Table 2
Epidemiological studies of the effects of exposures to low-LET radiation

Study	*Type of study*	*Population studied*		*Follow-up (years)*	*Total person years* [a]	*Type of exposure*	*Type of dosimetry*	*Cancers studied* [b]
		Characteristics	*National origin*					
HIGH-DOSE-RATE EXPOSURES								
Exposure to atomic bombings								
Life span study [S7, R23]	Mortality	39,593 exposed persons 46,716 unexposed persons 55.5% females Age: 0->90 (29.0) [c]	Japan	47 (maximum)	2,185,335 (28.8) [d]	Gamma and neutron radiation from nuclear explosions	Individual estimates derived from detailed shielding histories	Leukaemia,* lymphoma, myeloma, oral cavity, oesophagus,* stomach,* colon,* rectum, liver,* gall-bladder, pancreas, lung,* female breast,* uterus, ovary,* prostate, bladder,* central nervous system
Life span study [T15, P33]	Incidence	37,270 exposed persons 42,702 unexposed persons 55.5% females Age: 0->90 (26.8)	Japan	42 (maximum)	1,950,567 (24.4) [c]	Gamma and neutron radiation from nuclear explosions	Individual estimates derived from detailed shielding histories	Leukaemia,* non-Hodgkins lymphoma,* myeloma, oral cavity, salivary gland,* oesophagus, stomach,* colon,* rectum, liver,* gall-bladder, pancreas, lung,* female breast,* non-melanoma skin,* uterus, ovary,* prostate, bladder,* central nervous system, thyroid*
Treatment of malignant disease								
Cervical cancer [B11]	Incidence	82,616 exposed women 99,424 unexposed women Age: <30->70 (26.8)	Canada, Denmark Finland, Norway, Sweden, United Kingdom, United States, Yugoslavia	0->30	1,278,950 (7.0)	Radiotherapy, including external beam and intra-cavity application and experimental reconstruction	Data on typical range of estimates for specific organs and phantom measurements	Oral cavity, salivary gland, oesophagus,* stomach, small intestine,* colon, rectum,* liver, gall-bladder, pancreas,* lung, breast, uterus, other genital,* kidney, bladder, melanoma, other skin tumours, bone, connective tissue, leukaemia (non-CLL),* myeloma, lymphoma
Cervical cancer [B21]	Case-control 4,188 cases 6,880 controls	10,286 exposed women 782 unexposed women Age: <30->70 (26.8)	Austria, Canada, Czechoslovakia, Denmark, Finland, Germany, Iceland, Italy, Norway, Sweden	0->30 (7.0 years per case)	n.a.	Radiotherapy, including external beam and intra-cavity application and experimental reconstruction	Individual doses from therapy records	Stomach,* pancreas, small intestine, colon, rectum,* breast, uterine corpus,* vagina,* ovary, vulva, bladder,* bone,* connective tissue, leukaemia (non-CLL),* myeloma, lymphoma, thyroid
Breast cancer [B18]	Case-control 655 cases 1,189 controls from a cohort of 41,109 women	449 exposed women 1,395 unexposed women Age: <45->60 (51)	United States	7-55 (~13 years per case)	n.a.	Radiotherapy	Individual doses from therapy records and experimental measurements	Contralateral breast among women less than 45 years old at exposure,* contralateral breast in older women

Table 2 (continued)

Study	*Type of study*	*Population studied*		*Follow-up (years)*	*Total person years* [a]	*Type of exposure*	*Type of dosimetry*	*Cancers studied* [b]
		Characteristics	*National origin*					
Breast cancer [S60]	Case-control 529 cases 529 controls from a cohort of 56,540 women	157 exposed women 901 unexposed women Age: <45->60 (51)	Denmark	12-47 (~16 years per case)	n.a.	Radiotherapy	Individual doses from therapy records and experimental measurements	Contralateral breast
Breast cancer [C24]	Case-control 90 cases 264 controls from a cohort of 82,700 women	110 exposed women 244 unexposed women Age: <50->70 (61)	United States	<12 (~5 years per case)	n.a.	Adjuvant radiotherapy	Individual doses from therapy records and experimental measurements	Acute non-lymphocytic leukaemia and myelodysplasia syndrome*
Childhood cancers [T5, T6, T7]	Case-control within 9,170-member cohort	112 exposed persons [f] 388 unexposed persons 45% females Age: 0-18 (7)	Canada, France, Netherlands, Italy, United Kingdom, United States	5-48	50,609 (5.5)	Adjuvant radiotherapy	Individual doses from therapy records and experimental measurements	Thyroid,* leukaemia, bone sarcomas*
Treatment of benign disease								
Childhood skin haemangioma [F12, F15]	Case-control within 14,467-member cohort	144 exposed persons [g] 314 unexposed persons 67% females Age: 0-1.5 (0.6)	Sweden	25-64	n.a.	Radiotherapy	Average doses based on experimental measurements with age adjustment	Thyroid,* brain,* bone and soft tissue, breast
Ankylosing spondylitis [D6]	Mortality	14,106 exposed persons [h] 16.5% females Age: 20-60	United Kingdom	<3->50	183,749 (13.0)	X-ray therapy	Average doses based on information from a 1 in 15 sample	Leukaemia,* other neoplasms (except colon)*
Tinea capitis [M20, R5, R10, R15]	Incidence / mortality	10,834 exposed persons 16,226 unexposed persons 50% females Age: <1-15 (7.1)	Israel	26-38	686,210 (25.3) [d]	X-ray-induced epilation	Individual doses from phantom measurements based on institution and age	Incidence: thyroid,* skin,* brain,* salivary gland,* breast Mortality: head and neck,* leukaemia
New York tinea capitis [A1, S8, S61]	Incidence	2,226 exposed persons 1,387 unexposed persons 16.1% females Age: 1-19 (7.7)	United States	20-39	98,881 (25.4)	X-ray-induced epilation	Representative doses based on standard treatment	Thyroid,* skin,* brain, leukaemia, salivary gland
New York acute post-partum mastitis [S9]	Incidence	571 exposed women 993 unexposed women Age: 14->40 (27.8)	United States	20-35	38,784 (25.1)	X-ray therapy	Individual doses from therapy records	Breast*

Table 2 (continued)

Study	*Type of study*	*Population studied*		*Follow-up (years)*	*Total person years* [a]	*Type of exposure*	*Type of dosimetry*	*Cancers studied* [b]
		Characteristics	*National origin*					
Rochester thymic irradiation [H22, S10]	Incidence	2,652 exposed persons 4,823 unexposed persons 42% females Age: 0-1	United States	23->50	220,777 (29.5)	X-ray therapy	Individual doses from therapy records	Thyroid,* breast,* skin
Swedish benign breast disease [M8]	Incidence	1,216 exposed women 1,874 unexposed women Age: 10->85	Sweden	5-60	56,900 (18)	X-ray therapy	Individual doses from therapy records and phantom measurements	Breast*
Metropathia haemorrhagica [D23]	Mortality	2,067 exposed women Age: 35-60	United Kingdom	5->30	53,144	X-ray therapy	Individual doses from therapy records and phantom measurements	Pelvic sites,* leukaemia, multiple myeloma,* lymphoma, all other sites
Benign gynaecological disease [17, 18, 112]	Mortality	4,153 exposed women Age at exposure: 13-88 (46.6)	United States	0-60	109,910 (26.5)	Intra-uterine ^{226}Ra	Individual doses from therapy records and phantom measurements	Leukaemia,* other haematolymphopoietic cancers, uterus,* bladder,* rectum,* other genital,* colon, bone (in pelvis), liver and gall-bladder, stomach, kidney, pancreas*
Peptic ulcer [G11]	Mortality	1,831 exposed persons 1,778 unexposed persons 21.2% females Mean age: 49	United States	20-48	77,757 (21.5)	X-ray therapy	Individual doses from therapy records and experimental measurements	Stomach,* colon, pancreas,* lung,* leukaemia,* female breast,* oesophagus, rectum, liver, larynx, bone and connective tissue, bladder, kidney, brain, thyroid, non-Hodgkin's lymphoma,* myeloma
Diagnostic examinations								
Massachusetts TB fluoroscopy [B31]	Incidence	2,367 exposed women 2,427 unexposed women Age: 12-50 (26)	United States	0->50	54,609 (11.4)	Multiple chest fluoroscopies	Individual exposures from medical records and doses from phantom measurements and computer simulations	Breast*
Massachusetts TB fluoroscopy [D14]	Mortality	6,285 exposed persons 7,100 unexposed persons 49% females Age: 12-50 (26)	United States	0->50	331,206 (24.7)	Multiple chest fluoroscopies	Individual exposures from medical records and doses from phantom measurements and computer simulations	Breast,* oesophagus,* lung, leukaemia
Canadian TB fluoroscopy [M19]	Mortality	18,940 exposed women 12,800 unexposed women	Canada	28-50	773,400 (24.4)	Multiple chest fluoroscopies	Individual exposures from medical records and doses from phantom measurements	Breast*

Table 2 (continued)

Study	*Type of study*	*Population studied*		*Follow-up (years)*	*Total person years* [a]	*Type of exposure*	*Type of dosimetry*	*Cancers studied* [b]
		Characteristics	*National origin*					
Scoliosis [H24]	Incidence	973 exposed women Age: <5-20 (12.3)	United States	3->30	21,691 (25.3)	Diagnostic x rays	Average dose based on number of treatments and estimated doses from published literature	Breast*
LOW-DOSE OR LOW-DOSE-RATE EXPOSURES								
Prenatal exposures								
Oxford survey of childhood cancers [M22, B22]	Case-control 14,491 cases 14,491 controls	3,797 exposed persons 25,185 unexposed persons 56% females Exposure: *in utero*	United Kingdom	20 (maximum)	n.a.	Maternal x rays during pregnancy	Number of exposures with a model for dose per exposure [B23]	Leukaemia,* lymphoma,* Wilms' tumour,* tumours of the central nervous system,* neuroblastoma,* bone, other solid tumours,* all solid tumours*
Childhood cancers [M9]	Case-control 1,342 cases 14,294 controls	1,506 exposed persons 14,130 unexposed persons 49.2% females Exposure: *in utero*	United States	20 (maximum)	n.a.	Maternal x rays during pregnancy	Number of exposures	Leukaemia,* solid tumours
Survivors of atomic bombings [Y3]	Cohort	816 exposed persons 814 unexposed persons 53.1% females Exposure: *in utero*	Japan	39	50,811 (31.2) [d]	Maternal exposure to gamma and neutron radiation at high dose rate	Mother's estimated uterus dose	All cancer*
Occupational exposures								
United Kingdom workers registry [K20, K21]	Cohort	95,217 exposed persons 8.1% females	United Kingdom	4-40	1,218,000 (12.8)	Exposure in nuclear power plant and weapons production	Recorded exposures to external radiation	Leukaemia, all cancer
Sellafield [S14]	Cohort	14,000 subjects 19% females	United Kingdom	1-28 (22)	303,547	Fuel processing and reactor operation	Recorded exposures to external radiation	Leukaemia, all cancer
United Kingdom Atomic Energy Authority [F11]	Cohort	21,545 subjects 8% females	United Kingdom	1-42 (23)	473,990	Nuclear and reactor research and fuel processing	Recorded exposures to external radiation	Leukaemia, all cancer
United Kingdom Atomic Weapons Establishment [B5]	Cohort	9,389 subjects 9% females	United Kingdom	1-37 (18.3)	172,000	Weapons research	Recorded exposures to external radiation	Leukaemia, all cancer

Table 2 (continued)

Study	*Type of study*	*Population studied*		*Follow-up (years)*	*Total person years* [a]	*Type of exposure*	*Type of dosimetry*	*Cancers studied* [b]
		Characteristics	*National origin*					
Atomic Energy of Canada Ltd. [G3, H45]	Cohort	8,977 subjects 0% females	Canada	1-29	157,101	Nuclear and reactor research and related technologies	Recorded exposures to external radiation	Leukaemia, all cancer
Hanford [G16, G17]	Cohort	23,704 exposed men 0% females	United States (whites)	1-37	492,326 (20.8)	Exposures in nuclear fuel cycle and research	Recorded exposures to external radiation	Leukaemia, all cancer
Oak Ridge National Laboratory [G9, G17, W21]	Cohort	6,332 exposed men 0% females	United States (whites)	1-34	130,428 (20.6)	Exposures in nuclear fuel cycle and research	Recorded exposures to external radiation	Leukaemia, all cancer
Rocky Flats [G17, W7]	Cohort	5,897 exposed men 0% females	United States (whites)	1-28	82,721 (14.0)	Exposures in nuclear fuel cycle and research	Recorded exposures to external radiation	Leukaemia, all cancer
Chelyabinsk [B27]	Cohort	5,086 exposed men 0% females	Former USSR	35-40	167,790	Exposures in nuclear fuel cycle and research	Recorded exposures to external radiation	Leukaemia, all cancer
Environmental exposures								
Techa River [K18]	Incidence/ mortality	28,000 exposed persons 394,000 unexposed persons [i] 56% females 0-90 years	Former USSR (ethnic Russians and Tartar/Bashkirs	30	422,000 (15.7) [i]	Internal and external exposures to radioactive waste discharged by nuclear weapons production plant	Rough estimates of average doses based on preliminary dose reconstruction efforts and recent measurements of internal doses	Leukaemia,* other cancers
China background radiation, thyroid [W17]	Prevalence	1,001 high background 1,005 low background 100% females Age: 50-65	China	> 50	n.a.	Higher levels of natural background radiation	TLD, area and personal monitors	Thyroid (nodules)
International Chernobyl project [I3, M21]	Prevalence	853 contaminated areas 813 uncontaminated areas Age: fetal to >50	Former USSR	n.a.	n.a.	Releases and environmental contamination from power plant	Estimates of average dose by village	Thyroid (nodules)
Radionuclides exposures: iodine								
Swedish therapeutic ^{131}I [H12, H27]	Incidence	10,552 exposed persons 82% females Age: 13-70	Sweden	8-33	139,018 (13.6)	Treatment of hyperthyroidism	Average administered activity (multiple treatments)	Stomach,* kidney,* brain,* all other sites

