United Nations Scientific Committee on the Effects of Atomic Radiation

ELECTRONIC ATTACHMENT 2

SUMMARY OF THE COMMITTEE'S PRE-2016 METHODOLOGIES AND THEIR DEVELOPMENT

UNSCEAR 2016 Report, Annex A,
Methodology for estimating public exposures due to radioactive discharges

Contents

As part of the development of the 2016 methodology for estimating public exposures due to radioactive discharges, the Committee had requested a review of the main features of its previous methodology and how this had been developed. The following tables contain a summary of different aspects of the Committee's pre-2016 methodology (table 1), the dose quantities and integration times that had been used in previous assessments (table 2) and other related information and assumptions that formed the basis of the Committee's previous approach to assessing radiation doses to the public from discharges of radionuclides to the environment.

Notes

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Table 1. Key components of the Committee's pre-2016 methodology

Factors	*Previous approach*
FEATURES OF THE SCENARIO	
Discharges	Discharges considered: noble gases, tritium, ^{131}I and particulates (representative composition assumed)
Site description	Population distribution information representative of the situation in the early 1980s
GENERAL CONSIDERATIONS FOR DOSE ASSESSMENT	
End points	Local, regional and global components of collective effective dose integrated to 100 years. Some presentation of per caput and representative individual doses
Atmospheric dispersion	Dispersion factors based on long-term sector-averaged Gaussian plume model. Long-term average dilution factors derived for downwind distances between 1 and 2,000 km based on representative values of deposition velocity and washout coefficient of 0.002 m/s and 0.0001 m/s, respectively; precipitation for 500 hours in a year; 80% class D and 20% class C conditions, at average rate of 1.5 mm/h Variation of concentrations of radionuclides in air with downwind distance beyond 1 km approximated to the following function in Committee's assessments before 2000: $C_a(x) = D_1 Q x^{-n}$ Best approximation was found for D_1 of 5.3×10^{-7} s/m^3 and for n of 1.42 [U7], assuming uniform wind rose
Aquatic dispersion	Factors based on total volume of freshwater bodies; marine dispersion assumed that North Sea exchange rates were representative of situation elsewhere. Residence times based on information for ^{137}Cs, ^{90}Sr and ^{239}Pu Time-integrated concentration of radionuclide in water for discharge of activity A (Bq) assumed as follows: $A/V(\tau + \lambda_i)$ (Bq a/L), where V is volume of receiving water (L), τ (a^{-1}) is reciprocal of mean residence time in water assuming no radioactive decay (removal to sediments is implicitly included) and λ_i (a^{-1}) is radioactive decay constant for radionuclide, i. This factor may be alternatively described as the equilibrium concentration in water $C_{w,j}$ (Bq/L) for a continuing discharge rate (Bq/a) [U7]
Dosimetric quantities	Internal dose coefficients from [I7, I8]
ENVIRONMENTAL BEHAVIOUR OF RADIONUCLIDES	
Terrestrial	Empirical transfer parameters, primarily based on fallout observations for ^{137}Cs and ^{90}Sr, supplemented by transfer factors for grain for other radionuclides, excepting ^{131}I, for which transfer factor for milk applied [U7] Environmental transfer models presented in [U1, U2] primarily based on empirical data from fallout studies of ^{90}Sr and ^{137}Cs. [U4] cited dynamic models [C1] for the transfer of radionuclides in terrestrial environments for assessing exposures from nuclear facilities. Transfer coefficients for ^{90}Sr and ^{137}Cs derived in [U3, U4]. [U6] described transfer coefficients as having been derived by regression analysis to models relating measured radionuclide concentrations in diet to annual deposition density. Approach applied to derive transfer parameters for other radionuclides appears based on transfer parameters for grain, excepting ^{131}I for which transfer parameter associated with milk was used (in units of (mBq a)/kg per Bq/m^3)
Aquatic	Transfer parameters derived from [I1, I2]

Factors	*Previous approach*
EXTERNAL IRRADIATION	
Radionuclides in air: cloud shine and immersion exposure	Dose coefficients based on [E1] for semi-infinite cloud model and effective dose equivalent rather than effective dose. These factors were modified to allow for a contribution from skin dose
Radionuclides deposited on soil	Dose coefficients derived from [B1] For short-lived radionuclides, dose rate conversion factor for plane source was applied. For ^{137}Cs, [U7] used dose rate conversion coefficient for exponential profile in ground of mean depth of 3 cm. Mean lifetime of radionuclide and average air-to-tissue dose conversion factor applied, with indoor occupancy of 80% and shielding factor of 0.2 [U7]
INHALATION	
Radionuclides discharged to atmosphere	Age-weighted breathing rates and fractions of populations assumed in each age group were presented in [U7] Age-weighted inhalation rate corresponds to 19 m^3/d, close to nominal breathing rate of 20 m^3/d used in previous assessments (which assumed that collective dose substantially determined by intake by adults in population). Committee recommended that nominal value appropriate for most applications [U7]. For Committee's assessments, population groups specified as infants, children and adults assumed to correspond to ICRP age categories 1–2 years, 8–12 years and >17 years
Resuspension	Dust loading factor of 50 μg/m^3 assumed and applied to resuspension of naturally occurring radionuclides in soils
Nuclear installations/general	Population- and age-weighted inhalation rates and coefficients applied. Dust loading approach also applied to resuspension of radionuclides in soils
Mine and mill tailings/radon	Radon dose factors reviewed in detail in [U7]. Radon dose coefficient consistent with that recommended by Committee in [U8] Generic radon release rates and atmospheric dispersion factors applied to determine local, regional and global components of collective doses (truncated at 10,000 years) per unit electrical energy. Methodologies are outlined in [U3, U4]. Various factors initially derived in 1970s to represent conditions in USA [U3]. Basic methodology modified in [U6] The pre-2016 methodology assumed emanation rates of 10 and 1 Bq/s/m^2 from tailings at operational and decommissioned mines, respectively [U7] from nominal release height of 10 m. [U3, U4] used dispersion approach outlined above to determine activity concentrations in air at and beyond 1 km under atmospheric conditions. Dose coefficients of 9 nSv per Bq h/m^3 and 40 nSv per Bq h/m^3 applied for ^{222}Rn and ^{220}Rn, respectively. Equilibrium factors of 0.4 and 0.8 for indoors and outdoors assumed (with indoor occupancy of 80%)
INGESTION	
Radionuclides discharged to atmosphere	Collective doses from ingestion of radionuclides discharged to atmosphere assessed using environmental transfer factors relating deposition to activity concentrations in diet ((mBq a/kg) per Bq/m^3) to intake (Bq per Bq/m^2), from intake to dose (nSv/Bq), and thus from deposition to dose (nSv per Bq/m^2) [U7] Specific activity model used to estimate doses from tritium and ^{14}C. Specific activity model for tritium expressed in terms of tritium to hydrogen atom ratio, while for ^{14}C, specific activity of ^{14}C in ingested food and water assumed to be same as activity per gram of carbon in air at point of interest. [U7] considered this approach probably overestimates doses Representative individual consumption rates for following foods presented in [U7] for different geographical areas for milk, grain, leafy vegetables, fruit and vegetables and meat. In practice, combined global value of total consumption rate of all foods (500 kg/a) used to derive transfer factor relating deposition to intake (Bq per Bq/m^2). As above, factors relating deposition to diet for caesium and strontium isotopes based on empirical observations from fallout. Corresponding data for other radionuclides based on scaling these factors using transfer information for grain, excepting ^{131}I for which transfer for milk was applied

