Recommendations on the Radionuclide Composition of Aggregated Discharge Categories of Nuclear Sites Operating in the European Union

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Introduction

Nearly all the electrical energy generated by nuclear means is produced in thermal reactors. The fast neutrons produced by the fission process are slowed down to thermal energies by means of a moderator. The most common materials used as moderators are light water (in PWRs and in BWRs), heavy water (in HWRs) and graphite (in GCRs). In the fast breeder reactors (FBRs), fission is induced by neutrons; there is no moderator and the coolant is liquid metal e.g. sodium. During the production of power by a nuclear reactor, radioactive fission products are formed within the fuel and neutron activation products in structural and cladding materials. Radioactive contamination of the coolant occurs because fission products diffuse into the coolant from the small fraction of fuel with defective cladding, and particles arising from the corrosion of structural and cladding materials are activated as they are carried through the core. All reactors have treatment systems for the removal of radionuclides from gaseous and liquid wastes. The amounts of different radioactive materials released from the reactors depend on the reactor type, its design and the specific waste treatment plant installed.

To perform realistic calculations of radiation exposure of the population in the vicinity of nuclear installations the nuclide spectra of air-borne, gaseous and liquid-form releases are needed. These nuclide spectra should reflect the characteristic composition of the releases which are yearly given off during normal operation. The release of radioactive matter is taken to mean the emission of liquid, aerosol-related or gaseous matter from a facility by way of planned paths or routes. Gaseous release is understood to mean through the stack, liquid release via the waste water, machine-house water, auxiliary coolant water, main coolant water and outlet water.

Taking stock of radioactive matter consists of the identification and determination of the radioactivity of the radionuclides or groups of radionuclides released in a predetermined timeframe. Certain legal limits of detection are to be adhered to for the activity determinations. Monitoring of the stack emissions and liquid waste water from the nuclear installations goes on continually.

1 Radionuclides

1.1 Radionuclide Production

In nuclear reactors different radionuclide spectra are produced by nuclear fission, neutron capture and radioactive decay depending upon the fuel element assembly and the composition of elements in the materials exposed to the neutron flux. The following initiating processes are relevant thereby:

- Fission, activation and radioactive decay in the fuel.
- Activation of structural materials.
- Activation of the primary cooling water transported corrosion and erosion products.
- Activation of the coolant, the chemical impurities and additives.

- Activation of the air around the reactor pressure vessel.

A large portion of the radionuclides is retained by the various cleaning and retention systems. The radionuclide spectrum in the exhaust air of a nuclear power plant results from the sum of the individual emissions from the different exhaust air streams of the ventilation systems of the individual reactor building sections.

The absolute activity specification of the releases from a nuclear power plant can be divided into performance-independent and performance-related components.

The performance-related part is emitted over the exhaust systems, while the performance-independent part is determined by leakages in the system. The radioactive noble gases are performance-related, while iodine and the solid aerosol-bound radioactive particles are to be added to the performance-independent component.

Mostly tritium, iodine and the corrosion products from the cooling circuit are released with the liquid discharges.

The radionuclides produced in the process can be combined within different groups:

- Classification according to solubility behaviour in the water and their deposition behaviour: aerosols, halogens, aerosol-bound radionuclides.
- Classification according to radiation type: nuclides which mainly emit Alpha-, Beta- or Gamma rays.
- Classification according to manner of detection: as above, however nuclides having two forms of radiation can be assigned to groups other than simply Alpha-, Beta- or Gamma emitters.

1.2 Exposure Pathways of the Nuclide Groups

The following nuclides and nuclide groups are to be entered into the balance for gaseous and aerosol-related emissions [GRS 78]:

Nuclide group	Pathway		
	Submersion	Ingestion	Inhalation
Noble gases	X		
Radioactive Fission Products of Noble Gases with HL< 8d	X		x
H 3		X	X
C 14		X	X
Iodine isotopes		X	X
Radionuclides of solids with HL > 8d		X	X

The radioactive noble gas nuclides give rise mainly to an external radiation dose (submersion) in humans. The size of the dosage depends on the type of the ionising radiation and on the energy of the radiation. The radioactive half-life plays no role. Therefore, the short-lived noble gas nuclides because of their energy-rich radiation are of higher radiological significance than the long-lived ones. The short-lived decay products of the noble gas nuclides can play a role in the submersion dose and inhalation dose if the amount of activity coming from this group of nuclides comprises more than 1% of the noble gas activity release.

Tritium and carbon 14, each depending upon the chemical combination with the gases, are to be added to the liquids or the aerosols.

The iodine isotopes are shown separately because of their considerable contribution to the thyroid dose. Only the long-lived isotopes need to be regarded since the short-lived ones will have almost completely disintegrated before reaching the food chain.

The long-lived radionuclides because of their tendency to become enriched in the food chains and their somewhat long biological half-lives comprise a separate group.