Table 2 (continued)

Study	*Type of study*	*Population studied*		*Follow-up (years)*	*Total person years* [a]	*Type of exposure*	*Type of dosimetry*	*Cancers studied* [b]
		Characteristics	*National origin*					
United States thyrotoxicosis [D9, S2]	Incidence	21,740 exposed persons 12,148 unexposed persons 79% females Age: <10-80	United States	0-30	271,000 (8)	Treatment of hyperthyroidism	None	Leukaemia, thyroid
Marshall Islands fallout [H28, R21]	Prevalence	2,273 exposed persons 55% females Age: 5->60	Marshall Islands	29-31	n.a.	Short-lived radionuclides from nuclear explosion	Estimated average dose; distance was also used as surrogate	Thyroid
Utah ^{131}I fallout [R12, S48, S49]	Case-control	1,177 cases 5,330 controls	United States	up to 23	n.a.	Fallout from nuclear weapons tests	Based on residence histories and fallout deposition records	Leukaemia

[a] Mean per person in parentheses.
[b] An asterisk denotes sites for which statistically significant excesses are reported in the exposed group (cohort studies) or for which a higher proportion of the cases were exposed to radiation (case-control studies).
[c] Age at exposure, mean in parentheses.
[d] Excludes first five years.
[e] Excludes first 13 years.
[f] The distribution of patients is as follows: thyroid: 23 and 89; leukaemia: 25 and 90; bone sarcomas: 64 and 209 for exposed and unexposed persons, respectively.
[g] The distribution of patients is as follows: thyroid: 24 and 43; brain: 31 and 51; bone: 9 and 30; breast: 80 and 190 for exposed and unexposed persons, respectively.
[h] In the ankylosing spondylitis sample, 53% (7,431 persons) were censored 18 months after a second course of treatment. Persons in this group have an average of 3.5 years of follow-up. For the remaining 47% (6,675 persons), the average follow-up is 23.6 years.
[i] The control population in this study consists of the remaining population of unexposed areas near the contaminated zone. It is not a fixed cohort.
[j] Exposed group only.

Table 3
Strengths and limitations of major epidemiological studies of carcinogenic effects of radiation

Study	*Strengths*	*Weaknesses*
Exposures to atomic bombings		
Life span study [P33, R23, S7, T15]	Large population of all ages and both sexes not selected because of disease or occupation; Wide range of doses; Comprehensive individual dosimetry; Survivors followed prospectively for more than 40 years; Complete mortality ascertainment; Cancer incidence ascertainment	Acute, high-dose-rate exposure that provides no direct information on effects of gradual, low-dose-rate exposures; Restriction to 5-year survivors for mortality (13-year survivors for incidence); Possible contribution of neutrons somewhat uncertain; Possible effects of thermal or mechanical injury and conditions following the bombings uncertain
Treatment of malignant disease		
Cervical cancer cohort [B11]	Large-scale incidence study based on tumour registry records; Long-term follow-up; Relatively complete ascertainment of cancers; Non-exposed comparison patients	Very large doses to some organs result in cell-killing and tissue damage; Potential misclassification of metastatic disease for some organs; Potential misclassification of exposure; No individual dosimetry; Characteristics of patients with cervical cancer differ from general population
Cervical cancer case-control [B21]	Comprehensive individual dosimetry for many organs; Dose-response analyses; Other strengths as above [B8, B11]	As above [B11], except problem with individual dosimetry and comparisons with general population now removed; Small number of non-exposed cases; Partial-body and partial-organ dosimetry complex
Contralateral breast cancer [B18, S60]	Large numbers of incident cases within population-based tumour registries; Individual radiation dosimetry; Wide range of high doses	Limited number of young women; Possibility of overmatching resulting in some concordance of exposure between cases and controls; Potential misclassification of metastases or recurrence
Breast cancer, adjuvant radiotherapy [C24]	Comprehensive individual dosimetry for bone marrow compartments; Comprehensive ascertainment of treatment information to separate chemotherapy risk; Dose-response analyses	Very large high-dose partial-body exposure to chest wall probably resulting in cell-killing
Childhood cancers [T5, T6, T7]	Comprehensive individual dosimetry to estimate organ doses; Attempt to adjust for drug exposure; Dose-response analyses	Only high-dose exposures; Potential for some overmatching since hospital-based; Complete dosimetry not always available
Treatment of benign disease		
Childhood skin haemangioma [F12, F15]	Long-term and complete follow-up; Dosimetry for some cases and controls; Incidence ascertained; Protracted exposure to radium plaques	Relatively limited range of doses to most sites; Relatively small number of specific cancers
Ankylosing spondylitis [D6]	Large number of exposed; Long-term and complete mortality follow-up; Detailed dosimetry for leukaemia cases and sample of cohort; Small non-exposed groups evaluated for general assurance that leukaemia risk was unrelated to underlying disease	Comparisons with general population; Underlying disease related to colon cancer and possibly other conditions; Individual dose estimates available only for leukaemia cases and a 1 in 15 sample of the population
Israeli tinea capitis [M20, R5, R10, R15]	Large number exposed; Two control groups; Ascertainment of cancer from hospital records and tumour registry; Individual dosimetry for many organs	Dosimetry for some sites, e.g. thyroid, uncertain due to possible patient movement or uncertainty in tumour location; Limited dose range
New York tinea capitis [A1, S8, S61]	Relatively good dose assessment for skin and other cancers	Small number of cancers; No recent follow-up information; few females
New York acute post-partum mastitis [S9]	Individual estimates of breast dose from medical records; Incidence ascertained; Dose-response analyses	All exposed women were parous but comparison women were not (380 non-exposed and sisters of both exposed and non-exposed); Inflamed and lactating breast might modify radiation effect

Table 3 (continued)

Study	*Strengths*	*Weaknesses*
Rochester thymic irradiation [H22, S10]	Individual dosimetry for thyroid and some other sites; Sibling control group; Long follow-up; Fractionation effects could be evaluated; Dose-response analyses	Radiation treatment fields on newborns varied and dosimetry for some sites uncertain; Adjustment in analysis for sibship size uncertain; Questionnaire follow-up may have resulted in unascertained cases
Benign gynaecological disease [D23, I7, I8, I12]	Large number of exposed; Non-exposed women with benign gynaecological disease; Very long mortality follow-up; Individual dosimetry; Protracted exposure to radium implants (10-24 hours); Dose-response analyses	Uncertainty in proportion of active bone-marrow-exposed; Small numbers of certain cancers; Misclassification of certain cancers on death certificates, such as pancreas
Peptic ulcer [G11]	Individual dosimetry; Non-exposed patients with peptic ulcer; Exceptionally long follow-up (50 years); Some risk factor information available in records	Standardized radiotherapy precluded dose-response analyses; Non-homogeneous dose distribution within organs such that simple averaging might be misleading; Metastatic spread of stomach cancer was probably misclassified as liver and pancreatic cancer on death certificates; Possible selection of somewhat unfit patients for radiotherapy rather than surgery
Diagnostic examinations		
Massachusetts TB fluoroscopy [B31, B41, D14]	Incidence study with long-term follow-up (50 years); Individual dosimetry based on patient records and measurements; Non-exposed TB patients; Fractionated exposures occurred over many years; Dose-response analyses	Uncertainty in dose estimates related to fluoroscopic exposure time and patient orientation; Questionnaire response probably underascertained cancers; Debilitating effect of TB may have modified radiation effect for some sites, in particular the lung
Canadian TB fluoroscopy [M19]	Large numbers; Non-exposed TB comparison groups; Individual dosimetry for breast; Fractionated exposure over many years; Dose-response analyses	Mortality limits comparisons with incidence series, e.g. time response; Uncertainties in dosimetry limit precise quantification of risk; Different dose response for one sanatorium and rest of Canada may indicate errors in dosimetry, differential ascertainment of cancers, or biological response
Scoliosis [H24]	Adolescence possibly a vulnerable age for exposure; Dosimetry attempted based on number of films and breast exposure; Dose response attempted	Comparison with general population potentially misleading since disease associated with several breast cancer risk factors, such as nulliparity; Small numbers (11 cancers) compared with 6 expected; One cancer detected incidentally during special screening
Prenatal exposures		
Oxford survey of childhood cancers [B23, M22, S37, S52]	Very large numbers; Comprehensive evaluation of potential confounding; Early concerns over response bias and selection bias resolved	Uncertainty in fetal dose from obstetric x-ray examinations precludes precise estimate of radiation risk; Similar relative risks for leukaemia and other solid cancers may point to possible residual confounding
New England childhood cancer [M9]	Large numbers; Reliance on obstetric records to determine exposure	Uncertainty in fetal dose precludes precise estimate of radiation risk
Twin studies [H3, I15, M23, M32, R13, R16]	Higher proportion of twins than singletons received obstetric x-ray examinations for reasons unlikely to be due to maternal illness	Small number of cancers in general; Uncertainty in fetal dose precludes radiation risk estimate; For cohort studies, actual proportion exposed and comparisons with single births add uncertainty
Survivors of atomic bombings [Y1, Y2, Y3]	Not selected for exposure; Reasonably accurate estimate of dose; Mortality follow-up relatively complete; Follow-up until early adulthood	Small number of exposed individuals and small number of cases; Incidence determination may not be complete; Mechanical and thermal effects may have influenced results
Radionuclide exposures: iodine		
Diagnostic ^{131}I [H12, H27]	Large numbers; Nearly complete ascertainment of cancers through linkage with cancer registry; Administered activities of ^{131}I known for each patient; Low-dose-rate exposure	Comparison with general population; Reason for some examinations related to high detection of thyroid cancers, i.e. suspicion of thyroid tumour was often correct; Doses to organs other than thyroid very low; Population under surveillance

Table 3 (continued)

Study	*Strengths*	*Weaknesses*
United States thyrotoxicosis [D9, S2]	Large numbers of patients treated with ^{131}I; Large non-exposed comparison groups; Comprehensive follow-up effort	Individual radiation dose not computed; Short follow-up, not recent Only leukaemia and thyroid tumours evaluated
Swedish ^{131}I hyperthyroid [H40]	Large numbers; Nearly complete incidence ascertainment; Administered activities of ^{131}I known; Low-dose-rate exposure	Comparison with general population; Dose response not based on organ doses; High-dose cell-killing probably reduced possible thyroid effect; Patients selection for treatment
Marshall Islands fallout [H28, R21]	Population unselected for exposure; Comprehensive medical long-term follow-up; Individual dosimetry attempted	Mixture of radioiodines and gamma fields preclude accurate estimate of dose; Surgery and hormonal therapy probably influence subsequent occurrence of thyroid neoplasms; Small numbers
Utah ^{131}I fallout [R12, S48, S49]	Clinical examinations for thyroid cancer; Comprehensive dosimetry assessment attempted; Large number of leukaemia deaths; Protracted exposures at low rate	Great uncertainty in accurately estimating dose to thyroid and bone marrow; Estimated cumulative doses much lower than experienced from natural background radiation; Possible recall and surveillance bias
Environmental exposures		
Techa River [K18]	Large numbers exposed with relatively long follow-up; A wide range of estimated doses; Unselected population, attempted use of local population rates for comparison; Possibility to evaluate ethnic differences in cancer risk; Shows great potential for future studies	Dosimetry difficult and not individual; Quality of mixture of internal and external exposures complicates dosimetry Follow-up and cancer ascertainment uncertain; Contribution of chemical exposures unevaluated
China background radiation, thyroid [W17]	Blind clinical examinations of exposed and non-exposed; Lifetime exposure to low doses at low dose rate; Blood studies to confirm exposure; Extensive dosimetry for region; Stable population; Low prevalence of x-ray exposure; High participation rate; Assessment of possible confounders	Approximately one third of life-span exposed as children; Factors other than radiation levels existed that could not be evaluated; High prevalence of a mild goiter might have hindered detection of thyroid nodules; Doses very low
International Chernobyl project [I3, M21]	Dosimetry assessment for highly contaminated and control villages; Physical examination for thyroid nodules disease using ultrasound	Limited follow-up after accident (4.5 years) precluded detection of possible risk; Precise dosimetry uncertain Small sample size
Occupational exposures		
Nuclear workers [B27, D10, G16, G17, K20]	Often large numbers; Personnel dosimetry; Low-dose fractionated exposures; Could provide useful information in future	Doses so low that clear demonstration of radiation effect difficult; Possibly confounding influence of chemical, asbestos and other toxic exposures in workplace; Healthy worker effect; Mortality follow-up; Lifestyle factors, such as smoking histories, not available
Medical workers [A9, B39, E7, M24, S38, W14]	Often large numbers; Low-dose fractionated exposures over very long periods	Lack of information on individual doses precludes usefulness to date

