioactive aerosols and gaseous halogens" (Table V) can be attributed to I-131.

(d) See also Section 2.2.1.1.

TABLE XI

RADIOACTIVE WASTE DISCHARGE FROM NPSs PER UNIT NET ELECTRICAL ENERGY PRODUCED

Facility	Net electricity production		Activity Released per GWh		
			Gaseous effluent (noble gases)	Liquid effluent	
				Tritium excluded	Tritium alone
	Year	(GWh)	(Ci/GWh)	(mCi/GWh)	(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
	1977	5 407	0.14	3.13	87.85
	1978	5 482	0.09	3.43	115.29
Tihange 1	1975	3 091	0.15	0.12	19.48
	1976	4 405	1.05	0.19	36.48
	1977	5 843	0.25	0.61	
	1978	6 364	0.25	0.31	
GERMANY					
MZFR	1974	324	2.94		1 142
	1975	328	3.40		2 683
	1976	394	2.50		2 234
	1977	295	1.07		4 068
	1978	390	1.05		2 564
Gundremmingen	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	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	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
	1977	2 144	0.17	0.12	69.96
	1978	2 220	0.20	0.08	58.56
Würgassen	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
	1977	3 639	0.22	0.43	9.89
	1978	2 741	1.19	0.19	19.34
Stade	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
	1977	5 156	0.64	0.07	25.21
	1978	5 238	0.09	0.02	25.39
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
	1977	14 177	0.30	0.01	23.89
	1978	12 752	0.15	0.02	54.25

TABLE XI (continued 1)

Facility	Net electricity production		Activity Released per GWh		
			Gaseous effluent (noble gases) (Ci/GWh)	Liquid effluent	
				Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
	Year	(GWh)			
Neckarwestheim	1976	1 958	0.32	0.12	2.55
	1977	4 947	0.38	0.03	16.78
	1978	4 938	0.02	0.006	27.14
Brunsbüttel	1976	1 032	0.94	2.16	0.29
	1977	3 314	0.94	0.49	2.75
	1978	2 324	3.26	0.61	8.18
Isar	1977	76	0.30	0.53	0.53
	1978	2 337	0.46	0.09	1.97
Unterweser	1978	788	0.07	-	0.28
FRANCE					
Chinon	1974	1 475	1.41	0.27	
	1975	3 570	1.69	0.18	
	1976	2 452	2.01	0.23	43.23
	1977	3 305	1.19	0.07	33.28
	1978	3 361	0.75	0.10	38.98
Cheoz	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
	1977	2 462	1.14	0.91	1 056.05
	1978	2 008	1.61	0.40	870.52
Monts d'Arrée	1974	551	299.02	0.09	210.91
	1975	505	388.12	0.10	27.33
	1976	518	469.07	0.06	52.12
	1977	478		0.23	
	1978	526			
St-Laurent-des-Eaux	1974	5 965	0.73	0.71	
	1975	6 751	0.52	0.70	
	1976	5 771	0.50	0.51	88.20
	1977	5 523	0.76	0.89	63.37
	1978	6 160	1.10	1.31	111.04
Bugey 1	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
	1977	3 456	0.69	1.13	69.44
	1978	2 610	1.11	4.15	147.13
Bugey 2 + 3	1978	923	0.12	10.67	97.29
Phenix	1974	938			
	1975	1 298	0.13		
	1976	948	0.25		
	1977	296	0.43		
	1978	1 231	0.11		
Fessenheim	1977	994	1.91	6.97	83.50
	1978	11 832	0.17	0.40	70.32

TABLE XI (continued 2)

Facility	Net electricity production Year (GWh)		Activity Released per GWh		
			Gaseous effluent (noble gases) (Ci/GWh)	Liquid effluent	
				Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
ITALY					
Latina	1974	954	2.15	6.39	6.92
	1975	943	2.75	6.59	427.36
	1976	947	2.62	5.46	5.28
	1977	1 022	2.36	4.21	9.69
	1978	1 185	2.21	2.78	6.41
Garigliano	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
	1977	443	203.04	9.26	33.86
	1978	452	150.79	5.97	22.79
Trino	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
	1977	1 750	0.03	0.80	992.00
	1978	2 095	0.25	0.62	993.79
Caorso	1978	458	0.20	1.07	2.18
NETHERLANDS					
Dodewaard	1974	268	15.52	8.06	34.33
	1975	389	5.42	3.21	43.70
	1976	407	15.31	0.84	56.51
	1977	360	36.15	3.06	58.61
	1978	409	10.52	1.03	112.96
Borssele	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
	1977	3 142	0.32	0.14	12.64
	1978	3 424	0.12	0.08	66.00
UNITED KINGDOM			(a)		
Chapelcross	1974	1 561		0.77	0.77
	1975	1 503		11.5	4.72
	1976	1 527		21.2	5.76
	1977	1 376		6.61	1.31
	1978	1 424	22	53.72	21.63
Bradwell	1974	1 723		52.23	67.90
	1975	1 749		65.75	50.31
	1976	1 736		37.67	178.0
	1977	1 720		38.55	115.70
	1978	1 528	10	35.47	67.41

