

Chernobyl – Catastrophe and Consequences

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Contents

List of contributors	xi
Editors and principal authors	xiii
Contributing authors	xv
List of figures	xvii
List of tables	xxi
List of abbreviations	xxv
1 Introduction (<i>Jim T. Smith and Nick A. Beresford</i>)	1
1.1 History of the accident	1
1.1.1 Emergency response and early health effects	5
1.1.2 Emergency clean up and waste disposal	7
1.1.3 Radionuclides released and deposited	11
1.2 Radiation exposures	16
1.2.1 Health effects of radiation	16
1.2.2 Exposure pathways and change of dose over time after Chernobyl	19
1.2.3 Limiting the long-term dose to the population	23
1.2.4 Unofficial resettlement of the abandoned areas	24
1.3 Chernobyl in context	25
1.3.1 Previous radioactive releases to the environment	25
1.3.2 Natural radioactivity in the environment and medical radiation	27
1.4 References	31

2	Radioactive fallout and environmental transfers (<i>Jim T. Smith and Nick A. Beresford</i>)	35
2.1	Pattern and form of radioactive depositions	35
2.1.1	Element isotope ratios and 'hot' particles	37
2.1.2	Break up of hot particles	40
2.2	Environmental transfers of radionuclides	41
2.2.1	Migration of radionuclides in the soil	41
2.2.2	Rates of vertical migration	44
2.2.3	Change in external dose rate over time	46
2.2.4	Resuspension of radioactivity	48
2.2.5	Transport of radioactivity by rivers	53
2.3	Bioavailability, bioaccumulation and effective ecological half-lives	54
2.3.1	Aggregated Transfer Factor and Concentration Ratio	54
2.3.2	Physical, biological and ecological half-lives	55
2.3.3	Changes in radiocaesium bioavailability over time	57
2.3.4	Temporal changes in radiostrontium bioavailability	64
2.4	Characteristics of key Chernobyl radionuclides	65
2.4.1	Radioiodine	65
2.4.2	Radiostrontium	67
2.4.3	Radiocaesium	69
2.4.4	Plutonium and americium	71
2.5	References	73
3	Radioactivity in terrestrial ecosystems (<i>Jim T. Smith, Nick A. Beresford, G. George Shaw and Leif Moberg</i>)	81
3.1	Introduction	81
3.2	Agricultural ecosystems	85
3.2.1	Interception of radioactive fallout by plants	85
3.2.2	Transfer of radionuclides to crops and grazed vegetation	86
3.2.3	Transfers to animal-derived food products	93
3.2.4	Time changes in contamination of agricultural systems	103
3.2.5	Very long-lived radionuclides in agricultural systems	107
3.3	Forest ecosystems	108
3.3.1	Cycling of radioactivity in the forest ecosystem	108
3.3.2	Transfer of radionuclides to fungi, berries and understorey vegetation	110
3.3.3	Transfer of radionuclides to game and semi-domestic animals	116
3.3.4	Radionuclides in trees	118
3.4	Radiation exposures from ingestion of terrestrial foods	119
3.4.1	Reference levels of radioactivity in foodstuffs	119
3.4.2	Radiation exposures from agricultural foodstuffs	121
3.4.3	People now living in the abandoned areas	122
3.4.4	Radiation exposures via the forest pathway	124
3.4.5	Time dependence of exposures	126

3.4.6	Comparison of radiocaesium transfers to various products	128
3.5	References	128
4	Radioactivity in aquatic systems (<i>Jim T. Smith, Oleg V. Voitsekhovitch, Alexei V. Konoplev and Anatoly V. Kudelsky</i>)	139
4.1	Introduction	139
4.1.1	Distribution of radionuclides between dissolved and particulate phases	141
4.2	Radionuclides in rivers and streams	143
4.2.1	Early phase	144
4.2.2	Intermediate phase	149
4.2.3	Long-term ^{137}Cs contamination of water	149
4.2.4	Processes controlling declines in ^{90}Sr and ^{137}Cs in surface waters.	150
4.2.5	Influence of catchment characteristics on radionuclide runoff.	152
4.3	Radioactivity in lakes and reservoirs	154
4.3.1	Initial removal of radionuclides from the lake water	155
4.3.2	The influence of lake water residence time	157
4.3.3	The influence of lake mean depth d	159
4.3.4	The influence of sediment–water distribution coefficient K_d	159
4.3.5	Transport of ^{90}Sr in lakes.	160
4.3.6	Transport of ^{131}I in lakes.	161
4.3.7	Transport of Ruthenium in lakes	162
4.3.8	Radionuclide balance in water of open lakes	162
4.3.9	Closed lake systems.	163
4.4	Radionuclides in sediments	165
4.5	Uptake of radionuclides to aquatic biota	168
4.5.1	^{137}Cs in freshwater fish	168
4.5.2	Influence of trophic level on radiocaesium accumulation in fish.	170
4.5.3	Size and age effects on radiocaesium accumulation	170
4.5.4	Influence of water chemistry on radiocaesium accumulation in fish	171
4.5.5	^{131}I in freshwater fish.	173
4.5.6	^{90}Sr in freshwater fish	173
4.5.7	Radiocaesium and radiostrontium in aquatic plants	174
4.5.8	Bioaccumulation of various other radionuclides.	174
4.6	Radioactivity in marine systems	175
4.6.1	Riverine inputs to marine systems	177
4.6.2	Transfers of radionuclides to marine biota.	178
4.7	Radionuclides in groundwater and irrigation water.	179
4.7.1	Radionuclides in groundwater	179
4.7.2	Irrigation water	180

