Appendix A: List of severe accidents within the coal chain in the period 1945-1996

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$[1].

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 $US\$_{1996}$)
9.05.1945	USA	Sunnyside	Extraction	23	N.A.	N.A.	N.A.
13.09.1945	South Africa	Vryheid	Extraction	52	N.A.	N.A.	N.A.
26.12.1945	USA	Fourmile	Extraction	25	N.A.	N.A.	N.A.
?.?.1946	Germany	Grimberg	Extraction	439	N.A.	N.A.	N.A.
25.03.1947	USA	Centralia	Extraction	111	N.A.	N.A.	N.A.
15.08.1947	UK	Cumberland	Extraction	104	N.A.	N.A.	N.A.
22.08.1947	UK	Durham	Extraction	28	N.A.	N.A.	N.A.
?.?.1948	USA	Donora	Heating	17	N.A.	N.A.	N.A.
14.03.1948	Italy	Triestre	Extraction	71	N.A.	N.A.	N.A.
20.04.1948	France	Sallaumines	Extraction	13	N.A.	N.A.	N.A.
?.05.1948	Germany	Unknown	Extraction	50	76	N.A.	N.A.
8.05.1948	Belgium	Dampremy	Extraction	21	N.A.	N.A.	N.A.
19.10.1949	Germany	Oberschlema	Extraction	100	N.A.	N.A.	N.A.
20.05.1950	Germany	Gelsenkir-chen	Extraction	55	N.A.	N.A.	N.A.
26.09.1950	UK	Derbyshire	Extraction	80	N.A.	N.A.	N.A.
02.01.1951	Hungary	Tatabanya	Extraction	81	N.A.	N.A.	N.A.
29.05.1951	UK	Durham	Extraction	81	N.A.	N.A.	N.A.
21.12.1951	USA	West Frankfort	Extraction	119	N.A.	N.A.	N.A.
?.?.1952	USA	New York	Heating	360	N.A.	N.A.	N.A.
?.?.1952	UK	London	Heating	4000	N.A.	N.A.	N.A.
13.01.1952	USA	Stellarton	Extraction	19	N.A.	N.A.	N.A.
19.04.1952	Germany	Zwickau	Extraction	47	N.A.	N.A.	N.A.
24.10.1953	Belgium	Seraing	Extraction	26	N.A.	N.A.	N.A.
25.03.1954	Poland	Chorzow	Extraction	45	N.A.	N.A.	N.A.
31.08.1954	Japan	Kushiro	Extraction	34	N.A.	N.A.	N.A.
13.11.1954	USA	Farmington	Extraction	15	N.A.	N.A.	N.A.
24.01.1955	Turkey	Zonguldak	Extraction	39	N.A.	N.A.	N.A.
06.02.1955	India	Bihar	Extraction	55	N.A.	N.A.	N.A.
22.03.1955	Italy	Morgnamo	Extraction	24	N.A.	N.A.	N.A.
03.08.1955	Germany	Gelsen-kirchen	Extraction	40	N.A.	N.A.	N.A.
01.11.1955	Japan	Akahira	Extraction	60	N.A.	N.A.	N.A.
?.?.1956	UK	London	Heating	1000	N.A.	N.A.	N.A.
02.03.1956	Mozambique	Motize	Extraction	34	N.A.	N.A.	N.A.

[1]No severe coal accident with evacuees have been found
N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 $US\$_{1996}$)
08.08.1956	Belgium	Marcinelle	Extraction	270	N.A.	N.A.	N.A.
27.08.1956	Poland	Upper Silesia	Extraction	29	N.A.	N.A.	N.A.
01.11.1956	USA	Springhill	Extraction	38	N.A.	N.A.	N.A.
04.02.1957	USA	Bishop	Extraction	37	N.A.	N.A.	N.A.
19.11.1957	UK	Muirkirk	Extraction	17	N.A.	N.A.	N.A.
25.11.1957	Japan	Yawata	Extraction	18	N.A.	N.A.	N.A.
19.02.1958	India	Asansol	Extraction	181	N.A.	N.A.	N.A.
07.05.1958	Japan	Nagasaki	Extraction	29	N.A.	N.A.	N.A.
28.08.1958	Poland	Zabreze	Extraction	72	N.A.	N.A.	N.A.
01.10.1958	Yugoslavia	Podvis	Extraction	60	N.A.	N.A.	N.A.
23.10.1958	USA	Springhill	Extraction	74	N.A.	N.A.	N.A.
27.10.1958	USA	McDowell County	Extraction	22	N.A.	N.A.	N.A.
18.09.1959	UK	Lanarkshire	Extraction	47	N.A.	N.A.	N.A.
25.11.1959	Hungary	Szuesci	Extraction	31	N.A.	N.A.	N.A.
21.01.1960	South Africa	Coalbrook	Extraction	417	437	N.A.	N.A.
01.02.1960	Japan	Yubari	Extraction	32	N.A.	N.A.	N.A.
22.02.1960	Germany	Zwickau	Extraction	49	N.A.	N.A.	N.A.
08.03.1960	USA	Logan	Extraction	18	N.A.	N.A.	N.A.
22.05.1960	Czechoslo-vakia	Ostrava	Extraction	54	N.A.	N.A.	N.A.
28.06.1960	UK	Abertillery	Extraction	45	N.A.	N.A.	N.A.
20.08.1960	Japan	Kawasaki	Extraction	67	N.A.	N.A.	N.A.
25.09.1960	Czechoslo-vakia	Prague	Extraction	20	N.A.	N.A.	N.A.
02.03.1961	USA	Indiana	Extraction	22	N.A.	N.A.	N.A.
15.03.1961	Japan	Fukuoka	Extraction	26	N.A.	N.A.	N.A.
08.07.1961	Czechoslo-vakia	Dulna Suce	Extraction	108	N.A.	N.A.	N.A.
?.?.1962	UK	London	Heating	850	N.A.	N.A.	N.A.
?.?.1962	Japan	Osaka	Heating	60	N.A.	N.A.	N.A.
07.02.1962	Germany	Völklingen	Extraction	298	N.A.	N.A.	N.A.
27.02.1962	Yugoslavia	Banovici	Extraction	54	N.A.	N.A.	N.A.
09.03.1962	UK	Hapton Valley	Extraction	16	N.A.	N.A.	N.A.
05.11.1962	Norway	Ny-Aalesund	Extraction	21	N.A.	N.A.	N.A.
06.11.1962	USA	Carmichaels	Extraction	37	N.A.	N.A.	N.A.
09.11.1963	Japan	Miike Colliery,	Extraction	458	N.A.	N.A.	N.A.
04.12.1963	Hungary	Tatabanya	Extraction	26	N.A.	N.A.	N.A.
?.?.1964	Japan	Omuta	Extraction	447	N.A.	N.A.	N.A.

N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 US$$_{1996}$)
09.02.1964	Taiwan	Keelung	Extraction	17	N.A.	N.A.	N.A.
14.06.1964	Afghanistan	Karkar	Extraction	74	N.A.	N.A.	N.A.
02.02.1965	France	Lens	Extraction	21	N.A.	N.A.	N.A.
22.02.1965	Japan	Hokkaido	Extraction	35	N.A.	N.A.	N.A.
24.02.1965	Rumania	N.A.	Extraction	41	N.A.	N.A.	N.A.
19.03.1965	Turkey	Amasya	Extraction	68	N.A.	N.A.	N.A.
17.05.1965	UK	Tonypandy	Extraction	31	N.A.	N.A.	N.A.
28.05.1965	India	Dharbad	Extraction	375	N.A.	N.A.	N.A.
01.06.1965	Japan	Fukuoka	Extraction	236	N.A.	N.A.	N.A.
07.06.1965	Yugoslavia	Kakanj	Extraction	128	N.A.	N.A.	N.A.
?.?.1966	UK	N.A.	Heating	168	N.A.	N.A.	N.A.
21.10.1966	UK	Aberfan	Extraction	144	N.A.	N.A.	N.A.
19.01.1967	New Zealand	Greymouth	Extraction	19	N.A.	N.A.	N.A.
20.11.1968	USA	Mannington	Extraction	78	N.A.	N.A.	N.A.
31.03.1969	Mexico	Barrotean	Extraction	180	N.A.	N.A.	N.A.
07.07.1969	Taiwan	Juifang	Extraction	30	N.A.	N.A.	N.A.
07.07.1969	Taiwan	Taipei	Extraction	24	N.A.	N.A.	N.A.
14.03.1970	Yugoslavia	Breza	Extraction	49	N.A.	N.A.	N.A.
04.04.1970	Czechoslova-kia	Ostrawa	Extraction	26	N.A.	N.A.	N.A.
06.06.1970	Pakistan	Sharig	Extraction	30	N.A.	N.A.	N.A.
07.09.1970	Pakistan	Sorrange	Extraction	24	N.A.	N.A.	N.A.
30.12.1970	USA	Wooton	Extraction	38	N.A.	N.A.	N.A.
17.05.1971	Pakistan	Sinjadi	Extraction	32	N.A.	N.A.	N.A.
16.06.1971	Romania	Hunedoara	Extraction	51	N.A.	N.A.	N.A.
18.07.1971	Japan	Sapporo	Extraction	20	N.A.	N.A.	N.A.
30.10.1971	Romania	Hunedoara	Extraction	45	N.A.	N.A.	N.A.
02.12.1971	Taiwan	Tschi-Tu	Extraction	36	N.A.	N.A.	N.A.
07.12.1971	South Africa	Durban	Extraction	26	N.A.	N.A.	N.A.
06.06.1972	Zimbabwe	Bulwayo	Extraction	434	N.A.	N.A.	N.A.
21.10.1972	Iran	Teheran	Extraction	34	N.A.	N.A.	N.A.
02.11.1972	Japan	Hokkaido	Extraction	31	N.A.	N.A.	N.A.
02.11.1972	Romania	Hunedoara	Extraction	36	N.A.	N.A.	N.A.
02.11.1972[1]	Japan	Naie	Extraction	31	N.A.	N.A.	N.A.
12.12.1972	Iran	Teheran	Extraction	31	N.A.	N.A.	N.A.
19.03.1973	India	Dhanbad	Extraction	50	N.A.	N.A.	N.A.

[1] probably the same accident as two lines above

N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 $US\$_{1996}$)
05.05.1973	Republic of Korea	Changsong	Extraction	18	18	N.A.	N.A.
27.09.1973	Thailand	Unknown	Extraction	50	N.A.	N.A.	N.A.
?.05.1974	Turkey	Erzurum	Extraction	10	N.A.	N.A.	N.A.
28.06.1974	Poland	Kattowitz	Extraction	32	N.A.	N.A.	N.A.
10.10.1974	Yugoslavia	Soko Banja	Extraction	15	N.A.	N.A.	N.A.
03.11.1974	Spain	Figols	Extraction	27	2	N.A.	N.A.
27.12.1974	India	N.A.	Extraction	300	N.A.	N.A.	N.A.
27.12.1974	France	Lievin	Extraction	42	N.A.	N.A.	N.A.
14.04.1975	South Africa	Sasolburg	Extraction	14	N.A.	N.A.	N.A.
20.09.1975	Australia	Rockhamton	Extraction	13	N.A.	N.A.	N.A.
03.11.1975	Spain	Figolis	Extraction	27	N.A.	N.A.	N.A.
27.11.1975	Japan	Mikasa	Extraction	10	7	N.A.	N.A.
28.12.1975	India	Dbanbad, Bihar	Extraction	372	N.A.	N.A.	N.A.
11.03.1976	USA	Whitesburg	Extraction	26	N.A.	N.A.	N.A.
05.08.1976	Yugoslavia	Breza	Extraction	17	N.A.	N.A.	N.A.
07.09.1976	Poland	Walbrzych	Extraction	17	N.A.	N.A.	N.A.
16.09.1976	Mozambique	Tete	Extraction	140	N.A.	N.A.	N.A.
05.10.1976	India	Bihar	Extraction	39	30	N.A.	N.A.
31.12.1976	Czechoslova-kia	Stario, Chlebovice	Extraction	45	N.A.	N.A.	N.A.
01.03.1977	USA	Tower City(Pa.)	Extraction	9	3	N.A.	N.A.
23.03.1977	Czechoslova-kia	Karvina	Extraction	31	N.A.	N.A.	N.A.
11.05.1977	Japan	Hokkaido	Extraction	25	8	N.A.	N.A.
15.07.1977	Colombia	Amaga	Extraction	130	N.A.	N.A.	N.A.
02.08.1977	Mozambique	Moatize	Extraction	159	N.A.	N.A.	N.A.
17.02.1978	Hungary	Tatabanya	Extraction	26	19	N.A.	N.A.
03.04.1978	Yugoslavia	Aleksinac	Extraction	12	26	N.A.	N.A.
27.04.1978	USA	Willow Island (W.Va.)	Extraction	51	N.A.	N.A.	N.A.
10.11.1978	Republic of Korea	Near Changsong	Extraction	10	N.A.	N.A.	N.A.
21.11.1978	UK	Doncaster	Extraction	7	19	N.A.	N.A.
24.02.1979	Canada	Glace Bay	Extraction	12	4	N.A.	N.A.
18.03.1979	UK	N.A.	Extraction	10	1	N.A.	N.A.
14.04.1979	Republic of Korea	Chungsun	Extraction	26	40	N.A.	N.A.

N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 US$$_{1996}$)
16.05.1979	Japan	Oyubari	Extraction	15	14	N.A.	N.A.
05.10.1979	Poland	Walbrzych	Extraction	7	N.A.	N.A.	N.A.
10.10.1979	Poland	Bytom	Extraction	34	N.A.	N.A.	N.A.
28.10.1979	Republic of Korea	Mungyong	Extraction	42	N.A.	N.A.	N.A.
07.11.1979	USA	Madison	Extraction	5	N.A.	N.A.	N.A.
14.10.1980	USA	N.A.	Extraction	0	15	N.A.	N.A.
29.11.1980	Romania	Livezeni	Extraction	49	26	N.A.	N.A.
?.?.1981	USA	Unknown	Extraction	24	N.A.	N.A.	N.A.
17.04.1981	USA	Redstone	Extraction	15	N.A.	N.A.	N.A.
07.05.1981	South Africa	New Castle	Extraction	10	N.A.	N.A.	N.A.
03.09.1981	Czechoslova-kia	Zaluzi	Extraction	65	N.A.	N.A.	N.A.
16.10.1981	Japan	Yubar	Extraction	93	N.A.	N.A.	N.A.
07.12.1981	USA	Topmost	Extraction	8	N.A.	N.A.	N.A.
08.12.1981	USA	Whitwell	Extraction	13	N.A.	N.A.	N.A.
?.?.1982	China	Unknown	Extraction	284	N.A.	N.A.	N.A.
12.05.1982	Yugoslavia	Zenica	Extraction	39	N.A.	N.A.	N.A.
?.06.1982	Poland	Beuthen	Extraction	10	N.A.	N.A.	N.A.
29.11.1982	Poland	Beuthen	Extraction	18	N.A.	N.A.	N.A.
06.02.1983	Philippines	Cebu Island	Extraction	15	9	N.A.	N.A.
12.02.1983	USA	Chincoteague	Transport	33	N.A.	N.A.	N.A.
07.03.1983	Turkey	Zonguldak	Extraction	106	N.A.	N.A.	N.A.
06.06.1983	Yugoslavia	Nis	Extraction	35	N.A.	N.A.	N.A.
22.06.1983	Hungary	Oroszlany	Extraction	36	N.A.	N.A.	N.A.
22.06.1983	USA	Mcclure	Extraction	7	N.A.	N.A.	N.A.
13.07.1983	UK	Barnsley	Conversion Plant	0	N.A.	20.3	30.2
12.09.1983	South Africa	Natal Province	Extraction	63	N.A.	N.A.	N.A.
18.01.1984	Japan	Omuta	Extraction	83	N.A.	N.A.	N.A.
21.04.1984	Yugoslavia	Resavica	Extraction	33	14	N.A.	N.A.
20.06.1984	Taiwan	Near Taipei	Extraction	100	N.A.	N.A.	N.A.
10.07.1984	Taiwan	Northen Taiwan	Extraction	121	N.A.	N.A.	N.A.
10.09.1984	Brazil	Urussaga	Extraction	32	N.A.	N.A.	N.A.
05.12.1984	Taiwan	Taipei	Extraction	93	N.A.	N.A.	N.A.
19.12.1984	USA	Orangeville	Extraction	25	N.A.	85	121.7
25.02.1985	France	Forbach	Extraction	22	103	N.A.	N.A.
24.04.1985	Japan	Nagasaki	Extraction	11	N.A.	N.A.	N.A.
17.05.1985	Japan	Hokkaido	Extraction	36	22	N.A.	N.A.
12.07.1985	China	Guangdong	Extraction	55	N.A.	N.A.	N.A.

N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 US$$_{1996}$)
12.08.1985	South Africa	Secunda	Extraction	29	N.A.	N.A.	N.A.
14.08.1985	China	Guanxi	Extraction	21	N.A.	N.A.	N.A.
22.12.1985	Poland	Waldenburg	Extraction	18	N.A.	N.A.	N.A.
22.03.1986	Romania	Hundeora	Extraction	17	N.A.	N.A.	N.A.
16.07.1986	Australia	Brisbane	Extraction	12	N.A.	N.A.	N.A.
25.07.1986	Poland	Bytom	Extraction	9	N.A.	N.A.	N.A.
24.12.1986	former USSR	Donezk	Extraction	30	N.A.	N.A.	N.A.
04.02.1987	Poland	Myslowice	Extraction	17	22	N.A.	N.A.
09.04.1987	South Africa	Province Transvaal	Extraction	34	16	N.A.	N.A.
25.01.1988	Mexico	Barroteran	Extraction	37	20	N.A.	N.A.
05.04.1988	China	(Northeast)	Extraction	12	N.A.	N.A.	N.A.
06.05.1988	China	Guiyang	Extraction	45	N.A.	N.A.	N.A.
29.05.1988	China	Province Shanxi	Extraction	49	N.A.	N.A.	N.A.
01.06.1988	Germany	near Borken	Extraction	51	8	N.A.	N.A.
18.06.1988	China	Province Shanxi	Extraction	40	N.A.	N.A.	N.A.
05.08.1988	China	Province Gansu	Extraction	44	N.A.	N.A.	N.A.
01.10.1988	China	(Northeast)	Extraction	17	N.A.	N.A.	N.A.
26.11.1988	China	Jixi, Province Heilongjiang	Extraction	45	N.A.	N.A.	N.A.
04.12.1988	Hungary	near Budapest	Extraction	11	28	N.A.	N.A.
18.04.1989	China	Luanping	Extraction	19	N.A.	N.A.	N.A.
01.06.1989	China	Shanxi	Extraction	22	N.A.	N.A.	N.A.
13.09.1989	USA	Near Wheatcroft	Extraction	10	N.A.	N.A.	N.A.
07.11.1989	Yugoslavia	Aleksinac	Extraction	92	N.A.	N.A.	N.A.
10.01.1990	Poland	Ruda Slaska	Extraction	14	14	N.A.	N.A.
07.02.1990	Turkey	near Merzifon	Extraction	68	N.A.	N.A.	N.A.
14.02.1990	Russia	Makeyevka	Extraction	13	N.A.	N.A.	N.A.
07.03.1990	Russia	Tkvarcheli	Extraction	6	N.A.	N.A.	N.A.
15.04.1990	China	Qitaihe	Extraction	33	N.A.	N.A.	N.A.
08.05.1990	China	Heilongjiang	Extraction	24	N.A.	N.A.	N.A.
13.07.1990	China	Xinwen, Shandong	Extraction	45	11	N.A.	N.A.
08.08.1990	China	Hunan	Extraction	56	N.A.	N.A.	N.A.
26.08.1990	Yugoslavia	Dobrnja	Extraction	178	N.A.	N.A.	N.A.
19.10.1990	Czechoslo-vakia	Moravia, Karvina	Extraction	30	N.A.	N.A.	N.A.
18.12.1990	China	Nalaikh	Extraction	21	N.A.	N.A.	N.A.

N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 $US\$_{1996}$)
21.04.1991	China	Hongtong, Shanxi	Extraction	147	N.A.	N.A.	N.A.
30.06.1991	Ukraine	Donbas	Extraction	32	N.A.	N.A.	N.A.
03.03.1992	Turkey	Kozlu	Extraction	272	N.A.	N.A.	N.A.
17.04.1992	China	Province Heilongjiang	Extraction	28	N.A.	N.A.	N.A.
09.05.1992	Canada	Plymouth	Extraction	26	N.A.	N.A.	N.A.
09.06.1992	Ukraine	Krasnodon	Extraction	57	21	N.A.	N.A.
21.08.1992	Ukraine	Donezk	Extraction	17	N.A.	N.A.	N.A.
11.09.1992	China	Province Jianxi	Extraction	45	N.A.	N.A.	N.A.
11.09.1992	Russia	Siberia	Extraction	25	N.A.	N.A.	N.A.
25.11.1992	Russia	Savropol	Extraction	13	N.A.	N.A.	N.A.
01.12.1992	China	Province Heilongjang	Extraction	20	N.A.	N.A.	N.A.
20.1.1993	China	Anhui	Extraction	35	N.A.	N.A.	N.A.
01.03.1993	China	Jiaole	Extraction	42	N.A.	N.A.	N.A.
10.03.1993	China	Beilungang	Power Generation	20	25	N.A.	N.A.
29.03.1993	Ecuador	Cuenca	Extraction	200	N.A.	N.A.	N.A.
02.04.1993	China	Shenyang	Extraction	23	4	N.A.	N.A.
08.05.1993	China	Pingdingshan	Extraction	39	11	N.A.	N.A.
13.05.1993	South Africa	Secunda	Extraction	53	N.A.	N.A.	N.A.
11.08.1993	Germany	Gelsenkirchen - Scholven	Power Generation	0	0	37	39.2
11.08.1993	USA	Newark (AR)	Power Generation	0	0	35	37.1
01.09.1993	Philippines	T’boli	Extraction	21	N.A.	N.A.	N.A.
28.9.1993	China	Hebei	Extraction	N.A.	500	N.A.	N.A.
18.10.1993	China	Xuzhou	Extraction	40	4	N.A.	N.A.
11.12.1993	China	Weining	Extraction	25	N.A.	N.A.	N.A.
12.12.1993	China	Hebei	Extraction	6	585	N.A.	14
24.01.1994	China	Heilongjiang Province	Extraction	79	N.A.	N.A.	N.A.
25.01.1994	India	West Bengal	Extraction	55	N.A.	N.A.	N.A.
06.03.1994	China	Jilin	Extraction	12	N.A.	N.A.	N.A.
15.05.1994	China	Jiangxi	Extraction	38	N.A.	N.A.	N.A.
30.07.1994	China	Guizhou	Extraction	31	N.A.	N.A.	N.A.
07.08.1994	Australia	Queensland	Extraction	11	N.A.	N.A.	N.A.
29.08.1994	Philippines	Mindanao Island	Extraction	90	N.A.	N.A.	N.A.
05.09.1994	Ukraine	Sloyanosersk	Extraction	24	15	N.A.	N.A.

N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 US$$_{1996}$)
18.09.1994	India	Jamshedpur	Extraction	19	50	N.A.	N.A.
30.09.1994	Chile	Conception	Extraction	20	1	N.A.	N.A.
25.10.1994	Germany	Lünen	Power Generation	0	0	148	152.4
26.02.1995	Pakistan	near Quetta	Extraction	27	N.A.	N.A.	N.A.
27.02.1995[1]	Pakistan	Quetta	Extraction	36	N.A.	N.A.	N.A.
13.03.1995	China	Yunnan	Extraction	32	12	N.A.	N.A.
16.03.1995	China	Anhui	Extraction	21	N.A.	N.A.	N.A.
26.03.1995	Turkey	Sorgun	Extraction	40	11	N.A.	N.A.
30.03.1995	Russia	Vorkuta	Extraction	15	N.A.	N.A.	N.A.
29.04.1995	China	Xinjiang	Extraction	22	1	N.A.	N.A.
26.06.1995	Russia	Kuznetsk	Extraction	7	N.A.	N.A.	N.A.
29.06.1995	China	Guiyang	Extraction	21	N.A.	N.A.	N.A.
31.08.1995	Spain	Mieres	Extraction	14	N.A.	N.A.	N.A.
04.09.1995	Russia	Kemerovo	Extraction	15	N.A.	N.A.	N.A.
04.09.1995	Philippines	Manila	Extraction	20	N.A.	N.A.	N.A.
15.09.1995	Poland	Warsaw	Extraction	5	N.A.	N.A.	N.A.
27.09.1995	India	near Dhanbad	Extraction	70	N.A.	N.A.	N.A.
10.06.1995	Syria	El Isba oil field	Extraction	5	N.A.	N.A.	N.A.
18.06.1995	Netherlands	N.A.	Heating	16	2	N.A.	N.A.
21.11.1995	Philippines	Zamboanga	Extraction	12	N.A.	N.A.	N.A.
26.11.1995	Kazakhstan	Karaganda	Extraction	10	N.A.	N.A.	N.A.
23.12.1995	Colombia	La Biutrera	Extraction	7	N.A.	N.A.	N.A.
11.03.1996	Ukraine	Donetsk	Extraction	6	N.A.	N.A.	N.A.
09.04.1996	China	Hebei Province	Extraction	14	N.A.	N.A.	N.A.
10.05.1996	Mexico	Otaes	Extraction	16	3	N.A.	N.A.
21.05.1996	China	Hanan Province	Extraction	84	N.A.	N.A.	N.A.
13.08.1996	Pakistan	Baluchistan	Extraction	10	N.A.	N.A.	N.A.
29.08.1996	Russia	Spitsbergen	Extraction	141	N.A.	N.A.	N.A.
03.09.1996	Pakistan	Karachi	Power Generation	3	N.A.	100	100
13.09.1996	Philippines	Cebu	Extraction	3	11	N.A.	N.A.
02.11.1996	China	Pingdingshan	Extraction	32	6	N.A.	N.A.
15.11.1996	Russia	Magadan	Extraction	6	N.A.	N.A.	N.A.
26.11.1996	Russia	Baturinsk-kaya	Extraction	9	6	N.A.	N.A.
27.11.1996	China	Shanxi Province	Extraction	96	N.A.	N.A.	N.A.

[1] probably the same accident as one line above
N.A.: Not available

Table A.1

Severe coal accidents with at least 5 fatalities or 10 injured or 5 million 1996 US$ (Cont.).

Date	Country	Place	Energy chain stage	Max. No. fatalities	Max. No. injured	Max. Damage (10^6 US$)	Max. Damage (10^6 US$$_{1996}$)
01.12.1996	Turkey	Ovacik	Extraction	5	N.A.	N.A.	N.A.
03.12.1996	China	Gujiavao	Extraction	91	N.A.	N.A.	N.A.
21.12.1996	Poland	Warsaw	Extraction	7	6	N.A.	N.A.
28.12.1996	China	Yangchun	Extraction	9	N.A.	N.A.	N.A.

N.A.: Not available

Appendix B: List of severe accidents within the oil chain in the period 1969-1996

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
13.01.1969	USA	Lima (Ohio)	Transport to Refinery	0	0	7000	N.A.	N.A.
28.01.1969	USA	Santa Barbara (offshore California)	Extraction	0	0	0	560.0	1947.0
15.02.1969	Australia	Brisane	Regional Distribution	0	14	0	N.A.	N.A.
06.03.1969	Venezuela	Puerto La Cruz	Refinery	5	15	0	N.A.	N.A.
27.03.1969	USA	Long Beach	Regional Distribution	1	83	0	N.A.	N.A.
06.04.1969	USA	New Orleans (LA)	Transport to Refinery	25	0	0	N.A.	N.A.
25.04.1969	Germany	Godorf	N.A.	1	60	0	N.A.	N.A.
12.05.1969	USA	Flint (MI)	Regional Distribution	6	0	0	N.A.	N.A.
24.07.1969	France	Porquerolles	Transport to Refinery	20	0	0	11.6	47.1
18.11.1969	Mexico	Tampico	Refinery	8	42	0	N.A.	N.A.
20.11.1969	Netherlands	Amsterdam	Regional Distribution	0	1	0	4.9	17.1
15.12.1969	Qatar	off the coast of Dakar	Transport to Refinery	0	0	0	15	60.8
28.12.1969	UK	Fawley	N.A.	0	0	0	3.5	12.2
?.?.1970	Japan	Osaka	Refinery	5	0	0	N.A.	N.A.
24.01.1970	Indonesia	Semarang	Regional Distribution	50	41	0	N.A.	N.A.
01.03.1970	Colombia	Pasto, Aguacatal	Transport to Refinery	16	0	0	N.A.	N.A.
17.03.1970	Pakistan	Darya Khan	Regional Distribution	28	0	0	N.A.	N.A.
14.04.1970	UK	Cadishead	Regional Distribution	6	0	0	N.A.	N.A.
11.05.1970	USA	Philadelphia	N.A.	5	27	0	N.A.	N.A.
19.05.1970	Kenya	Nakuru	Regional Distribution	20	0	0	N.A.	N.A.
17.09.1970	USA	Beaumont	Refinery	0	0	0	6.5	24.9

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
23.10.1970	UK	Hull	Transport to Refinery	14	0	0	N.A.	N.A.
28.11.1970	Japan	N.A.	Transport to Refinery	25	0	0	N.A.	N.A.
05.12.1970	USA	Linden (New Jersey)	N.A.	0	44	0	69	266.6
16.12.1970	Italy	Milazzo	Refinery	0	16	0	N.A.	N.A.
06.01.1971	USA	Big John	Exploration	6	0	0	N.A.	N.A.
11.01.1971	UK	English Channel	Transport to Refinery	29	0	0	5	18.8
22.01.1971	Italy	Cagliari	Transport to Refinery	16	0	0	N.A.	N.A.
03.02.1971	USA	Lambertville	Transport to Refinery	8	0	0	N.A.	N.A.
18.02.1971	N.A.	Atlantic	Transport to Refinery	7	0	0	12.6	46.3
27.03.1971	USA	(North Carolina.)	Transport to Refinery	31	0	0	24	87.8
29.03.1971	N.A.	N.A.	Transport to Refinery	23	0	0	N.A.	N.A.
26.05.1971	USA	Times Beach	N.A.	0	10	100	N.A.	N.A.
10.06.1971	Thailand	Kantang	Transport to Refinery	5	0	1000	0.2	0.74
26.06.1971	Poland	Czechowice	Regional Distribution	33	56	0	N.A.	N.A.
10.07.1971	Netherlands	Amsterdam	Refinery	9	21	0	13.5	49.5
19.07.1971	Germany	Raunheim	Regional Distribution	7	0	0	N.A.	N.A.
04.08.1971	Italy	Augusta	N.A.	0	0	0	11.9	43.8
13.10.1971	N.A.	Western offshore 2	Exploration	16	0	0	N.A.	N.A.
19.10.1971	USA	Houston (Texas)	Regional Distribution	1	50	0	N.A.	N.A.
30.11.1971	Virgin Islands	Christiansted	Refinery	0	18	0	N.A.	N.A.
11.02.1972	Brazil	Macapa	Regional Distribution	5	10	0	N.A.	N.A.
09.03.1972	USA	Lynchburg (VA)	Regional Distribution	6	9	0	100	355.5

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$_{1996}$)
07.04.1972	Republic of Korea	Yosu	Regional Distribution	5	0	0	0.12	0.42
11.05.1972	Uruguay	N.A.	Transport to Refinery	84	0	0	N.A.	N.A.
28.06.1972	India	Bombay	Transport to Refinery	29	30	0	N.A.	N.A.
04.08.1972	Mexico	Pachuca	Regional Distribution	1	20	0	N.A.	N.A.
04.08.1972	Italy	Trieste	Transport to Refinery	0	17	0	10.6	37.4
21.08.1972	South Africa	N.A.	Transport to Refinery	47	0	0	N.A.	N.A.
26.08.1972	Iran	Mahshahr	Regional Distribution	5	5	0	N.A.	N.A.
26.08.1972	France	Donges	Transport to Refinery	6	32	0	N.A.	N.A.
25.10.1972	USA	Carteret (New Jersey)	Regional Distribution	0	0	0	5	17.8
24.11.1972	Bahrain	Bahrain	N.A.	0	60	1000	N.A.	N.A.
19.12.1972	N.A.	Gulf of Oman	Transport to Refinery	0	0	0	12	42.8
06.01.1973	USA	Bayone	N.A.	0	0	0	4.3	14.4
13.01.1973	Uganda	Kampala	Regional Distribution	10	70	0	N.A.	N.A.
14.05.1973	Canada	Toronto	N.A.	1	15	100	N.A.	N.A.
23.05.1973	Finland	Helsinki	N.A.	0	0	0	1.5	5.0
02.06.1973	USA	New York	Transport to Refinery	16	0	0	5	16.7
05.08.1973	Saudi Arabia	Abqaiq	Transport to Refinery	13	14	0	N.A.	N.A.
05.10.1973	UK	Langley, (Bucking-hamshire)	Regional Distribution	0	0	500	N.A.	N.A.
12.10.1973	Peru	near Requena	N.A.	11	4	0	N.A.	N.A.
24.10.1973	UK	Sheffield	N.A.	6	29	0	N.A.	N.A.
05.11.1973	Spain	Canary Island	Transport to Refinery	0	0	0	22.7	75.9
06.11.1973	UK	Falkirk	Regional Distribution	0	0	0	2.3	7.7
10.01.1974	Pakistan	Karachi	Regional Distribution	24	40	0	N.A.	N.A.
18.01.1974	USA	N.A.	N.A.	6	0	0	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
18.01.1974	USA	Mississippi (near Pilottown, LA)	Transport to Refinery	16	8	0	N.A.	N.A.
22.02.1974	N.A.	Pacific	N.A.	0	0	0	23.1	69.5
07.04.1974	USA	Fort Miffin	Transport to Refinery	13	8	0	2	7.1
10.04.1974	USA	Philadelphia	Transport to Refinery	0	0	0	8.1	24.4
11.04.1974	USA	Port Neches	N.A.	0	0	0	9	27.1
25.04.1974	Romania	Pitesti	Refinery	0	0	0	10.1	30.3
15.06.1974	USA	Main Pass, 69/A	Extraction	7	0	0	N.A.	N.A.
24.09.1974	USA	N.A.	Regional Distribution	7	6	0	N.A.	N.A.
09.10.1974	N.A.	Platform: Gemini	Exploration	18	0	0	N.A.	N.A.
13.10.1974	Indonesia	Sumatra	Transport to Refinery	15	4	0	N.A.	N.A.
22.10.1974	Kuwait	Raudhatan	Transport to Refinery	9	1	0	N.A.	N.A.
09.11.1974	Japan	Tonkya Bay	Transport to Refinery	33	0	0	N.A.	N.A.
01.12.1974	USA	Abilene	Transport to Refinery	6	1	0	N.A.	N.A.
?.12.1974	Japan	N.A.	N.A.	0	0	0	170	511.8
29.01.1975	Portugal	Leixoes	Transport to Refinery	6	4	0	N.A.	N.A.
30.01.1975	Ecuador	Lago Agrio (near Quito)	N.A.	30	0		N.A.	N.A.
31.01.1975	USA	Markus Hook	Transport to Refinery	26	11	0	7.8	23.5
12.03.1975	Algeria	Algerian Coast	Transport to Refinery	35	0	0	N.A.	N.A.
16.03.1975	USA	Avon	N.A.	0	0	0	18.8	51.8
02.08.1975	USA	Romulus	Regional Distribution	9	0	0	N.A.	N.A.
15.08.1975	USA	Gulf of Mexico (near West Cameron)	Extraction	6	10	0	10	27.7

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
17.08.1975	USA	Philadelphia	Refinery	8	16	0	13	35.8
14.10.1975	USA	Avon	N.A.	0	0	0	6.31	17.4
07.11.1975	Netherlands	Beek	N.A.	14	109	0	N.A.	N.A.
01.12.1975	Norway	Mongstadt	Refinery	0	0	0	13.4	37.1
10.12.1975	Belgium	Antwerpen	Refinery	6	0	0	50	137.8
30.12.1975	Philippines	off The East Coast of Mindanao	Transport to Refinery	30	0	0	N.A.	N.A.
?.?.1976	France	Brest	Transport to Refinery	13	0	0	83	217.3
02.01.1976	India	N.A.	Exploration	5	0	0	N.A.	N.A.
24.01.1976	N.A.	Atlantic	Transport to Refinery	0	0	0	50	130.9
01.03.1976	Norway	(Deep Sea Driller)	Exploration	6	0	0	18	47.1
05.04.1976	France	Donges, near Nazaire	Refinery	5	2	0	N.A.	N.A.
08.04.1976	Japan	Mizushima	Refinery	0	7	0	11.5	30.1
15.04.1976	Iraq	Rumaila	Extraction	0	0	0	12	31.5
16.04.1976	N.A.	Ocean Express	Extraction	13	0	0	N.A.	N.A.
23.04.1976	N.A.	Gulf of Mexico	N.A.	12	0	0	N.A.	N.A.
12.05.1976	Spain	La Coruña	Transport to Refinery	1	0	0	18.7	49.0
23.05.1976	Republic of Korea	near Seoul	Regional Distribution	19	95	0	N.A.	N.A.
16.06.1976	USA	Los Angeles	Regional Distribution	9	26	0	N.A.	N.A.
18.07.1976	USA	Big Springs	Heating	0	0	0	25	65.5
28.07.1976	India	Indian Ocean (offshore Bombay)	Transport to Refinery	0	0	0	5	13.1
30.07.1976	Malta	Mediter-ranean	Transport to Refinery	0	0	0	6	15.7
12.08.1976	USA	Chalmette	Refinery	13	10	0	N.A.	N.A.
15.10.1976	English Channel	N.A.	N.A.	32	0	0	N.A.	N.A.
17.10.1976	France	N.A.	Transport to Refinery	0	0	0	31.0	79.5
20.10.1976	USA	near Luling (Louisiana)	N.A.	102	18	0	N.A.	N.A.
26.11.1976	USA	Belt	Regional Distribution	2	22	200	4.5	11.8

