COMMISSION OF THE EUROPEAN COMMUNITIES

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DISCHARGE DATA 1976 □ 1980 RADIOLOGICAL ASPECTS

F. LUYKX and G. FRASER

MARCH 1983

DIRECTORATE-GENERAL EMPLOYMENT, SOCIAL AFFAIRS AND EDUCATION
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V/3267/83 EN

SUMMARY

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 1976 to 1980, 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 the 1980 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 circumstances the dose estimates rely entirely on theoretical models which frequently incorporate conservative assumptions; hence these estimates are likely to be greater than the doses actually received.

The estimated exposures have then been compared with the dose limits set out in the Euratom Directive of 15th July, 1980. 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.

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PREFACE

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 are published periodically. This report, the sixth in the series, deals with the years 1976-1980 and covers discharges from 41 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 will 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 of greatest interest from an environmental point of view.

Secondly, in comparing the estimates of radiation exposure to the relevant limits and to exposure from naturally-occurring radiation, it is hoped that the report will serve interested members of the public in putting the radiological significance of these discharges in perspective.

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

Dr. E. BENNETT

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
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor
SGHWR	Steam Generating Heavy Water Reactor
NFRP	Nuclear Fuel Reprocessing Plant
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.

- For brevity the word "equivalent" has been dropped from the expression "dose equivalent", "committed dose equivalent" and "committed effective dose equivalent".

- 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.

CONTENTS

TABLES

FIGURES

1. RADIOACTIVE EFFLUENTS

1.1 GENERAL

This report contains data on the discharge of gaseous and liquid radioactive effluents from 1976 to 1980 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.

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 1976 to 1980. 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. A total of 41 stations are listed in the tabel: compared with the 1974-78 edition of this report this represents the addition of 5 stations - Philippsburg (FRG), Gravelines, Dampierre and Tricastin (France) and Dounreay (UK) - and the removal of two stations which were shut down in 1976 - Gundremmingen and Lingen (FRG). The total net capacity in 1980 was 32.598 MW; the actual output was 16.823 MWa of which 62% from PWRs, 22.1% from GCRs, 7.4% from BWRs and 6.3% from AGRs.

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

1.2.2 Gaseous Effluents

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

Tables II 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. the gaseous discharge authorizations still rely on citing the use of the best practicable means to minimize discharges and do not quantify limits.

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 1980. GCRs and AGRs discharge mainly argon-41. Their discharge of fission gases is negligable, as defective fuel elements can be removed from the reactor on-load.

The argon-41 from British magnox stations is not monitored systematically as it is proportional to the power level; the annual discharges given in Table II were obtained from a limited number of measurements with adjustments for average load factors.

In LWRs the noble gas discharge consists mainly of the fission gases krypton and xenon; its isotopic composition, however, varies from plant to plant and depends mainly on the hold-up time of the gases prior to discharge.

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

- for PWRs from 0.18 to 39.8 Ci/MWa, with an average value of 2.86 Ci/MWa,

- for BWRs, equipped with a charcoal delay system, from 1.14 to 28.6 Ci/MWa with an average value of 7.07 Ci/MWa,
- for AGRs from 6.57 to 19.2 with an average value of 11.0 Ci/MWa,
- for the FBR, Phénix, from 0.70 to 3.77 Ci/MWa with an average value of 1.70 Ci/MWa.

This table also demonstrates the extent to which older BWRs, such as Garigliano, which are not equipped with a charcoal delay bed in the off-gas system, have considerably higher fission gas discharges (up to 1800 Ci/MWa) than these fitted with such a system.

Figure 1 shows how for PWRs and BWRs (equipped with a charcoal delay system) the normalized annual discharges have evolved from 1970 to 1980. It can be observed that for PWRs there has been a steady decrease since 1972 to about 2 Ci/MWa in 1980.

For BWRs there is a similar overall trend, 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

The tritium present in gaseous effluents is not measured systematically in all power stations and only few stations have a specific discharge limit imposed. Table IV shows the available data from which 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 0.05 Ci/MWa for both PWRs and BWRs. For the AGR, Hunterston B it was 0.21 Ci/MWa.

1.2.2.3 Radioactive aerosols

Table V gives the discharges of radioactive aerosols from NPSs together with the annual discharge limits. The aerosol activity referred to generally approximates to those nuclides with half-lives 1 week.

Aerosol release levels were in general extremely low for all types of power plants. The normalized discharge, averaged over the 5 year-period 1976 to 1980, is 4.5×10^{-5} Ci/MWa for PWRs, 3.5×10^{-5} Ci/MWa for GCRs and 1.2×10^{-4} Ci/MWa for BWRs. Figure 2 gives the normalized annual discharges for each of these 3 reactor types for the period 1970 to 1980.

The two AGRs, Hunterston B and Hinkley Point B, had from 1976 to 1980 a normalized discharge of 9.3×10^{-5} Ci/MWa.

The radioactivity of the aerosols may have two different origins, activation or fission. The following tables show for 1980 the nuclide composition (%) of the beta-gamma activity measured at the German and Italian NPSs, the only stations for which detailed data have been received.

Radionuclide composition (%) of beta-gamma emitting aerosols (1980)

1) GERMANY

Facility / Nuclide	Obrigheim	Würgassen	Stade	Biblis A	Biblis B	Neckar-westheim	Brunsbüttel	Isar	Unterweser	Philipps-burg
Cr-51	4.2	10.7	2.3	-	-	2.6	-	21.6	16.4	31.3
Mn-54	1.5	0.8	0.7	-	-	2.4	1.1	32.4	2.2	6.4
Fe-59	0.07	-	-	-	-	-	-	11.7	3.5	1.1
Co-58	10.3	3.9	6.4	-	-	3.2	0.03	3.7	2.3	15.0
Co-60	73.6	19.2	40.0	41	29	69.2	16.6	9.9	3.4	7.1
Zn-65	0.4	5.3	-	-	-	-	10.6	4.3	5.0	34.2
Sr-89	0.4	5.3	-	-	-	-	2×10^{-5}	0.05	< 0.2	-
Sr-90	0.02	0.2	-	-	-	-	0.03	3×10^{-3}	< 0.05	0.02
Zr-95	0.2	4.3	-	-	-	0.7	-	-	3.2	0.7
Nb-95	0.1	0.3	-	-	-	1.8	-	0.02	2.7	0.4
Ru-103	0.06	0.05	-	-	-	-	-	-	2.2	3.7
Ru-106	-	-	1.0	-	-	1.3	-	-	17.6	-
Ag-110m	2.0	-	1.8	-	-	5.8	-	15.0	3.4	-
Sb-124	0.04	-	4.4	-	-	3.8	-	0.4	5.3	-
Sb-125	0.2	-	-	-	-	1.0	-	-	-	-
I-131	-	11.2	-	-	-	6.5	0.3	0.9	< 3.0	-
Cs-134	1.5	3.4	9.2	-	-	0.4	15.1	-	2.6	-
Cs-137	5.1	6.9	34.0	-	-	0.1	55.3	-	2.1	0.02
Ba-140	-	0.3	-	-	-	-	-	-	8.6	0.1
La-140	-	24.0	-	-	-	-	-	-	3.5	-
Ce-141	-	-	-	-	-	-	-	-	2.5	-
Ce-144	-	2.8	-	-	-	-	-	0.1	9.0	-
others	-	1.2	-	59	71	0.1	-	-	2.2	-

2) ITALY

NUCLIDE \ FACILITY	LATINA	GARIGLIANO	TRINO (b)	CAORSO (c)
Cr-51				23.9
Mn-54			15.2	1.5
Fe-59				2.5
Co-58			2.8	7.6
Co-60	33.8	54.6	46.5	4.2
Zn-65				3.7
Sr-89				12.1
Sr-90				18.4
Zr-95	4.0 (a)			1.8
Ru-106	6.7			
Ag-110m			10.4	
Sb-124			3.2	1.0
Cs-134		6.6	7.7	0.7
Cs-136				4.9
Cs-137	21.3	38.8	14.2	0.9
Cs-138				0.8
Ba-140				12.8
Ce-144	34.2			3.2

(a) + Nb-95 (b) Data for 1979 (c) 1st six months of 1980 only

It appears that the nuclides most commonly found at significant levels are the activation products Cr-51, Mn-54, Co-58, Co-60, Zn-65 and the fission products Cs-134 and Cs-137.

Routine measurement of the nuclide composition of the alpha-emitting aerosols started in Germany in 1980. The following table presents the results (% compositions).

Radionuclide composition (%) of alpha-emitting aerosols

	Obrigheim	Würgassen	Stade	Biblis A	Biblis B	Neckarwest-heim	Brunsbüttel	Isar	Unterweser	Philippsburg
Pu-238	80.3	-	-		-		11.6		1.6	-
Pu-239	-	0.6	-		-		29.1		10.1	-
Pu-240	-	-	-		-		29.1		-	-
Am-241	-	3.9	-				11.6		-	-
Cm-242	5.9	45.2	-	100	1000		7.8		7.3	-
Cm-244	13.8	5.1	-		-		10.7		1.5	-
Others	-	45.2	-		-		-		78.8	-
Total(Ci)	1.9×10^{-7}	9.0×10^{-6}	-	2.3×10^{-8}	5.7×10^{-8}	3.2×10^{-6}	1.8×10^{-8}	4.1×10^{-6}	4.8×10^{-6}	-

The normalized discharge of alpha emitting aerosols from the above stations amounts to 2.8×10^{-9} Ci/MWa for PWRs and 1.3×10^{-8} Ci/MWa for BWRs.

1.2.2.4 Sulphur-35

Gaseous effluents from GCRs and AGRs contain relatively large quantities of sulphur-35 probably in the form of carbonyl sulphide (COS). This radionuclide originates mainly from activation of sulphur and chlorine impurities present in the graphite moderator. The available discharge data are given below.

Sulphur-35 discharge to atmosphere (Ci/year)

Facility	1976	1977	1978	1979	1980
GCRs					
Hunterston A			1.96	2.9	2.7
Trawsfynydd					4.2
Oldbury	1.4	0.46	0.76	2.3	2.5
Wylfa	2.4	5.5	4.7	5.0	4.2
AGRs					
Hunterston B			8.7	5.7	10.5
Hinkley Point B	2.2	5.7	5.6	3.2	2.6

Trawsfynydd, Oldbury and Wylfa discharges are spcific to conditioning of the reactor gas circuit.

Normalized to Ci/MWa gives for GCRs a value of 7.5×10^{-3} Ci/MWa and for AGRs 1.8×10^{-2} Ci/MWa.

1.2.2.5 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. The normalized release, averaged over the 5-year period considered in the report, is 1.3×10^{-5} Ci/MWa for PWRs and 1.0×10^{-4} Ci/MWa for BWRs. Figure 3 gives the normalized annual iodine-131 discharges from PWRs and BWRs from 1970 to 1980.

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, for aerosols and gaseous halogens, do not distinguish iodine-131 alone. Thus the only data available are for Latina for which the normalized discharge is 2.0×10^{-7} Ci/MWa for the 5-year period.

At the Hinkley Point B AGR, iodine-131 is measured routinely. The data available show that from 1977 to 1980 the normalized discharge was less than 4.1×10^{-5} Ci/MWa.

1.2.2.6 Carbon-14

Carbon-14 discharge data are only available for German nuclear power plants; they are summarized below (2).

Carbon-14 discharges to atmosphere (Ci/year)

Facility	1978		1979		1980	
	C-14(tot)	C-14(CO_2)	C-14(tot)	C-14(CO_2)	C-14(tot)	C-14(CO_2)
PWRs						
Obrigheim	0.9	0.5	1.1	0.2		0.6
Stade		1.2	3.4	1.5	3.2	1.1
Biblis A			2.1	0.6		
Biblis B			4.4	0.4		
Neckar-westheim	3.9	0.2	4.8	0.6	2.9	0.3
Unterweser			6.7	0.5		1.5
BWRs						
Würgassen		6.2		4.4		9.5
Brunsbüttel		4.5		0.2		0.8

In BWRs more than 95% of the carbon-14 is CO_2-bound whereas in PWRs the CO_2 fraction ranges from 5% to 56%; the remainder is bound to organic compounds.

1.2.3 Liquid Effluents

Table VII gives the gross beta-gamma activities, exclusive of tritium, released in liquid effluent together with the corresponding annual discharge limits; Table VIII gives the nuclide analyses for 1980. Table IX lists tritium discharges.

1.2.3.1 Beta-gamma 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 1980.

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

- for PWRs it varies from 2.2×10^{-6} to 8.6×10^{-2} Ci/MWa with an average value of 5.5×10^{-3} Ci/MWa;
- for BWRs from 6×10^{-5} to 8.1×10^{-2} Ci/MWa with an average value of 2.5×10^{-3} Ci/MWa;
- for GCRs from 6.1×10^{-4} to 4.6 Ci/MWa with an average value of 1.5×10^{-1} Ci/MWa (1.1×10^{-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 1980 from the AGRs Hunterston B and Hinkley Point B was 1.1×10^{-2} Ci/MWa, plus 2.3×10^{-2} Ci/MWa for sulphur-35.

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 XXII).

Table VIII gives the radionuclide composition of liquid effluents (excluding tritium) discharged from NPSs in 1980. 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 percentages of the principal radionuclides present in the liquid effluent (excluding tritium).

The data are for 1980 except for the French PWRs and BWRs for which 1978 data were the latest available.

Principal radionuclides present in liquid effluents

Radionuclide	PWR	BWR	GCR(UK)
S-35	-	-	15.9
Cr-51	5.9	6.0	-
Mn-54	2.0	9.6	-
Co-58	20.6	13.1	-
Co-60	33.7	25.1	0.3
Zn-65	-	5.6	-
Sr-89	0.3	2.0	0.3
Sr-90	0.3	0.1	6.6
I-131	2.0	0.8	-
Cs-134	5.6	15.8	9.0
Cs-137	15.4	22.2	46.1
Ce-144	1.4	0.5	1.4
Total	87.2	99.0	79.6

On average over 75% of the activity from LWRs was radioactive cobalt and caesium. For the GCRs (UK) caesium gave 55%.

As regards the nuclide composition of AGR liquid effluents, Table VIII shows that sulphur-35 predominated in 1980. From Table VII there appears to have been a sharp increase of sulphur-35 discharged in 1980 in both cases. At Hinkley Point B, however, this was associated with a revised analytical method, since the previous method had been found to significantly underestimate sulphur-35, although total radioactivity measurements were correct (3).

1.2.3.2 Alpha activity

The following table gives the available data on annual discharges of alpha activity in liquid effluents.

Alpha activity discharges in liquid effluents (Ci/Year)

Facility	1976	1977	1978	1979	1980
PWRs					
Obrigheim	$\leq 1\times10^{-4}$	2×10^{-5}	5.8×10^{-4}	$< 6.0\times10^{-4}$	5.1×10^{-5}
Stade		9×10^{-5}	1.4×10^{-5}	3.6×10^{-4}	1.8×10^{-5}
Biblis A		2×10^{-5}	1.1×10^{-5}	3×10^{-5}	1.0×10^{-5}
Biblis B			1.3×10^{-5}	5.1×10^{-5}	-
Neckarwestheim		2×10^{-5}	-	5.8×10^{-5}	$< 8.1\times10^{-5}$
Unterweser	n.a.	n.a.	-	$< 3.8\times10^{-4}$	$< 4.9\times10^{-5}$
BWRs					
Würgassen		4×10^{-5}	-	1.0×10^{-4}	7.3×10^{-5}
Brunsbüttel		5.0×10^{-5}	5.8×10^{-5}	4.6×10^{-5}	1.5×10^{-5}
Isar	n.a.	4×10^{-5}	3.3×10^{-4}	4.3×10^{-5}	3.8×10^{-4}
Philippsburg	n.a.	n.a.	n.a.	-	1.2×10^{-4}
Caorso (a)	n.a.	n.a.	1.9×10^{-3}	1.2×10^{-3}	1.9×10^{-3}
GCRs					
Latina (a)	2.8×10^{-4}	-	-	1×10^{-4}	2×10^{-5}
Chapelcross	3.7×10^{-2}	1.4×10^{-2}	3×10^{-1}	6×10^{-1}	3×10^{-2}
Bradwell	6.5×10^{-2}	1.3×10^{-1}	1.1×10^{-1}	1.3×10^{-1}	2.0×10^{-1}
Berkeley	$< 5.6\times10^{-2}$	$< 7.4\times10^{-2}$	$< 1.6\times10^{-2}$	$< 2.3\times10^{-2}$	$< 2.8\times10^{-2}$
Hunterston A					3.7×10^{-1}
Trawsfynydd		6.8×10^{-2}	5.3×10^{-2}	$< 3.2\times10^{-3}$	2.8×10^{-2}
Hinkley Point A	2.8×10^{-1}	5.8×10^{-1}	2.2×10^{-1}	1.2×10^{-1}	2.8×10^{-1}
Dungeness A	$< 2.3\times10^{-2}$	$< 2.3\times10^{-2}$	$< 1.9\times10^{-2}$	$< 1.5\times10^{-2}$	$< 1.2\times10^{-2}$
Sizewell A	$< 1.5\times10^{-2}$	$< 2.2\times10^{-2}$	$< 1.2\times10^{-2}$	$< 1.9\times10^{-2}$	$< 2.6\times10^{-2}$
Oldbury	5.0×10^{-2}	6.6×10^{-2}	1.5×10^{-1}	3.8×10^{-2}	3.8×10^{-2}
Wylfa	6.5×10^{-3}	$< 9.3\times10^{-3}$	$< 1.3\times10^{-2}$	$< 8.1\times10^{-3}$	$< 9.0\times10^{-4}$
AGRs					
Hunterston B					$< 2.2\times10^{-2}$
Hinkley Point B					1.9×10^{-3}

(a) Pu-239 equivalent

The normalized discharges of alpha activity from the above stations over the years for which data are available amounts to 2.6×10^{-7} Ci/MWa for PWRs, 2.0×10^{-6} Ci/MWa for BWRs, 3.4×10^{-4} Ci/MWa for GCRs and 2.2×10^{-5} Ci/MWa for the two AGRs.

1.2.3.3 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.

Another important source of tritium for AGRs (and also for GCRs) is the activation of lithium present in the graphite moderator as an impurity. This source, however, decreases over time as the lithium-6 disappears. The tritium thus produced in the graphite exchanges readily with hydrogen in water vapour and is removed from the reactor coolant gas by the humidriers; the rate of discharge from such reactors is in fact governed by the availability of moisture in the gaseous coolant.

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 1980. For the period 1976 to 1980 the normalized values may be summarized as follows:

- for PWRs with zircaloy clad fuel from 2.5×10^{-3} to 1.0 Ci/MWa in any one year with an average of 0.47 Ci/MWa,
- for PWRs with stainless steel clad fuel, Chooz and Trino, from 4.3 to 14.5 Ci/MWa with an average of 10.0 Ci/MWa,

- for BWRs from 2.5 x 10^{-3} to 1 Ci/MWa with an average of 0.11 Ci/MWa,
- for GCRs from 6.8 x 10^{-3} to 4.8 Ci/MWa with an average of 0.39 Ci/MWa,
- for AGRs from 1.8 x 10^{-2} to 9.3 Ci/MWa with an average of 6.2 Ci/MWa.

1.2.3.4 Carbon-14

The table below gives carbon-14 discharges with liquid effluents as measured at some German LWRs (4). Carbon-14 is essentially present as dissolved CO_2. The differences in discharges between stations could be due to different operating conditions of the evaporators (4).

Comparaison of this table with the one on carbon-14 discharges to atmosphere in 1.2.2.6 above shows that in most LWRs more than 99% of the carbon-14 goes to atmosphere.

Carbon-14 discharges in liquid effluents (Ci/year)

Facility	1977	1978	1979	1980
PWRs				
Obrigheim		1.6 x 10^{-2}	4.3 x 10^{-2}	4.2 x 10^{-2}
Stade	7 x 10^{-3}	4 x 10^{-3}	2.6 x 10^{-2}	6 x 10^{-3}
Neckarwestheim		1 x 10^{-3}	7 x 10^{-4}	7 x 10^{-4}
BWRs				
Würgassen		1 x 10^{-3}	1 x 10^{-3}	6 x 10^{-4}
Brunsbüttel	4 x 10^{-2}	6.7 x 10^{-2}	2.3 x 10^{-2}	3 x 10^{-3}
Isar		6 x 10^{-3}	5 x 10^{-3}	4 x 10^{-3}
Philippsburg	n.a.	n.a.	1.7 x 10^{-2}	2.6 x 10^{-2}

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 in the European Community.