(a) Discharges of noble gases (A-41) from U.K. GCRs are in most cases proportional to power levels; hence a single value is given in such cases.

TABLE XI (continued 3)

Facility	Net electricity production		Activity Released per GWh		
			Gaseous effluent (noble gases) (Ci/GWh)	Liquid effluent	
				Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
	Year	(GWh)			
Berkeley	1974	1 968		11.74	28.81
	1975	1 974		27.36	35.82
	1976	1 979		56.59	15.41
	1977	1 825		81.10	28.05
	1978	1 447	8	22.11	10.99
Hunterston A	1974	2 128		27.58	31.48
	1975	2 223		51.60	24.70
	1976	2 214		71.73	29.95
	1977	2 186		67.25	25.62
	1978	2 129	9	28.18	24.89
Hunterston B	1976	1 342	1.49	0.43	33.01
	1977	2 735	2.19	0.44	20.11
	1978	2 158	2.04	2.78	1 060.70
Trawsfynydd	1974	3 168		6.00	18.94
	1975	3 080		5.52	28.90
	1976	3 024		6.61	5.29
	1977	2 986		4.52	4.35
	1978	2 578	50	6.79	5.82
Hinkley Point A	1974	3 044		41.06	12.81
	1975	2 991		53.16	17.72
	1976	3 199		43.14	7.41
	1977	3 247		36.96	10.19
	1978	3 183	25	34.56	16.68
Hinkley Point B	1977	1 044		1.15	707.85
	1978	2 793		1.83	569.28
Dungeness A	1974	3 384		20.39	5.91
	1975	3 297		24.11	7.43
	1976	2 732		16.95	12.52
	1977	2 819		16.07	9.15
	1978	2 667	11	14.29	11.85
Sizewell A	1974	3 116		5.10	81.19
	1975	3 424		5.84	14.31
	1976	3 403		8.67	18.22
	1977	3 324		12.94	13.15
	1978	3 372	18	7.30	8.75
Oldbury	1974	2 710		12.03	13.80
	1975	2 873		9.47	4.91
	1976	3 017		16.71	6.43
	1977	3 110		21.22	4.69
	1978	3 067		9.91	2.41
Wylfa	1974	4 364		0.11	30.71
	1975	1 562		2.18	82.59
	1976	4 818		1.35	41.10
	1977	4 984		3.73	57.78
	1978	3 801		6.95	276.77

TABLE XII

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
GERMANY				
WAK (Karlsruhe) Baden-Wurtemberg	1 LWR 2 HWR	40	1971	Rhine (a)
FRANCE				
La Hague Manche	1 GCR 2 LWR 3 FBR	800 { 250 {(b) 4 {	1966 1976	{ English Channel
Marcoule Gard	GCR		1958	Rhône (a)
UNITED KINGDOM				
Dounreay Caithness	1 MTR 2 FBR	0.3 (c) 3	1958 1961	{ Atlantic Ocean (a)
Windscale Cumbria	GCR	2 000	1952 (d)	Irish Sea

(a) 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 WAK liquid effluent quoted is that 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.

(b) The capacity for LWR fuel will rise to 800 t per year by 1985-86 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.

(c) Initial capacity 0.12 t per year.

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

TABLE XIII

ANNUAL DISCHARGE OF KRYPTON-85 FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK	3.5×10^5 (a, b)	$< 8.5 \times 10^2$	4.3×10^4	8.57×10^4	1.15×10^5	3.36×10^4
La Hague		7.2×10^5	6.6×10^5	3.5×10^5	6.71×10^5	7.86×10^5
Marcoule		1.1×10^5	1.0×10^5	9.2×10^4	1.17×10^5	3.08×10^5
Dounreay	(d)			1.9×10^3 (c)	(c) 7×10^2	-
Windscale	(d)	8×10^5	1.2×10^6	1.2×10^6	8×10^5	7×10^5

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

(b) 2.5×10^5 Ci in 1974 and 1975.