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
17.12.1976	USA	San Pedro	Transport to Refinery	9	58	1000	21.6	56.6
?.?.1977	USA	North Atlantic	Transport to Refinery	38	0	0	N.A.	N.A.
12.01.1977	Taiwan	Coast	Exploration	0	0	0	21	51.5
17.03.1977	USA	Port Arthur	Regional Distribution	8	26	0	1.5	3.7
20.03.1977	USA	near Wilmington	Transport to Refinery	10	0	0	N.A.	N.A.
15.04.1977	Papa New Guinea	Coast	Transport to Refinery	0	0	0	11	26.9
11.05.1977	Saudi Arabia	Abqaiq	Transport to Refinery	1	26	0	100	244.9
04.06.1977	Saudi Arabia	Abqaiq	Transport to Refinery	0	0	0	11	26.9
18.06.1977	Mexico	Atzcapot-zalto	Refinery	0	10	0	1.5	3.7
01.07.1977	USA	N.A.	Transport to Refinery	0	0	0	13.5	33.3
08.07.1977	USA	Fairbanks (Alaska)	Transport to Refinery	0	0	0	35	85.8
29.07.1977	Spain	Ciudad Real	Regional Distribution	0	60	0	N.A.	N.A.
01.09.1977	Russia	Gorgi	Transport to Refinery	28	0	0	N.A.	N.A.
15.09.1977	USA	N.A.	Regional Distribution	7	0	0	N.A.	N.A.
24.09.1977	USA	Beattyville	Regional Distribution	7	1	0	N.A.	N.A.
24.09.1977	USA	Romeoville	Refinery	0	0	0	8.4	20.6
30.10.1977	Iran	Abadan, Teheran	Refinery	6	20	0	N.A.	N.A.
02.11.1977	Russia	N.A.	Regional Distribution	6	0	0	N.A.	N.A.
13.11.1977	Mexico	Ciudad Juares	Regional Distribution	37	0	0	N.A.	N.A.
08.12.1977	USA	South Marsh, 128	Extraction	17	2	0	N.A.	N.A.
14.02.1978	USA	Chicago	Transport to Refinery	8	29	0	N.A.	N.A.
14.02.1978	France	N.A.	Heating	9	0	0	N.A.	N.A.
23.02.1978	Colombia	Caribic	Transport to Refinery	5	0	0	14	31.9
25.02.1978	Norway	Statfjord	Extraction	5	0	0	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
15.03.1978	France	Amoco Cadiz	Transport to Refinery	0	0	0	75	171.0
21.03.1978	Indonesia	offshore Sumatra	Transport to Refinery	0	0	0	9	20.6
30.03.1978	Iran	Near Teheran	Regional Distribution	26	18	0	N.A.	N.A.
16.04.1978	Saudi Arabia	Abqaiq	Extraction	0	0	0	54	123.1
23.05.1978	Poland	Gdansk	Transport to Refinery	0	0	0	7.5	17.1
12.06.1978	Japan	Sendai	Regional Distribution	21	350	0	N.A.	N.A.
20.06.1978	USA	N.A.	Regional Distribution	0	106	0	N.A.	N.A.
06.09.1978	Japan	Kurushima	Transport to Refinery	0	0	0	10.2	23.3
18.09.1978	USA	Florence (Alabama)	Regional Distribution	0	0	1000	0.46	1.1
24.09.1978	USA	Beattyville	Regional Distribution	7	6	N.A.	N.A.	N.A.
27.09.1978	Spain	Oviedo	Regional Distribution	7	0	0	N.A.	N.A.
02.10.1978	Canada	Mississauga (Ontario)	Refinery	0	0	1000	N.A.	N.A.
03.10.1978	USA	Denver, CO	Refinery	4	12	0	22	50.1
12.10.1978	Singapore	N.A.	Transport to Refinery	64	86	0	N.A.	N.A.
09.11.1978	Philippines	Manila	Transport to Refinery	31	0	0	N.A.	N.A.
22.11.1978	Nigeria	Benue	Regional Distribution	100	0	0	N.A.	N.A.
03.12.1978	USA	Houston, Texas	Transport to Refinery	9	0	0	N.A.	N.A.
11.12.1978	Mexico	N.A.	Regional Distribution	2	120	0	N.A.	N.A.
21.12.1978	Mexico	Tula	Refinery	0	15	0	N.A.	N.A.
31.12.1978	Spain	North Coast of Spain	Regional Distribution	31	0		N.A.	N.A.
?.?.1979	Caribbean Sea	N.A.	N.A.	30	N.A.	N.A.	N.A.	N.A.
?.?.1979	Canada	N.A.	Transport to Refinery	0	0	0	30	58.3
08.01.1979	Ireland	Bantry Bay	Transport to Refinery	50	0	0	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
10.01.1979	Colombia	San Rafael de Lebrij	Transport to Refinery	14	53	0	N.A.	N.A.
01.02.1979	Germany	Risa	Extraction	14	53	0	N.A.	N.A.
12.02.1979	USA	Whiting, Indiana	Refinery	0	0	1500	N.A.	N.A.
02.03.1979	USA	Kansas City	N.A.	0	13	0	N.A.	N.A.
05.03.1979	USA	South Marsh, 281/C	Exploration	8	4	0	N.A.	N.A.
14.03.1979	Greece	Saloniki	Regional Distribution	30	22	0	N.A.	N.A.
23.03.1979	Mozam-bique	Beira, Sofala	Regional Distribution	19	0	0	3	6.1
02.04.1979	Thailand	Sara Buri Province	Regional Distribution	20	1	500	N.A.	N.A.
10.04.1979	USA	Columbus, Kansas	Regional Distribution	0	0	500	N.A.	N.A.
19.04.1979	USA	Port Neches	Transport to Refinery	2	30	0	N.A.	N.A.
21.04.1979	USA	Gulf of Mexico	Extraction	0	0	0	26	53.2
28.04.1979	France	Breton Coast	Transport to Refinery	0	0	0	12	24.6
11.05.1979	N.A.	Ranger 1	Extraction	8	0	0	N.A.	N.A.
03.06.1979	Thailand	Phangnga	Regional Distribution	52	15	0	N.A.	N.A.
03.06.1979	Mexico	Campeche, Gulf of Mexico	Extraction	0	0	0	152	310.9
14.06.1979	USA	Abilene	Refinery	0	14	0	N.A.	N.A.
16.06.1979	USA	Ann Arbour	Regional Distribution	0	0	200	N.A.	N.A.
26.06.1979	Italy	Civitavec-chia	Regional Distribution	5	0	0	N.A.	N.A.
26.06.1979	N.A.	N.A.	Transport to Refinery	23	0	0	N.A.	N.A.
03.07.1979	UK	Edinburgh, Lothian	Regional Distribution	0	0	200	N.A.	N.A.
08.07.1979	Ireland	Eire, Whiddy Island	Transport to Refinery	50	0	0	12.9	26.3
12.07.1979	Australia	Sydney	N.A.	0	0	0	3.5	7.2
20.07.1979	Trinidad	Tobago	Transport to Refinery	29	0	0	100	204.6

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
07.08.1979	Italy	Vercelli	Transport to Refinery	5	1	0	N.A.	N.A.
02.09.1979	USA	Deer Park	Regional Distribution	3	13	0	68	139.1
?.10.1979	Greece	Suda Bay	Regional Distribution	7	140	0	N.A.	N.A.
?.10.1979	Germany	Duisburg	N.A.	0	0	0	2.6	5.3
1.11.1979	USA	Burmah Agate (offshore Galveston)	Transport to Refinery	32	0	0	13	26.6
15.11.1979	Turkey	Istanbul	Transport to Refinery	75	3	0	40	81.8
25.11.1979	China	Bohai Ii	Exploration	72	0	0	N.A.	N.A.
15.12.1979	USA	Taylor	N.A.	0	0	8000	N.A.	N.A.
25.12.1979	USA	N.A.	Transport to Refinery	30	0	0	N.A.	N.A.
?.?.1980	Italy	Rome	Transport to Refinery	25	26	0	N.A.	N.A.
?.?.1980	USA	Alaska (Platform)	Extraction	51	0	0	N.A.	N.A.
17.01.1980	Atlantic	(Funiwa-5 oil well)	Extraction	180	3000	0	N.A.	N.A.
20.01.1980	USA	Borger	Refinery	0	40	0	N.A.	N.A.
27.01.1980	USA	St. Petersburg (Tampa Bay)	Transport to Refinery	26	0	0	N.A.	N.A.
28.1.1980[1]	USA	off the coast of Florida	Transport to Refinery	23	0	0	N.A.	N.A.
30.01.1980	Puerto Rico	Bayaman	Regional Distribution	0	0	1000	N.A.	N.A.
21.02.1980	USA	South Timbal, 171/B	Exploration	6	0	0	N.A.	N.A.
23.02.1980	Greece	Pylos	Transport to Refinery	2	0	0	6	10.8
03.03.1980	USA	Los Angeles	Regional Distribution	5	2	0	N.A.	N.A.
07.03.1980	France	Tanio (offshore Brittany)	Regional Distribution	8	0	0	30.0	54.0
11.03.1980	Mauritania	N.A.	Transport to Refinery	36	0	0	20	36.0
24.03.1980	USA	High Island	Exploration	6	0	0	N.A.	N.A.

[1]probably the same accident as one line above
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
27.03.1980	Norway	Alexander, L, Kielland	Extraction	123	0	0	66.2	119.5
01.04.1980	Japan	Tokuyama	Refinery	0	0	0	19.2	34.6
03.04.1980	Tanzania	Indian Ocean	Transport to Refinery	6	0	0	27	48.7
16.04.1980	USA	Roseville	N.A.	0	0	0	3	5.4
29.05.1980	Canada	Swift Current, (Saskatche-wan)	Regional Distribution	23	11	0	N.A.	N.A.
05.06.1980	Malaysia	Port Kelang	N.A.	3	200	3000	N.A.	N.A.
10.06.1980	Canada	London (Ontario)	Regional Distribution	0	0	300	N.A.	N.A.
15.06.1980	China	Gulf Von Po-Hai	Exploration	70	0	0	N.A.	N.A.
23.07.1980	Mexico	Salina Cruz	Refinery	0	0	0	10	18.0
30.08.1980	N.A.	Ocean King	Extraction	5	0	0	N.A.	N.A.
02.10.1980	Saudi Arabia	Ron Tappmayer	Exploration	19	0	0	N.A.	N.A.
05.10.1980	Netherlands	N.A.	Transport to Refinery	7	0	0	N.A.	N.A.
22.10.1980	USA	Pacific, South Alaska	Extraction	0	0	0	36	64.9
25.11.1980	USA	Kenner, Louisiana	Regional Distribution	7	6	300	N.A.	N.A.
01.12.1980	Canada	Moose Jaw	N.A.	0	0	0	8.5	15.3
11.12.1980	Egypt	Port Said	Extraction	0	0	0	25	45.1
20.12.1980	USA	Fort McMurray	N.A.	0	0	0	9	16.2
31.12.1980	USA	Corpus Christi	N.A.	0	0	0	17	30.6
19.01.1981	USA	New York	Regional Distribution	0	0	0	280	457.1
30.03.1981	Japan	Kashima	Refinery	8	3	0	14.35	23.4
13.04.1981	USA	Rocky Mountains	N.A.	0	0	300	N.A.	N.A.
16.04.1981	Republic of Korea	Chonan	Regional Distribution	0	0	1000	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 $US\$_{1996}$)
10.05.1981	Burma	N.A.	Regional Distribution	5	0	0	N.A.	N.A.
20.05.1981	Arab Emirates	Gulf of Oman	Transport to Refinery	0	0	0	11	18.0
28.05.1981	Angola	Atlantic	Extraction	0	0	0	22	36.0
22.06.1981	USA	Rocklin, California	Regional Distribution	10	0	0	N.A.	N.A.
12.07.1981	Italy	Genoa	Transport to Refinery	7	10	0	N.A.	N.A.
20.08.1981	Kuwait	Shuaiba	Refinery	0	0	0	175	286.2
27.08.1981	Indonesia	N.A.	Exploration	0	0	0	26	42.4
15.09.1981	USA	Huntsville, Alabama	Regional Distribution	7	3	0	N.A.	N.A.
17.09.1981	USA	Good Hope	N.A.	0	12	0	N.A.	N.A.
13.10.1981	Japan	Yakohama	Regional Distribution	0	0	2800	N.A.	N.A.
17.10.1981	Nigeria	Warri	Refinery	0	0	0	4.0 million Naira[1]	N.A.
02.11.1981	N.A.	N.A.	Transport to Refinery	12	0	0	N.A.	N.A.
03.11.1981	N.A.	Juckup off Brazil	Extraction	5	0	0	N.A.	N.A.
14.11.1981	USA	Canon City, CO	Regional Distribution	8	4	0	350	571.3
06.12.1981	UK	Immingham	Refinery	0	0	0	52	84.9
21.12.1981	USA	Danville	N.A.	0	16	0	N.A.	N.A.
?.?.1982	Mexico	N.A.	N.A.	15	17	0	N.A.	N.A.
20.01.1982	Mexico	La Venta	Regional Distribution	5	25	0	N.A.	N.A.
20.01.1982	Canada	Fort McMurray	N.A.	0	0	0	21	32.3
13.02.1982	Atlantic Ocean	N.A.	N.A.	16	0	0	N.A.	N.A.
15.02.1982	Canada	offshore Newfound-land, "Ocean Ranger"	Extraction	84	0	0	86	132.2
07.03.1982	Burma	Atlantic	Transport to Refinery	9	0	0	29	44.6

[1]The rate of exchange in US$ cannot be given
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$_{1996}$)
07.03.1982	USA	Oakland (C.A.)	Regional Distribution	7	2	N.A.	N.A.	N.A.
18.03.1982	Japan	Sabeso (Nagasaki)	Transport to Refinery	10	2	0	N.A.	N.A.
31.03.1982	USA	Mississippi	N.A.	0	0	0	14	21.5
07.04.1982	USA	Oakland	Regional Distribution	7	2	0	N.A.	N.A.
10.04.1982	USA	N.A.	Power Plant	0	0	0	19.7	30.3
08.05.1982	USA	Kilgore	N.A.	0	0	700	N.A.	N.A.
20.05.1982	USA	Cotton Valley (LA)	Regional Distribution	0	3	2000	4	6.1
10.06.1982	UK	Falkland	Transport to Refinery	0	0	0	20	30.8
25.06.1982	Mozam-bique	offshore Mozambique	Transport to Refinery	0	0	0	82 million Rupee[1]	N.A.
01.07.1982	UK	North Sea	N.A.	0	0	0	18.0	27.7
08.07.1982	N.A.	C202	Exploration	5	0	0	N.A.	N.A.
14.07.1982	USA	Rig: “West Cameron”	Extraction	0	0	0	8	12.3
01.08.1982	India	Rig: “Sagar Vikas”	Extraction	0	0	0	14	21.5
09.08.1982	N.A.	South China Sea	Transport to Refinery	0	0	0	16.7	25.8
10.09.1982	UK	Corringham	Refinery	0	12	0	N.A.	N.A.
11.09.1982	Japan	Kure	Transport to Refinery	6	8	0	N.A.	N.A.
04.10.1982	USA	Freeport	N.A.	0	0	0	14.7	22.6
14.10.1982	N.A.	Black Sea	Transport to Refinery	0	0	0	39.7	61.0
01.11.1982	Afghanistan	Salang Pass	Regional Distribution	2700	400	0	N.A.	N.A.
02.11.1982	Nigeria	Warri	Refinery	0	0	0	10 million Naira[1]	N.A.
17.11.1982	off the coast of Taiwan	N.A.	N.A.	15	0	0	N.A.	N.A.
13.12.1982	Colombia	Bogota	Regional Distribution	1	15	1000	5	7.7
19.12.1982	Venezuela	Tacoa	Power Plant	160	1000	40,000	40	61.5
07.01.1983	USA	New York	Regional Distribution	1	24	0	N.A.	N.A.
20.01.1983	Bermuda	N.A.	Transport to Refinery	0	0	0	33	49.2
29.01.1983	N.A.	Eniwetoc	Exploration	7	0	0	N.A.	N.A.

[1]The rate of exchange in US$ cannot be given
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Cost (10^6 $US\$_{1996}$)
12.02.1983	USA	off the coast of Chincoteague	N.A.	33	0	0	N.A.	N.A.
26.02.1983	N.A.	Gulf of Mexico	Transport to Refinery	5	0	0	N.A.	N.A.
01.03.1983	India	N.A.	Regional Distribution	20	40	0	N.A.	N.A.
20.03.1983	Zaire	Mibale, M Well Prot	Regional Distribution	13	0	0	N.A.	N.A.
06.04.1983	Thailand	Srichang Island	Transport to Refinery	21	0	0	N.A.	N.A.
10.04.1983	Syria	N.A.	Transport to Refinery	6	0	0	N.A.	N.A.
22.05.1983	Italy	between Genoa and Savona	Regional Distribution	8	22	0	N.A.	N.A.
02.07.1983	Canada	Fort McMuay	Refinery	0	0	0	15	22.5
16.07.1983	Papa New Guinea	Moresby	Transport to Refinery	0	0	0	14	20.9
06.08.1983	South Africa	Castillo de Bellver	Transport to Refinery	0	0	0	72	107.6
30.08.1983	UK	Milford Haven	Transport to Refinery	0	0	0	15	22.5
31.08.1983	USA	Chalmette (Louisiana)	Regional Distribution	0	0	3000	N.A.	N.A.
31.08.1983	Brazil	Pojuca	Regional Distribution	44	400	1000	N.A.	N.A.
01.09.1983	Australia	W. Coast	Exploration	0	0	0	50	74.7
09.09.1983	N.A.	Caspian Sea	Exploration	5	0	0	N.A.	N.A.
29.09.1983	Indonesia	Dhulwari	Regional Distribution	41	0	0	N.A.	N.A.
10.10.1983	Nicaragua	Corinto	Regional Distribution	0	17	25,000	25	37.4
16.10.1983	N.A.	South China Sea	Exploration	81	0	0	30	44.8
03.11.1983	India	Dhurabari	Regional Distribution	76	100	0	N.A.	N.A.
05.11.1983	USA	Byford Dolphin	Extraction	5	0	0	N.A.	N.A.
26.11.1983	Philippines	Luzon	Regional Distribution	7	0	0	N.A.	N.A.
05.12.1983	USA	Highlands	N.A.	0	0	2000	20	29.9
06.12.1983	Romania	Teleajen	Refinery	30	0	0	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Cost (10^6 $US\$_{1996}$)
?.?.1984	UK	Billingham	N.A.	0	11	0	N.A.	N.A.
?.?.1984	India	Bombay	Transport to Refinery	9	0	0	1	1.5
09.01.1984	Syria	Banias	N.A.	0	0	0	79.6	114.0
24.02.1984	Brazil	Duque de Caxias	Regional Distribution	3	19	0	N.A.	N.A.
25.02.1984	Brazil	Cubatao	Regional Distribution	508	150	2500	N.A.	N.A.
26.02.1984	N.A.	N.A.	Transport to Refinery	5	9	0	N.A.	N.A.
08.03.1984	India	Cochin,	Regional Distribution	4	0	0	9.53	14.1
25.03.1984	USA	Missouri City (Texas)	Regional Distribution	0	0	240	N.A.	N.A.
29.03.1984	UK	Beeston	N.A.	0	0	200	1.0	1.4
25.04.1984	Iran	Kharg	Transport to Refinery	0	0	0	9	13.4
10.05.1984	USA	Peabody	N.A.	1	125	0	N.A.	N.A.
06.06.1984	Indonesia	Cilacap	Refinery	5	12	0	N.A.	N.A.
08.06.1984	Germany	Marl	N.A.	0	0	0	4.6	6.8
08.06.1984	Venezuela	Tortuga	Transport to Refinery	0	0	0	8	11.9
15.06.1984	UK	Milford Haven, Dyfed	Regional Distribution	4	17	0	N.A.	N.A.
23.07.1984	USA	Romeoville	Refinery	15	0	0	203.2	301.6
30.07.1984	USA	Calcasieu Channel	Transport to Refinery	0	0	0	20	29.7
05.08.1984	USA	Herne	N.A.	0	0	0	55	81.6
16.08.1984	Singapore	Pulan	Refinery	0	0	0	12	17.8
16.08.1984	Canada	Fort McMurray	Extraction	0	0	0	76	112.8
16.08.1984	Brazil	Enchova, PCE1	Exploration	61	25	0	30	44.5
01.09.1984	Nigeria	Damagun	Regional Distribution	40	0	0	N.A.	N.A.
30.09.1984	USA	Basile	N.A.	0	0	1000	30	44.5
01.10.1984	Indonesia	N.A.	N.A.	0	0	0	55	81.6
13.10.1984	UK	Brombo-rough	N.A.	0	0	0	6.7	9.9
19.10.1984	Russia	Omsk	Extraction	150	0	0	N.A.	N.A.
24.10.1984	India	Bombay	Transport to Refinery	0	0	0	53 million rupees[1]	N.A.

[1]The rate of exchange in US$ cannot be given
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 $US\$_{1996}$)
27.10.1984	former Yugoslavia	Sisak	Refinery	0	11	0	N.A.	N.A.
04.12.1984	UK	Salford	Regional Distribution	3	76	400	N.A.	N.A.
11.12.1984	UK	Godstone, near London, Surrey-Kent Border	Regional Distribution	10	20	0	N.A.	N.A.
?.?.1985	N.A.	Union 525	Extraction	9	0	0	N.A.	N.A.
11.02.1985	Germany	N.A.	Regional Distribution	18	19	0	N.A.	N.A.
07.03.1985	Mexico	Guadalajara	Regional Distribution	30	0	0	N.A.	N.A.
07.03.1985	Trinidad	Los Bajos	Extraction	0	0	1000	6.5	9.0
26.03.1985	USA	Big Springs	Refinery	0	0	0	50.5	69.6
29.04.1985	Yugoslavia	N.A.	N.A.	0	0	0	45.3	62.4
20.05.1985	USA	near Morgan City, Rig "Tonkawa"	Exploration	11	0	0	N.A.	N.A.
24.05.1985	USA	N.A.	Regional Distribution	0	16	0	N.A.	N.A.
26.05.1985	Spain	offshore Algericas	Transport to Refinery	33	37	0	N.A.	N.A.
09.06.1985	USA	Pine Bluff	Transport to Refinery	0	0	3000	4	5.5
09.08.1985	USA	N.A.	Power Plant	6	0	0	24.8	34.1
22.08.1985	UK	N.A.	N.A.	55	0	0	N.A.	N.A.
18.09.1985	Malaysia	Bintolu	Exploration	0	0	0	24	33.1
01.10.1985	Colombia	Barranca-bermeja	N.A.	0	0	0	3	4.1
02.10.1985	Portugal	N.A.	Regional Distribution	5	24	0	N.A.	N.A.
13.10.1985	USA	Port Arthur, Texas	Refinery	5	8	0	N.A.	N.A.
17.10.1985	Trinidad and Tobago	Trintoc Atlas (near Point à Pierre)	Extraction	14	0	0	N.A.	N.A.
?.11.1985	India	Padaval	Regional Distribution	60	82	0	N.A.	N.A.
04.11.1985	Norway	Concem	Extraction	10	0	0	N.A.	N.A.
04.12.1985	India	New Delhi	Regional Distribution	1	340	0	N.A.	N.A.
05.12.1985	USA	Carson (CA)	Refinery	6	45	0	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
14.12.1985	Mexico	offshore Ciudad del Carmen	Extraction	33	0	0	N.A.	N.A.
21.12.1985	Italy	Naples	Refinery	6	170	2000	20	27.6
24.02.1986	Greece	Thessaloniki, Macedonia	Regional Distribution	3	25	0	300	407.3
21.03.1986	India	Calcutta, Bengal	Regional Distribution	2	33	0	N.A.	N.A.
30.03.1986	South Africa	Robben Island	Transport to Refinery	0	0	0	13	17.7
05.04.1986	Republic of Korea	Osan	Regional Distribution	16	12	0	N.A.	N.A.
11.08.1986	Taiwan	N.A.	Transport to Refinery	8	64	0	N.A.	N.A.
19.09.1986	UK	Hemel Hempsted	Regional Distribution	0	150	0	N.A.	N.A.
24.10.1986	USA	Platform: Mexico 2	Extraction	0	0	0	53	72.0
06.11.1986	UK (Shetland Islands)	Sumburgh Head	N.A.	45	2	0	N.A.	N.A.
29.11.1986	Australia	Sydney,	Heating	5	40	0	3	4.0
21.12.1986	Italy	Naples	Regional Distribution	5	150	2000	N.A.	N.A.
06.02.1987	Mexico	N.A.	Regional Distribution	25	0	0	N.A.	N.A.
05.03.1987	Ecuador	N.A.	Transport to Refinery	300	0	0	N.A.	N.A.
21.03.1987	Singapore	Tanjong Piai	Transport to Refinery	7	5	0	N.A.	N.A.
22.03.1987	UK	Grange-mouth, Central Region	Refinery	1	8	0	26.7	35.0
?.05.1987	India	N.A.	Regional Distribution	9	27	0	N.A.	N.A.
12.05.1987	Mexico	Ciudad Madero	Refinery	0	0	3000	N.A.	N.A.
30.05.1987	At Sea	English Channel	Transport to Refinery	0	16	40	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
30.05.1987	Nigeria	Port Harcourt	Refinery	5	0	0	700	916.4
12.06.1987	Spain	Tarragona	N.A.	0	0	1000	N.A.	N.A.
23.06.1987	France	Vieux Port	Transport to Refinery	6	2	0	N.A.	N.A.
07.07.1987	Germany	Herborn	Regional Distribution	6	38	0	10	13.0
18.07.1987	South Africa	Kwamashu	Regional Distribution	10	0	0	N.A.	N.A.
?.08.1987	India	N.A.	Regional Distribution	39	0	0	N.A.	N.A.
11.08.1987	Germany	N.A.	N.A.	9	15	0	N.A.	N.A.
31.08.1987	Brazil	N.A.	Regional Distribution	32	40	0	N.A.	N.A.
07.09.1987	Nigeria	Port Harcourt	N.A.	100	0	0	N.A.	N.A.
28.10.1987	UK	N.A.	Regional Distribution	12	6	0	N.A.	N.A.
29.10.1987	India	Bombay	Regional Distribution	7	60	0	N.A.	N.A.
24.11.1987	USA	Torrance	Refinery	0	0	0	15	19.6
24.11.1987	USA	N.A.	N.A.	0	0	0	52	67.8
29.11.1987	India	N.A.	Heating	22	16	0	N.A.	N.A.
20.12.1987	Philippines	off The Coast of Mindoro	Transport to Refinery	3000	26	0	N.A.	N.A.
21.12.1987	USA	Penrod 83, offshore Morgan City	Extraction	15	0	0	N.A.	N.A.
?.?.1988	Ethiopia	Addis Abeba	Regional Distribution	21	18	0	N.A.	N.A.
22.02.1988	USA	Golf of Mexico	Extraction	0	0	0	15	19.1
13.03.1988	USA	Baltimore	N.A.	0	0	0	10	12.7
14.04.1988	USA	N.A.	N.A.	0	0	0	88.53	93.8
22.04.1988	Canada	At sea	Regional Distribution	29	0	0	9.0	9.5
22.04.1988	USA	Marzinez	N.A.	0	0	0	28.3	36.0
24.04.1988	Brazil	Enchova, PCE, 1, (near Campos Basin)	Extraction	0	0	0	330	419.8

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 $US\$_{1996}$)
28.04.1988	Philippines	Manila	N.A.	0	4	1000	N.A.	N.A.
04.05.1988	USA	N.A.	N.A.	0	0	0	300	381.6
05.05.1988	USA	Narco	Refinery	7	47	0	N.A.	N.A.
16.05.1988	Nigeria	Kano	Regional Distribution	15	0	0	N.A.	N.A.
25.05.1988	Mexico	Chihuahua	Regional Distribution	0	70	100,000	N.A.	N.A.
12.06.1988	UK	Danbury	N.A.	0	0	200	N.A.	N.A.
23.06.1988	Mexico	Monterry	Regional Distribution	7	15	0	N.A.	N.A.
03.07.1988	Japan	Kure	Regional Distribution	4	30	0	N.A.	N.A.
07.07.1988	UK	Piper, 15/17, Alpha	Extraction	167	0	0	1500	1800
20.07.1988	Venezuela	Lake Maracaibo	Extraction	0	0	0	20	25.4
05.08.1988	USA	Nashua	N.A.	0	0	1700	N.A.	N.A.
28.08.1988	Mexico	San Juan de los Reyes	Refinery	12	80	8000	N.A.	N.A.
30.08.1988	India	Mathura	Regional Distribution	6	2	0	N.A.	N.A.
06.09.1988	Greece	Perama	Transport to Refinery	11	10	0	N.A.	N.A.
04.10.1988	Russia	Sverdolsk	Regional Distribution	5	1020	0	N.A.	N.A.
22.10.1988	China	Shanghai	Refinery	25	17	0	N.A.	N.A.
25.10.1988	Singapore	Pula Merlimau	Refinery	0	25	0	N.A.	N.A.
09.11.1988	India	Bombay	Refinery	32	26	0	N.A.	N.A.
10.11.1988	N.A.	North Atlantic	Transport to Refinery	27	0	0	N.A.	N.A.
30.11.1988	Bangladesh	Chittagong	Regional Distribution	33	0	0	N.A.	N.A.
25.12.1988	France	Berre	N.A.	0	0	0	26	32.6
?.?.1989	Iran	N.A.	Transport to Refinery	62	0	0	N.A.	N.A.
1.01.1989[1]	Ethiopia	Addis Abeba	Regional Distribution	21	N.A.	N.A.	N.A.	N.A.
03.01.1989	China	Yangtze River	Regional Distribution	8	7	0	N.A.	N.A.

[1] probably the same accident as the 7th last accident in the previous table
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$_{1996}$)
14.01.1989	Nigeria	N.A.	Regional Distribution	40	0	0	N.A.	N.A.
26.01.1989	Japan	N.A.	Transport to Refinery	17	0	0	N.A.	N.A.
28.01.1989	Nigeria	Port Harcourt	Refinery	5	0	0	300	360
30.01.1989	South Africa	Secunda	Regional Distribution	12	8	0	N.A.	N.A.
03.02.1989	France	N.A.	Power Plant	0	0	0	11.5	14.6
15.02.1989	Algeria	Skikda	Transport to Refinery	27	0	0	13	15.6
17.02.1989	Japan	N.A.	Transport to Refinery	10	12	0	N.A.	N.A.
20.02.1989	USA	Port Arthur	Transport to Refinery	0	30	7000	N.A.	N.A.
06.03.1989	Japan	N.A.	N.A.	0	0	0	74.39	89.1
08.03.1989	Vietnam	South China Sea	Transport to Refinery	130	0	0	N.A.	N.A.
19.03.1989	USA	South Pass, 60/B	N.A.	7	0	0	N.A.	N.A.
24.03.1989	USA	Exxon Valdez (Alaska)	Transport to Refinery	0	0	0	2000	2260
31.03.1989	Lebanon	East Beirut	Refinery	0	29	0	N.A.	N.A.
?.04.1989	Egypt	Tanta	Regional Distribution	5	43	0	N.A.	N.A.
10.04.1989	USA	N.A.	N.A.	0	0	0	78.53	94.0
26.04.1989	Iran	Bandar Abas	Transport to Refinery	12	0	0	N.A.	N.A.
27.04.1989	N.A.	Al Baz	N.A.	5	0	0	N.A.	N.A.
18.05.1989	Germany	Hamburg	N.A.	0	0	0	10	12.0
24.06.1989	USA	Philadelphia	Regional Distribution	0	115	0	3	3.6
20.07.1989	Venezuela	N.A.	N.A.	0	0	0	21	25.1
31.07.1989	USA	off the coast of Morgan City	Extraction	10	0	0	N.A.	N.A.
13.08.1989	China	Qingdao	Regional Distribution	16	86	0	N.A.	N.A.
17.08.1989	Iraq	Al-Hillah	Regional Distribution	19	0	0	N.A.	N.A.
17.09.1989	USA	US Virgin Islands	Refinery	0	0	0	272	326

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
03.10.1989	USA	High Island Pipeline	Extraction	11	0	0	N.A.	N.A.
22.10.1989	Russia.	Tobolsk	Regional Distribution	0	0	1000	N.A.	N.A.
31.10.1989	Germany	N.A.	Refinery	0	0	0	29.4	35.2
03.11.1989	India	Seacrest	Exploration	91	0	0	N.A.	N.A.
23.11.1989	UK	Manchester	Heating	0	35	0	N.A.	N.A.
18.12.1989	USA	Tulsa	Heating	0	0	1000	N.A.	N.A.
24.12.1989	USA	N.A.	Refinery	0	0	0	63.3	75.8
06.01.1990	USA	N.A.	Refinery	0	0	0	20	22.8
24.01.1990	China	near Anqing	Transport to Refinery	70	0	0	N.A.	N.A.
07.02.1990	USA	Huntington Beach (C.A.)	Transport to Refinery	0	0	0	15	17.1
12.02.1990	Canada	Hagersville	N.A.	0	0	1700	26	29.5
22.02.1990	France	N.A.	Transport to Refinery	2	18	0	29	32.9
14.04.1990	India	Padesh (Utar)	N.A.	0	0	0	739 million rupees[1].	N.A.
22.04.1990	USA	Craigsville	Transport to Refinery	0	0	200	N.A.	N.A.
22.04.1990	USA	Donca City	Refinery	0	0	500	N.A.	N.A.
07.05.1990	Jamaica	Montego Bay	Transport to Refinery	5	0	0	N.A.	N.A.
20.05.1990	India	Hazaribagh	Regional Distribution	16	0	0	N.A.	N.A.
21.05.1990	Australia	N.A.	Regional Distribution	0	100	0	N.A.	N.A.
09.06.1990	USA	Gulf of Mexico	Transport to Refinery	4	17	0	16	18.1
05.07.1990	USA	Channelview	N.A.	0	0	0	40	45.4
25.07.1990	UK	Brent Spar	Extraction	6	0	0	N.A.	N.A.
26.07.1990	Lebanon	Chtaura	Regional Distribution	45	22	0	N.A.	N.A.
09.08.1990	Spain	N.A.	Regional Distribution	8	12	0	N.A.	N.A.
11.08.1990	Russia	Yareslavi	Refinery	6	10	0	N.A.	N.A.
20.08.1990	N.A.	West Gamma (North Sea)	Extraction	0	0	0	24	27.2
25.08.1990	former Czechoslo-vakia	Spalov	Regional Distribution	11	30	0	N.A.	N.A.
09.09.1990	Spain	Tarragona	Refinery	0	0	0	4	4.6