1.3 Determining a Nuclide Spectrum

As indicated in chapter 1.1 it follows that there cannot be a consistent nuclide spectrum with unvarying proportions of activity for the several types of nuclear installations because of the performance-independent component of the radioactivity release. Therefore, basically all nuclides are included in the monitoring process for the radioactivity releases from normally operating nuclear installations. To demonstrate adherence to the licensing values, however, only individual nuclides or the nuclides of the following nuclide groups must be balanced:

- Radioactive noble gases (Tab. 1.1)
- Radioactive aerosols(Tab. 1.2)
- Radioactive gaseous iodine
- Tritium
- Radioactive strontium
- Alpha-emitters (Tab. 1.3)
- Carbon 14

The specified radionuclides because of their physical radioactive half-lives, their types of radiation, their dose factors and their radio-ecological characteristics are relevant, and were taken from [KTA 78] and [KTA 93] for German PWR and BWR reactors. The groups of nuclides are prescribed also in other European Union countries.

Table 1.1: Noble Gases

Nuclide	Nuclide
Ar-41	Xe-131m
Kr-85	Xe-133
Kr-85m	Xe-133m
Kr-87	Xe-135
Kr-88	Xe-135m
Kr-89	Xe-37
	Xe-138

Table 1.2: Aerosols

Nuclide	Nuclide
Cr-51	Ru-106
Mn-54	Ag-110m
Co-57	Sb-124
Co-58	I-131
Fe-59	Cs-134
Co-60	Cs-137
Zn-65	Ba-140
Zr-95	La-140
Nb-95	Ce-141
Ru-103	Ce-144

Table 1.3: Alpha-emitters

Nuclide	Nuclide
Pu-238	Am-241
Pu-239	Cm-242
Pu-240	Cm-244

Table 1.4: Others

Nuclide	Nuclide
H-3	I-131
C-14	

Table 1.5: The following nuclides are to be entered into the balance for liquid-related emissions:

Nuclide	Nuclide
H-3	Ru-106
Cr-51	Ag-110m
Mn-54	Te-123m
Co-57	Sb-124
Co-58	Sb-125
Co-60	I-131
Fe-59	Cs-134
Zn-65	Cs-137
Sr-89	Ba-140
Sr-90	La-140
Zr-95	Ce-141
Nb-95	Ce-144
Ru-103	Alpha
C-14	H-3

1.4 Appraisal of the EU-discharge Database

The retrospective calculation of realistic doses for the population living in the vicinity of nuclear installations follows from the basis data of the EU-discharge database with the help of the PC-Cream code. The definition of realistic nuclide spectra or nuclide vectors must be oriented about the available database information and be compatible as well.

In a first orientational poll for each installation type the stored nuclide spectra were brought together for the years 1987-1998 with the following results:

- As expected the particulars on the nuclides of the various releases differed for the different types of installation.
- The specification of the radionuclides differs both with respect to the time period observed as well as with the country referred to, given the same type of reactor.
- Half of the data records in the databank in lieu of individual nuclide activities gave total activity specifications for groups of nuclides, e.g. total beta, total alpha, noble gas etc.

The beta activity offered in the database caused considerable problems when gathering the nuclide spectra together. Of the radionuclides released by nuclear installations there are only 2 pure beta emitters: Sr-89 and Sr-90. All other nuclides have a more or less marked component of gamma radiation activity. The proportions of Sr-89 and Sr-90 in the total beta activity amounted to less than 5%.

Also the interpretation of the “beta activity value” regarding the manner of detection led to no unequivocal result.

A comparison of the activity values for PWR and BWR facilities in Germany to the entries in the EU-discharge database yielded that the “beta value” in the case of airborne releases corresponds to the value of the aerosols, and in the case of liquid discharges to the value of the fission and activation products, except for tritium.

2 Source Term

The calculation of realistic doses from the EU-discharge database has to be done in the following way:

- If for a nuclear installation a specific radionuclide spectrum according to the Tables 1.1 to 1.4 is available in the EU-discharge database, these data have to be applied. Total Alpha- or Beta-activity shall not be taken into account.
- If the EU-discharge database does not contain a nuclide spectrum according to the Tables 1.1 to 1.4, apart from H-3 and C-14, then the generalised spectra for the respective European countries and the nuclear installation of concern have to be applied. The procedure for the derivation of these general radionuclide spectra is presented in the following. The corresponding tables are given in Section 3.

The representative nuclide-spectra presented in Section 3 and derived from the data of the EU-discharge database of 1987 – 1998 are in accordance with the following steps:

- Extend the table "T:Produit" of the EU-discharge database by specifying the kind of radiation (e.g. Alpha-, Beta-radiation) and/or radionuclide group (e.g. noble gas, aerosols).
- Evaluate the EU-discharge database to assign the respective liquid and airborne releases to the respective types of nuclear installations.
- Consider only radionuclides
  - the contribution of which is larger than 0.01% of the total activity
  - and/or which are specified in the EU-discharge database more than twice within the period 1987 – 1998.
- Calculate averaged contributions of each radionuclide with respect to the total activity for all types of nuclear installations and all countries of concern. The averaged contributions of each nuclide of the spectrum were normalised such that the sum equals 100%.
- The tables in Section 3 were completed with nuclide-specific half-lives and dose-factors and placed in descending order with respect to the dose-factors.
- Following the nomenclature of the EU-discharge database the radionuclide group "Beta" is contained in the tables of Section 3. The percentages contributed by each radionuclide in the representative spectrum of the group can be read from the tables which are arranged corresponding to the type of nuclear installation as well as to the countries of concern.

