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ENVIRONMENTAL IMPACT ASSESSMENT OF RADIOACTIVE MATERIALS DURING SEA TRANSPORTATION: ---CASE STUDY OF PLUTONIUM RELEASED IN THE OCEAN ---

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1 - OBJECTIVES OF THE ENVIRONMENTAL IMPACT ASSESSMENT.

The safety of transports between France and Japan of radioactive materials is based on the packages, according to IAEA rules, and on the application of the INF code concerning the ships which carry these materials. Nevertheless, the environmental assessment of the release of such radioactive materials into the sea, during the years following the release, is valuable. The Science and Technology Agency (STA, Japan) and the Institut de Protection et de Sûreté Nucléaire (IPSN, France) are jointly involved in these assessments. Currently, STA is studying the case of vitrified waste release and IPSN the case of plutonium release.

The summary of the study [1] coordinated by IPSN is the object of the present paper.

Indeed, to perform this assessment, the marine environment has to be modelled on a large scale and the exposure path to be calculated. Hypothesis has been made on the release phenomena as well.

2 - MODELLING OF THE MARINE ENVIRONMENT.

The modelling of the marine environment has to cover a very large region from the Arctic sea to the Mediterranean and the Atlantic Ocean. It has to take into account the water streams and the sedimentation processes.

The model is based on a division of the European seas in 44 compartments (annex 1).

In each compartment, global parameters such as volume, depth, suspended sediment load and sediment rate, are defined (annex 3). Such parameters are supposed to be homogeneous inside the compartment. Moreover, above modelling approach imposes the radioactivity to be homogeneously distributed within each

compartment. Dispersion is evaluated using water exchange rate between compartments (annex 1).

These data were adapted from the Marina project about the radiological exposure of the population of the European Countries from radioactivity in North European marine waters performed by the European Commission[2].

3 - ORIGIN OF CONTAMINATION.

Two locations for the instantaneous release of 1 kg of plutonium were chosen , one in the North East part of the Atlantic Ocean and the other in the west part of the Channel.

The composition of the plutonium is that issued from the reprocessing of PWR spent fuel irradiated at 33000 Mwj/t and stored for 3 years, that is (annex 2) mainly:

Plutonium 239 (60 %)
Plutonium 240 (20%)
Plutonium 241 (10%)

4 - HYPOTHESES FOR THE CALCULATION.

Various hypotheses were made to perform the calculations. Indeed, it is supposed that :

- the physical parameters inside a compartment are uniform (suspended sediment load between 0.1 and 10g/m^3, sediment rate between 10g and 5kg/m^2/year, volume, volume exchange rate, depth).

- the above physical parameters are constant in time.

- the radionuclides are uniformly distributed in the volume of a compartment.

- the radioactive decay of radionuclides is taken in account.

5- THE EXPOSURE PATHWAY.

The exposure paths are calculated from the consumption of sea products (fish, shellfish, molluscs and seaweeds) using European fishing statistics. As a consequence, knowledge of the following data is needed (examples are given in annex 3).

- quantity of sea products in each compartment every year,

- concentration factor for each radionuclide expressing the relation between the radioactivity of the sea water and that of the sea products,

- edible fraction of the sea products.

All the sea products are supposed to be eaten within the European countries. The equivalent dose is then calculated from the activity ingested for each radionuclide using conversion factor from the ICRP 61.

6 - RESULT

The results are the following

	Cumulated collective dose for European countries after 50 years	Average cumulated individual dose in European countries after 50 years
Western part of the Channel	160 man Sv	0.45 µSv
North Eastern part of the Atlantic Ocean	4.47 man Sv	0.013µSv

7 - FURTHER DEVELOPMENTS

IPSN, in collaboration with IFREMER, is elaborating a refined modelling of sea water currents to evaluate short time effects more precisely.

Moreover, the study mentioned above analyses the effects of the release collectively but not on individuals. IPSN is presently defining so called "reference groups" whose habits can vary according to their cultural, social, or economic environment. It will then be possible to detail this evaluation of the impact on individuals.