[1]The rate of exchange in US$ cannot be given

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
20.09.1990	Borneo	N.A.	N.A.	17	0	0	N.A.	N.A.
22.09.1990	UK	North Sea	Exploration	0	0	0	50	56.7
24.11.1990	South Korea	Ulsan	Refinery	0	0	1000	N.A.	N.A.
20.12.1990	Bahamas	South Riding, Freeport	N.A.	0	0	0	654	742.0
19.01.1991	USA	Ferndale (WA)	Refinery	1	16	0	N.A.	N.A.
01.02.1991	Bahamas	Bahamas	N.A.	0	0	0	400	453.7
08.02.1991	Germany	Gelsen-kirchen	N.A.	0	0	0	43.2	47.2
22.02.1991	France	Aubette	Refinery	0	0	0	29	32.9
03.03.1991	USA	Lake Charles,LA	Refinery	6	12	0	23	26.1
11.03.1991	Mexico	Coatza-coalcos	Refinery	3	350	0	90	102.1
06.04.1991	Nigeria	Gongola state	N.A.	14	0	0	N.A.	N.A.
10.04.1991	Italy	Livorno	Transport to Refinery	141	6	0	N.A.	N.A.
11.04.1991	Italy	off Genoa	Transport to Refinery	5	30	0	N.A.	N.A.
13.04.1991	USA	Texas	Refinery	0	0	0	75	85.1
20.05.1991	USA	Bronx (New York)	Regional Distribution	5	0	0	1.1	1.3
29.05.1991	South Africa	Cape Town	Transport to Refinery	6	0	0	37.2	42.1
04.06.1991	Trinidad and Tobago	Pointe-A-Pierre	Refinery	1	12	0	3	3.4
14.06.1991	France	St. Ouen	Regional Distribution	0	13	300	N.A.	N.A.
26.06.1991	Malaysia	Straits of Malacca (near Bahu Pahat)	Transport to Refinery	124	0	0	N.A.	N.A.
26.06.1991	Japan	Ishiahara (near Tokyo)	Refinery	2	10	0	3	3.4
19.07.1991	N.A.	Strait of Formosa	Transport to Refinery	31	0	0	N.A.	N.A.
09.08.1991	Portugal	Lisbon	Regional Distribution	5	6	0	N.A.	N.A.
15.08.1991	Hong Kong	McDermont Lay Barge 29	Extraction	22	182	0	N.A.	N.A.
18.08.1991	Lebanon	Tripoli	Regional Distribution	7	4	0	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
23.08.1991	Norway	(Oil platform "Sleipner A")	Extraction	0	0	0	334.5	365.2
04.09.1991	Malaysia	Kota Kinabalu	N.A.	12	0	0	N.A.	N.A.
19.10.1991	Mexico	Tabasco, Samaria	Transport to Refinery	6	2	0	N.A.	N.A.
22.11.1991	India	N.A.	Regional Distribution	90	80	0	N.A.	N.A.
10.12.1991	Germany	Gelsen-kirchen	Refinery	0	0	0	184.6	201.5
12.12.1991	Netherlands	Rotterdam	N.A.	6	0	0	N.A.	N.A.
24.12.1991	Kenia	Nairobi	Regional Distribution	30	N.A.	N.A.	N.A.	N.A.
05.01.1992	UK	Shetland Islands	N.A.	0	0	0	115	121.9
21.01.1992	Indonesia	Straits of Malakka	N.A.	0	0	0	33	35.0
28.01.1992	Bahamas	Manama	Transport to Refinery	5	0	0	N.A.	N.A.
15.02.1992	Germany	Irsching	Power Plant	0	0	0	46.5	49.3
16.02.1992	Malaysia	Pengerang	N.A.	5	16	0	N.A.	N.A.
08.03.1992	Thailand	Gulf of Thailand	Transport to Refinery	112	0	0	N.A.	N.A.
14.03.1992	UK	(North Sea, Shetland Isles.)	Extraction	17	0	0	N.A.	N.A.
14.04.1992	Lebanon	Jiyeh	Regional Distribution	6	0	0	N.A.	N.A.
22.04.1992	Mexico	Guadalajara	Regional Distribution	200	1400	5000	300	318
29.04.1992	Indonesia	Straits of Malakka	N.A.	20	0	0	N.A.	N.A.
03.06.1992	Belgium	Ostende	N.A.	9	27	0	21	22.2
22.06.1992	Spain	Santa Cruz De Tenerife	Refinery	0	0	0	87	92.2
06.07.1992	Egypt	Suez Channel	N.A.	0	0	0	15	15.9
08.07.1992	Netherlands	Uithoorn	Refinery	3	11	0	N.A.	N.A.
24.08.1992	Egypt	N.A.	N.A.	1	70		N.A.	N.A.
?.09.1992	Greece	Elefsina, Athens	Refinery	14	30	0	9.5	10.1
02.09.1992	Netherlands	Vlaardingen	N.A.	0	0	0	15	15.9

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
20.09.1992	Indonesia	Straits of Malacca	Transport to Refinery	42	0	0	60	63.6
28.09.1992	Morocco	Rabat	N.A.	15	106	0	N.A.	N.A.
04.10.1992	Netherlands	N.A.	N.A.	51	27	0	N.A.	N.A.
08.10.1992	USA	California	Refinery	0	16	0	55	58.3
16.10.1992	Japan	Sodegaura	Refinery	9	8	0	157.8	167.3
28.10.1992	Russia	Caucasus	Transport to Refinery	1	18	0	N.A.	N.A.
02.11.1992	Vietnam	Quang Ninh	N.A.	44	55	0	N.A.	N.A.
07.11.1992	Nigeria	Iiorin (Kwara)	N.A.	60	0	0	N.A.	N.A.
09.11.1992	France	La Mede, Marseille	Refinery	6	8	0	370	392.2
19.11.1992	Bangladesh	Bengalen	N.A.	5	45	0	N.A.	N.A.
23.11.1992	Colombia	N.A.	Regional Distribution	15	0	0	N.A.	N.A.
03.12.1992	Spain	La Coruña	Transport to Refinery	0	0	0	22	23.3
21.12.1992	Portugal	N.A.	Regional Distribution	54	106	0	N.A.	N.A.
05.01.1993	UK	Shetland Isles	Transport to Refinery	0	0	0	115	121.9
14.01.1993	France	La Voulte	Regional Distribution	0	6	300	N.A.	N.A.
21.01.1993	Indonesia	Straits of Malakka	Transport to Refinery	0	0	0	33	35.0
20.02.1993	USA	Maumee Bay	Refinery	0	0	0	4	4.2
06.03.1993	Chile	San Vicente	Regional Distribution	0	0	0	50	53.0
17.03.1993	USA	Fort Lauderdale	Regional Distribution	6	15	0	N.A.	N.A.
29.04.1993	Indonesia	Straits of Malakka	Transport to Refinery	20	N.A.	N.A.	N.A.	N.A.
13.05.1993	Spain	Bilbao	Refinery	0	0	0	8.1	8.6
03.06.1993	Italy	Milazzo	Regional Distribution	7	16	N.A.	N.A.	N.A.
03.06.1993	Belgium	Ostende	Transport to Refinery	9	27	0	21	22.3
12.06.1993	China	Lingjian-chuan	Regional Distribution	8	N.A.	N.A.	N.A.	N.A.
24.06.1993	Russia	Moscow	Regional Distribution	11	N.A.	N.A.	N.A.	N.A.
06.07.1993	Egypt	Suez Channel	Extraction	0	0	0	15	15.9

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 $US\$_{1996}$)
06.07.1993	Pakistan	Shikarpur	Regional Distribution	0	0	0	11	11.7
02.08.1993	Netherlands	Vlaardingen	Transport to Refinery	0	0	0	15	15.9
24.08.1993	Egypt	Alexandria	Refinery	1	70	N.A.	N.A.	N.A.
25.08.1993	Turkey	Nurdagi	Regional Distribution	6	23	N.A.	N.A.	N.A.
28.09.1993	Morocco	Rabat	Regional Distribution	15	100	N.A.	N.A.	N.A.
03.10.1993	South Korea	Seoul	Regional Distribution	0	0	0	100	106.0
09.10.1993	USA	Galveston	Regional Distribution	3	12	N.A.	N.A.	N.A.
02.11.1993	Vietnam	Quang Ninh Province	Regional Distribution	47	60	N.A.	N.A.	N.A.
4.11.1993[1]	Vietnam	Nam Khe	Regional Distribution	39	60	N.A.	N.A.	N.A.
07.11.1993	Nigeria	Ilorin (Kwara)	Regional Distribution	60	N.A.	N.A.	N.A.	N.A.
13.11.1993	Bangladesh	Khalispur	Regional Distribution	5	2	N.A.	N.A.	N.A.
19.11.1993	Bangladesh	Bengalen	Transport to Refinery	50	N.A.	N.A.	N.A.	N.A.
01.01.1994	USA	Linden	Refinery	0	19	0	N.A.	N.A.
5.01.1994[2]	UK	Shetland Isles	Transport to Refinery	0	0	0	115	115
06.01.1994	Portugal	N.A.	Transport to Refinery	0	0	0	14	14
21.01.1994	Indonesia	Straits of Malakka	Transport to Refinery	0	0	0	33	33
30.01.1994	South China Sea	N.A.	Transport to Refinery	10	N.A.	N.A.	N.A.	
05.02.1994	India	Kerala	Regional Distribution	40	N.A.	N.A.	N.A.	N.A.
08.02.1994	Caribic sea	N.A.	Transport to Refinery	6	N.A.	N.A.	50	50
25.02.1994	Japan	Kawasaki	Refinery	0	0	0	80	80
13.03.1994	Turkey	Bosporus	Transport to Refinery	33	27	N.A.	24	24
20.03.1994	Oman	off the coast of Masirah	Transport to Refinery	18	N.A.	N.A.	N.A.	N.A.

[1]probably the same accident as one line above
[2]probably the same accident which occurred in 05.01.1993 and documented in the previous table
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
21.03.1994	Indonesia	(Minas Oilfield)	Transport to Refinery	1	31	N.A.	N.A.	N.A.
21.03.1994	Indian Ocean	N.A.	Transport to Refinery	24	N.A.	N.A.	N.A.	N.A.
11.04.1994	Mexico	Hidalgo	Refinery	0	10	0	N.A.	N.A.
27.05.1994	USA	Belpre	Refinery	3	0	1700	33	33
20.06.1994	South Africa	Captown	Transport to Refinery	37	N.A.	N.A.	N.A.	N.A.
26.06.1994	Venezuela	El Palito	Refinery	0	0	0	14	14
6.07.1994[1]	Egypt	Suez Channel	Extraction	0	0	0	15	15
24.07.1994	UK	Milford Haven	Refinery	0	0	0	106	106
02.09.1994	Netherlands	Vlaardingen	Transport to Refinery	0	0	0	15	15
21.09.1994	Ukraine	Lisichansk	Refinery	3	10	N.A.	N.A.	N.A.
28.09.1994	China	Hebei	Exploration	0	500	N.A.	N.A.	N.A.
03.10.1994	Vietnam	Ho Chi Minh City	Regional Distribution	0	0	0	6.75	6.75
09.10.1994	USA	St. Croix	Transport to Refinery	3	7	N.A.	13	13
20.10.1994	USA	Houston	Regional Distribution	0	70	12,000	15	15
23.10.1994	Philippines	Manila	Transport to Refinery	16	N.A.	N.A.	N.A.	N.A.
02.11.1994	Egypt	Durunkha	Regional Distribution	580	N.A.	N.A.	140	140
04.11.1994	Nigeria	Onitsha	Regional Distribution	60	0	0	N.A.	N.A.
09.12.1994	UK	London	Regional Distribution	0	0	400	N.A.	N.A.
12.12.1994	China	Hebei	Extraction	6	585	N.A.	N.A.	N.A.
13.12.1994	Brazil	(north eastern of Brazil)	Regional Distribution	13	29	N.A.	N.A.	N.A.
28.12.1994	Venezuela	near Maturin	Regional Distribution	30	15	N.A.	N.A.	N.A.
?.?.1995	Mexico	DLB 269 (Oil platform)	Extraction	26	0	0	N.A.	N.A.
?.?.1995	(West Africa)	Ubit (Oil platform)	Extraction	5	5	0	N.A.	N.A.
13.02.1995	USA	New Orleans	Regional Distribution	0	0	500	N.A.	N.A.
12.03.1995	India	near Madras	Regional Distribution	110	N.A.	N.A.	N.A.	N.A.

[1]probably the same accident which occurred in 06.07.1993 and documented on page B-23 of this appendix
N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 $US\$_{1996}$)
17.02.1995	Mexico	Villahermosa	Regional Distribution	1	22	500	N.A.	N.A.
25.02.1995	Japan	Kawasaki	Refinery	0	0	0	80	80
08.03.1995	Bahamas	Freeport	Regional Distribution	0	0	500	7	7
13.03.1995	USA	Blue Island	Refinery	2	46	N.A.	N.A.	N.A.
26.03.1995	Guatemala	Guatemala City	Regional Distribution	2	12	N.A.	N.A.	N.A.
12.04.1995	Romania	Dragos Voda	Regional Distribution	2	19	N.A.	N.A.	N.A.
26.04.1995	Thailand	Sri Racha	Refinery	0	0	0	15	15
28.04.1995	South Korea	Taegu	Regional Distribution	100	200	N.A.	N.A.	N.A.
27.05.1995	USA	Belpre	Refinery	3	N.A.	N.A.	33	33
30.05.1995	Japan	Kawasaki	Refinery	0	46	N.A.	N.A.	N.A.
13.06.1995	Syria	Deir Ez Zor	Extraction	5	0	0	N.A.	N.A.
19.06.1995	Belgium	Eynatten	Regional Distribution	16	3	0	N.A.	N.A.
29.06.1995	South Korea	Seoul	Regional Distribution	500	952	N.A.	N.A.	N.A.
23.08.1995	USA	Boynton	Regional Distribution	0	0	600	N.A.	N.A.
25.10.1995	Indonesia	Cilacap	Refinery	0	0	500	33	33
02.11.1995	Pakistan	Sukkur	Regional Distribution	21	13	N.A.	N.A.	N.A.
16.11.1995	UK	South Killingholm	Refinery	0	1	600	N.A.	N.A.
21.11.1995	USA	Houston	Refinery	0	80	N.A.	N.A.	N.A.
05.12.1995	USA	Covent (LA)	Refinery	20	30	N.A.	N.A.	N.A.
07.12.1995	Iraq	Shaqlawah	Regional Distribution	10	N.A.	N.A.	N.A.	N.A.
16.12.1995	Brazil	Rio Claro (Sao Paulo)	Regional Distribution	22	9	N.A.	N.A.	N.A.
09.01.1996	USA	Bogota	Regional Distribution	0	3	200	N.A.	N.A.
18.01.1996	Bangladesh	River Meghna	Transport to Refinery	49	N.A.	N.A.	N.A.	N.A.
28.01.1996	Egypt	Suez Channel	Extraction	0	0	0	25.7	25.7
15.02.1996	UK	Milford Haven	Transport to Refinery	0	0	0	30	30
07.06.1996	Zambia	Kapiri Mpholsi	Transport to Refinery	36	N.A.	N.A.	N.A.	N.A.

N.A.: Not available

Table B.1

Severe oil accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Fatalities	Injured	Evacuees	Costs (10^6 US$)	Costs (10^6 US$$_{1996}$)
08.10.1996	USA	near Warmbaths	Regional Distribution	38	12	N.A.	N.A.	N.A.
07.11.1996	Thailand	Bangkok	Regional Distribution	17	17	N.A.	N.A.	N.A.
05.12.1996	USA	Convent (LA)	Refinery	0	0	0	57	57

N.A.: Not available

Table B.2

Severe offshore oil spills exceeding 25,000 tonnes in the period 1969-1996.

Year	Month	Unit	Name of unit (ship or platform)	Country of origin of unit	Country affected/ Ocean	Quantity spilled (10^3 tonnes)
1969	February	Tanker	Julius Schindler	N.A.	Portugal	95.9
1969	November	Tanker	Keo	Liberia	USA	25.0
1969	November	Tanker	Paocean	Liberia	Bahrain	30.0
1970	N.A.	Tanker	Othello	N.A.	Sweden	73
1970	March	Tanker	Ennerdale	UK	Seychelles	49.0
1970	December	Tanker	Chrissi	Panama	USA	31.0
1971	N.A.	Oil platform	Wodeco 3	Iran	N.A.	60.0
1971	N.A.	Tanker	Hawaiian Patriot	N.A.	N.A.	93
1971	February	Tanker	Wafra	Liberia	South Africa	63.2
1971	March	Tanker	Texas Oklahoma	USA	USA	35.0
1971	December	Tanker	Texaco	Denmark	Belgium	106.3
1972	January	Tanker	Golden Drake	Liberia	Azores	31.7
1972	April	Tanker	Giuseppe Giulietti	Italy	Spain	26.0
1972	June	Tanker	Trader	Greece	Greece	35.0
1972	December	Tanker	Sea Star	South Korea	Gulf of Oman	120.3
1973	June	Tanker	Napier	Liberia	Chile	36.0
1974	August	Tanker	Metula	Dutch Antilles	Chile	53.5
1974	N.A.	Tanker	Yugo Maru 10	Japan	Japan	50.0
1975	January	Tanker	British Ambassador	UK	Japan (Pacific)	45.0
1975	January	Tanker	Jakob Maersk	Denmark	Portugal	84.0
1975	January	Tanker	Corinthos E.M. Queeny	USA-Liberia	USA (Delaware)	40.0
1975	April	Tanker	Spartan Lady	Liberia	USA	25.0
1975	Mai	Tanker	Epic Coloctronis	N.A.	Puerto Rico	60.8
1975	N.A.	Tanker	Epic Colocoltroni	Greece	St. Dominique	57.0
1975	December	Tanker	Berge Istra	Norway	Philippines	224
1976	February	Tanker	Saint Peter	Liberia	Colombia	33.0
1976	May	Tanker	Urquiola	Spain	Spain	101.0
1976	July	Tanker	Cretan Star	Cyprus	Indian Ocean	28.6
1977	January	Tanker	Irenes Challenge	Liberia	Pacific Ocean	34.0
1977	February	Tanker	Hawaiian Patriot	Liberia	Honolulu	99.0
1977	May	Tanker	Caribbean Sea	Panama	Nicaragua	30.0
1977	December	Tanker	Venoi II Venpet	Liberia	South Africa	26.0
1977	December	Tanker	Grand Zenith	Panama	USA (Massachusetts)	29.0
1978	N.A.	Oil platform	Fumiva 5	Nigeria	Nigeria	45
1978	March	Tanker	Amoco Cadiz	Liberia	France .	228.0
1978	June	N.A.	N.A.	N.A.	Japan	50.6

N.A.: Not available

Table B.2

Severe offshore oil spills exceeding 25,000 tonnes in the period 1969-1996 *(Cont.).*

Year	Month	Unit	Name of unit (ship or platform)	Country of origin of unit	Country affected/ Ocean	Quantity spilled (10^3 tonnes)
1978	July	Tanker	Cabo Tamar	Chile	Chile	60.0
1978	December	Tanker	Andros Patria	Greece	Spain	47.0
1978	December	Tanker	Tadotsu	N.A.	Indonesia	44.6
1979	January	Tanker	Betelgeuse	France	Ireland	27.0
1979	April	Tanker	Gino	Liberia	France	42.0
1979	June	Tanker	Aviles	Liberia	Arabian Sea	25.0
1979	June	Oil platform	Ixtoc 1	Mexico	Mexico, USA (Texas)	375.0
1979	July	Tanker	Atlantic Express	Greece	Tobago	276.0
1979	August	Tanker	lonnis Angeli-coussis	Greece	Angola	30.0
1979	November	Tanker	Burmah Agate	Liberia	USA (Texas)	40.0
1979	November	Tanker	Independenta	Romania	Turkey	94.6
1980	N.A.	Tanker	N.A.	Nigeria	N.A.	25.0
1980	January	Oil platform	Funiwa No. 5	Nigeria	Nigeria	28
1980	February	Tanker	Irenes Serenade	Greece	Greece	102.0
1980	March	Tanker	Tanio	Madagascar	France,UK	13.5
1980	December	Tanker	Juan A.Lavalleja	Uruguay	Algeria	40.0
1981	July	Tanker	Cavo Cambanos	Greece	France	18.0
1981	November	Tanker	Globe Assimi	Gibraltar	USSR	16.0
1983	January	Tanker	Assimi	N.A:	Gulf of Oman	53.3
1983	March	Oil platform	Nowruz 4	Iran	Iran, Iraq	266.7
1983	August	Tanker	Castello de Belver	Spain	South Africa	255.5
1983	December	Tanker	Pericles GC	N.A:	Persian Gulf	47.3
1985	February	Tanker	Neptunia	Liberia	Iran	60.0
1985	December	Tanker	Nova	Liberia	Iran	71.1
1988	April	Tanker	Athenian Venture	N.A.	Canada	35.8
1988	November	Tanker	Odysee	N.A.	N.A.	132
1989	March	Tanker	Exxon Valdez	USA	USA, Alaska	35.0
1989	December	Tanker	Kharg 5	Iran	Marocco	70
1990	January	Tanker	N.A.	Aragon (Madeira)	Portugal	25
1990	December	Tanker	N.A.	N.A.	Marocco	80
1991	April	Tanker	Haven	Genoa	Italy	80
1991	Mai	Tanker	Abt Summer	N.A.	South Africa	51
1992	April	Tanker	Katina P	N.A.	Mozambique	72

N.A.: Not available

Table B.2
Severe offshore oil spills exceeding 25,000 tonnes
in the period 1969-1996 *(Cont.).*

Year	Month	Unit	Name of unit (ship or platform)	Country of origin of unit	Country affected/ Ocean	Quantity spilled (10^3 tonnes)
1992	December	Tanker	Aegean Sea	N.A.	Spain	72
1993	January	Tanker	Braer	Liberia	UK	84.4
1993	January	Tanker	Sanko Honour	N.A.	Indonesia	32.0
1993	December	Tanker	Savonita	Pilottown (Louisiana)	USA	91.0
1993	December	Tanker	N.A.	New Orleans (Louisiana)	USA	71.1
1994	March	Tanker	N.A.	Bosporus Strait	Turkey	27.5
1994	October	Tanker	Thanassis	N.A.	Hong Kong	36.8
1996	February	Tanker	N.A.	Xiaoxi	China	57.0
1996	March	Tanker	N.A.	N.A.	Mexico	35.8
1996	June	Tanker	Sea Empress	Liberia	UK	70
1996	October	Tanker	Once	N.A.	Thailand	135

N.A.: Not available

Table B.3
Severe onshore oil spills exceeding 25,000 tonnes in the period 1969-1996.

Year	Month	Unit	Place	Country affected	Quantity spilled (10^3 tonnes)
1974	December	Refinery	Kurashiki	Japan	39.2
1978	December	Storage depot	Salisbury	Zimbabwe	67.5
1978	May	(Oil well and pipeline)	Ahvazin	Iran	94.5
1978	October	Pipeline	Mardin	Turkey	36.1
1978	December	Storage tank	Benuelan	USA (Puerto Rico)	35.4
1979	July	Terminal	Forcados	Nigeria	80.7
1980	August	Oil well D-103	(800 km Southeast of Tripoli)	Lybia	141.8
1980	November	Refinery	Naples	Italy	25.3
1981	August	Refinery	Shuaybah	Kuwait	105
1986	April	Refinery	Bahia Las Minas	Panama	33.6
1986	April	Storage tank	Colon	Panama	33.6
1986	October	(Oil well Abkatun 91)	(64 km Northwest of Ciudad del Carmen)	Mexico	35.1
1988	March	Storage tank	Puerto Rosales	Argentina	30
1992	March	(Oil well)	Fergana Valley	Uzbekistan	270
1994	October	Pipeline	Usinsk	Russia	103.6

Appendix C: List of severe accidents within the gas chain in the period 1969-1996

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
?.01.1969	Libya	Marsa el Brega	Long Distance Transport	3	12	0	0.5	2.1
?.?.1970	Virgin Islands	St. Thomas	N.A.	0	25	0	N.A.	N.A.
08.04.1970	Japan	Osaka	Regional Distribution	92	300	0	N.A.	N.A.
01.07.1970	Russia	N.A.	Long Distance Transport	23	0	0	N.A.	N.A.
28.09.1970	Mexico	San Lorenzo	Local Distribution	10	0	0	N.A.	N.A.
12.11.1970	USA	Hudson (Ohio)	Regional Distribution	6	0	0	0.25	1.1
23.11.1970	India	Charlotte Amalie-St.Thomas Islands	Heating	0	25	0	N.A.	N.A.
17.12.1970	Iran	Agha Jari, Khuzestan	Regional Distribution	34	10	0	N.A.	N.A.
17.11.1971	USA	N.A.	Long Distance Transport	6	0	0	N.A.	N.A.
09.12.1972	USA	N.A.	Long Distance Transport	8	7	0	N.A.	N.A.
15.12.1972	USA	Weirtonn (WV)	Heating	21	20	0	N.A.	N.A.
?.?.1973	USA	N.A.	Regional Distribution	0	300	0	N.A.	N.A.
10.02.1973	USA	Staten Island (NY)	Local Distribution	40	0	0	31	110.0
21.02.1973	USA	Coopersburg	Long Distance Transport	5	16	0	N.A.	N.A.
22.02.1973	USA	Austin (Texas)	Regional Distribution	6	2	0	N.A.	N.A.
30.03.1973	Germany	Lörrach	Regional Distribution	6	4	0	N.A.	N.A.
22.04.1973	USA	El Paso	Local Distribution	7	8	0	N.A.	N.A.

N.A.: Not available

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
22.04.1974	USA	New York	Long Distance Transport	0	70	0	N.A.	N.A.
21.05.1974	USA	Meridian (Mississippi)	Long Distance Transport	5	1	0	N.A.	N.A.
07.09.1975	USA	N.A.	Long Distance Transport	5	0	0	N.A.	N.A.
07.01.1976	USA	Cedradale (Mooreland, OK)	Regional Distribution	5	4	0	N.A.	N.A.
10.01.1976	USA	Fremont (Nebraska)	Long Distance Transport	20	39	0	N.A.	N.A.
25.02.1976	USA	N.A.	Long Distance Transport	5	2	0	N.A.	N.A.
10.03.1976	Ecuador	Guayaquil	Regional Distribution	0	50	0	1	2.8
27.03.1976	USA	N.A.	Local Distribution	6	0	0	N.A.	N.A.
18.07.1976	USA	Galeota Point	Regional Distribution	0	12	0	N.A.	N.A.
08.08.1976	USA	Allentown	Local Distribution	2	14	0	N.A.	N.A.
09.08.1976	USA	Cartwright	Long Distance Transport	6	1	0	N.A.	N.A.
29.10.1976	Uruguay	Montevideo	Heating	0	14	2000	N.A.	N.A.
02.11.1976	Hungary	N.A.	Local Distribution	7	9	0	N.A.	N.A.
26.11.1976	Mexico	Tlalnepantla	Long Distance Transport	11	48	0	N.A.	N.A.
07.12.1976	USA	Robston (Texas)	Long Distance Transport	1	2	0	5	13.8
10.12.1976	USA	Baton Rouge (Louisiana)	N.A.	0	0	10,000	N.A.	N.A.
03.04.1977	Qatar	Umm Said	Long Distance Transport	7	0	0	43	111.1
01.12.1977	USA	Atlanta	Long Distance Transport	0	0	1000	N.A.	N.A.
17.02.1978	France	Paris	Local Distribution	12	45	0	N.A.	N.A.
02.03.1978	Canada	Ontario	Long Distance Transport	0	0	20,000	N.A.	N.A.
15.04.1978	Saudi Arabia	Abqaiq	Refinery	4	16	0	80	193.3
25.05.1978	Iran	N.A.	Extraction	7	40	0	N.A.	N.A.

N.A.: Not available

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
28.06.1978	Bolivia	(near the Argentine border)	Long Distance Transport	10	6	0	N.A.	N.A.
15.07.1978	Mexico	N.A.	Long Distance Transport	12	0	0	N.A.	N.A.
24.10.1978	USA	Brookside Village	Long Distance Transport	6	47	0	N.A.	N.A.
02.11.1978	Mexico	Sanchez Magallans (Tabasco)	Long Distance Transport	58	32	0	N.A.	N.A.
03.12.1978	USA	N.A.	Local Distribution	9	4	0	N.A.	N.A.
30.01.1979	USA	N.A.	Local Distribution	7	4	0	N.A.	N.A.
10.02.1979	USA	Hastings (Nebraska)	N.A.	0	0	0	5	10.9
05.03.1979	USA	Penrod 30, Louisiana Shelf	Extraction	8	4	0	N.A.	N.A.
11.05.1979	USA	Philadelphia (Pennsyl-vania)	Long Distance Transport	7	19	0	N.A.	N.A.
04.09.1979	USA	Pierre Part (Louisiana)	Regional Distribution	2	1	0	5	10.9
24.10.1979	USA	Standardville (Virginia)	Local Distribution	0	13	0	N.A.	N.A.
05.12.1979	Mexico	Tampico	Long Distance Transport	7	8	0	N.A.	N.A.
?.?.1980	USA	Mount Belvue (Texas)	N.A.	0	0	70	8	15.3
26.02.1980	Canada	Brooks (Alberta)	Long Distance Transport	0	0	0	40	76.5
26.2.1980[1]	Canada	Princes	Long Distance Transport	0	0	0	47.2	90.1
24.03.1980	(Gulf of Mexico)	N.A.	Extraction	5	11	0	N.A.	N.A.
17.08.1980	Japan	N.A.	Local Distribution	15	199	0	N.A.	N.A.
30.08.1980	N.A.	N.A.	Extraction	5	6	0	N.A.	N.A.
30.08.1980	Germany	Frankenthal	N.A.	0	0	0	3	5.7
12.09.1980	Argentina	San Miguel de Tucuma	Long Distance Transport	6	5	0	N.A.	N.A.

[1] probably the same accident as one line above

N.A.: Not available

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
09.10.1980	USA	Independence (Kentucky)	Regional Distribution	1	38	0	N.A.	N.A.
13.10.1980	USA	N.A.	Long Distance Transport	9	15	0	N.A.	N.A.
23.10.1980	Spain	Ortuella	Heating	70	0	0	N.A.	N.A.
11.01.1981	France	N.A.	Local Distribution	5	6	0	N.A.	N.A.
24.04.1981	Belgium	Brussels	Local Distribution	22	0	0	N.A.	N.A.
01.06.1981	USA	Janesville (Wisconsin)	N.A.	0	12	0	N.A.	N.A.
12.10.1981	Italy	N.A.	Local Distribution	6	2	0	N.A.	N.A.
20.01.1982	Mexico	La Venta	Long Distance Transport	33	500	40,000	52	84.9
26.01.1982	USA	N.A.	Local Distribution	0	50	0	N.A.	N.A.
02.03.1982	South Africa	Johannes-burg	Local Distribution	11	91	0	N.A.	N.A.
06.04.1982	USA	Fort Worth (Texas)	Long Distance Transport	0	0	250	N.A.	N.A.
24.04.1982	Belgium	N.A.	Local Distribution	14	8	0	N.A.	N.A.
28.06.1982	USA	N.A.	Local Distribution	6	0	0	N.A.	N.A.
17.08.1982	Spain	N.A.	Local Distribution	10	12	0	N.A.	N.A.
04.11.1982	USA	Hudson (Iowa)	Long Distance Transport	5	0	0	N.A.	N.A.
11.11.1982	Israel	N.A.	Local Distribution	89	0	0	N.A.	N.A.
22.12.1982	Italy	N.A.	Local Distribution	6	10	0	N.A.	N.A.
14.02.1983	Indonesia	Bontang	Local Distribution	0	0	0	50	79.1
23.03.1983	Zaire	N.A.	Long Distance Transport	20	0	0	N.A.	N.A.
26.05.1983	USA	Prudhoe Bay (Alaska)	N.A.	0	0	0	35	55.4
15.03.1984	USA	N.A.	Long Distance Transport	6	4	0	N.A.	N.A.

N.A.: Not available

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
09.06.1984	Mexico	N.A.	Long Distance Transport	9	37	0	N.A.	N.A.
14.06.1984	Chechos-lovakia	N.A.	Local Distribution	12	9	0	N.A.	N.A.
16.08.1984	Brazil	Enchova	Extraction	40	0	0	N.A.	N.A.
25.09.1984	USA	N.A.	Local Distribution	5	7	0	N.A.	N.A.
17.10.1984	UK	Saunders-foot	Local Distribution	0	1	300	0.5	0.7
25.11.1984	USA	St. Francis-ville (Louisiana)	Long Distance Transport	5	23	0	N.A.	N.A.
02.12.1984	Russia	Tbilisi	Heating	100	0	0	N.A.	N.A.
13.12.1984	Pakistan	Kashmor	Long Distance Transport	16	14	0	N.A.	N.A.
31.12.1984	USA	San Antonio (Texas)	Heating	1	12	0	N.A.	N.A.
?.?.1985[1]	Pakistan	N.A.	Long Distance Transport	16	8	0	N.A.	N.A.
10.01.1985	UK	Putney	Local Distribution	8	7	0	N.A.	N.A.
12.01.1985	Poland	N.A.	Local Distribution	6	30	0	N.A.	N.A.
05.02.1985	France	N.A.	Local Distribution	5	38	0	N.A.	N.A.
06.03.1985	Mexico	N.A.	Regional Distribution	27	30	0	N.A.	N.A.
27.04.1985	USA	Beaumont (Kentucky)	Long Distance Transport	5	3	0	N.A.	N.A.
06.10.1985	Norway	Trondheim	Exploration	0	0	0	425.6	621.7
29.11.1985	UK	N.A.	Long Distance Transport	5	1	0	N.A.	N.A.
06.12.1985	USA	N.A.	Long Distance Transport	6	14	0	N.A.	N.A.
23.01.1986	Italy	N.A.	Local Distribution	7	9	0	N.A.	N.A.
10.02.1986	USA	Sullivan (Indiana)	N.A.	4	12	0	N.A.	N.A.
21.02.1986	USA	Lancaster (Kentucky)	Long Distance Transport	0	13	0	N.A.	N.A.
14.07.1986	Egypt	Maasara	Long Distance Transport	5	9	0	N.A.	N.A.

[1] probably the same accident as two lines above

N.A.: Not available

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
25.12.1986	Mexico	Cardenas (Tabasco)	Long Distance Transport	0	0	20,000	N.A.	N.A.
05.05.1988	USA	Henderson (Nevada)	N.A.	2	350	640	N.A.	N.A.
02.06.1988	USA	Catskill (New York)	Long Distance Transport	0	0	1200	N.A.	N.A.
03.12.1988	Algeria	Near Algiers	N.A.	18	8	0	N.A.	N.A.
15.12.1988	Germany	Walluf	N.A.	1	3	4000	N.A.	N.A.
10.02.1989	Australia	Sydney (New South Wales)	N.A.	0	0	1000	N.A.	N.A.
23.06.1989	Pakistan	Lahore Punjab	Long Distance Transport	12	20	0	N.A.	N.A.
08.08.1989	Russia	N.A.	Local Distribution	18	6	0	N.A.	N.A.
03.10.1989	USA	Sabine Pass (Texas)	Regional Distribution	11	3	0	N.A.	N.A.
03.10.1989	Mexico	Gulf of Mexico	Regional Distribution	8	3	0	N.A.	N.A.
04.11.1989	Thailand	Gulf of Thailand	Exploration	93	0	0	N.A.	N.A.
12.12.1989	China	Senyang	Long Distance Transport	6	26	0	N.A.	N.A.
29.12.1989	USA	New York	Long Distance Transport	2	27	0	N.A.	N.A.
22.02.1990	Persian Gulf	Shariah	Long Distance Transport	2	0	0	28.1	33.8
18.03.1990	Iran	Tehran	Heating	13	1	0	N.A.	N.A.
28.11.1990	Pakistan	Sui	Long Distance Transport	2	12	0	N.A.	N.A.
17.12.1990	India	N.A.	Regional Distribution	6	68	0	N.A.	N.A.
22.12.1990	Russia	N.A.	Regional Distribution	7	48	0	N.A.	N.A.
11.03.1991	Mexico	Pajaritos	Refinery	4	329	0	N.A.	N.A.
07.04.1992	USA	Wesley Oilfield (Texas)	Regional Distribution	3	16	0	6.6	7.9
15.04.1992	Venezuela	Jusedin	N.A.	1	34	0	N.A.	N.A.
30.06.1992	USA	N.A.	Regional Distribution	0	25	0	N.A.	N.A.
18.12.1992	Canada	Billings	Local Distribution	7	0	0	N.A.	N.A.

N.A.: Not available

Table C.1

Severe natural gas accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
29.7.1993	UK	Exeter	Local Distribution	0	0	1000	N.A.	N.A.
28.9.1993	Venezuela	Miranda	Local Distribution	51	0	0	N.A.	N.A.
05.02.1994	Mexico	Villaher-mosa	Local Distribution	8	30	500	N.A.	N.A.
06.02.1994	USA	West Valley	Local Distribution	0	0	200	N.A.	N.A.
24.03.1994	USA	Edison	Local Distribution	1	58	100	N.A.	N.A.
09.12.1994	UK	Camden Town	Local Distribution	0	0	400	N.A.	N.A.
03.01.1995	China	Jilan	Local Distribution	10	57	0	N.A.	N.A.
1.02.1995[1]	China	Jinan	Regional Distribution	10	7	N.A.	N.A.	N.A.
07.02.1995	Belgium	N.A.	Regional Distribution	0	22	N.A.	N.A.	N.A.
17.02.1995	Mexico	Villaher-mosa	Local Distribution	1	22	500	N.A.	N.A.
24.02.1995	Canada	Dorval	Local Distribution	0	32	0	N.A.	N.A.
28.04.1995	South Korea	Taegu	Local Distribution	100	200	0	N.A.	N.A.
13.12.1995	UK	Leeds	Regional Distribution	0	0	300	N.A.	N.A.
15.03.1996	Italy	Paese	Local Distribution	1	11	1	N.A.	N.A.
22.08.1996	Netherlands	N.A.	Heating	1	20	N.A.	N.A.	N.A.