Reprocessing of LWR fuel at La Hague has increased steadily since first undertaken in 1976 and is now appreciably more important than the throughput of GCR fuel as measured in terms of electricity produced at the power station - see Section 1.3.2.1. Indeed, GCR fuel reprocessing has reduced since 1978 with the progressive transfer of such work to Marcoule (6). In fact, the throughput at Marcoule, again in electrical terms, has increased even faster than the transfer would suggest, rising by a factor of 6 from 1976 to 1980 to approach the throughputs of La Hague and Sellafield. A small amount of FBR fuel is also processed at both Marcoule and La Hague.

Sellafield, processing only GCR fuel, still has marginally the largest throughput, although appreciably lower than in 1975-76.

WAK throughput has reduced since 1977 in electrical terms but this is largely explained by the processing of HWR and PHWR fuel at low burn-ups relative to those which would normally be associated with LWR fuel (9).

Dounreay processes MTR fuel and in addition the former plant for reprocessing metallic FBR fuel has been rebuilt and started handling oxide FBR fuel in 1980 (7).

The discharge data in Tables XIII to XXII are drawn mainly from the following sources:

U.K.: reports prepared annually by the Department of the Environment entitled, "Annual Survey of Radioactive Discharges in Great Britain [year]";

FRG: annual reports published by the Kernforschungszentrum Karlsruhe entitled, "Jahresbericht [year] der Hauptabteilung Sicherheit";

France: information supplied direct to the Commission by the competent French authorities.

Where additional sources have been drawn on, the references are cited in the text.

1.3.2 Gaseous Effluents

The discharge data for krypton-85, radioactive aerosols and tritium are given in Tables XIII to XVI. Additional information is given, to the extent available, in the text below.

1.3.2.1 Krypton-85

Because of the relatively short half-lives of the other radioactive noble gases, krypton-85 completely dominates radioactive noble gas releases from irradiated fuel reprocessing. The discharge data are given in Table XIII.

Since effectively all of the krypton-85 is released during reprocessing the data also provide a measure of the thermal power generated from the fuel in the reactor and hence of the electricity produced. In the absence of fuel burn-up data, this in turn allows other releases from reprocessing to be normalized to the corresponding electrical yields. Such normalized values are relevant to consideration of the nuclear fuel cycle as a whole.

Previous reports in the present series have relied entirely on krypton-85 discharges to calculate the "equivalent electrical throughput" (EET) of the plants. For this purpose two parameters are required, the krypton yield per unit thermal power and the power station efficiency (site electrical output/reactor thermal power) in the present case PWRs and BWRs may be grouped together under the heading LWRs. Based on a brief literature review the following values are proposed:

Fuel type	Krypton-85 yield* (MCi/GW(th)a)	Power station efficiency** (E)
GCR	0.085	0.26
LWR	0.095	0.32

* 2 year cooling period

** taken from data in (1)

For Marcoule and Sellafield the above values have been used to calculate the EETs. Since there are no krypton-85 data for Dounreay (except for 1980) the calculations could not be carried out; in any case the fuel was exclusively from MTR and FBR reactors.

Recently, however, data have been published for La Hague (8) and WAK (9) giving thermal burn-up values for the fuel processed. Relating the WAK data to the krypton discharges allow a krypton yield for LWR fuel to be calculated which is found to be in good agreement with the above. However, the corresponding calculation for La Hague gives krypton yields which are on average a factor of two higher for GCR fuel and over thirty percent lower for LWR fuel. (Further details are given in the Appendix.)

Since the WAK burn-up data cannot readily be transformed to throughput per calendar year, the EET values have been derived using the krypton yield in the table above. The La Hague EETs, however, have been calculated using the burn-up data; the krypton yields taken from the literature would have increased the total EET (1976-80) by about 45%.

The results of the calculations are summarized below:

Equivalent electrical throughputs

Plant	1976	1977	1978	1979	1980
GCR fuel					
La Hague	0.43	0.74	0.88	0.61	0.60
Marcoule	0.28	0.36	0.94	0.86	1.64
Sellafield	3.67	2.45	2.14	2.88	2.54
Totals	4.4	3.7	3.9	4.4	4.8
LWR fuel					
La Hague	0.16	0.36	0.74	1.15	1.57
WAK	0.29	0.39	0.11	0.17	0.11
Totals	0.45	0.75	0.85	1.3	1.7

1.3.2.2 Radioactive aerosols

Alpha-active aerosols

As noted in Table XIV no data have been received in respect of discharges from La Hague and Marcoule for 1979-80; the La Hague values rose by three orders of magnitude in 1976-78 but were at that time still the lowest of the five plants. Discharges from Dounreay have risen to equal those of Sellafield in 1980 but work other than reprocessing may have contributed significantly. Sellafield discharges have fallen slightly and WAK discharges have been reduced by an order of magnitude since 1978.

Since 1978 both WAK and Sellafield have been making more detailed analyses of alpha-active particulate discharges. The available data are summarized below:

Actinides discharged to atmosphere, 1980 (mCi)

Site and Year	Plutonium alpha		Am-241 + Cm-242	Gross alpha
	Pu-238	Pu-239 + Pu-240		
WAK:				
1978	0.33	0.75		4.64
1979	0.25	0.46		0.85
1980	0.096	0.12		0.44
Sellafield:				
1978	24		3.4	36
1979	27		2.9	
1980	12		3.2	

The Pu-238/(Pu-239 + Pu-240) ratio is strongly dependent on burn-up. For PWR fuel at 35 GW(th)d/t the ratio has been calculated to be about 2.5 (10). Whereas the WAK ratio appears to be consistently less than unity, the monthly values show that this is because processing of relatively low burn-up HWR and PHWR fuel dominated the period concerned (9). PWR fuel at about 30 GW(th)d/t gave a ratio of about 2.0 (on limited data) and for BWR

fuel at 17 GW(th)d/t the value was about 1.6. Sellafield liquid effluent data (section 1.3.3.1) for 1978-80 gives an average ratio of 0.30 (range 0.27-0.34) a value which would correspond to a burn-up of 5 EW(th)d/t for GCR fuel (10).

Since plutonium-242 can be expected to contribute less than 1%, the sum of the isotopes 238, 239 and 240 will effectively yield the total plutonium alpha activity. Inspection of the WAK monthly data shows that this varied from 0.04 to 1.25 times gross alpha activity measurements during operational campaigns. The very low value is associated with relatively high gross alpha readings in early 1978 when over 4 mCi were recorded in a three month period. Since mid-1978 operational values of the ratio Pu-α/Gross α have been in the range 0.5 to 1.25 with the majority of values in the range 0.7 to 0.9. The sole value available for Sellafield is 0.8 for 1978.

Based on the EET values calculated previously the normalized discharges were:

Sellafield	1.2×10^{-2} Ci/GWa	1976-80
WAK	1.1×10^{-2} Ci/GWa	
Marcoule	9.6×10^{-5} Ci/GWa	1976-78
La Hague	9.9×10^{-6} Ci/GWa	

Beta-active aerosols

The data are presented in Table XV. It should be noted that from 1978 onwards the Sellafield values correspond to the sums of seven specific-nuclide activities (see below) rather than total beta. The Dounreay values cover the same nuclides with the addition of antimony-125.

While the values for La Hague and Sellafield are reasonably self-consistent, Marcoule has shown considerable swings and WAK has dropped steadily since 1977.

Low-energy beta emitters such as technetium-99 and plutonium-241 are unlikely to have been detected by total beta methods. However, for WAK, plutonium-241 is stated to have been at most 10% of the total beta values recorded in 1979 and 1980. For Sellafield, liquid effluent data show plutonium-241 activity is consistently some thirty times plutonium-alpha

activity; assuming the same relationship for aerosol discharges would imply annual releases of about half a curie of plutonium-241.

The Sellafield nuclide specific data are summarized below.

Nuclide	Sellafield discharges to atmosphere (Ci)				
	1976	1977	1978	1979	1980
Sr-90	0.36	1.1	1.3	0.24	0.49
Zr/Nb-95			0.24	0.18	0.12
Ru-106			0.21	0.094	0.35
Cs-134			0.72	0.67	0.98
Cs-137	1.1	6.3	6.5	6.4	12.1
Ce-144			0.088	0.10	0.04

The caesium and strontium discharges are largely from a magnox storage silo whereas the increase in ruthenium-106 in 1980 was associated with a building vent. (Additional equipment was introduced in 1981 for both of these discharge points resulting in a substantial reduction in discharges (11)).

For WAK nuclide-specific aerosol data are limited to strontium-90 measurements from 1977 onwards; annual discharges for the years 1977-80 were 0.02, 0.0067, 0.0043, and 0.0029 Ci respectively, being of the order of 10% of the total beta values.

The Dounreay data for the period 1978-80 are as follows (12):

Nuclide	Dounreay discharges to atmosphere (Ci)		
	1978	1979	1980
Sr-90	0.04	0.057	0.26
Zr/Nb-95	<0.001	-	-
Ru-106	<0.006	0.017	0.15
Sb-125	-	-	0.042
Cs-134	-	-	0.034
Cs-137	0.11	0.08	0.40
Ce-144	<0.006	0.093	0.48

Values in previous years were below the limit of detection. It should be borne in mind that reprocessing in 1978 and 1979 at Dounreay was almost exclusively of MTR fuel; PFR fuel reprocessing began in 1980.

No nuclide specific data are available for La Hague and Marcoule.

Normalized to the EET values, the discharges for the four main plants over the period 1976-80 averaged:

Sellafield	3.3	Ci/GWa
WAK	5.7×10^{-1}	Ci/GWa
Marcoule	1.9×10^{-2}	Ci/GWa
La Hague	3.9×10^{-3}	Ci/GWa

1.3.2.3 Tritium

The available data are given in Table XVI. Normalized to the EET values the 1976-80 averages are:

Sellafield	3.0×10^{3}	Ci/GWa
Marcoule	1.5×10^{3}	Ci/GWa
WAK	6.2×10^{2}	Ci/GWa
La Hague	1.3×10^{2}	Ci/GWa

The Sellafield normalized values are relatively stable from year to year but considerable variations are found at other plants; the most extreme case is Marcoule where the range is from 0.20×10^{3} (1977) to 2.2×10^{3} (1979) Ci/GWa representing some 1% to 10% of the theoretical tritium content for GCR fuel.

1.3.2.4 Radioactive Iodine

The iodine-131 discharge data available are as follows:

Iodine-131 to atmosphere (Ci)

Facility	1976	1977	1978	1979	1980
La Hague	0.34	0.019	0.026	0.91*	0.48*
Marcoule	1.32	0.61	1.1	0.012*	0.022*
Dounreay: org.	<0.058	<0.036	<0.036	<0.036	<0.036
inorg.	<0.052	<0.036	<0.036	<0.036	<0.036
Sellafield	0.076	0.07	0.4	0.82	0.03

* Halogens

The eight day half life of iodine-131 means that the total release can be dominated by that from a small fraction of the fuel throughput which is processed at a relatively short cooling time. The 1978 and 1979 Sellafield discharges are significantly higher than in other years; that for 1978 has been specifically attributed to a batch of short-cooled fuel (13). Fuel equivalent to a GWa of electricity would contain less than a microcurie after one year's decay but at six months the value is a factor of 10^8 higher.

Since 1979 the two French sites have reported only the halogens which will include iodine-129. Prior to 1980 WAK published only iodine-129 and weighted total iodine values which can be almost entirely accounted for by iodine-129. The 1980 release of iodine-131 was 9 mCi.

Dounreay is the only site which attempts to measure organic and inorganic components separately but the individual sample results are rarely above the limit of detection.

Iodine-129 data is available only for Sellafield and WAK; the recorded discharges were as follows:

Iodine-129 to atmosphere (Ci)

Facility	1976	1977	1978	1979	1980
WAK	3.0×10^{-3}	2.2×10^{-3}	4.7×10^{-3}	2.0×10^{-3}	2.2×10^{-3}
Sellafield	0.22	0.16	0.07	0.15	0.40

Experimental work at WAK from November 1975 to August 1977 gave the inorganic/organic ratio as 3:1 on average, with only 2% as aerosols, but the individual measurements give a wide range of values (14).

The rise in the 1980 Sellafield value is attributed to a particular cell-ventilation exercise (7).

Normalized to electrical output over 1976-80 the results give:

Sellafield	7.3×10^{-2}	Ci/GWa
WAK	1.3×10^{-2}	Ci/GWa

The fuel content would be some 1 to 2 Ci/GWa.

1.3.2.5 Carbon-14

Discharge data have been reported for Sellafield where routine measurements began in 1978. Releases in 1978, 1979 and 1980 were respectively 112, 94 and 110 Ci. The normalized discharge rate is, therefore, for

Sellafield 42 Ci/GWa (1978-80)

with a range of some ± 25% in the individual years. The average value is equivalent to some 50% of the theoretical fuel content (GCR fuel).

In addition a 1980 result of 1.73 Ci has been reported for WAK giving a normalized rate of

WAK 16 Ci/GWa (1980).

This is in reasonable agreement with earlier experimental work at WAK which suggested a value of about 12 Ci/GWa (15). While this work measured only the carbon dioxide form, subsequent work established that some 99.9% of the carbon-14 is discharged in this form (16). Assuming a fuel content of 18 Ci/GWa, a value which is not well established, discharges would appear to be in the range 70-90% of the fuel content.

1.3.3 Liquid Effluents

Tables XVII to XXII give the liquid effluent discharges of alpha activity, beta activity (excluding tritium) and the individual nuclides tritium, strontium-90, ruthenium-106 and caesium-137.

For La Hague and Sellafield it can be assumed that the discharges effectively reflect reprocessing or directly related operations. The WAK discharges on the other hand would be more correctly referred to as the Karlsruhe discharges, since other installations on the site contributed anything from a fifth to two thirds of the effluent treatment plant input and must have significantly influenced the discharges, particularly as regards individual nuclides. At Marcoule and Dounreay the situation probably lies somewhere between these two extremes.

1.3.3.1 Alpha activity

Table XVII gives the annual discharges in terms of gross alpha activity. Almost all of the WAK samples have been at or below the limit of detection (currently 10 mCi/m^3) and have been deemed to have zero activity. However,

even if the samples had been at the limit of detection in every such case, site discharges would only have amounted to some 5 mCi/a.

Liquid effluents are discharged in batches and the timing of the releases may displace effluents from a given reprocessing run into the subsequent year. Thus the apparent drop in Sellafield discharges in 1977 and the subsequent rise in 1978 to above the earlier 1976 level resulted from the timing of discharges (17). For such reasons the changes in the data from year to year are not necessarily of significance. Nevertheless, it would appear that, while there was no clear upward trend in La Hague discharges despite the increased EET, Marcoule discharges have risen in response to the increasing throughput at that site. The reduction in Sellafield discharges in 1980 was associated with improvements to the effluent treatment system. WAK annual contributions of alpha activity to the site effluent treatment plant varied between 65% in 1976 and 23% in 1980: the discharges from the treatment plant will not necessarily have contained the same proportions.

No data on discharges of individual alpha-emitting nuclides are available for Marcoule and Dounreay. For La Hague data on plutonium-238/239 for the years 1966-77 have been published in the open literature (18). At Karlsruhe both plutonium-238 and plutonium-239/240 measurements are recorded; the limit of detection in each case is 20 pCi/m^3, substantially lower than for gross alpha activity, and hence the nuclide concentrations in the bulked samples for 1973-80 (9) could be measured. In 1978 the Sellafield analytical programme was expanded from plutonium-238/239/240 and americium-241 to yield a comprehensive nuclide breakdown.

The available data for 1976-80 are summarized in the table below.

Liquid effluent discharges of individual alpha emitters (Ci)

Site	Nuclide	1976	1977	1978	1979	1980
La Hague	Pu-238	4.23	6.46			
	Pu-239					
WAK	Pu-238	$5x10^{-4}$	$2x10^{-4}$	$5x10^{-5}$	$1.2x10^{-4}$	$9.62x10^{-4}$
	Pu-239	$2x10^{-4}$	$2x10^{-4}$	$7x10^{-5}$	$1.4x10^{-4}$	$9.25x10^{-3}$
	Pu-240					
Sellafield	Np-237			16	9	8
	Pu-238	1266	981	334	323	186
	Pu-239			1233	1012	550
	Pu-240					
	Am-241	323	99	214	212	223
	Cm-242			15	10	9
	Cm-243			9	4	5
	Cm-244					

For La Hague the sums of the given plutonium nuclides in 1976-77 corresponds to less than 40% of the gross alpha discharges. For Sellafield for the same period it represents over 80%, while the more complete analyses for 1978-80 give over 95% of the gross alpha values. It can be observed that the reduction in 1980 in gross alpha discharges was due entirely to a reduction in plutonium.

For the three principal plants, normalizing the discharges to the EET values over the period 1976-80, gives

Sellafield	540 Ci/GWa
La Hague	10 Ci/GWa
Marcoule	1 Ci/GWa

WAK, allowing for the attribution of zero values to samples at or below background and the contributions from other installations to the site discharges, is probably around the lower end of the range 10^{-2} to 10^{-3} Ci/GWa.

1.3.3.2 Beta activity (excluding tritium)

The discharge data in terms of gross beta activity are given in Table XVIII.

Taking into account the variations which can occur from year to year due to the timing of discharges, the fluctuations are of no particular significance except for the reduction of almost a factor of two in Sellafield discharges subsequent to 1978. This was associated with improvements to the pond water treatment system and an increase in the hold-up times of other effluents prior to discharge.

In terms of beta activity WAK contributed only some 20% of the effluent received by the Karlsruhe effluent treatment plant in 1976-78 rising to around 50% in 1979-80.

Data for individual nuclides, other than strontium-90, ruthenium-106 and caesium-137 as given in Tables XIX to XXII, are generally sparse. However, comparatively comprehensive nuclide inventories are available for La Hague for the years 1970-77 (18) and for Sellafield for the years 1978-80. The table below summarizes these data for the period 1976-80.

Liquid effluent discharges of individual beta-gamma emitters (Ci)

Nuclide	La Hague		Sellafield		
	1976	1977	1978	1979	1980
Co-60	5.4	6.0	28	14	21
Zn-65	0.21	0.6	1	0.6	0.9
Sr-89	21	73	267	203	318
Sr-90	1 078	1 965	16 160	6 812	9 506
Zr-95	92	20	2 210	1 610	1 610
Nb-95	53	35	3 995	2 651	2 713
Tc-99			4 839	1 175	1 534
Ru-103	60	31	231	157	124
Ru-106	15 004	14 591	21 897	10 615	9 295
Ag-110m	0.7	0.6	9	0.9	1.2
Sb-125	971	1 481	786	374	575
Cs-134	177	258	10 909	6 363	6 464
Cs-137	939	1 372	110 483	69 255	80 163
Ce-144	157	135	2 819	2 250	992
Eu-152			270	99	126
Eu-154			1 032	52	53
Eu-155			212	108	113
Total	18 558	19 968	176 148	101 340	113 609
Gross Beta	19 300	20 689	192 550	109 676	116 391

The total activities of the individual nuclides shown are consistent with the gross activities measured. Exact agreement could not be expected even if all nuclides present were accounted for, since the gross beta calibration factors are not adjusted for the nuclide spectra involved. Nevertheless, it is convenient to express the individual nuclide contributions as a percentage of gross activity to demonstrate more clearly their relative importance in different cases, even when the gross activity is significantly greater than the sum of the nuclides measured. Reformulating Tables XX to XXII in this way gives the following tabulation.