However, it must be noted here again that the derivation of representative radionuclide spectra can only produce a rough estimate. In Section 1 it was pointed out that the nuclide spectra of liquid and airborne radioactive releases, e.g. from nuclear power plants, depends not only on the reactor type but also on the burn-off of the nuclear fuel.

Each type of nuclear installation entails large country-specific differences. This is why the specification of a representative spectrum of radionuclides for Europe is not reasonable.

Based on the nuclide-specific percentage contributions for each type of nuclear installation and given for each European country of concern in the Tables of Section 3, dose calculations may be carried out for all years for which only total activity releases, e.g. specified as Alpha-emitters or noble gas, are available.

Criteria

The criteria for deciding whether to use aggregated discharges and the "average" spectra or the spectra given in the database are as follows:

If the sum of the nuclide activities for a given reactor (e.g. Beta without H-3, I-131) is equal to within 10% of the value of the aggregated amount (e.g. Beta), then use the activities of the individual nuclides for the dose-calculation.

All other cases use the aggregate values and the average-spectra in chapter 3.

3 Breakdown of Radionuclides

3.1 ADVANCED GAS-COOLED REACTORS (AGR)

The AGR reactor type is invariably found in United Kingdom (UK). The sites are: Dungeness, Hartlepool, Heysham, Hinkley Point, Hunterston and Torness.

3.1.1 Atmospheric discharges

3.1.1.1 Noble Gas

Nuclide	HL	Unit	UK [%][1]
Ar-41	1,827	hours	100

[1] This is the percentage contribution that the radionuclide makes to this aggregated discharge category.

3.1.1.2 Alpha

Nuclide	HL	Unit	UK [%]
Pu-239	24131	years	100

3.1.1.3 Beta

Nuclide	HL	Unit	UK [%]
Zn-65	244,4	days	100

3.1.1.4 Others[1]

Nuclide	HL	Unit	UK [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100
S-35	87,44	days	100

[1] These radionuclides are not included in an aggregated discharge category. Any recorded discharges of these radionuclides, for this type of reactor, on the EU-discharge database should be considered as entirely independent.

3.1.2 Liquid discharges

3.1.2.1 Alpha

Nuclide	HL	Unit	UK [%]
Pu-239	24131	years	100

3.1.2.2 Beta

Nuclide	HL	Unit	UK [%]
Sr-90	28,6	years	3,98
Co-60	5,271	years	38,04
Y-90	64,1	hours	0,47
Cs-134	2,062	years	17,32
Cs-137	30,17	years	21,91
Eu-154	8,8	years	0,45
Eu-155	4,96	years	0,41
Pm-147	2,6234	years	0,11
Pr-144	17,28	minutes	17,32

3.1.2.3 Others

Nuclide	HL	Unit	UK [%]
C-14	5730	years	100
H-3	12,28	years	100
S-35	87,44	days	100

3.2 BOILING WATER REACTORS (BWR)

Boiling water reactors are found in:

- Finland (SF) TVO 1+2.
- Germany (D): Brunsbüttel, Gundremmingen B+C, Isar 1, Krümmel, Phillipsburg, Würgassen.
- Italy: Caorso (no specific nuclide data available in EU-discharge database).
- Spain (ESP): Cofrentes, Sta. Maria de Garona.
- Sweden (S): Barsebäck 1+2, Forsmark, Oskarshamn 1+2+3, Ringhals 1.

3.2.1 Atmospheric discharges

3.2.1.1 Noble gas

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	S [%]	EU [%][1]
Ar-41	1,827	hours		10,24	0,15	3,05	4,48
Kr-85	10,72	years		31,67	1,60	8,33	13,87
Kr-85m	4,48	hours	45,96	0,62	12,37	4,26	5,75
Kr-87	76,3	minutes		0,74	1,73	7,74	3,4
Kr-88	2,84	hours	11,15	1,28	7,44	9,24	5,99
Kr-89	3,16	minutes		0,84	3,50	2,06	2,13
Xe-131m	11,84	days		0,56	0,18	3,87	1,54
Xe-133	5,245	days	40,31	15,98	21,06	12,68	16,57
Xe-133m	2,19	days	0,05	0,49	0,00	0,74	0,41
Xe-135	9,11	hours	2,47	23,86	19,68	22,07	21,87
Xe-135m	15,36	minutes	0,06	11,94	9,00	4,52	8,49
Xe-137	3,83	minutes		0,23	7,47	9,09	5,6
Xe-138	14,13	minutes		1,55	15,82	12,34	9,9

[1] Average value of D, ESP, S.

3.2.1.2 Alpha

Nuclide	HL	Unit	Adult (Sv/Bq)	EU [%]
Pu-239	24131	years	5,00E-05	100

Determining a definite spectrum from the available data was not possible.

