Appendix

Table A.1. Source term of parent nuclides following an accident CAT BP in a nuclear reactor model AP1000 2 loops

Rare gas are not taken into account

	(Parent) nuclide	Group No	Source term Bq	Half-life T1/2 (s)
1	I-131	2	1.60E+18	6.93E+05
2	Cs-134	3	1.95E+17	6.52E+07
3	Cs-136	3	5.56E+16	1.14E+06
4	Cs-137	3	1.14E+17	9.53E+08
5	Rb-86	3	2.30E+15	1.61E+06
6	Sb-127	4	6.20E+15	3.33E+05
7	Te-127M	4	7.95E+14	9.42E+06
8	Te-129M	4	2.71E+15	2.90E+06
9	Te-132	4	8.31E+16	2.77E+05
10	Ba-140	5	2.26E+16	1.10E+06
11	Sr-89	5	1.28E+16	4.37E+06
12	Sr-90	5	1.10E+15	9.09E+08
13	Mo-99	6	3.05E+17	2.37E+05
14	Ru-103	6	2.40E+17	3.39E+06
15	Ru-106	6	7.91E+16	3.23E+07
16	Ce-141	8	2.53E+13	2.81E+06
17	Ce-144	8	1.91E+13	2.46E+07
18	Np-239	8	2.99E+14	2.04E+05
19	Pu-238	8	5.94E+10	2.77E+09
20	Pu-239	8	5.22E+09	7.61E+11
21	Pu-240	8	7.66E+09	2.07E+11
22	Pu-241	8	1.72E+12	4.53E+08
	Total source term:		2.72E+18	

Source of primary data on the source term: (Sholly et al. 2014, 31-32). Source on half-lives (EPA 2019a)

Table A.2. List of 'parent' nuclides (of the source term) and the related 'progeny' taken into account in this study

	Parent nuclide	Group No	Progeny Yield	Progeny Name	Half-life T1/2 (s)
1	I-131	2	0.0118	Xe-131m	1.02E+06
2	Cs-137	3	0.944	Ba-137m	1.53E+02
3	Sb-127	4	0.823	Te-127	3.37E+04
4	Sb-127	4	0.177	Te-127m	9.42E+06
5	Te-127M	4	0.976	Te-127	3.37E+04
6	Te-129M	4	0.63	Te-129	4.18E+03
7	Te-129M	4	0.37	I-129	4.96E+14
8	Te-132	4	1	I-132	8.26E+03
9	Ba-140	5	1	La-140	1.45E+05
10	Sr-90	5	1	Y-90	2.31E+05
11	Mo-99	6	0.123	Tc-99	6.67E+12
12	Mo-99	6	0.877	Tc-99m	2.17E+04
13	Ru-103	6	0.988	Rh-103m	3.37E+03
14	Ru-106	6	1	Rh-106	2.98E+01
15	Ce-144	8	0.99	Pr-144	1.04E+03
16	Ce-144	8	0.00977	Pr-144m	4.32E+02
17	Np-239	8	1	Pu-239	7.61E+11
18	Pu-238	8	1	U-234	7.75E+12
19	Pu-239	8	0.999	U-235m	1.56E+03
20	Pu-239	8	0.0006	U-235	2.22E+16
21	Pu-240	8	1	U-236	7.40E+14
22	Pu-241	8	1	Am-241	1.36E+10
23	Pu-241	8	0.0000245	U-237	5.83E+05

Source: (EPA 2019a, Table A-1. Nuclides of ICRP Publication 107 ordered by atomic number)