Discharges of individual nuclides as percentages of gross beta discharges

Site	Nuclide	1976	1977	1978	1979	1980
WAK	Sr-90	16.6	22.4*	20.4*	13.5	6.3
	Cs-137	13.3	2.3	8.4	4.0	7.8
	Ru-106					
La Hague	Sr-90	5.6	9.5	12.8	6.5	5.8
	Cs-137	4.9	6.6	3.6	1.7	
	Ru-106	77.7	70.6	73.4	74.3	
Marcoule	Sr-90	1.8	1.2	2.5	2.6	2.2
	Cs-137		4.1	11.6	12.9	10.1
	Ru-106	86.7	95.8**	70.1**		
Dounreay	Sr-90	13.4	22.8	19.7	25.2	20.5
	Cs-137	26.7	17.1	20.4	27.4	33.6
	Ru-106	2.6	3.6	0.7	3.2	1.2
Sellafield	Sr-90	5.6	6.0	8.4	6.2	8.2
	Cs-137	63.2	62.8	57.4	63.1	68.9
	Ru-106	11.3	11.4	11.4	9.7	8.0

* incl. Sr-89
** incl. Ru-103

It can be seen that whereas ruthenium-106 dominates releases from La Hague and Marcoule, caesium-137 (coming from corroded fuel in the storage ponds) gives the largest contribution to Sellafield discharges. In all three cases these nuclides combine to give some 80% or more of the gross beta measurement. For WAK (Karlsruhe site discharges) there are no published ruthenium-106 results for later than 1975 but earlier data indicate that this only accounted for a few percent and hence the total remains in the range 15-30%. The Dounreay values total around 40% for 1976-78 rising to 55% in 1979-80; taking into account zirconium/niobium-95 and cerium-144 listed in the original data still leaves over 50% of the gross beta unattributed for 1977-78.

Low energy beta-emitters (other than tritium) and nuclides which decay by electron capture are not covered by the Sellafield authorisation in that the approved method of measuring gross beta is insensitive to such nuclides and no specific limits are allocated to these nuclides. Nevertheless, routine analyses have been introduced for a number of them as given in the table below. (For tritium see section 1.3.3.3.)

Additional liquid effluent nuclide discharges from Sellafield (Ci)

Nuclide	1976	1977	1978	1979	1980
S-35			49	39	28
Mn-54			6	<1	<1.7
Fe-55			63	48	29
Ni-63			40	4.9	11
I-129	4	3	2	< 3.3	< 6.5
Pm-147					2 323
Pu-241	35 048	26 517	47 928	40 383	19 684

No liquid effluent data for such nuclides have been identified for the other reprocessing plants.

Finally, normalizing the gross beta activity to the EET values for the period 1976-80 gives:

Sellafield	5.8×10^3	Ci/GWa
La Hague	1.7×10^3	Ci/GWa
Marcoule	1.0×10^3	Ci/GWa

WAK, allowing for the contributions from other installations to the site effluents, discharged appreciably less than 0.1 Ci/GWa.

1.3.3.3 Tritium

The discharges are given in Table XIX. In this case the WAK discharges are directly attributable to the reprocessing plant and do not include contributions from other installations. Normalizing to the EET values gives:

Sellafield	11.1×10^3	Ci/GWa
WAK	9.2×10^3	Ci/GWa
La Hague	9.0×10^3	Ci/GWa
Marcoule	8.1×10^3	Ci/GWa

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 with particular reference to 1980.

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 aquatic produce or of farm produce contaminated directly or indirectly by irrigation.

Since the levels of environmental contamination resulting from discharges are not usually readily detectable, dose evaluations frequently rely of necessity on generalised models used firstly to estimate environmental contamination and subsequently the resulting doses to man. In the models applied below to obtain dose estimates 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.

The factors expressing the dose per unit intake used throughout are in accordance with ICRP 30 (19) and the supplements thereto.

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 0.5 km and 5 km for external exposure and inhalation and at 5 km only for milk consumption; 0.5 km roughly corresponds to the immediate site surroundings and hence to a position where members of the general public are hardly ever present, whereas 5 km is a measure of the distance at which the group of dwellings and/or significant dairy farming 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 (100% occupancy factor);
- long-term atmospheric dilution factors (20) 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.

2.2.1.1 External gamma and beta doses

Table X gives the maximum external radiation doses in 1980 from the radioactive 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. At 5 km the doses are an order of magnitude lower.

In the case of those British GCRs for which discharge data are available, the annual exposure as calculated at 0.5 km due to argon-41 releases varied between 0.2 and 35 mrem; at 5 km the maximum dose was 1.5 mrem. Heap and Short (3) have indicated that the maximum dose received by a member of the public was about 10 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. The AGRs, Hunterston and Hinkley Point B, were calculated to have contributed 13% and 5% respectively to the site results given in Table X.

As regards external irradiation from deposited activity, assuming a constant aerosol discharge rate of 230 mCi per year (the maximum observed in 1980) consisting of cobalt-60 alone (this being the most potent gamma emitter commonly observed in LWR aerosol discharges - see tables on pages 5 and 6) the gamma dose-rate at equilibrium would be 1 mrem per year at 0.5 km and 0.07 mrem at 5 km.

In practice, since cobalt-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

As for external radiation from aerosol deposition the assessment has been restricted to the doses resulting from the maximum ascertained discharge during 1980, i.e. 230 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 5) would imply a committed effective dose to an adult of 0.03 mrem at 0.5 km. All other annual discharges having been less than 230 mCi, the maximized doses for other sites will have been correspondingly lower.

From the data available the maximum discharge of alpha-activity to atmosphere in 1980 was 9×10^{-6} Ci (see table on page 7). Assuming this activity was wholely plutonium-239, the committed effective dose at 0.5 km for an adult by inhalation would be 2×10^{-3} mrem and the committed bone surface dose 0.05 mrem.

2.2.1.3 Internal irradiation by sulphur-35

The highest reported discharge of sulphur-35 from the British GCRs and AGRs is 10.5 Ci. The critical pathway for uptake of this radionuclide is via milk produced by cows grazing contaminated pastures. An annual discharge of 10.5 Ci would result in a milk concentration at 5 km of about 50 pCi/liter, which, according to ICRP 30, would lead to a committed effective dose of 0.003 mrem for an adult consuming 0.3 l/d of this milk. However, Vennart and Ash (21) give data more directly related to sulphur-35 in milk which would imply a committed effective dose of 0.02 mrem to the adult and 0.1 mrem to the infant consuming 0.7 l/d.

2.2.1.4 Internal irradiation by iodine-131

Table X shows, for the 1980 discharges of iodine-131 to atmosphere, the calculated maximum doses to the thyroid of an infant drinking milk produced at 5 km from the discharge points. These doses were calculated using the ICRP-30 dose factors, increased by a factor of ten corresponding to the difference in thyroid masses. In no case does the thyroid dose exceed 1 mrem, corresponding to an effective dose of 0.03 mrem.

It should be noted that these 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 locally produced milk;
- the infant drinks only milk produced at the distance cited.

For adults the doses would be less than 10% of those indicated for the infant.

2.2.1.5 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 effective doses of less than 0.1 mrem at 0.5 km and less than 0.01 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 (22) 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.

2.2.1.6 Exposure to carbon-14

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

The highest annual release of carbon-14 measured at German LWRs amounts to 9.5 Ci.

Use has again been made of a specific activity model (23), assuming the food intake pattern given in Section 2.2.1.5. This indicates that the food pathway is predominant; for a stack height of 100 m the committed effective dose would not exceed 0.001 mrem at all distances from the discharge point.

Theoretical estimates of carbon-14 from the UK GCR and AGR stations give 25 and 50 Ci per year respectively; the above calculated dose would change in direct proportion.

2.2.2 Liquid Effluents

The highest mean increase in river-water activity concentration in 1980 due to effluent from a nuclear power station was in the Rhône downstream of the Bugey site. Using the radionuclide composition of the effluents from the Bugey plant, as given in Table VIII, the maximum committed effective doses from the above exposure paths have been assessed, taking account of local conditions, and the following results obtained:

Committed effective doses from liquid effluents (mrem) - Bugey, 1980

Exposure path	Average consumption rates (kg/a) or exposure times (h/a)	Committed effective dose (mrem)
Internal exposure		
- drinking water	440	0.1
- river fish	16	0.2
- milk (infant)	250	0.02
- meat	75	0.003
- crops	313	0.04
External exposure		
- swimming + boating	8	6×10^{-5}
- exposure on river banks	200	0.2

As regards marine and estuarine sites, U.K. estimates based on environmental monitoring (24) show that in 1980 the highest critical-group dose was local to Hunterston and was less than 10 mrem. However, the radionuclide concentrations in the area were predominantly due to Sellafield discharges. The next highest results were less than 2 mrem and were also attributable in some part to Sellafield discharges.

For Trawsfynydd, which discharges into a lake, the dose to the critical group was some 10 mrem.

2.3 NUCLEAR FUEL REPROCESSING PLANTS

As regards discharges to atmosphere, those from Sellafield are clearly higher than those from other plants except in the case of krypton-85; discharges of the latter from La Hague are closely comparable. Moreover, liquid effluent discharges from Sellafield are also significantly higher than from other plants except for ruthenium-106, for which discharges from La Hague are similar in quantity. The following discussion of the environmental radiological impact is therefore largely confined to Sellafield

which has the advantage that a great deal of district survey data have been published. A distinction must be drawn, however, between discharges to sea and to a river, the latter having a more limited dispersion capacity. For this reason the liquid effluent discharges from Marcoule are also considered.

2.3.1 Sellafield

2.3.1.1 Airborne pathways

Sellafield releases take place from a number of discharge points at various heights, which complicates modelling of the subsequent atmospheric dispersion, particularly as regards short distances from the site. However, by 1980, the published environmental survey data had been expanded to include continuous sampling of airborne particulates at 9 points situated at up to 11 km from the site, in addition to milk sampling from a number of local farms (25). With these results available the need for modelling in part obviated.

The airborne particulates have been analysed for strontium-90, caesium-137, plutonium alpha emitters and the combination americium-241 plus curium-242. Based on the published annual average concentrations the present authors have calculated the corresponding 1980 inhalation doses to adults in accordance with ICRP 30 and the supplements thereto (19); the calculations assume a 100% occupancy factor and conservatively attribute the plutonium alpha emitters and americium-241/curium-242 to plutonium-238/239 and americium-241 respectively.

It is not clear to what extent the measured concentrations are representative of the distances to which they relate in terms of the local dispersion patterns. Certainly at any given point the reported concentrations of individual nuclides do not bear a constant relationship to the site discharges for 1980, presumably reflecting the diversity of the release points - their distance from the site perimeter and their effective release height, the time pattern of releases as a function of dispersion conditions etc.. Also, topographical variations and windrose effects will influence the concentrations at individual points at any given distance. However, the general pattern of dose as a function of distance, as shown below for the points at up to 6 km, is satisfactory, suggesting that the points are reasonably representative.

Committed effective doses by inhalation (mrem) - Sellafield, 1980

Nuclide	Distance from site perimeter (km)			
	1	3	3	6
Pu- α	2.7	0.56	1.1	0.26
Am-241 + Cm-242	0.92	0.39	0.43	0.31
Sr-90	0.16	0.02	0.02	0.02
Ru-106	0.07	$<$0.02	$<$0.02	$<$0.02
Cs-137	0.15	0.01	0.01	0.00
Ce-144	$<$0.03	$<$0.01	$<$0.02	$<$0.01
Total	4.0	1.0	1.6	0.62

It can be observed that the fission products contributed only some 10% or less of the doses. Moreover, the transuranics do not take into account plutonium-241; assuming that, as for liquid effluents, discharges of the latter were some thirty times those of the plutonium alpha-emitters, the additional dose will have been 60% of that attributed to plutonium alpha.

For the actinides, doses to bone surface, although having a higher dose limit, are more restrictive and have been calculated to be:

Committed doses to bone surface by inhalation (mrem) - Sellafield, 1980

Nuclide	Distance from site perimeter (km)			
	1	3	3	6
Pu- α	48	10	20	4
Am-241 + Cm-242	16	7	8	6
Total	64	17	28	10

Again plutonium-241 could have added some 60% of the doses attributed to plutonium alpha emitters; strontium-90 also migrates to the bone surface but its dose contribution will have been negligible in relation to that from the actinides.

The phenomenon of airborne radioactivity originating from sea-spray contaminated by liquid effluents has been the subject of a series of studies. Plutonium and americium concentrations in the spray have been found to be an order of magnitude higher than in unfiltered sea-water due to sediment enrichment of the spray (26). However, an appreciable fraction of the resulting aerosols are larger than the upper limit of the respiratory particle-size range. Continuous samples have been taken over a twelve month period in 1978-79 using samplers which, while tending to discriminate against such large particles, nevertheless still overestimate the respirable fraction (27). Six sampling locations were investigated and the location showing the highest annual average concentrations of plutonium-238, plutonium-239/240 and americium-241 yielded levels corresponding to a committed effective dose by inhalation of these nuclides of 0.5 mrem calculated as above. The dose to bone surface would be 13 mrem and allowing for plutonium-241 as previously increases these values to 0.8 mrem and 19 mrem respectively. Again these estimates assume a 100% occupancy factor.

All of the results given above refer to the adult since ICRP 30 does not extend to younger age groups. However, Johnson et al. (28) have published preliminary data based on the ICRP approach but extended to cover the one year old child. For the alpha-emitters the bone surface dose is again limiting and although the breathing rate is only 17% of that for the adult (29) the calculated bone surface doses for both plutonium and americium are 40% higher than those for the adult.

Milk samples are analysed for strontium-90, caesium-137, ruthenium-106, iodine-129/131 and plutonium alpha emitters. In all, milk from twelve farms at distances of up to about 6 km is analysed; "background" levels of strontium and caesium are assessed using milk from two farms at some 30 km.

The committed effective doses have again been calculated on the basis of the ICRP recommendations. For this purpose an annual milk intake of 100 l per year has been assumed and the strontium concentrations (expressed in the original data "per gram of calcium") have been evaluated assuming 1.2 gCa/l of milk. Both strontium and caesium have been corrected for the "background" levels.

Committed effective doses by milk ingestion in Sellafield, 1980 (mrem)

Farm Dist. (km)	Sr-90	Cs-137	Ru-106	I-131	I-129	Pu-α
0 - 3.2	0.11	1.65	< 0.19	0.007	0.017	0.005
3.2 - 6.4	0.03	0.32	< 0.17	0.008	0.016	0.005

These values, giving in total less than 2 mrem in the inner zone, refer to the adult whereas for the milk pathway infants normally constitute the critical group. Changing the milk consumption rate to 260 l per year (0.7 l/day) and using the infant/adult dose factor ratios from Johnson et al. to adjust the ICRP factors, a total committed effective dose of some 6 mrem is obtained for infants consuming milk from the inner zones. Harrison (30) has suggested the plutonium uptake factor from foods for the 0-12 month child could be as much as 50 times the ICRP value for the adult, which would raise the committed effective dose for infants to about 15 mrem allowing for Pu-241 as before. A similar calculation for the bone surface dose suggests that this would still be less restrictive than the committed effective dose.

Neglecting the possibility of enhanced plutonium uptake, caesium-137 is the most significant single nuclide and it is widely recognised that the concentrations of caesium-137 in milk can reflect, in part, depositions in the preceding years. Studies on weapons fallout (31), averaged over the U.K., have suggested that, compared with the year of interest, deposition of caesium in the immediately preceding year has to be weighted by a factor of 2.0 and that in earlier years by a factor of 0.13 to explain changes in the concentrations in milk. However, for Sellafield, assuming the deposition proportional to the annual discharges and comparing the discharge patterns with those of milk contamination for the period 1976-81 suggests that, in the conditions existing there, the influence of concurrent discharges is much greater than the fallout studies imply.

For the nuclides covered by the environmental survey data two further dose pathways for airborne releases remain to be considered - the inhalation dose from iodine and the external radiation dose from caesium deposition. As regards iodine the inhalation doses will have been small compared with

that from the milk pathway and hence will have been of no significance compared with the inhalation doses already calculated. For caesium, the measured annual average airborne concentration at 1 km, assuming a velocity of deposition of 0.005 $m \cdot s^{-1}$, implies a deposition rate of 2.7×10^{-3} pCi/$m^2 \cdot s^{-1}$. From (32) the dose rate by the end of the year would have been some 3 mrem/year from the 1980 caesium-137 deposition. Taking account of previous years' discharges this figure would rise to the order of 10 mrem per year.

Nuclides not covered by the environmental data include tritium, carbon-14 and krypton. Applying Bryant's model (33) a skin dose of 1.7 mrem at 1 km from krypton-85 is obtained and for carbon-14 and tritium combined a total committed effective dose of less than 0.1 mrem at the same distance results, taking all pathways into account.

2.3.1.2 Marine pathways

The operator and the competent authority independently conduct comprehensive environmental monitoring programmes and the latter also carries out periodic habit surveys to determine the parameters characterizing the critical groups. The discussion below is based on the authority's results for 1980 (24, 34) but also draws on the operator's results (25) where appropriate.

For external exposure the "critical group" consists of one fisherman living on board his boat which, at low tides, may rest on harbour mud. He is estimated to have received some 55 mrem (corrected for natural background) in this way. His consumption of marine produce is estimated to have given a committed effective dose of a further 30 mrem giving a total of 85 mrem.

Previously the critical group for external exposure was deemed to be a bailiff working in a nearby salmon garth. The operator had assessed his theoretical external exposure as 15 mrem in 1980 but in practice the garth fell into disuse.

For internal exposure two critical sub-groups have been identified and their intakes of marine produce are surveyed to allow dose estimation. The intakes and the corresponding values for earlier years are given below, where "local consumers" correspond to those consuming local produce and "commercial consumers" correspond to a group in the nearest commercial fishing ports having higher consumption rates of produce at lower average concentrations of radioactivity.

Marine produce consumption for critical group - Sellafield (g/day/person)*

Category	Local consumers			Commercial consumers		
	1973**	1978	1980	1973	1977	1978
Fish	224	170	100	300	290	360
Crustacea	41	15	18	-	70	70
Molluscs	-	6	18	-	45	50

* Prior to 1973 the critical marine produce pathway was laverbread incorporating porphyra collected locally.

** Maximum individual consumption rates.

While the commercial sub-group consumption rates have changed little over the years the 1980 values for local consumers reflect genuine changes as revealed by the habit survey. It is conservatively assumed that consumption rates for each of the three categories of produce are additive. The habit survey also provides data as to representative species within each category and these too have changed over the years. (See also (35).)

Environmental samples were analysed for a large range of nuclides to allow calculation of the critical group doses on the basis of the above consumption rates. However, strontium-90 and plutonium-241 analyses were not carried out by the competent authority; instead the concentrations of these two nuclides were estimated on the basis of the amounts discharged. For plutonium-241 the other plutonium isotopes provide a straightforward guide and for strontium-90 analytical results obtained by the operator are in excellent agreement with the estimated concentrations. Eliminating nuclides which give a negligible dose contribution, the doses per nuclide to each of the two sub-groups were calculated to be:

Committed effective doses to marine-produce critical groups (mrem) - Sellafield, 1980

Nuclide	Local consumers	Commercial consumers
Sr-90	2.0	2.0
Ru-106	15.1	0.6
Cs-134	4.1	4.9
Cs-137	41.9	54.9
Pu-238	2.2	0.3
Pu-239/240	9.5	1.6
Pu-241	6.9	1.2
Am-241	38.6	9.8
Total	120	75

Despite the lower consumption rates the local sub-group is seen to have received the higher dose overall because of the much higher contributions from ruthenium and the transuranics. These nuclides are subject to rapid losses from sea-water by take-up on silt etc. and hence their concentrations in sea-water reduce more rapidly with distance from the discharge point. Correspondingly their presence in silt leads to relatively high concentrations in molluscs and some crustacea. In terms of dose, molluscs (winkles and mussels) provided over 85% of the dose to the local sub-group from ruthenium and the transuranics, which in turn represents over 50% of the total dose. For this reason the 1978 dietary pattern (assuming the same species) would have implied only some 80% of the dose calculated using the 1980 pattern, despite the much lower fish intakes in the latter year.

The operator's results for environmental concentrations are lower overall than those provided by the competent authority and would imply a dose some 25% lower.

The concentrations in 1980 will in part reflect discharges in previous years. However, the net caesium-137 concentrations in fish have fallen subsequent to the reduction in discharges in 1979. Ruthenium-106 having a radioactive half-life of 1 year its concentrations must also tend to reflect relatively recent discharges. The overall situation can be complicated by changes in dispersion conditions. Thus, locally reduced ruthenium-106 concentrations in 1978 were attributed to changes in dispersion conditions close to the site for these nuclides which absorb

readily onto sediments (36); plutonium and americium concentrations in molluscs were reduced at the same time but not in crustacea.