References:

[1] Raffestin D.: *Evaluation des conséquences radiologiques associées à un rejet de poudre d'oxyde de plutonium: application du code Poseidon, CEPN, NTE 95/16*

Raffestin D., Lepicard S.: *Poseidon: Un modèle de dispersion de matières radioactives en milieu maritime, CEPN, Report 236, February 1995*

Raffestin D., Lepicard S.: *Poseidon: a dispersion computer code for assessing radiological impacts in marine environment,* paper presented at the PATRAM'95 meeting, Las Vegas. 3-8 december 1995

[2] European Commission: *The radiation exposure of the population of the european community from radioactivity in Noth European Marine Waters Project 'Marina',RP 47, EUR 12483, 1990*

Annex 1

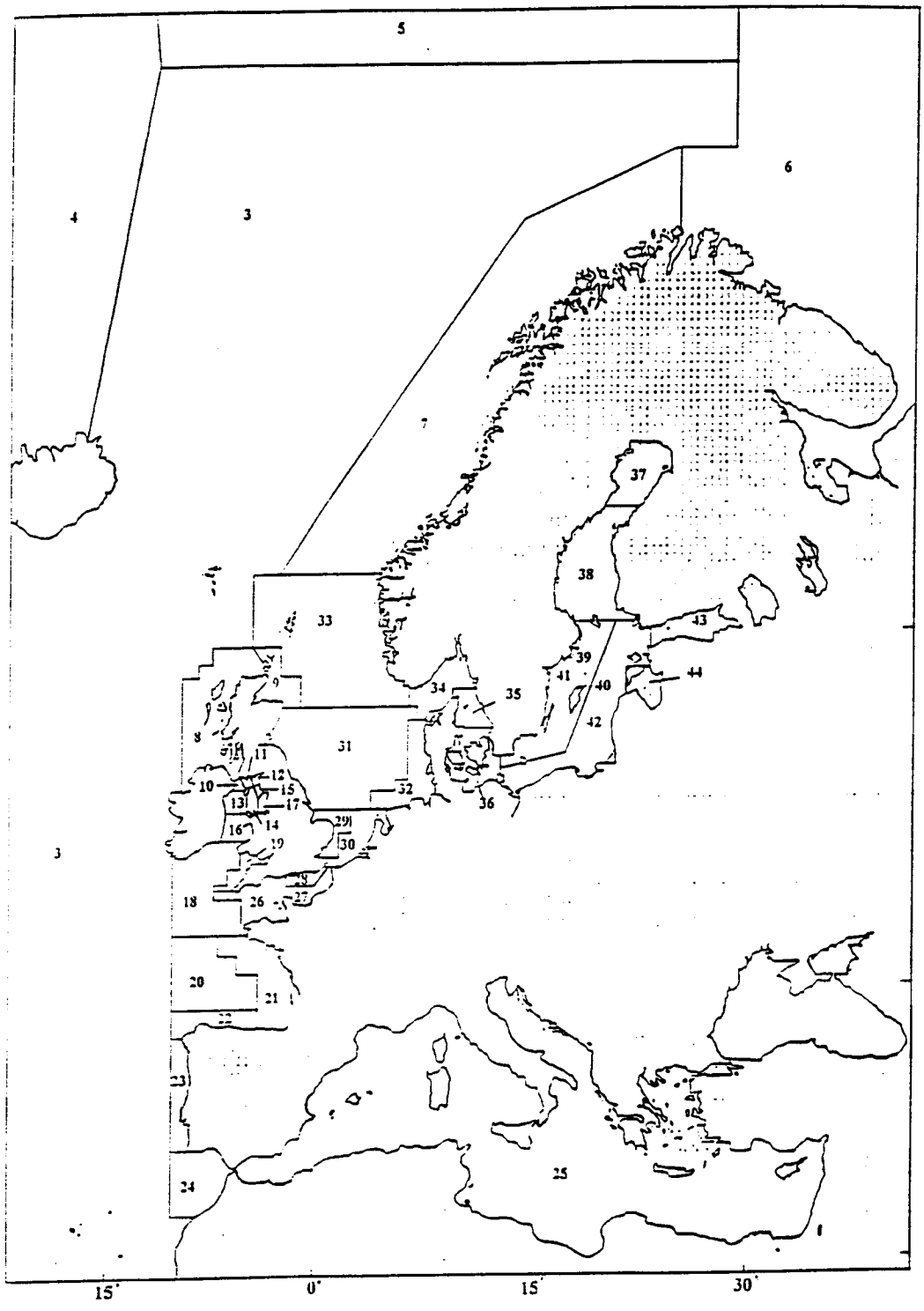

Figure 1. Carte des compartiments du modèle

Annex 1

Dénomination des compartiments régionaux

n°	Nom des compartiments Régionaux
1	Other Oceans
2	Atlantic Ocean
3	Atlantic North East
4	Arctic Ocean
5	Spitzbergen
6	Barents Sea
7	Norwegian Waters
8	Scottish Waters West
9	Scottish Waters East
10	Irish Sea North West
11	Irish Sea North
12	Irish Sea North East
13	Irish Sea West
14	Irish Sea South East
15	Cumbrian Waters
16	Irish Sea South
17	Liverpool & Morecambe Bays
18	Celtic Sea
19	Bristol Channel
20	Bay of Biscay
21	French Continental Shelf
22	Cantabrian Sea
23	Portuguese Continental Shelf
24	Gulf of Cadiz
25	Mediterranean Sea
26	English Channel West
27	English Channel South East
28	English Channel North East
29	North Sea South West
30	North Sea South East
31	North Sea Central
32	North Sea East
33	North Sea North
34	Skagerrak