Table A.3. - Classes of CLC2018 (Land cover)						
ObjectID	Value	Count	LABEL3	CODE_18	CLASS_ENG	Vcatg
1	1	800699	Continuous urban fabric	111	Others	4
2	2	17085234	Discontinuous urban fabric	112	Others	4
3	3	3210212	Industrial or commercial units	121	Others	4
4	4	414626	Road and rail networks and associated land	122	Others	4
5	5	122685	Port areas	123	Others	4
6	6	352020	Airports	124	Others	4
7	7	820443	Mineral extraction sites	131	Others	4
8	8	125373	Dump sites	132	Others	4
9	9	201018	Construction sites	133	Others	4
10	10	330596	Green urban areas	141	Herbaceous	3
11	11	1310736	Sport and leisure facilities	142	Herbaceous	3
12	12	121469220	Non-irrigated arable land	211	Others	4
13	13	10943399	Permanently irrigated land	212	Cultivated	1
14	14	821737	Rice fields	213	Cultivated	1
15	15	4112102	Vineyards	221	Vineyards	2
16	16	4304276	Fruit trees and berry plantations	222	Cultivated	1
17	17	5247375	Olive groves	223	Cultivated	1
18	18	43061005	Pastures	231	Herbaceous	3
19	19	558481	Annual crops associated with permanent crops	241	Cultivated	1
20	20	24295716	Complex cultivation patterns	242	Cultivated	1
21	21	27014639	Land princip. occupied by agricult. with significant areas of natural vegetation	243	Cultivated	1
22	22	3312024	Agro-forestry areas	244	Cultivated	1
23	23	58678001	Broad-leaved forest	311	Others	4
24	24	81743560	Coniferous forest	312	Others	4
25	25	31065342	Mixed forest	313	Others	4
26	26	21557169	Natural grasslands	321	Herbaceous	3
27	27	17478178	Moors and heathland	322	Others	4
28	28	10890506	Sclerophyllous vegetation	323	Others	4
29	29	29721311	Transitional woodland-shrub	324	Others	4
30	30	763776	Beaches, dunes, sands	331	Others	4
31	31	8952679	Bare rocks	332	Others	4
32	32	23594478	Sparsely vegetated areas	333	Others	4
33	33	226982	Burnt areas	334	Others	4
34	34	1554720	Glaciers and perpetual snow	335	Others	4
35	35	1377227	Inland marshes	411	Others	4
36	36	11566473	Peat bogs	412	Others	4
37	37	586549	Salt marshes	421	Others	4
38	38	73892	Salines	422	Others	4
39	39	1218413	Intertidal flats	423	Others	4
40	40	1353727	Water courses	511	Others	4
41	41	12964044	Water bodies	512	Others	4
42	42	652034	Coastal lagoons	521	Others	4
43	43	382221	Estuaries	522	Others	4
44	44	148586809	Sea and ocean	523	Not relevant	5
45	48	40471	NODATA	999	Not relevant	5

Table A.4. Model B1: Radioinduced cancer: Risk factors for mortality (adults) according to the literature since 2005

Pathology	*Risk factor**	*Reference*	*Remarks*
Cancers other than leukemia	ERR 0.97/Sv	Cardis et al. 2005 (Nuclear workers)	
Cancer	EAR 0.24/Sv	Körblein & Hoffmann 2006 (Background radiation, population Bavaria)	
Cancer	EAR 0.2/Sv	IPPNW 2014 (Review)	
Solid cancer	ERR 0.48/Sv	Richardson et al. 2015 (INWORKS)	
Cancer		Hoffmann 2017 et al. (Population exposed by Mayak nuclear facility according to Krestinina 2005 and Cardis 2007)	EAR 4.4 x higher than ICRP 103**
Cancer		Hoffmann 2017 et al. (Indoor radon exposure)	EAR 4.4 x higher than ICRP 103**
Solid cancer		Hoffmann 2017 et al. (Nuclear workers according to Richardson et al. 2015)	EAR 4.7 x higher than ICRP 103**

* The risk factors used for the collective dose concept describe the likelihood of further cancer cases over and above the spontaneous cancer incidence. Excess absolute risk (EAR) is normally given as a unit of 1/ Sv. Thus, a mortality EAR of 0.2/Sv means that on radiation with 1 Sievert, the added risk of dying of cancer is 20 % – in addition to a 25 % basic risk. This is equivalent to an excess relative risk (ERR) of 0.2/0.25, which is equal to 0.8/Sv (Claussen & Rosen 2016, page 26).

**Ref. ICRP 103 (2007), Table A 4.1 page 179; full text version: EAR for cancer mortality 5.5% (4.1% for lethal and 1.4% for debilitating nonlethal cases combined)

Table A.5. Model B2: Radio-induced non-cancer diseases: Risk-factors for mortality due to cardio-vascular diagnoses

(In brackets: not statistically significant; x: unknown)

Pathology	*Risk factor*	*Reference*
Cardio-vascular diseases (CVD)	(x)	Nyagu 1994; Prysyazhnuk et al. 2002, 188-287; Lazyuk 2005, 24-25. (Chernobyl: children & adults)
Circulatory diseases	ERR 0.11/Gy	Ozasa et al. 2012, 229-243 (A-bomb-survivors)
Circulatory diseases combined	EAR from 2.5%/Sv [France] to 8.5%/Sv [Russia]	Little et al. 2012, 1503-1511 (Meta-analysis)
Ischemic heart disease (IHD)	ERR 0.10/Sv	
Non-IHD	ERR (0.12/Sv)	
Cerebrovascular diseases (CVA)	ERR 0.20/Sv	
Circulatory diseases apart from heart disease and CVA	ERR 0.10/Sv	
Circulatory diseases	ERR 0.22/Sv	Gillies et al. 2017, 276-290 (Nuclear workers)
Cerebrovascular disease	ERR 0.50/Sv	
Ischemic heart disease	ERR 0.18/Sv	