The significant contributions of the transuranics to the committed effective dose to the local sub-group suggests that the bone surface dose may be limiting. In fact, using the ICRP data, this dose is found to be 1100 mrem (one third from plutonium, two thirds from americium) and hence is marginally less restrictive, in terms of the relevant limits, than is the committed effective dose. However, if the plutonium uptake factor were to be increased by a factor of five for the adult as has been suggested (30), the bone surface dose would be affected to a much greater extent than the effective dose and would be clearly limiting.

2.3.2 Marcoule - liquid effluents

In the table below, the committed effective doses calculated for the Marcoule 1980 discharges, taking account of local conditions, are presented together with the assumed consumption rates and exposure times as appropriate to the various pathways.

Committed effective doses from liquid effluents - Marcoule, 1980 (mrem)

Exposure pathway	Average consumption rate (kg/a) or exposure time (h/a)	Committed effective dose (mrem)
Internal exposure:		
Drinking water	440	0.3
Fish	16	1
Milk (child)	250	0.02
Meat	75	0.02
Crops	313	0.03
External exposure:		
Swimming and boating	8	3×10^{-4}
Exposure on river banks	200	0.1

Fish consumption is the dominant pathway and the calculated dose is almost entirely attributable to caesium-137.

2.4 COLLECTIVE DOSES FROM RADIOACTIVE EFFLUENTS DISCHARGED BY NUCLEAR POWER PLANTS AND NUCLEAR FUEL REPROCESSING PLANTS

A comprehensive methodology to evaluate the radiological impact of radioactive effluents routinely discharged by nuclear installations has been developed by the National Radiological Protection Board (N.R.P.B.), U.K., and the Commissariat à l'Energie Atomique (C.E.A.), France, on behalf of the European Commission (32).

This methodology has been applied by N.R.P.B. (37) to estimate the total collective effective dose commitment to the population of the European Community from the 1978 discharges by nuclear power plants and nuclear fuel reprocessing plants given in the present report.

The effective dose commitment from gaseous and liquid effluents by all Community nuclear power stations was calculated to be 5700 man·rem. Airborne effluents make by far the largest contribution, i.e. 96%.

As regards individual stations, the effective dose commitments from LWRs range from about 10 to 100 man-rem with an average of 30 man-rem; for GCRs and AGRs they range from 50 to 500 man-rem with an average of 270 man-rem. In all cases the dominant nuclide is carbon-14, responsible for more than 80% of the dose. Its dominant pathways are ingestion subsequent to the first pass of the activity and global circulation. The first pass ingestion dose is delivered within a few years of the discharge while the dose resulting from global circulation is spread out over thousands of years.

The effective dose commitment from nuclear fuel reprocessing plants was calculated to be 44500 man-rem, i.e. nearly an order of magnitude greater than from the power stations; of this dose 38000 man-rem comes from Sellafield discharges, 4400 from La Hague and 1900 from Marcoule. For the two coastal plants the larger part comes from liquid effluents: 97% at Sellafield and 73% at La Hague; for Sellafield the nuclide delivering the highest dose contribution is caesium-137 (70%), and for La Hague ruthenium-106 (60%). The main exposure pathway for the two plants is ingestion of marine produce. Most of the dose is delivered within a few years of the discharge.

At Marcoule the nuclide delivering the highest dose contribution is carbon-14 (50%) in the airborne effluents.

In 1980 caesium-137 discharged in liquid effluents by Sellafield decreased by 27% compared with 1978 corresponding to a reduction of some 7200 man-rem i.e. 14% of the effective dose commitment to the E.C. population. This is by far the most significant difference between 1978 and 1980.

On the basis of environmental monitoring results for 1978, Hunt (38) has indicated that the annual collective dose from fish and shelfish consumption in the U.K. and other Western European Countries was some 27000 man-rem, almost all due to the Sellafield discharges. When the results of the N.R.P.B. assessment are adjusted for the range of nuclides considered by Hunt, the collective dose commitment to the Community population from the Sellafield discharges is 32500 man-rem which is in line with Hunt's value for the committed dose received in 1978. His estimate of the 1980 dose was 24000 man-rem (36).

3. DISCUSSION AND CONCLUSIONS

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

In some cases in Section 2 the doses have been derived from theoretical models which evaluate the committed dose received in 1980 discharges. In other cases the measured environmental concentrations in 1980 have been used which thus include any contributions from discharges in previous years but discount future environmental exposure to materials discharged in 1980. If discharges were to remain constant from year to year in an unchanging environment the two approaches would be directly equivalent. In practice of course, both the discharges and the environmental patterns do change but even so there remains some degree of equivalence. For simplicity, therefore, all doses evaluated in Section 2 may be considered, in general, as relating to the equilibrium annual dose rates corresponding to annual discharges at the 1980 levels and compared with annual dose limits and doses received from natural background.

3.1.1 Significance in relation to radiological protection standards

As applied to critical groups ICRP have recommended a stochastic limit of 500 mrem per year for the committed effective dose and a non-stochastic limit of 5000 mrem per year for most individual organs, including the thyroid and bone surface (39). These recommendations have been taken up in a Directive of the European Community (40). For collective dose there is no corresponding recommendation but ICRP anticipates that the system of dose limitation proposed will ensure that the average dose will not exceed 50 mrem per year. The doses given in Section 2 can be compared with these criteria.

For nuclear power station discharges to atmosphere, the exposure of members of the public living close to a station (i.e. at 0.5 km) can be expressed as follows in terms of the stochastic limit:

- Inhalation of particulates; less than 0.001%.
- Milk consumption*; adult - less than 0.01%, child - less than 0.04%.
- External exposure from ground deposition; less than 0.2%.
- External exposure from the plume; less than 0.2% except in the case of British GCRs for which the doses are at most about 2% (3).

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* for dairy farming at 5 km

Assuming the doses to be additive the totals (adult and child) are less than 0.5% except in the case of British GCRs where the values are some 2% and are mainly attributable to argon-41 in the plume giving rise to external exposure. At 5 km the doses, other than from milk, would be an order of magnitude lower. As regards the non-stochastic limit, the dose from iodine-131 to the child's thyroid via milk has been calculated as less than 0.02% of the limit (6×10^{-3}% of the stochastic limit) and hence is less restrictive than doses from other nuclides.

Doses to critical groups from liquid effluent discharges do not exceed 0.1% of the stochastic limit in almost all cases and in the maximum case gave less than 3%. The non-stochastic limit is less restrictive.

The evaluation of doses from nuclear reprocessing plant discharges to critical groups was confined to Sellafield and (for liquid effluents) Marcoule, representing the highest levels of discharges for a coastal and a river-sited plant respectively.

Discharges to atmosphere from Sellafield have been assessed as giving doses of more than 0.1% of the stochastic limit to an individual situated 1 km from the plant throughout 1980 via the following pathways:

- inhalation of particulates; adult 1.1%, child 1.8%;
- milk consumption*; adult 0.4%, child 1.2%;
- external exposure from ground deposition, about 2%;
- external exposure from the plume, 0.3%.

Assuming the doses to be additive the totals are 4% and 5% for the adult and child respectively. In both cases caesium-137 is the most important nuclide giving some 60% of the total, partly from external radiation from ground deposition (which unfortunately is the most uncertain of the four contributions) and partly from milk consumption. Only for the inhalation pathway is the non-stochastic limit more restrictive, the dose to bone surface from the actinides reaching 1.9% of the limit in the case of adults, 2.6% in the case of children.

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* The concentrations in milk are averaged over farms within 3 km of the site.

For the liquid effluent discharges from Sellafield three critical groups have been defined. The most limiting of these consists of consumers of local marine produce - fish, crustacea and molluscs. Consumption rates for representative species have been obtained by habit surveys and the 1980 doses calculated as follows in terms of the stochastic limits:

- from fish, 13%;
- from crustacea, 3%;
- from molluscs, 7%.

If it is conservatively assumed that consumption of these three species is additive, a total of 24% of the limit is obtained on rounding-off after the summation. Americium-241 (mainly in molluscs) and caesium-137 (mainly in fish) each contribute about one third of the total. Based on ICRP 30 (19) the stochastic limit is marginally more restrictive than the non-stochastic limit.

For Marcoule liquid effluents only one pathway gives in excess of 0.1% of the stochastic limit, namely fish consumption which contributes 0.2% of the limit. Summing over all other pathways gives an additional 0.05% and hence a grand total of less than 0.3% assuming all pathways to be additive. The dose via the fish pathway is almost entirely from caesium-137. The non-stochastic limit is less restrictive.

There are no recommended limits on collective dose with which the estimates can be compared.

3.1.2 Significance in relation to exposure from natural radiation

The estimated annual effective dose from natural sources of radiation in areas of "normal" background is 200 mrem, of which one third is attributed to external irradiation (41).

By comparison the maximum committed doses from effluents from nuclear power stations as calculated in the present report would be appreciably less than 3 mrem in general. For a limited number of installations the dose to a few of individuals will have been about 10 mrem. These values correspond respectively to 1.5% and 5% of the average annual dose from natural sources and are well within the range of variations in natural background which can occur locally.

The doses from effluents from nuclear reprocessing plants can be appreciably higher for members of the critical groups and for the worst case are conservatively estimated to total 120 mrem to an individual, i.e. 60% of the annual dose from "normal" natural background. While variations in natural background of the order of 100 mrem/a above the "normal" value are less common, they do occur, even within the Community (41).

It has been estimated that the 1980 discharges will give rise to a collective effective dose commitment of some 4×10^4 man-rem in the Community. By comparison natural radiation has been estimated (37) to give an annual collective dose of 5×10^7 man-rem to the same population, i.e. more than a factor of 1000 higher.

3.2 CONCLUSIONS

For LWRs there was in general a downward trend in the normalized discharges. The decrease reached one order of magnitude or more, for some components - noble gases for PWRs, beta aerosols and iodine-131 from BWRs, and gross beta activity in liquid effluents from PWRs and BWRs. This could be attributed in part to new plants coming on line with more efficient effluent treatment systems. (See Figs. 1-5.)

However, in the later seventies there appears to have been a levelling off of LWR discharge levels, except in respect of gross beta activity in liquid effluents for which the downward trend continues (Fig. 4).

For GCRs the values show no significant trend.

Any downward trend in doses to the individual would be much less evident since the doses given in the present report 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 1980 was extremely low; the most exposed individuals seldom received more than 0.5% of the dose limit i.e. about 1% of the average annual 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 Sellafield 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 Sellafield discharges the exposure of members of some critical groups in 1980 was some 20% 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.

The collective effective dose commitment to the population of the Community as a result of the 1980 discharges was estimated to be less than 0.1% of the annual collective dose from natural radiation. Since it is mainly associated with NFRP effluents no trend could be expected even if a series of calculations had been carried out for the different years. However, since the Sellafield discharges are of particular importance, the value should decrease when the improvements mentioned above come into operation.

Hence the doses to 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 relevant admissible limits. For the individual they are comparable with the differences in exposure from natural radiation background experienced in everyday life; for the population as a whole the dose from natural radiation is orders of magnitude greater.

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KRYPTON-85 YIELDS

1. Values obtained from the literature

For GCR fuel three values for the krypton-85 yield have been identified and normalized to a two year decay period:

- 0.10 MCi/GW(th)a for 3.5 GW(th)d/t (A1),
- 0.083 MCi/GW(th)a for 5.0 GW(th)d/t (A2),
- 0.088 MCi/GW(th)d for 4.5 GW(th/d/t (A3).

The values should not be particularly sensitive to rating or total burn-up within the range of interest. All are based on calculation.

Of the three values given, the first-mentioned originates from a 1969 code (A4) and, while still in reasonable agreement with the later values, probably relied on input data which have since been updated. A value of 0.085 MCi/GW(th)a based on the latter two references has, therefore, been adopted.

For LWR fuel the same three references give the following values:

- 0.10 MCi/GW(th)a for 30 GW(th)d/t (A1),
- 0.076 MCi/GW(th)a for 35 GW(th)d/t (A2),
- 0.086 MCi/GW(th)a for 32 GW(th)d/t (A3).

LEUDET and LESEUR (A5) measured the yield experimentally for five PWR fuel pins all in the range 31-32 GW(th)d/t and obtained excellent agreement with results taken from calculated values supplied by the French CEA. Correction to two years' decay gives:

- 0.096 MCi/GW(th)a for 32 GW(th)d (A5)

The data presented in the INFCE study and in the German Risk Study correspond respectively to yields of

- 0.11 MCi/GW(th)a - burn-up not stated (A6)
- 0.112 MCi/GW(th)a for 33.5 GW(th)d/t (A7)

allowing in both cases for a two year decay period. In the latter case the value was obtained using the ORIGEN code (A8).

The highest value found was equivalent at two years' decay to

- 0.113 MCi/GW(th)a at 33 GW(th)d/t (A9).

A value of 0.095 MCi/GW(th)a at 32 000 GW(th)d/t was adopted on the basis of the above, the other values lying within 20% of this.

Fuel withdrawn from a reactor before the refuelling cycle reaches equilibrium will have a lower burn-up and for the LWR fuel reprocessed this is relevant. However, the effect on the krypton yield is unlikely to have been very significant since, for example, at 24 GW(th)d/t the increase in yield is only 7% (A5). Equally, the decay period of two years adopted above is not well substantiated but a difference of one year would change the krypton inventory by only 6%.

The above review of values in the literature is certainly not complete and the codes used to obtain the values given in references (A3), (A5), (A6) and (A9) are not stated. However, all the values lie within 20% of the values adopted.

2. Evidence from NFRPs

Data are now available on the burn-up of fuel processed at La Hague (A10) and at WAK (A11); relating these data to the recorded krypton-85 discharges allows the krypton-85 yields to be estimated since the discharges effectively represent the entire fuel content of this nuclide.

La Hague has processed small amounts of FBR fuel but this has been relatively insignificant; this apart, only GCR fuel was processed prior to 1976. Relating the krypton discharges for 1972-75 (A12) to the corresponding burn-up data gives an average krypton-85 yield of 0.17 MCi/GW(th)a for GCR fuel with the values for the individual years all lying in the range 0.16 - 0.18 MCi/GW(th)a. The average value is twice that adopted on the basis of the brief literature review described above. This discrepancy, which cannot be explained in terms of differences in burn-up, or decay times, is unresolved.

APPENDIX

In order to attempt a check on the krypton-85 yield from LWR fuel using the La Hague data for 1976-80, it is necessary firstly to attribute part of the annual krypton-85 discharges (Table XIII) to GCR fuel; then the remainder can be attributed to LWR fuel and related to the burn-up data (A10). Using the La Hague 1972-75 yield for GCR fuel results in an average krypton-85 yield of 0.070 Ci/GW(th)a for LWR fuel; the values for individual years ranging from 0.052 to 0.12 MCi/GW(th)a. The average yield is only some 70% of that adopted above; moreover, the lower average burn-up (22 GW(th)d/t) would have been tended to result in a yield slightly higher. than that predicted. Using the GCR krypton-85 yield from the literature produces no improvement, the average yield for LWR fuel now obtained on this basis is 0.14 MCi/GW(th)a with a range of 0.10 to 0.33 MCi/GW(th)a for individual years.

The WAK burn-up data (A11) can be used in the same way to calculate LWR yields, although in this case the krypton-85 monthly discharge data have to be sought in the earlier editions of the same reference since the burn-up data are not presented in calender year form. Three individual runs with LWR fuel gave the following results:

- 0.093 MCi/GW(th)a at 24.5 GW(th)d/t (PWR),
- 0.114 MCi/GW(th)a at 17.6 GW(th)d/t (BWR),
- 0.104 MCi/GW(th)a at 29.3 GW(th)d/t (PWR).

The results from the WAK data are therefore in good agreement with the value of 0.095 MCi/GW(th)a taken from the literature; even the small discrepancies which exists could be largely explained in terms of the lower burn-up and the pssibility of differences in decay times.

Three other reprocessing runs at WAK have involved, in various combinations, PHWR and HWR fuel as well as fuel from pilot BWRs of some 20 MW electrical capacity. Individually these runs correspond to:

- 0.125 MCi/GW(th)a at 4.2 GW(th)d/t average (BWR/PHWR),
- 0.096 MCi/GW(th)a at 6.6 GW(th)d/t average (PHWR),
- 0.101 MCi/GW(th)a at 10.5 GW(th)d/t average (BWR/PHWR/HWR).

Taking into account the low burn-up values, these are again in good agreement with the value of 0.095 MCi/GW(th)a despite the mixture of fuel types.

3. CONCLUSIONS

The WAK data provide strong support for the value of 0.095 MCi/GW(th)a for LWR fuel based on the literature. The data from La Hague give a significantly different value for the yield from GCR fuel compared with that taken from the literature. Moreover, using the La Hague yield for GCR fuel to check the yield from LWR fuel processed at La Hague results in a low value for LWR fuel; using the literature value for GCR fuel gives a high result.

In calculating EET values, therefore, the krypton-85 yields for GCR and LWR fuel based on the literature may be used except for La Hague, where the thermal burn-up data must be used to resolve the GCR and LWR contributions.

APPENDIX

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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 Oost Vlaanderen	PWR	1 192	395	24.08.75	Scheldt
Tihange 1 Liège	PWR	2 652	870	07.03.75	Meuse
GERMANY					
MZFR (Karlsruhe) Baden-Wurtemberg	PHWR	200	52	09.03.66	Rhine
Obrigheim Baden-Wurtemberg	PWR	1 050	328	29.10.68	Neckar
Würgassen N.Rhine-Westphalia	BWR	1 912	640	18.12.71	Weser
Stade Lower Saxony	PWR	1 900	630	29.01.72	Elbe
Biblis A	PWR	3 515	1 146	25.08.74	Rhine
Biblis B Hesse	PWR	3 733	1 240	25.04.76	Rhine
Neckarwestheim Baden-Wurtemberg	PWR	2 497	810	03.06.76	Neckar
Brunsbüttel Schleswig-Holstein	BWR	2 292	770	13.07.76	Elbe
Isar Bavaria	BWR	2 575	870	03.12.77	Isar
Unterweser Lower Saxony	PWR	3 733	1 230 (c)	29.09.78	Weser
Philippsburg	BWR	2 575	864	05.05.79	Rhine

TABLE 1 (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	800	180 (d)	24.02.65	Loire
Tr-3	GCR	1 560	360 (e)	04.08.66	Loire
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	1 660	390 (f)	14.03.69	Loire
Tr-2	GCR	1 660	450 (g)	09.08.71	Loire
Loir-et-Cher					
Bugey					
Tr-1	GCR	1 950	540	15.04.72	Rhône
Tr-2	PWR	2 774	920	10.05.78	Rhône
Tr-3	PWR	2 774	920	21.09.78	Rhône
Tr-4	PWR	2 774	900	08.03.79	Rhône
Tr-5	PWR	2 774	900	31.07.79	Rhône
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	Rhine
Haut-Rhin					
Gravelines					
Tr-1	PWR	2 785	920	13.03.80	North Sea / English Channel
Tr-2	PWR	2 785	920	26.08.80	North Sea / English Channel
Tr-3	PWR	2 785	920	12.12.80	North Sea / English Channel
Pas-de-Calais, Nord					
Dampierre					
Tr-1	PWR	2 785	900	23.03.80	Loire
Tr-2	PWR	2 785	900	10.12.80	Loire
Loiret					
Tricastin					
Tr-1	PWR	2 785	920	31.05.80	Rhône
Tr-2	PWR	2 785	920	07.08.80	Rhône
Pierrelatte, Drôme					
ITALY					
Latina	GCR	575	153	12.05.63	Thyrrhenian Sea
Latina					

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
Garigliano Sessa, Casserta	BWR	506	151.5	23.01.64	Garigliano
Trino Trino Vercellese, Vercelli	PWR	825	260	22.10.64	Po
Caorso Plaisance	BWR	2 651	548 (i)	23.05.78	Po
NETHERLANDS					
Dodewaard Gelderland	BWR	163	51.5	25.10.68	Waal
Borssele Zeeland	PWR	1 365	447 (h)	04.07.73	Scheldt Estuary
UNITED KINGDOM					
Calder Cumbria	GCR	4 x 268	200	10.56	Irish Sea
Chapelcross Dumfries and Galloway	GCR	4 x 248	192	02.59	Solway Firth
Bradwell Essex	GCR	2 x 531	250	06.62	Blackwater Estuary
Berkeley Gloucestershire	GCR	2 x 555	276	06.62	Severn Estuary
Hunterston A	GCR	2 x 535	300	02.64	Firth of Clyde
Hunterston B Ayrshire	AGR	2 x 2 170	1 000 (i)	06.02.76	Firth of Clyde
Trawsfynydd Gwynedd	GCR	2 x 860	390	12.64	Lake Trawsfynydd
Hinkley Point A	GCR	2 x 971	430	02.65	Severn Estuary
Hinkley Point B Somerset	AGR	2 x 1 493	1 000	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

TABLE 1 (continued 3)

Facility/Location	Reactor type (b)	Thermal capacity MW(th)	Maximum output capacity MW(e)	First Grid Connection	Water body receiving liquid effluents
Wylfa Gwynedd	GCR	2 x 1 500	840	11.71	Irish Sea
Dounreay Caithness	FBR	600	183	10.01.75	Pentland Firth

(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) Until 01.08.79: 984 MW(e)

(d) Until 01.04.79: 240 MW(e)

(e) Until 01.04.79: 400 MW(e)

(f) Until 01.04.79: 460 MW(e)

(g) Until 01.04.79: 515 MW(e)

(h) Until 05.79: 445 MW(e)

(i) Interim rating.