4.8	Radiation exposures via the aquatic pathway	180
4.9	References	181
5	Application of countermeasures (<i>Nick A. Beresford and Jim T. Smith</i>). .	191
5.1	Countermeasure techniques	191
5.1.1	Methods of reducing uptake of radioiodine to the thyroid	192
5.1.2	Methods of reducing the soil-to-plant transfer of radionuclides	192
5.1.3	Methods of reducing the radionuclide content of animal-derived foodstuffs	193
5.1.4	Countermeasures for freshwater systems	197
5.1.5	Reduction of the external dose in residential areas	200
5.1.6	Social countermeasures.	201
5.2	Countermeasures to reduce internal doses applied within the agricultural systems of the FSU	204
5.2.1	Key foodstuffs contributing to ingestion doses	207
5.3	Discussion	208
5.4	References	209
6	Health consequences (<i>Jacov E. Kenigsberg and Elena E. Buglova</i>)	217
6.1	Introduction	217
6.2	Radiation-induced health effects	218
6.3	Deterministic health effects after the Chernobyl accident	219
6.4	Stochastic health effects after the Chernobyl accident	220
6.4.1	Leukaemia.	220
6.4.2	Thyroid cancer	222
6.4.3	Non-thyroid solid cancer	231
6.4.4	Non-cancer diseases.	232
6.5	Discussion	232
6.6	References	233
7	Social and economic effects (<i>Ingrid A. Bay and Deborah H. Oughton</i>). .	239
7.1	Social and economic effects and their interactions	239
7.2	Health detriments and associated harms due to radiation exposure	242
7.2.1	Radiation exposure of the Chernobyl 'liquidators'	243
7.2.2	Physiological health effects	244
7.2.3	Psychological and social effects	245
7.3	Economic impact.	247
7.3.1	Expenditures related to countermeasures	247
7.3.2	Capital losses	249
7.3.3	Rural breakdown	250
7.4	Social costs of countermeasure implementation	251
7.4.1	Evacuation and resettlement	252
7.4.2	Countermeasures in agricultural food chains.	254
7.4.3	Compensation	254

7.4.4	Communication and information	255
7.4.5	The European response	257
7.4.6	Risk perception	258
7.4.7	Factors influencing risk perception	258
7.4.8	Control.	260
7.5	Conclusions	261
7.6	References	262
8	Effects on wildlife (<i>Ivan I. Kryshev, Tatiana G. Sazykina and Nick A. Beresford</i>).	267
8.1	Terrestrial biota	268
8.1.1	Radiation effects in forests	268
8.1.2	Radiation effects in herbaceous vegetation	272
8.1.3	Radiation effects in soil faunal communities and other insects	274
8.1.4	Radiation effects in mammal populations	275
8.1.5	Radiation effects in bird populations	276
8.2	Freshwater biota	277
8.2.1	Exposure of aquatic biota.	277
8.2.2	Radiation effects in aquatic biota.	279
8.3	The Chernobyl exclusion zone – a nature reserve?	280
8.4	References	282
9	Conclusions (<i>Jim T. Smith and Nick A. Beresford</i>).	289
9.1	Contamination of the environment	289
9.1.1	Current radiation exposures in the Chernobyl affected areas	289
9.1.2	Future environmental contamination by Chernobyl	290
9.1.3	Countermeasures and emergency response	293
9.2	Consequences of the accident.	294
9.2.1	Damage to the ecosystem	294
9.2.2	Direct health effects of the accident	296
9.2.3	Social and economic consequences	298
9.2.4	Future management of the affected areas.	300
9.2.5	Chernobyl and the Nuclear Power Programme	301
9.3	References	302
Index		307

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Figures

1.1	The destroyed Unit 4 reactor building at the Chernobyl Nuclear Power Plant	3
1.2	Aerial view of the destroyed reactor	3
1.3	The abandoned town of Pripyat with the Chernobyl Nuclear Power Station in the background	6
1.4	Satellite photo of the area around Chernobyl NPP	7
1.5	Sarcophagus construction, early September 1986	9
1.6	Sarcophagus photographed in 2003	9
1.7	Estimated daily releases of ^{131}I from the reactor for the period from the initial explosion to the extinction of the fire	12
1.8	(a) Percentage of the initial radioactivity remaining in the environment at different times after the Chernobyl accident, based on release data given in Table 1.2. (b) Changes in the amounts of some key radionuclides over time due to radioactive decay	14
1.9	^{137}Cs fallout in Ukraine, Belarus and Russia	15
1.10	^{137}Cs fallout in Europe	16
1.11	^{90}Sr and $^{239,240}\text{Pu}$ fallout in the Ukrainian part of the 30-km zone	17
1.12	(a) Fatal solid cancer; (b) leukaemia rates in the follow up group of people exposed to radiation from the Hiroshima and Nagasaki atomic bombs	18
1.13	Effective dose to the populations of Belarus, Russia and the Ukraine (excluding thyroid dose) during the period 1986–1995	20
1.14	Thyroid dose to children less than 18 years old in the two most affected regions of Belarus	21
1.15	Change in external gamma dose rate over time after the accident	22
1.16	Contrasting contributions of internal and external dose rates to overall dose in areas of different soil types, Bryansk Region, Russia	23
2.1	Electron micrograph of a uranium fuel particle from Chernobyl	36
2.2	Concentration of different radionuclides in the air and deposition as a function of distance from Chernobyl, expressed as a ratio of radionuclide: ^{137}Cs	38
2.3	Half-time of dissolution of fuel particles as a function of soil pH	41