[1] probably the same accident as one line above

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$_{1996}$)
15.01.1969	USA	Springville, (Alabama)	Regional Distribution	0	1	500	N.A.	N.A.
25.01.1969	USA	Laurel	Regional Distribution	2	976	100	3	12.9
20.02.1969	Italy	Bologna	Regional Distribution	10	0	0	N.A.	N.A.
01.10.1969	Spain	Escombreras	Refinery	4	3	5000	7.0	30.1
?.?.1970	USA	Philadel-phia (PA)	Regional Distribution	7	0	0	N.A.	N.A.
21.06.1970	USA	Crescent City (Illinois)	Regional Distribution	0	66	0	3	12.1
09.12.1970	USA	Port Hudson (Missouri)	Long Distance Transport	0	10	1	N.A.	N.A.
25.12.1971	Republic of Korea	Seoul	Heating	169	0	0	N.A.	N.A.
09.02.1972	USA	Tewksbury (Massachus-setts)	Regional Distribution	2	21	0	N.A.	N.A.
30.03.1972	Brazil	Duque de Caxias	Refinery	39	51	0	4.8	17.1
01.07.1972	Mexico	Jimenez	Regional Distribution	8	800	300	1.3	3.6
01.02.1973	France	St Amand-Les-Eaux	Regional Distribution	9	37	1	N.A.	N.A.
10.02.1973	USA	New York	Regional Distribution	40	0	0	31	103.6
22.02.1973	USA	Austin (Texas)	Long Distance Transport	6	2	0	N.A.	N.A.
23.05.1973	Germany	Köln	Regional Distribution	0	0	0	15.4	51.4
05.07.1973	USA	Kingman (Arizona)	Regional Distribution	13	96	100	1	3.4
09.01.1974	Japan	Tokyo Bay	Long Distance Transport	33	0	0	N.A.	N.A.
12.02.1974	USA	Oneonta (New York)	Regional Distribution	0	54	0	N.A.	N.A.
25.08.1974	USA	Petal (Mississippi)	Regional Distribution	0	24	3000	N.A.	N.A.
13.09.1974	USA	Griffith (Indiana	Regional Distribution	0	0	1000	N.A.	N.A.
29.04.1975	USA	Eagle Pass (Texas)	Regional Distribution	16	35	0	50	138.2
07.11.1975	Netherlands	Beek	N.A.	14	106	N.A.	40	110.2

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$.

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
22.10.1975	USA	Fertile (Minnesota)	Regional Distribution	0	5	0	1	2.8
07.11.1975	Netherlands	Beek	N.A.	14	106		40	110.2
14.02.1976	USA	Chicago	Regional Distribution	8	0	0	N.A.	N.A.
24.06.1976	Spain	Zaragoza	Regional Distribution	7	40	0	N.A.	N.A.
30.09.1976	Switzerland	Chiasso	Regional Distribution	0	0	2000	N.A.	N.A.
26.11.1976	USA	Belt (Montana)	Regional Distribution	2	22	200	4.5	12.0
07.02.1977	UK	Glasgow (Strathclyde)	Regional Distribution	0	1	2000	0.04	0.1
03.04.1977	Qatar	Umm Said	Regional Distribution	7	50	0	100	245.4
25.08.1977	Egypt	Cairo	Regional Distribution	14	6	0	N.A.	N.A.
28.12.1977	USA	Goldona (Louisiana)	Regional Distribution	2	10	900	N.A.	N.A.
22.02.1978	USA	Waverly (Tennessee)	Regional Distribution	25	50	0	1.8	4.1
30.05.1978	USA	Texas City (Texas)	Local Distribution	7	10	100	N.A.	N.A.
15.07.1978	Mexico	Xilatopec (near Tula)	Regional Distribution	100	200	0	N.A.	N.A.
05.08.1978	USA	Collinsville	Regional Distribution	2	2	200	N.A.	N.A.
26.09.1978	Spain	Barcelona	N.A.	2	14	0	N.A.	N.A.
03.10.1978	USA	Dencer (Colorado)	Refinery	4	24	0	22	50.1
15.02.1979	Poland	Warsaw	N.A.	49	0	0	N.A.	N.A.
02.03.1979	Canada	Edmonton (Alberta)	Regional Distribution	0	1	19,000	N.A.	N.A.
20.03.1979	USA	Linden (New Jersey)	Processing	0	6	0	17.5	35.8
01.06.1979	Turkey	Batman	Refinery	2	20	0	N.A.	N.A.
07.06.1979	USA	Jay (Florida)	Regional Distribution	0	3	300	N.A.	N.A.
27.06.1979	USA	Pittsfield Township	Regional Distribution	0	0	1000	N.A.	N.A.
30.08.1979	USA	Good Hope (Louisiana)	Regional Distribution	12	36	300	10.5	21.2
06.10.1979	USA	Cove Point	Regional Distribution	1	1	0	3	6.0

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
11.11.1979	Canada	Mississauga	Regional Distribution	0	0	220,000	10	20.5
02.03.1980	USA	Mobino (Florida)	Regional Distribution	11	91	0	5.5	10.0
07.08.1980	USA	New York City	Regional Distribution	0	0	5000	N.A.	N.A.
16.08.1980	Japan	Shizuoka	Regional Distribution	14	199	0	N.A.	N.A.
23.10.1980	Spain	Ortuella	Regional Distribution	53	90	0	N.A.	N.A.
20.11.1980	UK	Wealdstone (Middlesex)	Heating	0	1	2000	N.A.	N.A.
25.11.1980	Turkey	Danaciobasi	Regional Distribution	107	0	0	N.A.	N.A.
?.?.1981	USA	N.A.	Regional Distribution	13	17	0	N.A.	N.A.
30.03.1981	USA	East Flagstaff (Arizona)	Regional Distribution	0	0	1000	N.A.	N.A.
24.04.1981	Belgium	Brussels	N.A.	22	N.A.	0	N.A.	N.A.
26.05.1981	USA	Artesia (New Mexico)	Processing	1	16	0	N.A.	N.A.
31.05.1981	Belgium	N.A.	Regional Distribution	5	0	0	N.A.	N.A.
21.06.1981	USA	Morrisville	Heating	0	0	0	113	179.7
31.07.1981	USA	Moab (Utah)	Long Distance Transport	2	8	2000	8	13.0
13.08.1981	Republic of Korea	Anyang	Regional Distribution	12	0	0	N.A.	N.A.
27.12.1981	Italy	Pisa	Heating	9	0	0	N.A.	N.A.
05.03.1982	Australia	Melbourne	Regional Distribution	0	0	200	N.A.	N.A.
25.04.1982	Italy	N.A.	Heating	34	40	0	N.A.	N.A.
31.05.1982	Indonesia	N.A.	Heating	16	0	0	N.A.	N.A.
26.06.1982	Canada	Lundbreck (Alberta)	Long Distance Transport	0	0	200	2	3.1
28.09.1982	USA	Livingston (Louisiana)	N.A.	0	0	3000	7	10.8
20.11.1982	Turkey	N.A.	Heating	19	32	0	N.A.	N.A.
29.12.1982	Italy	Lucca	Regional Distribution	6	30	0	N.A.	N.A.

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
15.03.1983	USA	West Odessa	Long Distance Transport	6	5	0	N.A.	N.A.
25.05.1983	Egypt	Nile River (South of Abu Simbel)	Regional Distribution	317	44	0	N.A.	N.A.
22.11.1983	Japan	Kakegawa	Regional Distribution	14	27	0	N.A.	N.A.
05.12.1983	USA	Highlands (Texas)	Heating	0	0	2000	20	29.9
27.12.1983	USA	Buffalo (New York)	Regional Distribution	11	70	100	10	14.9
29.02.1984	Taiwan	N.A.	Regional Distribution	9	0	0	N.A.	N.A.
14.05.1984	Greece	Athens	Heating	0	90	0	N.A.	N.A.
13.06.1984	Canada	Salmon Arm (British Columbia)	Regional Distribution	1	23	0	N.A.	N.A.
23.07.1984	USA	Romeoville (Illinois)	Refinery	17	22	0	142	203.2
31.10.1984	USA	San Francisco	Long Distance Transport	0	90	0	35	50.1
04.11.1984	Spain	N.A.	Heating	9	2	0	N.A.	N.A.
19.11.1984	Mexico	San Juan Ixhuatepec (Mexico City)	Regional Distribution	498	7231	200,000	2	2.9
23.01.1985	USA	Wood River (Illinois)	Heating	0	7	0	22.5	4.1
13.02.1985	USA	Delta (Mississippi)	Regional Distribution	0	0	600	0.1	0.1
22.05.1985	Spain	Granada	Heating	0	79	10	N.A.	N.A.
24.05.1985	USA	Eastland (Texas)	Long Distance Transport	0	7	1300	2.5	3.4
23.06.1985	Japan	Osaka	Regional Distribution	6	4	0	N.A.	N.A.
01.07.1985	USA	Knoxville	Regional Distribution	0	0	2000	N.A.	N.A.
13.12.1985	USA	Delta	Regional Distribution	0	0	600	0.1	0.1
16.12.1985	USA	Glenwood Springs (Colorado)	Regional Distribution	12	15	0	1.5	2.1
23.01.1986	Italy	Modena	Regional Distribution	7	0	0	N.A.	N.A.

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
01.05.1986	USA	Severna Park	Regional Distribution	1	2	300	N.A.	N.A.
22.05.1986	Portugal	N.A.	Regional Distribution	8	50	0	N.A.	N.A.
15.06.1986	Mexico	Coatzacoalcos (Pajaritos Lagoon)	Regional Distribution	2	15	0	N.A.	N.A.
22.07.1986	USA	Petal (Mississippi)	Regional Distribution	0	12		N.A.	N.A.
07.10.1986	USA	Houston (Texas)	Regional Distribution	12	7	0	N.A.	N.A.
28.12.1986	Germany	Garmisch-Patenkirchen	Regional Distribution	11	8	0	N.A.	N.A.
13.03.1987	Italy	Porto San Vitale	Regional Distribution	13	0	0	N.A.	N.A.
06.07.1987	Germany	Langen-wendigen	Regional Distribution	83	0	0	N.A.	N.A.
22.07.1987	USA	Brooklyn (New York)	Heating	4	11	0	N.A.	N.A.
15.08.1987	Saudi Arabia	Juaymah	N.A.	0	4	0	65	84.8
17.08.1987	Australia	Cairns (Queensland)	N.A.	1	23	300	5	6.6
14.11.1987	USA	Pampa (Texas)	Refinery	3	37	0	N.A.	N.A.
05.05.1988	USA	Norco (Louisiana)	Refinery	7	42	4500	150	187.6
22.10.1988	China	Shanghai	Refinery	25	17	0	N.A.	N.A.
23.12.1988	USA	Memphis	Regional Distribution	9	10	0	N.A.	N.A.
26.02.1989	USA	Akron (Ohio)	Regional Distribution	0	0	2000	N.A.	N.A.
21.03.1989	Australia	Maryboroug h	Regional Distribution	6	0	0	N.A.	N.A.
20.05.1989	Russia	N.A.	Long Distance Transport	5	100	0	N.A.	N.A.
04.06.1989	Russia	Asha-Ufa	Long Distance Transport	600	755	0	N.A.	N.A.
12.07.1989	USA	Almetyevsk	Processing	4	6	1000	N.A.	N.A.
27.12.1989	USA	Batesville (Arkansas)	Heating	0	0	4800	N.A.	N.A.

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 $US\$_{1996}$)
01.04.1990	Australia	St. Peters (New South Wales)	N.A.	0	0	600	N.A.	N.A.
16.04.1990	India	Kumrahar (Bihar State)	Regional Distribution	100	65	0	N.A.	N.A.
23.05.1990	Arab Emirates	Dubai	Extraction	5	0	0	N.A.	N.A.
31.05.1990	Egypt	Abu Hamad (Sharqiya)	Regional Distribution	10	7	0	N.A.	N.A.
10.07.1990	Brazil	Rio de Janeiro	Refinery	0	11	0	N.A.	N.A.
24.09.1990	Thailand	Bangkok	Regional Distribution	68	100	0	N.A.	N.A.
06.11.1990	India	Nagothane	Regional Distribution	35	30	0	22.6	25.7
13.03.1991	UK	N.A.	Regional Distribution	10	25	0	N.A.	N.A.
?.05.1991	USA	Sterlington (Louisiana)	Regional Distribution	8	125	0	N.A.	N.A.
?.09.1991	Indonesia	Borneo	Long Distance Transport	17	0	0	N.A.	N.A.
29.12.1991	Mexico	San Luis Potosi	Heating	30	0	0	N.A.	N.A.
08.04.1992	USA	Breham	Regional Distribution	1	20	0	N.A.	N.A.
23.06.1992	China	Jiangxi	Regional Distribution	37	600	0	N.A.	N.A.
?.12.1992	Turkey	Sekorya	Regional Distribution	22	0	0	N.A.	N.A.
07.01.1993	South Korea	Chongju	Heating	27	50	0	N.A.	N.A.
08.02.1993	Pakistan	Lahore	Regional Distribution	14	7	0	N.A.	N.A.
17.03.1993	USA	Fort Lauderdale	Regional Distribution	6	15	0	N.A.	N.A.
25.03.1993	Venezuela	Maracaibo	Long Distance Transport	11	1	0	N.A.	N.A.
03.06.1993	Italy	Milazzo	Refinery	7	16	0	N.A.	N.A.
05.07.1993	USA	Harriman	Local Distribution	0	4	200	N.A.	N.A.
02.08.1993	USA	St.Louis	Regional Distribution	0	0	11,500	N.A.	N.A.

N.A.: Not available

Table C.2

Severe LPG accidents with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ (Cont.).

Date	Country	Place/Name of the unit	Energy chain stage	Max. No. Fatalities	Max. No. Injured	Max. No. Evacuees	Max. Costs (10^6 US$)	Max. Costs (10^6 US$$_{1996}$)
05.08.1993	China	Qingshuine	Local Distribution	15	160	N.A.	N.A.	N.A.
23.08.1993	Egypt	Alexandria	Refinery	1	70	0	N.A.	N.A.
25.08.1993	Turkey	Nurdagi	Regional Distribution	6	23	0	N.A.	N.A.
25.09.1993	USA	Yountville	Local Distribution	0	1	1600	N.A.	N.A.
29.11.1993	South Korea	Ulsan	Regional Distribution	6	10	0	N.A.	N.A.
27.02.1994	Canada	Burlington	Regional Distribution	0	11	200	N.A.	N.A.
27.07.1994	USA	White Plains	Local Distribution	0	23	0	N.A.	N.A.
19.10.1994	USA	Torrance	Refinery	0	21	0	N.A.	N.A.
09.02.1995	USA	Bennington	Regional Distribution	0	0	264	N.A.	N.A.
17.02.1995	Mexico	Villaher-mosa	Regional Distribution	1	22	500	N.A.	N.A.
12.03.1995	India	Madras	Regional Distribution	120	N.A.	N.A.	N.A.	N.A.
26.04.1995	Jamaica	St. Ann	Heating	2	12	0	N.A.	N.A.
24.06.1995	Canada	Lennoxville	Regional Distribution	0	0	300	N.A.	N.A.
17.12.1995	Brazil	Sao Paulo	Regional Distribution	22	9	0	N.A.	N.A.
04.03.1996	USA	Weyauwega	Regional Distribution	0	0	1700	N.A.	N.A.
26.03.1996	USA	Hunterdon County	Regional Distribution	0	0	200	N.A.	N.A.

N.A.: Not available

Appendix D: Historical nuclear accidents

This Appendix is divided into two parts. The first includes a table summarising the severe nuclear accidents. The table is followed by a short description of the included severe accidents as well as other selected nuclear accidents. Part two of this Appendix separately and more accurately describes the Chernobyl accident because of the dimensions of its impacts to the population, the environment and the economy of Belarus, Russian Federation and Ukraine.

D.1 Survey of nuclear accidents

Table D.1, on the next page, shows an overview of the severe nuclear accidents recorded from the early times of the nuclear industry up to end of 1996, according to the classification given in this report. Table D.1 uses a format similar to the appendixes in this report related to other energy chains.

The second part of this section, following the table, contains an overview of selected nuclear accidents, in reverse temporal order, including major ones. Relevant for this report are primarily the accidents in the civil nuclear industry which occurred in power plants as well as in other stages of the nuclear fuel chain. Nevertheless, notes are also given on some accidents which took place in military installations (when information was available) and at research facilities. However, information about accidents occurred in nuclear-powered submarines and ships are not included here.

The present compilation is not complete. The collected accidents have not been rigorously classified; the information on accident characteristics given here relies solely on the references used. The description of the principal accidents includes, if available, the initiating event, the main steps in the sequence of events, some information on the source term, the estimated health and environmental consequences, and the cost. This list is based on several references, including [UNSCEAR, 1993], [IAEA/NEA, 1992], [Nathwani et al., 1992], [Pharabod et al., 1988].

Table D.1

Severe[a] nuclear accidents

Date	Place	Country	Type of facility [b]	Source Term to air (Bq) [c]	Early fatalities (workers)	Estimated latent fatalities W=workers P=population	Injured	Contaminated Land [d] (km^2)	Evacuees	Costs (10^6 US$)
06.04.1993	Tomsk-7	Siberia, Russian Federation	Rp (M)	$2 \cdot 10^{13}$-$4 \cdot 10^{13}$	na	na	na	~100 (> 10 µR/h)	0	na
26.04.1986	Chernobyl	Ukraine (former USSR)	R (C)	$1.2 \cdot 10^{19}$-$1.5 \cdot 10^{19}$	31	W≈2200-2700 P≈7000-30000	370 [e]	~154620 [f] (> 37 kBq/m^2 Cs-137) [e]	115000-135000 [g]	~$20 \cdot 10^3$-$320 \cdot 10^3$
28.03.1979	Three Mile Island	Pennsylvania (USA)	R (C)	$3.7 \cdot 10^{17}$	0	P≈1	0	0	144000 [h]	~$5 \cdot 10^3$
1967	Lake Karachay	Mayak site Southern Urals, (former USSR)	WS (M)	$2.2 \cdot 10^{13}$	---	P≈16	---	1800-2700 (> 3.7 kBq/m^2 Cs-137/Sr-90)	0	na
08.10.1957	Windscale	UK	R (M)	$1 \cdot 10^{15}$-$5 \cdot 10^{15}$	0	P≈100	0	520 (ban of milk for I-131)	0	£ 60000 [i]
29.09.1957	Chelyabinsk 40 (now Chelyabinsk 65)	Mayak site Southern Urals, (former USSR)	Rp (M)	$7.4 \cdot 10^{16}$	na	P≈125	na	~23000 (> 3.7 kBq/m^2 Cs-137/Sr-90)	10800 [j]	na
15.07.1955	Aue	Sachsen (former East Germany)	M (M)	---	33	---	na	---	---	na

Notes to Table D.1

na = not available

[a] According to the classification given in this report. Accidents which had minor or negligible consequences outside the plant's fence are not included here unless referenced economic damage data were available.

[b] R = Reactor; Rp = Reprocessing Plant; WS = Waste storage; M = Mine. (C) = Civil; (M) = Military.

[c] No isotopic composition given here (see following sub-sections). No comparisons of impacts can be done among the shown accidents on the basis of this figure alone.

[d] No attempt has been made here to use a reference radioactive species for all accidents. Therefore, the areas given in the table are only indicative of the order of magnitude of contamination. Details about the type of contamination are given in the text.

[e] Assuming about 400 persons hospitalised soon after the accident occurred minus 31 who died (see Subsection **D2**).

[f] This includes only areas within the three most affected countries.

[g] Permanently. These persons were evacuated in 1986. Other groups have been resettled during the past ten years after the accident, but in the literature the number of these people is not separated from the number of persons who voluntarily moved away from contaminated areas.

[h] Temporarily.

[i] Includes only the main cost of the accident for condemned milk. According to [Arnold, 1992] the two piles closed after the event in the unit No.1 would have been closed down soon independently of this event because they were uneconomic.

[i] Within 18 months from the accident.

⇒ **Most severe reactor accidents:**

- Chernobyl (Ukraine, former USSR) 26 April 1986.

  The accident and its consequences are described in Section D.2. It has been classified at the highest rank (level 7) on the IAEA/NEA international nuclear accidents severity scale INES[1] [IAEA/NEA, 1992].

- Three Mile Island TMI-2 (Pennsylvania, USA) 28 March 1979.

  The accident occurred in a 843 MW_e PWR as a result of equipment failure combined with human errors. The sequence of events was initiated at about 4 a.m. by a interruption in the water flow of the secondary loop (condensate pump trip). Following this, the control and emergency systems intervened as intended: the turbine generator tripped and the Emergency Feedwater System (EFS) started. However, the feedwater could not enter the Steam Generators (SG) because the valves had been left erroneously closed following a test operation of the EFS. This caused loss of heat sink for the primary coolant[2] and overpressurization of the primary loop. The reactor was shut-down (scram); this occurred few seconds after the initial event. The pressurizer's power-operated relief valve opened to relieve pressure. Unfortunately, instead of closing at its reset value, it remained stuck-open, thus initiating a Loss of Coolant Accident (LOCA). This valve was defect (it had been leaking) and its substitution already planned. The signal of "valve closed" actually referred to "valve energised to close" but not to its actual position. Therefore, the operators were not in the condition to have a correct picture of the real plant situation at that time. The primary side continued to depressurize and the High Pressure Injection System (HPIS), one of the Emergency Core Coolant Systems (ECCS), started operation two minutes into the event. After about two more minutes, the operators stopped one of the two ECCS pumps in order to prevent the primary to become "solid" (i.e., completely filled with subcooled water), a condition that they had been trained to absolutely avoid. Due to the continuous spill of primary water and the insufficient replacement of lost inventory, the depressurization continued. The water became saturated, steam-filled voids formed and the mass swelled thus giving high level signal in the pressurizer. The operators did not interpret it correctly, and decided to throttle the ECCS water delivery which in turn caused further decrease of the water inventory. The primary pumps were turned off at different times into the events, after about 70 and 100 minutes, because the two-phase mixture was causing cavitation and vibrations. Just before two hours from the beginning, the core began to uncover because of boil off of the water in the vessel. The fuel overheated for lack of cooling, the zircaloy cladding burst and started to react with

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1 The INES scale has been established at the beginning of the 90s with the main purpose of improving communication of the significance of nuclear events to the public.

2 The plant was equipped with SGs of the once-through type (Babcock & Wilcox), whose secondary has little water capacity. The operators realised what was going on only after a few minutes, with the secondary side already dried out.

steam to give hydrogen. The core lost its integrity and started to partially melt at about 140 minutes; shortly afterwards, radioactivity was released through the primary into the containment and was detected by the instrumentation. At 225 minutes into the events, part of the core slumped into the vessel lower plenum. Ultimately, the operators understood that a LOCA was taking place, succeeded to circumvent the failed valve, and managed to cool down the disassembled core with the operation of the HPIS. The melting stopped completely at approximately 300 minutes. Any spread of core material inside the containment was prevented: the corium remained confined inside the pressure vessel. The developed hydrogen formed a bubble which initially obstructed the coolant flow in the primary. From 29 March to 1 April, there was fear of an in-vessel hydrogen explosion, but later this was proven to be unrealistic. The hydrogen was ultimately released into the containment where it partly deflagrated about 10 hours into the accident giving a pressure spike, without any damage to the containment structure [3].

The bulk of the radioactive emissions to the environment was made of noble gases (mostly Xe-133), which leaked through the vent gas header of the waste gas system. Various estimations of the source term and the cumulative dose to the population within 50 miles of radius around the plant (about two million people) were performed soon after the accident. A survey of these estimations is given in [Knight et al., 1981]. Estimations based on calculations using records of in-plant radiation monitors gave a release of noble gases to the environment of the order of 370 PBq (~10 MCi)[4]. Only 0.55 TBq (15 Ci) of iodine were released to the environment ([Bennett, 1995] after [Clarke, 1989]). The exposure to public was on the average a few percent of the natural background radiation and no one was exposed to amounts comparable to it[5]. The early estimates of cumulative population dose ranged 0.5-50 person-Sv (50-5000 person-rem)[6]. One extra cancer fatality has been estimated for the public.

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3 Information taken from various sources, among others: [Kemeny, 1979], [Williams et al., 1981], [Thomas, 1986], [Tolman et al., 1986].

4 Auxier et al. [1979] estimated 2.37 MCi up to 7 April from measurement of noble gases from the station vent monitor. From calculations performed by PL&G [1979] using thermoluminescent dosimeter (TLD) measurements, the total noble gases release was 10 MCi. Knight et al. [1981] give 7.1-16.6 MCi. 2.5 MCi are given in [Williams et al., 1981]. 10 MCi is the value mentioned in [Bennett, 1995]. Residual noble gases (about 1.6 PBq or 44000 Ci, mostly Kr-85) were vented in controlled conditions between 28 June and 11 July 1980 [Morrell, 1982].

5 UNSCEAR [1993] reports that in the worst case the dose was < 1 mSv, i.e. less than the yearly world-wide average individual dose, which is 2.4 mSv/a, given in the same reference.

6 Based on a limited number of TLD dose readings, without shielding during indoor occupancy, the cumulated dose for the population within 50 miles around the plant was estimated by the Ad Hoc Interagency Dose Assessment Group [NUREG, 1979] in the range 1600-5300 person-rem, with 3300 person-rem as the best estimate. DOE [1979] calculated 2000 person-rem, from measurements of the radiation exposure rates in the plume recorded during helicopter flights, but subsequent instrument calibration revealed that the raw exposure should be halved to take into account the instrument over-response. Therefore, the DOE estimate [1979] should be referred to as 1000 person-rem. General Public Utilities' Consultants PL&G [1979] with an approach similar to the Ad Hoc Group calculated 3500 person-rem, without indoor shielding. The President's Commission on the Accident at Three Mile Island concluded, using the assessments performed by various national scientific organisations, that the

144000 people were evacuated from the area around the plant [Sorensen et al., 1987][7]. Cleanup work inside the containment continues to date. Komanoff [1986] estimated the total cost of the TMI accident to be about 130 Billion US$. The direct costs including evacuation and cleaning are, however, only a small part of this estimate, 4 Billion US$.

The accident has been classified at level 5 of the IAEA scale of nuclear accidents, based on the off-site impact [IAEA/NEA, 1992].

- Windscale (UK) 8 October 1957; military reactor.

  The reactor was a graphite moderated, air-cooled (open-circuit) pile for military plutonium (and tritium) production. During the planned (8 October) operation (annealing) to allow the release of the 'Wigner energy' stored in the graphite, by using nuclear heating, the graphite in some 140 channels out of 3440 caught fire (pile cold on 12 October). Possible originating causes of the fire were assessed to be: an excessive increase in the temperature of the fuel which caused fuel cladding to fail and uranium to oxidise adding heat to the pile; or, lithium-magnesium cladding failure and following oxidation; or, highly irradiated graphite oxidation at relatively low temperatures. Eventually water was used to quench the fire. Of 180 t of uranium fuel in the pile, about 22 where not recovered; it was estimated that 5 t have been burnt.

  Radioactivity was released, in particular much of I-131 inventory, while high proportion of other fission products was retained inside the pile and, to a lesser extent, in the filters at the top of the chimney. Approximately 16200-27000 Ci of I-131, 600-1230 Ci of Cs-137, 80-200 Ci of Sr-89, 2-9 Ci of Sr-90, 12000-16100 Ci of Te-132, 80-160 Ci of Ru-106, 80-109 Ci of Ce-144, a few hundred curies of Po-210 and possibly 100000 Ci of H-3[8] were released to air, according to various estimations (this gives a total radioactive emission to air of approximately $1\cdot10^{15}$-$5\cdot10^{15}$ Bq)[9]. Milk was found to be contaminated by I-131 and its consumption banned in a restricted area of 200 square miles (520 km^2). Several assessments of health impacts have been performed to date. Differences were in the source term, recognition of pathways, and dose-effect relationships especially at low levels. Approximately an upper bound of additional 33 fatal cancers (to thyroid — 13 cases—, lung, intestines) with 237 non-fatal cancers in several decades following the accident in the UK have been calculated using the collective dose approach (including very low

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most probable cumulated population dose was 500 person-rem [Auxier et al., 1979]. However, as a result of the many variables, the result could be in error by as much as one order of magnitude, therefore in the range 50-5000 person-rem. From TLD measurements, the President's Commission estimated cumulative dose of 2800 person-rem withou indoor shielding and 2000 person-rem with shielding. The President's Commission conservatively assumed 3000 person-rem for the purpose of the assessment of health risks, and 2000 person-rem for the genetic effects risks [Casarett et al., 1979].

7 The extent of population evacuation was early estimated at about 35% of the inhabitants within 10 mile radius of TMI; most of these people did not leave the area before 30 March [Knight et al. 1981].

8 Value for tritium is according to one only author.

9 Figures were given by one author about releases of Kr-85, Y-90, Zr-95, Ni-95, Ru-103, Te-129, Xe-131, Xe-133, Xe-135, Ba-140, Mo-99 and Ce-141. Some contaminated water was discharged to sea.

individual levels), 5% thyroid cancer mortality rate, and ICRP 1977 risk coefficients [Crick et al., 1982/3]; using the UNSCEAR 1988 risk coefficients an upper bound of 100 cancer deaths (mostly lung cancer) over a period of 40-50 years in the UK and 90 non-fatal cancers (mostly thyroid cancer) and 10 hereditary defects have been assessed by Clarke [1988]. The main cost of the accident was for condemned milk, approximately £60000 (the two piles closed after the event in the unit No.1 would have been closed down soon in any case because they were uneconomic compared with the Calder Hall reactors). All information on the Windscale fire has been extracted from [Arnold, 1992].

The accident has been classified at level 5 of the IAEA scale of nuclear accidents, based on the off-site impact [IAEA/NEA, 1992].

⇒ **Additional accidents at commercial, demonstration, research and military nuclear reactors[10]:**

° Monju (Japan) 8 December 1995.

The accident occurred in a 280 MWe Fast Breeder Reactor. Sodium leaked from the secondary coolant loop piping, on the outlet side of the intermediate heat exchanger. There was neither release of radioactivity nor damages to personnel [NEI, 1996 b].

° Constituyentes (Argentina) 23 September 1983.

The accidental power excursion caused by a change in the configuration of the critical assembly RA-2, done without observing safety rules, determined the severe irradiation of one operator probably standing only 3-4 m away from the core, who died for the received gamma dose of 21 Gy and neutron dose of 22 Gy [IAEA/NEA, 1992], [Pharabod et al., 1988].

The accident has been classified at level 4 of the IAEA scale of nuclear accidents, based on the on-site impact [IAEA/NEA, 1992].

° Saint-Laurent-des-Eaux (France) 10 February 1980.

Due to a too rapid power increase in the 515 MW_e gas-graphite reactor Saint-Laurent 2, 20 kg of irradiated uranium melted. The plant was contaminated. The doses to the public were lower than the maximum allowable. Reparation work took more than one year [Pharabod et al., 1988].

The accident has been classified at level 4 of the IAEA scale of nuclear accidents, based on the on-site impact [IAEA/NEA, 1992].

[10] The accidents listed under this heading involve fatalities and/or external release of radioactivity and/or substantial economic loss. They are not considered "severe" with view to the environmental and health effect components in the definition of "severe accident" used in the present work. However, the extent of economic damages is not known to the authors of this report. The list is not complete.

° Bohunice (former Czechoslovakia) 5 January 1976.

During re-charging operations, sudden depressurization occurred in a 110 MW_e heavy-water moderated, CO_2-cooled reactor. Two operators asphyxiated. Radioactivity (not quantified) was released to the environment [Pharabod et al., 1988].

° Grenoble (France) 19 July 1974.

$9 \cdot 10^{13}$ Bq or 2500 Ci of Sb-124 were released into the pool of the high enriched fuel, high-flux reactor at the Laue-Langevin Institute (47 MW_{th}), followed by external release. Contamination of underground water occurred [Pharabod et al., 1988].

° Savannah River (South Carolina, USA) 2 May 1974.

Radioactivity was released from a heavy-water military reactor. External tritium contamination [Pharabod et al., 1988].

° Chevtchenko (former USSR) September 1973.

In a 1000 MW_{th}, 150 MW_e breeder reactor (partly used to desalinate water from the Caspian Sea) 400 kg of water went into the secondary circuit with non-radioactive sodium, causing an explosion sodium-water to occur, release to the atmosphere and hydrogen fire. No information is available on the possible fatalities [Pharabod et al., 1988].

° Lucens (CH) 21 January 1969.

The accident occurred in a 6 MW_e (28 MW_{th}) heavy water moderated, CO_2-cooled prototype reactor, located in an underground cavern. During a shut-down period, leakage from a water seal of a primary gas blower had caused severe corrosion damage to the magnesium cladding of several fuel elements. At start-up, the product of such corrosion caused gas flow obstruction. Many fuel elements heated up, melted down and the cladding of a peripheral element caught fire. Pressure tubes burst, then burst the moderator tank (loss of integrity of the primary) [SGK, 1992]. Thus, contaminated heavy water and CO_2 were released in the cavern but negligible radioactivity reached the environment (approximately $3.4 \cdot 10^{12}$ Bq or 92 Ci of noble gases isotopes and $2.7 \cdot 10^{7}$ Bq or 740 μCi of aerosols [UKL, 1979]).

° Grenoble (France) 7 November 1967.

One fuel element (90% enrichment) in the experimental pool reactor Siloé (15 MW_{th}) melted. $2 \cdot 10^{15}$ Bq or 55000 Ci were released into the pool, $7.4 \cdot 10^{13}$ Bq or 2000 Ci were released to air [Pharabod et al., 1988].

° Mol (Belgium) 30 December 1965.

Power excursion occurred in a research rector. One person was severely irradiated (amputation of one foot) [Pharabod et al., 1988].

- Idaho Falls (Utah, USA) 3 January 1961; National Reactor Testing Station.

  The accident occurred in the 3 MW_{th} reactor SL1 (Stationary Low Power Reactor No. 1) in the research centre in Idaho Falls. This reactor, fuelled with highly enriched uranium (93%) in slabs of uranium-aluminium alloy, moderated and refrigerated by light water, was designed to be utilised in an Arctic military base for the generation of 200 kW_e and hot water. The control rods had the tendency to stick and the operators had to manually move them up and down from time to time. The 3 military staff members charged of the maintenance work died. The accident was probably caused by one of the operators who manually lifted the central control rod, which caused the core to become supercritical. The fuel possibly broke into fragments and the tank containing the core burst due to overpressure. That operator was found hanging from the ceiling with the rod stuck in his body. Some small amount of iodine and noble gases were released to air, but 99.99% of the radioactivity remained confined in the building which was decontaminated and finally decommissioned in about one year and an half [Pharabod et al., 1988].

  This accident was preceded at the same research centre by two other events of the same kind (reactivity accidents) without serious consequences. The first occurred on 29 November 1955 at EBR-1 (Experimental Breeder Reactor, 1.2 MW_{th}, fast reactor cooled by liquid metal). Following a decrease in the cooling rate, the reactor experienced a power increase which was arrested before it diverged, though causing the melting of half of the core; the personnel was not irradiated. The second occurred on 18 November 1958 at HTRE-3 (Heat Transfer Reactor Experiment, 120 kW_{th} reactor cooled by air and moderated by a compound hydrogenated of zirconium). It also underwent an uncontrolled power increase because of an error in the instrumentation, which caused part of the core to melt [Pharabod et al., 1988].

- Vinca (former Yugoslavia) 24 October 1958; research reactor.

  On 24 October a power excursion took place in a heavy water research reactor without explosions. Six persons were seriously irradiated, one died [Pharabod et al., 1988].

- Marcoule (France) 14 December 1956.

  During a power increase operation in the gas-graphite military reactor G2 (200 MW_{th}, 36 MW_e) the temperature in one channel increased without being detected, the cladding burst and 100 channels out of 1200 were contaminated. The coolant CO_2 was discharged to the environment to allow repair work on the core. Irradiation to the public was considered small by the authorities. High doses were received by the personnel during the reparation [Pharabod et al., 1988].

- Marcoule (France) October 1956.

  The fuel in one channel oxidised and melted the first time the gas-graphite military reactor G1 was reaching the maximum power (40 MW_{th}, 3 MW_e). Due to the filters, negligible external contamination occurred [Pharabod et al., 1988].

° Chalk River (Ontario, Canada) 21 December 1952.

The core of the NRX heavy water 40 MW_{th} reactor was damaged due to a power increase caused by a wrong manoeuvre of the control rods. The radiation exposure of the workers was small (31 persons received doses 4-17 rem [Pharabod et al., 1988]). The core was replaced in two years. The reactor is still in operation [Nathwani et al., 1992].

⇒ **Most severe accidents in other commercial installations of the nuclear energy chain and in military nuclear facilities other than reactors:**

° Tomsk-7 (Siberia, Russian Federation) 6 April 1993; chemical combine (reprocessing plant), military installation.

An explosion resulted from the decomposition of the organic phase of a uranium solution when interacting with concentrated nitric acid [probably in a separator]. A facility of the complex was destroyed by the explosion of the steam/gas mixture. Activity was released to the environment, contaminating an area 25 km long, up to 6 km wide, of about 100 km^2 outside the combine's fence, with exposure rates > 10 μR/h. Within this area, 20-22 TBq (530-590 Ci) were deposited[11], thereof 1% Ru-103, 31% Ru-106, 22% Zr-95, 45% Nb-95, and 0.02% Pu-139[12]. Hot particles were deposited on the ground. Because of wash out, the contamination was uneven. Some areas had to be decontaminated. The passage of the cloud gave the population an average individual dose <15 μSv (1.5 mrem) from inhalation of Pu-239. The village of Georgevka was the only one contaminated, with level of 60 kBq/m^2 (1.6 Ci/km^2) immediately after the event. The average lifetime dose from external irradiation to the population of this village was calculated to be only a small fraction of the dose due to natural background. The limits for contamination of drinking water may be exceed. The above information has been summarised from [Shershakov et al., 1995] (also [Vakulovski et al., 1996]).