Table 4
Comparison of incidence and mortality data for solid tumours in Life Span Study of survivors of the atomic bombings
[T15]

Cancer type	*Number of incident cases 1958-1987*	*Number of deaths 1950-1987* [a]
Oral cavity and pharynx	132	79
Digestive system		
Oesophagus	185	211
Stomach	2658	2365
Colon	457	277
Rectum	351	273
Liver	585	761
Gall-bladder	295	187
Pancreas	240	243
Other	26	91
Total	4797	4408
Respiratory system		
Nasal cavity	55	51
Larynx	80	52
Trachea, bronchus, lung	872	816
Other	20	22
Total	1027	941
Skin		
Melanoma	13	8
Other skin	168	28
Total	181	36
Female breast	529	186
Female genital		
Uterus, not otherwise specified	86	315
Cervix uteri	553	110
Uterine corpus	85	15
Ovary	133	104
Other	34	31
Total	891	575
Male genital		
Prostate	140	69
Other	20	6
Total	160	75
Urinary system		
Bladder	210	104
Kidney	73	45
Renal pelvis and ureter	28	4
Other	14	3
Total	325	156
Nervous system	125	75
Thyroid	225	49
Other and ill-defined sites	221	307
Total	8,613	6,887

[a] In some cases the number of deaths exceeds the number of incident cases. There are various reasons for this. First, the mortality follow-up is more than seven years longer than the follow-up for the incidence data. Secondly, for some sites, e.g. the liver and the pancreas, death certificate diagnosis is poor. For other, e.g. the uterus, no detail is provided.

Table 5
Summary risk estimates for solid tumours derived from data on survivors of the atomic bombings [a]

Cancer type	Cancer mortality [S7] [b] 1950-1985		Cancer mortality [R23] [c] 1950-1987		Cancer incidence [T15] [c] 1958-1987	
	Excess relative risk (Sv^{-1})	Excess absolute risk (10^4 PYSv)$^{-1}$	Excess relative risk (Sv^{-1})	Excess absolute risk (10^4 PYSv)$^{-1}$	Excess relative risk (Sv^{-1})	Excess absolute risk (10^4 PYSv)$^{-1}$
Salivary gland	Not reported	Not reported	Not reported	Not reported	1.8 (0.2-6.0)	Not reported
Oral cavity	Not reported [d]	Not reported [d]	-0.2 (<0-0.3)	-0.1 (<0-0.1)	0.3 (<0-0.9)	0.2 (<0-0.7)
Digestive system	0.3 (0.2-0.4) [e]	4.0 (2.7-5.4) [e]	0.3 (0.2-0.5)	5.1 (3.0-7.3)	0.4 (0.3-0.5)	10.4 (7.0-14.0)
Oesophagus	0.6 (0.1-1.2)	0.5 (0.1-0.9)	0.6 (0.09-1.3)	0.5 (0.07-0.9)	0.3 (<0-1.0)	0.3 (<0-1.0)
Stomach	0.3 (0.1-0.4)	2.4 (0.5-3.5)	0.2 (0.1-0.4)	1.9 (0.5-3.5)	0.3 (0.2-0.5)	4.8 (2.5-7.4)
Colon	0.9 (0.4-1.5)	0.8 (0.4-1.3)	0.5 (0.1-1.2)	0.5 (0.06-1.1)	0.7 (0.3-1.3)	1.8 (0.7-3.0)
Rectum	-0.09 (<-0.2-0.4)	-0.1 (<-0.2-0.6)	0.1 (<-0.2-0.6)	0.1 (<-0.3-0.6)	0.2 (-0.2-0.8)	0.4 (-0.4-1.5)
Liver	0.1 (<-0.2-0.7) [f]	0.2 (<-0.2-0.5) [f]	0.5 (0.2-0.8) [h]	1.3 (0.5-2.2) [h]	0.5 (0.2-0.9)	1.6 (0.5-2.9)
Gall-bladder	0.5 (-0.1-1.6)	0.3 (-0.03-0.7)	0.3 (-0.1-1.0)	0.2 (-0.07-0.6)	0.1 (<0.2-0.7)	0.2 (<-0.4-1.1)
Pancreas	-0.2 (<-0.2-0.4)	-0.1 (<-0.2-0.3)	-0.2 (<-0.2-0.2)	-0.2 (<-0.3-0.2)	0.2 (<-0.2-0.8)	0.2 (<-0.4-1.1)
Respiratory system	1.9 (0.3-0.9) [e]	1.8 (1.0-2.7) [e]	0.6 (0.3-0.9)	2.0 (1.1-3.0)	0.8 (0.5-1.2)	4.4 (2.9-6.1)
Lung	0.6 (0.3-1.0)	1.7 (1.0-2.5)	0.7 (0.3-1.0)	1.9 (1.0-2.9)	1.0 (0.6-1.4)	4.4 (2.9-6.0)
Non-melanoma skin	0.2 (<-0.2-2.5)	0.0 (<-0.2-0.12)	0.31 (<-0.1-1.5)	0.03 (<0-0.1)	1.0 (0.4-1.9)	0.8 (0.4-1.4)
Female breast	1.2 (0.6-2.1) [e]	1.2 (0.6-1.9) [e]	1.3 (0.6-2.1)	1.3 (0.6-2.1)	1.6 (1.1-2.2)	6.7 (4.9-8.7)
Uterus	0.4 (0.02-0.8)	1.0 (0.07-2.1)	0.1 (<-0.2-0.6)	0.3 (<-0.5-1.4)	-0.2 (-0.3-0.1)	-1.1 (-1.9-0.7)
Ovary	1.3 (0.5-2.3) [e]	0.7 (0.2-1.3) [e]	1.2 (0.2-2.8)	0.7 (0.1-1.4)	1.0 (0.2-2.3)	1.1 (0.2-2.3)
Prostate	0.1 (<-0.2-0.9) [e]	0.0 (<-0.2-0.5) [e]	0.3 (-0.2-1.6)	0.2 (-0.1-0.9)	0.3 (-0.1-1.2)	0.6 (-0.3-2.2)
Urinary tract	1.3 (0.5-2.4)	0.7 (0.3-1.1)	1.3 (0.4-2.6)	0.7 (0.2-1.2)	1.2 (0.6-2.1)	2.1 (1.1-3.2)
Urinary bladder	1.4 (0.5-2.9) [e]	0.5 (0.2-0.9) [e]	1.5 (0.3-3.3)	0.5 (0.1-0.9)	1.0 (0.3-2.1)	1.2 (0.3-2.1)
Brain and CNS	Not reported [g]	Not reported [g]	0.4 (-0.1-2.0)	0.1 (-0.04-0.5)	0.3 (-0.1-1.3)	0.2 (-0.1-0.8)
Thyroid	Not reported	Not reported	0.094 (<-0.1-1.4)	0.016 (<-0.03-0.2)	1.2 (0.5-2.1)	1.6 (0.8-2.5)
All solid tumours	0.40 (0.3-0.5)	10.1 (7.8-12.4)	0.45 (0.3- 0.6)	11.1 (8.4-14.0)	0.63 (0.52-0.74)	29.7 (25-34)

[a] 90% CI given in parentheses.
[b] Based on organ-absorbed dose (neutron RBE = 1).
[c] Based on weighted dose in the organ (neutron RBE = 10).
[d] Shielded-kerma-based excess relative risk and excess absolute risk estimates for cancers of the nose (-0.2 and -0.03, respectively), larynx (0.5 and 0.1), and pharynx (-0.4 and -0.02), and tongue (-0.6 and -0.02) are presented in [S7].
[e] Values derived from shielded-kerma risk estimates in [S7].
[f] Based on cases explicitly coded as primary on the death certificates; excludes cases not explicitly coded as primary or secondary. Inclusion of such cases leads to an ERR estimate of 0.46 (0.2-0.8).
[g] Shielded kerma-based excess relative risk and excess absolute risk estimates for malignant brain tumours (0.03 and 0.01, respectively) and other CNS tumours (2.1 and 0.1) are presented in [S7].
[h] Includes liver cancer deaths specified as primary and also those specified as either primary or secondary.

Table 6
Summary risk estimates for lympho-haematopoietic tumours derived from data on survivors of the atomic bombings

Cancer type	Cancer mortality 1950-1985 [S7] [a]		Cancer incidence 1950-1987 [P33] [b]	
	Excess relative risk (Sv^{-1})	Excess absolute risk (10^4 PYSv)$^{-1}$	Excess relative risk (Sv^{-1})	Excess absolute risk (10^4 PYSv)$^{-1}$
Leukaemia	5.2 (3.8-7.1)	2.9 (2.4-3.5)	4.4 (3.2-5.5)	2.7 (2.2-3.2)
Lymphomas	-0.1 (<0-0.5) [c]	0.0 (<0-0.2) [c]	-0.1 (<0-0.7) [d]	-0.1 (<0-0.5) [d]
Multiple myeloma	2.3 (1.7-6.3)	0.3 (0.1-0.5)	0.4 (<0-1.7)	0.1 (<0-0.4)

[a] Based on organ-absorbed dose (neutron RBE = 1).
[b] Based on weighted dose in the organ (neutron RBE = 10). Estimates derived from summary tables in [P33].
[c] Values derived from shielded-kerma risk estimates in [S7]. Includes both Hodgkin's and non-Hodgkin's cases.
[d] Non-Hodgkin's cases only.

Table 7
Cancer incidence and mortality in survivors of the atomic bombings

Absorbed dose [a] *(Gy)*	*Mean weighted dose* [b] *(Sv)*	*Person-years*	*Number of subjects*	*Observed*	*Expected*
Solid tumour incidence, 1958-1987 [T15]					
<0.01	0.00	893,767 [c]	42,702	4,286	4,281
0.01-0.1	0.04	454,734 [c]	21,479	2,223	2,174
0.1-0.2	0.14	113,414 [c]	5,307	599	553
0.2-0.5	0.33	124,131 [c]	5,858	759	637
0.5-1	0.74	60,096 [c]	2,882	418	290
1-2	1.42	30,031 [c]	1,444	273	146
>2	2.52	6,175 [c]	300	55	20
Total	0.11	1,682,349 [c]	79,972	8,613	8,103
Solid tumour mortality, 1950-1987 [R23]					
<0.01	0.00	1,385,374	46,176	3,435	3,433
0.01-0.1	0.04	693,935	23,147	1,868	1,837
0.1-0.2	0.14	171,130	5,713	472	444
0.2-0.5	0.33	188,444	6,283	582	508
0.5-1	0.74	93,116	3,111	312	234
1-2	1.42	46,891	1,543	178	108
>2	2.52	9,984	336	40	18
Total	0.11	2,588,873	86,309	6,887	6,581
Leukaemia incidence, 1950-1987 [P33]					
<0.01	0.00	1,166,110 [c]	45,159	90	81
0.01-0.1	0.04	609,964 [c]	23,304	38	42
0.1-0.2	0.15	155,982 [c]	5,880	8	11
0.2-0.5	0.34	167,675 [c]	6,387	27	12
0.5-1	0.76	85,711 [c]	3,304	24	6
1-1.5	1.35	31,295 [c]	1,209	19	2
1.5-2	1.92	15,082 [c]	584	8	1
2-4	2.83	11,101 [c]	444	17	1
Total	0.12	2,242,919 [c]	86,271	231	156

[a] Dose categories are defined in terms of unweighted intestinal doses for solid tumours and unweighted bone marrow doses for leukaemia.
[b] The mean doses are expressed as weighted intestinal doses for solid tumours and weighted bone marrow doses for leukaemia (RBE for neutrons = 10).
[c] Person-years adjusted for migration.

Table 8
Risk estimates for cancer incidence and mortality from studies of external low-LET exposures
The number of observed and expected cases as well as the mean dose and person-years for cohort studies are computed throughout this Table for exposed persons only. In the life span study the exposed group included survivors with organ doses of 0.1 Gy or more.