35	Kattegat
36	Belt Sea
37	Bothnian Bay
38	Bothnian Sea
39	Baltic Sea West (Surface)
40	Baltic Sea East (Surface)
41	Baltic Sea West (Deep Waters)
42	Baltic Sea East (Deep Waters)
43	Gulf of Finland
44	Gulf of Riga

Annex 1

Taux d'échange entre compartiments

Compartiment de départ	Compartiment d'arrivée	Echange en km3/y	Compartiment de départ	Compartiment d'arrivée	Échange en km3/y
1	2	1.00E6	22	23	1.50E4
2	1	1.00E6	23	3	4.60E5
2	3	5.00E5	23	22	1.30E5
3	2	5.00E5	23	24	6.00E4
3	5	1.00E5	24	3	5.10E5
3	6	1.00E5	24	23	5.80E4
3	8	10375.	24	25	5.29E4
3	18	1.00E4	25	24	5.06E4
3	20	6.70E5	26	18	2000.
3	22	1.09E5	26	27	3500.
3	23	4.60E5	26	28	3500.
3	24	5.10E5	27	26	1000.
3	33	4.60E4	27	28	39.
4	3	2.40E5	27	30	2538.
5	3	2.00E4	28	26	1000.
5	4	2.20E5	28	27	39.
6	4	2.00E4	28	30	2538.
6	5	1.40E5	29	30	609.
7	6	6.00E4	29	31	381.
8	3	2575.	30	27	38.
8	9	10700.	30	28	38.
8	10	200.	30	29	294.
9	8	500.	30	31	512.
9	31	8000.	30	32	5007.
9	33	2400.	31	9	100.
10	8	2600.	31	29	696.
10	11	333.	31	30	54.
10	13	514.	31	32	2660.
11	10	833.	31	33	8957.
11	12	183.	31	34	268.
11	14	173.	32	30	150.
12	11	238.	32	31	1625.
12	15	100.	32	34	5902.
13	10	2414.	33	3	1730.
13	14	933.	33	7	6.00E4
13	16	600.	33	9	100.
14	11	568.	33	31	2049.
14	13	433.	33	34	25811.
14	15	230.	34	31	168.
14	16	75.	34	32	10.
14	17	129.	34	33	32333.
15	12	205.	34	35	1545.
15	14	145.	35	34	2020.
15	17	35.	35	36	720.
16	13	3000.	36	35	1170.
16	14	75.	36	41	270.
16	18	600.	36	42	220.
17	14	109.	37	38	275.
17	15	55.	38	37	175.
18	3	4600.	38	39	715.
18	16	3000.	39	36	720.
18	19	2000.	39	40	107.
18	20	1.50E5	39	41	6971.