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[11] The early official report about the accidents ([Vladimirov et al., 1993], mentioned in [Vakulovski et al., 1996]) gives for the inventory contained in the affected facility at the time of the explosion 500 Ci of beta-active and 20 Ci of alpha-active products, including 19.3 Ci (714 GBq) of Pu-239. The species Ru-103, Ru-106, Zr-95 and Nb-95 were not included in the list. When these species are considered, the estimated total inventory in the failed facility prior to the explosion would be 3000-3500 Ci [Shershakov et al., 1995]. The release to the environment was reconstructed on the base of ground contamination measurements. A release of 720 Ci was calculated, which is within the expected range (~10^3 Ci or ~40 TBq) of approximately one third of the inventory [Shershakov et al., 1995]. Based on poor information, Aarkrog [1995] reported that 1.5 TBq of radioactivity, mostly Nb-95 and Ru-106, and 50 GBq of Pu-239 may have been released.

[12] Traces of Ce-144 and Sb-125 were also found in the samples. Soil contamination with Cs-137 was said to be originated by releases in previous years of operation of the complex [Vakulovski et al., 1996].

° Lake Karachay (Mayak site, southern Urals, former USSR) 1967; military complex.

Since September 1951 diluted high level radioactive waste which had been discharged in the Techa River, was diverted into the lake. In 1953 an intermediate waste storage facility was put into operation and the discharge of high level waste stopped but the discharge of medium level waste continued [Cochran et al., 1993]. The total discharged activity was 3.6 EBq of Cs-137 and 0.74 EBq of Sr-90 [Aarkrog, 1995][13]. In summer 1967 an extreme draught occurred which caused an activity of about 22 TBq or nearly 600 Ci[14] to be dispersed by the wind over an area of 1800-2700 km^2 at a level > 3.7 kBq/m^2 (> 0.1 Ci/ km^2) and to a distance of up to 75 km, affecting about 41000 people [Kossenko, 1991], [Cochran et al., 1993][15]. This contamination overlapped the south-eastern part of the area contaminated as a consequence of the so-called Kyshtym accident (see below).

The area of the lake is still heavily contaminated. Kryshev et al. [1996] report that in year 1990 the Cs-137 and Sr-90 contamination of the water was $4.4 \cdot 10^8$ Bq/l and $6.3 \cdot 10^7$ Bq/l, respectively, and of the sediments $5.2 \cdot 10^{10}$ Bq/kg and $1.1 \cdot 10^{10}$ Bq/kg, respectively. In the same year, the dose rate for a person standing on its shores was 18-20 rem/hr [Cochran et al., 1993]. An estimated volume of 4 million m^3 [Kossenko, 1991] of groundwater up to a distance of 2.5-3 km from the lake is contaminated with approximately 5000 Ci of caesium and strontium [Cochran et al., 1993]. Since 1985, the lake is slowly being filled and covered to reduce the dispersion of radioactivity. The plan should have been completed by the end of 1995.

° Chelyabinsk 40 (now Chelyabinsk 65, Mayak site, southern Urals, former USSR) — so-called Kyshtym accident, 29 September 1957; military complex.

For more than thirty years, up to the time the USSR collapsed, a strict secrecy on the causes and consequences of this accident was maintained by the Soviet authorities. Early guesses were made by the Russian biochemist Medvedev [1979] and American researchers of the Oak Ridge National Laboratory (ORNL) [Trabalka et al., 1979]. They said that probably an explosion in a military reprocessing facility or depository of radioactive waste had occurred[16], either caused by a nuclear criticality accident or

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[13] The same total radioactivity is given in [Kryshev et al., 1996].

[14] According to Kossenko [1991] and Aarkrog [1995]; 20 TBq are given in [UNSCEAR, 1993].

[15] Kossenko [1991] reports that of 41500 people living in the 2700 km^2 contaminated area 4800 received external irradiation dose of 13 mSv whereas the remaining 36700 received about 7 mSv. This would make about 320 person-Sv from external irradiation, which would correspond to about 16 additional cancer deaths. Kossenko also quotes Romanov et al. [1990] who stated that the overall effective equivalent doses did not exceed 2-4 mSv (the upper value would make about 170 person-Sv).

[16] Included in the complex are: plutonium production graphite-moderated reactors, light water reactors for tritium production, chemical separation plants, mixed-oxide fuel fabrication plants, tritium handling facilities, spent fuel storage facility, plutonium storage facility, site for three fast breeder reactors

(more likely) by violent chemical reactions. An area of approximately 1000 km^2 was said to had been interdicted to the public due to high contamination. The ORNL team concluded that an area ~100 km^2 was contaminated at a level of approximately 1000 Ci/km^2 of Sr-90 (reference radionuclide), and that the total area of the contamination zone (≥1 Ci/km^2) might exceed 1000 km^2. The total release of strontium was estimated of the order 10^5-10^6 Ci [Pharabod et al., 1988].

Information that was previously classified in the former Soviet Union has been recently disclosed. As reported in [Bennett, 1995] and [Aarkrog, 1995] it was confirmed that a chemical explosion of a 300 m^3 [UNSCEAR, 1993] tank containing solutions of fission products (70-80 t of waste [UNSCEAR, 1993]) in sodium nitrate (up to 100 g/l) and in sodium acetate (up to 80 g/l) [Bradley et al., 1996] occurred in a high level radioactive waste storage tank containing a total activity of 20 MCi [Bradley et al., 1996], [Cochran et al., 1993] (approximately 1 EBq or 27 MCi according to [UNSCEAR, 1993]). The explosion was triggered by a failure in the water cooling system which resulted in self-heating of the salts. They dried out becoming explosive. The total source term to the environment was 74 PBq or 2 MCi [Buldakov et al., 1996], [Bradley et al., 1996], [Aarkrog, 1995], while the rest remained in the immediate vicinity of the tank [Bradley et al., 1996], [UNSCEAR, 1993]. Most of the dispersed activity deposited within an area 300×50 km [Aarkrog, 1995], also called East-Ural radioactive trace; 23000 km^2 were contaminated to a level > 0.1 Ci/km^2 (or > 3.7 kBq/m^2) of Sr-90[17]. This oblong contaminated surface was due to the stable wind and no precipitation conditions [UNSCEAR, 1993]. The most important radioisotopes released were Ce-144 (49 PBq), Zr-95 and Nb-95 (19 PBq) Sr-90 (4.0 PBq) and Ru-106 (2.7 PBq); Cs-137 amounted only to 27 TBq [Bennett, 1995]. Due to the isotopic composition of the release, 3 years after the accident Sr-90 and its daughter product Y-90 have become the dominant species (99.3% of total is reported in [Cochran et al., [1993]).

In total, about 10800 persons were evacuated ([Buldakov et al., 1996], also in [UNSCEAR, 1993]). The evacuation of the majority of the people was initiated 8 months after the accidents and was completed 10 month later, from areas with contamination of Sr-80 > 150 kBq/m^2 [UNSCEAR, 1993][18]. The average effective dose

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(construction stopped), nuclear waste facilities, other military manufacturing facilities [Cochran et al., 1993].

17 Alexakhin et al. [1996] give the following contaminated surfaces: 23000, 1400, 400 and 280 km^2 with > 3.7, > 37, > 370, and > 3700 kBq/m^2, respectively. The highest density of contamination, along the axis and near to the source, was $5.6 \cdot 10^6$ kBq/m^2, including all radionuclides. Similar figures for the contaminated areas are given in [Kossenko, 1991]. Buldakov et al. [1996] give only 15000 km^2 with > 3.7 kBq/m^2 (270000 people living within this area).

18 The dynamics of evacuation and doses given by Buldakov et al. [1996] is as follows: 1150 people in 7-10 days, from areas with average Sr-90 contamination of 18500 kBq/m^2, who received an individual effective dose equivalent of 520 mSv; 280 people, 250 days, 2400 kBq/m^2, 440 mSv; 2000 people, 250 days, 670 kBq/m^2, 120 mSv; 4200 people, 330 days, 330 kBq/m^2, 56 mSv; and, 3100 people, 670 days, 120 kBq/m^2, 23 mSv. The total commitment dose would be approximately 1300 person-Sv.

for the 1154 people evacuated within 10 days from the accident was about 520 mSv, 170 mSv from external irradiation and 1500 mSv from irradiation to the gastro-intestinal tract ([UNSCEAR, 1993], from various sources), giving a collective dose for this group of about 600 person-Sv.

The accumulated internal doses up to year 1993 in the most affected sites, Rybnikovo and Scherbakovo is estimated as: 112-196 mSv to the bones; 51-88 mSv to the red bone-marrow; 4-7 mSv of effective equivalent dose. The average irradiation doses to the lower part of the large intestine were 15-110 mSv with an effective equivalent dose to the gastrointestinal tract of 4-7 mSv [Chukanov et al., 1995]. The accumulated doses due to external irradiation in the most contaminated areas are in the range 3-17 mSv. The integral effective equivalent dose due to all sources estimated for the most critical group, which includes children born between 1955 and 1957, is about 48-52 mSv [Chukanov et al., 1995]. The same source states that an epidemiological analysis of the health indexes of the population living within the radioactive trace demonstrated that the primary morbidity, and chronic and protracted diseases exceed significantly the mean regional values and the morbidity in other rural areas.

The estimated total collective dose over 30 years is 2500 person-Sv [Bennett, 1995], [UNSCEAR, 1993]. The collective dose was shared equally between the people evacuated from the highly contaminated areas (1300 person-Sv) and the people remaining in the low-contaminated areas (approximately 260000 persons) [UNSCEAR, 1993]. Applying a risk factor of 0.05 fatal cancers/Sv the total would give 125 fatal cancers.

Cases of acute radiation disease with lethal consequences were observed in farm animals in the early aftermath of the accident. An area of 6200 hectares was decontaminated by means of deep ploughing. In 1958 106000 hectares were excluded from agricultural use, but already in 1961 47000 hectares cold be cultivated again; in 1990, about 19000 hectares in the Chelyabinsk region were not yet in economic use [Alexakhin et al., 1996].

In a 20 km^2 area with deposition > 180 Ci/km^2 (> 6660 kBq/m^2) all the pine-trees, whose needles had received doses between 3000-4000 rad in the first year, died by the

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Buldakov et al. [1996] claim that the doses can be doubled considering the non-uniformity of contamination and the conditions of exposure and intake.

Somewhat different values are given in [Kossenko, 1991], who reports that 10200 people were resettled from the most contaminated districts of the Chelyabinsk province for a period of more than two years. The average dose of the people of the three villages (Berdyanish, Satlykova and Galikayeva) which were evacuated soon after the release, was about 0.57 Sv. 2280 people were resettled 250 days after the accident received approximately 0.17 Sv, and 7300 people who remained in the contaminated territory for 770 days the effective equivalent dose was about 0.06 Sv [Kossenko]. Summing up all doses we would obtain about 1200 person-Sv, consistently with [UNSCEAR, 1993].

Cochran et al. [1993] mentions that 23 villages were evacuated. These authors report, from many other sources, that in an area with average contamination of 500 Ci/km^2 (or 18500 kBq/m^2) the three most affected villages, Berdyanish, Saltikovka, and Galikaeva, in which 1054-1908 people lived, were evacuated but first 7-10 days after the accident.

autumn of 1959 [Cochran et al., 1993]. Karavaeva et al. [1994] report that the contamination in forested areas in the Sverdlovsk region ranges 1.5-63.4 kBq/m^2 of Sr-90 and < 13 kBq/m^2 of Cs-137. Chukanov et al. [1995] report that measurements made in 1992-1994 in an area of 1600 km^2 in the south-eastern part of Sverdlovsk Oblast assessed that large territories north-east of Lake Tygish along the axis of the radioactive trace presents average contamination for Sr-90 of 37-111 kBq/m^2, with spots > 185 kBq/m^2.

The accident has been classified at level 6 of the IAEA scale of nuclear accidents, based on the off-site impact [IAEA/NEA, 1992].

° Aue, Wismuth-pit 250 (Erzgebirge/Sachsen, former East Germany) 15 July 1955.

A fire in an underground cable led to the death of 33 miners. According to sources of the German Ministry of Economy (Bundesministerium für Wirtschaft [BfW, 1996]), this is the only severe accident (i.e. with ≥ 5 fatalities) in uranium mining occurred in the former East Germany in the period 1955-1990[19], when the mines were managed by the Soviet-East German Company Wismut SDAG. According to BfW [1996], the extracted uranium was most likely used for military purposes in the USSR.

⇒ **Additional accidents in other commercial installations of the nuclear energy chain and in military nuclear facilities other than reactors[20]:**

° La Hague (France) 20 May 1986; reprocessing complex.

During maintenance in a pipeline, unexpected surge of highly active solution. Two persons received doses of 11 and 25 rem, respectively (the second man also 200 rem at the skin) [Pharabod et al., 1988].

° Windscale (UK) 26 September 1973.

The accident occurred in the reprocessing facility B204 where uranium dioxide fuel elements were treated (the cladding sheared, the fuel dissolved with nitric acid and the insoluble particles separated) before the obtained solution was routed to the works of

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[19] Nash [1976] reported about an explosion in a uranium mine in Zwickau (former East Germany) on 6 November 1949, which should have caused 70 fatalities. According to [BfW, 1996], the above information should refer to an explosion in a colliery, which experienced a second event in 1960. Nash [1976] also reports of two other accidents in uranium mines in the former East Germany: a flood occurred in Oberschlema on 1 February 1953, which should have caused 22 fatalities; and, an explosion in Johanngeorgenstadt on 29 November 1949, which was said in the press to have caused 2300-3700 deaths. Comparying to other mine accidents included in the present report, the high numbers seem to be unrealistic. According again to BfW [1996], these two cases are evidently false news.

[20] The accidents listed under this heading involve fatalities and/or external release of radioactivity and/or substantial economic loss. They are probably not "severe" with view to the environmental and health effect components in the definition of "severe accident" used in the present work. Furthermore, the extent of economic damages is generally not known to the authors of this report. The list is not complete.

Windscale-2 (which reprocess Magnox fuel) for the extraction of uranium and plutonium. The facility had operated since 1969. 120 t of fuel had been reprocessed up to the time of the accident. The cause of the accident were exogenous violent chemical reactions in a tank containing insoluble residuals, fines of zirconium and Butex[21] solvent. The developed gases containing the radioactive Ru-106 diffused from the cell were the tank was placed, through the interconnection (used for mechanical operation of the equipment) with an adjacent compartment, to the entire building. 35 employees who were inside the building at the time of the accident absorbed high activities by air intake, 0.01-40 μCi ($370\text{-}1.5 \cdot 10^6$ Bq) corresponding to lifetime doses between few rem and hundreds of rem (5 rem was the yearly limit for workers exposed to radiation). There was no radioactive release to the atmosphere. The operation of this facility was stopped for 5 years, the building decontaminated. Then, after a fire it was definitively closed in 1978 [Pharabod et al., 1988].

The accident was classified at level 4 of the IAEA scale of nuclear accidents, based on the on-site impact [IAEA/NEA, 1992].

Other significant abnormal releases occurred from the Sellafield site, as reported in [Jones et al., 1995]. A fire[22] in the B30 facility on 16 October 1979 caused the release to air of 1.04 GBq of Sr-90, 0.44 GBq of Ru-106, 2.2 MBq of I-131, 13.8 GBq of Cs-134, 92 GBq of Cs-137, 24 MBq of Ce-144, 1.4 MBq of Pu-239 and 1.34 MBq of Am-241. On 11 November 1979, unit B242 released 11 GBq of Pu-239 and 2.5 GBq of Am-241. Finally, 0.01 GBq of Pu-239 and 0.36 GBq of Am-142 were released on 17 July 1984 from the sludge tank of unit B241.

° Rocky Flats (Colorado, USA) 11 May 1969.

Due to a fire, plutonium was released to the environment. Together with a fire in 1957 and leakages of plutonium-contaminated oil in 1958 and 1968, the contamination inside the fences of the factory reached 74 kBq/m^2. Some additional cancers were predicted [Pharabod et al., 1988].

° Wood River Junction Plant (USA) 24 July 1964.

Criticality accident due to the transfer of a solution containing enriched uranium into a tank with unfavourable geometry. Three operators were irradiated. One of these who had received a dose of about 15000 rem died [Pharabod et al., 1988].

° Hanford (Washington DC, USA) 7 April 1962.

Criticality accident due to the transfer of a solution containing plutonium into a tank with unfavourable geometry. Three operators received doses of 16, 33 and 87 rem, respectively [Pharabod et al., 1988].

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[21] ββ dibutoxy-diethyl ether; its use is now abandoned, being substituted with tributilphosphate (TBP).

[22] It is unclear from the available references whether this fire corresponds to the second accident mentioned in [Pharabod et al., 1988].

- National Reactor Testing Station (Idaho, USA) 16 October 1959.

  Criticality accident during the transfer of a solution containing enriched uranium. Two operators received doses of 32 and 50 rem, respectively [Pharabod et al., 1988].

- Los Alamos (New Mexico, USA) 30 December 1958.

  Criticality accident in a separator containing an organic solution with plutonium and an aqueous phase. The event occurred at the time the agitator started mixing the phases. One operator died due to a dose of approximately 6000 rem. Two other operators received doses of 50 and 180 rem, respectively [Pharabod et al., 1988].

- Oak Ridge (Tennessee, USA) 16 June 1958.

  Criticality accident due to the inadvertent routing of a solution containing enriched uranium into a tank with unfavourable geometry, during maintenance work. Five persons were irradiated with 250-350 rem, three with 20-70 rem. [Pharabod et al., 1988], [UNSCEAR, 1993].

- Rocky Flats (Colorado, USA) September 1957; nuclear weapons factory.

  Due to a fire, plutonium was released to the environment [Pharabod et al., 1988].

- Los Alamos (New Mexico, USA) 21 May 1946.

  Criticality accident, one death [Pharabod et al., 1988].

- Los Alamos (New Mexico, USA) 21 August 1945.

  Criticality accident, one death [Pharabod et al., 1988].

D.2 Consequences of the Chernobyl accident

In the history of civil nuclear power, only one accident had serious health consequences for the public, the accident at the unit No. 4 in Chernobyl, Ukraine, on 26 April 1986. The failed reactor was of the RBMK type, water-cooled and graphite-moderated, 1000 MW electric power output. This type of plant is operated exclusively in some countries of the former Soviet Union. The accident revealed in an utmost dramatic way the deficiencies of the design of this reactor type, and the insufficient preparation and safety culture of the plant management and staff.

A short description of the sequence of events of the accident, some information on the estimated source term and a survey of health and environmental consequences reported to date, are given in this section.

Here, the predicted number of fatalities is normalised by the total electricity generated by nuclear power plants world-wide until the end of 1995, to put the health consequences of the accident into perspective for comparison with the acute fatalities assessed for the other energy chains which are reported in the preceding chapters. However, the definite evaluation of the consequences of the Chernobyl accident is not yet available. Currently, there is a continuous and steadily growing flow of information from field studies and from calculations. Therefore, the present outline should be considered as preliminary. It is our intention in the frame of the GaBE project to continue to follow up the new developments and findings concerning this accident.

The survey of the available information presented in this report indicates that the data as well as the models available are insufficient for a precise prediction of the consequences of the Chernobyl accident. Therefore, the estimations provided in this report are subject to reservations and will need to be updated on the basis of emerging new insights.

Sequence of events

On 25 April 1986, the plant had to be shut down for scheduled maintenance. Taking this opportunity, a test was carried out, which had been planned to be performed before the start-up of the facility but was postponed to meet the national energy plan schedule. The test consisted of the verification of the capability of the primary cooling systems to self generate electricity to feed the primary pumps by means of the inertia of the turbogenerator after scram of the reactor and before the start-up of the emergency diesel engines. The circumstances of the test deviated from the prescribed ones. This brought the core of the reactor into unstable conditions at low power, with implications that had not been envisaged by the test designer and the crew. To gain the initially intended power, safety systems were sequentially disconnected and safety procedures were broken leading to increasingly hazardous conditions. In the early morning of 26 April the operators finally decided to start the key part of the test in spite of the conditions. After few tens of seconds, the operators noticed a sharp increase of the reactor power and decided to immediately insert the emergency control rods. However, the combined effect of this action and the design of portions of these rods as well as neutronic and thermal-hydraulic instabilities caused the power to further increase in a couple of seconds up to hundreds of times the nominal level of the reactor. Part of the fuel fragmented which in turn initiated a steam explosion. The reactor was destroyed and part of reactor material ejected to air.

Fires started in the reactor building which were extinguished in a few hours by the plant personnel and firemen. The major part of the core remained inside the reactor cavity and began to melt down, later interacting with structural and other materials. The graphite burned for some days. Thus, substantial releases of radioactivity continued for ten days (active phase of the accident) in spite of the attempts to stop the melting and cover the corium by dropping from helicopters 5020 tonnes of sand, dolomite, boron carbide and lead into the reactor shaft. This action failed: most of the materials accumulated beside the reactor cavity in the reactor hall where a glow (fire) was visible during these days. The Soviets planned to cool down the molten mass of the core (corium) by means of nitrogen, but this measure (of questionable effectiveness) was apparently never implemented during the active phase. According to early Soviet data, the release of radioactivity had a bathtub shape, with the maximum occurring on the first day and a second peak on about the seventh day to drop on the tenth, indicating that the corium had solidified. Later information has indicated that the release continued with lower intensity for many weeks, including some remarkable peaks[23]. During the first two months after the accident, the emergency teams dug a 168 m tunnel and reinforced the concrete shield underneath the reactor building to prevent the radioactivity to reach the ground and the groundwater table. Furthermore, the idea was to create a heat sink (by means of a sub-foundation flat-bed heat exchanger) to arrest any possible further corium-concrete interaction but its construction only started some days after the end of the active phase. Other teams of workers, professionals and soldiers often named ‘liquidators’ intervened during the emergency to clean-up the buildings and the surrounding area from the scattered core material. Subsequently, starting in August 1986, they constructed a thick shield around the ruins of the reactor, the so-called ‘sarcophagus’, that was completed at the end of the year. The units 1 and 2, less affected by the accident, resumed operation already in October and November 1986, respectively. Unit 2 was closed after a fire in the turbine hall in October 1991. Unit 1 and 3 are still operating. [24]

Source term

The Soviet authorities attempted to estimate the total radioactive emissions already in 1986. This early assessment was based only on the activity deposited within the former USSR. Of particular importance for the health consequences, 20% of the iodine inventory of the reactor core was said to be released to air, as well as 15% of Cs-134 and 13% of Cs-137 ([IAEA, 1991] after [INSAG, 1986]). 50 MCi (excluding noble gases) was the

[23] See for example the reconstruction of the source rate performed by Goloubenkov et al. [1996]. For dose reconstruction Morgenstern et al. [1995] (from various sources) consider releases in the period 26 April-20 May.

[24] The information included in this sub-section is taken from various sources, among others: [IAEA, 1986], [INSAG, 1986], [Sich, 1994], [NEA, 1995], [Borovoi et al., 1995], [Sich, 1995], [Sich, 1996].

estimate for the total release presented in 1986, calculated for the period between 26 April and 6 May, neglecting the decay taking place in the meantime — this means roughly the double at the time of the emission — with an uncertainty of about 50% [IAEA, 1986]. 30-100 MCi had been estimated by various sources as the total release to the atmosphere in the mentioned period. A range 25-50 MCi was still the reference at the IAEA Chernobyl conference in 1991 [IAEA, 1991]. Before year 1988 the estimations of total deposited isotopes of caesium (the reference element for measuring the contamination) made by various authors ranged between 26 PBq and 100 PBq (reported in [Anspaugh et al., 1988]).

The total source term from the Chernobyl accident has been recently reassessed to approximately 12 EBq (or 325 MCi) ([EC/IAEA/WHO, 1996-V] from [NEA, 1995] after [Devell et al., 1996]), thereof 100% of the inventory of the noble gases present in the fuel elements at the time of the accident (6-7 EBq), 3-4% of the fuel (e.g., 0.03 PBq of Pu-239), 50-60% of the volatile iodine (~1760 PBq), 20-40% of the caesium[25] (~85 PBq of Cs-137 and ~54 PBq[26] of Cs-134), 25-60 % of the Te-132 (~1150 PBq), 4-6 % of Sr isotopes (~10 PBq of Sr-90), > 3.5 % of Mo-99 and Ru[27] isotopes.

Another estimation also reported in [EC/IAEA/WHO, 1996-V], after [Borovoy, 1992] and [Buzulukov et al., 1993], gives for the total release corrected to 26 April 1986 the value of approximately 14.5-15 EBq (or 390-405 MCi), thereof 8-8.5 EBq of volatile, intermediate and refractory elements. Pitkevich et al. [1996 a, b] averaged data available in the literature obtaining 380 MCi, nearly 225 MCi without noble gases (Xe-133). Buzulukov et al. [1993], quoted in Bennett [1995] (UNSCEAR), report the following values for volatile isotopes: 1670 PBq for I-131, 85 PBq for Cs-137, and 8.1 PBq for Sr-90.

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[25] Borovoi et al. [1995] assessed that approximately 35% (unexpectedly high concentration) of the calculated inventory of Cs-137 remains within the (solidified) Lava-like Fuel-Containing Materials (LFCM, i.e. the corium slumped in the lower part of the reactor building). According to Borovoi et al. [1995], the LFCM includes approximately 135 t of partially burned nuclear fuel, i.e. 71% of the core fuel load (190.3 t). Therefore, 65%×71%=46% (or 3.2 MCi) of the initial inventory of Cs-137 in the core may have been released to the environment from the LFCM. Additional caesium may have been released from the remaining 29% of the core which was either ejected beyond the bounds of the reactor, or remained in the central hall under piles of materials in the form of fragments or chunks, or partly released to the environment (3.5±0.5% of the total core mass). Hence, the figures assumed by IAEA and NEA may underestimate the caesium source term (and possibly the iodine). Higher values, according to Borovoi et al. [1995], may in turn contribute to explain the higher than expected incidence of thyroid cancers in children.

[26] 46 PBq in [EC/IAEA/WHO, 1996-V].

[27] Borovoi et al. [1995] assessed an almost complete lack of ruthenium in the LFCM and the high activity in the metallic fuel-containing materials within the sarcophagus. The results of radiochemical analyses reveal that only 5 % of the LFCM inventory of Ru-106 remains. Therefore, Borovoi et al. [1995] strongly criticise the Soviet evaluation of 2.9% of ruthenium in the source term made in past years. They mention as evidence the findings of hot particles of nearly pure ruthenium in Sweden. The authors call for a reassessment of the dose from isotopes of ruthenium.

Early fatalities

31 early fatalities occurred [UNSCEAR, 1988], [NEA, 1995], [EC/IAEA/WHO, 1996]. Among them 2 operators died at the site; one at the time of the explosion, the second of coronary thrombosis[28]. A third person died few hours later as a result of severe burns[29]. About 400 persons among the operators (300) and the fire fighters (100) were admitted in hospitals for observation, 237 of these were suspected of suffering from acute radiation sickness (ARS) [NEA, 1995], [EC/IAEA/WHO, 1996-I]; most of them participated in the emergency action on the first day. Of these 237 people, the diagnosis was confirmed in 134 cases [EC/IAEA/WHO, 1996-I]. According to [EC/IAEA/WHO, 1996-I], 21 of these 134 men suffered of Grade IV ARS (estimated approximate absorbed dose > 6 Gy), all but one died; 22 suffered of Grade III ARS (4-6 Gy), 7 died; 50 had Grade II ARS (2-4 Gy), 1 died; and, 41 (plus one uncertain case) had Grade I ARS (1-2 Gy) without deaths[30] [EC/IAEA/WHO, 1996-I]. No one of the remaining hospitalised persons who received doses below 1 Gy (not leading to ARS) died.

Of these 237 people, 11 who had received doses greater than 10 Gy, suffered severe gastrointestinal damage which resulted in early and lethal changes in intestinal function. Deaths of 26 among the 28 were associated with radiation inflicted skin lesions involving over 50% of the total body surface area (a total of 56 men had such injury, other two in addition thermal burns) [EC/IAEA/WHO, 1996-I]. In the ten years following the accident, further 14 persons died, thereof 9 belonging to the ARS patients group, 5 to the rest [EC/IAEA/WHO, 1996-I]. It is stated in the same source that their deaths do not correlate with the original severity of ARS and may not be directly attributable to the radiation exposure although it is difficult to exclude an impact from the accident. No member of the public suffered from acute radiation syndrome [IAEA, 1986].

Emergency workers

Various estimations exist about the number of the emergency workers (EW), named liquidators by the Soviets. Approximately 650000 were involved according to Savchenko [1995]. An interval of 600000-800000 is given in [EC/IAEA/WHO, 1996]. The upper value is mentioned in [Balter, 1996 b], [WHO, 1995 a], [NEA, 1995],

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28 From the limited information available to the authors of this report, it seems that the heart attack happened at the site due to the highly stressful situation of the first day. Therefore this death must be included in the total early fatalities, along with official sources.

29 As only reference, Pharabod et al. [1988] mention two more fatalities, including one medical doctor and one film director who died because of the dose absorbed while filming on the site of the accident; these two are not accounted here because of lack of further verification.

30 According to [NEA, 1995], 21 of the 237 emergency workers absorbed 6-16 Gy (20 died); 21 absorbed 4-6 Gy (7 died); 55 received 2-4 Gy (1 died); and, 140 took less than 2 Gy (no death). Therefore, out of the 237 men, 28 died of ARS (and burns) in the hospitals within a few months. Early sources gave 299 total hospitalized EW with symptoms of radiation sickness; 11 persons were still hospitalised by August 1986 ([Pharabod et al., 1988] after [IAEA, 1986]).

[Kreisel et al., 1994] for the period 1986-1990. The latter reference and WHO also report that 350000 were from Russia, while according to Voznyak [1996 a] about 300000 citizens of the Russian Federation took part in the cleaning up in the exclusion zone.

In the following, information is given from the available literature. However, the data is affected by high uncertainty. In particular, key radiation dose measurements for the most exposed accident recovery workers are missing because of lack or unreliability of dosimetry in the early events. To date, no clear correlation has been found comparing data recorded in official registries with biological dosimetry methods [Balter, 1996 b], [Sevan'kaev et al., 1995 a].

Consistently with Kreisel et al. [1994], as reported by Ivanov et al. [1994], approximately 285000 clean-up workers had been monitored in the frame of the All-Union Distributed Registry (AUDR) of people exposed to radiation from the Chernobyl accident, established in 1987 by a directive of the Ministry of Public Health of the USSR[31] [EC/IAEA/WHO, 1996-III]. Starting from 1992 the National Registries of Belarus, Russia and Ukraine substituted AUDR.

As of September 1995 the Russian National Medical and Dosimetric Registry (RNMDR)[32] contained information on 435276 persons categorised under five primary registration groups: EW (35.0% of total), evacuees and resettlers (3.0%), residents of contaminated territories (57.7%), and children born of EW who worked in 1986-1987 (4.3%) [Ivanov, 1996][33]. The studied cohort of EW includes 143032 people, of which about 80% (113936 persons) are said to have a record of dose from external radiation received in cleanup activities[34]. However, the registered dose for the Russian EW is the dose from external exposure measured by individual TLD-dosimetry in one member of each team [Ivanov et al., 1995][35]. For the exposed people, the average external dose is 10.5 cGy, and does not differ much in the various age groups. In the studied cohort, nearly 65% received doses higher than 5 cGy, nearly 35% >10 cGy, about 17% > 20 cGy[36].

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[31] A total of 659292 people were registered in AUDR until the end of 1991 (when the USSR collapsed), thereof 43.2% were clean-up workers, 10.5% (about 69200) evacuees, and 45.2% (298000) residents in the contaminated areas [Ivanov et al., 1995], [Ivanov et al., 1994]. Children within the above groups were also considered separately [EC/IAEA/WHO, 1996-III].

[32] In 1995 the RNMDR was reorganised and renamed “National Radiation and Epidemiological Registry”.

[33] Medical Radiological Research Center of Russia Academy of Medical Science, Russian Federation.

[34] Same percentage given by Sevan'kaev et al. [1995 a] referring to the EW who worked in April-July 1986.

[35] It is stated in [Morgenstern et al., 1995] that for only about 15% of the EW registered in the RNMDR the recorded absorbed dose were obtained from reading of individual dosimeter. Furthermore, in the case of the liquidators registered in the Belarus Chernobyl registry, dose estimates are missing for 73.8% of the cases [Okeanov et al., 1996]. In the case of the registered Ukrainian liquidators, there are no data for 48% of the people who worked in 1986-1987, 17% for the rest [Buzunov et al., 1996].

[36] Other sources estimated that approximately 30% of the total EW have received doses in excess of 20 cGy [Kreisel et al., 1994]. These figures are in disagreement with the ones mentioned by UNSCEAR [1993],

The distribution of doses changed with the date of intervention at the site. In 1986 and 1987, 83.1% and 75.3%, respectively, of the EW included in the RNMDR received doses greater than 5 cGy, whereas in the following three years the number of this subgroup of EW decreased to 14.1%, 4,5% and 4.4% [Ivanov et al., 1996 b]. The cleanup workers included in the RNMDR received an average individual dose due to external irradiation of 15.9 cGy in 1986, 9.0 cGy in 1987, 3.3 cGy in 1988, 3.2 cGy in 1989 [Ivanov, 1996], and 3.7 cGy in 1990-1993 [Ivanov et al., 1996 b], [Ivanov et al., 1995]. The 1986-1989 collective dose estimated for these EW is 12483 person-Gy, thereof 59.3% in 1986 and 34.5% in 1987 [Ivanov et al., 1996 b]. [37]

More than 63000 EW are registered in Belarus (thereof 31200 worked within the 30 km zone) [Okeanov et al., 1996], nearly 175000 in Ukraine (thereof about 93200 worked in 1986 and 42700 in 1987) [Buzunov et al., 1996].

For 46000 EW included in the RNMDR and employed in the 30 km exclusion area in 1986 predictions have been made in compliance with [ICRP, 1991] using a multiplicative model for the estimation of the excess cancer mortality. Using the lifetime radiation-induced cancer death risk coefficient of $4.1 \cdot 10^{-2}$ Gy^{-1}, the number of predicted excess deaths estimated in [Ivanov et al., 1995] is 670 per 100000 persons[38] (or 3.4% of mortality for natural cancer); for leukaemia the corresponding prediction leads to 96 cases per 100000 persons[39] (or 24% of mortality for natural leukaemia). The maximum of annual excess cancer deaths, estimated at about 18 deaths/year/100000 persons, is expected 20-25 years after the time of exposure [Ivanov et al., 1995].

For the estimation of late consequences [EC/IAEA/WHO, 1996-III] focuses on the approximate 200000 liquidators who worked in 1986-1987 and who absorbed the highest doses. For these, the assumed average dose is 100 mSv (from [Ivanov et al., 1996 a]),

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where it is stated that 247000 workers received an average external dose of 0.12 Sv for a total collective dose of about 30000 person-Sv (the internal doses were in the range of 10% of the external).

37 Sevan'kaev et al. [1995 a] based on a paper of Tsyb et al. written in 1992 (in Russian) give the following average individual doses to 86046 liquidators included in the registry maintained in Obninsk: 170 mSv in 1986, 130 mSv in 1987, 30 mSv in 1988, 15 mSv in 1989. These figures were used in [NEA, 1995]. Moreover, Sevan'kaev et al. [1995 a] analysed the chromosomal aberrations in lymphocytes in a cohort of 875 liquidators obtaining the following results for the average individual dose: 300 mSv in early 1986 (this group includes 170 persons who had no dosimeter); 200 mSv for the entire 1986; 150 mSv both in 1987 and 1988.

38 This means 270 additional cancer deaths among those 40000 liquidators. If we pessimistically used this figure as rough coefficient to extrapolate the total number of additional cancer deaths among 800000 EW as if they all were working with high exposures, we would calculate about 5400 excess cancer deaths (close to the number estimated in [Prêtre, 1994]).

39 For a total of 800000 liquidators we would then pessimistically obtain approximately 770 excess leukaemia deaths.

which means a collective dose for this group of 20000 person-Sv[40]; due to the relatively high individual doses involved, the expected consequences are approximately 2000 solid fatal cancers and 200 leukaemias.

Among the liquidators, three groups with the corresponding assumed average absorbed doses have been considered in [Prêtre, 1994]. About 524000 relatively highly exposed liquidators were considered divided into three groups: 4000 persons who received an average individual dose of 2.1 Sv; 20000 with 1 Sv; and 500000 persons with 0.2 Sv[41]. The numbers of expected fatalities, using a risk coefficient of 8% Sv^{-1} for the first two categories and 4% Sv^{-1} for the last, would be about 6400 potential fatal cancers. Later on, based on 600000 clean-up workers, a cautious estimate for the average individual dose of 0.1 Sv and an average risk coefficient factor of 4% Sv^{-1}, the potential fatal cancers among liquidators have been estimated to be not above 2400 [Stoll, 1996].

The crude all ages death rate from all causes in the EW group in the Russian Federation grew from 0.46% in 1990 through 0.51% in 1991 to 0.69% in 1992 [Ivanov et al., 1995], [1994]. The yearly cases of malignant neoplasms in the same group were growing from approximately 0.045% in 1991, to 0.061%, 0.092%, and 0.095%, respectively in the following three years [Ivanov et al., 1996 b]. These rates and increases are lower than the corresponding death rates for the male population in the Russian Federation (standardised to the Russian Federation male EW cohort), which were for the overall death rate 0.61% in 1990, and 0.68%, 0.88% in the following two years [Ivanov et al., 1995], [1994], whereas for malignant neoplasms only they were 0.069% in 1990 and 0.081%, 0.092% and 0.108% respectively in the following three years [Ivanov et al., 1996 b].