PART I: OESOPHAGUS

Study		Observed cases	Expected cases	Mean dose (Sv)	Person-years	Average excess relative risk [a] (Sv^{-1})	Average excess absolute risk [a] (10^4 PYSv)$^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	68	65.5	0.24	298,700	0.16	0.35
	Female	17	13.7	0.23	493,900	1.06	0.29
Age at exposure	<20 years	8	4.5	0.24	365,200	3.32	0.41
	>20 years	77	74.7	0.23	427,300	0.13	0.24
All		84	78.9	0.23	788,580	0.29 (-0.2-1.0)	0.29 (-0.2-1.0)
Cervical cancer cohort [B11] [b]		12	11.0	0.35	178,243	0.26 (<-0.2-2.2)	0.16 (<-0.6-1.4)
Mortality							
Life span study [R23]							
Sex	Male	81	74.7	0.23	471,800	0.37	0.58
	Female	22	16.1	0.23	731,300	1.61	0.36
Age at exposure	<20 years	8	6.2	0.23	574,500	1.20	0.13
	>20 years	95	84.6	0.22	628,600	0.56	0.75
All		103	90.8	0.23	1,203,100	0.59 (-0.0-1.4)	0.44 (<0-0.9)
Massachusetts TB fluoroscopy [D14]		14	13.8	1.06	169,425	0.01 (-0.2-0.6)	0.01 (-0.3-0.4)
Ankylosing spondylitis [D6, L6]		28	12.7	4.00	183,749	0.30 (0.1-0.5)	0.21 (0.1-0.3)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] Excludes cases during first 10 years of follow-up.

PART II: STOMACH

Study		Observed cases	Expected cases	Mean dose (Sv)	Person-years	Average excess relative risk [a] (Sv^{-1})	Average excess absolute risk [a] (10^4 PYSv)$^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	679	660.4	0.24	298,700	0.12	2.61
	Female	628	561.3	0.23	493,900	0.52	5.86
Age at exposure	<20 years	167	142.0	0.24	365,200	0.74	2.87
	>20 years	1140	1079.7	0.23	427,300	0.24	6.15
All		1307	1221.7	0.23	792,500	0.30 (0.2-0.5)	4.68 (2.5-7.4)
Cervical cancer case-control [b] [B21]		348	117.3	2.00	n.a.	0.54 (0.1-1.5)	0.37 (0.03-1.0)
Mortality							
Life span study [R23]							
Sex	Male	649	623.0	0.24	471,800	0.17	2.30
	Female	514	484.5	0.23	731,300	0.26	1.75
Age at exposure	<20 years	96	91.2	0.24	574,500	0.22	0.35
	>20 years	1067	1016.3	0.22	628,600	0.22	3.51
All		1163	1107.5	0.23	1,203,100	0.22 (0.1-0.4)	2.02 (0.5-3.5)
Ankylosing spondylitis [D6, L6]		55	54.3	1.65	130,616	0.01 (-0.1-0.2)	0.03 (-0.5-0.7)
Benign gynaecological disease [I8] [c]		23	21.8	0.20	77,878	0.28 (<-0.2-2.5)	0.78 (-2.6-4.6)
Peptic ulcer [G11]		40	17.4	14.80	35,815	0.09 (0.05-0.14)	0.43 (0.2-0.7)
Metropathia haemorrhagica [D23]		33	26.8	0.23	47,144	1.01 (<-0.2-2.8)	5.72 (<-2.4-16)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] The excess absolute risk estimate was computed using background incidence rates estimated using the cervical cancer cohort study [B11].
[c] The observed and expected number of cases are for 10-year survivors. The estimated number of expected cases incorporated an adjustment based upon the Poisson regression model given in [I8].

PART III: COLON

Study		Observed cases	Expected cases	Mean dose (Sv)	Person-years	Average excess relative risk (Sv^{-1}) [a]	Average excess absolute risk [a] (10^4 $PYSv)^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	109	90.7	0.23	297,500	0.87	2.66
	Female	114	103.0	0.22	491,100	0.48	1.01
Age at exposure	<20 years	32	28.0	0.23	363,300	0.62	0.48
	>20 years	191	165.7	0.22	425,300	0.70	2.71
All		223	193.7	0.23	788,600	0.67 (0.1-1.3)	1.65 (0.7-3.0)
Cervical cancer case-control [b] [B21]		409	409	24.0	n.a.	0.00 (0.00-0.01)	0.00 (0.00-0.01)
Mortality							
Life span study [R23]							
Sex	Male	63	56.8	0.23	471,800	0.47	0.57
	Female	66	59.7	0.23	731,300	0.47	0.38
Age at exposure	<20 years	11	9.6	0.23	574,500	0.60	0.10
	>20 years	118	106.9	0.22	628,600	0.47	0.80
All		129	116.5	0.23	1,203,100	0.47 (0.1-1.1)	0.45 (0.3-1.3)
Benign gynaecological disease [18] [c]		75	46.6 [d]	1.30	77,878	0.47 (0.2-0.7)	2.81 (1.5-4.4)
Peptic ulcer [e] [G11]		25	20.6	6.00	118,300	0.04 (0.0-0.1)	0.07 (0.0-0.02)
Metropathia haemorrhagica [D23]		47	33.0	3.20	47,144	0.13 (0.03-0.3)	0.93 (0.2-1.8)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] The excess absolute risk estimate was computed using background incidence rates estimated using the cervical cancer cohort study [B12].
[c] The observed and expected number of cases are for 10-year survivors. The estimated number of expected cases incorporated an adjustment based upon the Poisson regression model given in [18].
[d] Incorporates a standardized mortality ratio based upon internal comparison model in [18].
[e] Since the original paper provides only a range of doses for this site, the value given here is a very crude estimate.

PART IV: LIVER

Study		Observed cases	Expected cases	Mean dose (Sv)	Person-years	Average excess relative risk (Sv^{-1}) [a]	Average excess absolute risk [a] (10^4 $PYSv)^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	174	151.5	0.24	299,600	0.61	3.09
	Female	110	107.2	0.23	496,600	0.11	0.24
Age at exposure	<20 years	63	47.2	0.24	367,000	1.39	1.78
	>20 years	221	211.4	0.23	429,200	0.19	0.95
All cases		284	258.6	0.24	796,300	0.41 (0.2-0.9)	1.33 (0.5-2.9)
Total (microscopically verified)		109	94.7	0.24	796,300	0.64	0.76
Cervical cancer cohort [b] [B11]		19	20	0.70	342,786	-0.13 (<0-0.9)	-0.03 (<0-0.2)
Mortality							
Life span study [R23]							
Sex	Male	202	178.6	0.24	471,800	0.54	2.04
	Female	150	141	0.23	731,300	0.27	0.53
Age at exposure	<20 years	56	43.4	0.24	574,500	1.26	0.90
	>20 years	296	276.2	0.22	628,600	0.31	1.35
All cases		352	319.6	0.23	1,203,100	0.44 (0.2-0.8)	1.18 (0.5-2.2)
Total [c] (primary on death certificate)		48	46.2	0.24	1,203,100	0.16	0.06
Ankylosing spondylitis [D6, L6]		6	5.6	1.60	130,616	0.05 (<0-0.7)	0.02 (<0-0.3)
Benign gynaecological disease [18]		9	16.6	0.21	77,878	-0.5 (-0.5- -0.3)	<-1 (<-1- -0.5)
Peptic ulcer [G11]		9	9.0	4.60	35,815	0.00 (<0-0.2)	0.00 (<0-0.4)
Metropathia haemorrhagica [D23]		2	6.0	0.27	47,144	-0.5 (<-0.5-0.2)	<-0.2 (<-0.6-0.2)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] Excludes cases during first 10 years of follow-up.
[c] Estimate is based on deaths coded as primary liver cancer or liver cancer not specified as secondary or primary.

PART V: LUNG

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1}) [a]*	*Average excess absolute risk [a] (10^4 PYSv)$^{-1}$*
Incidence							
Life span study [T15]							
Sex	Male	245	224.7	0.25	302,000	0.36	2.67
	Female	211	140.1	0.24	500,700	2.08	5.81
Age at exposure	<20 years	30	26.2	0.25	370,000	0.57	0.41
	>20 years	426	338.5	0.24	432,700	1.06	8.27
Time since exposure	5-19 years	85	67.8	0.24	288,566	1.04	2.45
	20-29 years	146	116.3	0.24	317,535	1.05	3.85
	30-42 years	225	186.4	0.24	314,545	0.85	5.05
All		456	364.7	0.25	802,700	1.00 (0.6-1.4)	4.55 (2.4-6.0)
Mortality							
Life span study [R23]							
Sex	Male	226	214.7	0.25	471,800	0.21	0.95
	Female	207	149.0	0.24	731,300	1.59	3.24
Age at exposure	<20 years	27	29.8	0.25	574,500	-0.38	-0.20
	>20 years	406	334.0	0.24	628,600	0.88	4.68
Time since exposure	5-19 years	71	63.5	0.24	566,780	0.48	0.54
	20-29 years	135	90.3	0.24	316,912	2.04	5.80
	30-42 years	227	194.4	0.24	319,418	0.69	4.19
All		433	363.8	0.25	1,203,100	0.76 (0.3-1.0)	2.30 (1.0-2.9)
Ankylosing spondylitis [D6, L6]		224	184.5	1.80	130,616	0.12 (0.0-0.2)	1.68 (0.7-2.8)
Massachusetts TB fluoroscopy [D14]		69	81.8	0.84	169,425	-0.19(<-0.2-0.04)	-0.90 (<-1.8-0.2)
Peptic ulcer [G11]		99	58.4	1.80	35,815	0.39 (0.2-0.6)	6.29 (3.8-9.1)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.

PART VI: BONE AND CONNECTIVE TISSUE

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1}) [a]*	*Average excess absolute risk [a] (10^4 PYSv)$^{-1}$*
Incidence							
Life span study [T15]							
Sex	Male	9	6.4	0.23	297,500	1.78	0.38
	Female	7	5.7	0.22	491,100	0.99	0.12
Age at exposure	<20 years	4	1.1	0.23	363,300	11.0	0.34
	>20 years	12	11.0	0.22	425,300	0.42	0.11
All		16	12.1	0.23	788,600	1.42 (<-0.2-4.5)	0.22 (<-0.1-0.7)
Skin haemangioma [F12]		8	2.9	0.4	379,283	4.33 (0.9-9.8)	0.33 (0.1-0.8)
Childhood radiotherapy [T6]		54	20.0	27.0	n.a.	0.06 (0.01-0.2)	n.a.
Mortality							
Life span study [R23]							
Sex	Male	14	10.8	0.23	471,800	1.26	0.29
	Female	10	8.5	0.23	731,300	0.81	0.09
Age at exposure	<20 years	3	1.9	0.23	574,500	2.58	0.08
	>20 years	21	17.4	0.22	628,600	0.92	0.26
All		24	19.3	0.23	1,203,100	1.07 (<-0.2-3.3)	0.17 (<-0.1-0.5)
Ankylosing spondylitis [D6, L6] (bone only)		4	1.4	3.00	130,616	0.65 (0.00-1.9)	0.07 (0.00-0.2)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.

PART VII: SKIN (NON-MELANOMA)

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk* (Sv^{-1}) [a]	*Average excess absolute risk* [a] $(10^4\ PYSv)^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	41	31.4	0.33	324,100	0.92	0.89
	Female	57	44.4	0.32	538,900	0.88	0.72
Age at exposure	<20 years	21	7.7	0.32	399,300	5.37	1.04
	>20 years	77	68.2	0.33	463,700	0.39	0.58
	All	98	75.9	0.33	863,000	0.88 (0.4-1.9)	0.78 (0.4-1.4)
Israeli tinea capitis [R10, R19]		42	10.0	6.8	265,070	0.47 (0.3-0.7)	0.18 (0.1-0.25)
Cervical cancer case-control [B21]		80	85.7	9.6	342,786	-0.01 (-0.02-0.01)	-0.02 (-0.06-0.03)
New York tinea capitis (whites) [b] [S62]		83	24.0	4.5	52,000 [c]	0.55 (-0.02-0.01)	2.50 (1.9-3.2)
Rochester thymic irradiation [b] [S62]		14	4.2	2.3	87,000 [c]	1.04 (0.5-1.9)	0.50 (0.2-0.9)
Massachusetts TB fluoroscopy [b] [S62]		80	75.3	9.6	122,000 [c]	0.01 (-0.01-0.03)	0.04 (-0.08-0.2)
New York mastitis [b] [S62]		14	10.7	2.6	14,000 [c]	0.12 (-0.08-0.4)	0.90 (-0.6-3.1)
Thyroid irradiation [b] [S62, S63]		63	45.0	3.8	96,000 [c]	0.11 (0.03-0.2)	0.50 (0.2-0.9)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] From data presented in a review paper by Shore [S62].
[c] Person-years estimated from data in the review paper by Shore [S62].