(c) Calculated production of Kr-85 in the Dounreay Fast Reactor (DFR) fuel some or all of which will have been discharged to atmosphere. DFR is no longer operational.

(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 discharged. Quantified limits are being prepared.

TABLE XIV

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (ALPHA)
FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK	1×10^{-2} (a)	1.5×10^{-4}	3.0×10^{-3}	3.0×10^{-3}	2.9×10^{-3}	4.6×10^{-3}
La Hague		6.8×10^{-6}	1.6×10^{-8}	2×10^{-8}	2.9×10^{-6}	3.0×10^{-5}
Marcoule		3.8×10^{-5}	2.2×10^{-5}	1.8×10^{-5}	8.7×10^{-5}	4.6×10^{-5}
Dounreay	(b)	1.2×10^{-2}	1.4×10^{-2}	$< 2.1 \times 10^{-2}$	$< 5 \times 10^{-3}$	1.4×10^{-3}
Windscale	(b)	0.18	7.6×10^{-2}	5.1×10^{-2}	2.8×10^{-2}	3.6×10^{-2}(c)

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

(b) See foot-note (d) to Table XIII.

(c) Includes 2.5×10^{-2} Ci of plutonium isotopes; other alpha emitters include Am-241 and Cm-242.

TABLE XV

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (BETA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK	2 (a)	1.4×10^{-2}	0.17	0.14	0.3	8.4×10^{-2}
La Hague		1.3×10^{-2}	1.4×10^{-2}	8.9×10^{-3}	3.7×10^{-3}	3.3×10^{-3}
Marcoule		5.9×10^{-4}	3.4×10^{-2}	3.6×10^{-2}	4.5×10^{-3}	9.3×10^{-3}
Dounreay (b)	(c)	< 6.2	< 4.0	< 5.8	< 2.0	0.32
Windscale (d)	(c)	2.8	3.1	4.6	9.7	8.4

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

(b) Results correspond to total gamma measurements.

(c) See foot-note (d) to Table XIII.

(d) Discharges in 1978 include 6.5 Ci Cs-137, 1.3 Ci Sr-90 with small amounts of Ru-106, Ce-144 , Zr-95 and Nb-95.

TABLE XVI

ANNUAL DISCHARGE OF TRITIUM TO ATMOSPHERE FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK	1 000 (c)	< 30 (a)	68 (a)	102 (a)	189.8	125.4
La Hague		190	88	49	304	112
Marcoule		340	120	120	75.3	1 712
Dounreay	(b)					
Windscale	(b)	8×10^3	1.2×10^4	1.2×10^4	8×10^3	6×10^3

(a) Calculated results based on later experimental work.

(b) See foot-note (d) to Table XIII.

(c) See foot-note (a) to Table XIII.

TABLE XVII

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (ALPHA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK (a)		- (b)	- (b)	- (b)	- (b)	1.5×10^{-3} (b)
La Hague		27.0	13.3	9.9	18.2	13.9
Marcoule (a)		0.4	0.5	0.3	0.36	0.36
Dounreay (a)	240 (c)	12	23	11	6	8
Windscale	6 000 (d)	4 572	2 309	1 614	1 241	1 837

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

(b) Until 1978 gross alpha-activity was below the detection limit; nuclide specific measurement gave discharge results for Pu-238 and Pu-239 in 1974, 1975, 1976, 1977, 1978 respectively (see Section 1.3.3.1).

(c) 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".

(d) 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.

TABLE XVIII

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

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK (a)		0.24	0.09	0.04	0.017	0.014
La Hague		25 300	31 900	19 300	20 689	29 501
Marcoule (a)		575	1 126	624	816	952
Dounreay (a)	24 000 (b, c)	5 441	5 517	1 365	921	408
Windscale	300 000 (c, d)	207 000	245 000	183 000	192 768	192 550

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

(b) This is a derived maximum limit based on the requirement given in the liquid effluent authoriza-
tion 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 XVII, foot-note (c).

(c) 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.