Any comparison of the disease rates of the EW with the ones recorded for the general population should be made with caution, because the average level of medical check-ups and treatments is certainly lower for the population compared to the active follow-up and the more qualified examinations of the individuals belonging to the EW. However, for some diseases (especially of the endocrine system, but also of circulatory system, digestive system, blood and blood-forming organs, thyroid) the rate is higher in EW than in the general population[42]. Among EW, the recorded diseases rates are higher for higher doses (i.e., the EW who worked in 1986-1987) [Ivanov, 1996], [Buzunov et al., 1996]. In 1993, the disability rates in three groups of EW included in the RNMDR with dose between 0-5 cGy, 5-20 cGy and > 20 cGy were growing in the period 1990-1993, to reach in 1993 43.5‰, 74.0‰ and 87.4‰, respectively for the three dose classes [Ivanov, 1996].

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[40] Using the data in [Ivanov et al., 1996 b] and mentioned in the text above, the 94652 Russian EW included in the RNMDR who worked in 1986-1987 received a collective dose of 11703.8 person-Gy, i.e. 12.4 cGy, which would give a collective dose of approximately 25000 person-Gy for 200000 liquidators.

[41] These assumed average doses are the highest found in the literature.

[42] See for example [Okeanov et al., 1996] and [Ivanov, 1996], although data on morbidity have not been corrected there for age distribution.

Sevan'kaev et al. [1995 c] reported that a group of 15 scientists worked inside the sarcophagus accumulating doses from external irradiation ranging approximately 1-15 Gy, which are far in excess of ICRP's [1991] recommended occupational intervention levels for extraordinary situations. No effects have been manifested to date due to radiation except in one person who suffers of chronic leucopenia.

Evacuees

Various estimates can be found in the literature on the number of people evacuated from an area of 30 km radius around the power station, the so-called "30-km zone" (2830 km^2) or exclusion zone, and the corresponding collective dose. An upper limit is given in [Savchenko, 1995], 150000 people, thereof about 115000 were evacuated before 6 May 1986. The same number is mentioned in [UNSCEAR, 1993]. According to Balonov [1993] 116000 individuals were evacuated, thereof 49000 from the town of Pripyat on 27 April, 11000 from 15 villages in the area 10 km around the plant in the period 2-3 May, and additional 42000 from 83 villages in the 30 km zone between 4 and 7 May; the remaining people were resettled from 57 villages in Belarus, 1 village in Ukraine and 4 villages in Russia between June and September 1986.

Also according to the Summary of the 1996 Vienna conference [EC/IAEA/WHO, 1996], 116000 people were evacuated from the exclusion zone in 1986. However, a contradicting figure can be found in two of the Background Papers [EC/IAEA/WHO, 1996-III and VIII], where 135000 people are said to have been evacuated soon after the accident; 49000 were from the town of Pripyat within approximately 40 hours from the explosion, 40000 on 3-5 May 1986; the evacuation was completed during the period 5-14 May. 135000 people are considered also in [WHO, 1995 a], as well as in [NEA, 1995].

It has been reported in [EC/IAEA/WHO, 1996] that between 1990 and 1995 there was resettling or voluntary moving out from contaminated zones of about 107000 people in Belarus, about 53000 in Ukraine and about 50000 in Russia (total of approximately 210000 persons). But also the inverse has happened, although in a smaller scale: some people have returned to their original settlements, also into the 30 km exclusion zone.

Recorded cases of thyroid cancers among children

Due to the very marked increase in the annual incidence of childhood thyroid cancer, detected in the most affected areas shortly after the event, this aspect of the consequences of the accident has drawn great attention of the scientific community and the general public. The cases among adults have increased at a much lower rate and have not been studied to the same extent as the cases among children. Therefore, this sub-section mainly addresses the thyroid cancer cases in the most sensitive group.

The increase among children corresponds to few to about one hundred times higher number of cases than recorded in the years before the accident, depending on the area. The geographical distribution of these cases[43], the recorded thyroid doses as well as the latency period from the irradiation[44] and the type and characteristics of carcinomas[45] indicate that there is a correlation with the fallout of the accident ([WHO, 1995 a]; also in [EC/IAEA/WHO 1996-II], [Baverstock, 1994], [Nagataki, 1994], [NCRP, 1985]). The main cause of the radiation-induced thyroid cancer is the internal irradiation of I-131[46] absorbed in the thyroid gland during the first days of the accident mainly through milk consumption, but calculations of the number of possible cancer cases made with current models show marked underestimation due to still not clear reasons (e.g., dose assessment, iodine deficiency, role of other short-lived isotopes of iodine, genetic predisposition to develop radiation-induced thyroid cancer) [Balter, 1996 a].

According to Balonov et al. [1996] (from various sources), children under 6 (the most sensitive group) received doses (reconstructed) to thyroid 3-10 times higher than adults, on the order of 3-5 Gy in the most affected areas. The individual doses were up to 8-10 Gy in Russia and 30 Gy and even 50 Gy in Belarus and Ukraine. WHO [1995 a] also reports that the highest thyroid doses were recorded in the Gomel and Mogilev oblasts of Belarus (300 km far from the plant, Cs-137 contamination > 555 kBq/m^2), up to 50 Gy. About 1% of the children evacuated from the heavily contaminated areas had doses exceeding 10 Gy. The highest doses were received by children aged 3 or less.

According to WHO [1995 a], of the children who have contracted cancer, 60% had doses < 0.3 Gy, 22% had 0.3-1 Gy, and 12% > 1 Gy; adults had individual doses to the thyroid in the range 0.1-50 Gy. In the Russian Federation, the doses absorbed by children were estimated to be in the range 10 mGy-2.2 Gy, while adults had doses in the range 1-2 Gy [WHO, 1995 a]. In Ukraine, direct measurement of I-131 showed that in the contaminated

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[43] For example, more than 60% of all cases in Ukraine in the period 1990-1994 were registered in the 5 most contaminated oblasts out of 25 total (oblasts are administrative regions) [Tronko et al., 1996]. Likhtarev et al. [1995] (also in [Sobolev et al., 1996]) reported that there is a more than 30-fold gradient in the distribution of thyroid cancer incidence rate in Ukraine corresponding to the gradient in I-131 average thyroid doses, whose assessment was based on 150000 measurements and dose reconstruction.

[44] The actual latency period ranges between 4-10 years, with a mean of 6 years after the accident, which is somewhat shorter than expected on the basis of previously recorded radiation-induced thyroid cancers [EC/IAEA/WHO 1996-II], [Balter, 1996].

[45] 93-95% of all cases in Belarus and Ukraine are papillary carcinomas [Demidchik et al., 1996], [Tronko et al., 1996], mostly of a subtype with a solid/follicular architecture which has less frequent natural occurance [Williams et al., 1996]. Spontaneous thyroid cancer is usually about 75% papillary and 25% follicular; the latter rate can be higher in regions with iodine deficiency [Baverstock, 1994]. The natural frequency of papillary carcinomas in the UK is 68% [Williams et al., 1996]. From the survey made by Robbins [1994], the rate of the papillary type in the reported childhood thyroid cancer cases in Western countries is 68-93% of the total, but the author argues that the lower values probably reflect the failure to distinguish the follicular variant of papillary thyroid cancer. Other differences between carcinomas in the three most affected countries and in the UK lie in the age and sex distributions [Williams et al., 1996].

[46] Its physical half-life is 8.05 days.

regions the children received doses in the range 1-2 Gy, with individual doses up to 30 Gy, while adults had doses 2-8 times lower [WHO, 1995 a].

Table D.2.1 summarises data from Demidchik et al. [1996], Tronko et al. [1996], [Tronko, 1997], and Tsyb et al., [1996] concerning the incidence rate of thyroid cancer in children and adults (where available) for Belarus, Ukraine and Russia up to year 1995. In Belarus the proportion of children among all thyroid cancer patients has increased from 0.5% in the years 1978-1985 to 2.3% in years 1986-1989 up to about 15% in years 1990-1994 [Demidchik et al. 1996]. The crude rate for thyroid cancer in children in the highly contaminated region of Gomel in the period 1990-1994 is nearly 200 times the rates for England and Wales[47] [EC/IAEA/WHO, 1996-II].

According to [EC/IAEA/WHO, 1996-II], the number of reported cases up to the end of 1995 are about 800 in children between 0-15 years old at the time of diagnosis. Of them, more than 400 have occurred in Belarus. However, Sinnaeve et al. [1996] at the same Vienna conference in April 1996 reported of nearly 900 cases of occurred thyroid cancers in children and three deaths. Nevertheless, the confirmed cases, i.e. where analyses of tissue had been made by international medical teams, were around 500. Later, Tronko [1997] reported for the period up to 1995 a higher number of thyroid cancers in children aged 0-18 at the time of the accident (see Table D.-2.1). The incidence of this type of cancer in children born more than 6 months after the accident drops dramatically to the low levels that are expected in populations unexposed to radiation [EC/IAEA/WHO, 1996-II][48].

According to [EC/IAEA/WHO, 1996], three children died before the end of 1995[49]. Another source reported 10 deaths of radiation-induced thyroid cancer (unspecified whether it includes only children), already before the end of 1995 [NucNet, 1995].

According to the experience of Demidchik et al. [1994], the radiation induced childhood thyroid cancer is "highly aggressive with rapid development accompanied by invading surrounding tissues and metastatic involvement of lymph nodes and lungs". In 1996 the same authors reported that 56 children out of 292, whose cases have been followed up after surgery, had metastases in regional lymph nodes (48) or recurrence in thyroid remnant (8); all 56 children underwent a second operation. These doctors have also recorded 55 cases of lung metastases. In Ukraine, metastases in lymph nodes were observed in 59% of the cases

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[47] 0.5 thyroid cancers per million children per year in the UK. In most countries of the world, the naturally occuring rate is about 1 thyroid cancer per million children per year, with few cases up to 3 thyroid cancers per million children per year [Williams et al., 1996].

[48] Only four cases of thyroid carcinomas have been recorded among children born in Belarus after I-131 has decayed, as opposed to the hundreds of cases affecting those children who were born before or immediately after the accident and diagnosed in the same time period [Demidchik et al., 1996].

[49] This number may be underestimated, because three deaths had been already recorded before 1994: Nagataki [1994 b] mentions 2 children who had died of thyroid cancer in Belarus and one in Ukraine, out of 251 and 276 considered cases, respectively.

[Tronko et al., 1996]. From the survey made by Robbins [1994] the metastases according to diagnoses in the reported childhood thyroid cancer cases in Western countries were 73-90% of the total thyroid cancer cases in lymph nodes, 8-19% in lungs; for Belarus he reported 59-74% and 3-7%, respectively for the two types of metastases.

Table D.2.1

Annual thyroid cancer cases in Belarus and Ukraine in the period 1977-1995 [Tronko, 1997], [Tronko et al., 1996], [Demidchik et al., 1996], [Tsyb et al., 1996].

Year	Belarus		Ukraine		Russia
	Children (0-14) [a]	Adults	Children (0-14) [b]	Teenagers (15-18) [b]	Children
1977	2	121	nr	nr	nr
1978	2	97	nr	nr	nr
1979	0	101	nr	nr	nr
1980	0	127	nr	nr	nr
1981	1	132	4	4	nr
1982	1	131	5	8	nr
1983	0	136	4	7	nr
1984	0	139	5	6	nr
1985	1	148	7	9	nr
1986	2	162	8	7	0
1987	4	202	8	10	1
1988	5	207	11	11	0
1989	7	226	23	13	0
1990	29	289	40	19	4
1991	59	340	43	18	4
1992	66	416	75	33	8
1993	79	512	75	38	13
1994	82	553	93	41	21
1995	91 [c d]	nr	106	60	11 [c d]
total 1986-1995	333	2907	482	250	51

[a] At the date of diagnosis.
[b] At the date of surgery (1977-1985). At the time of the accident (1986-1995).
[c] Preliminary data. [d] [EC/IAEA/WHO, 1996-III].

An increase of thyroid cancers in adults has been reported among liquidators (28 cases registered in 1993-1994) and among people living in contaminated areas, but it is unclear whether these cases are related to the exposure to radiation from the Chernobyl accident only [EC/IAEA/WHO, 1996-III]. The data reported in [Demidchik et al., 1996] show an increase of a factor of approximately three in the number of cases in adults for Belarus. The authors do not provide explanations. Some of the cases may involve young persons who were exposed as children. However, thyroid carcinoma in adults presents a low death rate.

A few thousands additional thyroid cancer cases are expected [EC/IAEA/WHO, 1996]. The predictions are associated with large uncertainties. Discrepancies have been found between predictions based on standard thyroid dosimetry and current risk projection models (with the latter underestimating the effects [EC/IAEA/WHO, 1996-III]). This may be due to the characteristics of the accident. According to Williams et al. [EC/IAEA/WHO, 1996-II], in the contaminated oblasts of Belarus, Russian Federation and Ukraine well over 3.5 million children were exposed to radioiodine, with doses in the above mentioned range but the accuracy of the estimations is difficult to assess. The authors state that it is possible that about one million children 0-14 years old in 1986 received a thyroid dose in the order of 500 mSv. Therefore, considering a risk factor of 0.008 Sv^{-1}, 4000 excess cancers can be estimated over their lifetime [EC/IAEA/WHO, 1996-II]. Projections based on the follow-up of the Japanese survivors of atomic bombings were made for population groups living in various oblasts in Belarus and one in Russia (no data for Ukraine). Nearly 4400 excess thyroid cancers deaths have been predicted for these groups. Summarising, 4000-8000 such cases may be predicted [EC/IAEA/WHO, 1996-VIII]. Assuming 5-10% fatality rate[50], 200-800 additional fatalities may occur in the future. Continuous lifetime monitoring of the persons exposed during their childhood is required.

Recorded cases of other types of cancer

So far, three major international studies have failed to detect any statistical evidence of deviation in the incidence rates of types of cancer other than thyroid cancer, that may be expected as a consequence of irradiation ([EC/IAEA/WHO, 1996-III], [Williams, 1996], and [WHO, 1995 a] for leukaemia; see also [Prisyazhniuk et al., 1996]). “Although some increases in the frequency of cancer in exposed populations have been reported, these results are difficult to interpret, mainly because of differences in the intensity and method

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[50] In the assessment of the radiological impact of the Windscale fire in 1957 (see description of the accident in Section D.2) performed by Taylor [1981] of the Political Ecology Research Group in Oxford, and commissioned by the Union of Concerned Scientists in Massachusetts, the assumed fatality rate of thyroid cancer in the population in the United Kingdom, including all age classes, was 5%. To estimate the mortality rate, Taylor reviewed 16 reports from Western Europe and the USA and one from Japan. Out of 771 children affected in the western countries, whose cancer was diagnosed before the age of 16 years, only 19 died from the cancer (2.5%). Some of them died early but the median survival time was 22 years and the longest 42 years. In addition, 9 children (1.2%) died from surgical complications. In the Japanese analysis, 5% of the affected children died from the cancer, none from surgery (but half of the dead children had not been operated). A comparison of the recorded cases of childhood thyroid cancers in USA and Europe with Belarus and Ukraine can be found in [Robbins, 1994]. Of course, nothing can be said at present on the mortality rate of the affected children in Belarus, Ukraine and Russia [Egloff, 1995]. One of the main reasons is that different approaches have been adopted for the therapy (hemithyroidectomy is the prefered treatment in Belarus [Demidchik et al., 1996], while in Ukraine, total thyroidectomy is used [Tronko et al., 1996]). However, according to Robbins [1994] the mortality rate from thyroid cancer among the children exposed to radiation is in the western cases described in the literature as low as for other children patients with the same cancer; therefore, there should be a similar trend also from thyroid cancers in children, related to the Chernobyl accident. Consequently, a coefficient of 10% may represent an upper limit of the fatality rate in preliminary estimations. This was taken into account in [EC/IAEA/WHO, 1996-VIII].

of follow-up between exposed populations and the general population with which they are compared" [EC/IAEA/WHO, 1996-III].

In particular, according to predictions of total doses and assumed dose-effect relationships, some **leukaemia** cases caused by the exposure to radiation were expected to be detected within the first 10 years after the accidents in the most exposed categories. Approximately 150 cases were anticipated to occur among the 200000 most exposed liquidators, out of a total (i.e. including the naturally occurring ones) of about 190 leukaemias, but no increase has been reported to date [EC/IAEA/WHO, 1996-III][51]. The predicted number of expected increase of leukaemia cases within the first 10 years among the residents in strict control zones is about 60, which would have corresponded to a 32% relative increase in that group; furthermore, about 190 cases were expected in the low contaminated zones, corresponding to a 5.5% relative increase [EC/IAEA/WHO, 1996-III][52]. As a matter of fact, no increase has been observed to date for leukaemia in the population of the three most affected countries [EC/IAEA/WHO, 1996-III].

Conservatively, 100% fatality rate should be considered for leukaemia. In fact, quite high mortality rates for the various types of leukaemia can be deduced from current literature[53].

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[51] Buzunov et al. [1996] report an average of 13.35 leukaemia cases per 100000 males per year in the period 1987-1992 for the 1986 registered Ukrainian EW, opposed to 7.04 for the EW employed in 1987 and later, but these data are not clearly discussed in the reference.

[52] In the latter case, this low excess in comparison with the natural incidence in the same group would have been very difficult or even impossible to detect through epidemiological studies. As an indication, about 10 new cases of leukaemia per 100000 persons living in the USA are diagnosed each year according to [NCI, 1995]. To give an example, approximately 8.1 fatal leukaemias/10^5 men/year and 6.2 fatal leukaemias/10^5 women/year (i.e., approximately 7.1 fatal leukaemias/10^5 persons/year) occurred in the USA in year 1988; approximately 5.4 fatal leukaemias/10^5 men/year and 4.5 fatal leukaemias/10^5 women/year (about 4.9 fatal leukaemias/10^5 persons/year) occurred in the former USSR in the same year 1988[52] [WHO, 1991]. The same source gives 6.2 and 5.5 leukaemia deaths/10^5 person/year, respectively for men and women, for the former Bielorussian SSR, whereas for the former Ukrainian SSR the values were 6.8 and 5.2 leukaemia deaths/10^5 person/year, respectively for men and women. Assuming for the moment an occurrence of 10 new cases of leukaemia per 100000 persons per year, as in the USA, approximately 2500 leukaemia cases would be diagnosed each year in a population of the order of 25 million persons around Chernobyl. Therefore, the total predicted additional leukaemias from the Chernobyl accident would remain hidden behind the statistical fluctuations, apart from following-up the most affected groups.

[53] To give an example, the following data have been taken from [NCI 1995]. In the USA, the five-year relative survival rate for patients diagnosed as having acute myeloid leukaemia (54% of all adult's cases and 20% of all children's cases) is only 10%, whereas the five-year relative survival rate for patients with chronic lymphocytic leukaemia (25% of all adult's cases, less than 1% of all children's cases) is around 65%. However, the five-year survival rate for some types has improved since the 1950s, sometimes dramatically as in the case of the acute lymphocytic leukaemia in children between the ages of 2 and 10 years —almost 75% of the total cases of leukaemia in children — which has changed from 52.5% in the years 1974-1976 to 72.3% in 1983-1988. Fewer than 10% of all leukaemia cases diagnosed in the USA in 1992 concerned children. About 60% of all 1992 new leukaemias in the USA were acute leukaemias.

For what concerns radiation-induced **solid cancers,** in addition to thyroid cancers, most likely to occur are breast, lung and gastro-intestinal cancers. According to current risk models no increase should be detectable to date [EC/IAEA/WHO, 1996-III]. However, a 11% increase of solid cancers has been detected in liquidators registered in Russia. In Ukrainian liquidators, a 20% increase in the incidence of all cancers has been detected, as well as increases in the incidence of specific cancer types [EC/IAEA/WHO, 1996-III]. In the population living in contaminated areas of Belarus and Russia, a 3% increase of cancers altogether has been registered. In the light of the past experience with radiation-induced cancers, the above mentioned facts seem to be inconsistent with the lack of detection of excess leukaemia cases, which should come first. It can be argued that these increases may be partially attributable to the active follow-up of such groups of people as compared to the general population and to possible underestimation of the natural cancer cases in the past [EC/IAEA/WHO, 1996-III].

Estimation of collective doses to workers and the public

The total additional collective dose to workers from the accident includes the sum of the doses absorbed by all emergency and clean-up workers. The total collective dose to the public consists of several contributions: the dose absorbed by the people evacuated from the 30-km zone shortly after the accident (short-term external plus internal); the dose absorbed from the plumes (short-term external); the dose absorbed by people still living in the contaminated regions (long-term external and internal exposures); and, the dose received from people living in non-contaminated areas (world-wide). This total dose should be calculated for a sufficient number of years, typically 70 years, taking into account the effective environmental decay of the emitted radioisotopes and the average human lifetime.

The collective dose early estimated by the Soviets for the European Soviet Union was of the order of $2 \cdot 10^6$ person-Sv, mostly from internal dose from intake of caesium via food chain; however, it was also stated that realistic assumptions could reduce this value by one order of magnitude [INSAG, 1986]. Since then, other estimations have followed, like for example the one reported by Storm et al. [1996] after Ilyin et al. [1990] which is reproduced in Table D.2.2. The total commitment dose that can be calculated from these values for the same region, approximately 500000 person-Sv, is of the same order as in the estimation used in [UNSCEAR, 1993] for the global effective collective dose (see below).

An attempt of assembling he newest findings on the estimation of the health impacts from the accident has been made at the Vienna International Chernobyl conference in 1996 [EC/IAEA/WHO, 1996]. The results are summarised in the following and critically compared with other references.

All assessments of the effective dose received directly from the initial plume concur that it was small compared to other contributions [EC/IAEA/WHO, 1996-V].

The **collective dose** for the 135000 **evacuees** was early estimated about $1.6 \cdot 10^4$ person-Sv by the Soviets (average individual dose of 120 mSv) [INSAG, 1986]. The same collective dose has been reported in [UNSCEAR, 1993] for external irradiation only; this reference gives for the collective thyroid dose the value of 400000 person-Gy, with an average thyroid dose of 0.3 Gy (from [Clarke, 1989]).

Table D.2.2

Exposure levels as a result of the Chernobyl accident ([Storm et al., 1996] after [Ilyin et al., 1990]).

Category	Population size	Exposure type	Exposure sub-group	Exposure exposure level
Liquidators (1986-1989)	600000	whole body γ	0.02% 8% 47% 45%	> 500 mSv 250-500 mSv 100-250 mSv < 100 mSv
Evacuees (1986)	130000	whole body γ-rays internal to thyroid of children (I-131)	range average range average	30-500+ mSv 120 mSv 0.1-2(5) Gy 0.3 Gy
Residents of "Strict control zones"	270000	committed effective dose equivalent from γ-rays	average 4% 800 persons	60 mSv > 100 mSv > 200 mSv
Residents of European part of former USSR	75000000	total committed effective dose equivalent	average	6-7 mSv

The recalculated collective effective dose from external exposure to the 135000 evacuees according to [EC/IAEA/WHO, 1996-III] is 1600 Sv[54]. This whole-body dose was mainly due to external exposure to Te-132, I-132, Cs-134, Cs-137 and other short-lived radionuclides. However, other estimations seem to contradict the minor importance given by the above reference to pathways other than the external (see below). The average dose to the 49000 residents of Pripyat was 11.5 mSv, that of the other evacuees who were moved before 4 May was 18.2 mSv[55]; the maximum individual dose within this group was 383 mSv ([EC/IAEA/WHO, 1996-III] after [Likhtarev et al., 1994]; also in [Likhtarev et al., 1996] and [Balonov et al., 1996]). According to [EC/IAEA/WHO, 1996],

[54] At the conference, the reported value was 1300 Sv. The reference mentions that the data is derived from the estimation made by I.A. Likhtarev who also contributed to the paper. Actually, Likhtarev et al. [1995] (also reported in [NEA, 1995]) attributed this smaller collective dose to 90000 persons only, with an average individual dose of approximately 15 mSv.

[55] The value for the 24000 persons evacuated from the part in Belarus might be higher due to the prevailing wind direction during the first days of the accident.

of the 116000 evacuees between April 27 and mid-August 1986, fewer than 10% received more than 50 mSv, fewer than 5% more than 100 mSv[56].

The **internal doses to the thyroid glands of evacuees** had to be reconstructed (see for example [Goulko et al., 1995]) because the measurements taken immediately after the accident were not reliable [Balonov et al., 1996]. The evacuated 0-3 years old children from the town of Pripyat had an average individual dose of 1.4 Sv, corresponding to a collective dose of 3300 person-Sv; 4-10 years old children received 0.3 Sv (2400 person-Sv); and the rest of population of the town 0.07 Sv (2600 person Sv) ([NEA, 1995] after [Goulko et al., 1995])[57]. Therefore, the 49400 inhabitants evacuated from Pripyat received a collective internal dose to the thyroid of approximately 8300 person-Sv. Using a lifetime risk factor for thyroid cancer for the children of 0.008 Sv^{-1}, we would calculate about 50-60 cases, of which 5-10% lethal.

130000 evacuees were considered in [Prêtre, 1994] with an average individual dose of approximately 0.3 Sv and a corresponding collective dose of 40000 person-Sv; assuming 5% risk factor this would mean 2000 additional fatal cancers (1.5% of that group). Later on, on the base of more recent information, assuming 120000 evacuees and an average individual dose of approximately 0.02 Sv (rounded figures), the collective dose has been re-estimated to 2400 person-Sv, corresponding to 120 fatal cancers [Stoll, 1996].

The **internal doses to the thyroid glands of people living in contaminated areas** have been reconstructed through measurements performed in May/June 1986 but the estimations are subject to high uncertainties [NEA, 1995]. For the entire Belarus the collective thyroid dose to 0-14 years old children has been estimated as about 170000 person-Sv ([NEA, 1995] after [RIRMM, 1995]). In the eight most contaminated districts of Ukraine, the collective dose to children was 60000 person-Sv while for the entire population it was about 200000 person-Sv ([NEA, 1995] after [Little, 1993]). Likhtarev et al. [1995] estimated a collective dose of 400000 person-Gy to all Ukrainian children of 0-18. In the Russian Federation, the collective dose to the entire population was approximately 100000 person-Sv, according to [NEA, 1995] after [Zvonova et al., 1993].

The **whole-body dose to people living in high contaminated areas** (or strict control zones, with Cs-137 activity higher than 555 kBq/m^2) can be divided in two contributions: external exposure and internal exposure from the intake of caesium, where the first gives the greatest part of total population exposure, the second the highest doses to individuals. An estimate of whole-body doses to people living in high contaminated areas has been

56 According to Balonov [1993], the average and maximum effective individual dose equivalent from external radiation to the inhabitants of Pripyat were 10 mSv and 100 mSv, respectively, while the corresponding values for the rural population among the evacuees were 20 mSv and 400 mSv.

57 Balonov et al. [1996] from various sources give an average of 0.4 Gy for the adult population of Pripyat and the most contaminated areas of Belarus and Ukraine, 0.1-0.2 for the most contaminated areas of Russia (Bryansk). Balonov had previously estimated [1993] for the average internal dose to the thyroid of adults and children of Pripyat about 0.2 Gy.

recently obtained, giving a total collective dose of 9700 person-Sv for 273000 people in years 1986-89 ([NEA, 1995] after [Barkhudarov et al., 1994]). Of this total, 7300 person-Sv are estimated to be due to the external exposure. About 20% of the persons in this group have received a whole-body individual dose greater than 50 mSv, 48% a dose in the range 20-50 mSv. A different estimate is reported in [EC/IAEA/WHO, 1996-III] after [Balonov et al., 1996]. Assuming for these strict control zones an average deposition intensity of Cs-137 of 925 kBq/m^2, an average external and internal dose of approximately 50 $\mu Sv/kBq/m^2$ in the period 1986-1995, and an average effective individual dose of 50-60 mSv[58], a collective effective dose of 10000-20000 person-Sv can be estimated for these 270000 people. The addition of 50% to the assessed 10 years' doses would give a total collective dose over 70 years in the range 15000-30000 person-Sv, according to [EC/IAEA/WHO, 1996-III][59].

The estimate of the **collective dose to people living in (low) contaminated areas** (i.e., in areas with deposition densities of Cs-137 between 37-555 kBq/m^2) has been attempted in

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58 The original source [Balonov et al., 1996] correlate the internal dose to the soil type, because the transfer factor of cesium to plants is strongly dependent on it. It has been estimated for the Russian rural population living in contaminated areas and without active countermeasures, an internal dose for the first ten years after the accident of about 30 $\mu Sv/kBq/m^2$ for turf-podzol soil and 170 $\mu Sv/kBq/m^2$ for black soil, without considering additional doses from the consumption of food gathered in non-cultivated areas (which may be substantially high: for example, the effective half life of caesium in mushrooms practically equals the physical half life). In the first case more than 90% of the dose, in the second more than half is estimated to have been absorbed during the first year, when the internal dose was greater then the external one. For Ukrainian peaty soil, an interval of 90-570 $\mu Sv/kBq/m^2$ has been estimated for the first four years ([Likhtariov] also reported in [Balonov et al., 1996]). After the early emergency, soil decontamination, special treatments as well as import of uncontaminated food stuff have contributed to substantially decrease the yearly internal dose. This dose has become insignificant for areas with black and turf-podzol clay soils, but still significant for areas with sandy and peaty soils [Balonov et al., 1996].

For comparison with the total individual doses given in the text, Sevan'kaev et al. [1995 b] estimated, for people who lived over five years after the accident in contaminated areas of Russia and Belarus with average Cs-137 contamination in the range 75-1000 kBq/m^2 and average Sr-90 contamination in the range 4-20 kBq/m^2, average doses in the range 8-102 mSv. These values were calculated using dosimetric models, with pessimistic assumptions for internal doses.

59 Balonov et al. [1996] estimated the following external doses to adults living in contaminated areas during the first ten years after the accident: rural population in Ukraine approximately 42 $\mu Sv/kBq/m^2$ [Likhtariov]; rural population of Russia about 26 $\mu Sv/kBq/m^2$; and, urban population of Russia about 23 $\mu Sv/kBq/m^2$. For strict control zones this would mean an average external individual dose of about 20-40 mSv. According to the authors, these values would correspond for these people, on the average, to about 60% of their total lifetime additional external dose from the accident. Roughly one third of the ten years dose was absorbed in the first year. The effective half-life of Cs-137 was assumed to be 19 years — an interval of 10-20 years is regarded as typical in [EC/IAEA/WHO, 1996-V]. These estimations should be considered with caution, mainly because of the uncertainties in the actual distribution of doses. Moreover, the physical half-life of Cs-137 is 30 years and the effective half-life may be up to 25 years [Likhtariov et al., 1996]. Based on this effective half-life, which may be regarded as an upper limit, the total collective dose over seventy years would be a factor of approximately three times greater than the one taken in the first ten years (assuming the population permanently resides in the same areas for 70 years). With this factor, a total commitment dose for this group of 30000-60000 person-Sv from external irradiation can be calculated.

[EC/IAEA/WHO, 1996-III] using an average deposition density of 111 kBq/m^2, an average external and internal dose of approximately 50-150 µSv/kBq/m^2 in the period 1986-1995[60], and an average effective individual dose of 6-20 mSv[61], a collective effective dose of 35000-100000 person-Sv can be estimated for 6.8 million people[62]. An estimation of the same order of magnitude, 22000 person-Sv, is given in [Kenigsberg et al., 1995] for the entire population of Belarus[63]; 47500 person-Sv have been given for the entire population of Ukraine, 15000 of which absorbed by inhabitants of areas with less than 37 kBq/m^2 [EC/IAEA/WHO, 1996-III][64]. The addition of 50% to the assessed 10 years' doses would give, according to [EC/IAEA/WHO, 1996-III], an estimate of the total collective dose over 70 years, 53000-150000 person-Sv[65].

Total latent fatalities

From the above described estimation of collective doses and assuming the past experience with Japanese survivors to the atomic bombing in Hiroshima and Nagasaki, the excess of fatal cancers can be predicted. Table D.2.3 summarises the previously described findings concerning the estimated fatalities of the 1996 Chernobyl Conference in Vienna [EC/IAEA/WHO, 1996-III, VIII]. A number of 2000 excess fatal cancers has been estimated for 200000 liquidators who worked in 1986-1987 receiving the highest doses in their group. Approximately 4600 excess fatal cancers have been estimated for the 6.8 million residents[66] in "contaminated" areas (Cs-137 deposition in the range

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60 In the reference these values, greater than the ones assumed for the strict control zones, are justified by less control on internal dose.

61 The reconstruction and prognosis of the average effective dose to adult population for the period 1986-2056 in the zone between 100 and 1000 km from Chernobyl gives values for the external exposure of 40 µSv/kBq/m^2 for urban population and 64 µSv/kBq/m^2 for rural population; the internal doses are in the range 25-184 mSv/MBq/m^2 for the rural population depending on the type of soil ([Balonov et al., 1996], used in [EC/IAEA/WHO, 1996-V]). Considering the density of 555 kBq/m^2, the previous would give for the external dose a total over a lifetime of approximately 20-35 mSv, for the internal dose 15-100 mSv.

62 The value presented at the conference was 3.7 million persons, the corresponding collective effective dose interval was 30000-90000 person-Sv over 70 years, and the predicted excess fatalities 2500.

63 This value may be underestimated. It appears to have been calculated by excluding internal doses from radioiodine and assuming that all mitigation actions were successful (which imply that about 2/3 of the additional lifetime dose due to the accident was absorbed in the first ten years after the event) [Stoll, 1996].

64 Using on the one hand the 2404861 inhabitants of Ukraine living in areas contaminated with > 37 kBq/m^2 of Cs-137 for the number of exposed people (19456 persons living in areas with contamination 555-1480 kBq/m^2, see Sub-section "Contaminated areas") and a collective dose of about 32500 person-Sv on the other hand, we would get a lifetime average individual dose of approximately 14 mSv.

65 Using instead a factor of three, as explained in Footnote **60**, we would calculate a total commitment dose for this group of 105000-300000 person-Sv.

66 See Footnote **63**. From other contributions to the Conference, here reported in the Section "Contaminated areas", this population consists of about 6.9 million people.

37-555 kBq/m^2). In addition, approximately 1500 fatalities are predicted in the "highly contaminated" areas (Cs-137 contamination > 555 kBq/m^2). Summing-up all collective doses reported in [EC/IAEA/WHO, 1996-III] for 70 years, a total of approximately 90000-200000 person-Sv is derived. Using the average figures predicted for cancers in the population, and the interval given for EW and thyroid cancer deaths among children, the estimated total latent fatalities are 9130-9730.

This assessment appears to have been made with different risk factors considering the distribution of doses and the absorption rates[67]. As already stated, for the bulk of population living in low contaminated areas the expected relatively small number of excess cancers would make them difficult to detect, also considering that the most affected countries are lacking efficient national cancer registries.

The above estimation excludes the 400000-600000 liquidators who worked after year 1987 (see relevant sub-section), the people living in areas with contamination lower than 37 kBq/m^2 and the people living outside the three most affected countries.

Assuming an average individual dose of 20 mSv for this second group of liquidators, we would calculate 8000-12000 person-Sv, or approximately further 320-480 fatal cancers if we use a risk factor of 0.04 Sv^{-1}. Therefore, the total latent fatalities among **liquidators** would be approximately 2500-2700. Adding these 320-480 fatalities to the numbers given in [EC/IAEA/WHO, 1996-VIII], the estimated interval for all cases would be **9450-10200 latent fatalities**[68].

[67] With its Position Statement of March 1996, the Health Physics Society has recently recommended: "[...] against quantitative estimation of health risks below an individual dose of 5 rem (50 mSv) in one year or a lifetime dose of 10 rem (100 mSv) in addition to background radiation. Risk estimation in this range should be strictly qualitative accentuating a range of hypothetical health outcomes with an emphasis on the likely possibility of zero adverse health effects. [...] Below 10 rem [...] risks of health effects are either too small to be observed or are non-existent." [HPS, 1996]. In order to be consistent with this authoritative recommendation concerning long-term exposure to radiation, the estimation of the consequences of the Chernobyl accident would require an accurate assessment of the distribution of lifetime individual doses in the exposed groups of population.

[68] Using the given ranges for the considered doses to the population living in contaminated areas, as well as the ranges for EW and the children, we would get 6300-12600 late fatalities [EC/IAEA/WHO, 1996-VIII].

Using pessimistically a factor of three to multiply the first 10 years' commitment dose to the population in the contaminated areas to get the lifetime doses in seventy years (see Footnote **60**), we would calculate a total commitment dose for all mentioned groups of the population (excluding internal doses to the thyroid of children) of 137000-362000 person-Sv. Using for these doses a risk factor of 0.05 Sv^{-1}, and including fatal thyroid cancers in children as well as all potential excess cancers in liquidators, the total death toll for the most affected people in Belarus, Russia and Ukraine would be 9600-21600 excess fatal cancers due to the accident (excluding potential cancers in the population of these three countries living in zones with contamination below 37 kBq/m^2).

Table D.2.3

Estimated fatal cancers attributable to the Chernobyl accident in the most exposed groups of people in Belarus, Russia and Ukraine (after [EC/IAEA/WHO, 1996-III], [EC/IAEA/WHO, 1996-VIII]).