Annex 1

Compartiment de départ	Compartiment d'arrivée	Échange en km3/y	Compartiment de départ	Compartiment d'arrivée	Échange en km3/y
18	21	1.40E5	40	36	220.
18	26	7000.	40	39	107.
19	18	2000.	40	42	220.
20	3	6.70E5	41	38	525.
20	18	1.50E5	41	39	6965.
20	21	5.80E5	41	42	208.
20	22	3.90E5	41	43	595.
21	18	1.40E5	41	44	312.
21	20	5.80E5	42	40	440.
21	22	7.40E4	42	41	208.
22	3	1.09E5	43	41	720.
22	20	3.90E5	44	41	344.
22	21	7.50E4			

Annex 2

Caractéristiques de la poudre de PuO2

Elément	Période (années)	Fc ingestion (Sv/Bq)	Poids relatif (%)	Activité (Bq/kg de PuO_2)	Filiation
Pu-238	8.74E+01	5.1E-07	1.60	1.01E+10	U-234
Pu-239	2.41E+04	5.6E-07	53.49	1.23E+12	U-235
Pu-240	6.56E+03	5.6E-07	21.14	1.78E+12	U-236
Pu-241	1.44E+01	1.1E-08	8.96	3.41E+14	Am-241
Pu-242	3.73E+05	5.3E-07	0.33	4.78E+08	U-238
Am-241	4.32E+02	5.7E-07	2.69	3.41E+12	Np-237