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

TABLE XIX

ANNUAL DISCHARGE OF TRITIUM IN LIQUID EFFLUENT FROM MFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK		300	1 500	3 100	2 400	1 300
La Hague					8 957	19 882
Marcoule (a)					3 156	7 295
Dounreay (a, b)	(c)	< 600	< 600	104	30	356
Windscale	(c)	32 396	37 952	32 460	24 710	20 371

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

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

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

TABLE XX

ANNUAL DISCHARGE OF STRONTIUM-90 IN LIQUID EFFLUENT FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1974	1975	1976	1977	1978
WAK (a, b)		1.1×10^{-2}	2.4×10^{-2}	8.7×10^{-3}	3.8×10^{-3}	3.0×10^{-3}
La Hague		2 820	2 030	1 080	1 965	3 789
Marcoule (a)		21.4	24.9	11	10.1	23.7
Dounreay (a)	2 400 (c)	1 165	541	183	210	80
Windscale	30 000 (c)	10 600	12 600	10 300	11 534	16 160

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

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

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

TABLE XXI

ANNUAL DISCHARGE OF RUTHENIUM-106 IN LIQUID EFFLUENT FROM NFRPs

Facility		Discharge Limit (Ci/year)	Activity Released (Ci/year)				
			1974	1975	1976	1977	1978
WAK	(a)		1.0×10^{-2}	2.1×10^{-3}	-	-	-
La Hague	(b)		14 500	22 400	15 000	14 603	21 661
Marcoule	(a)		435	879	541	738	667
Dounreay	(a)		155	146	36	33	3
Windscale		60 000 (c)	29 200	20 800	20 700	22 053	21 897

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

(b) Ru-106 + Ru-103 discharges in 1977-78.