Factors	*Previous approach*
Radionuclides discharged to aquatic environment	Based on generic assumption of relationship between volume of water and number of people receiving doses from it, validated by global aquatic food-catch data Collective doses assessed based on following: $S_i^c = A_i / V(\tau + \lambda_i) \times \sum_k N_k f_{k,i} d_i$ where A_i (Bq) is activity of radionuclide, *i*, discharged to water; V (L) is volume of receiving water; τ (a^{-1}) is reciprocal of mean residence time of radionuclide in receiving water assuming no decay; λ_i (a^{-1}) is radioactive decay constant for radionuclide, *i*; N_k is number of individuals for exposure pathway *k*; $f_{k,i}$ is concentration factor for item in exposure pathway, *k*, for radionuclide, *i*; d_i (Sv/Bq) is effective dose per unit activity ingested For calculating collective doses, Committee traditionally assumed crude relationship between number of people and volume of receiving water body. Annual per caput drinking water consumption, V/N_k, taken to be 2.2×10^7 L [U7]. For freshwater fish $N_k I_k / V$ assumed to be 4.6×10^{-8} man kg/a/L, based on average fish consumption rate of 8 kg/a, giving global consumption of 6×10^9 kg/a. This agreed generally with global harvest of 10^{10} kg [U7], when 50% edible weight was assumed [U7] $N_k I_k / V$ factor for fish and shellfish within continental shelf estimated to be 3×10^{-8} man kg/a/L [U7]. Value noted to be significantly higher than used in [U3]. Residence time, assumed to be that observed for North Sea, of 3 years for ^{137}Cs and ^{90}Sr [C1] and 3.5 years for ^{239,240}Pu ("first pass") was less than that assumed in earlier reports [U7]
GLOBALLY DISPERSED RADIONUCLIDES	
Tritium	Based on simplified model developed 1975 [K1] Committee's approach to modelling global circulation of tritium from nuclear installations was based on results from a review and comparison of models [K1], NCRP [N1], Bergman et al. [B2] and Killough and Kocher [K3]. Concentration of tritium within compartments determined from distribution of tritium in each compartment divided by volume of water in each compartment. Concentration in humans then determined from concentration in environment weighted by fractional intake from each compartment Most reliable estimate of global collective dose from near-surface atmospheric discharges considered to be given by model by Killough and Kocher [K3] for discharges to 30°–50° band of troposphere in northern hemisphere, which gave estimate of 2.3 man Sv/PBq. Estimated global collective dose arising from discharges to ocean available from NCRP [N1] and Bergman et al. [B2] approaches, which indicated that these doses were around one tenth of those from atmospheric discharges. Collective dose estimate of 0.2 man Sv/PBq for discharges of tritium to ocean thus applied. These global circulation models were reviewed and compared in some detail [U7] and were considered still appropriate
Carbon-14	Based on a 23-compartment model developed by Titley et al. [T1]. [U7] reported that dose estimates using different models were within a factor of 1.5 The 23-compartment model (see figure VI, annex A of [U7]) was applied [T1] to estimate activity per gram of carbon in each environmental compartment over time. Atmospheric component adapted from model used by Emanuel et al. [E2], while ocean model accounted for temperature changes, surface areas and varying ice cover in winter. Once mixing achieved, specific activity model used to estimate collective dose commitments from ^{14}C, assuming that specific activity of ^{14}C in carbon ingested by humans was same as in most relevant compartments for food intake (ground vegetation for terrestrial foods and relevant surface water compartments for marine foods). The incomplete (to 10,000 years) collective effective dose commitment per unit discharge to atmosphere was around 109,000 man Sv/PBq. Doses following discharge to soils or surface oceans considered to be about the same as for atmospheric discharges, but doses from discharge to deep ocean were around 20% lower [U7]. [K2] found predictions of six models ranged over factor of only 1.5, suggesting remarkable agreement. Attributed to long half-life of ^{14}C relative to its rate of environmental transport, making estimated dose commitments insensitive to detailed model structure [K2]