Table A.6. Model C1: Non-cancer diseases (other than cardiovascular) observed after ionizing radiation
(In brackets: not statistically significant)

Pathology	*Increase of non-cancer diseases in Chernobyl victims: Gomel and Ukrainian populations; Liquidators (Yablokov et al. 2009) comparing pre- and post-Chernobyl era (first decade)*	*Relative risk factor (ERR)*	*Reference*	*Remark*
Respiratory diseases	11 to 109 fold		Nyagu 1994; Prysyazhnuk et al. 2002, 188-287; Pflugbeil et al. 2006, 17, 21, 57,59; Yablokov et al. 2009, 58-160; Yablokov et al. 2016, 294. (Chernobyl)	Morbidity
Gastrointestinal diseases	60 to 213 fold			
Neurological and psychiatric diseases	6 to 53 fold			
Endocrine diseases	26 to 300 fold			
Immunological diseases, infections	18 to 12 fold			
Skin diseases	16 to 51 fold			
Musculo-skeletal diseases	80 to 97 fold			
Hematological and diseases of the lymphatic system	15 to 21 fold			
Respiratory diseases		0.23/Gy	Ozasa et al. 2012, 229-243 (A-bomb survivors)	Mortality
Pneumonia and influenza		0.24/Gy		
Digestive diseases		0.20/Gy		
Genitourinary diseases		0.18/Gy		
Non-neoplastic diseases of the blood		1.7/Gy		
Mental disorders		1.3/Sv	Gillies et al. 2017, 276-290 (Nuclear workers)	Mortality
Non-malignant respiratory disease		0.13/Sv		
Digestive diseases		0.11/Sv		

Table A.7. Model C2: Reproductive and developmental hazards by ionizing radiation

Precondition	*Pathology*
Female endocrine dysfunction	Infertility
Preexisting parental irradiation	Sterility Spontaneous abortions Chromosomal / Genome alterations Downs Syndrome (trisomy 21) Sex odds changes (loss of female life births) Low birth weight Perinatal mortality Infant mortality Congenital malformations Malignancies Immune deficiency
In utero exposure to radiation	Malignancies: Leukemia, solid cancer Chromosomal aberrations Down's Syndrome (trisomy 21) Spontaneous abortions Congenital malformations Organ dysfunction – e.g. mental retardation, low IQ Excess perinatal mortality
(Hoffmann et al. 2017)	

Table A.8. Distribution of the number of persons impacted by the radioactive cloud at different levels

(1096 meteorological simulations over 2017 – 2020)

Zarnowiec(Kopal.)

Cloud

ZA2	EUR31 ≥ 1 mSv (persons)	EUR31 ≥ 6 mSv (persons)	EUR31 ≥ 20 mSv (persons)	EUR31 ≥ 50 mSv (persons)	EUR31 ≥ 100 mSv (persons)	EUR31 ≥ 250 mSv (persons)	EUR31 ≥ 500 mSv (persons)	EUR31 ≥ 1000 mSv (persons)	EUR31 ≥ 1500 mSv (persons)	EUR31 ≥ 2000 mSv (persons)
Average	7 762 070	862 495	158 651	49 255	18 807	4 327	1 114	204	77	36
Max	82 859 424	10 804 524	4 514 625	956 706	667 079	236 621	108 999	14 562	6 472	3 120
Q99	44 997 426	6 555 566	1 377 335	746 949	270 472	57 800	17 956	4 595	2 008	1 166
Q95	22 513 730	3 324 696	863 842	272 784	87 472	22 415	5 150	1 050	339	120
Q90	18 499 955	2 356 530	505 697	113 757	46 310	9 683	2 265	373	73	0
Q85	14 852 560	1 795 119	286 377	76 219	30 232	5 944	1 169	146	10	0
Q75	10 025 068	1 079 325	139 427	34 386	12 503	1 862	450	38	0	0
Q50	4 763 317	393 571	29 532	4 428	1 415	466	108	0	0	0
Q25	2 053 757	77 371	1 676	715	467	153	12	0	0	0
Q15	1 218 644	26 256	762	234	163	107	0	0	0	0
Q10	866 843	10 132	459	164	152	91	0	0	0	0
Q5	452 113	1 538	164	152	131	8	0	0	0	0
Q1	71 359	222	152	8	0	0	0	0	0	0
Min	20 977	153	8	0	0	0	0	0	0	0

EUR31 (POL, DEU, DNK, SWE, FIN, RU1, EST, LVA, LTU, BLR, UKR, SVK, CZE, AUT, BEL, BIH, CHE, FRA, GBR, HRV, HUN, ITA, LIE, LUX, MDA, NLD, NOR, ROU, SMR, SRB, SVN)

Table A.9. Distribution of the number of persons impacted by radioactive deposition ≥ 1 mSv

(1096 meteorological simulations over 2017 – 2020)

Zarnowiec(Kopal.)