(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

$$\frac{a}{15\ 000} + \frac{b}{90\ 000} + \frac{c}{300\ 000} \quad \text{shall not exceed 1".}$$
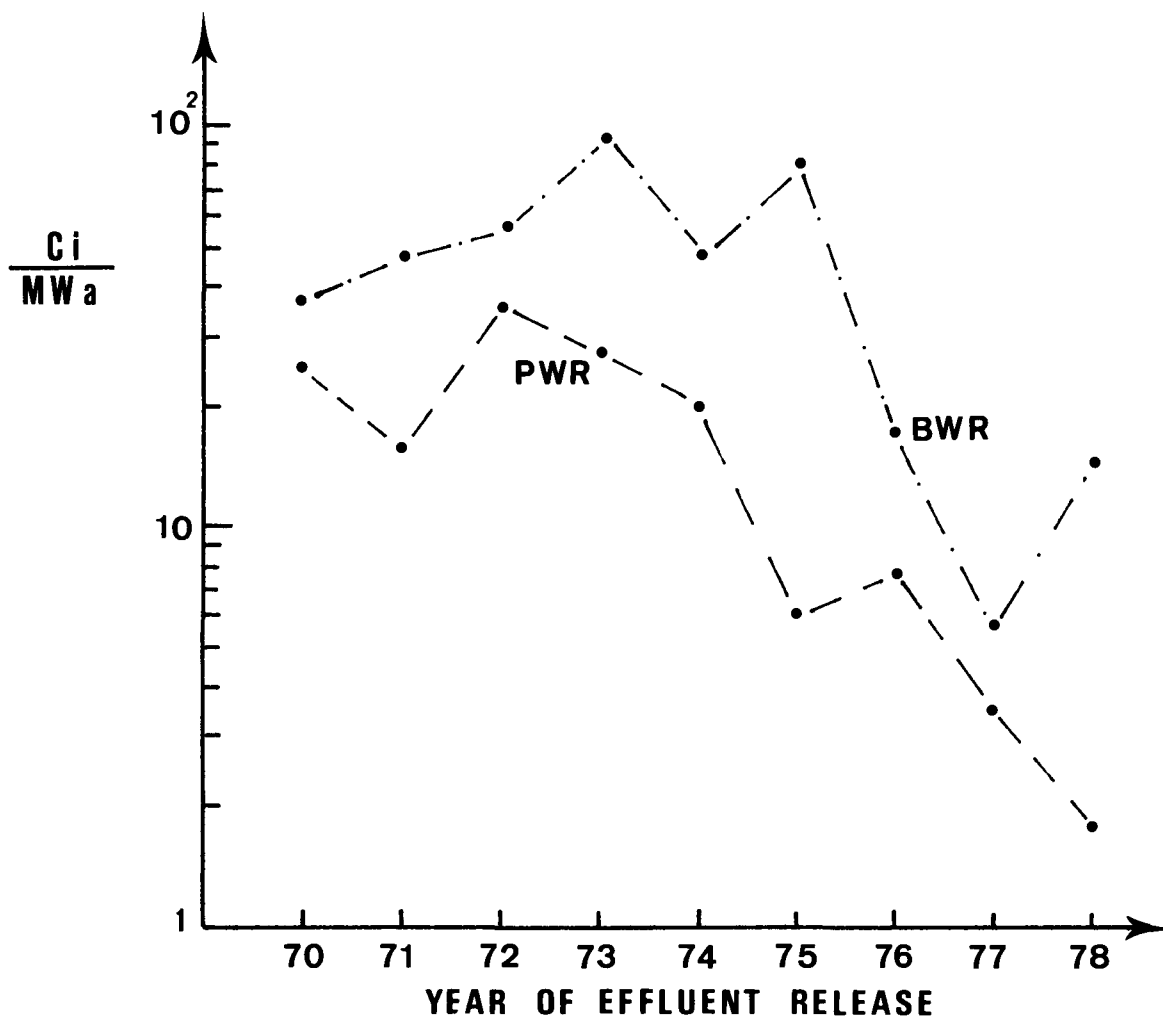
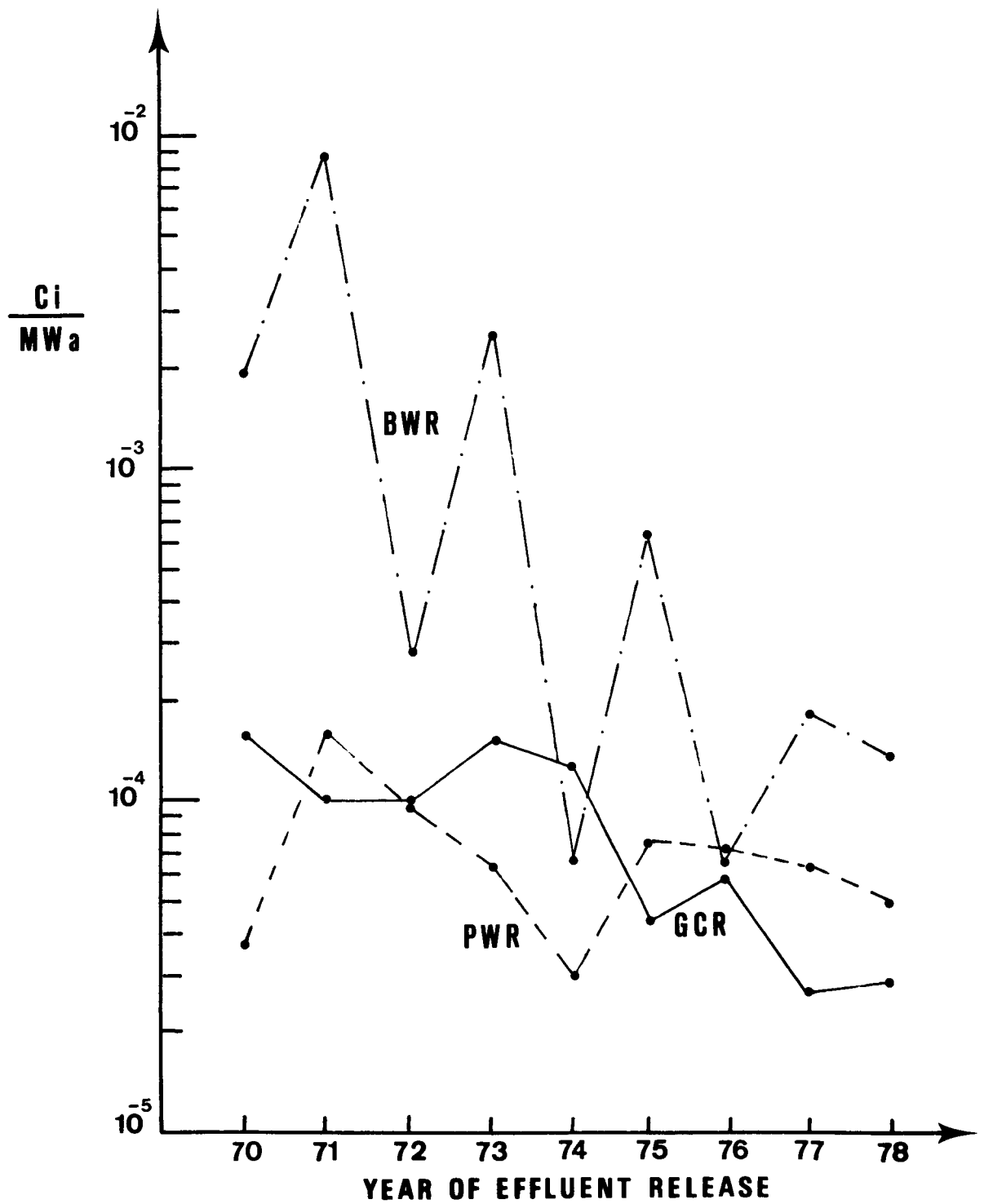FIG. 1 — Normalized annual discharges (Ci/MWa) of noble gases from E.C. PWRs and BWRs