Factors	*Previous approach*
Iodine-129	Global circulation compartment model for ^{129}I developed by Titley et al. [T1] used in assessment in UNSCEAR 2000 Report (see figure VIII, annex A [U7]). Represented a revision of that developed by Kocher [K4], used in earlier assessments, and modified by Smith and White [S3]. Inventories of stable iodine in model compartments, and fluxes between compartments, were derived from environmental measurements and mass balance assumptions. Iodine intakes from each compartment were determined from average food consumption and inhalation rates and concentrations of stable iodine in air and foods or by a specific activity approach. Pathway analysis approach applied, comprising following five pathways: inhalation from land atmosphere (0.29 μg/d); deposition from land atmosphere onto food crops ingested directly by humans or by dairy or beef cattle (6.6 μg/d); ingestion of land surface water (5.3 μg/d); ingestion of marine fish and shellfish (11 μg/d); root uptake from surface soil (200 μg/d). Equivalent dose to the thyroid and appropriate tissue weighting factor then applied
Krypton-85	Based on simple two-compartment model, originally presented in 1979 [C1] Committee's approach for determining global dispersion of ^{85}Kr described in detail in [U5], citing approach presented in [U4], where simple two-compartment model used to model introduction of ^{85}Kr into northern hemisphere [N2]. Two compartments represented tropospheres of northern and southern hemispheres, and transfer coefficient of 0.5 a^{-1} between compartments was used. Activity concentrations in air as function of time [U4]. Time integral of activity concentration in air was 10^{-10} Bq/m^3 per Bq/s. Dose coefficients from activity concentration in air to absorbed dose rate in air and to absorbed dose rate in skin from beta radiation emitted derived from [C1] Collective effective dose equivalent derived in [U4] was 0.17 man Sv/PBq (assuming world population of 4×10^9), scaled to 0.2 man Sv/PBq in [U5] for population of 4.6×10^9. This dose commitment was delivered during first 50 years after discharge. Production of ^{85}Kr for LWRs and GCRs normalized to electricity generated was 2.3 man Sv/(GW a). The dose, weighted for amount of fuel currently reprocessed (0.05), led to estimate of 0.12 man Sv/(GW a)

Table 2. Dose quantities and integration times used in past Committee assessments

UNSCEAR 2008 Report (annex B [U9])	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
GENERAL METHODOLOGY				
Cites [U7]	Cites [U4, U5, U6]			Acknowledged value of dose distribution information. Purpose of truncation to derive maximum future dose equivalent rate from practice continuing for set time
	Integration to 50 or 100 km for local and to 2,000 km for continental or regional components of collective dose; most particles from near surface discharges deposited within 2,000 km. Ingestion based on time-integrated concentration factors used since 1962			Per caput dose equivalent rate Simplest assumption for population: uniform density of 100 km^{-2}. Assumptions for local and regional components given in annex F. Average for mining and power production sites: 3 km^{-2} for mining site; 300 km^{-2} for reactor site up to 100 km; 20 km^{-2} out to 20,000 km
				Integration for shorter-lived radionuclides assumed world population of 4×10^9; for ^{14}C and ^{129}I, assumed increases to 10^{10} and then constant
GLOBALLY DISPERSED RADIONUCLIDES				
^{3}H, ^{14}C, ^{85}Kr and ^{129}I: doses (man Sv/(GW a)) truncated to 100 years: ^{3}H: 0.004; ^{14}C: 6.3; ^{85}Kr: 0.12; ^{129}I: 0.0008 [U5]	^{14}C 9% of total dose commitment from single discharge delivered in 100 years; 23% in 1,000 years; 75% in 10,000 years [T1]. Truncation time depends on period of nuclear power use. Population stabilizes at 10^{10} for ^{14}C and ^{129}I; 5×10^9 for ^{3}H and ^{89}Kr	Truncation at 10,000 years by which time contributions of ^{3}H and ^{85}Kr insignificant. ^{14}C: 70% of dose commitment calculated for all time. Globally dispersed contribution almost entirely due to ^{14}C	Results for alternative truncation periods provided	Integration times in 1977 for global components: 10^1, 10^2, 10^4, 10^6, 10^8 years Only 10% ^{14}C dose delivered in 70 years

UNSCEAR 2008 Report (annex B [U9])	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
MINING AND MILLING				
Cites [U3, U4]: 0.2 operational and 0.00075 man Sv/(GW a) residual	Cites [U3, U4]. Unchanged release over 10,000 years. Population density: 3 km^2 at 0–100 km; 25 km^2 at 100–2,000 km. Comparisons with actual sites included	1.5 man Sv/(GW a) is 3 times greater than 1988 value. Assumed duration of release 10,000 years—maximum period of integrity of tailings piles (and ^{230}Th and ^{222}Rn release); after this erosion complete or covered with ice	Truncated dose commitment for 10,000 years. Data given for 100, 1,000, 5,000 and 10,000 years. Different assumptions on continuation of nuclear power: maximum 500 years, with greater contribution for alternative means, so that mining and milling complete in 100 years	Primary release airborne. Population density 3 km^{-2} within few 100 km; uniform population of 25 km^{-2} to 2,000 km [U3]
FUEL FABRICATION				
0.003 man Sv/(GW a)—no specific references	Cites [U6], same value as annex B of [U9]. Collective dose to local population (3.1×10^6 within 50 km) and corresponding individual dose 10 µSv/a			Assumed located in northern Europe or North America
POWER PRODUCTION				
Cites [U7], local and regional components; model site, population density 400 km^{-2} in 50 km radius; regional 20/km^{-2} in 2,000 km radius. Values for man Sv/PBq from [U7]	Some changes to calculation factors for some radionuclides applied in [U4, U5]—differences presented but not explained	Cites [U5]. Population within 2,000 km is 250 million. Average within 50 km of 400 km^{-2} referenced to siting practice		[U3]: dose per unit discharge for noble gases presented for 1–10, 10–100 and 100–1,000 km. Collective dose commitment chosen to reflect dose received by most exposed individuals. Page 262 gives cumulative population to 2,000 km and within 50 km
REPROCESSING				
Cites [U6]	Cites [U6]	Cites [U5]		
WASTE				
L and ILW disposal 0.5 man Sv/(GW a) [U4, U6]		L/ILW releases to groundwater 0.5 man Sv/(GW a) and from handling spent fuel 0.05 man Sv/(GW a)	Times at which dose delivered presented (table 54 of [U5])	
TRANSPORTATION				
Transportation of spent fuel: 0.1 man Sv/(GW a) cites [U2, U4, U7]		Transportation of 0.1 man Sv/(GW a) based on [U5]		
Other transport (incl. non-nuclear) verifiably low–detailed discussion				

Table 3. Distances used to define local and regional components of collective dose in UNSCEAR reports since 1972