Category	**Population size and doses (average individual dose) [collective dose[a]]**	**Cancer type**	**Expected number of natural cancer deaths**	**Potential lifetime excess of fatal cancers due to the accident**	
				Fatalities	**Fraction of natural**
Liquidators (1986-1987)	200000 (100 mSv) [20000 person-Sv]	leukaemia other	800 41500	200 2000	20% 5%
Evacuees (1986)	135000 (12 mSv) [b] [1600 person-Sv]	leukaemia other	500 21500	10 150	2% 0.1%
Residents of “Strict control zone” (>555 kBq/m^2)	270000 (50 mSv) [15000-30000 person-Sv] [c]	leukaemia other	1000 43500	100 1500	9% 3%
Residents of other contaminated areas	6800000 (7 mSv) [53000-150000 person-Sv] [c]	leukaemia other	24000 1088000 [d]	370 4600 [e]	1.5% 0.4% [f]
Children, age 0-14 in 1986	1000000 [g] (500 mGy)	thyroid	<1-2 [h]	200-800 [i]	100-400 times
TOTAL	7405000 1000000 children	leukaemia other thyroid	26300 1194500 (2)	680 8250 200-800	2.6% 0.7% 100-400 times
		all cancers	~1221000	9130-9730 **2.5-2.6 (total)** [j] **0.5-0.6 (workers)** [j] **1.9-2.0 (public)** [j] **Fatalities/GW$_e$·a**	~0.8%

[a] Collective effective doses given for 70 years exposure after the accident.
[b] The reference [EC/IAEA/WHO, 1996-III] shows 10 mSv which is not consistent with the given collective dose of 1600 person-Sv but with 1300 person-Sv presented at the Conference (see also Footnote **55**).
[c] The lowest value roughly corresponds to the average individual dose times the number of people.
[d] Recalculated. Although it is stated in the reference [EC/IAEA/WHO, 1996-III] that 16% of inhabitants would die of natural cancer, which is consistent with WHO health statistics, the value reported for natural cancer deaths among the considered 6.8 million people is 800000, which corresponds to only 12%.
[e] Average value shown [EC/IAEA/WHO, 1996-III]. The interval would be 2700-7500 deaths (including leukaemias).
[f] Obtained using the corresponding values in the fourth and fifth columns. In [EC/IAEA/WHO, 1996-III] 0.6% is given, using 800000 for the background number of cancer deaths for the same group of people.
[g] Children are treated separately from the general population for the thyroid cancers.
[h] 10-40 cases are reported in the reference. Here the fatalities have been calculated using 5% fatality rate.
[i] 4000-8000 cancer cases are reported in the reference. [J] Assuming 3680 GW$_e$·a for normalisation.

Normalising by the total world-wide net electricity generated by nuclear power plants in the period 1969-1996, which is about 3685 GW_e·a (see Section 6.5), approximately **2.5-2.6 latent fatalities per GW_e·a** are obtained, thereof **0.5-0.6 latent fatalities per GW_e·a for the workers** and **1.9-2.0 latent fatalities per GW_e·a for the population**.

An evaluation presented in [UNSCEAR, 1993], based on Cs-137 deposition estimates, gives for the **global effective collective dose** a value of 600000 person-Sv[69], thereof 36% in the territories of the former USSR, 53% in the rest of Europe and 11% in other parts of the north hemisphere[70]. If we apply the no-threshold linear dose-effect principle[71] and an average risk factor of 0.05 fatal cancer/Sv, **30000 latent fatalities** would be calculated, thereof about 11000[72], 16000 and 3000 respectively in the three above mentioned areas[73]. Using this estimation, the normalised total death toll in the population would be about **8.2 latent fatalities/GW_e·a**. If we add 2700 additional cancer deaths among liquidators, the total public and occupational death toll due to the accident would be **32700 latent fatalities**, which normalised by the electricity generated by nuclear plants would give approximately **8.9 latent fatalities/GW_e·a**.

Figure D.2.1 illustrates the late fatalities from the Chernobyl accident normalised by the unit of electricity, using the estimation presented in [EC/IAEA/WHO, 1996-I/VIII] and the global effective collective dose given in [UNSCEAR, 1993]. In the case of the global value, the predicted fatalities reported in [EC/IAEA/WHO, 1996-I/VIII] are included as part of it.

To put in perspective the values for the doses given above, a collective dose of approximately 13 million person-Sv[74] is annually delivered to the world-wide population

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69 This values was first reported by UNSCEAR in 1988 (see also [Bennett, 1996]).

70 In [Bennett, 1995] the reported shares were: 40% in the territories of the former USSR, 57% in the rest of Europe and 3% in other parts of the world.

71 This approach is opposite to the statement reported in Footnote **68**.

72 Considering all types of cancer, 188.6 cancer deaths per 10^5 men per year and 137.3 cancer deaths per 10^5 women per year (i.e., 161.5 cancer deaths/10^5 person/year) occurred in the United States in year 1988, while 215.5 cancer deaths per 10^5 men per year and 180.0 cancer deaths per 10^5 women per year (i.e., 197.3 cancer deaths/10^5 person/year) were recorded in the former USSR in the same year [WHO, 1991]. The same source reports for the former Bielorussian SSR 196.9 and 130.6 cancer deaths/10^5 person/year, respectively for men and women, whereas for the former Ukrainian SSR the values were 225.7 and 155.6 cancer deaths/10^5 person/year, respectively for men and women. Using the average rate in the former USSR, the number of fatalities caused by any sort of cancer in a population of 25 million inhabitants around Chernobyl in 60 years, supposing the number of living people remains constant, would be approximately 3 million. Therefore, these 11000 additional cancers would be only less than 0.5% of the total.

73 Goldman et al., [1994] estimated for the population (excluding EW) a total of approximately 28000 fatal cancers projected over 70 years, thereof about 14000 in the former USSR, 13000 in the rest of Europe and less than 1000 in other parts of the Northern Hemisphere.

74 Calculated multiplying an average individual dose of 2.4 mSv/a times 5.6 billion persons.

from natural sources ([Bennett, 1995] after [UNSCEAR, 1993]). Moreover, the estimated collective effective dose from all atmospheric testing of nuclear weapons is 30 million person-Sv. The total collective dose from civil nuclear power production (mines, mills, reactors and reprocessing plants, till the end of year 1989, assuming 1844 $GW_e \cdot a$) has been estimated at approximately 11000 person-Sv, plus a long-term component over 10000 years of about 400000 person-Sv from Rn-222 released from mill tailings and from C-14 ([Bennett, 1995] after [UNSCEAR, 1993]).

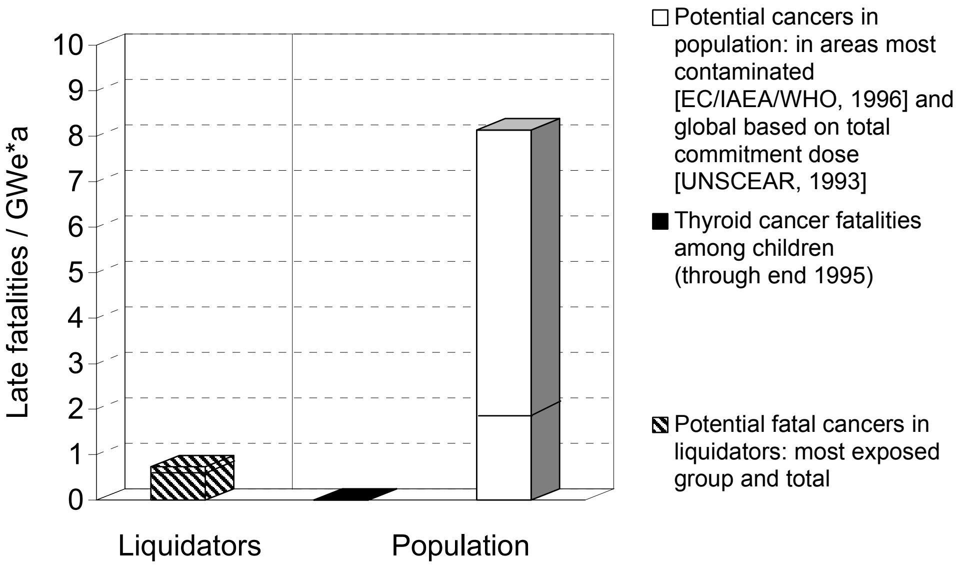

Fig. D.1.1 Estimated late fatalities from the Chernobyl accident normalised by the unit of electricity (total nuclear power generation in the period 1969-'96).

Several other estimations of the total potential latent fatalities have been made to date. [Savchenko, 1995] reported that at the time he was writing his book, estimates of the death toll from cancer deaths ranged 14000-475000 fatalities (there is no specific source given for this range of values).

For the public, Prêtre [1994] classified the population into six groups for a total of approximately 24 million people living within a circular area of 600 km of radius around Chernobyl, and including the evacuees. The relevant assumed individual average doses ranged from 0.4 Sv for the highest contaminated zone down to 0.01 Sv for the largest area with the smallest considered contamination; the evacuees were accounted with 0.3 Sv average individual dose. Considering 10 year time integration for the exposure of the public and an individual dose cut-off of about 10 mSv, a collective dose of approximately 372000 person-Sv was estimated, which corresponds to approximately 20000 potential fatal cancers. Considering no cut-off criteria, an additional 20000 radiation-induced potential fatal cancers were estimated. Later on, based on updated information on doses, the latent fatalities in all exposed groups in the three most affected countries were estimated to about 7000-10000 [Stoll, 1996].

Among early assessments, Anspaugh et al. [1988] calculated a collective 50-years dose commitment (external and internal) to the about 3 billion inhabitants of the Northern Hemisphere of 930,000 person-Gy, thereof 97% in the western part of the former Soviet Union and Europe. The best estimate for the lifetime expectation of fatal radiogenic cancer would increase the risk from 0 to 0.02% in Europe and from 0 to 0.003% in the Northern Hemisphere. These authors have assumed approximately a total of 100 PBq (2.7 MCi) of Cs-137 deposited on land. Anspaugh et al. [1988] considered the 50-year[75] radiation-dose commitment to the total body from the external pathway as well as the individual dose commitments from the ingestion pathway for the thyroid and the total body. This was done country by country. The best or central estimate value calculated for the Northern Hemisphere was approximately 17400 fatal cancers, including 6500 in the former USSR[76], 10400 in Europe without the former USSR, and only about 500 in Asia and 20 in North America. Anspaugh et al. [1988] used radiogenic risk factors from various sources including the NRC report on the "summed site" health effects model for nuclear power plants accident-consequence analysis ([NUREG, 1985], and [UNSCEAR, 1986]). Since then, the risk coefficients have increased by a factor of approximately three due to the new findings about the source term from the atomic bombing in Japan (see for example [Delpla, 1985], [UNSCEAR, 1993]). Taking this into account, the death toll calculated in [Anspaugh et al., 1988] would increase by about the same factor.

To conclude this overview, when using estimations of health consequences of the Chernobyl accident it should be borne in mind that they are all associated with many uncertainties. Among others, the patterns of contamination are very uneven which makes the precise distribution of radiation doses not well known for the various groups of exposed people. Furthermore, the migration flows of residents from one area to another, which changes the individual exposure rates, should be properly considered [Storm et al., 1996], but there are no specialised statistics to systematically cover all the contaminated areas [Arutyunyan et al., 1996] (see sub-section "Evacuees" above) [77].

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[75] The 50-year exposure used in the study for the calculation of the doses for lifetime cancer risk is more than 75% of the exposure over infinite time. The first year exposure is estimated by the authors as 10 % of the 50-year exposure [Anspaugh et al., 1988].

[76] For this group the calculated interval was between 2000 and 17000 excess fatal cancers [Anspaugh et al., 1988]. The normally expected number of fatal cancers in the population of the former USSR is approximately 35 million cases during 70 years; 88 million fatal cancers are expected in the same time period in Europe excluding the former USSR. Therefore, the estimated additional cases are of the order of 0.02 % and 0.01%, respectively.

[77] As example of population changes, it is reported in [Voznyak, 1996 a] that in the most contaminated (>555 kBq/m^2) districts of the Briansk region the loss of population (overall death rate minus birth rate) in 1995 was 8‰ (5.1‰ for the entire Russia). The overall mortality index for these districts was 18.7‰, the highest for the last 10 years (14.5‰ for the entire Russia). It has also to be considered that the analysis of the age structure shows that these contaminated areas have older population than in the entire Russian Federation, a factor which contributes to the higher death rates [Arutyunyan et al., 1996].

Health impacts in Switzerland and other countries

A booklet summarising information on the Chernobyl accident and its consequences for Switzerland has been recently issued by the Eidgenössische Kommission für AC-Schutz (KOMAC), the Eidgenössische Kommission für die Sicherheit von Kernanlagen (KSA), the Eidgenössische Kommission für Strahlenschutz (EKS), and the Eidgenössische Kommission für die Überwachung der Radioaktivität (KUeR) [KOMAC et al., 1995]. Of interest for the present report are the doses to the Swiss population associated with the accident. The most affected Cantons were Tessin, Graubünden and Türgau. In particular, in Tessin the individual dose absorbed at present is approximately 30-40% of the total natural without radon[78]. The additional individual dose from Chernobyl has been estimated on the average for Switzerland, including all possible contributions, 0.5 mSv over 50 years; the most exposed population in Tessin will absorb a dose about ten times higher. In the past ten years, 90% of the estimated total has been already absorbed by the population. With the above, the excess risk of cancer due to the accident can be calculated for the Swiss population as 0.0025%, to be compared with the present 25% risk to die of any form of cancer.

For the population outside the former Soviet Union, the internal doses to the thyroid in children ranged from 1 to 20 mSv in Europe, 0.1-5 mSv in Asia and about 0.1 mSv in North America [UNSCEAR, 1988]. The whole-body doses (external plus internal) received during the first year, mostly from isotopes of caesium, are estimated as 0.05 to 0.5 mSv in Europe, 0.005-0.1 mSv in Asia and of the order of 0.001 mSv in North America [UNSCEAR, 1988].

Genetic effects

There seems to be lack of extensive statistical studies about birth defects and other genetic effects, although some cases have been reported in the press. However, no reliable evidence of any significant change in the number of birth defects, congenital abnormalities, adverse pregnancy outcomes exists at present which can be attributed to the exposure from the accident, according to [NEA, 1995]. The predicted levels of excess birth defects are considered as undetectable [EC/IAEA/WHO, 1996-III]. Anyhow, registries of hereditary effects are lacking in the affected countries, which makes any statistical analysis questionable.

If it is assumed that in the first generation offspring of a population of one million persons, including all ages and both sexes, an upper limit of 30 cases with hereditary disorders[79] would be observed per 480000 births per 10 mSv to each parent [NUREG, 1991], the

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[78] The natural average dose in Switzerland is about 2.8 mSv/a, thereof 1.6 mSv/a from radon and radon daughters, 0.8 mSv/a from other external sources, and 0.4 mSv/a from sources internal to the body.

[79] Including autosomal dominant, X-linked, recessive, chromosomal and congenital abnormalities.

estimation for the four groups of persons considered in [EC/IAEA/WHO, 1996-III][80] gives a very low predicted occurrence of radiation induced hereditary effects, ranging from 0% to 0.03% of all live births (the background number of hereditary disorders is 7.5%) and from less than 0.1% to 0.4% of all hereditary disorders among the live births in the exposed population.

Other sources report that considering data in the period 1980-1991, the frequency of congenital malformations (primarily characterised by dominant mutations) in foetuses from clinical abortions and new-borns has increased in heavily contaminated areas (> 555 kBq/m^2) of Belarus following the accident. In particular, the increase of developmental abnormalities among 5-12 week human embryos from the most contaminated rural regions exceeds that of the control group and of the urban population (where the exposure is lower) after the accident by a factor of 1.5-2, while no increase has been detected in medical abortions made in Minsk and Gomel as well as in the control group before and after the accident [Lazyuk et al., 1994]. However, the observed increases cannot be unequivocally associated with dominant mutations as a result of the parents' absorbed radiation doses, but may be caused also by chemical contaminants, characteristics of inbreeding in rural areas, defective nourishment, and multiple psychological stress ([Dubrova et al., 1996] after [Lazyuk et al., 1994] and [Lazyuk et al., 1993]).

Recent studies document surprisingly high increases in mutation rates in small mammals living at the Chernobyl site and in humans exposed to various degrees to radiation [Hillis, 1996]. Baker et al. [1996] examined two species of vole living at the reactor site (which is also heavily contaminated by chemical pollutants and heavy metals) and compared the data with control population of the same species in relatively unaffected areas 32 km far away. They have found high increases in substitution rates in mitochondrial protein-coding genes of the exposed animals[81]. However, the population of voles as well as many other plants and animals continue to thrive (for less competition, abundance of food, few predators etc.). The increased substitution rate may reflect the presence of mutagens other than, or in addition to, radioactivity, with possible synergistic effects [Baker et al., 1996]. While radioactivity has greatly decreased with time, the presence of heavy metals and mutagenic chemicals persists, making the consequences of the Chernobyl accident very different from those of nuclear weapons and therefore difficult to predict on the base of the past experience [Baker et al., 1996]. The study by Dubrova et al. [1996] shows that increases in mutation rate occur in children living in Belarus few hundred kilometres north of Chernobyl, who received high doses of I-131 and are exposed to Cs-137 contamination. This effect consists of germline mutations, specifically length

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[80] Assuming average individual doses of 100 mSv for the 200000 liquidators, 10 mSv for the 135000 evacuees from the exclusion zone, 50 mSv in a lifetime for the 270000 residents in the strict control zones and 7 mSv in a lifetime for 6800000 residents in other contaminated areas.

[81] More than $2 \cdot 10^{-4}$ substitutions per nucleotide site per generation for both analysed species of vole, which is at least two orders of magnitude higher than reported rates for vertebrates. These results have been estimated by two independent methods from phylogenetic analyses of the population data [Baker et al., 1996]. The substitution rates unlikely extend to nuclear genes [Hillis, 1996].

changes in nuclear minisatellite loci[82], twice as much as common in other population living in Belarus as well as in control populations in the UK. In this case, the researchers found a correlation between surface caesium contamination levels and the observed mutation rates, but there remains the possibility that other non-radioactive contaminants may be responsible for these effects [Dubrova et al., 1996]. Both observed effects are not fully consistent with the expected consequences of radiation damage and the responsible are mechanisms not yet fully understood [Hillis, 1996].

Other health effects in the population

Increases in the frequency of a number of non-specific detrimental health effects other than cancer (particularly among liquidators) have been reported[83] which may be partially explained because of stress and anxiety resulting from the accident [EC/IAEA/WHO, 1996-III, a], [NEA, 1995]. Although the extensive psychological effects and psychosomatic disorders among the affected persons are not directly caused by radiation, they have been considered among the most important consequences of the Chernobyl accident (IAEA Conference in 1991 and EC/IAEA/WHO Conference in 1996). Social stress and manifestations of social disruption have clearly been observed among the population in the contaminated areas and in the communities that have received the evacuees. Resettlement has failed to produce reduction of anxiety when compared to restricted areas [EC/IAEA/WHO, 1996-IV]. All the before mentioned effects are also strongly influenced by the difficult social, political and economical conditions experienced by the countries of the former USSR since its collapse.

The morbidity rate as well as the mortality rate are increasing in the three most affected countries, due to instabilities and economic difficulties. If this trend continues, it can lead to higher uncertainties and false interpretation of statistics [EC/IAEA/WHO, 1996].

In the frame of the haematology project of IPHECA (WHO), it has been found that the yearly number of blood disorders has slightly increased in the group of 270000 people living in the strictly controlled zones with respect to the pre-accident situation. However, a similar trend is generally valid for the three countries. Furthermore, no significant differences were detected in areas with different contamination levels [WHO, 1995 a].

The preliminary investigations of the brain damage *in utero* project of IPHECA (WHO) found a higher incidence of mental retardation as well as an upward trend in behavioural disorders and emotional problems in children of the exposed group compared to the

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[82] Specific genome sites that feature an unusually high number of repetitions [NW, 1996].

[83] Diseases of the endocrine system, diseases of the blood and blood forming organs, mental disorders, diseases of the circulatory and digestive system are quoted in [EC/IAEA/WHO, 1996-III]. According to Bebeshko [1995] 15000 people lost their ability to work owing to disease. This author also mentions that the observed main health disorders are: gastrointestinal disorders (inflammatory soon after the accident and ulcerative in later years); immunological disorders; problems in the homeostasis; metabolic disorders; respiratory, primarily obstructive bronchitis; and, haemapoietic disorders.

children of the control group living in clean areas [WHO, 1995 a]. However, no conclusion can be drawn from these indications because of many factors that may have distorted the results.

Contaminated areas

According to [EC/IAEA/WHO, 1996], the “exclusion zone” covers in total 4300 km^2 in Belarus, Ukraine and Russia.

Voznyak [1996 a] reported that as of January 1995 the total area of the **Russian Federation** contaminated by Cs-137 with surface deposition density > 37 kBq/m^2 was **57650 km^2** (310 km^2 with contamination > 1840 kBq/m^2 or 40 Ci/km^2). From the same source, the number of people residing in these contaminated areas as of June 1995 was **2687400** in 7661 settlements, thereof 90800 people still living in the 555-1480 kBq/m^2 zone (called “Evacuation zone” in the paper), and 347200 people in the 185-555 kBq/m^2 zone (in the paper identified as the “Zone where the inhabitants have the right to be evacuated”, or zone of voluntary resettlement)[84].

In [Rolevich et al., 1996], the total contaminated area of **Belarus** is **46450 km^2**, which corresponds to 23% of the entire surface of the republic. According to the same source, the number of persons living in these contaminated areas as at beginning of 1996 was about **1841000** in 3211 settlements, thereof about 41300 people in the 555-1480 kBq/m^2 zone and 314200 in the 185-555 kBq/m^2 zone.

About **2404861** inhabitants live in 2218 Ukrainian settlements on an area of **50520 km^2** contaminated with > 37 kBq/m^2 of Cs-137, thereof about 19456 people in the “Compulsory evacuation zone” and 653263 in the “Guaranteed voluntary evacuation zone”. 91235 people were evacuated from 76 settlements in 1986 [Ukraine, 1996].

The summation of the above surfaces gives for the **areas contaminated with Cs-137 > 37 kBq/m^2** a **total** of **154620 km^2** [85], with a population of about 6.9 million inhabitants.

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[84] Similar figures are given in [Arutyunyan et al., 1996].

[85] Different values were reported by other groups at the same conference. According to [EC/IAEA/WHO, 1996-V] the total contaminated areas in Belarus, Russia and Ukraine are: 3030 km^2 with Cs-137 surface deposition density > 1480 kBq/m^2; 7190 km^2 with Cs-137 density 555-1480 kBq/m^2 (both previous are called in the reference “Obligatory evacuation zones”); 19070 km^2 with Cs-137 density 185-555 kBq/m^2 (“Voluntary evacuation zone”); and, 115930 km^2 with Cs-137 density 37-185 kBq/m^2 (“Control zone”), for a total of 145220 km^2 contaminated with > 37 kBq/m^2.

Furthermore, according to [EC/IAEA/WHO, 1996-III] after [Balonov et al., 1996] approximately 131000 km^2 are contaminated with 37 kBq/m^2 or more. According to Savchenko [1995], they are 104000 km^2. According to [EC/IAEA/WHO, 1996-III] after [Ilyin et al., 1990], about 270000 people (106000 in Belarus, 111800 in Russia and 52000 in Ukraine) used to live in 1986 in the 10300 km^2 strict control zone with Cs-137 deposition activity > 555 kBq/m^2. Savchenko [1995] gives a different figure for the people living in the 10190 km^2 strict control zone in year 1994, approximately 240000.

Nearly 3 million acres (12140 km^2) of land is lost for decades for agricultural production because of contamination with radioactive caesium, strontium and plutonium according to Savchenko [1995]. Different estimations can be found in other sources: according to [NEA, 1995], the total contaminated area in the three most affected countries is 125000 km^2 with Cs-137 levels > 37 kBq/m^2, thereof 52000 km^2 were used for agriculture. In 1994, 2640 km^2 of agricultural land in Belarus was still excluded from use ([NEA, 1995] after an Information Bulletin of the Republic of Belarus). Based on [Ukraine, 1996], the accident resulted in a contamination of 31000 km^2 of arable Ukrainian land (thereof more than 1800 km^2 are unusable because contamination is > 1480 kBq/m^2), 15000 km^2 of natural pastures and 44000 km^2 of forests[86].

In the first year after the catastrophe 144000 hectares of agricultural land and 492000 hectares of forest (total 6360 km^2) were withdrawn from use [Savchenko, 1995]. The 30-km radius exclusion zone is contaminated by isotopes of plutonium, but spots with 0.1 Ci/km^2 (or 3.7 kBq/m^2) have been found outside it [Savchenko, 1995].

Waste

It has been estimated that the total volume of the waste from decontamination operations is about one million cubic meters, spread over large areas and many sites [Savchenko, 1995] (811 waste dumps are located around the plant according to Perera [1995]).

Environmental impacts

In the first three years from the accident short term damage was widely reported to forests and some mammals in the exclusion zone. As reported in [EC/IAEA/WHO, 1996-V], the contamination in 1986 within parts of the 30 km exclusion zone typically reached several tens of MBq/m^2, the corresponding external doses to plants and animals being of the order of several tens of Gy in the first month, decreasing by a factor of 10-100 already in early autumn. The accident occurred in spring, during the most radiosensitive period for plants. Especially coniferous trees were affected because of their high sensitivity to radiation. The main long term damage has been the total destruction of about 600 ha of pine forest (so-called "red forest") in the vicinity of the reactor[87] and the partial destruction of a further 3000 ha (0.5% of the trees have died; many abnormalities are observed) [EC/IAEA/WHO, 1996-V]. Other sources specify that 375 ha of dead forest was cut and 10-15 cm of soil removed; the resulting 100000 m^3 of waste buried in trenches

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As reported in [EC/IAEA/WHO, 1996-III], the territory contaminated with Cs-137 in excess of 185 kBq/m^2 (or 5 Ci/km^2) is 29200 km^2 wide, thereof 16500 in Belarus, 4600 in Ukraine and 8100 in Russia, while about 28000 km^2 of land with 2225 settlements in Belarus, Russia and Ukraine are quoted in [Savchenko, 1995] for the same class, thereof 17800 km^2 (under permanent control) have a contamination level of 185-555 kBq/m^2, with 584500 inhabitants.

[86] 35000 km^2 was reported at the conference.

[87] The doses were of the order of 80-100 Gy, to be compared to doses of 10-1000 Gy which are typically used to artificially induce mutations in seeds for plant breeding [EC/IAEA/WHO, 1996-V].

[NEA, 1995]. More than 30000 km^2 of forests received a deposition of Cs-137 > 37 kBq/m^2 ([EC/IAEA/WHO, 1996-V] after [Belli et al., 1996]). However, there have been apparent signs in flora and fauna that show capacity for recovery already by 1988-1989[88] [EC/IAEA/WHO, 1996-V]. Particularly wild mushrooms still show high concentrations of isotopes of caesium, which decreased in comparison with the 1986 levels only according to the physical decay rate [EC/IAEA/WHO, 1996-V]. This retention of radioisotopes is due to the high organic content and the stability of forest soil [NEA, 1995]. From [Tikhomirov et al., 1994], the stand canopy of trees has a high retention capacity of radioactive fallout. More than 95% of the total nuclides contained in the forest system is in the forest litter already 1-2 years after an accident. Strontium and caesium migrate very slowly along the forest profile[89]; therefore, forests act as “radionuclide pools”, sort of barrier against the migration of radionuclides to other systems [Tikhomirov et al., 1994]. In general, the main part of the dose was absorbed by the majority of forest species within the second month after the accident. Workers in contaminated forests are considered professionally exposed (average annual less than 5 mSv, maximum about 10 mSv) [Tikhomirov et al., 1994].

A reduction in the population of several species of wild animals has been observed, but in some cases returned to normal in a few years [EC/IAEA/WHO, 1996-V]. The cases of severe birth defects in agricultural animals in high contaminated zones reported in the press have been shown to have an occurrence comparable to that in non-contaminated parts of Ukraine ([EC/IAEA/WHO, 1996-V] after [Prister et al., 1996]).

The worst contaminated water body is the cooling pond of the failed plant, where fuel particles are found in the sediments at its bottom [Sansone et al., 1996]. The contamination of Cs-137 in these sediments has increased three to four orders of magnitude, up to $4.6 \cdot 10^5$ Bq/kg in 1987-1990; in 1986, measured Sr-90 contamination was up to $1.4 \cdot 10^5$ Bq/kg [Kryshev et al., 1996]. The radioactivity of Cs-137 in the water of the cooling pond changed from 0.013 Bq/l in 1985 to 300-1700 Bq/l in 1986, and 14-240 Bq/l in 1987-1990; water contamination of Sr-90 was 10-40 Bq/l in 1986. About other water bodies for water use, the highest radiation risk to the population from drinking water has been estimated for the lakes in the Bryansk region (10^{-4}-10^{-3} risk from Cs-137 for the years 1991-1993 [Kryshev et al., 1996]), which can be comparable or even greater than the risk associated to the background radiation. However, in general, the surface aquatic ecosystems are considered to be less important to human exposure than other pathways; for example, the lifetime individual effective dose from water consumption from the river Pripyat is estimated to be only 0.4 mSv[90] [EC/IAEA/WHO, 1996-V]. The aquatic

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[88] It can be argued that the situation might not be recovering uniformly throughout the zone, due to the existence of areas with hot spot contamination. However, the authors of the present report lack detailed information about it.

[89] Tikhomirov et al. [1994] state that only < 0.1% of Sr-90 and 0.01% of Cs-137 are washed out annually to a depth below 30 cm.

[90] In the early phase of the accident, the contribution to the total dose from water bodies did not exceed 2% ([NEA, 1995] after [Likhtarev et al., 1989]).

organisms showed high tolerance to the radiation. In some European countries (e.g., Sweden and UK), the level of radioactivity concentrated in lake fish has been and in many cases still is higher than permitted for selling, causing economic losses; this may remain as a long-term problem (the ecological half-life ranges between few years and few decades) [NEA, 1995].

The water pathways (surface and groundwater) are practically the only manner radioactivity can be transferred from high contaminated areas, including many sites with buried high radioactive waste in the 30-km zone[91] with long term radioisotopes[92] [EC/IAEA/WHO, 1996-VIII], [NEA, 1995]. In particular, the watershed areas of the Pripyat and Dniepr rivers are the main potential secondary sources into those rivers and the Black Sea [Sansone et al., 1996]. It has been estimated an annual outflow from the exclusion zone of 10-20 TBq of Cs-137 and 2-4 TBq of Sr-90. The exposed population of the Dniepr region consists of more than 30 million people, with estimated collective cumulative (70 years) committed effective dose of about 3000 person-Sv due to water uses (drinking, irrigation and fishing); some additional individual doses may be up to 2 mSv/a due to high rate of fish consumption [Berkovski et al., 1996].

The results of a hydro-geological study of groundwater [Vovk et al., 1995] (quoted in [NEA, 1995]) indicated that Sr-90[93] in the 30 km zone could contaminate drinking-water above acceptable limits in 10 to 100 years from now. At present, the contamination of Kiev water reservoirs (0.004-0.04 Bq/l of Cs-137[94], one order of magnitude higher for Sr-90) is well below any safety criteria in normal conditions (i.e., non-accident conditions) ([EC/IAEA/WHO, 1996-V] after [Sansone et al., 1996]).

Another uncertainty factor is associated with the difficulties to predict future changes of the destroyed reactor and the sarcophagus.

Economic costs

Use of past experience to evaluate economic costs is subject to serious limitations. In the case of nuclear energy, the statistical material consists of only two accidents, i.e. Three Mile Island (TMI) and Chernobyl. The estimated costs for the Chernobyl accident cited in

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91 Especially the 600-800 unlined trenches around the plant. These waste sites contain the stripped 10-15 cm soil from about 8 km^2 of land and trees and grass affected by the fallout, with an estimated total activity of 1 PBq [NEA, 1995]. Some of the trenches are periodically flooded. One of the measures taken to prevent the contamination from the 30-km zone to the Kiev water reservoirs was to build in 1986 a concrete wall 3.5 km long 35 m (sic) deep around the reactor. However, this construction might be the cause of the increase of the water table level in the vicinity of the plant [NEA, 1995].

92 Pu-239 has half-life of approximately 24000 a.

93 The most mobile isotope; at present, the upper unconfined aquifer in the area around the reactor presents a Sr-90 contamination level of 4 Bq/l [NEA, 1995]. Caesium and plutonium show less mobility.

94 It was 0.4 Bq/l in 1989. To compare, the level of contamination in European drinking water was below 0.1 Bq/l in the period 1987-1990 [NEA, 1995].

Nucleonics Week [1994] range between 20 to 320 billion US$ (the range depends on the assumed exchange rate for roubles). It is not clear which cost elements are included in this estimate.

Voznyak [1996 b], first deputy minister of the Ministry of Emergency Situations of the Russian Federation, stated at the 1996 conference in Vienna that the total direct losses and outlays due to the accident in the period 1986-1991 before the disintegration of the USSR were 23837 million roubles[95]. For the period 1986-1989, an estimation of 9200 million roubles was officially presented by the USSR, Ukrainian SSR and Belarussian SSR delegations to ECOSOC in a letter dated 6 July 1990 addressed to the UN Secretary-general [Voznyak, 1996 b][96]. In 1990 the expenditures were 3324 million roubles from USSR plus additional 1014 million roubles from the single affected republics. In 1991, before the collapse of the USSR, 10300 million roubles had been earmarked as the costs taken over by the individual republics. These expenses covered losses of capital assets, agriculture losses, mitigating actions, construction of new houses and infrastructure as well as moving costs and daily allowances for the resettled people, soil decontamination, forest and water sources protection actions and compensation money [Voznyak, 1996 b]. During 1988-89, 2.97 million roubles was received from foreign funds, thereof 2.2 million in convertible currencies [Voznyak, 1996 b].

Voznyak [1996 a] also presented at the 1996 Vienna conference data for the resources invested for mitigating the consequence of the accident in the Russian Federation in the years 1992-1995. The total is 3349 billion roubles or 1155 billion US dollars, using official exchange rates at the end of each year [Voznyak, 1996 a]. This corresponds to a few per thousands of the GDP. The yearly budget has increased from 67 billion roubles in 1992 to 1736 billion roubles (provisional) in 1995.

From September 1991, a special fund has been set in Ukraine, named "Measure to Eliminate the Consequence of the Chernobyl Disaster and Provide for Social Welfare" [Ukraine, 1996]. Up to 1995, the costs have ranged 1.7-2.8% of the national income. For example, they were about 94200 billion karbovanets in 1995. The reference [Ukraine, 1996] claims that in the past three years, the expenditures amounted to over 3 billion US$ using the official exchange rate. However, they would appear significantly higher if the real purchasing power of the local currency would be taken into account.

Rolevich et al. [1996] claimed that the economic damage to Belarus due to the accident is equal to 32 pre-accident annual budgets or 235 billion US$[97], calculated over 30 year

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[95] No conversion to US$ is given in the reference.

[96] Also Savchenko [1995] reports that the total cost of the cleaning up in years 1986-1989 is estimated around 10 billion roubles (original source(s) of information not mentioned).

[97] No year is given in this reference for the conversion to dollars from the local currency. Savchenko [1995] reports that the estimated economic losses for the period 1986-2015 in the Republic of Belarus would be more than 600 billion roubles based on 1 January 1995 prices. This economic burden includes 214 billion roubles for social protection, 187 billion roubles of losses caused by radionuclide pollution of natural resources, and 80 billion roubles as the cost of radioactive waste control.

recovery period. Recent yearly expenditures have been of the order of thousands of billion roubles. For example, in year 1995 the costs were 3002 billion roubles or 11.5% of the Republican budget, distributed as follows: 58.7% for improving living conditions; 10.6% for resettlement; 28% for compensation; 2% for health care; and, 0.2% for radioecological monitoring [Rolevich et al., 1996].

The data presented from the three most affected countries at the 1996 Vienna conference and summarised above show apparent discrepancies. Therefore, the authors consider any attempt to give a unique figure for the total predicted expenditures still premature on the base of these data. However, the Belarussian, Russian and Ukrainian data seem to suggest a total cost higher than the upper range given in Nucleonics Week [1994].