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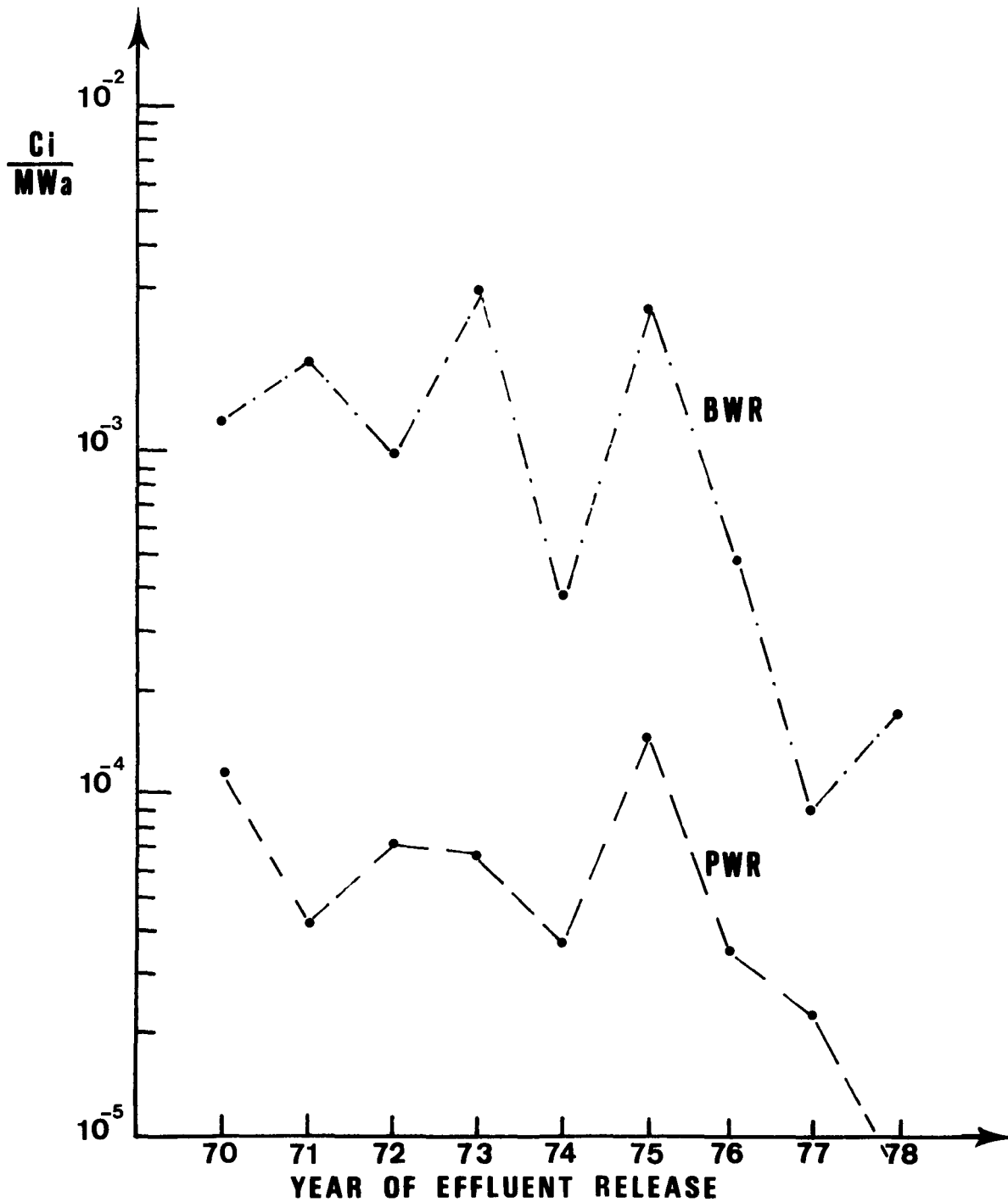aerosols (beta) from E.C. PWRs, BWRs and GCRs