3.2.1.3 Beta

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	EU [%][1]
Ce-144	284,3	days		0,19	0,03	0,11
Sr-90	28,6	years		0,23	6,02	3,13
Co-60	5,271	years	42,48	41,21	21,1	34,93
Ag-110m	249,85	days		0,11		0,06
Sb-124	60,2	days	1,15	0,5	0,63	0,76
Sr-89	50,55	days	7,38	3,7	15,96	9,01
Ba-140	12,789	days		6,83	7,84	7,34
Sb-125	2,77	years	1,59	0,67		0,75
Zr-95	64,02	days	3,64	0,8		1,48
Fe-59	44,63	days	3,94	1,06	5	3,33
Ce-141	32,5	days		0,74	0,71	0,73
Ru-103	39,35	days		0,36	0,06	0,21

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	EU [%][1]
Cs-134	2,062	years	0,61	1,12	1,17	0,97
Co-58	70,8	days	9,37	2,06	2,51	4,65
Zn-65	244,4	days		6,49	6,25	6,37
La-140	40,22	hours		4,26	7,23	5,75
Mn-54	312,7	days	12,19	10,14	6,34	9,56
Cs-137	30,17	years	0,7	12,07	3,75	5,51
Nb-95	35,06	days	3,94	0,68		1,54
Mo-99	66,02	hours			7,29	3,65
Cr-51	27,704	days	14,46	6,77	8,11	9,78

[1] Average value of D, ESP, S.

3.2.1.4 Others

Nuclide	HL	Unit	EU [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100

3.2.2 Liquid discharges

3.2.2.1 Alpha

Nuclide	HL	Unit	Adult (Sv/Bq)	EU [%]
Pu-239	24131	years	2,50E-07	100

3.2.2.2 Beta

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	S [%]	NL [%]	EU [%][1]
Cs-137	30,17	years	22,10	10,68	14,85	6,25	6,19	8,03
Sb-122	2,7	days	0,09		0,11	0,87	0,83	0,51
La-140	40,22	hours	0,35	0,61	0,25	3,44	3,52	1,66
Ag-110m	249,85	days		0,92	0,1	1,63	1,62	0,91
Fe-59	44,63	days	0,09	0,71	4,52	0,39	0,39	1,27
Tc-99m	6,02	hours	0,16		0,22			0,19
Se-75	119,78	days		0,06				0,05
Cs-134	2,062	years	11,78	1,43	1,94	2,96	2,94	1,96
Zn-65	244,4	days	0,02	8,97	2,77	3,26	3,26	3,87
Sb-124	60,2	days	0,29	0,32	0,42	1,2	1,20	0,67
Sr-89	50,55	days	0,21	0,37	3,86	0,69	0,66	1,19
Ba-140	12,789	days	0,04	0,11	0,53	0,43	0,41	0,31
Co-57	270,9	days			0,03	0,03	0,03	0,03
Na-24	15	hours			0,34			0,29
Cr-51	27,704	days	7,13	6,64	3,28	20,33	20,29	10,7
Cs-136	13,16	days				0,03	0,03	0,03
Fe-55	2,7	years		19,63				16,62
Ba-131	11,8	days				0,13	0,12	0,11
Co-60	5,271	years	36,13	24,46	41,99	41,24	41,06	31,49
Mn-54	312,7	days	13,65	6,22	14,27	6,16	6,14	6,94
Nb-95	35,06	days	1,24	0,37	0,15	0,42	0,42	0,29
Mo-99	66,02	hours			0,66	0,01	0,01	0,19
Ce-144	284,3	days		2,06	0,15	0,02	0,03	0,48
Co-58	70,8	days	5,40	2,13	1,12	9,03	8,98	4,5
Ru-103	39,35	days		0,14		0,06	0,06	0,08
Ru-106	368,2	days				0,06	0,06	0,05
Sn-113	115,1	days			0,29	0,01	0,01	0,08
Ce-141	32,5	days	2,26	1,34	0,12	0,07	0,07	0,34
Zr-95	64,02	days	0,59	0,32	0,18	0,18	0,18	0,19
Sb-125	2,77	years	0,13	8,7	0,04	1,09	1,10	2,31

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	S [%]	NL [%]	EU [%][1]
Sr-90	28,6	years	0,06	0,38	7,81	0,02	0,03	1,74
Ni-63	100,1	years		3,42				2,9
Te-123m	119,7	days		0,03				0,03

[1] Average value of D, ESP, S, NL.