PART VIII: FEMALE BREAST

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1})* [a]	*Average excess absolute risk* [a] *(10^4 PYSv)$^{-1}$*
Incidence							
Life span study [T15]							
Age at exposure	<20 years	122	62.8	0.28	202,600	3.32 (2.3-4.4)	10.3 (7.2-14)
	>20 years	173	137.1	0.27	308,000	0.98 (0.4-1.6)	4.36 (1.8-7.2)
Time since exposure	5-19 years	49	36.9	0.28	161,400	1.19	2.72
	20-29 years	87	63.5	0.27	175,800	1.34	4.86
	30-42 years	159	99.5	0.27	173,400	2.21	12.68
All		295	199.9	0.27	510,500	1.74 (1.1-2.2)	6.80 (4.9-8.7)
Massachusetts TB fluoroscopy [B31]		142	107.6	0.79	54,600	0.40 (0.2-0.7)	7.98 (3.6-13)
New York acute post-partum mastitis [S9]		54	20.8	3.70	9,800	0.43 (0.3-0.6)	9.14 (6.0-13)
Ankylosing spondylitis [D6, L6]		26	16.1	0.50	22,033	1.24 (0.3-2.5)	9.01 (2.0-18)
Swedish breast irradiation [B1, M8]		115	28.8	8.46	37,400 [b]	0.35 (0.3-0.4)	2.72 (2.2-3.3)
Cervical cancer case-control [c] [B21]		953	1083.0	0.31	n.a.	-0.2 (<-0.2-0.3)	<-0.3 (<-0.3-0.2)
Without ovaries		91	82.6	0.31	n.a.	0.33 (<-0.2-5.8)	n.a.
Contralateral breast							
Denmark [S60]		529	508.7	2.51	n.a.	0.02 (<-0.1-0.2)	n.a.
United States [B18]		655	550.4	2.82	n.a.	0.07 (<-0.1-0.2)	n.a.
Rochester thymic irradiation [d] [H22]		22	7.8	0.76	38,200	2.39 (1.2-4.0)	4.89 (2.4-8.1)
Skin haemangioma [F12]		56	36.4	0.20	379,283	4.2 (1.8-7.2)	4.1 (1.8-6.9)
Scoliosis patients [d] [H24]		11	6.1	0.13	21,691	6.37 (0.9-15)	17.8 (2.4-43)
Hodgkin's disease (Stanford) [I12]		25	6.1	~44.0	100,057	0.07 (0.04-0.11)	0.04 (0.03-0.07)
Mortality							
Life span study [R23]							
Age at exposure	<20 years	34	13.0	0.28	303,200	5.69 (3.2-9)	2.44 (1.4-3.7)
	>20 years	70	61.1	0.27	428,100	0.55 (<-0.2-1.5)	0.78 (<-0.3-2.1)
Time since exposure	5-19 years	35	28.7	0.28	338,258	0.80	0.68
	20-29 years	26	20.7	0.27	194,149	0.92	0.99
	30-42 years	43	24.2	0.27	198,925	2.87	3.49
All		104	74.1	0.27	731,300	1.79 (0.6-2.1)	1.81 (0.6-2.1)
Canada TB fluoroscopy [M19] [e]		212	157.5	0.43	282,300	0.81 (0.5-1.2)	4.52 (2.6-6.6)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.

[b] For cohort studies the numbers of observed and expected cases as well as the mean dose and person-years are computed for exposed persons only.

[c] Excess absolute risk of cervical cancer is computed using baseline incidence data derived from the cohort study [B12].

[d] Populations exposed as children.

[e] Original model included a factor to allow for differences between Nova Scotia and other Canadian provinces. The computation of the expected number of cases includes an allowance for this effect.

PART IX: BLADDER

Study		Observed cases	Expected cases	Mean dose (Sv)	Person-years	Average excess relative risk (Sv^{-1}) [a]	Average excess absolute risk [a] (10^4 PYSv)$^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	76	70.3	0.23	297,500	0.35	0.84
	Female	39	27.9	0.22	491,200	1.80	1.02
Age at exposure	<20 years	12	10.3	0.23	363,300	0.71	0.20
	>20 years	103	87.8	0.22	425,300	0.79	1.62
All		115	98.1	0.23	788,600	0.76 (0.3-2.1)	0.95 (0.3-2.1)
Cervical cancer case-control [b] [B21]		273	65.8	45	n.a.	0.07 (0.02-0.2)	0.12 (0.04-0.3)
Mortality							
Life span study [R23]							
Sex	Male	36	26.9	0.23	471,800	1.45	0.83
	Female	24	20.0	0.23	731,300	0.88	0.24
Age at exposure	<20 years	5	1.8	0.23	574,500	7.43	0.24
	>20 years	55	45.1	0.22	628,600	0.99	0.71
All		60	46.9	0.23	1,203,100	1.22 (0.3-3.3)	0.48 (0.1-0.9)
Ankylosing spondylitis [D6, L6]		20	16.7	1.45	130,616	0.14 (-0.1-0.5)	0.17 (-0.2-0.6)
Benign gynaecological disease [18]		19	9.0	6.00	77,878	0.19 (0.1-0.3)	0.21 (0.1-0.4)
Metropathia haemorrhagica [D23]		20	6.7	5.20	47,144	0.39 (0.2-0.6)	0.54 (0.3-0.9)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] The excess absolute risk estimate was computed using background incidence rates estimated using the cervical cancer cohort study [B12].

PART X: BRAIN AND CENTRAL NERVOUS SYSTEM

Study		Observed cases	Expected cases	Mean dose (Sv)	Person-years	Average excess relative risk (Sv^{-1}) [a]	Average excess absolute risk [a] (10^4 PYSv)$^{-1}$
Incidence							
Life span study [T15]							
Sex	Male	20	21.7	0.27	307,100	-0.30	-0.21
	Female	51	45.3	0.26	509,300	0.48	0.43
Age at exposure	<20 years	20	15.7	0.26	376,100	1.05	0.44
	>20 years	51	51.4	0.26	440,200	-0.03	-0.03
All		71	67.1	0.26	816,300	0.22 (<0-1.3)	0.18 (<0-0.8)
Israeli tinea capitis [R10]		60	8.4	1.5	283,930	4.08 (3.1-5.2)	1.21 (0.9-1.5)
New York tinea capitis [A1]		8	1.4	1.4	48,115	3.37 (1.3-6.7)	0.98 (0.4-1.9)
Skin haemangioma [F12]		16	17.1	0.1	379,283	<-0.2 (<-0.2-4.2)	<-0.1 (<-2-1.5)
Mortality							
Life span study [R23]							
Sex	Male	18	17.9	0.27	487,200	0.03	0.01
	Female	28	16.6	0.26	757,900	3.05	0.67
Age at exposure	<20 years	14	12.1	0.26	601,000	0.67	0.13
	>20 years	32	22.4	0.26	757,900	1.95	0.68
All		45	39.7	0.26	1,203,100	0.52 (<0-2)	0.17 (<0-0.5)
Ankylosing spondylitis [b] [D6, L6]		22	14.0	0.14	130,616	4.06 (0.4-8.9)	4.36 (0.5-9.5)
Pituitary adenoma (UK) [B9]		5	0.5	45.0	3760	0.19 (0.1-0.4)	0.26 (0.1-0.6)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] Excludes tumours of the spinal cord.

PART XI: THYROID INCIDENCE

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1})* [a]	*Average excess absolute risk* [a] *(10^4 $PYSv)^{-1}$*
Life span study [T15]							
Sex	Male	22	14.9	0.27	307,167	1.80	0.87
	Female	110	79.4	0.26	510,388	1.49	2.32
Age at exposure	0-9 years	24	7.6	0.21	185,507	10.25	4.21
	10-19 years	35	14.6	0.31	190,087	4.50	3.46
	20-29 years	18	17.5	0.28	132,738	0.10	0.13
	>20 years	73	67.1	0.26	442,000	0.3 (<-0.2-1.2)	0.5 (-0.3-1.9)
	>30 years	55	54.5	0.25	309,224	0.04	0.06
All		132	94.3	0.26	817,600	1.5 (0.5-2.1)	1.8 (0.8-2.5)
Tuberculosis, adenitis screening							
Age at exposure	<20 years	6	0.0	8.20	950	36.5 (16-72)	7.7 (3.3-15)
[H1, S61]	>20 years	2	0.2	8.20	3,100	1.2 (0.1-3.7)	0.7 (0.1-2.4)
Cohort studies in children							
Life span study [T15]							
Age at exposure	0-19 years	59	22.2	0.26	375,600	6.3 (5.1-10.1)	3.8 (2.7-5.4)
Israeli tinea capitis [R15] [b]		43	10.7	0.1	274,180	34 (23-47)	13 (9.0-18)
New York tinea capitis [S61]		2	1.4 [c]	0.1	79,500	7.7 (<0-60)	1.3 (<0-10.3)
Rochester thymic irradiation [d] [S54]		37	2.7	1.4	85,204	9.5 (6.9-12.7)	3.0 (2.2-4.0)
Childhood cancer [e] [T5]		23	0.4	12.5	50,609	4.5 (3.1-6.4)	0.4 (0.2-0.5)
Skin haemangioma [F12, F15]		14	7.1	0.23	n.a.	4.2 (0.1-29)	n.a.
Screening studies in children							
Lymphoid hyperplasia screening [d f] [P8, S61]		13	5.4 [b]	0.24	34,700	5.9 (1.8-11.8)	9.1 (2.7-18.3)
Thymus adenitis screening [M2, S61]		16	1.1 [b]	2.90	44,310	4.5 (2.7-7.0)	1.2 (0.7-1.8)
Michael Reese, tonsils [g] [S63]		309	110.4	0.60	88,101	3.0 (2.6-3.5)	37.6 (32-43)
Tonsil/thymus/acne screening [D18, S61]		11	0.2 [b]	4.50	6,800	12.0 (6.6-20)	3.5 (2.0-5.9)
Studies in adults							
Cervical cancer case-control [e]	[B21]	43	18.8	0.11	n.a.	12.3 (<0-70.0)	5.8 (<0-32.9)
Cervical cancer cohort [e h]	[B11]	16	12.5	0.11	342,786	2.5 (<0-6.8)	0.9 (<0-2.5)
Stanford thyroid [H6]		6	0.4	45.0	17,700	0.3 (0.1-0.7)	0.07 (0.03-0.1)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.

[b] Doses to the thyroid in this study may be much more uncertain than doses to organs directly in the x-ray beam.

[c] Expected number of cases computed using excess relative risk estimates given in [S61].

[d] Known dose. Person-years and expected number of cases estimated from data given in [S61].

[e] Based on cohort members with 15 or more years of follow-up and population expected rates for non-melanoma skin tumours of the head and neck tumours.

[f] This was a study of nodular disease and cancer cases were not confirmed.

[g] Study includes no unexposed controls; estimates of the number of expected cases were computed using the fitted excess relative risk reported in [S63]. Results are based on the new dosimetry described in [S63]. The large excess absolute risk in this study illustrates the impact of screening on thyroid cancer risk estimates. As described in [S63], a special thyroid screening programme in this cohort was initiated in 1974. This screening led to a large increase in the number of incident cases detected among both cases and controls. The paper describes an analysis in which allowance was made for the effect of screening. The screening-adjusted excess absolute risk was estimated as 1.7 $(10^4 \text{ PYGy})^{-1}$.

[h] Excludes cases diagnosed during first 10 years of follow-up.

PART XII: LEUKAEMIA

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1})* [a]	*Average excess absolute risk* [a] *(10^4 PYSv)$^{-1}$*
Incidence							
Life span study [P33]							
Sex	Male	71	35.3	0.26	412,300	3.91	3.35
	Female	70	32.1	0.25	664,500	4.75	2.29
Age at exposure	<20 years	46	17.9	0.26	478,100	6.11	2.28
	>20 years	95	49.5	0.25	598,700	3.70	3.06
Time since exposure	5-10 years	29	5.1	0.25	160,900	18.69	5.87
	11-20 years	45	40.3	0.25	367,200	0.46	0.50
	21-30 years	34	18.5	0.25	277,900	3.32	2.21
	31-42 years	33	28.1	0.25	270,800	0.70	0.72
All		141	67.4	0.25	1,076,800	4.37 (3.2-5.6)	2.73 (2.0-3.5)
Cervical cancer case-control [b] [B21]		141	n.a.	7.20	n.a.	0.74 (0.1-3.8)	0.50 (0.1-2.6)
Childhood cancer [c] [T7]		25	n.a.	10.00	n.a.	0.00 (0.000-0.004)	n.a.
Breast cancer therapy [d] [C24]		38	n.a.	7.50	n.a.	0.19 (0.00-0.6)	0.89 (0.00-3.0)
Techa River population [K18]		37	19.3	0.50	388,880	1.84 (0.9-3.1)	0.91 (0.4-1.5)
Mortality							
Ankylosing spondylitis [D6, L6]		36	11.9	3.83	165,758	0.53 (0.3-0.8)	0.38 (0.2-0.6)
Israeli tinea capitis [e] [R5]		14	6.0	0.30	279,901	4.44 (1.7-8.7)	0.95 (0.4-1.9)
Benign gynaecological disease [I12]		47	27.6	1.19	246,821	2.97 (2.2-4.0)	1.25 (0.9-1.7)
Massachusetts TB fluoroscopy [f] [D14]		17	18.0	0.09	157,578	<-0.2 (<-0.2-4.5)	<-0.2 (<-0.2-5.1)
Peptic ulcer [G11]		8	2.9	1.55	35,815	1.13 (0.4-2.5)	0.92 (0.3-2.0)
Metropathia haemorrhagica [D23]		12	5.6	1.30	53,144	0.88 (0.3-1.9)	0.93 (0.3-2.0)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.

[b] CIs for the cervical cancer data on excess relative risk were estimated from the confidence region curves in [B42]; the excess absolute risk estimate uses incidence estimates from the cohort study [B12].