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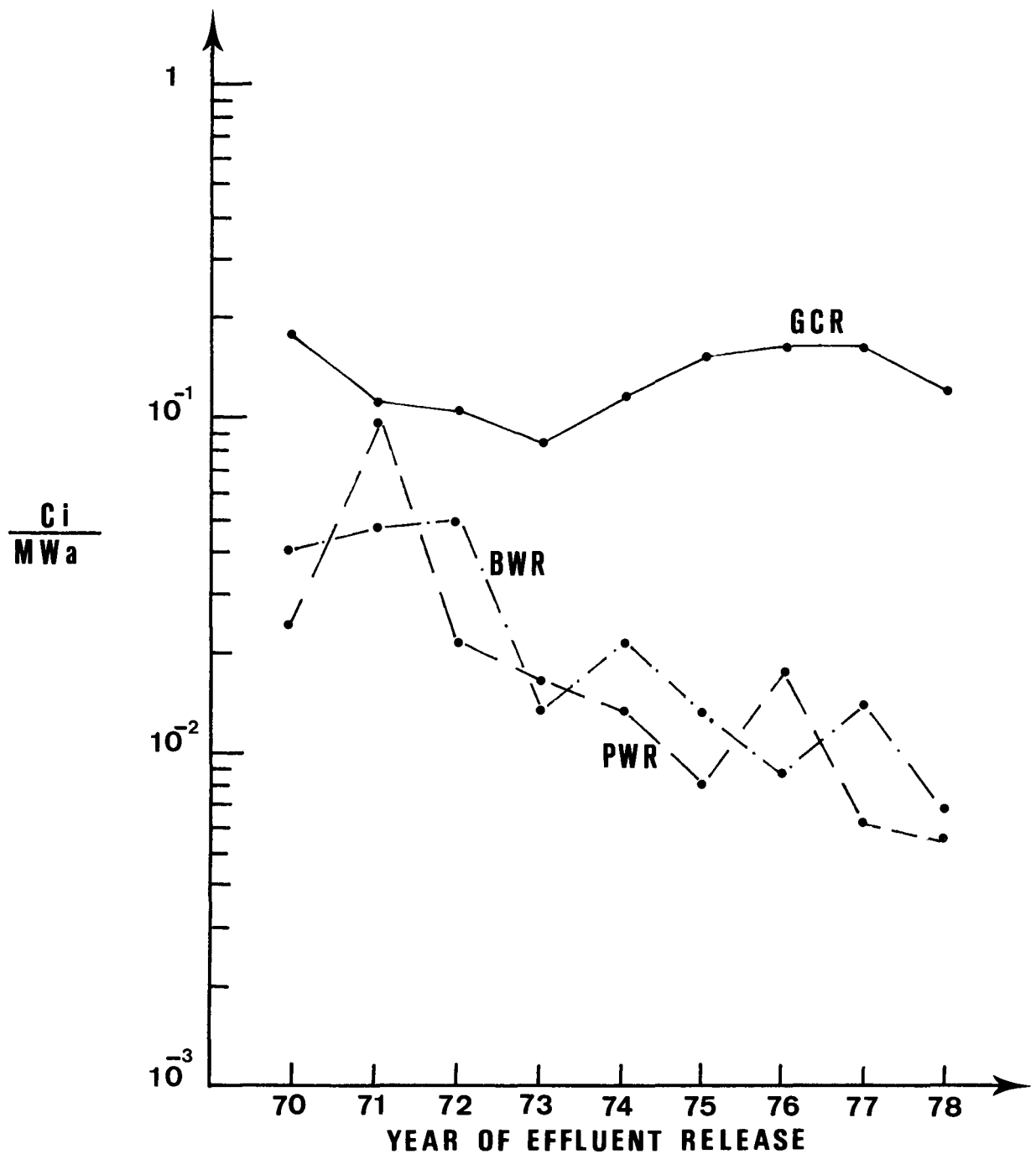to atmosphere from E.C. PWRs and BWRs