1st year deposition

ZA2	EUR31 ≥ 1 mSv (persons)	POL ≥ 1 mSv (persons)	DEU ≥ 1 mSv (persons)	KLL ≥ 1 mSv (persons)	SDE ≥ 1 mSv (persons)	CSUB ≥ 1 mSv (persons)
Average	6 692 110	1 464 349	951 974	498 284	465 850	1 268 796
Max	76 570 011	18 168 525	31 731 481	4 057 310	7 389 495	22 265 363
Q99	40 765 024	12 187 360	21 267 158	3 089 299	5 077 458	10 866 255
Q95	19 587 476	7 998 732	7 322 026	2 147 107	3 088 157	6 149 921
Q90	16 032 136	5 318 606	1 647 460	1 684 566	1 857 740	4 318 767
Q85	12 709 593	3 875 209	139 870	1 301 019	1 049 915	3 283 536
Q75	8 634 014	1 518 641	0	855 378	124 078	1 638 369
Q50	4 158 513	34 521	0	18 704	0	6 297
Q25	1 748 559	1 295	0	0	0	0
Q15	1 018 391	279	0	0	0	0
Q10	704 811	164	0	0	0	0
Q5	373 938	161	0	0	0	-1
Q1	65 120	8	0	0	0	-1
Min	12 450	7	0	0	0	-2

EUR11: Poland (POL), Germany (DEU), Kaliningr.-Obl.+ Latvia + Lithuania (KLL), Sweden + Denmark (SDE), Czechia, Slovakia, Ukraine, Belarus

Table A.10. Distribution of the number of persons impacted by radioactive deposition ≥ 6 mSv

(1096 meteorological simulations over 2017 – 2020)

Zarnowiec(Kopal.)

1st year deposition

ZA2	EUR31 ≥ 6 mSv (persons)	POL ≥ 6 mSv (persons)	DEU ≥ 6 mSv (persons)	KLL ≥ 6 mSv (persons)	SDE ≥ 6 mSv (persons)	CSUB ≥ 6 mSv (persons)
Average	687 379	332 220	85 280	104 740	89 765	37 061
Max	9 600 260	8 068 628	8 682 564	2 006 043	3 563 449	3 324 323
Q99	5 822 632	3 228 619	3 259 905	1 272 749	2 200 850	745 821
Q95	2 579 936	1 673 078	172 693	668 025	501 888	203 000
Q90	1 899 731	1 196 760	2 227	398 636	173 434	37 072
Q85	1 455 845	767 839	0	204 031	54 716	8 519
Q75	856 185	335 591	0	54 767	544	131
Q50	284 177	11 616	0	0	0	0
Q25	53 387	898	0	0	0	0
Q15	15 014	262	0	0	0	0
Q10	5 167	164	0	0	0	0
Q5	1 032	155	0	0	0	-1
Q1	221	8	0	0	0	-1
Min	152	7	0	0	0	-2

EUR11: Poland (POL), Germany (DEU), Kaliningr.-Obl.+ Latvia + Lithuania (KLL), Sweden + Denmark (SDE), Czechia, Slovakia, Ukraine, Belarus

Table A.11. Distribution of the number of persons impacted by radioactive deposition ≥ 20 mSv

(1096 meteorological simulations over 2017 – 2020)

Zarnowiec(Kopal.)

1st year deposition

ZA2	EUR31 ≥ 20 mSv (persons)	POL ≥ 20 mSv (persons)	DEU ≥ 20 mSv (persons)	KLL ≥ 20 mSv (persons)	SDE ≥ 20 mSv (persons)	CSUB ≥ 20 mSv (persons)
Average	125 661	96 465	5 328	14 730	6 715	1 124
Max	2 971 581	2 971 581	1 797 878	863 879	1 664 311	549 219
Q99	1 184 292	1 105 528	45 124	503 923	110 241	11 604
Q95	696 515	603 215	0	60 641	15 088	1
Q90	377 167	267 771	0	15 823	955	0
Q85	235 453	161 863	0	943	0	0
Q75	98 786	60 509	0	0	0	0
Q50	24 013	7 984	0	0	0	0
Q25	1 422	754	0	0	0	0
Q15	697	226	0	0	0	0
Q10	259	164	0	0	0	0
Q5	163	152	0	0	0	0
Q1	148	8	0	0	0	-1
Min	5	0	0	0	0	-1

EUR11: Poland (POL), Germany (DEU), Kaliningr.-Obl.+ Latvia + Lithuania (KLL), Sweden + Denmark (SDE), Czechia, Slovakia, Ukraine, Belarus