Annex 3

Caractéristiques des compartiments du modèle

n°	Volume m3	Qté poissons t/an	Qté crustacés t/an	Qté mollusques t/an	Qté algues t/an	Sédimen-tation t/m2.an	Profon-deur m	Mat. en Suspens. t/m3	Nom des compartiments Régionaux
1	1.00E18	0	0	0	0	5.20E-5	4000	1.00E-7	Other Oceans
2	3.00E17	0	0	0	0	1.00E-4	3500	1.00E-7	Atlantic Ocean
3	5.00E16	3.50E5	1.10E4	4.20E3	0	1.00E-5	3500	1.00E-7	Atlantic North East
4	1.70E16	0	0	0	0	1.00E-5	1200	1.00E-7	Arctic Ocean
5	1.00E14	1.50E4	7.60E3	0	0	1.00E-5	1200	1.00E-7	Spitzbergen
6	3.00E14	2.20E4	3.00E3	7.00E1	0	1.00E-5	200	1.00E-7	Barents Sea
7	1.00E15	1.20E5	6.70E2	6.20E2	0	1.00E-5	1200	1.00E-7	Norwegian Waters
8	1.00E13	3.10E5	6.90E3	4.80E3	1.40E4	1.00E-4	110	1.00E-6	Scottish Waters West
9	3.00E12	9.40E4	1.90E3	1.30E3	4.30E3	1.00E-4	110	1.00E-6	Scottish Waters East
10	4.08E11	6.80E3	1.10E3	1.70E3	0	3.00E-3	93	3.00E-6	Irish Sea North West
11	6.10E10	1.00E3	3.70E2	5.80E2	0	5.10E-3	34	3.00E-6	Irish Sea North
12	5.20E10	8.70E2	8.40E2	1.30E3	0	3.60E-3	24	3.00E-6	Irish Sea North East
13	6.62E11	1.10E4	1.60E3	2.30E3	0	2.00E-3	63	3.00E-6	Irish Sea West
14	1.62E11	2.70E3	4.50E2	6.90E2	0	4.70E-3	31	3.00E-6	Irish Sea South East
15	3.80E10	6.30E2	2.80E2	4.40E2	0	4.20E-3	28	3.00E-6	Cumbrian Waters
16	1.10E12	1.80E4	2.60E3	3.80E3	0	1.00E-4	57	1.00E-6	Irish Sea South
17	3.20E10	5.30E2	7.80E2	1.20E3	0	2.00E-3	13	3.00E-6	Liverpool & Morecambe Bays
18	2.00E13	9.40E4	5.40E3	4.20E3	0	1.00E-4	150	1.00E-6	Celtic Sea
19	1.00E12	2.60E4	5.40E2	3.40E3	0	1.00E-4	50	1.00E-6	Bristol Channel
20	6.50E14	0	0	0	0	1.00E-5	3990	1.00E-7	Bay of Biscay
21	3.50E13	5.20E4	1.70E4	1.20E5	3.60E1	1.00E-4	350	5.00E-7	French Continental Shelf
22	3.00E13	3.90E5	5.40E3	2.60E4	1.40E3	2.00E-4	760	1.00E-6	Cantabrian Sea
23	1.50E13	2.20E5	5.10E3	1.70E4	7.40E1	2.00E-4	490	1.00E-6	Portuguese Continental Shelf
24	2.30E14	6.40E4	5.20E3	1.20E4	0	5.00E-5	1670	2.00E-7	Gulf of Cadiz
25	3.57E15	4.80E5	4.40E4	2.50E5	0	7.50E-5	1400	1.00E-6	Mediterranean Sea
26	3.20E12	9.70E4	1.10E4	4.20E4	0	1.00E-4	60	1.00E-6	English Channel West
27	6.50E11	3.20E4	1.60E3	3.80E4	2.40E4	1.00E-4	40	1.00E-6	English Channel South East
28	6.50E11	3.20E4	3.80E2	1.50E3	0	1.00E-4	40	1.00E-6	English Channel North East
29	4.50E11	2.80E4	8.00E2	1.50E4	0	1.60E-4	31	6.00E-6	North Sea South West
30	9.50E11	5.90E4	5.90E3	7.90E4	0	1.90E-4	37	6.00E-6	North Sea South East
31	1.28E13	2.70E5	5.90E3	1.30E3	0	1.00E-4	50	6.00E-6	North Sea Central
32	1.20E12	2.50E4	2.40E4	4.40E4	0	4.40E-5	22	6.00E-6	North Sea East
33	5.60E13	3.60E5	4.50E3	1.50E3	0	1.00E-4	240	6.00E-6	North Sea North
34	6.78E12	1.20E5	1.80E3	6.70E2	0	5.00E-3	210	1.00E-6	Skagerrak
35	5.15E11	8.80E3	2.30E3	1.40E3	0	5.00E-4	23	1.00E-6	Kattegat
36	2.85E11	4.60E4	6.80E1	4.90E3	0	5.00E-4	14	1.00E-6	Belt Sea
37	1.48E12	1.80E4	5.80E-2	0	0	5.00E-4	41	1.00E-6	Bothnian Bay
38	4.89E12	6.00E4	1.10E-1	0	0	5.00E-4	62	1.00E-6	Bothnian Sea
39	3.79E12	4.60E4	3.60E0	0	0	5.00E-4	49	1.00E-6	Baltic Sea West (Surface)
40	6.97E12	8.50E4	0	0	0	5.00E-4	515	1.00E6	Baltic Sea East (Surface)
41	7.70E11	0	0	0	0	5.00E-4	108	1.00E-6	Baltic Sea West (Deep Waters)
42	1.53E12	0	0	0	0	5.00E-4	114	1.00E-6	Baltic Sea East (Deep Waters)
43	1.10E12	1.30E4	0	0	0	5.00E-4	37	1.00E-6	Gulf of Finland
44	4.05E11	5.00E3	0	0	0	5.00E-4	23	1.00E-6	Gulf of Riga