3.2.2.3 Others

Nuclide	HL	Unit	EU [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100
S-35	87,44	days	100

3.3 PRESSURISED WATER REACTORS (PWR)

Pressurised water reactors are found in:

- Finland (SF): Loviisa 1+2.
- Belgium (B): Doel 1+2+3+4 und Tihange 1+2+3.
- France (F): Belleville 1+2, Blayais 1+2+3+4, Bugey 2+3+4+5, Cattenom 1+2+3+4, Chinon B1+B2+B3+B4, Chooz A, Chooz B1+B2, Civaux 1+2, Cruas 1+2+3+4, Dampierre 1+2+3+4, Fessenheim 1+2, Flamanville 1+2, Golfech 1+2, Gravelines 1+2+3+4+5+6, Nogent 1+2, Paluel 1+2+3+4, Penly 1+2, St Alban 1+2, St Laurent B1+B2, Tricastin 1+2+3+4.
- Germany (D): Biblis A, Biblis B, Brokdorf , Emsland, Grafenrheinfeld, Greifswald 1+2+3+4, Grohnde, Isar 2, Muelheim-Kärlich, Neckarwestheim 1+2, Obrigheim, Philippsburg 2, Rheinsberg, Stade, Unterweser.
- Italy (I): Trino (no specific nuclide data available in EU-discharge database).
- Spain (ESP): Almaraz 1+2, Asco 1+2, Jose Cabrera, Trillo, Vandellos 1.
- Sweden (S): Ringhals 2+3+4.
- The Netherlands(NL): Borssele.
- United Kingdom (UK): Sizewell B (no specific nuclide data available in EU-discharge database).

3.3.1 Atmospheric discharges

3.3.1.1 Noble gas

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	S [%]	EU [%][1]
Ar-41	1,827	hours	52,2	28,96	18,58	11,11	19,55
Kr-85	10,72	years	25,61	19,26	0,99	0,92	7,06
Kr-85m	4,48	hours	1,34	0,45	0,43	0,69	0,52
Kr-87	76,3	minutes	1,19	0,16	0,45	0,31	0,31
Kr-88	2,84	hours	1,43	1,01	0,71	0,88	0,87
Kr-89	3,16	minutes	0	0,06			0,06
Xe-131m	11,84	days		7,7	0,36	0,7	2,92
Xe-133	5,245	days	13,75	35,02	66,6	74,48	58,7
Xe-133m	2,19	days		0,44	0,26	0,56	0,42
Xe-135	9,11	hours	4,47	6,09	8,71	10,11	8,3
Xe-135m	15,36	minutes		0,35	2,54	0,18	1,02
Xe-137	3,83	minutes		0,24		0,02	0,13
Xe-138	14,13	minutes		0,25	0,37	0,05	0,22

[1] Average value of D, ESP, S.

3.3.1.2 Alpha

Nuclide	HL	Unit	EU [%]
Pu-239	24131	years	100

No other proposal was suggested by the data of the EU-discharge database.

3.3.1.3 Beta

Nuclide	HL	Unit	SF [%]	D [%]	ESP [%]	S [%]	EU [%][1]
Ce-144	284,3	days			0,06		0,05
Sr-90	28,6	years		0,05	6,56	26,56	9,3
Ru-106	368,2	days		3,45		0,25	1,56
Co-60	5,271	years	21,99	41,00	17,83	30,68	23,44
Ag-110m	249,85	days	11,67	7,12	2,01		5,83
Sb-124	60,2	days	19,08	11,10	12,24		11,89
Sr-89	50,55	days	0,09	0,35	14,46	17,73	6,86
Ba-140	12,789	days			0,00		0
Sb-125	2,77	years		0,70	1,07		0,75
Zr-95	64,02	days	3,09	2,41	1,98	8,56	3,37
Fe-59	44,63	days	5,48	0,37	0,76		1,85
Ce-141	32,5	days		0,32	0,82		0,48
Ru-103	39,35	days	0,04	0,37			0,18
Cs-134	2,062	years		1,12	3,48		1,93
Zn-65	244,4	days		0,28			0,24
Mn-54	312,7	days	14,40	1,85	2,84	0,97	4,22
Sb-122	2,7	days	4,01	12,58			6,98
Cs-137	30,17	years	0,22	4,22	15,66	2,89	4,83
Nb-95	35,06	days	5,99	5,04	7,45	12,36	6,48
Cs-136	13,16	days			0,87		0,73
Cr-51	27,704	days	13,94	7,68	10,68		9,05
Cd-109	462,2	days			0,83		0,7

[1] Average value of D, ESP, S, SF

3.3.1.4 Others

Nuclide	HL	Unit	UK [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100

3.3.2 Liquid discharges

3.3.2.1 Alpha

Nuclide	HL	Unit	EU [%]
Pu-239	24131	years	100

3.3.2.2 Beta

Nuclide	HL	Unit	B [%]	SF [%]	F [%]	D [%]	ESP [%]	S [%]	NL [%]	EU [%][1]
Sr-90	28,6	years	0,6	0,63		0,32	1,78	0,02	0,02	0,43
Ru-106	368,2	days				0,91	0,03	9,78	9,94	3,98
Ce-144	284,3	days				0,9	4,26	0,05	0,05	1,02
Co-60	5,271	years	11,94	18,94	23,23	13,36	15,42	15,41	43,36	15,57
Ba-140	12,789	days				5,5	0,01	0,07	0,07	1,08
Sr-89	50,55	days	0,05	0,05		2,67	1,25	0,02	0,02	0,52
Cs-134	2,062	years	12,52	9,46	4,52	0,82	17,07	0,85	0,54	5,03
Zn-65	244,4	days	0,42	0,44		0,69	0,62	0,16	0,16	0,32
Sb-124	60,2	days	7,95	17,83	5,83	4,87	1,45	7,06	3,02	5,28
Na-22	2,602	years				8,06	0			3,1