2.4	Examples of activity–depth profiles of various radionuclides in soils	43
2.5	Decline in the observed dispersion coefficient as a function of time in a grassland soil at Veprin, Belarus.	44
2.6	External dose rate 0.05 m above the ground as a function of ^{137}Cs inventory in the soil.	47
2.7	Change in annual effective external dose for rural indoor workers living in wood-framed houses	48
2.8	Change in resuspension factor as a function of time after fallout at a number of sites around Europe.	49
2.9	Annual mean ^{137}Cs resuspension factors measured at 20 different sites around Europe at large distances from Chernobyl for two different time periods. . . .	50
2.10	Illustration of Cs sorption to specific FES on illitic clay minerals and competition for sorption sites by ions of similar hydrated radius (K^+ , NH_4^+) but not ions with much larger hydrated radius such as Ca^{2+} , Mg^{2+}	57
2.11	Illustration of the dynamic model for radiocaesium sorption to illitic clay minerals showing rapid uptake to ‘exchangeable’ sites and slower ‘fixation’ in the mineral lattice	57
2.12	Schematic diagram indicating timescales of release of radiocaesium from soils to terrestrial and aquatic ecosystems during the years after a fallout event	58
2.13	Illustration of changes in radiocaesium in milk in a system with declining activity concentrations in vegetation and relatively rapid rates of uptake and removal from milk	59
2.14	(a) Examples of changes in ^{137}Cs activity concentration in different ecosystem components after Chernobyl. (b) Frequency distribution of effective ecological half lives in different ecological components during the first five years after Chernobyl. (c) Long-term changes in ^{137}Cs in brown trout, Norway, and perch, terrestrial vegetation and water, UK	60
2.15	Change in CR of wheat on soddy–podzolic soil	65
3.1	Ranges in ^{137}Cs activity concentration in various products from the Luginsk district, Zhitomir region, Ukraine in 1995	84
3.2	Plot of T_{ag} vs. organic matter content in soils in 5 catchments in Cumbria, UK	88
3.3	CR of ^{90}Sr and ^{137}Cs in various vegetables in Finland, clay and silt soils, 1987	93
3.4	Comparison between calcium intake and F_m for strontium with additional recent data for cattle	96
3.5	Variation in ^{137}Cs activity concentration in 1,144 sheep, Cumbria, UK	99
3.6	Increase in feed–milk transfer coefficient over time at a farm in Bavaria. . . .	101
3.7	Time changes in (a) ^{131}I and (b) ^{137}Cs in air, grass and milk in north-western Italy during the first month after the accident	104
3.8	Time changes in the aggregated transfer factor of ^{137}Cs in the decade after the accident	106
3.9	Seasonal trends in the ^{137}Cs activity concentrations of study ewes at one of the farms of Beresford <i>et al.</i> (1996)	106
3.10	Major storages and fluxes in radionuclides in contaminated forest ecosystems	110
3.11	Radiocaesium profiles in forest soils in (a) the Chernobyl 30-km zone at two different times after the accident and (b) in a forest soil in Germany (in 1996) contaminated by Chernobyl and weapons test fallout	111
3.12	Aggregated transfer factor for ^{137}Cs in a very highly accumulating mushroom species	113