List of Abbreviations

ARS	Acute Radiation Sickness
AUDR	All-Union Distributed Registry (Chernobyl Registry in the former USSR)
BWR	Boiling Water Reactor
EC	European Community
ECCS	Emergency Core Coolant Systems
ECOSOC	United Nations Economic and Social Council
EFS	Emergency Feedwater System
EKS	Eidgenössische Kommission für Strahlenschutz
EW	Chernobyl Emergency Workers (or liquidators)
GDP	Gross Domestic Product
HPIS	High Pressure Injection System
HPS	Health Physics Society
HSK	Hauptabteilung für die Sicherheit von Kernanlagen
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INES	International Nuclear Event Scale (IAEA/NEA)
IPHECA	International Program on the Health Effects of the Chernobyl Accident (WHO)
KOMAC	Eidgenössische Kommission für AC-Schutz
KSA	Eidgenössische Kommission für die Sicherheit von Kernanlagen
KUeR	Eidgenössische Kommission für die Überwachung der Radioaktivität
LFCM	(solidified) Lava-like Fuel-Containing Materials (corium within the Chernobyl sarcophagus)
LOCA	Loss of Coolant Accident
NEA	Nuclear Energy Agency (OECD)
OECD	Organisation for Economic Co-operation and Development
ORNL	Oak Ridge National Laboratory
PERG	Political Ecology Research Group (Oxford, UK)
PWR	Pressurized Water Reactor
RBMK	Large-Capacity Boiling-Water Reactor (translated from Russian)
RNMDR	Russian National Medical Dosimetric Registry
SG	Steam Generator
SGK	Schweizerische Gesellschaft der Kernfachleute
TBP	Tributilphosphate
TLD	Thermoluminescent Dosimeter
TMI	Three Mile Island
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

Glossary

Absorbed Dose	The dose to specific organs or tissues is defined in terms of the energy absorbed per unit mass; it is expressed in Gray (Gy), in the past it was measured in rad. For internal irradiation of thyroid due to iodine isotopes, a dose of 1 Gy corresponds to a (weighted) equivalent thyroid dose of 1 Sv.
Becquerel (Bq)	Unit of radioactivity; 1 Bq = 1 disintegration/second. 1 EBq = $1 \cdot 10^{18}$ Bq; 1 PBq = $1 \cdot 10^{15}$ Bq; 1 TBq = $1 \cdot 10^{12}$ Bq; 1 GBq = $1 \cdot 10^{9}$ Bq; 1 MBq = $1 \cdot 10^{6}$ Bq; 1 kBq = $1 \cdot 10^{3}$ Bq.
Collective Dose	It expresses the societal impact of radiation exposures on population groups. It is the product of the number of people exposed and their average dose. It is expressed in terms of person-Sv (in the past, person-rem). It may be expressed in terms of collective equivalent (to a single organ or tissue) as well as effective (to the whole body) dose.
Committed Dose	Dose to which an individual is committed due to the intake of radionuclides in his body. It may be expressed in terms of committed equivalent (to a single organ or tissue) as well as effective (to the whole body) dose.
Curie (Ci)	Old unit of radioactivity; 1 Ci = $3.7 \cdot 10^{10}$ disintegration/second = $3.7 \cdot 10^{10}$ Bq.
Exposure	Quantity of electric charge produced in air by ionising radiation; it is expressed in Roentgen (R).
Gray (Gy)	SI unit of absorbed dose; 1 Gy = 1 J/kg = 100 rad.
Effective Dose	Unit expressing partial-body or single-organ exposures in terms of an equivalent dose (or risk) to the whole body. For this purpose, tissue weighing factors have been developed by ICRP.
Equivalent Dose	Unit introduced to express the doses from different types and energies of ionising radiation on a biologically equivalent basis. It is measured in Sievert (in the past, rem).
Exposure Rate	Rate of electric charge produced in air by ionising radiation; it is expressed in Roentgen per hour (R/h).
person-Sv	Unit of collective dose (equivalent); 1 person-Sv = 100 person-rem.
rad	Special unit of radiation absorbed dose, corresponding to the absorption of about 100 erg of energy per gram of soft tissue (or organ); 1 rad = 100 erg/g or 10^{-2} J/kg; now substituted with the Gray.
rem	Roentgen equivalent man. Special unit of equivalent dose; it is equal to the absorbed dose in rad multiplied by the appropriate radiation weighing factor which depends on the nature of the radiation; now substituted with the sievert 100 rem = 1 Sv.
Roentgen (R)	Special unit of exposure (now obsolete), defined as quantity of electric charge produced in air by ionising radiation; 1 R = $2.58 \cdot 10^{-4}$ C/kg, or 1 ues/cm^3 of dry air.
Sievert (Sv)	SI unit of equivalent dose (often referred to simply as the unit of dose). Therefore, one sievert represents an amount of biological effects irrespective of the type of radiation. 1 Sv = 100 rem.

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Appendix E: Lists of dam accidents.

Table E.1

Failures of dams of all purposes in Western Europe, Canada, USA, Australia and New Zealand with total loss of the stored water.

Country	Dam name	Year of failure	Dam type	Purpose	Max. No. fatalities	Min. No. fatalities
Australia	Briseis	1929	Er	S	14	14
Australia	Lake Cawndilla	1962	Te	N.A.	0	0
France	Bouzey	1895	Pg(M)	N	156	86
France	Malpasset	1959	Va	S, I	421	400
Italy	Gleno	1923	Mv, Pg	H	600	500
Italy	Zerbino	1935	Pg	S	130	100
New Zealand	Ruahihi	1981	Er	H	0	0
Spain	Leguaseca (Fonsagrada)	1987	Mv	S	0	0
Spain	Odiel	1968	Er	S	0	0
Spain	Puentes	1802	Pg(M)	I	680	608
Spain	Tous	1982	Er	I, S	40	7
Spain	Vega de Tera	1959	Cb(M)	H	150	123
Spain	Xuriguera	1944	Pg	S	0	0
Sweden	Noppikoski	1985	Te	H	0	0
Sweden	Selsfors	1943	Cb(M)	H	0	0
UK	Bilberry	1852	Te	S	81	81
UK	Blackbrook I	1799	Te	S	0	0
UK	Blackbrook II	1804	Pg(M)	S	0	0
UK	Dale Dike	1864	Te	S	244	244
UK	Killington	1836	Te	N, R	0	0
UK	Rhodes-wood	1852	Te	S	0	0
UK	Torside	1854	Te	S	0	0
USA	Alamo Arroyo, Site 2	1960	Te	C	0	0
USA	Anaconda	1938	Te	S	0	0
USA	Angels	1895	Pg(M)		1	1
USA	Apishapa	1923	Te	I	0	0
USA	Ashley	1909	Cb	S	0	0
USA	Austin I, (Lake McDonald)	1893	Pg(M)	H, S	0	0
USA	Austin II	1915	Cb(M)	H, S	0	0
USA	Avalon I	1893	Te/Er	I	0	0
USA	Avalon II	1904	Te/Er	I	0	0
USA	Baldwin Hills	1963	Te	S	5	3
USA	Balsam	1929	Te	C, R	0	0

N.A.: Not available

Table E.1

Failures of dams of all purposes in Western Europe, Canada, USA, Australia and New Zealand with total loss of the stored water.(Cont.).

Country	Dam name	Year of failure	Dam type	Purpose	Max. No. fatalities	Min. No. fatalities
USA	Bayless	1911	Pg	S	100	80
USA	Black Rock (Zuni)	1909	Te/Er	I	0	0
USA	Bully Creek	1925	Er		0	0
USA	Castlewood	1933	Er	I	2	2
USA	Caulk Lake	1973	Te	R	0	0
USA	Cazadero	1965	Er	H	0	0
USA	Chambers Lake I	1891	Te	I	0	0
USA	Chambers Lake II	1907	Te	I	0	0
USA	Colley Lake	1963	N.A.		0	0
USA	Corpus Christi	1930	Te	S	0	0
USA	Cuba	1868	Te		0	0
USA	Dykstra	1926	Er		0	0
USA	Elwha River	1912	Pg	H	0	0
USA	Emery	1966	Te	S	0	0
USA	English	1833	Er		0	0
USA	English Water Supply	1965	Te	S	0	0
USA	Fred Burr	1948	Te	I	0	0
USA	Gallinas (Las Vegas)	1957	Pg(M)	S	0	0
USA	Goose Creek	1900	Er	S	0	0
USA	Graham Lake	1923	Te	H	0	0
USA	Greenlick	1904	Te/Er	S	0	0
USA	Hatchtown	1914	Te	I	0	0
USA	Hauser Lake I	1908	Sp	H	0	0
USA	Hauser Lake II	1969	Sp	H	0	0
USA	Hebron I	1914	Te	I	0	0
USA	Hebron II	1942	Te	I	0	0
USA	Hell Hole	1964	Er	I, S, H	0	0
USA	Horse Creek	1914	Te	I	0	0
USA	Jennings Creek 16	1964	Er	C	0	0
USA	Jennings Creek 3	1963	Er	C	0	0
USA	Jumbo (Julesburg)	1910	Te	I	0	0
USA	Lake Barcroft	1972	Te	S	0	0
USA	Lake Francis I	1899	Te	H	0	0
USA	Lake Francis II	1935	Te	H	0	0
USA	Lake Hemet	1927	Te	I, S	0	0
USA	Lake Toxaway	1916	Te	R	0	0
USA	Lake Vera	1905	Er	H	0	0
USA	Little Deer Creek	1963	Te	I	1	1
USA	Littlefield	1929	Er	I	0	0

N.A.: Not available

Table E.1

Failures of dams of all purposes in Western Europe, Canada, USA, Australia and New Zealand with total loss of the stored water.(Cont.).

Country	Dam name	Year of failure	Dam type	Purpose	Max. No. fatalities	Min. No. fatalities
USA	Lookout Shoals	1916	Te	H	0	0
USA	Lower Idaho Falls	1976	Er/ Pg(M)	H	0	0
USA	Lower Otay	1916	Er	S	30	30
USA	Lyman	1915	Te	I	0	0
USA	Mammoth	1917	Te	I	1	1
USA	McMahon Gulch	1925	Te	I	0	0
USA	Mill Creek	1957	Te	S	0	0
USA	Moyie River	1926	Va	S	0	0
USA	Overholser	1923	Er	S	0	0
USA	Owen	1914	Te	I	0	0
USA	Qail Creek	1988	Te	I	0	0
USA	Schaeffer	1921	Te	I	0	0
USA	Sepulveda	1914	Te	C	0	0
USA	Sheep Creek	1970	Te	R	0	0
USA	Sinker Creek	1943	Te	I	0	0
USA	Snake Ravine	1898	Te	I	0	0
USA	South Fork	1889	Te/Er	S	0	0
USA	St. Francis	1928	Pg	H	426	426
USA	Stockton Creek	1950	Er	S	0	0
USA	Sweetwater Main	1916	Te	I, S	0	0
USA	Swift	1964	Te/Er	I	19	19
USA	Teton	1976	Te/Er	I, H	14	11
USA	Toreson	1953	Te	I	0	0
USA	Utica	1902	Te	I, H	0	0
USA	Van Norman Lake	1971	Er	S	0	0
USA	Vaughn Creek	1926	Va	R	0	0
USA	Wagner Creek	1938	Te	I	1	1
USA	Wallnut Grove	1890	Er	I	150	150
USA	Walter Bouldin	1975	Te	H	0	0
USA	Wesley E. Seale	1965	Te	S, C, H	0	0
USA	Whitewater Brook Upper	1972	Te	S	0	0
USA	Wisconsin Dells	1911	Er	H	0	0

Table E.2

Fatal accidents with dams of all purposes in Asia and Africa in the period 1900 - 1996

Date Of Accident	Country	Dam Name	Dam Purpose	Fatalities
?.?1917	India	Tigra	I, S	1000
?.?.1959	India	Bhakra (Gobind Sagar)	I, H	10
?.?.1961	India	Panshet	I, S	1000
?.?.1961	India	Khadakwvasla	I, S	250
12.07.1961	South Korea	Hyokiri (Hyo Gi)	I	250
?.?.1964	India	Macherla	I	1000
?.?.1967	India	Koyna	H, I	180
08.09.1967	India	Nanak Sigar (Nanaksagar)	I	100
29.11.1967	Indonesia	Sempor	I	200
05.08.1975	China	Shimantan, Banquiao	I, C	86,000-230,000
14.02.1977	Mozambique	Macarretane	I	200
14.01.1978	Japan	N.A.	N.A.	21
11.08.1979	India	Machhu II	I, H, S	2500
18.09.1980	India	Hirakud	I, H, C	1000
20.04.1986	Sri Lanka	Kantale (Kantalai)	I	82
16.04.1987	Tajikistan	Sargozan	I	19
?.?.1988	Nigeria	Bagaudo	I, S	23
01.05.1989	China	N.A.	H	28
25.08.1989	Ghana	N.A.	N.A.	7
27.08.1993	China	Gouhou	S	1250

N.A.: Not available

Table E.3

Fatal dam accidents with dams of all purposes in USA, Canada, Australia, New Zealand and Western Europe in the period 1900 - 1996.

Date of accident	Country	Dam Name	Dam Purpose	Fatalities
7.4.1900	USA	Austin (Lake McDonald, Colorado Dam)	H	8
11.3.1901	USA	Randall's Pond (Lower)	N.A.	1
28.3.1902	USA	(near McMinnville/ Warren County, TN)	N.A.	5
05.07.1903	USA	Jeannette	R	40
03.11.1904	USA	N.A. (near Winston, NC)	N.A.	9
?.?.1910	USA	Red Rock (Teller)	I	1
30.09.1911	USA	Bayless (Austin)	S	100
?.?.1915	USA	Lyman	I	8
?.?.1916	USA	Lower Otay	S	30
?.7.1916	USA	N.A.	N.A.	34
02.08.1916	USA	John Thompson's Mill Dam	N.A.	25
09.08.1916	USA	N.A. (Cabin Creek Valley/ Acme, WV)	N.A.	44-60
10.08.1916[1]	USA	(Jarrolds Valley/ Boone County, WV)	N.A.	75
?.?.1917	USA	Mammoth	I	1
29.05.1918	USA	Woodward	H	1
01.12.1923	Italy	Gleno	H	600
02.11.1925	UK	Coedty	H	60
02.11.1925	UK	Eigiau	H	16
?.?.1927	USA	Lake Hemet	I, S	1
14.6.1927	USA	Wise River (Pattengail Creek Dam)	N.A.	4
12.03.1928	USA	St. Francis	H	426
29.06.1928	USA	Little Indian Creek	N.A.	3
29.06.1928	USA	Burgess Falls Power Dam	N.A.	5
?.?.1929	Australia	Briseis	I, S	14
?.2.1932	USA	Eastwick RR Fill	N.A.	7
?.?.1933	USA	Castlewood	N.A.	2
?.?.1935	USA	Lake Ludlow Club	N.A.	3
13.08.1935	Italy	Zerbino	I, S	130
?.?.1938	USA	Schenectady	N.A.	1

[1]probably the same accident as one line above
N.A.: Not available

Table E.3

Fatal dam accidents with dams of all purposes in USA, Canada, Australia, New Zealand and Western Europe in the period 1900 - 1996. (Cont.).

Date of accident	Country	Dam Name	Dam Purpose	Fatalities
?.?.1938	USA	Wagner Creek	I	1
?.?.1951	USA	N.A.	N.A.	11
25.09.1954	Switzerland	Mauvoisin	H	6
?.?.1955	USA	Yuba	N.A.	38
?.5.1956	USA	Schoelkopf Station	N.A.	1
02.12.1959	France	Malpasset	H	421
10.01.1959	Spain	Vega De Tera	H	144
01.10.1961	USA	Newell	S	4
?.?.1963	USA	Little Deer Creek	S, I	1
06.03.1963	USA	Spaulding Pond (Mohegan Park)	R	6
09.10.1963	Italy	Vajont	H	1917
14.12.1963	USA	Baldwin Hills	S	5
?.?.1964	Spain	Ortuella	N.A.	6
01.06.1964	USA	Swift	I	28
8.06.1964	USA	Two Medicine	N.A.	9
?.?.1965	USA	Skagway	N.A.	2
?.?.1965	USA	N.A. (near Denver, CO)	N.A.	1
?.?.1965	Spain	Torrejon-Tajo	H	30
30.08.1965	Switzerland	Mattmark	H	88
?.?.1968	USA	Lee Lake	I	2
?.03.1968	USA	East Lee (Mud Pond)	N.A.	2
17.07.1968	USA	Virden Creek	N.A.	1
07.02.1972	USA	Anzalduas	N.A.	4
26.02.1972	USA	Buffalo Creek	C	125
?.04.1972	USA	Lake O’ the Hills	N.A.	1
09.06.1972	USA	Canyon Lake Dam	N.A.	237
?.07.1972	USA	Knife Lake Dam	N.A.	4
18.09.1975	USA	Lakeside	N.A.	1
?.?.1976	USA	(near Newfound, NC)	N.A.	4
?.?.1976	USA	Big Thomson	I	144
22.02.1976	USA	Bear Wallow	R, S	5
05.06.1976	USA	Teton	I, H	14
?.?.1977	USA	N.A.	N.A.	20
?.?.1977	USA	Laurel Run	S	40
20.07.1977	USA	Sandy Run	N.A.	5
06.11.1977	USA	Kelley Barnes	R, S	39
?.?.1978	USA	N.A.	N.A.	25

N.A.: Not available

Table E.3

Fatal dam accidents with dams of all purposes in USA, Canada, Australia, New Zealand and Western Europe in the period 1900 - 1996. (Cont.).

Date of accident	Country	Dam Name	Dam Purpose	Fatalities
?.10.1978	USA	Lake Keowee Cofferdam	N.A.	7
?.?.1979	USA	Swimming Pool Dam	N.A.	4
?.6.1979	USA	N.A.	N.A.	2
?.?.1981	USA	Austin	N.A.	13
18.12.1981	USA	Eastover Mining Co. Dam	N.A.	1
20.11.1982	Spain	Tous	I, S	40
15.07.1982	USA	Lawn Lake	I	4
26.09.1982	USA	Bishop	H	1
?.?.1983	USA	Dmad	I, R	1
07.01.1984	USA	Bartlett Dam	I	1
17.08.1984	USA	Bass Haven	R, I	1
29.03.1989	USA	Nix Club Lake	N.A.	1
15.09.1989	USA	Evans	N.A.	2
10.10.1990	USA	Kendall Lake Dam	N.A.	4
Summer, 1994	USA	Dozier Lake Dam	N.A.	3
22.06.1995	USA	Timber Lake Dam	N.A.	2
13.03.1996	USA	Meadow Pond (Bergeron) Dam	N.A.	1

N.A.: Not available

Table E.4

Severe accidents with dams involved in hydro power with at least 5 fatalities or 10 injured or 200 evacuees or 5 million 1996 US$ in 1969-1996 during construction and operation.

Date	Country	Name of the dam	Max. No. fatalities	Max. No. injured persons	Max. No. evacuees	Economic loss (10^6 US$)	Economic loss (10^6 $US\$_{1996}$)
?.?.1975	Norway	Ropptjern	0	0	0	20	52.1
?.02.1975	USA	Walter Bouldin	0	0	0	40	104.3
05.06.1976	U.S.A	Teton	14	800	35,000	900	2219
07.10.1976	Colombia	Belmonte	80	N.A.	N.A.	N.A.	N.A.
21.01.1977	Brazil	Euclides da Cunha, Armando de Salles	0	N.A.	4000	50	116
07.08.1978	Switzerland	Palagnedra	0	0	0	30	65
11.08.1979	India	Machhu II	2500	N.A.	150,000	530	1024
18.09.1980	India	Hirakud	1000	N.A.	N.A.	N.A.	N.A.
28.07.1983	Colombia	Guavio	160	N.A.	N.A.	N.A.	N.A.
?.?.1987	Colombia	Chivor II	5	3	N.A.	N.A.	N.A.
29.07.1991	Romania	Belci	116	N.A.	10,000	N.A.	N.A.
14.02.1993	Russia	N.A.	15	N.A.	N.A.	N.A.	N.A.
27.08.1993	China	Gouhou[1]	1250	336	N.A.	27	27

[1]The Gouhou dam was built to supply water for people moved to accommodate the Longyangxia Hydroelectric Project.

N.A.: Not available

Table E.5

Severe accidents of dams of all purposes with economic loss of at least 5 million 1996 US$ in the period 1900 - 1996.

Date	Dam-Name	Country	Purpose	Economic loss (10^6 US$)	Economic loss (10^6 US$$_{1996}$)
?.?.1911	Bayless	USA	S	3	43.1
?.?.1915	Lyman	USA	I	0.4	5.3
?.?.1916	Lower Otay	USA	S	0.8	8.7
?.?.1917	Mammoth	USA	I	1	8.0
?.?.1923	Apishaba	USA	I	1	9.2
01.12.1923	Gleno	Italy	H	7.1	58.0
?.?.1928	St. Francis	USA	H	10	96.4
?.?.1929	Balsam	USA	C,R	0.5	5.3
13.08.1935	Zerbino	Italy	I, S	2.1	23.5
?.?.1938	Brokaw 2	USA	H	0.7	8.3
02.12.1959	Malpasset	France	H,S,I	65	278.7
?.?.1961	Babii Yar	Russia	N.A.	4.0	16.7
06.07.1963	Mohegan Park	USA	N.A.	3	12.3
14.12.1963	Baldwin Hills	USA	S	11.3	46.3
08.06.1964	Lower Two Medicine	USA	N.A.	3.7	15.0
08.06.1964	Swift	USA	I	3.8	15.3
?.?.1965	Mayfield	USA	H	2.5	9.9
30.08.1965	Mattmark	Switzer-land	H	1.8	7.2
24.03.1968	Lee Lake	USA	I	15	54.0
?.?.1969	Wyoming	USA	N.A.	1.5	5.1
?.?.1970	Pardo	Argentina	I, C	20.0	64.4
26.02.1972	Buffalo Creek	USA	C	50	150.0
09.06.1972	Canyon Lake Dam	USA	N.A.	60	180.0
?.?.1975	Ropptjern	Norway	H	20	44.0
?.?.1975	Walter Bouldin	USA	H	>40	>88.0
05.06.1976	Teton	USA	H,I	400-900	880-1980.0
?.?.1977	Armando de Salles Oliviera and subse-quent failure of Euclides da Cunha	Brazil	H	40	82.5
06.11.1977	Kelly Barnes	USA	R,S	2.8	5.8
07.08.1978	Palagnedra	Switzer-land	H	30	57.6
11.08.1979	Machhu II	India	I,H,S	530	916.0
15.07.1982	Lawn Lake and Cascade Lake	USA	I	30.7	40.0
20.10.1982	Tous	Spain	I,S	60	77.8

N.A.: Not available

Table E.5

Severe accidents of dams of all purposes with economic loss of at least 5 million 1996 US$ in the period 1900 - 1996.(Cont.).

Date	Dam-Name	Country	Purpose	Economic loss (10^6 US$)	Economic loss (10^6 US$$_{1996}$)
20.11.1982	Tous	Spain	I,S	60	77.8
15.07.1982	Lawn Lake and Cascade Lake	USA	I	30.7	40.0
06.06.1985	Carsington	UK	S	14.5	16.7
29.05.1989	N.A.	Brazil	H	19.8	21.0
15.09.1989	Evans and subsequent failure of Lockwood	USA	N.A.	10	10.6
02.05.1990	Dartmouth	Australia	I, H, S	36	38.2
22.09.1990	Calderas	Colombia	H	35	37.1
27.08.1993	Gouhou	China	I, H	27	27

N.A.: Not available

Appendix F: Aggregated, chain-specific data for comparative evaluation.

Table F.1

Produced energy world-wide, by OECD and non-OECD countries and by different energy options for different time periods.

Period	Energy option: Coal [GWe·a]			Oil [GWe·a]			Natural gas [GWe·a]			LPG[1] [GWe·a]			Hydro [GWe·a]			Nuclear [GWe·a]		
	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD
1969-1986	14178	6738	7440	23364	5112	18252	9557	5503	4054	431	272	159	3253	2111	1142	1307	1118	189
1969-1996	24196	11022	13174	37338	8293	29045	17520	8853	8667	837	526	311	5819	3474	2345	3685	3102	583

[1] In the case of LPG the world production differs by at most 14% from the world consumption (see next table) for both time periods. This originates from the inconsistencies of the sources of information used in this work. For the other energy options the difference between world consumption and production is not more than 3%.

Table F.2

<u>Consumed</u> energy world-wide, by OECD and non-OECD countries and by different energy options for different time periods.

Period	Energy option																	
	Coal [Gwe·a]			Oil [Gwe·a]			Natural gas [Gwe·a]			LPG[1] [Gwe·a]			Hydro [GWe·a]			Nuclear [GWe·a]		
	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD	World	OECD	Non-OECD
1969-1986	14178	6737	7441	23364	13739	9625	9557	5839	3718	482	358	123	3253	2111	1141	1307	1118	189
1969-1996	24196	11021	13175	37338	20994	16344	17520	9765	7755	968	725	243	5819	3474	2343	3685	3102	583

[1] In the case of LPG the world production differs by at most 14% from the world consumption for both time periods (see previous table). This originates from the inconsistencies of the sources of information used in this work. For the other energy options the difference between world consumption and production is not more than 3%.

Table F.3

Number of events, number of immediate fatalities, number of fatalities per event and number of fatalities per produced energy for severe accidents with at least 5 fatalities which occurred world-wide in the period 1969-1986.

Energy Option	No. of Events	Min. Fatalities	Max. Fatalities	Min. Fatalities per Event	Max. Fatalities per Event	Min. Fatalities per GWe·a	Max. Fatalities per GWe·a
Coal	95	4711	4753	50	50	0.332	0.335
Oil	199	4377	7600	22	38	0.187	0.325
Natural gas	70	976	1104	14	16	0.102	0.116
LPG	48	1286	1851	27	39	2.671	3.844
Hydro power	5	3751	3754	750	751	1.153	1.154
Nuclear	1	31	31	31	31	0.024	0.024

Table F.4

Number of events, number of immediate fatalities, number of fatalities per event and number of fatalities per produced energy for severe accidents with at least 5 fatalities which occurred world-wide in the period 1969-1996.

Energy Option	No. of Events	Min. Fatalities	Max. Fatalities	Min. Fatalities per Event	Max. Fatalities per Event	Min. Fatalities per GWe·a	Max. Fatalities per GWe·a
Coal	187	8172	8272	44	44	0.338	0.342
Oil	334	12344	15623	37	47	0.331	0.418
Natural gas	86	1313	1482	15	17	0.075	0.085
LPG	77	2565	3175	33	41	2.649	3.279
Hydro power	9	5137	5140	571	571	0.883	0.884
Nuclear	1	31	31	31	31	0.008	0.008

Table F.5

Number of events, number of injured , number of injured per event and number of injured per produced energy for severe accidents with at least 10 injured which occurred world-wide in the period 1969-1986.

Energy Option	No. of Events	Min. Injured	Max. Injured	Min. Injured per Event	Max. Injured per Event	Min. Injured per GWe·a	Max. Injured per GWe·a
Coal	12	346	346	29	29	0.024	0.024
Oil	102	8578	9500	84	93	0.367	0.407
Natural gas	42	2166	2328	52	55	0.227	0.244
LPG	44	10419	11035	237	251	21.637	22.917
Hydro power	1	800	800	800	800	0.246	0.246
Nuclear	1	370	370	370	370	0.283	0.283

Table F.6

Number of events, number of injured , number of injured per event and number of injured per produced energy for severe accidents with at least 10 injured which occurred world-wide in the period 1969-1996.

Energy Option	No. of Events	Min. Injured	Max. Injured	Min. Injured per Event	Max. Injured per Event	Min. Injured per GWe·a	Max. Injured per GWe·a
Coal	28	1698	1698	61	61	0.070	0.070
Oil	187	15484	16463	83	88	0.415	0.441
Natural gas	62	3573	3735	58	60	0.204	0.213
LPG	72	12623	13439	175	187	13.035	13.878
Hydro power	2	1136	1136	568	568	0.195	0.195
Nuclear	1	370	370	370	370	0.100	0.100

Table F.7

Number of events, number of evacuees, number of evacuees per event, number of evacuees per produced energy for severe accidents with at least 200 evacuees which occurred world-wide in the period 1969-1986.

Energy Option	No. of Events	Min. Evacuees	Max. Evacuees	Min. Evacuees per Event	Max. Evacuees per Event	Min. Evacuees per GWe·a	Max. Evacuees per GWe·a
Coal	0	0	0	0	0	0	0
Oil	38	105300	119340	2771	3141	4.507	5.108
Natural gas	8	87500	93550	10,938	11,694	9.156	9.789
LPG	29	461900	475900	15,928	16,410	959.234	988.308
Hydro power	2	39000	189000	19,500	94,500	11.991	58.109
Nuclear	2	259000	279000	129,500	139,500	198.202	213.507

Table F.8

Number of events, number of evacuees, number of evacuees per event, number of evacuees per produced energy for severe accidents with at least 200 evacuees which occurred world-wide in the period 1969-1996.

Energy Option	No. of Events	Min. Evacuees	Max. Evacuees	Min. Evacuees per Event	Max. Evacuees per Event	Min. Evacuees per GWe·a	Max. Evacuees per GWe·a
Coal	0	0	0	0	0	0	0
Oil	65	24,9700	26,9740	3842	4150	6.688	7.224
Natural gas	18	95850	10,3290	5325	5738	5.471	5.895
LPG	29	488,664	50,5564	16,850	17,433	504.625	522.077
Hydro power	3	49,000	199,000	16,333	66,333	8.421	34.200
Nuclear	2	259,000	279,000	129,500	139,500	70.291	75.719

Table F.9

Number of events, damage, damage per event and damage per produced energy for severe accidents with at least 5 million 1996 US$ which occurred world-wide in the period 1969-1986.

Energy option	No. of events	Min. Damage (10^6 US$_{1996}$)	Max. Damage (10^6 US$_{1996}$)	Min. Damage per Event (10^6 US$_{1996}$)	Max. Damage per Event (10^6 US$_{1996}$)	Min. Damage per Energy (10^6 US$_{1996}$/ GWe·a)	Max. Damage per Energy (10^6 US$_{1996}$/ GWe·a)
Coal	2	151.9	151.9	75.95	75.95	0.011	0.011
Oil	137	9617	11202.4	70.20	81.77	0.412	0.479
Natural gas	13	1142	1478.7	87.85	113.75	0.119	0.155
LPG	23	1092	1378.2	47.48	59.92	2.268	2.862
Hydro power	6	2200	3580.4	366.67	596.73	0.676	1.101
Nuclear	2	25120	344627.2	12560	172313.6	19.223	263.729

Table F.10

Number of events, damage, damage per event and damage per produced energy for severe accidents with at least 5 million 1996 US$ which occurred world-wide in the period 1969-1996.

Energy option	No. of events	Min. Damage (10^6 US$_{1996}$)	Max. Damage (10^6 US$_{1996}$)	Min. Damage per Event (10^6 US$_{1996}$)	Max. Damage per Event (10^6 US$_{1996}$)	Min. Damage per Energy (10^6 US$_{1996}$/ GWe·a)	Max. Damage per Energy (10^6 US$_{1996}$/ GWe·a)
Coal	7	494.6	494.6	70.66	70.66	0.020	0.020
Oil	226	20782.2	23772.2	91.96	105.19	0.557	0.637
Natural gas	15	1179	1520.4	78.6	101.36	0.067	0.087
LPG	27	1270	1682.9	47.04	62.33	1.311	1.738
Hydro power	7	2227.2	3607.4	318.17	515.34	0.383	0.620
Nuclear	2	25120	344627.2	12560	172313.6	6.817	93.530

Table F.11

Number of immediate fatalities and number of immediate fatalities per consumed energy for different energy options. The severe accidents with at least 5 fatalities occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries (no allocation of consequences).

Energy Option	Number of fatalities			Number of fatalities per GWe·a		
	World	OECD	Non-OECD	World	OECD	Non-OECD
Coal	8272	1410	6862	0.342	0.128	0.521
Oil	15623	2595	13028	0.418	0.124	0.797
Natural gas	1482	536	946	0.085	0.055	0.122
LPG	3175	790	2385	3.279	1.089	9.806
Hydro power	5140	14	5126	0.883	0.004	2.187
Nuclear	31	0	31	0.008	0.000	0.053

Table F.12

Number of injured and number of injured per consumed energy for different energy options. The severe accidents with at least 10 injured occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries (no allocation of consequences).

Energy Option	Number of injured			Number of injured per GWe·a		
	World	OECD	Non-OECD	World	OECD	Non-OECD
Coal	1698	184	1514	0.070	0.017	0.115
Oil	16463	3846	12617	0.441	0.183	0.772
Natural gas	3735	1904	1831	0.213	0.195	0.236
LPG	13439	3046	10393	13.878	4.201	42.729
Hydro power	1136	800	336	0.195	0.230	0.143
Nuclear	370	0	370	0.100	0.000	0.635

Table F.13

Number of evacuees and number of evacuees per consumed energy for different energy options. The severe accidents with at least 200 evacuees occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries (no allocation of consequences).

Energy Option	Number of evacuees			Number of evacuees per GWe·a		
	World	OECD	Non-OECD	World	OECD	Non-OECD
Coal	0.000	0.000	0.000	0.000	0.000	0.000
Oil	269740	71240	198500	7.224	3.393	12.145
Natural gas	103290	40290	63000	5.895	4.126	7.233
LPG	505564	304764	200800	522.077	420.282	825.563
Hydro power	199000	35000	164000	34.200	10.073	69.970
Nuclear	279000	144000	135000	75.719	46.418	231.780

Table F.14

Economic damage and economic damage per consumed energy for different energy options. The severe accidents with losses of at least 5 million 1996 US$ occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries (no allocation of consequences).

Energy Option	Economic damage (10^6 US$_{1996}$)			Economic damage per energy (10^6 US$_{1996}$/ GWe·a)		
	World	OECD	Non-OECD	World	OECD	Non-OECD
Coal	494.6	380.6	114.0	0.020	0.035	0.009
Oil	23772.2	16761.1	7011.1	0.637	0.798	0.429
Natural gas	1520.4	1018.2	502.2	0.087	0.104	0.065
LPG	1682.9	1309.9	373.0	1.738	1.806	1.534
Hydro power	3607.4	2440.4	1167	0.620	0.702	0.498
Nuclear	344627.2	5120.0	339507.2	93.530	1.650	582.896

Table F.15

Number of immediate fatalities and number of immediate fatalities per consumed energy for different energy options with and without allocation. The severe accidents with at least 5 fatalities occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries.

Energy Option	Number of fatalities					Number of fatalities per GWe·a				
	-	No allocation		With allocation		-	No allocation		With allocation	
	World	OECD	Non-OECD	OECD	Non-OECD	World	OECD	Non-OECD	OECD	Non-OECD
Coal	8272	1410	6862	1506	6765	0.342	0.128	0.521	0.137	0.514
Oil	15623	2595	13028	8134	7489	0.418	0.124	0.797	0.387	0.458
Natural gas	1482	536	946	640	842	0.085	0.055	0.122	0.066	0.109
LPG	3175	790	2385	1312	1863	3.279	1.089	9.806	1.810	7.658
Hydro power	5140	14	5126	14	5126	0.883	0.004	2.187	0.004	2.187
Nuclear	31	0	31	0	31	0.008	0.000	0.053	0.000	0.053

Table F.16

Number of injured and number of injured per consumed energy for different energy options with and without allocation The severe accidents with at least 10 injured occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries.

Energy Option	Number of injured					Number of injured per GWe·a				
	-	No allocation		With allocation		-	No allocation		With allocation	
	World	OECD	Non-OECD	OECD	Non-OECD	World	OECD	Non-OECD	OECD	Non-OECD
Coal	1698	184	1514	205	1493	0.070	0.017	0.115	0.019	0.113
Oil	16463	3846	12617	9211	7252	0.441	0.183	0.772	0.439	0.444
Natural gas	3735	1904	1831	2105	1630	0.213	0.195	0.236	0.216	0.210
LPG	13439	3046	10393	5322	8117	13.878	4.201	42.729	7.339	33.372
Hydro power	1136	800	336	800	336	0.195	0.230	0.143	0.230	0.143
Nuclear	370	0	370	0	370	0.100	0.000	0.635	0.000	0.635

Table F.17

Number of evacuees and number of evacuees per consumed energy for different energy options with and without allocation. The severe accidents with at least 200 evacuees occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries.

Energy Option	Number of evacuees					Number of evacuees per GWe·a				
	-	No allocation		With allocation		-	No allocation		With allocation	
	World	OECD	Non-OECD	OECD	Non-OECD	World	OECD	Non-OECD	OECD	Non-OECD
Coal	0	0	0	0	0	0.000	0.000	0.000	0.000	0.000
Oil	269740	71240	198500	155639	114101	7.224	3.393	12.145	7.413	6.981
Natural gas	103290	40290	63000	47197	56093	5.895	4.126	8.124	4.833	7.233
LPG	505564	304764	200800	348738	156826	522.077	420.282	825.563	480.924	644.769
Hydro power	199000	35000	164000	35000	164000	34.200	10.073	69.970	10.073	69.970
Nuclear	279000	144000	135000	144000	135000	75.719	46.418	231.780	46.418	231.780

Table F.18

Economic damage and economic damage per consumed energy for different energy options with and without allocation The severe accidents with at least 5 million 1996 US$ occurred in the period 1969-1996 world-wide, in OECD and in non-OECD countries.

Energy Option	Economic damage (10^6 US$_{1996}$)					Economic damage per GWe·a (10^6 US$_{1996}$/ GWe·a)				
	-	No allocation		With allocation		-	No allocation		With allocation	
	World	OECD	Non-OECD	OECD	Non-OECD	World	OECD	Non-OECD	OECD	Non-OECD
Coal	494.6	380.6	114.0	382.2	112.4	0.020	0.035	0.009	0.035	0.009
Oil	23772.2	16761.1	7011.1	19742.1	4030.1	0.637	0.798	0.429	0.940	0.247
Natural gas	1520.4	1018.2	502.2	1073.3	447.1	0.087	0.104	0.065	0.110	0.058
LPG	1682.9	1309.9	373	1391.6	291.3	1.738	1.806	1.534	1.919	1.198
Hydro power	3607.4	2440.4	1167.0	2440.4	1167.0	0.620	0.702	0.498	0.702	0.498
Nuclear	344627.2	5120	339507.2	5120	339507.2	93.530	1.650	582.896	1.650	582.896