Annex 3

Élément	Facteurs de concentration (Kd) (Bq/t)/(Bq/m3)				Période (an)	Kd (Bq/t)/(Bq/m3)		Fils 1	%1	Fils 2	Fc (Sv/Bq)
	Poisson	Crustacés	Mollusque	Algue		régional	local				
Th-231	6.00E2	1.00E3	1.00E3	2.00E2	2.91E-3	5.00E6	2.00E6	Pa-231	1	*	4.90E-10
Th-232	6.00E2	1.00E3	1.00E3	2.00E2	1.41E10	5.00E6	2.00E6	Ra-228	1	*	1.80E-6
Th-234	6.00E2	1.00E3	1.00E3	2.00E2	6.60E-2	5.00E6	2.00E6	U--234	1	*	5.70E-9
Pa-231	5.00E1	1.00E1	5.00E2	1.00E2	3.28E4	1.00E6	1.00E6	Ac-227	1	*	1.40E-6
Pa-233	5.00E1	1.00E1	5.00E2	1.00E2	7.39E-2	1.00E6	1.00E6	U--233	1	*	1.40E-9
Np-237	1.00E1	1.00E2	4.00E2	5.00E1	2.14E6	5.00E3	5.00E3	Pa-233	1	*	6.40E-7
Np-239	1.00E1	1.00E2	4.00E2	5.00E1	6.43E-3	5.00E3	5.00E3	Pu-239	1	*	1.20E-9
U--232	1.00	1.00E1	3.00E1	1.00E2	7.20E1	5.00E2	1.00E3	Th-228	1	*	1.70E-7
U--233	1.00	1.00E1	3.00E1	1.00E2	1.59E5	5.00E2	1.00E3	Th-229	1	*	4.00E-8
U--234	1.00	1.00E1	3.00E1	1.00E2	2.45E5	5.00E2	1.00E3	Th-230	1	*	3.90E-8
U--235	1.00	1.00E1	3.00E1	1.00E2	7.04E8	5.00E2	1.00E3	Th-231	1	*	3.80E-8
U--236	1.00	1.00E1	3.00E1	1.00E2	2.34E7	5.00E2	1.00E3	Th-232	1	*	3.70E-8
U--237	1.00	1.00E1	3.00E1	1.00E2	1.85E-2	5.00E2	1.00E3	Np-237	1	*	7.30E-10
U--238	1.00	1.00E1	3.00E1	1.00E2	4.47E9	5.00E2	1.00E3	Th-234	1	*	3.60E-8
Pu-238	4.00E1	3.00E2	3.00E3	2.00E3	8.77E1	1.00E5	1.00E5	U--234	1	*	5.10E-7
Pu-239	4.00E1	3.00E2	3.00E3	2.00E3	2.41E4	1.00E5	1.00E5	U--235	1	*	5.60E-7
Pu-240	4.00E1	3.00E2	3.00E3	2.00E3	6.57E3	1.00E5	1.00E5	U--236	1	*	5.60E-7
Pu-241	4.00E1	3.00E2	3.00E3	2.00E3	1.44E1	1.00E5	1.00E5	Am-241	0.99	U--237	1.10E-8
Pu-242	4.00E1	3.00E2	3.00E3	2.00E3	3.76E5	1.00E5	1.00E5	U--238	1	*	5.30E-7
Am-241	5.00E1	5.00E2	2.00E4	8.00E3	4.33E2	2.00E6	2.00E6	Np-237	1	*	5.70E-7
Am-243	5.00E1	5.00E2	2.00E4	8.00E3	7.37E3	2.00E6	2.00E6	Np-239	1	*	5.70E-7
Cm-242	5.00E1	5.00E2	3.00E4	8.00E3	4.46E-1	2.00E6	2.00E6	Pu-238	1	*	2.40E-8
Cm-243	5.00E1	5.00E2	3.00E4	8.00E3	2.85E1	2.00E6	2.00E6	Pu-239	0.99	Am-243	4.00E-7
Cm-244	5.00E1	5.00E2	3.00E4	8.00E3	1.81E1	2.00E6	2.00E6	Pu-240	1	*	3.20E-7