3.13	Change in ^{137}Cs activity concentration in roe deer meat in a spruce forest, Ochsenhausen, Germany	117
3.14	A summary of the ^{137}Cs activity concentration measured in the milk of cattle owned by people living within the 30-km exclusion zone.	124
3.15	A comparison of the consumption rate of fungi and the whole body ^{137}Cs burden determined in people living in an urban area of Russia	125
4.1	Pripyat–Dnieper River–Reservoir system showing Chernobyl and Kiev with the Kiev Reservoir in between	140
4.2	Fraction of a radionuclide absorbed to particulates as a function of suspended solids concentration in water for different values of K_d	143
4.3	The change in activity concentration of ^{137}Cs and ^{90}Sr in the Pripyat River over time after the accident	145
4.4	The initial activity concentrations of radionuclides in various rivers vs. the total amount released from the reactor	147
4.5	(a) Normalised activity concentration of ^{137}Cs in the dissolved phase of different rivers after Chernobyl. (b) Correlation between the normalised ^{137}Cs activity concentration and the percentage catchment coverage of organic, boggy soils in six different catchments	153
4.6	Radionuclide transfers in a catchment–lake system.	154
4.7	Comparison of initial ^{137}Cs activity concentration in 15 lakes determined from measurements with that estimated from a simple dilution model	155
4.8	Change in the ^{137}Cs activity concentration in water and fish of: (a) a small shallow lake in Germany, Lake Vorsees and; (b) the large, deep Lake Constance	156
4.9	(a) The relationship between ^{137}Cs removal rate from 14 lakes and the removal rate of water through the outflow. (b) The relationship between the fraction of the total ^{137}Cs transferred to the outflow and the lake water residence time. (c) The relationship between ^{137}Cs removal rate and the lake mean depth.	158
4.10	Changes in average annual content of ^{137}Cs and ^{90}Sr in the water of the first (Vishgorod, Kiev Reservoir) and last (Novaya Kahovka, Kahovka Reservoir) reservoirs of the Dnieper cascade	161
4.11	Graphs of ^{137}Cs activity–depth profiles in sediments in (a) Baltic Sea, muddy and sandy sediments; (b) Lake Constance; (c) Lake Svyatoye, Kostikovichi, Belarus.	167
4.12	Illustration of a simple model for uptake in fish via the food chain	169
4.13	Radiocaesium in fish in the Kiev Reservoir after Chernobyl, illustrating the ‘size effect’ in predatory perch, but not in the non-predatory roach.	171
4.14	Relationship between ^{137}Cs concentration factor in fish and the potassium concentration in 17 lakes around Europe.	172
4.15	Radiocaesium in the Baltic and Black Seas	177
5.1	Nick Beresford live-monitoring a sheep in upland west Cumbria in 1993 to determine Cs-137 activity concentration in muscle	196
5.2	Decrease in ^{137}Cs activity concentrations in perch in Lake Svyatoye over a 15-year period after a potassium countermeasure was applied	199
5.3	Variability within the ^{137}Cs activity concentration of private milk within the Belarussian village.	208

xx **Figures**

6.1	Increase in thyroid cancer in children (aged 0–18 years at the time of the Chernobyl accident) in Belarus during the period 1986–2002	229
6.2	Increase in excess thyroid cancer risk in the period 1991–1995 in children born between 1971 and 1986	230
7.1	Interaction between health, social and economic effects.	241
8.1	Area of Red Forest where coniferous trees were killed as a consequence of acute irradiation but deciduous trees continued to grow	268
8.2	Pripyat sports stadium.	281
8.3	Kestrels nesting on the roof of a tower block, Pripyat	281
9.1	Rise in world primary energy consumption from 1970–2025	301
9.2	World consumption of nuclear energy from 1970 and projected future use . . .	302

Tables

1.1	Confirmed cases of acute radiation sickness in emergency workers.	5
1.2	Physical half-lives and amounts of radionuclides released from Chernobyl . . .	12
1.3	Estimates of releases of some additional radionuclides compared with ^{137}Cs . .	13
1.4	Main pathways and nuclides contributing to the population exposure after the Chernobyl accident	20
1.5	Radiation exposures of different groups after Chernobyl.	21
1.6	Population dynamics within abandoned settlements of Belarus in selected years after Chernobyl.	25
1.7	Summary of previous major releases of radioactive material to the environment	26
1.8	Examples of some measurements of ^{137}Cs in the environment before the Chernobyl accident	27
1.9	Population average doses from natural radiation sources and average dose in various European and North American countries from medical diagnostic procedures	28
1.10	Doses from various X-ray medical diagnostic procedures	28
1.11	Primordial radionuclides and some of their decay products.	29
1.12	Concentrations of natural radioactive potassium in various foodstuffs	30
2.1	Radionuclide resuspension factors from agricultural activity, traffic and forest fires compared with natural wind resuspension.	52
2.2	Summary of mean values of rate of decline in ^{137}Cs activity concentrations in different environmental compartments, and comparison with rate of diffusion of ^{40}K into the illite lattice	61
	Radioiodine Isotope data	65
	Examples of stable iodine concentrations in the environment	67
	Radiostrontium isotope data	67
	Examples of stable strontium concentrations in the environment	68
	Radiocaesium isotope data.	69
	Examples of stable caesium concentrations in the environment	70
	Plutonium and americum isotope data	71