TABLE II

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

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1976	1977	1978	1979	1980
BELGIUM						
Doel 1 + 2	4×10^4	822	759	469	1 205	2 542
Tihange 1	4×10^4	4 606	1 480	1 577	379	2 720
GERMANY						
MZFR	3×10^3	985	316	411	541	351
Obrigheim	2×10^4	328	370	455	103	103
Würgassen	3.2×10^4	482	785	3 268	4 300	7 838
Stade	3×10^4	10 500	3 320	490	231	297
Biblis A	9×10^4	1 200	106	362	284	514
Biblis B	9×10^4	304	4 100	1 768	880	838
Neckarwestheim	2.4×10^4	634	1 880	117	185	1 324
Brunsbüttel	7×10^4	970	3 130	7 568	1 235	165
Isar	9×10^4	n.a.	23	1 070	2 300	757
Unterweser	2.4×10^4	n.a.	n.a.	53	1 043	568
Philippsburg	6×10^4	n.a.	n.a.	n.a.	570	568
FRANCE						
Chinon	6×10^3	4 924	3 920	2 530	2 036	2 940
Chooz	7×10^3	4 945	2 800	3 230	7 691	2 662
Monts d'Arée		242 978	200 000	196 240		
St-Laurent-des-Eaux	8×10^3	2 893	4 200	6 750	2 781	2 700
Bugey 1	7×10^4 (a)	3 080	2 400	2 890	2 740	3 100
Bugey 2 + 3 + 4 + 5	7×10^4 (a)	n.a.	n.a.	110.5	1 330	3 080
Phénix	1.1×10^4	234	129	136	141	136
Fessenheim 1 + 2	4×10^4	n.a.	1 900	1 972	2 131	2 461
Gravelines 1 + 2 + 3	6×10^4 (b)	n.a.	n.a.	n.a.	n.a.	2 200
Dampierre 1 + 2	6×10^4 (b)	n.a.	n.a.	n.a.	n.a.	1 300
Tricastin 1 + 2	6×10^4 (b)	n.a.	n.a.	n.a.	n.a.	2 200
ITALY						
Latina	5×10^3 (c)	2 478	2 413	2 613	1 958	2 343

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1976	1977	1978	1979	1980
Garigliano	6.3×10^5 (d)	239 486	89 946	68 158	-	-
Trino (e)	5×10^4	179	59	532	193	-
Caorso	5×10^3 (f)	n.a.	n.a.	91	279	100
NETHERLANDS						
Dodewaard	7×10^5 (g)	6 230	13 013	4 302	3 211	2 011
Borssele	1.2×10^4	3 897	999	416	213	367
UNITED KINGDOM (h)	(i)					
Calder (j)		30 000	26 000	29 000	31 000	30 000
Chapelcross		32 000	32 000	32 000	32 000	33 000
Bradwell		15 000	18 000	16 000	15 000	1 000
Berkeley		16 000	15 000	12 000	12 000	10 000
Hunterston A		15 000	15 000	20 000	20 000	19 800
Hunterston B		2 000	6 000	4 400	2 400	3 070
Trawsfynydd		150 000	150 000	130 000	140 000	50 000
Hinkley Point A		80 000	80 000	80 000	70 000	80 000
Hinkley Point B						4 000
Dungeness A		30 000	30 000	30 000	12 000	500
Sizewell A		60 000	60 000	60 000	60 000	50 000
Winfrith (k)	3.24×10^5	17 900	16 670	25 280	21 110	15 678
Dounreay (k)		< 500		< 600	< 400	< 400

(a) Overall limit for Bugey site

(b) Limit for four units

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

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

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 1979 discharge (see Table III) is only 14 Ci.

(f) The complete discharge formula which applies is:

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

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.

TABLE II (continued 2)

(g) Provisional limit

(h) The quantities of discharged radioactive gases from GCRs and AGRs are not measured routinely. A limited number of measurements indicate the A-41 annual discharges given in the table.

(i) For the period under review, 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.

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

(k) Limit and discharges given in Curie-MeV; principal contribution neon-23 ($T\frac{1}{2}$:38s)

TABLE III

RADIONUCLIDE COMPOSITION (%) OF NOBLE GAS DISCHARGES IN 1980 (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	0.2	0.02	0.2		92.0	3.2	4.4			
GERMANY												
Obrigheim	26.3	0.21	0.09	0.1	0.07	-	50.0	-	23.2	0.05	-	-
Würgassen (c)	0.04	0.49	0.01	0.18	0.97	8.3	18.4	1.1	18.1	20.2	12.5	9.7
Stade (d)		12.9			12.9		23.3	12.8	24.7	13.4		
Biblis A (c)	1.1	-	0.02	0.04	0.12	0.06	76.0	4.2	4.7	0.79	1.8	0.08
Biblis B (c)	0.35	-	0.02	0.01	<0.01	0.02	87.1	0.94	9.0	0.35	0.20	<0.01
Neckarwestheim	2.1	4.5	0.87	0.39	0.54	0.62	68.0	0.62	19.6	0.12	-	2.7
Brunsbüttel (c)	0.06	-	0.15	0.56	0.20	-	93.3	-	2.6	1.3	-	0.33
Isar (c)	1.5	4.3	0.32	5.0	21.4	1.3	42.9	0.31	10.0	5.7	2.1	2.6
Unterweser (c)	0.04	16.2	-	-	-	-	81.2	0.46	1.6	-	-	-
Philippsburg	56.7	-	-	-	-	-	1.1	6.0	19.8	16.4	-	-
FRANCE												
Chinon	x											
Monts d'Arrée	x											
St-Laurent-des-Eaux	x											
Bugey 1	x											
ITALY												
Latina	99.7	2×10^{-2}	3×10^{-3}	8.5×10^{-3}	8.5×10^{-3}	-	0.06	-	8×10^{-2}	-	-	-
Garigliano (e)			6.9	12.2	11.7		17		27.5	6		18.7
Trino (d)	0.02	22.5	1×10^{-3}	6.10^{-3}			77.0	0.40	0.02			
NETHERLANDS												
Dodewaard (f)	-	-	7.7	8.9	17.9	-	26.9	0.8	35.9	-	0.9	0.5
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 only discharges gas storage tanks, i.e. 66% of total.

(c) + 10.1% unspecified unclides for Würgassen, 11.4% for Biblis A, 2.1% for Biblis B, 1.5% for Brunsbüttel, 2.5% for Isar and 0.48% for Unterweser.

(d) Data for 1979 (e) Data for 1978 (f) Data for 1979, measured at the outlet of the offgas delay line

TABLE IV

ANNUAL DISCHARGE OF TRITIUM TO ATMOSPHERE (a)

FROM NPSs

Facility	Discharge Limit (Ci/year)(a)	Activity Released (Ci/year)				
		1976	1977	1978	1979	1980
GERMANY						
MZFR	4 000	703	1 019	1 037	990	1 189
Obrigheim		62.3	23	26	17	9
Würgassen			6	-	9	17
Stade		21	16	27	33	43
Biblis A		9.5	16	51	46	92
Biblis B		3.5	18	11	18	32
Neckarwestheim		2	25	28	30	51
Brunsbüttel		0.5	4.8	6.4	9	0.3
Isar	500	n.a.	-	1.5	7	84
Unterweser		n.a.	n.a.	-	6	10
Philippsburg		n.a.	n.a.	n.a.	0.4	0.6
FRANCE						
Monts d'Arrée		1 395				
Phénix		10.8			-	
Bugey 1				0.5		
Bugey 2 + 3		n.a.	n.a.	1		
ITALY						
Latina	100 (b)	2.7	3.1	0.3	1.8	2.0
Garigliano	100 (c)	14.7	13.3	6.4	1.3	0.3
Trino		16.3		48.8		
NETHERLANDS						
Borssele	50	9	10	25	25	17
UNITED KINGDOM						
Hunterston A				72	60	61
Hunterston B		46	145	82	54	54
Oldbury (d)		7	8	5	17	14
Winfrith	1.8×10^4	775	602	386	468	603
Dounreay						150

(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.

(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 after shutdown.

TABLE V

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (BETA) FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1976	1977	1978	1979	1980
BELGIUM						
Doel 1 + 2	2	2.1×10^{-1}	1.7×10^{-1}	1.8×10^{-1}	1.7×10^{-1}	2.3×10^{-1}
Tihange 1	2	4.8×10^{-5}	3.0×10^{-2}	8.6×10^{-2}	1.1×10^{-1}	1.4×10^{-2}
GERMANY	(a)					
MZFR			6.6×10^{-4}	9.2×10^{-4}	9.8×10^{-4}	3.0×10^{-4}
Obrigheim	0.5	8.0×10^{-3}	6.6×10^{-3}	4.2×10^{-3}	2.0×10^{-2}	1.9×10^{-3}
Würgassen	10.5	1.7×10^{-2}	1.5×10^{-2}	1.9×10^{-2}	4.0×10^{-2}	3.7×10^{-2}
Stade	8.75	7×10^{-3}	8.9×10^{-3}	1.0×10^{-2}	7.2×10^{-4}	5.9×10^{-4}
Biblis A	3.25	2.8×10^{-2}	1.5×10^{-3}	1.2×10^{-5}	2.7×10^{-4}	1.8×10^{-3}
Biblis B	3.25	2×10^{-3}	4.0×10^{-3}	2.2×10^{-5}	1.5×10^{-4}	3.8×10^{-4}
Neckarwestheim	0.5	5.0×10^{-4}	1.2×10^{-2}	5.0×10^{-3}	6.7×10^{-4}	7.0×10^{-4}
Brunsbüttel	17.5	7×10^{-3}	7.3×10^{-2}	3.4×10^{-2}	2.0×10^{-1}	1.3×10^{-2}
Isar	1.5	n.a.	3.0×10^{-5}	4.2×10^{-3}	3.2×10^{-2}	1.7×10^{-2}
Unterweser	0.125	n.a.	n.a.	3.2×10^{-4}	2.3×10^{-5}	$<2.1\times10^{-3}$
Philippsburg	1	n.a.	n.a.	n.a.	3.5×10^{-3}	3.8×10^{-3}
FRANCE (b)						
Chinon	0.1	1.8×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	3.5×10^{-3}	7.6×10^{-3}
Chooz	0.2	1.7×10^{-3}	9.3×10^{-2}	1.2×10^{-2}	6.0×10^{-3}	7.1×10^{-2}
Monts d'Arrée		4.9×10^{-3}	2.7×10^{-2}	7.6×10^{-3}		
St-Laurent-des-Eaux	0.2	1.9×10^{-3}	6.3×10^{-3}	4.3×10^{-3}	5.1×10^{-3}	$.2\times10^{-1}$
Bugey 1	3 (c)	8×10^{-3}	7.5×10^{-3}	1.8×10^{-2}	3.6×10^{-2}	2.2×10^{-2}
Bugey 2 + 3 + 4 + 5	3 (c)	n.a.	n.a.	1.6×10^{-3}	7.1×10^{-3}	2.5×10^{-2}
Phénix	1.1	1.6×10^{-5}	3.9×10^{-5}	7.6×10^{-5}	$< 1\times10^{-2}$	$< 1\times10^{-2}$
Fessenheim 1 + 2	3	n.a.	-	1.8×10^{-2}	1.9×10^{-2}	1.4×10^{-2}
Gravelines 1 + 2 + 3	2 (d)	n.a.	n.a.	n.a.	n.a.	4.3×10^{-2}
Dampierre 1 + 2	2 (d)	n.a.	n.a.	n.a.	n.a.	4.5×10^{-4}
Tricastin 1 + 2	2 (d)	n.a.	n.a.	n.a.	n.a.	1.3×10^{-3}
ITALY						
Latina (e)	0.1	1.2×10^{-4}	1.8×10^{-4}	1.6×10^{-5}	2.3×10^{-4}	1.0×10^{-3}
Garigliano (f)		3.2×10^{-2}	2.0×10^{-2}	1.4×10^{-2}	2×10^{-4}	2×10^{-4}

TABLE V (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1976	1977	1978	1979	1980
Trino (e)	0.2	-	3.1×10^{-5}	2.8×10^{-5}	1.0×10^{-5}	-
Caorso (g)	0.008	n.a.	n.a.	1.4×10^{-6}	5.6×10^{-5}	8.5×10^{-5}
NETHERLANDS						
Dodewaard	0.2 (h)	3.6×10^{-3}	3.1×10^{-3}	9.4×10^{-4}	1.0×10^{-3}	1.6×10^{-3}
Borssele	1	1.3×10^{-4}	6.7×10^{-4}	1.4×10^{-5}	1.2×10^{-4}	-
UNITED KINGDOM	(i)					
Bradwell		3×10^{-3}	3×10^{-3}	4×10^{-3}	4×10^{-3}	1×10^{-3}
Berkeley		3×10^{-3}	3×10^{-3}	2×10^{-3}	3×10^{-3}	3×10^{-3}
Hunterston A		1×10^{-2} (j)	1×10^{-2} (j)	1×10^{-2}		
Hunterston B		7×10^{-3} (j)	7×10^{-3} (j)	5×10^{-4}	6×10^{-2}	8×10^{-2}
Trawsfynydd		1.3×10^{-2}	1.8×10^{-2}	1.0×10^{-2}	1.1×10^{-2}	8×10^{-3}
Hinkley Point A		1.3×10^{-2}	1.0×10^{-2}	1.1×10^{-2}	2.0×10^{-2}	9×10^{-3}
Hinkley Point B		1.9×10^{-2}	1.8×10^{-2}	3.0×10^{-2}	3.0×10^{-2}	2.5×10^{-2}
Dungeness A		1.9×10^{-2}	1.1×10^{-2}	1.4×10^{-2}	9.0×10^{-3}	1×10^{-3}
Sizewell A		1.1×10^{-2}	1.5×10^{-2}	1.3×10^{-2}	1.2×10^{-2}	1.0×10^{-2}
Oldbury		2×10^{-3}	3×10^{-3}	2×10^{-3}	3×10^{-3}	4×10^{-3}
Winfrith		1.4×10^{-1}	-	-		
Wylfa		8×10^{-3}	1.0×10^{-2}	1.0×10^{-2}	7×10^{-3}	8×10^{-3}

(a) Limits for nuclides with $T1/_2 > 8$ d.

(b) Limits and discharges comprise aerosols and halogens.

(c) Overall site limit, instituted in 1978.

(d) Limit for four units.

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

(f) The limiting overall discharge formula applied is :

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

in which Q is the activity discharged in Ci/a, Q(alpha) is expressed in Pu-239 equivalent, and Q(other particulates) in Cs-137 equivalent. The discharges are, however, the sum of the individually measured radionuclides.

(g) The limiting discharge formula is :

$$Q_0 + 0.2\ Q_{60} + 0.1\ Q_{75} \leq 0.008\ Ci/a$$

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.

TABLE V (continued 2)

(h) Under revision.

(i) For the period under review, 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.

(j) Estimated discharges.

TABLE VI

ANNUAL DISCHARGE OF IODINE-131 TO ATMOSPHERE

FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1976	1977	1978	1979	1980
BELGIUM						
Doel 1 + 2	0.2	5.0×10^{-3}	2.4×10^{-3}	-	9×10^{-3}	7×10^{-3}
Tihange 1	0.2	2.0×10^{-2}	2.2×10^{-3}	1.0×10^{-2}	3.0×10^{-3}	3.8×10^{-2}
GERMANY						
MZFR			5×10^{-5}	-	3.2×10^{-5}	4.6×10^{-4}
Obrigheim	0.5	2×10^{-4}	6.0×10^{-4}	7.0×10^{-4}	8.1×10^{-5}	6.2×10^{-5}
Würgassen	0.26	4.6×10^{-2}	2.8×10^{-2}	0.11	6.7×10^{-2}	6.0×10^{-2}
Stade	2.6×10^{-2}	2×10^{-2}	2.6×10^{-2}	3.7×10^{-3}	2.3×10^{-3}	1.1×10^{-4}
Biblis A	0.7	1.3×10^{-2}	5.0×10^{-4}	9.0×10^{-3}	6.5×10^{-3}	7.0×10^{-3}
Biblis B	0.7	9.7×10^{-3}	3.5×10^{-3}	7.0×10^{-3}	1.2×10^{-2}	5.1×10^{-3}
Neckarwestheim	0.25 (a)	2×10^{-3}	4.6×10^{-2}	7.0×10^{-3}	8.6×10^{-4}	6.2×10^{-3}
Brunsbüttel	0.26	2×10^{-5}	1.5×10^{-2}	4.8×10^{-2}	$<2.5\times10^{-4}$	1.0×10^{-3}
Isar	0.5	n.a.	-	-	7.6×10^{-5}	2.1×10^{-3}
Unterweser	0.125	n.a.	n.a.	2×10^{-5}	1.2×10^{-3}	2.2×10^{-3}
Philippsburg	0.5	n.a.	n.a.	n.a.	7.0×10^{-6}	-
FRANCE (b)						
ITALY (c)						
Latina	1×10^{-3}	2.5×10^{-5}	-	1.8×10^{-5}	-	7×10^{-5}
Garigliano	1.0	3.5×10^{-2}	1.5×10^{-2}	2.5×10^{-2}	-	-
Trino	0.05	7.3×10^{-7}	9×10^{-5}	4.2×10^{-5}	1.0×10^{-4}	-
Caorso	0.1 (d)	n.a.	n.a.	1.3×10^{-3}	4.2×10^{-4}	3.8×10^{-4}
NETHERLANDS						
Dodewaard (e)	0.15 (f)	4.5×10^{-3}	6.2×10^{-3}	4.4×10^{-3}	2.0×10^{-3}	2.3×10^{-3}
Borssele	0.24	8.3×10^{-3}	3.5×10^{-3}	2.1×10^{-4}	-	-
UNITED KINGDOM (g)						
Hinkley Point B		$<1.4\times10^{-2}$	$<1.6\times10^{-2}$	$<1.8\times10^{-2}$	$<1.7\times10^{-2}$	$<1.4\times10^{-2}$
Winfrith	2.16	0.13	0.15	0.13	3×10^{-2}	6×10^{-2}

(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.

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

(d) The following discharge formula is applied:

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

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.

(e) "Halogen" results.

(f) Provisional limit.

(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.