[c] Risk estimates based on an unmatched analysis of data given in [T5].

[d] The excess absolute risk for this study is computed based on annual incidence estimates and average follow-up times reported in [C35].

[e] A re-estimate of the dose to bone marrow in this study indicates a mean dose of 0.60 rather than 0.30. Consequently the excess relative risk becomes 2.22 [R27].

[f] Excludes cases of chronic lymphocytic leukaemia.

PART XIII: NON-HODGKIN'S LYMPHOMA

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1})* [a]	*Average excess absolute risk* [a] *(10^4 PYSv)$^{-1}$*
Incidence							
Life span study [P33]							
Sex	Male	41	33.2	0.26	412,400	0.91	0.73
	Female	35	38.3	0.25	664,500	-0.34	-0.20
Age at exposure	<20 years	17	15.8	0.26	478,100	0.30	0.10
	>20 years	59	55.7	0.25	598,800	0.24	0.22
All		76	71.5	0.25	1,076,900	0.25 (<-0.2-1.1)	0.17 (<-0.3-0.8)
Cervical cancer case-control [b] [B21]		94	n.a.	7.10	n.a.	0.21 (0.1-1.1)	0.04 (0.02-0.2)
Mortality							
Ankylosing spondylitis [D6, L6]		16	7.1	3.83	130,616	0.32 (0.1-0.6)	0.18 (0.1-0.3)
Benign gynaecological disease [I12]		40	42.5	1.19	246,821	-0.05 (<-0.2-0.2)	-0.08 (<-0.3-0.3)
Massachusetts TB fluoroscopy [D14]		13	13.1	0.09	157,578	-0.05 (<-0.2-6.5)	-0.04 (<-0.2-5.4)
Peptic ulcer [G11]		12	6.4	1.55	35,815	0.57 (0.1-1.3)	1.01 (0.1-2.4)
Metropathia haemorrhagica [D23]		4	5.3	1.30	47,144	-0.19 (<-0.2-0.6)	-0.22 (<-0.2-0.6)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] CIs for the cervical cancer data on excess relative risk were estimated from the confidence region curves in [B42]; the excess absolute risk estimate uses incidence estimates from the cohort study [B11].

PART XIV: MULTIPLE MYELOMA

Study		*Observed cases*	*Expected cases*	*Mean dose (Sv)*	*Person-years*	*Average excess relative risk (Sv^{-1})* [a]	*Average excess absolute risk* [a] *(10^4 PYSv)$^{-1}$*
Incidence							
Life span study [P33]							
Sex	Male	12	9.2	0.26	412,400	1.17	0.26
	Female	18	19.3	0.25	664,500	-0.28	-0.08
Age at exposure	<20 years	4	3.1	0.26	478,100	1.07	0.07
	>20 years	26	25.4	0.25	598,800	0.09	0.04
All		30	28.6	0.25	1,076,900	0.20 (<-0.2-1.7)	0.05 (<-0.05-0.4)
Cervical cancer case-control [b] [B21]		56	n.a.	7.10	n.a.	-0.10 (<-0.1-0.1)	-0.01 (<-0.03-0.02)
Mortality							
Ankylosing spondylitis [D6, L6]		8	4.7	3.83	130,616	0.19 (<-0.04-0.5)	0.07 (<-0.01-0.2)
Benign gynaecological disease [I12]		14	12.4	1.19	246,821	0.11 (<-0.2-0.6)	0.05 (<-0.1-0.3)
Peptic ulcer [G11]		3	3.1	1.55	35,815	-0.02 (<-0.2-1.0)	-0.02 (<-0.2-0.8)
Metropathia haemorrhagica [D23]		9	3.5	1.30	47,144	1.23 (0.3-2.7)	0.90 (0.2-2.0)

[a] 90% CI in parentheses derived from published data for the life span study and using exact Poisson methods for the other studies.
[b] The excess absolute risk estimate was computed using background incidence rates estimated from the cervical cancer cohort study [B12].

Table 9
Sex-specific risk estimates for cancer incidence and mortality from the Life Span Study

Cancer type	*Average excess relative risk* (Sv^{-1})		*Average excess absolute risk* (10^4 $PYSv)^{-1}$		*Sex ratio*		
	Males	*Females*	*Males*	*Females*	*Average excess relative risk* (Sv^{-1}) *(Female : male)*	*Average excess absolute risk* (10^4 $PYSv)^{-1}$ *(Female : male)*	*Normal cancer incidence (Male : female)*
Incidence 1958-1987 [T15]							
All solid tumours	0.33	0.81	18.96	34.44	2.45	1.82	1.36
Non-sex specific solid tumours	0.34	0.88	18.89	26.19	2.59	1.39	1.85
Oesophagus	0.16	1.06	0.41	0.24	6.63	0.59	6.64
Stomach	0.12	0.52	2.61	5.86	4.33	2.25	1.94
Colon	0.87	0.48	2.66	1.01	0.55	0.38	1.35
Liver	0.61	0.11	3.09	0.24	0.18	0.08	2.43
Lung	0.36	2.08	2.67	5.81	5.78	2.18	2.85
Skin	0.92	0.88	0.89	0.72	0.96	0.81	0.86
Bladder	0.35	1.80	0.84	1.02	5.14	1.21	3.60
Thyroid	2.21	1.94	0.99	2.78	0.88	2.81	0.29
Bone and connective tissue	1.78	0.99	0.38	0.12	0.56	0.32	1.25
Incidence 1950-1987 [P33]							
Leukaemia	3.91	4.75	3.35	2.29	1.21	0.68	1.76
Non-Hodgkin's lymphoma	0.91	-0.34	0.73	-0.20	-0.37	-0.27	
Myeloma	-1.17	-0.28	0.26	-0.08	-0.24	-0.31	
Mortality 1950-1987 [R23]							
All solid tumours	0.26	0.72	8.74	15.81	2.77	1.81	1.48
Non-sex specific solid tumours	0.25	0.60	7.90	10.45	2.42	1.32	1.82
Oesophagus	0.45	0.94	0.71	0.22	2.09	0.31	6.39
Stomach	0.16	0.35	2.04	2.26	2.19	1.11	1.84
Colon	0.66	0.03	0.82	0.03	0.05	0.04	1.35
Liver	0.49	0.33	2.06	0.66	0.67	0.32	2.02
Lung	0.20	1.96	0.96	3.89	9.80	4.05	2.56
Bladder	1.59	0.41	0.93	0.12	0.26	0.13	1.69
Bone and connective tissue	1.26	0.81	0.29	0.09	0.64	0.31	1.82

Table 10
Risk estimates for cancers other than leukaemia in relation to age at exposure

Age at exposure (years)	*Life span study mortality [R23]*				*Ankylosing spondylitis [D6]*	
	Both sexes		*Males only*		*Mainly males*	
	Excess relative risk (Sv^{-1})	*Excess absolute risk* (10^4 $PYSv)^{-1}$	*Excess relative risk* (Sv^{-1})	*Excess absolute risk* (10^4 $PYSv)^{-1}$	*Excess relative risk* (Sv^{-1})	*Excess absolute risk* (10^4 $PYSv)^{-1}$
0-15	0.95	3.72	0.66	2.72		
15-24	0.74	8.39	0.52	6.71	0.20	1.67
25-34	0.56	14.40	0.39	13.85	0.12	2.41
35-44	0.42	19.35	0.30	19.24	0.14	6.08
45-54	0.31	21.85	0.24	21.98	0.17	12.75
>55	0.23	22.84	0.18	23.72	0.08	8.21

Table 11
Excess relative risk estimates for breast cancer in various cohorts in relation to age at exposure

Study	*Excess relative risk (Sv^{-1}) for age at exposure* [a]								
	0-9 years	*10-19 years*	*20-24 years*	*25-29 years*	*30-34 years*	*35-39 years*	*40-44 years*	*45-49 years*	*>50 years*
Life span study [T15]	3.4 (58)	2.5 (141)	1.3 (77)	1.4 (54)	1.2 (58)	1.4 (49)	0.7 (92)		
Massachusetts TB fluoroscopy [B31]		0.7 (71)	0.5 (102)		0.2 (31)		0.2 (13)		
Canada TB fluoroscopy [M19] Nova Scotia Other provinces		1.9 (14) 0.4 (48)	1.6 (47) 0.4 (233)		0.8 (8) 0.2 (73)		0 (4) 0 (55)		
New York acute post-partum mastitis [S9]		0.4 (33)		0.4 (44)	0.6 (43)				
Swedish benign breast [B1]		2.5 (15)	1.9 (18)		0.4 (28)		0.1 (20)		0.1 (7)
Hodgkin's disease [H2]		0.9 (4)		0.4 (9)		0.1 (2)			
Contralateral breast [B18]					0.2 (78)			0.0 (128)	

[a] Numbers in parentheses are numbers of cases involved.

Table 12
Excess relative risk for thyroid cancer in various cohorts in relation to age at exposure

Study	*Excess relative risk (Sv^{-1}) for age at exposure*						
	<1 year	*1-4 years*	*5-9 years*	*10-14 years*	*15-19 years*	*20-39 years*	*>40 years*
Life span study [T15]	9.5			3.0		0.3	-0.2
Israeli tinea capitis [R15] Israeli-born Non-Israeli-born	20.0 67.0		7.0 27.0				
Michael Reese tonsil irradiation [S63]	3.6	2.8	1.4				

Table 13
Estimated relative risk of cancer mortality per sievert weighted dose (RBE for neutrons = 10) in the life span study cohort [a]
[S7]

Cancer type	*Sex*	*Age at exposure*				
		<10 years	*10-19 years*	*20-29 years*	*30-39 years*	*≥40 years*
Leukaemia	Male	17.9	4.8	5.9	4.5	3.9
	Female	18.8	5.0	6.2	4.7	4.0
All except leukaemia	Male	1.96	1.60	1.52	1.23	1.16
	Female	2.92	2.20	2.04	1.45	1.32
Stomach	Male	1.40	1.71	1.65	1.09	1.09
	Female	1.83	2.47	2.36	1.19	1.20
Female breast	Female	2.54	2.89	1.96	2.09	1.03
Lung	Male	1.78		1.08	1.22	1.32
	Female	3.93		1.31	1.84	2.19
Colon	Male	3.82		1.39	1.67	1.17
	Female	8.09		1.97	2.67	1.42

[a] DS86 dosimetry, both cities, 1950-1985.

Table 14
Studies of obstetric x-ray examinations in relation to childhood cancer (including leukaemia) [a]
[B22]

Study	*Units of information*	*Per cent of total*	*Relative risk estimate [b]*	*Comments*
Oxford survey of childhood cancers [c]				
1975 [B23]	434.2	39.1	1.41	
1987 [K6, M22]	812.0	73.0	1.40	RR: 1.94 [K6], -1.4 [M22]
Prenatal x-ray examinations, United States [M9]	114.7	10.3	1.47	
Inter regional epidemiological study of childhood cancer [H48] [d]	39.0	3.5	1.23	Weighting of matched estimates
Los Angeles [P16]	23.9	2.2	1.34	Leukaemia only
Louisiana [F13]	18.3	1.6	1.70	
Helsinki [S36]	17.9	1.6	1.18	
California [K13]	16.6	1.5	1.48	Leukaemia only
Tri-state [G14]	16.6	1.5	1.40	
Minnesota [A8]	10.2	0.92	1.28	Leukaemia only
Edinburgh/London [C15]	9.0	0.81	0.86	Leukaemia only; cohort study
Baltimore [D16]	8.3	0.75	1.02	Cohort study
Connecticut twins [H3]	5.4	0.49	1.83	RR adjusted for birth weight = 2.4
New Zealand [G15]	5.4	0.49	1.13	Leukaemia only
All others	14.3	1.3	-	
Total	1,111.6	100	1.39 [e]	

[a] The measure of information is the reciprocal of the variance of the log relative risk.
[b] Unadjusted unless otherwise stated.
[c] Based on deaths in England, Wales and Scotland, but not including cases in the Interregional epidemiological study of childhood cancer.
[d] A study of incident cases in north and central England.
[e] 95% CI: (1.31-1.47).

Table 15
Estimated excess absolute risk of incidence of all cancers over ages 0-14 years associated with prenatal x-ray examinations in the Oxford survey of childhood cancers
[M22]

Year of birth	*Excess absolute risk (10^{-4} Gy^{-1}) based on*	
	Deaths during 1964-1979 with adjustment for pregnancy illnesses and drugs	*Deaths during 1953-1979 with no adjustment for pregnancy illnesses and drugs* [a]
1946	203	185 (98-304)
1952	100	96 (50-152)
1957	49	56 (21-98)
1962	27	36 (6-73)

[a] Approximate 95% CI given in parentheses.

Table 16
Estimated excess absolute risk for all cancers except leukaemia in the life span study cohort
[P23]

Age at exposure	*Excess absolute risk* [a] *(10^{4} $PYSv)^{-1}$*		
	Follow-up time 1956-1965	*Follow-up time 1966-1975*	*Follow-up time 1976-1985*
0-19 years	0.083	0.31	0.73
20-34 years	0.49	0.79	1.6
≥35 years	0.35	1.4	3.5

[a] Estimates are for males. The corresponding values for females are obtained by multiplying by a factor 1.56.