FIG. 4 — Normalized annual discharges (Ci/MWa) of liquid radioactive effluents (excluding tritium) from E.C. PWRs, BWRs and GCRs
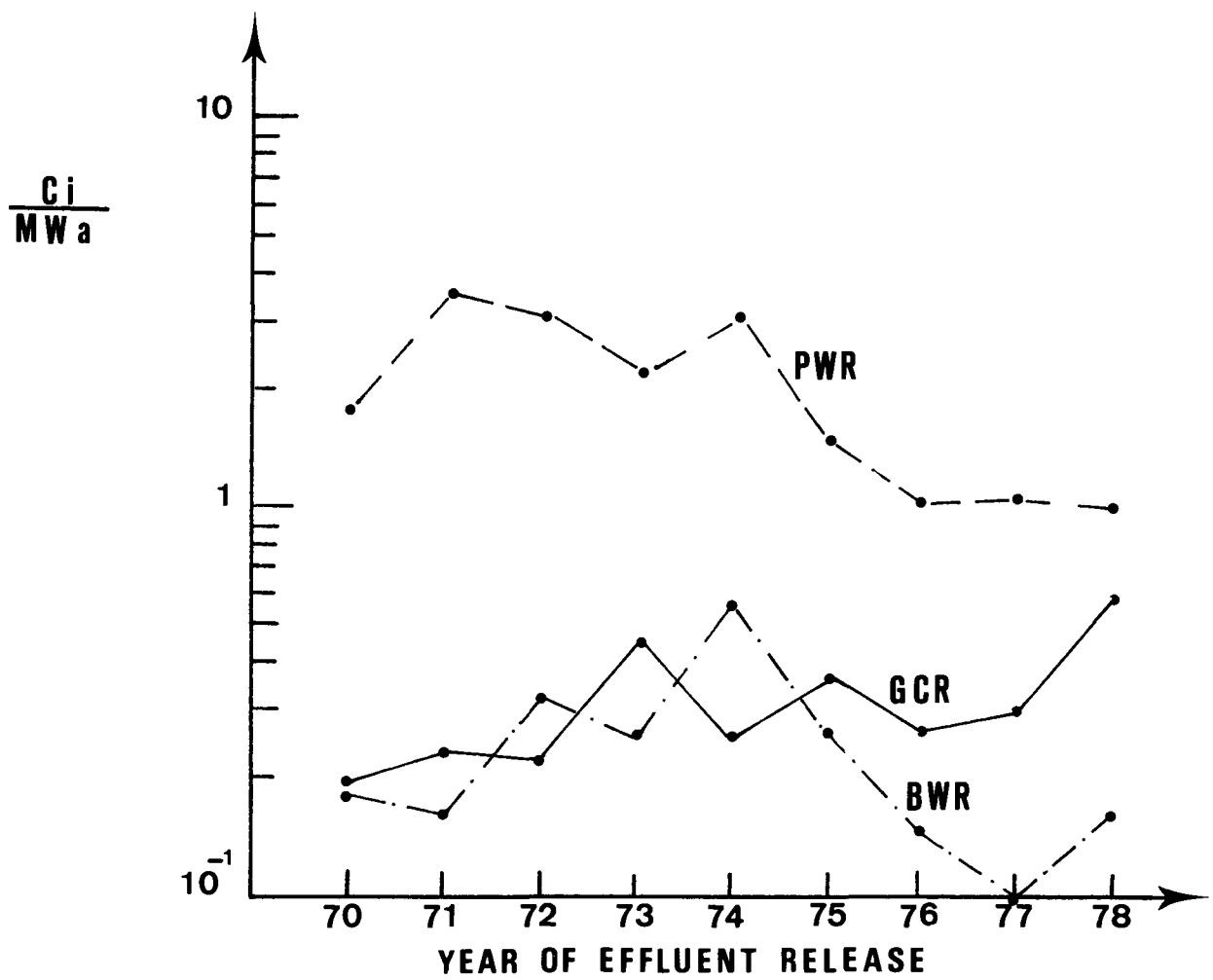
FIG. 5 — Normalized annual discharges (Ci/MWa) of tritium
in liquid effluents from E.C. PWRs, BWRs and GCRs