	UNSCEAR 1972 Report [U2]	*UNSCEAR 1977 Report [U3]*	*UNSCEAR 1982 Report [U4]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 2008 Report [U9]*
Definition of local and regional components	Local component discussed as distinct from global component, but contributions to annual collective dose not presented separately	Subdivision of world population. Local and regional components estimated for 1–100 and 100–1,500 km, respectively	Local and regional populations described as being within few hundred and few thousand kilometres, respectively. Local and regional components not separated in definition of collective dose parameters	Local population referred to as those within about 100 km and regional within about 1,000 km. This definition was not described in terms of dispersion or dose distributions	Approach based on that presented in 1982 and 1988	The integrated dose to 50 or 100 km to define local component, with further integration to 2,000 km to define regional or continental component	Based on approach outlined in [U7]
Other related issues	Some examples of site-specific local exposures	Doses from noble gases as function of distance (1, 10, 100, 1,000 km)	Basis for models of representative sites for each stage of nuclear fuel cycle on which later assessments were based. Population distributions defined for distances 0–100 km and 100–2,000 km		Representative site-specific critical group doses for perspective on individual doses	Sensitivity of dose estimates to atmospheric dispersion assumptions, including stack height, considered. Gaussian plume model over distances >100 km considered appropriate for population assessment because of implicit averaging	
			Population and distribution assumed to continue indefinitely. World population of 4×10^9 assumed; for long-lived nuclides, assumed to increase to 10^{10} and then stay constant				

Table 4. General factors and parameters used in Committee assessments since 1977

	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
General	Methodology referenced to [U7]		Environmental and dosimetric models and parameters referenced to [U5]	[U4] considered still valid for assessing impact of discharges from fuel cycle, although reprocessing treated differently in 1988. Fractions of fuel reprocessed added to contributions from rest of fuel cycle	
Radionuclide composition		90% activity of particulates discharged assumed composed of: ^{54}Mn, ^{58}Co, ^{60}Co, ^{89}Sr, ^{134}Cs, ^{137}Cs and ^{140}Ba (including ^{140}La). 10% of activity assumed composed of: ^{51}Cr, ^{59}Fe, ^{65}Zn, ^{90}Sr, ^{90}Y, ^{95}Zr (including ^{95}Nb), ^{124}Sb, ^{136}Cs, ^{141}Ce and ^{144}Ce			Activity of particulates assumed comprised of equal distribution of: ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{65}Zn, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{95}Zr, ^{95}Nb, ^{124}Sb, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{141}Ce and ^{144}Ce
Atmospheric dispersion		Long-term average dispersion based on Gaussian plume model fitting gave simplified dilution factor at 1 km (5×10^{-7} Bq/m^{-3} per Bq/s discharged) and further reduction in inverse proportion to the 1.4 power of distance from the discharge point. The value of D_1 was lower than in 1982; owing to wind direction assumptions—uniform wind rose. Value of n taken to be 1.2 for noble gases which do not deposit	Models and parameters referenced to [U5]		Statistical methods considered adequate for long-term average assessments for routine discharges; Gaussian plume recognized as most useful and commonly used. Simplified relationship derived to estimate time integrated air concentrations.[a] Assumed wind blows towards location 50% of time

	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
Uncertainty in dispersion modelling		Variability of results to changes in input parameters demonstrated; D_1 insensitive to wind speed and discharge height, while n sensitive to these and deposition. Uncertainties at regional scales acknowledged large, but probably within factor of 10 for simple situations			Accuracy of equations considered by Hoffman et al. [H1]; within factor of 10
Discharge height		Representative effective discharge height of 30 m used for nuclear installations			Effective release height of 10 m used for mines and mills Height of release considered to have little effect on collective dose estimates
Deposition		Effective deposition velocity of 0.002 m/s for annual average deposition. Value appropriate for dry deposition; range for wet and dry deposition 0.005–0.013 m/s, depending on downwind distance. Larger deposition velocity values inconsistent with dispersion assumptions on mass balance			
Aquatic dispersion (freshwater)		Mean residence time of ^{90}Sr and ^{137}Cs assumed to be 3 and 5 years, respectively. Radionuclides with high K_d (^{144}Ce and ^{239}Pu) assumed to behave as ^{137}Cs, others as ^{90}Sr, correcting for radioactive decay			In 1979, model for isolated water body applied. Removal of radionuclides onto sediment using distribution coefficient [C1][b] River model based on [C1], itself based on observation that average activity concentrations in transversely well-mixed river water decreased exponentially with distance [c]

	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
Aquatic dispersion (marine)		Residence times for North Sea assumed representative of all coastal seas. Mean residence time assumed to be 3 years for ^{90}Sr and ^{137}Cs [C1] and 3.5 for ^{239}Pu ("first pass")			Simple single compartment model (for isolated waters) assumed to apply, extended to include interactions with adjacent compartments, of type described in [C1]
Drinking water intake		V/N_k (where N_k is number of people exposed by particular pathway and V is volume of water in water body) used to indicate water use for particular pathway. For drinking water: 2.2×10^7 L/person assumed			
Fish and seafood intake		Average intake by individual: 8 kg/a (6 kg/a marine fish; 1 kg/a each for freshwater fish and shellfish) ranging from 4 to 6 in West Asia and Africa to 10–14 kg/a in East Asia and Europe. $N_k I_k/V$ from freshwater fish estimated as 4.6×10^{-8} kg/(a L). For salt water fish and shellfish the $N_k I_k/V$ value estimated to be 3×10^{-8} kg/(a L)			
Concentration factors for fish		Values taken from [I2] for freshwater and [I1] for marine foods			
Age groups	Noted that few assessments included estimates of doses to children, but intakes by infants (1 year), children (10 years) and adults provided in table 8 of annex B	Fractional age distribution and intakes noted in 1993 used [U6], together with age-dependent dose coefficients "for most purposes" for age groups: 1-2, 8–12 and >17 years	Age-weighted annual intakes of naturally occurring radionuclides derived assuming fractional distribution of adults, children and infants in population of: 0.65, 0.3 and 0.05		Doses to 0–1-year-age group from ^{131}I considered in 1977; 6 months, 4 years and 14 years also considered for ^{131}I from nuclear reactors in 1982