Table 17
Estimated relative risk of mortality for ranges of absorbed dose above and below 2.0 Gy in the life span study cohort [a]
[S7]

Site of cancer	*Organ absorbed dose (Gy)* [b]						
	0.01-0.05	*0.06-0.09*	*0.10-0.19*	*0.20-0.49*	*0.50-0.99*	*1.00-1.99*	*≥ 2.00*
All cancers except leukaemia	1.06 (1.0-1.12)	1.08 (0.98-1.19)	1.06 (0.97-1.16)	1.12 (1.03-1.21)	1.36 (1.23-1.51)	1.66 (1.45-1.90)	2.05 (1.66-2.50)
Leukaemia	0.99 (0.68-1.40)	0.61 (0.25-1.22)	1.08 (0.61-1.82)	1.79 (1.18-2.68)	4.15 (2.76-6.19)	8.01 (5.34-11.9)	18.6 (12.1-28.2)
Stomach	1.06 (0.96-1.16)	0.93 (0.78-1.10)	1.05 (0.90-1.22)	1.16 (1.02-1.32)	1.28 (1.07-1.53)	1.29 (0.99-1.64)	1.73 (1.19-2.43)
Lung	1.30 (1.11-1.54)	1.21 (0.89-1.62)	1.02 (0.75-1.36)	1.54 (1.22-1.93)	1.63 (1.19-2.19)	2.45 (1.73-3.38)	2.14 (1.16-3.59)
Female breast	1.12 (0.80-1.59)	1.02 (0.49-1.89)	1.10 (0.60-1.89)	1.39 (0.85-2.21)	2.67 (1.62-4.27)	2.39 (1.09-4.59)	4.22 (1.77-8.54)
Colon	1.04 (0.80-1.37)	1.01 (0.61-1.59)	0.53 (0.29-0.91)	0.93 (0.60-1.38)	1.04 (0.56-1.78)	2.23 (1.20-3.81)	5.87 (3.02-10.3)

[a] DS86 dosimetry, both cities, both sexes, all ages at exposure, 1950-1985; comparison is with the control (0 Gy) group.
[b] 90% CI given in parentheses.

Table 18
Adjusted and fitted relative risk of thyroid tumours among Israeli children irradiated for tinea capitis [a]
[R15]

Absorbed dose in thyroid (Gy)	*Malignant tumours*				*Benign tumours*			
	Observed cases	*Person-years*	*Relative risk*		*Observed cases*	*Person-years*	*Relative risk*	
			Adjusted [b]	*Fitted [c]*			*Adjusted [b]*	*Fitted [c]*
0	16	412,030	1.0	1.0	41	316,840	1.0	1.0
0.04-0.07 (mean dose 0.062)	15	106,690	3.3	3.0	17	82,350	1.1	1.9
0.08-0.14 (mean dose 0.102)	24	149.720	4.2	4.3	32	114,930	3.0	2.4
0.15-0.50 (mean dose 0.214)	4	17,770	6.1	8.0	6	12,840	4.5	4.0

[a] Considerable uncertainty may exist in the estimates of dose to the thyroid gland.
[b] Adjusted for sex, ethnic origin and attained age.
[c] Assuming a linear increase in relative risk with increasing dose.

Table 19
Cancer incidence and risks of breast cancer among women with tuberculosis given chest x-ray fluoroscopy
[B31]

Absorbed dose in breast (Gy)	*Number of women*	*Person-years*	*Mean absorbed dose (Gy)*	*Breast cancer cases*			*Relative risk [a] [b]*	*Excess risk [a] [b] (10^4 PY)$^{-1}$*
				Observed	*Expected*	*Observed/ expected*		
0	2,367	48,919	0	87	100.9	0.86	1.00 (1.00)	0.00 (0.00)
0.01-0.99	1,675	33,724	0.36	75	70.6	1.06	1.21 (1.18)	3.89 (3.36)
1.0-1.99	553	15,453	1.36	44	28.0	1.57 [c]	1.66 [c] (1.76)	11.3 [c] (12.9)
2.0-2.99	135	3,757	2.42	14	6.62	2.11 [c]	2.22 [c] (2.46)	20.5 [c] (24.3)
>3	64	1,675	3.75	9	2.44	3.68 [c]	3.83 [c] (3.60)	39.7 [c] (36.2)
Unknown	146	2,356	-	5	5.98	0.84	1.02	0.45
Total [d]	2427	54,609	0.79	142	107.6	1.32 [c]	1.44 [c] (1.48)	8.00 [c] (8.50)

[a] Based on maximum likelihood methods to compute adjusted risk estimates of the ratio observed/expected values between exposed and non-exposed, adjusting for differences in background rates between subcohorts. Excess risk also derived from this approach.
[b] Fitted relative risk and fitted excess risk in parentheses. Based on best-fitting linear dose-response model accounting for age, calendar year, follow-up and subcohort.
[c] $p < 0.05$ (one-sided).
[d] For exposed individuals with known dose (excludes 0 and unknown dose).

Table 20
Evaluation of various dose-response models for breast cancer incidence among women with tuberculosis given chest x-ray fluoroscopy
[B31]

Model	*Mathematical expression [a]*	*Parameter*	*Estimate [b]*	*95% CI*	*Deviance [c] difference*
Linear	$I = a_{age,time}(1 + a_1 D)$	a_1	0.71	(0.40-1.08)	0.26
Quadratic	$I = a_{age,time}(1 + a_2 D^2)$	a_2	0.22	(0.10-0.41)	6.29
Linear-quadratic	$I = a_{age,time}(1 + a_1 D + a_2 D^2)$	a_1 a_2	0.85 -0.07	(0.19-1.73) (-0.28-0.21)	0.00

[a] I denotes breast cancer incidence. D denotes breast dose (cGy). $a_{age,time}$ denotes background parameter adjusted for age and time. The model also includes a multiplicative age-at-exposure effect on the excess relative risk (not shown).
[b] Based on these models, the estimated RRs for a 20-year-old exposed to 1 Gy are 1.70, 1.22 and 1.81 for the linear, quadratic and linear-quadratic models, respectively.
[c] The deviance is a measure of unexplained variance used to assess goodness of fit of different nested models. The deviance differences are between the indicated model and the linear-quadratic model. This difference can be interpreted as a single degree-of-freedom χ^2 statistic of the adequacy of the simpler method. The results indicate that the linear model describes these data as well as the linear-quadratic model ($p > 0.5$), but that the pure quadratic model does not fit well ($p = 0.01$).

Table 21
Dose fractionation effects in thyroid cancers among individuals in Rochester, New York, given x-ray treatment in infancy for supposed enlarged thymuses [a]
[S10]

Radiation characteristics	*Mean total dose (Gy)*	*Person-years*	*Number of cancers observed*	*Excess absolute risk* $(10^4\ PYGy)^{-1}$ [b]
Dose per fraction (Gy)				
0.01-0.49	0.18	34,268	4	6.1
0.50-1.99	2.22	8,622	6	2.2
2.0-5.99	3.14	14,340	12	2.3
Number of dose fractions				
1	0.74	29,414	7	2.9
2	1.55	22,417	6	1.5
3	2.54	5,445	9	3.8
Average interval between treatments				
0 days	0.74	29,334	7	2.9
1-4 days	1.41	13,896	5	2.4
>4 days	2.07	13,980	10	1.9

[a] Data shown are for individuals with total thyroid doses of less than 6 Gy.
[b] Excess in comparison to control group rates, with adjustment by sex, ethnicity and interval since irradiation to the combined distribution of these groups plus the control group.

Table 22
Summary of studies of medical personnel exposed to radiation showing cancer types with significantly ($p < 0.005$) increased risks
[C25]

Study	*Number of persons*	*Study period*	*Period of subgroup entry*	*Cancer types in excess*	*Relative risk* [a]	*Number of cases*
Mortality in male radiologists (United Kingdom) [S38]	1,338	1897-1954	Pre-1921	All [b]	1.41	64
				Pancreas	3.23	6
				Lung	2.18	8
				Skin	7.79	6
				Leukaemia	6.15	4
			1920-1954	No cancers differed significantly from expectation in this subgroup but cancer mortality increased significantly with time since entry to the study		
Mortality in male radiologists (United States) [M24]	6,524	1920-1969	1920-1939	All	1.38	
				Mouth and pharynx	2.17	
				Liver (secondary)	3.22	
				Skin	3.38	
				Unspecified sites	1.69	
				Acute leukaemia	2.23	
				Myeloid leukaemia	2.39	
				Lymphosarcoma	2.73	
			1940-1969	All	1.15	
				Mouth and pharynx	2.88	
				Lung	1.22	
				Multiple myeloma	2.05	
Cancer incidence in Chinese x-ray workers [W14]	27,011	1950-1985	Pre-1960	All	1.3	193
				Oesophagus	5.5	13
				Liver	1.8	37
				Skin	2.9	7
				Leukaemia	2.6	17
			1960-1969	All	1.3	90
				Liver	2.2	20
				Skin	1.6	1
				Leukaemia	3.0	13
			1970-1985	All	0.8	49
				Oesophagus	3.8	2
				Liver	1.2	8
				Skin	4.8	1
				Leukaemia	1.3	4
Mortality in Japanese radiological technologists [A9]	9,179	1969-1986	1969-1982 [c]	All	1.32	137
				Large intestine	2.22	20
				Neurocerebral	8.16	4
			1983-1986 [c]	Leukaemia	5.83	7
				Other [d]	1.92	27
Cancer incidence in Danish radiotherapists [E7]	4,281	1954-1982 [e]	≥10 years [c]	All	1.13	103
				Prostate	6.25	4

[a] Adjusted for age and period.
[b] Expected deaths calculated using rates in social class I males; RR = 1.72, using rates in male medical practitioners.
[c] Period of observation.
[d] All malignant neoplasms other than oesophagus, stomach, liver, pancreas, lung and leukaemia.
[e] Provisional results available only to 1984.

Table 23
Cancer incidence in diagnostic x-ray workers in China
[W14]

Age at first employment	*All cancers except leukaemia*		*Leukaemia*		*Breast cancer*		*Thyroid cancer*	
	Observed number	*Rate ratio*	*Observed number*	*Rate ratio*	*Observed number*	*Rate ratio*	*Observed number*	*Rate ratio*
<20 years	24	1.5	5	5.9	0	0.0	2	5.4
20-24 years	70	1.1	15	4.1	6	1.4	3	2.0
25-29 years	91	1.3	8	2.2	10	3.3	2	1.6
30-34 years	60	1.3	5	1.9	4	1.6	1	1.2
35-39 years	28	0.9	1	0.6	0	0.0	0	0.0
≥40 years	25	0.8	0	0.0	0	0.0	0	0.0
All ages	298	1.1	34	2.4	20	1.5	8	1.7

Table 24
Parameter estimates from the life span study used in lifetime risk computations [a]

Site	*Males*		*Females*	
	Excess relative risk (Sv^{-1})	*Age-at-exposure effect*	*Excess relative risk* (Sv^{-1})	*Age-at-exposure effect*
Oesophagus	0.23	0.015	1.59	0.015
Stomach	0.16	-0.035	0.62	-0.035
Colon	0.54	-0.033	1.00	-0.033
Liver	0.97	-0.027	0.32	-0.027
Lung	0.37	0.021	1.06	0.021
Bladder	1.00	0.012	1.19	0.012
Breast	-	-	1.95	-0.079
Ovary	-	-	1.42	-0.042
Other	0.59	-0.059	0.39	-0.059
All solid tumours	0.45	-0.026	0.77	-0.026

[a] The parameters are a (excess relative risk per sievert) and b (age-at-exposure effect) in the model ERR(D,e) = aD exp [b(e - 25)], where D is the weighted dose in intestines (RBE for neutrons = 10) and e is the age at exposure.

Table 25
Estimates of excess relative risk per sievert for solid tumours based on fits to data of the life span study [a]

Site	*Excess relative risk (Sv^{-1})*					
	For males at age of exposure			*For females at age of exposure*		
	10 years	*30 years*	*50 years*	*10 years*	*30 years*	*50 years*
Oesophagus	0.18	0.25	0.34	1.26	1.72	2.34
Stomach	0.27	0.13	0.07	1.05	0.52	0.26
Colon	0.90	0.46	0.23	1.64	0.84	0.43
Liver	1.45	0.85	0.49	0.48	0.28	0.16
Lung	0.27	0.41	0.63	0.78	1.17	1.77
Bladder	0.83	1.06	1.36	0.99	1.27	1.62
Breast	-	-	-	6.38	1.32	0.27
Ovary	-	-	-	2.64	1.15	0.50
Other	1.43	0.44	0.13	0.95	0.29	0.09
All solid tumours	0.66	0.40	0.23	1.14	0.68	0.40

[a] The parameters and model are presented in Table 24 and its footnote.