3.1	Average ratio of fresh weight:dry weight of various products	83
3.2	Illustrative productivities and radiocaesium transfer factors of food products derived from different ecosystem types	84
3.3	Percentage of the total plant contamination from different contamination pathways	87
3.4	Soil-grass aggregated transfer factor for radiocaesium	89
3.5	^{137}Cs and ^{90}Sr soil-to-grass aggregated transfer coefficient for different soil groups, Bragin, Belarus, 1994–1995	90
3.6	Aggregated transfer factors of ^{90}Sr and ^{137}Cs to various crops	92
3.7	Recommended factors for radiocaesium to convert CR or T_{ag} values for cereals to values for other crops	93
3.8	Recommended factors for radiostrontium to convert CR or T_{ag} values for cereals to values for other crops	94
3.9	Recommended transfer coefficients for radiocaesium and dry matter feed intake rates	95
3.10	Radiocaesium transfer coefficients to various organs of cows, goats and sheep	97
3.11	Examples of radioactivity concentrations in milk and meat of domestic animals in various parts of Europe contaminated by the Chernobyl accident	98
3.12	Feed-milk transfer coefficient following intake of contaminated herbage by cows	100
3.13	Ratios of activity concentrations of ^{90}Sr and ^{137}Cs in milk products to those in milk	103
3.14	Estimated activity concentrations in milk and beef from a hypothetical pasture located in an area very highly contaminated by transuranium elements	108
3.15	Estimated activity concentrations of cereals and potatoes grown on hypothetical agricultural land in an area very highly contaminated by transuranium elements	108
3.16	^{137}Cs in various components of a pine forest, Bourakovka, Chernobyl in 1990. ^{90}Sr (from weapons tests) in different components of a pine forest in Sweden in 1990	109
3.17	Aggregated transfer factors of ^{137}Cs in various species of edible fungi collected in Belarus	112
3.18	Comparison of mean T_{ag} values for ^{137}Cs and ^{90}Sr in fungi in the Bragin district of Belarus, 1994–1995	113
3.19	Comparison of concentration ratios of ^{137}Cs with other radionuclides in understorey vegetation	114
3.20	Range in transfer factors and effective ecological half-lives observed in game during the first few years after Chernobyl	117
3.21	^{137}Cs and ^{90}Sr in game animals in the Bragin district of Belarus, 1994–1995	118
3.22	Radiocaesium transfer factors in different parts of trees at Dityatki, 28 km south of Chernobyl during 1987	118
3.23	Agreed CFILs of radionuclides in foods in place in the EC	120
3.24	Intervention limits for the ^{137}Cs activity concentration in foodstuffs within Belarus, Russia and the Ukraine as in place in 1999	121
3.25	Average annual consumption of foodstuffs by the population of a village in Bryansk, Russia, before and after the Chernobyl accident	122
3.26	Example of consumption rates of different foodstuffs and the contribution of each foodstuff to the daily ^{137}Cs intake, as determined during June/July 1997 in Milyach, the Ukraine	123

3.27	Mean effective dose in 15 forest units in the Novozybokov district, Bryansk region, Russia	125
3.28	^{137}Cs transfer factors and illustrations of activity concentrations of different foodstuffs from measurements made in the early 1990s	127
4.1	K_d values for radiostrontium, radioiodine, radiocaesium and plutonium in freshwaters	142
4.2	Radionuclide levels in the Pripyat River at Chernobyl	146
4.3	Temporary allowable levels of radionuclides in drinking water in the Ukraine at different times after Chernobyl	147
4.4	Estimates of the initial rate of decline of radionuclides in river water after Chernobyl	148
4.5	Rates of change in ^{137}Cs and ^{90}Sr activity concentrations in different rivers in the medium to long term (1987–2001) after Chernobyl	150
4.6	Comparison of radiocaesium K_d determined from removal rate measurements with K_d measured in the field or laboratory	160
4.7	Mean ^{137}Cs and ^{90}Sr activity concentration in inflow streams compared with concentrations in the lake water/outlet of different lakes	163
4.8	Normalised water concentrations of ^{137}Cs and ^{90}Sr in various water bodies 4–10 years after fallout	164
4.9	Radionuclides in Chernobyl Cooling Pond bed sediments approximately one month after the accident, expressed as a percentage of the total amount in both sediments and water	165
4.10	Typical radionuclide activity concentrations in the most contaminated silty sediments of the Cooling Pond	166
4.11	^{90}Sr concentration factors in freshwater fish after Chernobyl	173
4.12	Mean CF of radiocaesium in aquatic plants	175
4.13	Radionuclide CFs in biota of the Dnieper River in June 1986	176
4.14	Radionuclides in marine macroalgae and fallout compared to ^{137}Cs in July 1986 and August–September 1987	178
5.1	The reduction achieved in the radiocaesium content of fungi following commonly used cooking procedures	203
5.2	Summary of the effectiveness of different agricultural countermeasures to reduce ^{137}Cs activity concentrations employed within the fSU	205
5.3	Suggested feeding regime for beef cattle at various times prior to slaughter and the effect on the activity concentration in meat	205
5.4	Changes in the amount of meat and milk produced by collective farms with ^{137}Cs activity concentrations in excess of intervention limits	206
6.1	The most critical radiation-induced health effects resulting from a radiation exposure	218
6.2	Examples of stochastic health effects from exposure to radiation	219
6.3	Emergency workers with ARS	220
6.4	Distribution of external doses to emergency workers as recorded in the registry of emergency workers	222
6.5	Results of studies of the risk of thyroid cancer development following acute	

	external radiation from atomic bombs and from radiation therapy at an age of <20 years	224
6.6	Results of studies of the risk of thyroid cancer development following exposure to ¹³¹ I at an age of <20 years.	225
6.7	Risk of radiation-induced thyroid cancer following radiation exposure at an age of <20 years	227
6.8	Thyroid dose distribution for various age groups in Belarus	228
6.9	Risk of thyroid cancer for children and adolescents of Belarus considering gender and age at the time of the accident.	230
6.10	Thyroid cancer risk for the exposed adult population of Belarus	231
7.1	Estimated number of people affected by the accident in terms of evacuation, resettlement, people living in contaminated areas, liquidators and invalids . . .	239
7.2	Registered cases of 'class 16 illnesses' in the Ukraine (1982–1992)	246
7.3	Estimates of total expenditures, proportion of national budgets, numbers of newly built houses, schools and hospitals as a part of remediation and relocation actions in the three most affected countries; Belarus, Russia and the Ukraine	248
7.4	Chernobyl budget expenditures for the Ukraine (US\$ million in 2000).	249
7.5	Selected losses related to agricultural/forest land, and economic units	250
7.6	Benefits and costs of remediation efforts	252
7.7	Factors commonly used to explain the perception of risk	259
8.1	Distribution of radiation damage in forests around the Chernobyl NPP.	269
8.2	The dynamics of external irradiation dose from soil at study plots with coniferous trees close to the Chernobyl NPP	270
8.3	Radionuclide activity concentration in pine needles and estimated internal dose rate in October 1987	271
8.4	Frequency of meiotic chromosomal aberrations in pine microsporocytes	272
8.5	Temporal dynamics of conditions in study pine stands	273
8.6	Frequency of mutation in the stamen filament hair of spiderwort at different dose rates	274
8.7	Effects of chronic radiation exposure on reproduction and off-spring of silver carp in the Chernobyl Cooling Pond.	278
9.1	Estimated activity concentrations of long-lived radionuclides at Kopachi, 6 km south-east of Chernobyl.	291
9.2	Tentative prediction of future contamination by Chernobyl.	292