	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
EXTERNAL IRRADIATION					
Relationship between air kerma and absorbed dose		Assumed equivalent; charged particle equilibrium			
External dose factors	Specific reference made to use of occupancy and shielding factors for indoor occupancy	Recalculation identified as necessary in future for effective dose rather than effective dose equivalent			Modification of factors based on effective dose equivalent (H_E) using 0.01 H_{skin} to simulate effective dose (E) first used in 1982 for noble gases
Cloud shine and immersion		Approach referenced to [U4] and [E1]			Coefficients from [C1], based on semi-infinite cloud model
External irradiation from deposition		Based on dose rate conversion coefficients from [B1]. No account taken of different behaviour of radionuclides in urban and rural environments (except for Chernobyl accident)			
INHALATION					
Inhalation rate		Breathing rates from [I8]	Nominal breathing rate of 20 m^3/d assumed; collective dose assumed dominated by intake by adults		Breathing rate of 20 m^3/d, close to that given in [U4]
Dose coefficients		Age-dependent dose coefficients from [I7, I8]		Dose coefficients for adult workers from [I3, I4]	Dose coefficients for adult workers from [I3, I4]
Dose coefficients for radon		Dose conversion convention from [I6] giving dose coefficients in range 6-15 nSv/(Bq h/m^3) supporting use of previous value of 9 nSv/(Bq h/m^3). For ^{220}Rn, value of 40 nSv/(Bq h/m^3), including dose from ^{214}Pb derived by analogy with risk factors from [I5]	Dose coefficient for ^{222}Rn, in equilibrium with its short-lived progeny of 9 nSv/(Bq h/m^3)	Dose coefficient for ^{222}Rn, in equilibrium with its short-lived progeny of 9 nSv/(Bq h/m^3)	

	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982/1977 Reports [U3, U4] (where specified)*
Resuspension (of radionuclides from nuclear power production)					Time-dependent resuspension factor applied; initial and intermediate factors of 10^{-5} and 10^{-9} m^{-1}, respectively. Decay constants for initial and longer-term decline in resuspension factor: 1.46×10^{-7} s^{-1} and 2.2×10^{-10} s^{-1}
Resuspension (of naturally occurring radioactive material)					Dust-loading factor of 50 μg/m^3 assumed in [U3, U4], appropriate for long-lived radionuclides, uniformly mixed in soil surface
Environmental transfer					Compartment models and transfer from [C1] used to derive matrices of time integrals of activities of radionuclides in unit mass of food over different time periods
INGESTION					
Water intake rates		500 L/a for adults, 350 L/a for children and 150 L/a for infants			
Ingestion rates		Applied values from [U5]. Rates categorized as western (greater amounts of dairy products and meat) and eastern (grain products, vegetable products and fish)	Age-dependent consumption rates derived. Milk consumption 120 kg/a and 110 kg/a for infants and children, respectively (compared with average of 500 kg/a). For other foods, assumed children eat two thirds and infants one third of adult values [U7]	Population-weighted consumption rates	
Food preparation losses		Not included in Committee's calculations			

[a] Dispersion approximation: $\chi_a(x) = A_0 f (x/x_1)^{-p}$, where $\chi_a(x)$ is the time-integrated concentration of the radionuclide in air at distance x; x_1 (normalization distance) = 10^3 m; A_0 is the source activity, f is a coefficient with units s/m^3, and p is a numerical exponent. For most weather categories and discharge heights, a reasonable approximation is obtained for $f = 3 \times 10^{-6}$ s/m^3 and $p = 1.5$, within 100 km.

[b] Change in activity concentration with time in isolated water body: $d\chi_w/dt = A_0/V - (\lambda_\tau + \lambda_s + \lambda)\chi_w$, where χ_w is the activity concentration per unit volume in the water at time t; A_0 is the rate of input of activity; V is the volume of water; λ_τ is the fractional rate of renewal of water; λ_s is the fractional rate of removal of activity by sorption onto sediments and λ is the radioactive decay constant.

[c] River dispersion: activity concentration χ_w in water (including suspended sediments) at distance x is: $\chi_w(x) = A_0/V\, e^{-kx}$, where V is the volume flow rate of the river; k is a coefficient dependent on the river and radionuclide, which is given by $k = (\lambda + \lambda_s)/v$, where v is the river velocity and other parameters are as given above.

Table 5. Assumptions and factors included by the Committee for assessing collective doses due to radon emissions from mines and mill tailings, and in three papers that consider their applicability to particular sites

Factor	*Reference*					
	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*SENES [S1]*	*Tort et al. [T2]*	*Mudd [M2]*
Uranium fuel requirements		(250 t U_3O_8) per GW(e) a	210 t U (250 t U_3O_8) per GW(e) a			
Tailings surface area normalized to electricity generated			1 ha/(GW a)			0.95 ha/(GW a)
Radon release rate		1 Bq/s/m^2, taking account of information in [S1] and that some areas are to be rehabilitated	10 Bq/s/m^2 from operational, 3 Bq/s/m^2 from abandoned but stabilized tailings	After decommissioning, <7 Bq/s/m^2. For long-term management with water coverage, emission rate 0–0.2 Bq/s/m^2	Release rate from Lodève site before remediation: 28 Bq m^{-2} s^{-1}. After remediation, radon flux almost zero	Up to 11.6 GBq/d (from tailings, waste rock and low grade ore) compared with Committee's approach, which implies 2.6 GBq/d (tailings only)
Radon emission rate normalized to electricity generated	Similar approach to [U6]: 3 TBq/(GW a) operational, and 1 TBq/(GW a) from abandoned but stabilized tailings	Underground mines 75 TBq/(GW a); mills 3 TBq/(GW a)	3 TBq/(GW a) operational; 1 TBq/(GW a) from abandoned but stabilized tailings	0.946 TBq/(GW a)		
Population density			3 km^{-2} at <100 km and 25 km^{-2} at 100−2,000 km	Used 100 × 100 km grids around sites in Canada and Mexico; compared with uniform density; reduced population densities: <3 km^{-2} at <100 km, 2-7 km^{-2} at 100-2,000 km	63 km^{-2} at 0-100 km, 44 km^{-2} at 100-2,000 km for Lodève mining site	
Air dispersion factor at 1 km		5 × 10^{-7} s/m^3	3 × 10^{-6} Bq/m^3 per Bq/s	Used US EPA ISC3[a] model for 1–100 km and CALPUFF/CALMET[b] for 100–2,000 km. Reduced concentration at 10 km by factor of 2 and at 2,000 km by 17	Atmospheric dispersion modelling	
Release height			10 m	10 m		