TABLE VII

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (EXCLUDING TRITIUM)

FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1976	1977	1978	1979	1980
BELGIUM (a)						
Doel 1 + 2	(24)	49.8	16.9	18.8	4.50	2.64
Tihange 1	(8)	0.83	3.58	1.95	0.97	1.36
GERMANY						
MZFR (b)						
Obrigheim	5	1.2	0.20	0.17	0.17	9.5×10^{-2}
Würgassen	6.7	1.07	1.57	0.53	0.42	0.27
Stade	5	0.24	0.20	0.10	0.26	8.1×10^{-2}
Biblis A	10	0.20	0.13	0.10	5.1×10^{-2}	0.10
Biblis B	10	0.26	3×10^{-2}	0.12	0.21	0.24
Neckarwestheim	1	0.24	0.16	3×10^{-2}	5.8×10^{-2}	8.1×10^{-3}
Brunsbüttel	5	0.63	1.15	1.42	0.39	0.26
Isar	5	n.a.	0.04	0.22	0.26	0.14
Unterweser	2	n.a.	n.a.	-	1.8×10^{-3}	4.9×10^{-2}
Philippsburg	4	n.a.	n.a.	n.a.	0.38	0.12
FRANCE (q)						
Chinon	4	0.57	0.23	0.34	0.96	1.03
Chooz	5	2.56	1.7	0.53	0.64	0.26
Monts d'Arrée		3×10^{-2}	4×10^{-2}	3×10^{-2}		
St-Laurent-des-Eaux	8 (c)	2.97	4.9	8.1	5.7	11.0 (c)
Bugey 1	55 (d)	3.59	3.9	10.83	2.3	3.2
Bugey 2 + 3 + 4 + 5		n.a.	n.a.	4.9	19.3	15.3
Phénix (e)						
Fessenheim 1 + 2	25	n.a.	2.5	2.4	5.4	7.1
Gravelines 1 + 2 + 3	40 (f)	n.a.	n.a.	n.a.	n.a.	4.0
Dampierre 1 + 2	40 (f)	n.a.	n.a.	n.a.	n.a.	1.6
Tricastin 1 + 2	40 (f)	n.a.	n.a.	n.a.	n.a.	2.1
ITALY						
Latina	(g)	5.17	4.3	3.3	4.8	1.6
Garigliano	(h)	3.77	4.1	2.7	0.76	0.77
Trino	(i)	2.71	1.4	1.3	2.0	2.9×10^{-2}
Caorso	(j)	n.a.	n.a.	0.49	6.7×10^{-3}	1.2×10^{-2}

TABLE VII (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1976	1977	1978	1979	1980
NETHERLANDS						
Dodewaard	2.6	0.34	1.1	0.42	0.50	0.48
Borssele	5	0.85	0.43	0.29	0.30	0.12
UNITED KINGDOM						
Calder (k)						
Chapelcross	700	32.4	9.1	76.5	245.9	8.75
Bradwell	200 (incl. Zn-65)	65	66	52	43	39
	5 Zn-65	0.2	0.3	0.2	0.3	0.1
Berkeley	200	112	148	32	46	57
Hunterston A	200 (1)	159	147	60	113	366 (1)
Hunterston B	100	0.6	1.2	6.	2.	2.6
	plus 700 S-35	0.6	1.2	1.2	0.45	42 (m)
Trawsfynydd	40 (incl. Cs-137)	20	13.5	17.5	6	14
	7 Cs-137	4.3	2.9	3.7	1.5	1.6
Hinkley Point A	200 (n)	138	120	110	62	138
Hinkley Point B	100 (n)	1.1	1.2	5.1	14	3.8
	plus 700 S-35	1.1	1.3	1.3	2.2	17
Dungeness A	200	46	45	38	30	24
Sizewell A	200	33	43	25	38	52
Oldbury	100	50	66	30	19	38
Winfrith (o)	3×10^4 (p)	336	379	272	387	487
Wylfa	65	6.5	19	26	16	2

(a) Limits are expressed in Currie 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 : 5 Ci-eq in 1976, 0.55 Ci-eq in 1977, 0.67 Ci-eq on 1978. 0.90 Ci-eq in 1979 and 0.36 Ci-eq in 1980.

Tihange: 0.9 Ci-eq in 1976, 3.7 Ci-eq in 1977, 2.4 Ci-eq in 1978, 1.44 Ci-eq in 1979 and 1.67 Ci-eq in 1980.

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

(c) Exceptional discharge limit of 12 Ci for 1980
in which Q is the activity discharged in Ci/a and tritium is excluded.

(d) Overall site limit.

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

(f) Limit for four units.

(g) Discharge authorization is:

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

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

(h) Discharge authorization is:

$$\frac{\text{H-3}}{5\times10^3} + \frac{\beta}{1} + \frac{0.5\text{Cs-137} + \text{Cs-134} + 0.1\text{Co-58} + 0.3\text{Co-60} + 21\text{-131}}{25} + \frac{\beta\gamma}{2} + \frac{\alpha}{1} \leq 1 \text{ Ci/a}$$

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

(i) Discharge authorization is:

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

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

(j) Discharge authorization is :

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

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 Sellafield and is not separately discharged to the Irish Sea (see Tables XVII to XXII).

(l) For the 12 month period to the end of May 1980, the discharge was 194 Ci. From June 1980 to the end of 1980 the discharge was 267 Ci, i.e. 62% of the new limit of 432 Ci, applicable from June 1980.

(m) Estimate.

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

(o) Site discharges.

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

(q) The values given for the French power stations correspond to total beta activity; total gamma activity discharges for the PWR stations were in 1980: Bugey 2+3+4+5 44Ci; Fessenheim 1+2 16.6 Ci; Gravelines 1+2+3 16 Ci; Dampierre 1+2 6.8 Ci; Tricastin 1+2 7.0 Ci (5).

TABLE VIII

RADIONUCLIDE COMPOSITION (%) OF LIQUID EFFLUENT (EXCLUDING TRITIUM) IN 1980 FROM NPSs

Facility / Isotope	BELGIUM		GERMANY				
	Doel 1 + 2	Tihange 1	Obrigheim (a)	Würgassen (b)	Stade (c)	Biblis A	Biblis B (d)
C-14							
P-32							
S-35							
Ca-45							
Cr-51	4.4	6.8	2.2	0.9	6.1		2.7
Mn-54	1.4	2.1	1.7	0.4	2.2	1.6	1.5
Fe-55							
Co-57	0.04	0.07			0.1	0.02	3×10^{-3}
Co-58	23.0	29.4	11	0.9	9.4	4.2	4.6
Fe-59	0.15				0.2		0.06
Co-60	21.8	35.2	50.7	18.9	37.1	57.3	30.3
Ni-63							
Zn-65		0.8	0.1	2.4			
Sr-89			< 0.4	1.2		0.15	0.11
Sr-90	0.4		< 0.3	0.5		0.32	0.04
Y-90							
Y-91							
Zr-95	0.08	1	0.2	0.06	0.7	0.06	0.02
Nb-95	0.4	2.8	0.6	0.1	1.1	2.9	1.5
Ru-103					0.5	0.06	0.3
Ru-106							
Rh-106							
Ag-110m			3.4		3.7	0.08	0.3
Te-123m					2.5	7.6	2.5
Sb-124			0.03		4.0	12.2	18.7
Sb.125			0.05		0.4		
I-131	1.4	10.3	0.2	3.0	0.04	0.8	0.9
I-133	0.9	7.5					
Cs-134	22.0	1.4	4.5	19.9	7.7	1	7.4
Cs-137	23.9	2.7	19.4	41.8	22.2	4.2	24.5
Ba-140				0.5		0.06	0.2
La-140				2.2	0.1	0.5	3.6
Ce-141				0.1			0.1
Ce-144	0.2	0.02		0.4	1	6.9	0.7
Pr-144							
Pm-147							
Eu-154							
Eu-155							

(a) Plus 5.7% other nuclides

(b) Plus 6.9% other nuclides

(c) Plus 0.9% other nuclides

(d) Plus 0.14% Te-132

TABLE VIII (continued 1)

Facility / Isotope	GERMANY					FRANCE (f)	
	Neckar-westheim (e)	Bruns-büttel	Isar (e)	Unter-weser	Philipps-burg	Chinon	Chooz (g)
C-14							
P-32							
S-35							
Ca-45							
Cr-51			8	5.7	23.9		46.8
Mn-54	2.9	1.2	30.5	0.2	10.5	18.2	
Fe-55							
Co-57							
Co-58	6	0.1	4.4	8.5	40.6	1.13	3.08
Fe-59			7.3			1.05	0.25
Co-60	39.7	18.9	10.3	4.8	7.9		19.7
Ni-63							
Zn-65		7.7	2.2		16	0.92	
Sr-89	0.46	7×10^{-4}		0.85	0.15		
Sr-90		0.02		0.16	0.04	39.4	1.72
Y-90							
Y-91							
Zr-95				3	0.03		
Nb-95	0.4			4.3			0.12
Ru-103							
Ru-106							
Rh-106							
Ag-110m	13.2	0.3	35.6				
Te-123m	2.1						
Sb-124	12.6		0.2	21.6	1		
Sb-125							
I-131	5.6	0.2	0.9	5.1			0.74
Cs-134	6.6	15.9	0.1	14.8			
Cs-137	9.9	55.6	0.07	28.4		39.4	18.5
Ba-140							
La-140							
Ce-141			0.02	0.9			
Ce-144				1.8			7.02
Pr-144							
Pm-147							
Eu-154							
Eu-155							

(e) Plus 0.5% other nuclides

(f) 1978 data. 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

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

TABLE VIII (continued 2)

Facility / Isotope	FRANCE (f)				ITALY		
	St-Laurent	Bugey 1 (h)	Bugey 2+3 (i)	Fessenheim 1 + 2 (j)	Latina	Garigliano	Trino
C-14							
P-32					0.22		
S-35					2.4		
Ca-45					0.78		
Cr-51		11.0	0.10	1.89	1.2		
Mn-54	0.14		0.50	6.58	0.05	0.6	4.0
Fe-55							
Co-57							
Co-58		0.52	86.8	75.4			
Fe-59			0.09	0.87	0.04		
Co-60	18.8	1.56	10.3	8.07	0.19	66.4	54
Ni-63							
Zn-65	0.61	0.17			0.10		
Sr-89					0.20	0.02	
Sr-90	16.4	52.7			30.3	0.07	0.04
Y-90							
Y-91					0.26		
Zr-95	0.61			0.13			
Nb-95	3.79	21.4			1.0		
Ru-103							
Ru-106					9.2		
Rh-106	21.9						
Ag-110m					0.51		1.0
Te-123m							
Sb-124		1.27		3×10^{-3}	0.17		
Sb-125					7.0		
I-131				1.30	0.16		
Cs-134					6.1	4.4	4.1
Cs-137	9.93	10.4		0.06	25.1	28.6	37.0
Ba-140					0.47		
La-140							
Ce-141							
Ce-144	27.8		0.09		14.6		
Pr-144							
Pm-147							
Eu-154							
Eu-155							

(h) Plus 0.93% Na-24

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

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

TABLE VIII (continued 3)

Facility / Isotope	ITALY	NETHERLANDS		UNITED-KINGDOM			
	Caorso (k)	Dodewaard (k)	Borssele	Chapelcross	Bradwell	Berkeley	Hunterston A
C-14					< 0.05	< 0.05	< 0.05
P-32	0.1				< 0.05	< 0.05	< 0.05
S-35				10.3	2.1	14.6	1.7
Ca-45					0.9	3.0	< 0.05
Cr-51	14.2	1.7			< 0.05	< 0.05	1.8
Mn-54	8.7	15.2	1.1		< 0.05	< 0.05	0.2
Fe-55	0.5				1.7	0.1	< 0.05
Co-57							
Co-58	44.6	1.0	6.4		< 0.05	< 0.05	< 0.05
Fe-59	1.2	2.6			< 0.05	< 0.05	0.1
Co-60	9.8	43.4	69.4	0.3	0.5	0.1	0.2
Ni-63					< 0.05	< 0.05	< 0.05
Zn-65	10.2	0.6		0.07	0.1	< 0.05	0.1
Sr-89	0.3				0.4	0.5	< 0.05
Sr-90	0.2	0.3		24	6.5	12.8	4.6
Y-90					6.5	12.8	4.6
Y-91					0.1	0.1	< 0.05
Zr-95	1.2				< 0.05	< 0.05	0.2
Nb-95					< 0.05	< 0.05	1.0
Ru-103							
Ru-106				6.9	0.1	< 0.05	0.4
Rh-106					0.1	< 0.05	< 0.05
Ag-110m	0.9		0.1		< 0.05	< 0.05	< 0.05
Sb-124	0.9		10.6		< 0.05	0.1	< 0.05
Sb-125				1.1	0.1	0.5	0.4
Te-125m					< 0.05	0.1	< 0.05
I-131	0.6	0.6					
Cs-134	0.7	5.6	2.7	6.9	14.8	9.2	22.1
Cs-137	0.8	28.5	9.5	41.1	62.7	45.7	61.9
Ba-140	2.0						
La-140							
Ce-141							
Ce-144	3.1		0.1	9.1	0.1	0.1	0.9
Pr-144					0.1	0.1	< 0.05
Pm-147					2.6	0.2	< 0.05
Eu-154				0.2	0.1	< 0.05	< 0.05
Eu-155					< 0.05	< 0.05	< 0.05

(k) 1979 data

TABLE VIII (continued 4)

Facility / Isotope	UNITED-KINGDOM							
	Hunter-ston B	Traws-fynydd	Hinkley Point A	Hinkley Point B(i)	Dungeness	Sizewell	Oldbury	Wylfa
C-14	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
P-32	0.2	< 0.05	< 0.05	0.5	< 0.05	< 0.05	< 0.05	< 0.05
S-35	95.0	34.7	11.4	81.7	2.4	9.1	50.0	33.1
Ca-45	0.5	0.2	0.1	7.0	0.6	0.9	1.0	0.4
Cr-51	0.3	< 0.05	< 0.05	2.6	< 0.05	< 0.05	< 0.05	< 0.05
Mn-54	0.1	< 0.05	< 0.05	0.09	< 0.05	< 0.05	< 0.05	0.5
Fe-55	< 0.05	0.4	0.1	0.3	0.6	0.3	0.8	15.0
Co-57								
Co-58	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Fe-59	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.1
Co-60	1.2	0.1	< 0.05	1.8	0.1	< 0.05	0.2	1.8
Ni-63	0.1	< 0.05	< 0.05	0.2	< 0.05	< 0.05	< 0.05	< 0.05
Zn-65	0.5	< 0.05	< 0.05	1.5	< 0.05	< 0.05	0.1	0.1
Sr-89	< 0.05	< 0.05	0.4	1	0.3	0.6	0.6	0.3
Sr-90	< 0.05	12.7	7.9	< 0.05	9.0	7.0	6.7	3.6
Y-90	< 0.05	12.7	7.9	< 0.05	9.0	7.0	6.7	3.6
Y-91	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.1	< 0.05	0.2
Zr-95	0.5	< 0.05	0.3	0.07	< 0.05	< 0.05	< 0.05	< 0.05
Nb-95	< 0.05	1.7	0.4	0.2	< 0.05	< 0.05	< 0.05	0.1
Ru-103								
Ru-106	0.2	4.6	1.5	< 0.05	< 0.05	0.1	0.1	0.2
Rh-106	< 0.05	4.6	1.5	< 0.05	< 0.05	0.1	0.1	0.2
Ag-110m	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.1
Sb-124	0.1	0.1	0.1	0.9	< 0.05	0.1	0.5	< 0.05
Sb-125	< 0.05	12.5	3.5	< 0.05	0.1	0.1	0.3	0.1
Te-125m	< 0.05	2.6	0.9	< 0.05	< 0.05	< 0.05	0.1	0.1
I-131								
Cs-134	0.1	2	8	0.2	9.5	13.3	2.0	2.5
Cs-137	0.2	7.4	50.7	0.2	67.2	59.3	29.6	35.7
Ba-140								
La-140								
Ce-141								
Ce-144	0.2	0.9	1.9	0.7	0.1	0.7	0.1	0.1
Pr-144	< 0.05	0.9	1.9	0.7	0.1	0.7	0.1	< 0.05
Pm-147	< 0.05	1.7	1.0	0.2.	1.0	0.6	0.9	2.2
Eu-154	< 0.05	< 0.05	0.2	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Eu-155	< 0.05	< 0.05	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

(i) Composition based on discharges for one calendar quarter.

TABLE IX

ANNUAL TRITIUM DISCHARGE IN LIQUID EFFLUENT FROM NPSs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1976	1977	1978	1979	1980
BELGIUM						
Doel 1 + 2	3 600	280	475	632	631	670
Tihange 1	4 000	162.3	320	356.1	282	334
GERMANY						
MZFR		880	1 200	1 000	1 100	700
Obrigheim	500	144	116	130	136	89
Würgassen	300	25	42	53	41	57
Stade	1 300	45	142	133	146	62
Biblis A	1 600	320	180	345	168	405
Biblis B	1 600	22	155	400	320	541
Neckarwestheim	500	5	83	134	102	81
Brunsbüttel	1 000	2	9.1	19	2.2	2.4
Isar	500	n.a.	0.04	4.6	22	38
Unterweser	950	n.a.	n.a.	0.22	107	238
Philippsburg	500	n.a.	n.a.	n.a.	2.1	10.3
FRANCE						
Chinon	500	106	110	131	139	120
Chooz	3 000	1 929	2 600	1 748	2 810	2 986
Monts d'Arrée		27	41	28	116	13.8
St-Laurent-des-Eaux	1 000	509	350	684	770	420
Bugey 1	5 000 (a)	195.	240	384	36	33
Bugey 2 + 3 + 4 + 5		n.a.	n.a.	89.8	960	1 440
Phénix (b)						
Fessenheim 1 + 2	2 000	n.a.	83	832	670	780
Gravelines 1 + 2 + 3	3 000 (c)	n.a.	n.a.	n.a.	n.a.	110
Dampierre 1 + 2	3 000 (c)	n.a.	n.a.	n.a.	n.a.	204
Tricastin 1 + 2	3 000 (c)	n.a.	n.a.	n.a.	n.a.	280
ITALY	(d)					
Latina		5	9.9	7.6	20.2	0.7
Garigliano		18	15.0	10.3	2.0	2.2

TABLE IX (continued 1)

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year) 1976	1977	1978	1979	1980
Trino		743	1 736	2 082	929	101
Caorso		n.a.	n.a.	1	2.4	5.0
NETHERLANDS						
Dodewaard	200	23	21.1	46.2	30	15
Borssele	(e)	41	39.7	226	225	169
UNITED KINGDOM						
Calder (f)						
Chapelcross	150	8.8	1.8	30.8	75.9	2.54
Bradwell	1 500	309	199	103	119	63
Berkeley	1 500	30	51	16	43	76
Hunterston A	1 200	66	56	53	89	21
Hunterston B	40 000	44	55	2 289	2 025	2 969
Trawsfynydd	2 000	16	13	15	56	27
Hinkley Point A	2 000 (g)	24	33	53	96	53
Hinkley Point B	18 000 (g)	2.5	739	1 590	4 320	4 430
Dungeness A	2 000	34	26	32	21	8
Sizewell A	3 000	62	44	29.5	43	28
Oldbury	2 000	19	15	7	6	8
Winfrith (h)	30 000 (i)	5 119	2 075	1 181	2 765	1 210
Wylfa	4 000	198	288	1 052	123	306

(a) Overall site limit.

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

(c) Limit for four units

(d) See foot-notes (h) to (k) to Table VII.

(e) No annual limit; only a concentration limit on cooling water discharges

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

(g) See foot-note (o) Table VII.

(h) Site discharges.