Abbreviations

ACF	aggregated concentration factor
ARS	acute radiation syndrome
BNFL	British Nuclear Fuels Plc.
BAF	bioaccumulation factor
CF	concentration factor
CR	concentration ratio
CEC	cation exchange capacity
CFILs	Council Food Intervention Limits
CLL	Chronic Lymphocytic Leukaemia
CI	confidence interval
d.w.	dry weight
EC	electrical conductivity
ERR	excess relative risk
EAR	excess absolute risk
fSU	former Soviet Union
f.w.	fresh weight
FES	'Frayed Edge Sites'
GDL	Generalised Derived Limit
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiation Protection
IRG	inert radioactive gases
NPP	Nuclear Power Plant
NWT	nuclear weapons test
RBE	relative biological effectiveness
RN	radionuclide
SEER	US Program Surveillance Epidemiology and Results
TUE	transuranium elements

UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UN-OCHA	UN Office for the coordination of Humanitarian Affairs
WHO	World Health Organisation

1

Introduction

Jim T. Smith and Nick A. Beresford

The explosion at Unit 4 of the Chernobyl nuclear power station was the worst nuclear accident in history. Radioactive fallout from the accident (directly or indirectly) affected the lives of hundreds of thousands of people in the former Soviet Union and contamination spread throughout Europe. In the 19 years since the accident, thousands of scientific papers have been published on Chernobyl and its consequences. In this book we have tried to summarise this vast literature, focusing particularly on the long-term consequences of the accident to people and the environment.

There are many historical accounts of the Chernobyl accident (e.g., Shcherbak, 1989; IAEA, 1991; UNSCEAR, 2000; Mould, 2000; Kryshev and Ryazantsev, 2000; OECD/NEA, 2002). Whilst this book focuses primarily on the longer term impacts of the accident, here we briefly summarise the history of the accident and its immediate consequences. In particular, we aim to put Chernobyl within the context of other (natural and man-made) sources of radioactivity in the environment. This chapter also introduces some key concepts and units of radiation measurement and risk assessment. Many of these will be familiar to some readers, and are therefore where possible included in boxes separate from the main text.

1.1 HISTORY OF THE ACCIDENT

At the time of the accident in 1986, Chernobyl was one of four nuclear power stations in the Ukraine and was part of a rapid expansion in nuclear generating capacity. The Chernobyl power station consisted of four ‘RBMK-1000’-type reactors, the first of which, Unit 1, began electricity generation in 1977. Electricity generation at Unit 4 (the reactor at which the accident occurred) was begun in 1983

and in 1986 two other Units (5 and 6) were being built. Construction of these last units stopped after the accident.

The accounts of the accident and its immediate aftermath (Shcherbak, 1989; IAEA, 1991; Mould, 2000) make truly chilling reading. There are still some uncertainties regarding the exact causes and events leading to the accident, though the key factors are now known. The accident occurred during an experiment to test the behaviour of an electrical system which powered the station in the event of a failure of the main electricity supply. In order to conduct the experiment, the reactor thermal power output had to be reduced to 700–1,000 MegaWatts (MW), about 25% of its maximum power output.

At 13:00 on 25 April, 1986, the plant operators began reduction of the reactor power in preparation for the experiment. At 14:00, however, the operators received a request from Kiev to continue supplying electricity until 23:10 that evening, so the experiment was postponed. At 23:10 reduction of the reactor power output began again and at just after midnight on 26 April, reactor power was 720 MW. Approximately 30 minutes later, however, power output had fallen to just 30 MW. This unexpected fall in the power output is believed to have been due to a problem in the operation of the automatic control rods (which were designed to control the reactor power under low-power conditions).

At 01:00, the operators had stabilised reactor power at 200 MW by removing some of the control rods. During the next 20 minutes the operators varied the flow rate of water in the coolant circuit, leading to a significant variation in temperature of the inlet water. The reactor has been described as being in an unstable condition during this period (UNSCEAR, 2000): the coolant flow was almost completely liquid water with no steam entrained. At 01:22:30 the operator received an automatic printout which indicated that the reactor should be shut down immediately (IAEA, 1986). This warning was ignored. At 01:23 the experiment began, despite the fact that:

- the reactor power output was well below that required by the experimental procedure;
- certain reactor safety systems had been deliberately disabled in order to carry out the experiment; and
- the number of control rods in the reactor was only half the minimum required for its safe operation.