Factor	*Reference*					
	UNSCEAR 2008 Report [U9]	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*SENES [S1]*	*Tort et al. [T2]*	*Mudd [M2]*
Concentration with distance, x			$x^{-1.5}$ (x in km)			
Dose conversion factor	9 nSv/h per Bq/m^3 (EEC) 40 nSv per Bq h/m^3 (EEC) for thoron from [U8]	9 nSv/h per Bq/m^3 (EEC)	9 nSv/h per Bq/m^3 (EEC)	6.4 nSv/h per Bq/m^3 (EEC) derived from [I6][c]		
Radon progeny equilibrium factors			0.4 (indoors 80%) 0.8 (outdoors 20%)	Suggests 0.6 more appropriate based on European and US studies		
Collective effective dose factor			0.015 man Sv/TBq			
Truncation period		10,000 years	10,000 years	10,000 years[d]		
Collective effective dose (range)	0.2 man Sv/(GW a) operational, and 0.00075 man Sv/(GW a) from residual tailings	0.2 man Sv/(GW a) operational, and 0.00075 man Sv/(GW a) from residual tailings	150 (1–1,000) man Sv/(GW a)	0.96 man Sv/(GW a). In Committee's evaluation, quoted as 1.4 man Sv/(GW a) over 10,000 years using radon dose coefficient specified by Committee	380 man Sv/(GW a) (from unremediated site)	
Annual effective dose	40 μSv (assuming collective dose received by population <100 km)				Individuals within 10 km 20 μSv (from unremediated site)	
Relevant comments noted in references		Imperceptible from variations in normal background dose rates from natural sources		Up to 97% dose to population within 100–2,000 km. Unclear whether radioactive decay taken into account in Committee's estimates		Committee's data for solid waste parameters reasonable although major sources (waste rock and low grade ore) lead to underestimation
	Dosimetry consistent with annex E of [U8]	Higher population densities around mills in China		Population grids lead to estimates of collective dose factor of 3–4 lower than uniform distribution		Given level of variation, using rates normalized to electricity generated (expressed per GW a) unrealistic

[a] See http://www.epa.gov/ttn/scram/dispersion_alt.htm#isc3.
[b] See http://www.src.com/calpuff/calpuff1.htm.
[c] Based on 4 mSv/WLM. SENES [S1] noted lower conversion factors are used in some epidemiological studies (<2 mSv/WLM).
[d] SENES [S1] states that this is used by the Committee for the sake of illustration.

Table 6. Development of the Committee's approach for assessing exposures from globally dispersed radionuclides

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
Overall approach	Cites [U5]			States that environmental transfers of ^{3}H, ^{14}C, ^{85}Kr were established, and that reliable estimates made in [U4][a]	
Truncation period	10,000 years	10,000 years	10,000 years	10,000 years [b]	
Global population		For ^{14}C and ^{129}I assumed 10^{10} at time of discharge; for ^{3}H and ^{85}Kr, 5×10^{9} assumed			
Reprocessing		Weighting for reprocessing 0.11 for period 1990–1994		Reprocessing plant discharges weighted by fraction of energy value of total nuclear fuel reprocessed (5%)	Model reprocessing facility described. All reactor fuel assumed to be reprocessed
TRITIUM					
Basis		Range of models discussed, with range of complexity. Value to consolidate results			Simple model by [K1], as implemented in [C1]
Collective dose factor	0.004 man Sv/(GW a)	2 and 0.2 man Sv/PBq for atmospheric and aquatic discharges from nuclear installations, respectively		3.2×10^{-5} man Sv/PBq for population of 4.6×10^{9} Total[c]: 0.004 man Sv/(GW a)	2.8×10^{-5} man Sv/PBq for population of 4×10^{9}
Incomplete dose commitments				Table 70 of annex B of [U5]: dose received in first few years	
Local and regional component				Add 0.6 man Sv/(GW a) (factor >100 greater than global contribution)	

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
CARBON-14					
Basis		Model comprising 23 compartments [T1], illustrated in figure VI of annex A of [U7]. Terrestrial model adapted from [E2], with minor modification [d]	Approach developed in [E2]	Used [C1]. Compartments: two hemispheres, comprising humus, circulating carbon surface and deep ocean. ^{14}C assumed instantaneously mixed in compartment into which discharge occurs. Results similar to those produced from more complex models	
Collective effective dose commitment factor	6.3 man Sv/(GW a)	Complete commitment per unit discharge of 109,000 man Sv/PBq (population of 10^{10})[e]	Incomplete collective dose commitment of 85 man Sv/TBq (population of 10^{10})	67 man Sv/TBq average for both atmospheric and aquatic discharges (population of 10^{10})[f]. Total: 6 man Sv/(GW a)	
Delivery of dose commitment		9% of commitment from single discharge delivered within 100 years, 23% within 1,000 years and 75% within 10,000 years [g]		Above commitment delivered over 10,000 years Table 70 of annex B [U5]: 3% in 10 years; 10% in 100 years and 19% in 1,000 years	
IODINE-129					
Basis		Titley et al. [T1] and revision of Kocher [K4][h]. Collective doses with time from different discharges		Future global population of 10^{10}; 1.4×10^4 man Sv/TBq; 0.003% delivered in 100 years; 0.03% in 10,000 years and 5% in 10^6 years. Most of the commitment received between 10 and 40 million years Incomplete commitment to 10^6 years used: 700 man Sv/TBq	
Reprocessing				2.2 GBq/(GW a)[i]	
Collective dose factor (man Sv/(GW a))	0.008			10^6 years: 1.5; 10,000 years: 0.0093; and 100 years 0.0008	
KRYPTON-85					
Basis				Reference to 1982 Report	Two-compartment model comprising the tropospheres of the northern and southern hemispheres. Exchange rate of 0.5 a^{-1} assumed [C1]
Collective effective dose commitment per discharge				0.2 man Sv/PBq (population 4.6×10^9)	0.17 man Sv/PBq (population 4×10^9)

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
Time for delivery of dose commitment				Within 50 years	Inert gas disperses through atmosphere and achieves uniform concentration in 2 years
Collective dose factor (man Sv/(GW a))	0.12			Normalized production of ^{85}Kr for different reactor types [j]; weighted by 0.12, the fraction of fuel reprocessed	

[a] The UNSCEAR 1988 Report [U5] also stated that ^{129}I posed a problem because of its very long half-life and the uncertainties in predictions over tens of millions of years—and "therefore little use can be made of these collective dose commitments for decision-making purposes".