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

TABLE X

MAXIMUM HYPOTHETICAL EXPOSURE IN 1980 FROM GASEOUS EFFLUENTS (NOBLE GASES AND IODINE-131) FROM NPSs (a)

Facility	Height (b) of release (m)	Dose (mrem) at 0.5 km		at 5 km		
		Whole body (gamma)	Skin (beta only)	Whole body (gamma)	Skin (beta only)	Thyroid (c)
BELGIUM						
Doel 1 + 2	48	0.1	0.1	0.006	0.009	0.07
Tihange 1	160	0.07	0.03	0.01	0.01	0.05
GERMANY						
MZFR	100	0.01	0.004	< 0.001	< 0.001	0.002
Obrigheim	60	0.01	0.006	< 0.001	< 0.001	< 0.001
Würgassen	67	0.7	1	0.04	0.1	0.5
Stade	80	0.02	0.009	0.001	< 0.001	< 0.001
Biblis A + B	100	0.007	0.01	< 0.001	0.002	0.06
Neckarwestheim	150	0.03	0.02	0.002	0.003	0.03
Brunsbüttel	100	0.003	0.001	< 0.001	< 0.001	0.005
Isar	130	0.05	0.01	0.004	0.003	0.008
Unterweser	100	0.006	0.004	< 0.001	< 0.001	0.01
Philippsburg	100	0.06	0.02	0.004	0.002	
FRANCE (d)						
Chinon	50	0.8	0.5	0.05	0.04	0.08
Chooz	18	0.2	0.5	0.009	0.01	1
St-Laurent-des-Eaux	78	0.5	0.2	0.03	0.02	1
Bugey 1	85	0.7	0.3	0.04	0.04	0.3
Bugey 2 + 3 + 4 + 5	62					
Phénix	70	0.007	0.002	< 0.001	< 0.001	0.08
Fessenheim 1 + 2	56	0.1	0.09	0.005	0.008	0.1
Gravelines 1 + 2 + 3	62	0.09	0.08	0.005	0.007	0.4
Dampierre 1 + 2	62	0.05	0.05	0.003	0.004	0.004
Tricastin 1 + 2	62	0.09	0.08	0.005	0.007	0.01
ITALY						
Latina	52	0.7	0.4	0.03	0.03	0.01
Caorso	57	0.01	0.01	< 0.001	< 0.001	

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)	Whole body (gamma)	Skin (beta only)	Thyroid (c)
NETHERLANDS						
Dodewaard	100	0.2	0.07	0.01	0.009	0.005
Borssele	57	0.001	0.01	< 0.001	< 0.001	
UNITED KINGDOM						
Calder		12	12	0.5	0.5	
Chapelcross		14	13	0.6	0.5	
Bradwell		0.4	0.4	0.02	0.02	
Berkeley		4	4	0.2	0.2	
Hunterston A + B		9	9	0.4	0.4	
Trawsfynydd		21	20	0.9	0.8	
Hinkley Point A + B		35	34	1.5	1	
Dungeness A		0.2	0.2	0.01	0.008	
Sizewell A		21	20	0.9	0.8	
Winfrith		6	6	0.3	0.3	0.5

(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. 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) No discharge data for Monts d'Arrée are available for 1980 but the energy output was similar to that in 1978 and hence the discharges, being mainly argon-41, were probably little different: The calculated 1978 doses were 46 mrem to the whole body and 19 mrem to the skin (beta dose) at 0.5 km; at 5 km the doses were more than an order of magnitude lower.

TABLE XI

RADIOACTIVE WASTE DISCHARGE FROM NPSs PER UNIT NET ELECTRICAL ENERGY PRODUCED

Facility	Net electricity production		Activity Released per GWh		
			Gaseous effluent	Liquid effluent	
	Year	(GWh)	(noble gases) (Ci/GWh)	Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
BELGIUM					
Doel 1 + 2	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
	1979	5 810	0.21	0.77	108.6
	1980	5 680	0.45	0.46	118.0
Tihange 1	1976	4 405	1.05	0.19	36.84
	1977	5 843	0.25	0.61	54.77
	1978	6 364	0.25	0.31	56.0
	1979	5 154	0.07	0.19	54.71
	1980	6 173	0.44	0.22	54.11
GERMANY					
MZFR	1976	394	2.50		2 234
	1977	295	1.07		4 068
	1978	390	1.05		2 564
	1979	379	1.43		2 902
	1980	327	1.07		2 141
Obrigheim	1976	2 210	0.15	0.54	65.16
	1977	2 144	0.17	0.12	54.10
	1978	2 220	0.20	0.08	58.56
	1979	2 372	0.04	0.07	57.33
	1980	2 125	0.05	0.04	41.88
Würgassen	1976	3 679	0.13	0.30	6.80
	1977	3 639	0.22	0.43	11.54
	1978	2 741	1.19	0.19	19.34
	1979	1 529	2.81	0.27	26.81
	1980	3 798	2.06	0.07	15.0
Stade	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
	1979	4 217	0.05	0.06	34.62
	1980	4 167	0.07	0.02	14.88
Biblis A + B	1976	5 722	0.26	0.08	59.77
	1977	14 177	0.30	0.01	23.62
	1978	12 752	0.15	0.02	54.25
	1979	12 589	0.09	0.02	38.76
	1980	9 351	0.09	0.04	101.17

TABLE XI (continued 1)

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)
Neckarwestheim	1976	1 958	0.32	0.11	2.55
	1977	4 947	0.38	0.03	16.78
	1978	4 938	0.02	0.006	27.14
	1979	3 525	0.05	0.02	28.94
	1980	5 474	0.24	0.001	14.80
Brunsbüttel	1976	1 032	0.94	0.61	1.94
	1977	3 314	0.94	0.35	2.75
	1978	2 324	3.26	0.61	8.18
	1979				
	1980	715	0.23	0.36	3.36
Isar	1977	76	0.30	0.53	0.53
	1978	2 337	0.46	0.09	1.97
	1979	5 214	0.44	0.05	4.22
	1980	4 209	0.18	0.03	9.03
Unterweser	1978	788	0.07	-	0.28
	1979	8 079	0.13	0.0002	13.24
	1980	9 274	0.06	0.005	25.66
Philippsburg	1979	1 677	0.34	0.23	1.25
	1980	1 735	0.33	0.07	5.94
FRANCE					
Chinon	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
	1979	2 750	0.74	0.35	50.54
	1980	3 756	0.78	0.27	31.95
Chooz	1976	1 362	3.63	1.88	1 416.30
	1977	2 462	1.14	0.69	1 056.05
	1978	2 008	1.61	0.26	870.52
	1979	1 693	4.54	0.38	1 659.77
	1980	1 810	1.47	0.14	1 649.72
Monts d'Arrée	1976	518	469.07	0.06	52.12
	1977	478		0.08	
	1978	526		0.06	
	1979	539			
	1980	521			
St-Laurent-des-Eaux	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
	1979	6 054	0.46	0.94	127.19
	1980	2 687	1.0	4.09	156.31
Bugey 1	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
	1979	3 029	0.90	0.76	11.89
	1980	4 048	0.77	0.79	8.15

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)
Bugey 2 • 3 • 4 • 5	1978	923	0.12	5.3	97.29
	1979	12 657	0.11	1.52	75.85
	1980	22 053	0.14	0.69	65.30
Phenix	1976	948	0.25		
	1977	296	0.43		
	1978	1 231	0.11		
	1979	1 718	0.08		
	1980	1 316	0.10		
Fessenheim 1 • 2	1977	994	1.91	2.52	83.50
	1978	11 832	0.17	0.20	70.32
	1979	9 053	0.24	0.60	74.01
	1980	11 109	0.22	0.64	70.21
Gravelines 1 • 2 • 3	1980	3 341	0.66	1.20	32.92
Dampierre 1 • 2	1980	2 784	0.47	0.57	73.28
Tricastin 1 • 2	1980	4 277	< 0.51	0.49	65.47
ITALY					
Latina	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
	1979	787	2.49	6.10	25.67
	1980	893	2.62	1.79	0.78
Garigliano	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
	1979	-			
	1980	-			
Trino	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
	1979	705	0.27	2.84	1 317.73
	1980	-			
Caorso	1978	458	0.20	1.07	2.18
	1979	982	0.28	0.007	2.44
	1980	1 222	0.08	0.10	
NETHERLANDS					
Dodewaard	1976	407	15.31	0.84	56.51
	1977	360	36.15	3.06	58.61
	1978	409	10.52	1.03	112.96
	1979	384	8.36	1.30	78.12
	1980	382	5.26	1.26	39.27
Borssele	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
	1979	2 901	0.07	0.10	77.56
	1980	3 593	0.10	0.03	47.03

TABLE XI (continued 3)

Facility	Net electricity production		Activity Released per GWh		
			Gaseous effluent (noble gases)	Liquid effluent	
	Year	(GWh)		Tritium excluded	Tritium alone
			(Ci/Gwh)	(mCi/GWh)	(mCi/GWh)
UNITED KINGDOM			(a)		
Chapelcross	1976	1 527		21.2	5.76
	1977	1 376		6.61	1.31
	1978	1 424	22	53.72	21.63
	1979	1 318		186.57	57.59
	1980	1 294		6.76	1.96
Bradwell	1976	1 736		37.67	178.0
	1977	1 720		38.55	115.70
	1978	1 528	10	34.03	67.41
	1979	1 384		31.07	85.98
	1980	114		342.11	552.63
Berkeley	1976	1 979		56.59	15.41
	1977	1 825		81.10	28.05
	1978	1 447	8	22.11	7.51
	1979	1 478		31.12	29.09
	1980	1 233		46.23	61.64
Hunterston A	1976	2 214		71.82	29.95
	1977	2 186		67.25	25.62
	1978	2 129	9	28.18	24.89
	1979	2 099		53.84	42.40
	1980	2 089			10.05
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
	1979	2 249		0.89	900.40
	1980	3 961	0.78	0.49	749.56
Trawsfynydd	1976	3 024		6.61	5.29
	1977	2 986		4.52	4.35
	1978	2 578	50	6.79	5.82
	1979	2 812		2.13	19.91
	1980	1 466		9.55	18.42
Hinkley Point A	1976	3 199		43.14	7.41
	1977	3 247		36.96	10.19
	1978	3 183	25	34.56	16.68
	1979	2 789		22.2	34.42
	1980	3 083		44.76	17.19
Hinkley Point B	1977	1 044		1.15	707.85
	1978	2 793		1.83	569.28
	1979	4 554		3.07	948.62
	1980	5 346	0.75	0.96	828.66
Dungeness A	1976	2 732		16.95	12.52
	1977	2 819		16.07	9.22
	1978	2 667	11	14.29	12.0
	1979	1 169		25.66	17.96
	1980	46		521.74	173.91

(a) Discharges of noble gases (Ar-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 4)

Facility	Net electricity production		Activity Released per GWh		
			Gaseous effluent (noble gases)	Liquid effluent	
	Year	(GWh)	(Ci/GWh)	Tritium excluded (mCi/GWh)	Tritium alone (mCi/GWh)
Sizewell A	1976	3 403		9.70	18.22
	1977	3 324		12.94	13.24
	1978	3 372	18	7.41	8.75
	1979	3 310		11.48	12.99
	1980	2 792		18.62	10.03
Oldbury	1976	3 017		16.71	6.43
	1977	3 110		21.22	4.82
	1978	3 067		9.91	2.41
	1979	3 184		5.97	1.88
	1980	3 296		11.53	2.43
Wylfa	1976	4 818		1.35	41.10
	1977	4 984		3.81	57.78
	1978	3 801		6.95	276.77
	1979	5 200		3.08	23.65
	1980	5 764		0.35	53.09
Dounreay	1976	93	< 5.38		
	1977	175	0.006		
	1978	232	< 2.59		
	1979	158	< 2.53		
	1980	70	< 5.71		

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	35	1971	Rhine (a)
FRANCE				
La Hague	1 GCR	800 (b)	1966	English Channel
Manche	2 LWR	250 (b)	1976	English Channel
	3 FBR	4 (b)		English Channel
Marcoule (e)	GCR		1958	Rhône (a)
Gard	FBR	(e)	1974	
UNITED KINGDOM				
Dounreay	1 MTR	0.3	1958	Atlantic Ocean (a)
Caithness	2 FBR		1961 (c)	Atlantic Ocean (a)
Sellafield 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 in the main plant. An additional small plant for FBR fuel alone processed about 1 t of fuel in the period 1966-1979.

(c) Present plant commissioned 1980.

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

(e) Total throughput of about 9 t of fuel.

TABLE XIII

ANNUAL DISCHARGE OF KRYPTON-85 FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity Released (Ci/year)				
		1976	1977	1978	1979	1980
WAK	2.5×10^5 (a)	8.57×10^4	1.15×10^5	3.36×10^4	5.06×10^4	3.24×10^4
La Hague	1.3×10^7	3.5×10^5	6.71×10^5	7.86×10^5	6.43×10^5	8.25×10^5
Marcoule	1.6×10^6	9.2×10^4	1.17×10^5	3.08×10^5	2.80×10^5	5.35×10^5
Dounreay	(b,c)	-	-	-	-	3×10^3
Sellafield	(b)	1.2×10^6	8×10^5	7×10^5	9.4×10^5	8.4×10^5

(a) Management allocation within the overall site provisions; the WAK allocation for krypton-85 was 3.5×10^5 Ci pior to 1980

(b) There is no quantified limit; the authorization requires that the best practicable means be used to minimize the discharge of radioactive substances

(c) Noble gas discharges are not monitored. Prior to 1980 reprocessing was confined to Dounreay Fast Reactor (DFR) and MTR fuel. It was assumed for DFR fuel that all noble gases escaped into the reactor coolant and were then released from the reactor; in consequence discharges from reprocessing are assumed to be "nil". MTR fuel contains little krypton-85.

Fuel from the Prototype Fast Reactor (PFR) was first processed in 1980 and it is assumed that all krypton-85 generated in the fuel is released on reprocessing. Thus the 1980 discharge value corresponds to the calculated krypton-85 inventory.

TABLE XIV

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (ALPHA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Acitivity Released (Ci/year)				
		1976	1977	1978	1979	1980
WAK	$1x10^{-2}$ (a)	$3.0x10^{-3}$	$2.9x10^{-3}$	$4.6x10^{-3}$	$8.1x10^{-4}$	$4.4x10^{-4}$
La Hague	2 (e)	$2x10^{-8}$	$2.9x10^{-6}$	$3.0x10^{-5}$	(d)	(d)
Marcoule	$1.1x10^{-3}$ (f)	$1.8x10^{-5}$	$8.7x10^{-5}$	$4.6x10^{-5}$	(d)	(d)
Dounreay	(b)	$<2.1x10^{-2}$	$<5x10^{-3}$	$1.4x10^{-3}$	$2x10^{-3}$	$1.6x10^{-2}$
Sellafield	(b,c)	$5.1x10^{-2}$	$2.8x10^{-2}$	$3.6x10^{-2}$	$3.0x10^{-2}$	$1.5x10^{-2}$

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

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

(c) No gross alpha values are available for 1979 and 1980; the values shown represent the sum of plutonium - 238/239/240, americium-241 and curium - 242. In 1978 these nuclides totalled 0.0274 Ci compared with 0.036 Ci attributed to gross alpha activity.

(d) No data have been received on alpha activity discharged to atmosphere.

(e) Total aerosol activity; limit introduced 22.10.80

(f) Limit introduced 20.05.81

TABLE XV

ANNUAL DISCHARGE OF RADIOACTIVE AEROSOLS (BETA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK	2.0 (a)	0.14	0.3	8.4×10^{-2}	6.6×10^{-2}	2.5×10^{-2}
La Hague	2 (e)	8.9×10^{-3}	3.7×10^{-3}	3.3×10^{-3}	9.3×10^{-3}	3.3×10^{-3}
Marcoule	2.2 (f)	3.6×10^{-2}	4.5×10^{-3}	9.3×10^{-3}	2.8×10^{-2}	1.1×10^{-3}
Dounreay	(b,c)	<8.3	<2.0	0.16	0.25	1.32
Sellafield	(b,d)	4.6	9.7	8.4	7.7	14.1

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

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

(c) Values represent the sum of zirconium/niobium -95, ruthenium -106, caesium -137 and cerium -144 in 1976 and 1977; strontium -90 is also included for 1978, 1979 and 1980.

(d) The 1979 and 1980 values represent the sum of strontium-90, zirconium/niobium -95, ruthenium -106, caesium -134/137 and cerium -144. In 1978 these nuclides totalled 9.06 Ci compared with the gross beta result of 8.4 Ci

(e) Total aerosol activity; limit introduced 22.10.80

(f) Limit introduced 20.05.81

TABLE XVI

ANNUAL DISCHARGE OF TRITIUM TO ATMOSPHERE FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK	1×10^3 (a)	102 (c)	190	125	167	80
La Hague	6×10^4 (d)	49	304	112	193	248
Marcoule	2.7×10^5 (e)	120	75	1 712	1 912	2 172
Dounreay	(b)					
Sellafield	(b)	1.2×10^4	8×10^3	6×10^3	7.8×10^3	6.8×10^3

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

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

(c) Calculated result based on later experimental work.

(d) Limit introduced 22.10.80

(e) Limit introduced 20.05.81

TABLE XVII

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (ALPHA) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK (a) (b)		-	-	$<1.5\times10^{-3}$	$<2.3\times10^{-3}$	$<1.8\times10^{-3}$
La Hague	45 (c)	9.9	18.2	13.9	18.6	13.8
Marcoule (a)	4 (d)	0.3	0.36	0.36	0.7	2.4
Dounreay (a)	240 (e)	11	6	8	13	5
Sellafield	6 000 (f)	1 614	1 241	1 837	1 677	1 045

(a) May include significant contributions from other site installations

(b) In 1976-77 all samples were below the limit of detection for gross alpha activity as were over 95% samples in 1978-80.

(c) Limit introduced 22.10.80

(d) Limit introduced 20.5.81

(e) Not more than 60 Ci in any period of three successive calendar months

(f) In addition a limit of more than 2 000 Ci in any period of three successive calendar months is imposed.

TABLE XVIII

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

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK (a)		0.038	0.017	0.014	0.017	0.022
La Hague	45 000 (b)	19 300	20 689	29 501	26 956	25 355
Marcoule (a)	4 000 (c)	624	816	952	605	1 019
Dounreay (a)	24 000 (d)	1 365	920	406	844	1 710
Sellafield	300 000 (e)	183 482	192 768	192 550	109 676	116 391

(a) May include significant contributions from other site installations

(b) Introduced 22.10.80

(c) Global limit (excluding tritium, strontium -90 and caesium -137) introduced 20.5.81

(d) Not more than 6 000 Ci in any period of three consecutive calendar months including alpha but, in application, excluding tritium.

(e) Not more than 75 000 Ci in any period of three consecutive calendar months ; the method of applying the limit effectively excludes tritium.

TABLE XIX

ANNUAL DISCHARGE OF RADIOACTIVE LIQUID EFFLUENT (TRITIUM) FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK		3 100	2 400	1 300	2 100	1 000
La Hague	10^6 (a)	7 132	8 957	19 682	14 571	14 580
Marcoule (b)	6.8×10^4 (c)	3 204	3 156	7 295	8 014	11 185
Dounreay (b)		104	30	356	30	350
Sellafield		32 460	24 716	28 371	31 779	34 678

(a) Limit introduced 22.10.80

(b) May inclue significant contribution from other site installations

(c) Limit introduced 20.5.81

TABLE XX

ANNUAL DISCHARGE OF STRONTIUM-90 IN LIQUID EFFLUENT FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK (a)		6.3×10^{-3}	3.8×10^{-3} (b)	3.0×10^{-3} (b)	3.4×10^{-3}	1.5×10^{-3}
La Hague	6 000 (c)	1 078	1 965	3 789	1 746	< 1 479 (c)
Marcoule (a)	160 (d)	11	10.1	23.7	16	22
Dounreay (a)	2 400 (e)	183	210	80	213	350
Sellafield	30 000 (f)	10 344	11 534	16 160	6 812	9 506

(a) May include significant contribution from other site installations.

(b) Sr-89 + Sr-90.

(c) Sr-90 + Cs-137; limit introduced 22.10.80.

(d) Limit introduced 20.5.81.

(e) Not more than 600 Ci in any period of three consecutive calendar months.

(f) Not more than 7 500 Ci in 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 discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK						
La Hague		15 004	14 591	21 681	20 197	
Marcoule (a)		541	738 (b)	667 (b)		
Dounreay (a)		36	33	3	27	20
Sellafield	60 000 (c)	20 698	22 053	21 897	10 615	9 295

(a) May include significant contribution from other site installations.

(b) Ru-103 + Ru-106.

(c) Not more than 15 000 Ci in any period of three consecutive calendar months.