Nuclide	HL	Unit	B [%]	SF [%]	F [%]	D [%]	ESP [%]	S [%]	NL [%]	EU [%][1]
Fe-59	44,63	days	8,17	6,16		4,34	0,9	5,43	2,92	3,58
La-140	40,22	hour				5,8	0,02	0,99	1	1,5
Cs-137	30,17	years	16,11	16,28	18	2,67	21,52	1,09	2,03	8,54
Sb-122	2,7	days	0	0,78			0,25	0,69	0,7	0,37
Cs-136	13,16	days					0,01	0,01	0,01	0,01
Sb-125	2,77	years	10,76	9,03		3,92	2,63	2,56	2,6	4,04
Zr-95	64,02	days	1,12	0,75		0,68	0,69	1,17	1,31	0,73
Ce-141	32,5	days				0,81	0,33	0,01	0,11	0,25
Ru-103	39,35	days				0,37	0,03	0,02	0,22	0,12
Co-58	70,8	days	19,62	4,97	25,14	3,56	22,72	45,52	15,58	15,07
Mo-99	66,02	hour					5,49			4,22
Nb-95	35,06	days	4,36	4,28		0,59	1,09	2,56	2,77	2,01
Mn-54	312,7	days	3,53	2,21	1,59	1,04	1,14	1,4	1,26	1,34
Co-57	270,9	days	0,91	0,95		0,12	0,01	0,21	0,21	0,31
Ni-63	100,1	years				31,76			8,69	15,56
Ag-110m	246,2	days	1,94	7,21	21,69	2,81	0,65	4,91	3,38	4,68
Te-132	76,3	hour				3,43	0,09			1,35

[1] Average value of B, SF, F, D, ESP, S, NL.

3.3.2.3 Others

Nuclide	HL	Unit	EU [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100

3.4 GAS COOLED REACTORS (GCR)

Gas cooled reactors are found in:

- France (F): Bugey 1, Chinon A3, Marcoule (APM), St Laurent A1+A2.
- Italy (I): Latina.
- Spain (ESP): Vandellos 1.
- United Kingdom (UK): Berkeley A+B, Bradwell A+B, Calder Hall A+B+C+D, Chapelcross A+B+C+D, Dungeness AA+AB, Hinkley Point:AA+AB, Hunterston: AA+AB, Oldbury AA+AB, Sizewell AA+AB, Trawsfynydd A+B, Wylfa A+B.

3.4.1 Atmospheric discharges

3.4.1.1 Noble gas

Nuclide	HL	Unit	ESP [%]	UK [%]
Ar-41	1,827	hour	0	100
Kr-85	10,72	years	100	0

For French reactors no specific discharge data in the discharge database available.

3.4.1.2 Alpha

Nuclide	HL	Unit	EU [%]
Pu-239	24131	years	100

3.4.1.3 Beta

Nuclide	HL	Unit	UK [%]
Co-60	5,271	years	22,57
Cs-137	30,17	years	77,43

3.4.1.4 Others

Nuclide	HL	Unit	UK [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100
S-35	87,44	days	100

3.4.2 Liquid discharges

3.4.2.1 Alpha

Nuclide	HL	Unit	F [%]	UK [%]
Pu-239	24131	years	40	100
Pu-238	375800	years	14	
Am241	432,2	years	38	
CM-242	163,2	days		
Cm-243	28,5	years	4	
Cm-244	18,11	years	4	

3.4.2.2 Beta

Nuclide	HL	Unit	ESP [%]	UK [%]
Sr-90	28,6	years	7,99	22,66
Ru-106	368,2	days	0,53	0,38
Ce-144	284,3	days		0,65
Co-60	5,271	years	1,72	0,95
Y-90	64,1	hours		7,06
Sr-89	50,55	days	14,93	
Cs-134	2,062	years	3,93	2,7
Zn-65	244,4	days	0,02	0,14
Fe-59	44,63	days		0,12
Cs-137	30,17	years	70,21	55,95
Eu-154	8,8	years		0,08
Sb-125	2,77	years	0,67	0,3
Zr-95	64,02	days		0,1
Ca-45	162,7	days		1,9
Ru-103	39,35	days		3,83
Nb-95	35,06	days		0,12
Fe-55	2,7	years		1,86
Eu-155	4,96	years		0,07
Pm-147	2,6234	years		0,37
Pr-144	17,28	minutes		0,68
Ag-110m	253	days		0,06

3.4.2.3 Others

Nuclide	HL	Unit	EU [%]
C-14	5730	years	100
H-3	12,28	years	100
S-35	87,44	days	100

3.5 HIGH TEMPERATURE GAS COOLED REACTORS (HTGR)

One high temperature gas cooled reactor is found in:

Germany (D): Hamm-Uentrop (THTR 300), decommissioned in 1988. Within the period of time considered the reactor was running during 1987 – 1988 only. Shutdown was begun in 1988. The percentages stated in the following tables are the authorised releases [TÜV 85]. The actual releases can be very much less.