[b] Results for alternative integration periods were presented. Results for 10^6 years presented and discussed (for ^{129}I); it was stated that incomplete collective dose commitments are useful to demonstrate time distribution of dose and to estimate per caput doses arising per year from finite duration of practice.

[c] Atmospheric discharge from reactor operations: 46 TBq/(GW a); aquatic discharges: 40 TBq/(GW a). Reprocessing (averaged over Sellafield and Cap de la Hague) aquatic and atmospheric discharges add up to 600 TBq/(GW a). Since only 5% fuel is reprocessed, this adds 30 TBq/(GW a) to reactor discharges.

[d] Unchanging global inventory of carbon assumed. The ocean model takes account of temperature changes, surface areas and varying ice cover in winter. Exchanges between oceanic and atmospheric compartments are based on estimates of the dissolution of CO_2 from [M1] and [S2]. The model was tested and validated.

[e] Table 44 annex C of [U7] gives collective effective dose commitment (10,000 years) due to globally dispersed radionuclides from reactors and reprocessing.

[f] Reactors: 57 man Sv/(GW a) from HWR, LWR, LWGR, GCR operation. Normalized discharges from reprocessing averaged over Sellafield and Cap de la Hague (3.5 TBq/(GW a) for Sellafield and 0.66 TBq/(GW a) for Cap de la Hague). This represents for Sellafield, 234 man Sv/(GW a), and for Cap de la Hague, 44 man Sv/(GW a). Taking account of 5% fuel reprocessed annual value averaged over the two sites, the total is 6 man Sv/(GW a).

[g] The UNSCEAR 2000 Report [U7] states this is similar to other estimates: Killough and Rohwer [K2] found estimates from six models ranged over a factor of only 1.5. The UNSCEAR 2000 Report [U7] also stated that the maximum annual dose for continuing practice was 1 μSv, and that limited practice of nuclear power generation would lead to progressively lower annual doses.

[h] Model assumes circulation compartments (figure VII, annex A [U7]) for atmosphere, hydrosphere, lithosphere, and terrestrial. Fluxes determined from environmental measurements and mass balance. Assumes mean residence time in surface soil of order of 10,000 years, mixing in the ocean 1,000 years. [U7] states that global iodine cycle and dynamic behaviour of iodine is being further studied. Iodine measurements in vicinity of nuclear installations markedly higher and retained in surface layer <10 cm.

[i] Discharges from Sellafield and Cap de la Hague normalized to electricity generated were 40 GBq/(GW a) to sea and 4 GBq/(GW a) which, when weighted for 5% fuel reprocessed gives 2.2 GBq/(GW a).

[j] For LWRs, the factor is 11.5 PBq/(GW a) or 2.3 man Sv/(GW a); for GCRs the factor is 14 PBq/(GW a) or 2.8 man Sv/(GW a).

Table 7. Development of the Committee's approach for assessing impacts of non-nuclear forms of electrical energy production

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
Key issues			Three different aerosol capture methods and one with different site characteristics assumed	Initial consideration of oil, peat, natural gas	Coal and geothermal sources only; detailed specification of dose assessment methodology used in subsequent reports
General	Focus on coal mining and power production from coal. Additional literature sources referred to	Updates the UNSCEAR 1993 Report but detailed methodology referenced to the UNSCEAR 1982 Report	Slightly modified assumptions on proportions of site characteristic of coal energy production. Data for China significantly different from default for OECD countries. In China, assumed usage representative of non-OECD countries; average worldwide use of coal assumed as follows: 40% coal used for energy production, 50% by other industries and 10% in dwellings	Main difference between [U5] and [U4] is duel assessment of discharges from coal-fired power stations with different capture efficiencies. Additional source information on geothermal and initial consideration of oil, natural gas and peat for energy production	Provides the basis for methodology
ENERGY PRODUCTION FROM COAL					
Annual coal production					Annual world production of coal: 3.7×10^{12} kg in 1979. Percentage use in energy and household fuel varied between countries
Coal mining					Primarily occupational exposure; maximum collective effective dose equivalent of 3 man Sv/(GW a)
			Reference to crude approach included in [U5]	Two approaches used to determine release of radon in exhaust air, estimates of 30 and 800 TBq, collective effective dose equivalent of 0.5 and 10 man Sv	Public exposure estimated on basis of emission of radon from coal ore, mass of ore required per unit of electricity generated, mean radon concentration in coal

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
Use of coal			See above general statement	Mass of coal for power production assumed from [U4]	3×10^9 kg of coal assumed to produce 1 GW a
Activity concentration in coal			Assumption about activity concentration in coal from [U4]	Assumption about activity concentration in coal from [U4]	Assumed activity concentration of 20 Bq/kg each of ^{238}U and ^{232}Th in equilibrium with their precursors. Noted possible exceptions of ^{210}Pb and ^{210}Po; enhanced activity of ^{210}Pb may occur if large quantities of ^{222}Rn diffuse from adjacent rocks
Activity concentration in ash			Cites [U5]	Large power plants assumed to give rise to 20% bottom ash and 80% fly ash. Activity concentrations in fly ash from [U4] applied. Enrichment factor of 3 for ^{210}Pb and ^{210}Po assumed	Radionuclides partitioned between bottom and fly ash. Averages in escaping ash (Bq/kg): 265 for ^{40}K; 200 for ^{238}U; 240 for ^{226}Ra; 930 for ^{210}Pb; 1700 for ^{210}Po; 70 for ^{232}Th; 110 for ^{228}Th; and 130 for ^{228}Ra
Fly ash release				Two types of station assumed; one that releases around 10% of fly ash while the other releases 0.5%	Average concentrations in fly ash escaping through stack depend on filtration. Small particles caught less efficiently and some trace elements concentrated on small particles. Modelled using an enhancement factor of 1–11 for ^{210}Po and ^{210}Pb and 1–2 for uranium, radium and thorium isotopes
Activity concentrations released				Applies assumptions from [U4]	^{220}Rn released per GW a; 60 GBq assuming all radon contained in coal is discharged to atmosphere