TABLE XXII

ANNUAL DISCHARGE OF CAESIUM-137 IN LIQUID EFFLUENT FROM NFRPs

Facility	Discharge Limit (Ci/year)	Activity discharged (Ci/year)				
		1976	1977	1978	1979	1980
WAK (a)		5.3×10^{-3}	5×10^{-4}	1.2×10^{-3}	7×10^{-4}	1.7×10^{-3}
La Hague	6 000 (b)	939	1 372	1 056	453	1 479 (b)
Marcoule (a)	160 (c)		33.6	110	78	103
Dounreay (a)		365	157	83	231	574
Sellafield		115 926	121 032	110 483	69 255	80 163

(a) May include significant contribution from other site installations.

(b) Sr-90 + Cs-137, limit introduced 22.10.80.

(c) Limit introduced 20.5.81.

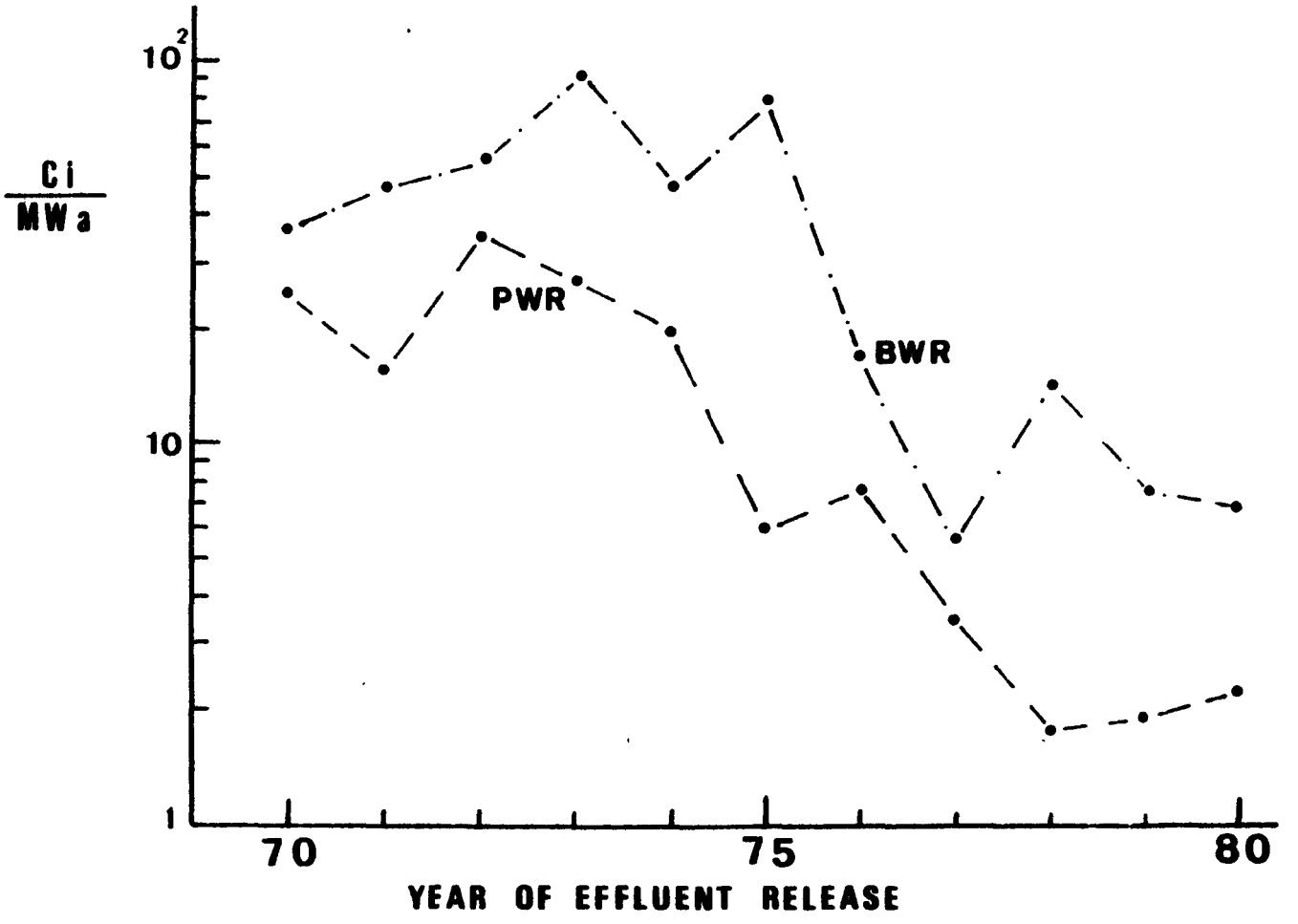

FIG. 1 — Normalized annual discharges (Ci/MWa) of noble gases from E.C. PWRs and BWRs

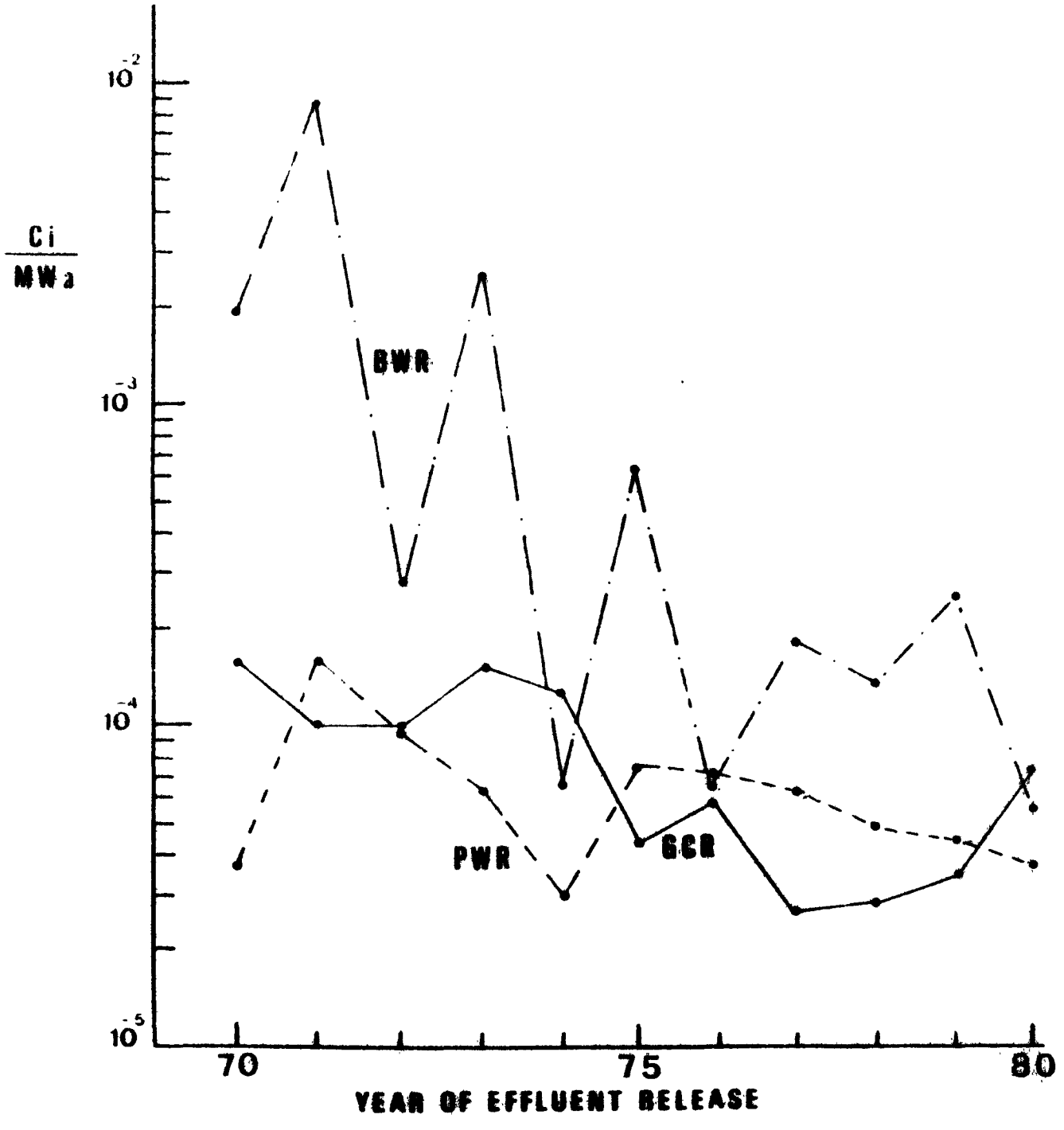

FIG. 2 — Normalized annual discharges (Ci/MWa) of radioactive aerosols (beta) from E.C. PWRs, BWRs and GCRs

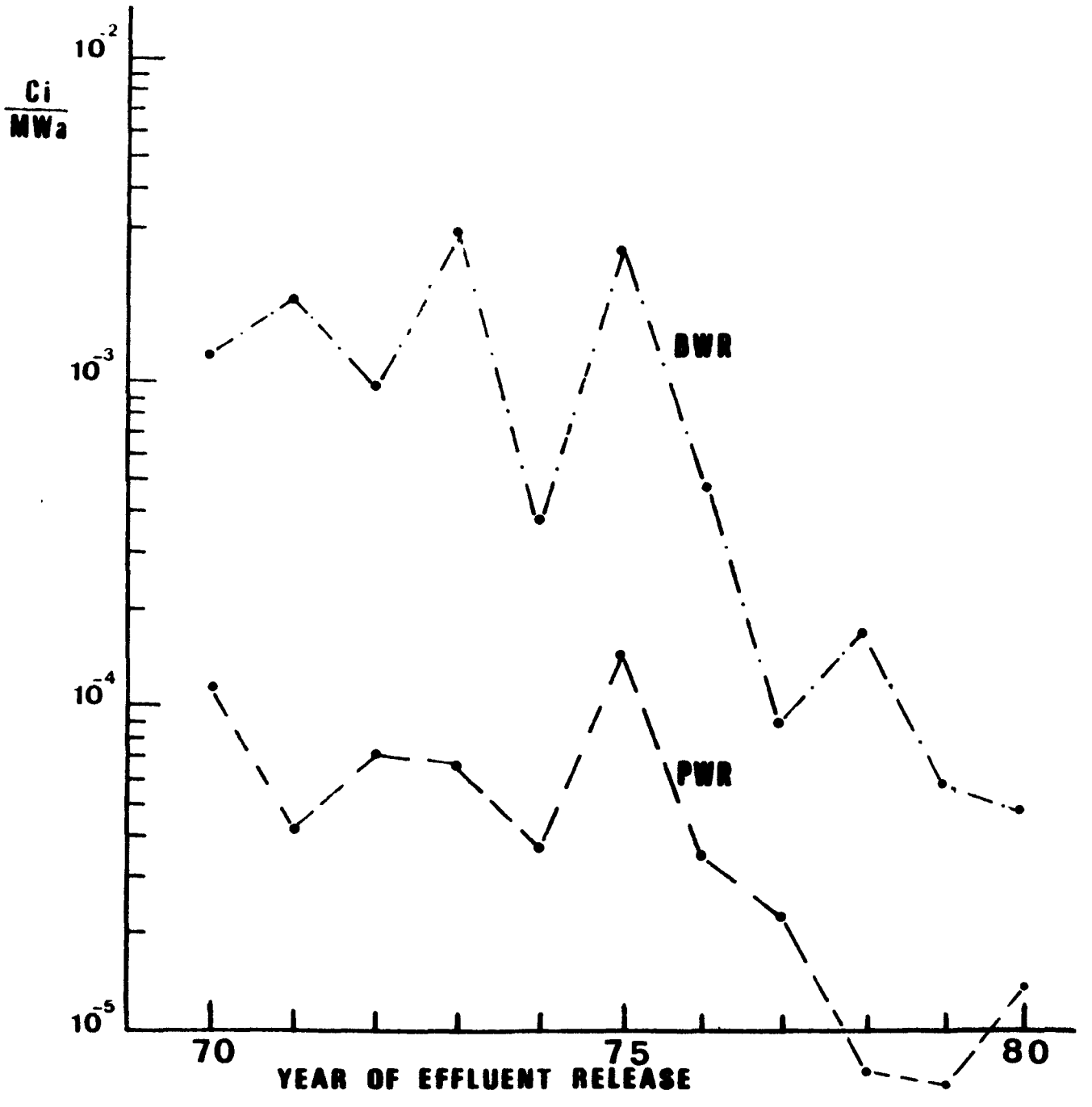

FIG. 3 — Normalized annual discharges (Ci/MWa) of iodine-131 to atmosphere from E.C. PWRs and BWRs

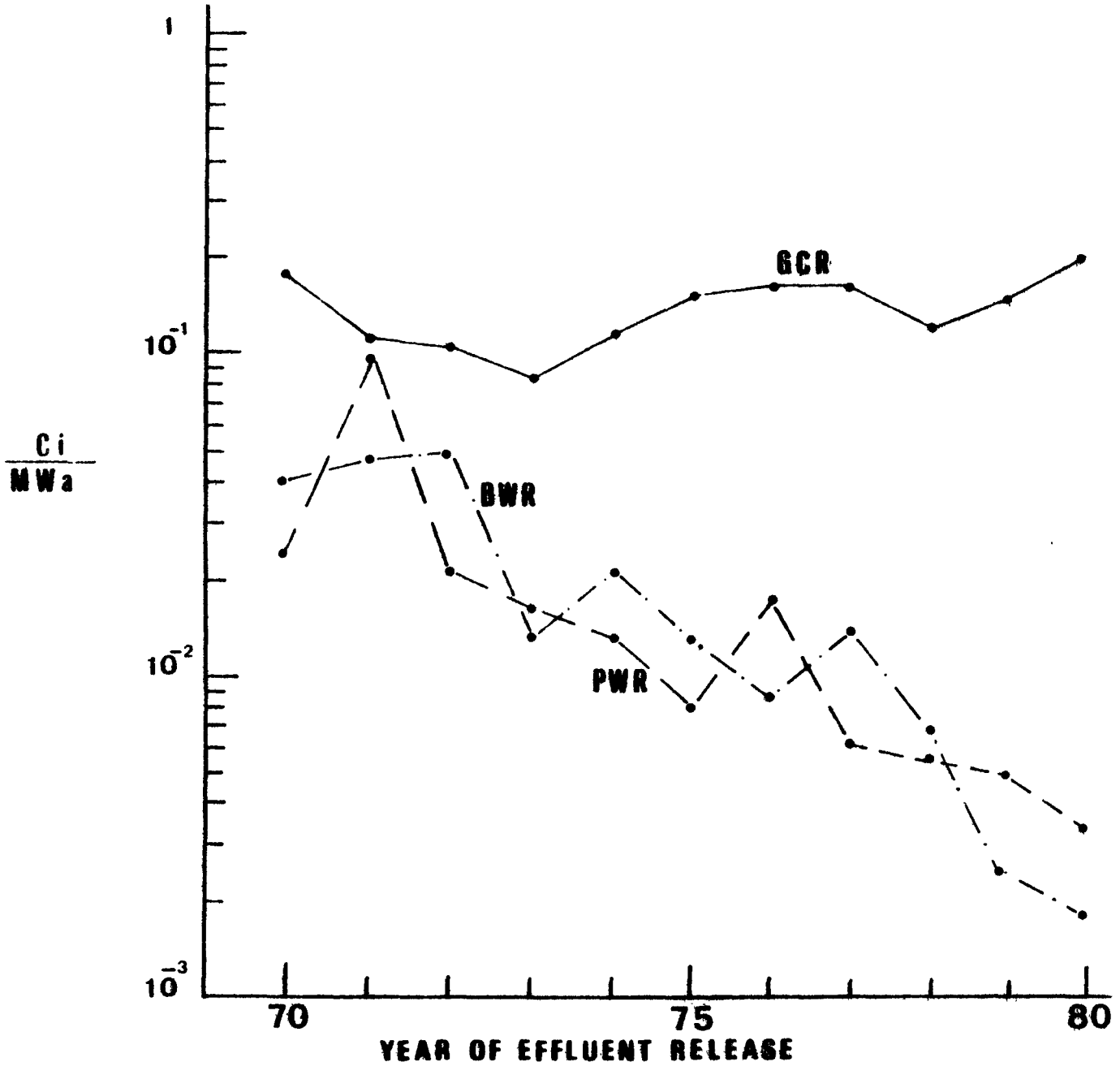

FIG. 4 — Normalized annual discharges (Ci/MWa) of liquid radioactive effluents (excluding tritium) from E.C. PWRs, BWRs and GCRs

945

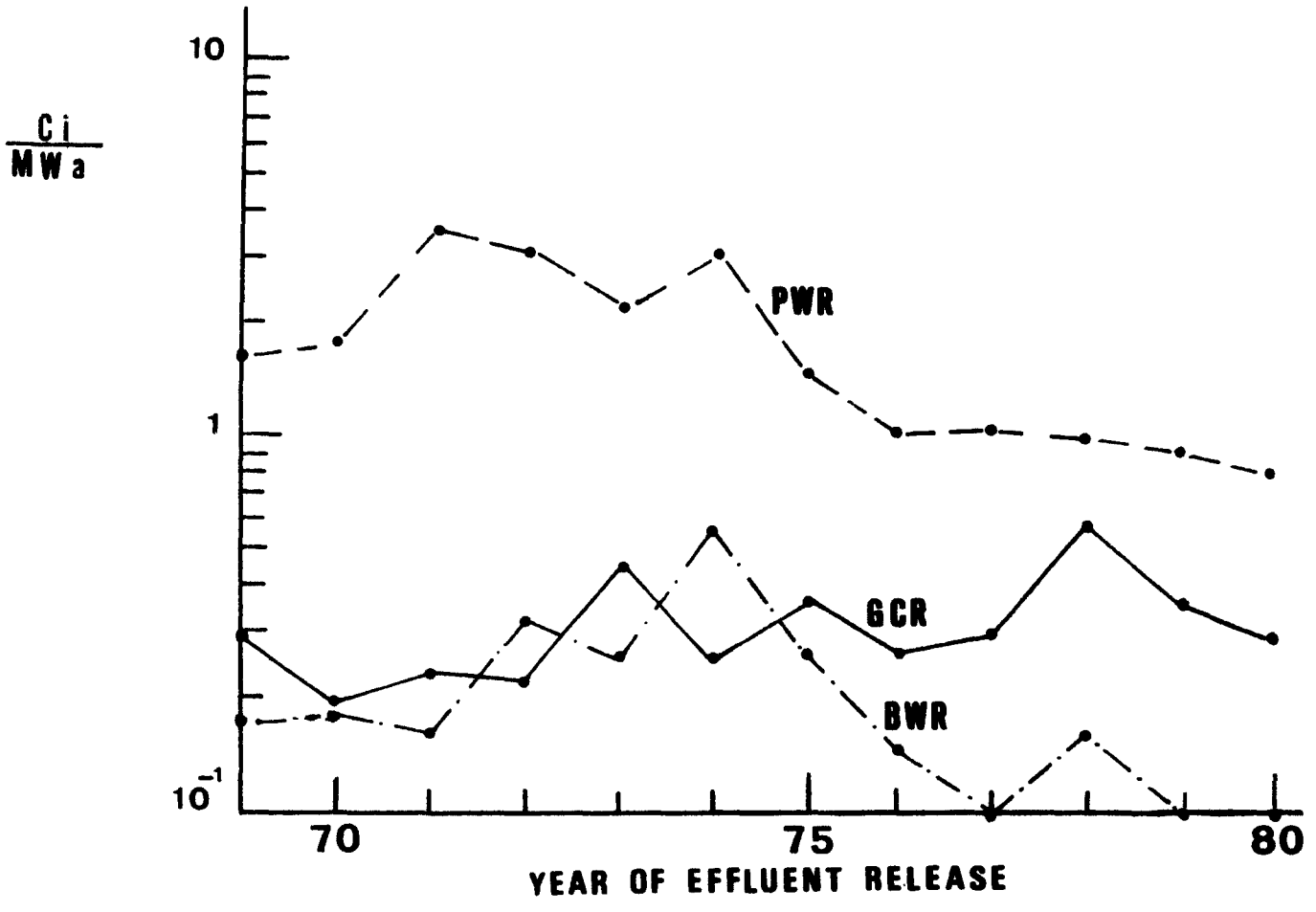

FIG.5— Normalized annual discharges (Ci/MWa) of tritium in liquid effluents from E.C. PWRs, BWRs and GCRs