Thirty seconds after the experiment began, the reactor power began to increase rapidly and ten seconds later the operators attempted a full emergency shut down by re-inserting the control rods. The reactor power was now increasing exponentially leading to a failure in the pressurised cooling water system. Eight seconds later, the reactor exploded (an explosion of steam, not a nuclear explosion) scattering burning core debris over the surrounding area. The ruined reactor is shown in Figures 1.1 and 1.2.

Box 1.1. Design flaw in the RBMK reactor.

The RBMK nuclear reactor used at Chernobyl, in contrast to most nuclear reactors, had what is known in the nuclear industry as a 'positive void coefficient'. In an accident situation, should cooling water be lost or turned to steam, most reactors (with 'negative void coefficient') naturally reduce their power output. In the RBMK reactor, loss of cooling water results in an increase in power output and consequent temperature rise in the reactor core. This in turn causes more of the coolant water to turn to steam, leading, potentially, to an uncontrolled rise in power output.



Figure 1.1. The destroyed Unit 4 reactor building at the Chernobyl Nuclear Power Plant (NPP). The edge of the Cooling Pond can be seen top left.



Figure 1.2. Aerial view of the destroyed reactor.

Over 100 firemen were called to the scene and they worked with plant personnel to put out many small fires in the reactor building and on the roofs of Unit 4 and the adjacent Unit 3 building. This work exposed the emergency workers to extremely high doses of radiation. The report of the IAEA International Chernobyl Project (IAEA, 1991) describes the scene:

By dawn on the Saturday [26 April], more than 100 firemen had succeeded in putting out the roof fires, and by about 05:00 all but the graphite fire in the [reactor] core had been extinguished. These courageous actions by the early firefighters and plant personnel resulted in many injuries, but they were essential to preventing the spread of the fire to the other units and to preventing a hydrogen explosion or fire that might have ignited the oil in the turbines. Many firemen stayed on the alert on the premises for several hours after the fire was out, which resulted in a number of radiation exposures.

Radiation levels were so high in the damaged part of the plant and just outside it that monitoring equipment in the plant could not measure them. Available portable radiation meters went off-scale and systematic monitoring became impossible. It seems that many of those who entered the buildings to rescue others, fight fires, perform critical operations or assess damage did not appreciate the radiation risk.

Although the initial fires had been put out, the destroyed reactor core continued to burn. During the days after the explosion, helicopters were used to dump thousands of tonnes of various materials onto the exposed reactor core. These materials included boron, lead, sand and clay to smother the fire, absorb radiation and reduce nuclear reactions in the molten core material. In total, 1,800 helicopter flights were made at great risk to the pilots (UNSCEAR, 2000). Despite the heroic efforts of firemen, helicopter pilots and many other emergency workers to put out the fire, the reactor continued to burn for 10 days.

Box 1.2. Myths and revelations.

Soon after the accident, an article appeared in the *New York Times* claiming that the Ukrainian word ‘Чорнобиль’ (Chernobyl) translates to English as ‘Wormwood’ (a bitter herb) and quoting a verse from the Book of Revelations:

The third angel sounded and there fell a great star from heaven, burning, as it were a lamp, and it fell on the third part of the rivers and upon the fountains of water; And the name of the star is Wormwood; and the third part of the waters became Wormwood, and many men died of the waters because they were made bitter.

This has been interpreted by some as giving an apocalyptic dimension to the tragedy, particularly since radioactivity polluted rivers and reservoirs in the Ukraine. In fact, the herb named Chernobyl (‘Чернобыльник’ – Russian, Чорнобиль – Ukrainian) is the Mugwort (*Artemisia vulgaris*). The Wormwood (Полынь горькая, polyn gorkaya – Russian, Полин гіркий’ polyn girkiy – Ukrainian) is a related, but different species, *Artemisia absinthum*.

1.1.1 Emergency response and early health effects

In the early stages of the accident, many power plant operators and emergency workers were exposed to very high doses of radiation. This was a result of external gamma radiation from the exposed reactor core and core debris, as well as exposure to beta radiation from contamination of their skin and clothes (see Box 1.3 for a description of different radiation types). One hundred and thirty four emergency workers were confirmed as suffering from acute radiation sickness (UNSCEAR, 2000), 28 of whom died during the months after the accident (Table 1.1). Internal radiation exposure of these people (mainly from inhalation of radioiodine and radiocaesium) was in general much lower than the external exposure. Chapter 6 presents a fuller discussion of the health consequences of the accident.

Box 1.3. Characteristics of some radioactive emissions.

Radiation type	Description	Stopped by:	Approximate relative biological effectiveness*
Alpha particle	Helium nucleus	Air or outer layers of skin	20
Beta particle	Electron	Few mm of aluminium	1 [†]
Gamma ray	Electromagnetic wave	Few cm of lead	1

* Relative biological effectiveness is used to convert radiation energy absorbed by the human body into a radiation dose: for a given absorbed energy alpha radiation is estimated to be approximately 20 times more biologically damaging than high-energy beta or gamma.

† For beta energies <10 keV a value of 3 is often used.

Table 1.1. Confirmed cases of acute radiation sickness in emergency workers.

Adapted from UNSCEAR (2000).