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
Technology-related factors			Three types of plant considered: one third assumed modern; one third old and the remaining third characteristics based on Chinese data. Collective dose normalized to electricity generated 20 man Sv/(GW a)		Release depends on temperature of combustion and efficiency of filtration. Two types of system in place: those with sophisticated retention devices releasing 1% of ash, and those with less sophisticated systems where 10% is more reasonable estimate. Assumption: plant burning coal with 10% ash content and 97.5% retention in filtration systems. Enrichment factor 3 for ^{210}Po and ^{210}Pb and 1 for other radionuclides
Radon releases				Applies data and approach from [U4]	Release of ^{222}Rn and ^{220}Rn assumed in equilibrium with ^{238}U and ^{232}Th in coal and discharged in their entirety. Average activity concentration 20 Bq/kg and combustion of 3×10^9 kg/(GW a) give estimated release of 60 GBq/(GW a)
Carbon-14 discharges				Discharge of activity-free carbon dioxide reduction in collective effective dose commitment of 60 man Sv/(GW a)	
Use of ash			5% ash production used in construction of buildings. External dose rate measurements indicate that wooden and concrete houses give rise to annual effective doses of 30 and 70 μSv, respectively		Use in manufacture of cement and concrete, as a road stabilizer

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
OTHER FORMS OF ENERGY PRODUCTION					
Oil			Data and method referenced to [U5]	2×10^9 kg oil assumed needed to generate 1 GW a of electricity. Estimated discharge to generate 1 GW a derived from information on plants in France. When normalized to electricity generated, levels similar to discharges from coal-fired plants with efficient aerosol capture. Collective effective dose equivalent 0.5 man Sv/(GW a)	
Peat			Data from [U5] cited; no estimate of worldwide impact made owing to lack of information on worldwide production	Finland and Sweden process; average ^{238}U concentration in peat of 40 Bq/kg and dust control efficiency of 99% assumed (together with general assumptions applied for coal fired power stations) and 5×10^9 kg of peat needed to produce 1 GW a; collective effective dose commitment: 2 man Sv/ (GW a). No assessment of total collective dose	
Natural gas			Data from [U5] cited	Typical value for radon concentrations in natural gas taken to be 1,000 Bq/m^3. 2×10^9 m^3 natural gas required to produce 1 GW a of electrical energy, radon emission 2 TBq, corresponding to 0.03 man Sv/(GW a). Assuming 15% world production of natural gas (10^{12} m^3) used for electrical power, collective effective dose equivalent is 3 man Sv	

Factor	*UNSCEAR 2008 Report [U9]*	*UNSCEAR 2000 Report [U7]*	*UNSCEAR 1993 Report [U6]*	*UNSCEAR 1988 Report [U5]*	*UNSCEAR 1982 Report [U4]*
Geothermal energy			Data from [U5] cited	Additional plant data available suggesting atmospheric discharge of around 150 TBq/(GW a)	Annual release of radon estimated based on literature survey. Data from Italian plants suggest average atmospheric discharge of ^{222}Rn of 400 TBq/(GW a). Resulting collective effective dose equivalent commitment 6 man Sv/(GW a). Individual effective dose: 30 μSv to critical group living at 1 km from geothermal plant of 1 GW (100 m stack height)
Environmental levels and doses				Equilibrium factor between radon and short-lived progeny 0.8	Equilibrium factor between radon and short-lived progeny 0.6
Inhalation dose				Effective dose equivalent per unit activity of radon inhaled 1.1×10^{-8} Sv/Bq	No decay assumed; calculation based on integrated atmospheric concentration at ground level[a] Dose from ^{222}Rn and short-lived progeny compared with natural emanation rate[b]
Dose from deposition					Evaluated from comparison with natural soil activity concentrations and annual absorbed doses in tissues from naturally occurring radionuclides. Deposited activity assumed to have mean life of 100 years and upper 30 cm involved in uptake.[c] Deposition on vegetation and foods not taken into account

[a] Collective dose commitment from inhalation is given by:

$M^c_q = A_0/v_d S \times S\delta_N B \times D_q/I_{ih}$

$A_0/v_d S$ is the integrated atmospheric concentration at ground level (Bq s/m^3); S is the area in which deposition occurs, δ_N is the population distribution (10^{-4} m^{-2}); B adult breathing rate (2.3×10^{-4} m^3/s) and D_q/I_{ih} is the committed absorbed dose to organ or tissue q per unit activity inhaled. A quality factor of 20 for α particles assumed. 80% assumed insoluble in line with ICRP [I6].

[b] Collective dose commitment from inhalation of ^{222}Rn and short-lived progeny:

$M^c_q = A_0/S \times 1.8$ (Bq/m^3)/2 10^{-2} (Bq/m^2/s) $S\delta_N B \times D_q/I_{ih}$

Equilibrium factor between ^{222}Rn and progeny 0.6; average outdoor equilibrium equivalent concentration: 1.8 Bq/m^3; average emanation rate of ^{222}Rn 2×10^{-2} Bq/m^2/s.

[c] Collective dose commitment from deposited material:

$M^c_q = A_0 D_q \delta N \tau/hC$

D_q is the natural dose rate in organ q; δ_N is the population density; τ is the mean life in soil (100 years); h is the thickness of soil expressed as mass per unit area (assumed to be 500 kg/m^2) and C is the natural concentration of the radionuclide in soil.

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