3.5.1 Atmospheric discharges

3.5.1.1 Noble Gas

Nuclide	HL	Unit	D [%]
Kr-83m	1,83	hour	19,1
Kr-85	10,72	years	19,1
Kr-85m	4,48	hour	4,13
Kr-87	76,3	minutes	6,06
Kr-88	2,84	hour	10,06
Kr-89	3,16	minutes	15,33
Xe-133	5,245	days	15,89
Xe-135	9,11	hour	6,32
Xe-137	3,83	minutes	1,27
Xe-138	14,13	minutes	2,74

3.5.1.2 Beta

Nuclide	HL	Unit	D [%]
Te-129	34	days	55,57
Ag-111	7,5	days	36,47
Te-127	109	days	4,19
La-140	40,22	hour	1,43
Cs-135	3000000	years	1,23
Sr-89	50,55	days	1,12

3.5.1.3 Others

Nuclide	HL	Unit	D [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100

3.5.2 Liquid discharges

3.5.2.1 Beta

Nuclide	HL	Unit	D [%]
Sr-90	28,6	years	0,06
Ce-144	284,3	days	0,04
Co-60	5,271	years	2,01
Sr-89	50,55	days	0,83
Ba-140	12,789	days	0,06
Cs-134	2,062	years	0,26
Fe-59	44,63	days	0,8
La-140	40,22	hours	0,04
Cs-137	30,17	years	1,45
Zr-95	64,02	days	0,06
Ce-141	32,5	days	0,1
Nb-95	35,06	days	0,1
Mn-54	312,7	days	2,01
Fe-55	2,7	years	26,92
Na-24	15	hour	0,6
Ni-63	100,1	years	2,01
Cr-51	27,704	days	10,85
Ag-110m	253	days	0,12
Cu-64	12,9	hour	19,69
Sc-46	83,8	days	1
Mn-56	2,57	hour	30,53
Te-132	78	hour	0,44

3.5.2.2Others

Nuclide	HL	Unit	EU [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100

3.6 FAST BREEDER REACTORS (FBR)

Only two fast breeder reactors are found in:

France (F): Phenix and Creys Malville (Superphenix). The Creys Malville reactor was operating normally for ca. 19 months in 1994 –1995 and was then, because of technical difficulties, slowed for a time, and finally shutdown in 1998. Except for an incomplete entry there are no data in the database regarding the Phenix reactor. The following tables are based solely on the data set of operation in 1995 of the Creys Malville reactor.

3.6.1 Atmospheric discharges

3.6.1.1 Noble Gas

Nuclide	HL	Unit	F [%]
Kr-85	10,72	years	22,62

3.6.1.2 Beta

Nuclide	HL	Unit	F [%]
Co-60	5,271	years	100

3.6.2 Liquid discharges

3.6.2.1 Beta

Nuclide	HL	Unit	F [%]
Cs-137	30,17	years	17,17
Cs-134	2,062	years	17,17
Co-60	5,271	years	22,28
Mn-54	312,7	days	26,21
Co-58	70,8	days	17,17

3.6.2.2 Others

Nuclide	HL	Unit	F [%]
C-14	5730	years	100
H-3	12,28	years	100
I-131	8,04	days	100

3.7 HEAVY-WATER/LIGHT WATER REACTORS (SGHWR)

The following plant is mentioned in the EU-discharge database: Winfrith (UK).
There are few data to be found in the EU-discharge database. The nuclide spectra were taken from [NRPB 00] and are based on the averaged liquid and gaseous discharges of 1993 – 1995.

3.7.1 Atmospheric discharges

3.7.1.1 Noble Gas

Nuclide	HL	Unit	UK [%]
Kr-85	10,72	years	100

3.7.1.2 Others

Nuclide	HL	Unit	UK [%]
C-14	5730	years	100
H-3	12,28	years	100

3.7.2 Liquid discharges

3.7.2.1 Alpha

Nuclide	HL	Unit	UK [%]
Pu-239	24131	years	54,89
Pu-238	375800	years	22,06
Am241	432,2	years	19,04
U-234	28,5	years	3,31
U-238	163,2	days	0,7

3.7.2.2 Beta

Nuclide	HL	Unit	UK [%]
Cs-137	30,17	years	69,1
Cs-134	2,062	years	0,27
Zn-65	244,4	days	0,49
Fe-55	2,7	years	3,86
Co-60	5,271	years	9,79
Mn-54	312,7	days	0,27
Ce-144	284,3	days	0,18
Sr-90	28,6	years	5,29
Ni-63	100,1	years	10,75

3.7.2.3 Others

Nuclide	HL	Unit	UK [%]
C-14	5730	years	100
H-3	12,28	years	100

3.8 NUCLEAR FUEL REPROCESSING PLANTS (NFRP)

The following plants are mentioned in the EU-discharge database:

France (F):Cap de la Hague.
Germany (D): WAK (Wiederaufbereitungsanlage Karlsruhe).
United Kingdom (UK-D, UK-S): Dounreay, Sellafield.