Degree of acute radiation sickness	Range of external radiation dose*	Number of people affected	Number of deaths
Mild	0.8–2.1 gray	41	0
Moderate	2.2–4.1 gray	50	1
Severe	4.2–6.4 gray	22	7
Very severe	6.5–16 gray	21	20
<i>Total</i>		<i>134</i>	<i>28</i>

* See Box 1.4 for a definition of the gray.

Measures to protect both the people on the site, and the population of the surrounding areas were, in the very early stages of the accident, inadequate. Firemen had not been trained in radiation protection and had no dosimeters to control their radiation exposure. Although potassium iodide tablets (to block radioiodine uptake by the



Figure 1.3. The abandoned town of Pripjat with the Chernobyl Nuclear Power Station in the background.

thyroid) were distributed to power plant workers within half an hour of the accident (UNSCEAR, 2000), there was ‘no systematic distribution’ (IAEA, 1991) of tablets to the population of Pripjat, a town approximately 3 km from the plant (Figures 1.3 and 1.4). Face masks to protect from inhalation of radioactivity were not available to the population and there were no official warnings for people to stay indoors, out of the contaminated air. Many children in Pripjat were playing outdoors on 26 April (the accident occurred in the early hours of 26 April), unaware of the potential danger.

At 14:00 on Sunday 27 April, the 44,000 population of Pripjat were evacuated in 1,200 buses. On 2 May it was decided to evacuate people and cattle from an area of approximately 30 km radius around the plant (the ‘30-km zone’), the boundary being based on a map of radiation dose rate. By 6 May, the entire 30-km zone had been evacuated. Subsequent mapping of contamination later led to more evacuations, including areas in Belarus and the Bryansk region of Russia around 150 km to the northwest of the reactor. In total, approximately 116,000 people (Belyaev *et al.*, 1996) and 60,000 cattle (UNSCEAR, 2000) were initially evacuated from an area of approximately 3,500 km². In subsequent years many more people were evacuated, reaching approximately 350,000 (UNDP/UNICEF, 2002). At present, many of the evacuated areas remain uninhabited, though some small areas have been resettled.

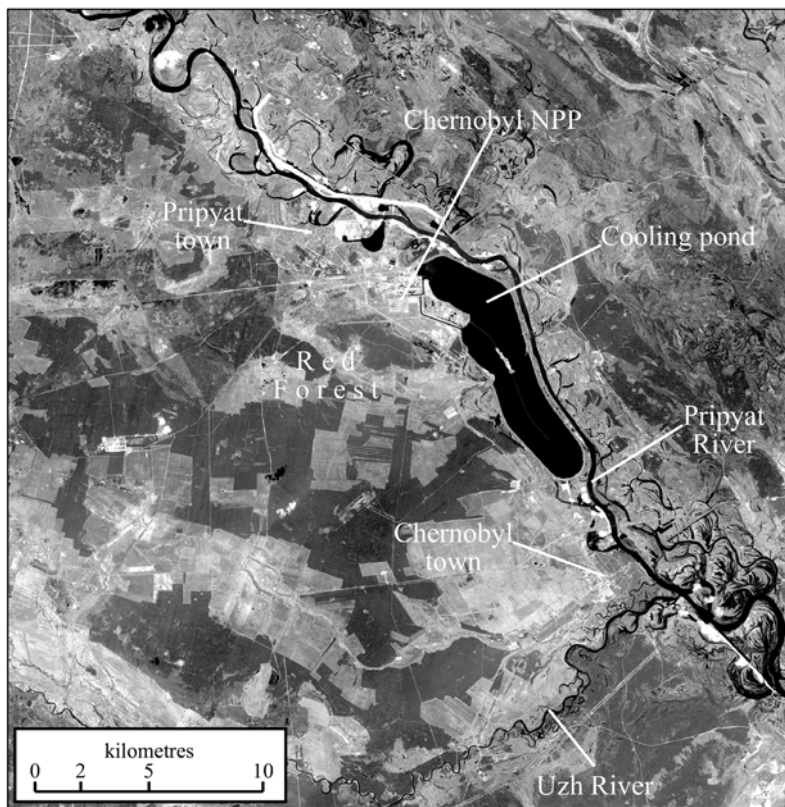


Figure 1.4. Satellite photo of the area around Chernobyl NPP. Note that the town of Chernobyl is about 15 km south of the plant: it had much lower radioactive fallout than many other areas. In this book 'Chernobyl' refers to the nuclear reactor rather than the town unless otherwise stated.

Photo adapted by Simon Wright from the original with the kind permission of Valery Kashparov of the Ukrainian Institute of Agricultural Radiology (UIAR, 2001).

1.1.2 Emergency clean up and waste disposal

A concrete structure (the 'shelter' or 'sarcophagus') was built around the destroyed reactor building in order to prevent further releases of radioactive material (Figures 1.5 and 1.6). The sarcophagus was built rapidly under extremely difficult conditions; work was completed in November 1986 (Belyaev *et al.*, 1996). Since its construction, there have been concerns about the structural integrity of this temporary building. The sarcophagus was (necessarily) built using existing parts of the reactor building as support and the stability of these existing structures is not precisely known.

There has been particular concern that the sarcophagus could collapse in the event of an earthquake, for example (though seismic activity in this area is not high).