The WAK was built as a research facility in 1971and shut down in 1990. Very few data are available over this. In the year 1997 a radioecological study [NCR 00] was entrusted to a group of experts – the Nord-Cotentin Radioecological Group. Its principal objective was to realistically assess the exposure to ionising radiation of young people from 0 to 2 years of age who lived near the La Hague nuclear reprocessing plant. The group reconstructed the releases of some radionuclides and added 36 radionuclides to the spectra of measured radionuclides. These additions did not modify the order of magnitude but they defined the composition of discharges in more detail. We hence propose that these data be likewise placed in the EU-discharge database, rather to be taken into account when calculating realistic doses. In the following tables these data however were not considered:

3.8.1 Atmospheric discharges

3.8.1.1 Noble gas

Nuclide	HL	Unit	F [%]	D [%]	UK-D [%]	UK-S [%]
Ar-41	1,827	hour			0,48	3
Kr-85	10,72	years	100	100	98,6	97
Kr-85m	4,48	hour			0,01	
Kr-87	76,3	minutes			0,01	
Kr-88	2,84	hour			0,01	
Xe-133	5,245	days			0,79	
Xe-133m	2,19	days			0,08	
Xe-135m	15,36	minutes			0,03	

3.8.1.2 Alpha

Nuclide	HL	Unit	UK-D [%]	UK-S [%]	F [%][1]	D [%][2]
Pu-239	24131	years	14,17	61,8	17,95	20,8
Am241	432,2	years	72,81	38,2	27,37	26,8
CM-243	28,5	years	1,98		0,2	
Cm-242	163,2	days	11,04		0,28	6
Pu-238	87,75	years			27,65	45,3
Cm-244	18,11	years			26,55	1,1

[1] Values are taken from [NCR 00], [2] Values are taken from [KfK 88].

3.8.1.3 Beta

Nuclide	HL	Unit	F [%][1]	D [%]	UK-D [%]	UK-S [%]
Pu-241	14,4	years	1,58	78	19,14	25,45
Sr-90	28,6	years		22	15,73	3,5
Ru-106	368,2	days	15,3		5,05	37,04
Cs-134	2,062	years	0,2		1,27	
Ce-144	284,3	days			35,22	
Cs-137	30,17	years	0,81		23,60	17,33
Sb-125	2,77	years	82,08			3,5
Co-60	5,271	years	0,03			2,45

[1] Values are taken from the GT1 source term in [NCR 00].

3.8.1.4 Others

Nuclide	HL	Unit	F [%][1]	D [%]	UK [%]
C-14	5730	years	100	100	
H-3	12,28	years	100	100	100
I-131	8,04	days	100	100	100
I-129	15700000	years		100	100
S-35	87,44	days			100

3.8.2 Liquid discharges

3.8.2.1 Alpha

Nuclide	HL	Unit	F [%]	D [%]	UK-D [%]	UK-S [%]
Pu-239	24131	years	85	100	20,84	53,57
Am241	432,2	years	15		66,62	28,13
U-238	4,47E+09	years			0,04	
U-235	7,04E+08	years			0,03	
U-234	244500	years			0,82	
Pu-238	87,75	years			8,38	
Cm-242	163,2	days			2,63	2,36
Cm-243	28,5	years			0,63	0,88
Np-237	2,14E+06	years				15,06

3.8.2.2 Beta

Nuclide	HL	Unit	F [%]	D [%][1]	UK-D [%]	UK-S [%]
Cs-137	30,17	years	6,44	41,92	54,42	22,58
Ce-144	284,3	days			0,67	1,38
Sr-89	50,55	days				0,19
Tc-99m	6,02	hour	1,23			22,7
Cs-134	2,062	years	0,93	8,44	6,83	2,25
Zn-65	244,4	days				0,07
Ag-110m	253	days			0,09	0,11
Eu-154	8,8	years				0,06
Eu-152	13,6	years				0,08
Pu-241	14,4	years	5,02	34,21	12,43	15,6
Co-60	5,271	years	1,90		0,25	0,45
Zr-95	64,02	days			0,32	4,85
Mn-54	312,7	days	0,19			0,04
Ru-103	39,35	days	0,76			0,24
Nb-95	35,06	days			0,38	2,95
Ru-106	368,2	days	51,09		8,56	9,92
Fe-55	2,7	years				0,09
Eu-155	4,96	years				0,04
Pm-147	2,6234	years				1,05
Sb-125	2,77	years	19,81			7,45
Sr-90	28,6	years	12,63	7,35	16,04	7,05
Ni-63	100,1	years				0,51
Rb-83	83	days		8,08		

[1] Values are taken from [KfK 89].

3.8.2.3 Others

Nuclide	HL	Unit	F [%]	D [%]	UK-D [%]	UK-S [%]
C-14	5730	years		100		100
H-3	12,28	years	100	100	100	100
I-131	8,04	days		100		
I-129	15700000	years	100			100
S-35	87,44	days				100

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