Table 26
Estimates of excess absolute risk for leukaemia for acute exposures of 0.2 Sv and 1 Sv of low-LET radiation based on fits to data of the life span study [a]
[P33]

Age at exposure (years)	*Excess absolute risk for males (10^4 PYSv)$^{-1}$ [b]*						*Excess absolute risk for females (10^4 PYGy)$^{-1}$ [b]*					
	0.2 Sv			*1 Sv*			*0.2 Sv*			*1 Sv*		
	5 years after exposure	*20 years after exposure*	*40 years after exposure*	*5 years after exposure*	*20 years after exposure*	*40 years after exposure*	*5 years after exposure*	*20 years after exposure*	*40 years after exposure*	*5 years after exposure*	*20 years after exposure*	*40 years after exposure*
0-19	2.3	0.18	0.01	17.7	1.4	0.05	0.62	0.22	0.05	4.8	1.7	0.4
20-39	1.5	0.21	0.02	11.6	1.6	0.12	0.41	0.26	0.14	3.2	2.0	1.1
≥40	1.2	0.43	0.11	9.5	3.3	0.82	0.34	0.53	0.96	2.3	3.9	8.2

[a] Using an excess absolute risk model with time-, sex- and age-at-exposure dependence (see equation 14).
[b] Dose is weighted dose to bone marrow (RBE for neutrons = 10).

Table 27
Death rates for selected causes in the population of Japan, 1985
[J5]

Age category (years)	*Males*				*Females*				*Both sexes*			
	Population	*Death rates (10^{-5})*			*Population*	*Death rates (10^{-5})*			*Population*	*Death rates (10^{-5})*		
	(thousands)	*All causes*	*Leukaemia*	*Solid tumours*	*(thousands)*	*All causes*	*Leukaemia*	*Solid tumours*	*(thousands)*	*All causes*	*Leukaemia*	*Solid tumours*
0-4	3,792	158.8	1.3	2.9	3,615	131.2	1.4	2.4	7,408	145.3	1.4	2.6
5-9	4,345	26.6	2.6	2.1	4,131	15.3	1.7	1.5	8,476	21.1	2.2	1.8
10-14	5,115	19.9	2.2	2.0	4,865	13.1	1.6	1.9	9,980	16.5	1.9	2.0
15-19	4,571	69.8	2.7	3.5	4,351	23.7	1.7	2.1	8,922	47.2	2.2	2.8
20-24	4,134	81.4	2.2	3.6	4,000	31.8	1.3	3.2	8,133	57.1	1.8	3.3
25-29	3,915	80.7	2.1	6.9	2,840	40.7	1.5	8.3	7,754	60.9	1.8	7.6
30-34	4,524	93.3	2.8	12.3	4,461	55.6	1.9	16.9	8,985	74.5	2.3	14.6
35-39	5,365	131.9	3.4	25.5	5,309	76.0	2.3	29.5	10,675	104.2	2.8	27.5
40-44	4,527	227.7	3.8	50.4	4,559	124.1	3.0	52.4	9,086	175.6	3.4	51.4
45-49	4,072	371.7	4.8	98.4	4,125	184.6	3.6	79.9	8,197	277.1	4.2	89.0
50-54	3,911	624.6	5.8	207.7	3,991	289.7	4.7	124.2	7,902	455.6	5.2	165.6
55-59	3,395	906.7	7.5	356.4	3,577	414.9	5.4	180.3	6,972	654.3	6.5	266.0
60-64	2,365	1,314.9	10.2	536.5	3,013	663.0	6.4	269.2	5,377	948.7	8.1	386.3
65-69	1,770	2,159.4	14.6	822.3	2,404	1,106.4	7.6	382.1	4,174	1,554.0	10.6	569.2
70-74	1,497	3,707.7	20.4	1,204.2	2,053	1,998.4	9.9	555.4	3,549	2,717.5	14.3	828.4
75-79	1,014	6,581.0	25.8	1,705.0	1,472	3,871.3	12.9	794.3	2,485	4,980.5	18.2	1,167.1
80-84	541	10,799.1	25.6	2,019.0	889	7,165.7	12.5	980.2	1,429	8,540.5	17.4	1,373.3
85-89	203	18,136.2	24.5	2,267.3	399	13,067.1	12.7	1,142.8	602	14,725.6	16.5	1,510.4
>90	53	25,429.3	21.7	1,764.5	129	22,490.8	10.0	1,018.4	181	23,364.8	13.5	1,240.3

Table 28
Comparison of measures of lifetime risk of mortality from solid tumours following acute whole-body exposure of 1 Sv [a] [b]

Age at exposure (years)	*Risk of exposure-induced death (REID) (%)*	*Excess lifetime risk (ELR) (%)*
10	17.0	14.5
30	9.3	8.1
50	7.0	6.4
70	2.8	2.6

[a] Estimates were computed using sex- and age-at-exposure-specific relative risks estimated for the life span study cancer mortality data for the period 1950-1987. Risks were applied to 1985 death rates in Japan [J5]. Since sex-specific estimates of the excess risk were virtually identical, the estimates in this Table are averages of both the sexes. Projection beyond the follow-up period assumes constant relative risks.

[b] Dose is weighted dose with neutron RBE = 10.

Table 29
Estimates of lifetime risk for leukaemia following acute whole-body exposures of 0.2 Sv or 1 Sv from low-LET radiation

Age at exposure (years)	*Risk of exposure-induced death (REID) (%)* [a]			*Years of life lost per case (YLC)* [b]		
	Males	*Females*	*Both*	*Males*	*Females*	*Both*
Exposure of 0.2 Sv [c]						
Newborn	0.22	0.11	0.16	67	64	66
5	0.22	0.11	0.16	62	59	60
10	0.22	0.10	0.16	58	54	56
15	0.22	0.10	0.16	53	50	52
20	0.16	0.12	0.14	46	38	42
25	0.16	0.11	0.14	42	34	38
30	0.16	0.11	0.14	37	30	34
35	0.16	0.10	0.13	33	27	30
40	0.18	0.24	0.21	25	16	20
45	0.17	0.19	0.18	21	14	18
50	0.16	0.15	0.16	18	13	15
55	0.15	0.12	0.13	15	11	13
60	0.13	0.09	0.11	12	9	11
65	0.11	0.06	0.09	9	8	8
70	0.09	0.04	0.07	7	6	6
Exposure of 1 Sv [c]						
Newborn	1.66	0.81	1.23	67	64	66
5	1.67	0.81	1.24	63	59	61
10	1.67	0.81	1.24	58	54	56
15	1.66	0.80	1.23	53	50	51
20	1.25	0.91	1.08	46	38	42
25	1.25	0.88	1.06	42	34	38
30	1.24	0.84	1.04	37	31	34
35	1.23	0.80	1.01	33	27	30
40	1.40	1.80	1.60	25	16	20
45	1.34	1.45	1.39	21	14	18
50	1.25	1.15	1.20	18	13	15
55	1.15	0.90	1.03	15	11	13
60	1.03	0.68	0.86	12	9	10
65	0.88	0.50	0.69	9	8	8
70	0.71	0.34	0.53	7	6	6

[a] Computed using time-, sex- and age-at-exposure-specific excess absolute risk model for the life span study leukaemia incidence data for 1950-1987 [P33]. Risks were applied to Japanese death rates of 1985 [J5].

[b] Average years of life lost per exposure-induced death. The average years of life lost per exposed person is equal to years of life lost per case multiplied by risk of exposure-induced death divided by 100.

[c] Dose is weighted dose with neutron RBE = 10.

Table 30
Estimates of projected lifetime risk of solid tumours following acute whole-body exposure of 0.2 Sv or 1 Sv from low-LET radiation

Age at exposure (years)	*Risk of exposure-induced death (REID) (%)* [a] *for projection method with a 10-year latent period and relative risk*			*Years of life lost per case (YLC)* [b] *for projection method with a 10-year latent period and relative risk*		
	Assumed constant from 10 years after exposure	*Declining to risk for age 50 years at exposure* [c]	*Declining to zero risk at age 90 years* [d]	*Assumed constant from 10 years after exposure*	*Declining to risk for age 50 years at exposure* [c]	*Declining to zero risk at age 90 years* [d]
Exposure of 0.2 Sv [e]						
Newborn	5.8	3.5	2.6	14.3	17.4	20.2
5	4.6	3.1	2.2	14.0	16.6	19.7
10	3.8	2.8	2.0	13.8	15.9	18.9
15	3.1	2.5	1.8	13.5	15.1	18.1
20	2.6	2.2	1.6	13.2	14.3	17.1
25	2.2	2.0	1.5	12.8	13.6	16.0
30	2.0	1.9	1.5	12.4	12.8	14.7
35	1.8	1.7	1.5	11.9	12.1	13.5
40	1.6	1.6	1.5	11.4	11.5	12.3
45	1.5	1.5	1.5	10.7	10.7	11.2
50	1.5	1.5	1.5	10.0	10.0	10.0
55	1.4	1.4	1.4	9.1	9.1	9.1
60	1.3	1.3	1.3	8.3	8.3	8.3
65	0.8	0.8	0.8	5.9	5.9	5.9
70	0.6	0.6	0.6	4.2	4.2	4.2
Exposure of 1 Sv [e]						
Newborn	24.9	16.1	12.1	15.3	17.9	20.6
5	20.6	14.4	10.6	14.8	17.1	20.0
10	17.0	12.9	9.3	14.4	16.3	19.2
15	14.2	11.6	8.4	14.0	15.5	18.3
20	12.1	10.6	7.8	13.6	14.7	17.3
25	10.5	9.7	7.5	13.1	13.9	16.1
30	9.3	8.9	7.3	12.7	13.1	14.9
35	8.4	8.3	7.2	12.1	12.3	13.6
40	7.8	7.8	7.2	11.6	11.6	12.4
45	7.4	7.4	7.1	10.9	10.9	11.3
50	7.0	7.0	7.0	10.1	10.1	10.1
55	6.7	6.7	6.7	9.2	9.2	9.2
60	6.4	6.4	6.4	8.4	8.4	8.4
65	4.1	4.1	4.1	6.0	6.0	6.0
70	2.8	2.8	2.8	4.3	4.3	4.3

[a] Estimated percentage of population that would die due to radiation-induced cancer. Computed using sex- and age-at-exposure-specific relative risk estimated for the life span study cancer mortality data for 1950-1987. Risks were applied to Japanese death rates of 1985 [J5]. Since sex-specific estimates of the excess risk were virtually identical, the estimates are averaged over sex.

[b] Average years of life lost per exposure-induced death. The average years of life lost per exposed person is equal to years of life lost per case multiplied by risk of exposure-induced death divided by 100.

[c] Constant relative risk for first 45 years after exposure; risk then decreases linearly with age. At attained age 90 years, the risk is equal to that for a person aged 50 years at exposure.

[d] Constant risk for first 45 years after exposure; risk then decreases linearly with age. At attained age 90 years, the risk is zero.

[e] Dose is weighted dose with neutron RBE = 10.

Table 31
Comparison of estimates of lifetime risk of mortality from solid tumours and leukaemia following acute whole-body exposures of 0.2 and 1 Sv [a]

Projection method	*Risk of exposure-induced death (REID) (%)*		*Years of life lost per case (YLC)*	
	Following exposure of 0.2 Sv	*Following exposure of 1 Sv*	*Following exposure of 0.2 Sv*	*Following exposure of 1 Sv*
Solid tumours				
Constant relative risk [b]	2.4	10.9	11.2	11.6
Decline to risk for age at exposure 50 [b]	1.9	9.2	12.1	12.3
Decline to zero risk at age 90 years [b]	1.6	7.5	13.6	13.3
Constant relative risk (UNSCEAR 1988) [c]	-	9.7	-	11.4
Leukaemia				
Linear-quadratic dose-response model [d]	0.14	1.1	31	31
Constant relative risk (UNSCEAR 1988) [c]	-	1.0	-	26

[a] Dose is weighted dose with neutron RBE = 10. Values are projections based on data for 1950-1987 [R23]. Age distribution of population is that of Japan in 1985 [J5].
[b] Based on a linear dose-response model with sex- and age-at-exposure-specific risks. Projection methods are described in footnotes c and d of Table 30.
[c] Risks computed using age-specific risk coefficients and multiplicative risk projection [U2].
[d] Projection was made using the excess absolute risk model fit to the life span study pooled leukaemia data, using a non-linear dose-response model.

Table 32
Site-specific lifetime risks for solid tumours and leukaemia following a whole-body acute exposure of 1 Sv [a]

Site of cancer	*Risk of exposure-induced death (REID) (%)*		
	Males	*Females*	*Both*
Leukaemia [b]	1.3	0.9	1.1
Oesophagus	0.3	0.7	0.5
Stomach	0.9	2.0	1.4
Colon	0.5	0.6	0.6
Liver	2.2	0.3	1.2
Bladder	0.4	0.2	0.3
Lung	1.8	3.1	2.5
Breast	-	2.0	1.0
Ovary	-	0.5	0.3
Other	4.3	2.0	3.1
Total (except leukaemia) [c]	10.4	11.4	10.9
Total	11.7	12.3	12.0

[a] Projections are based on age-at-exposure-specific values computed using death rates for Japan in 1985 [J5]. Rates were averaged over age at exposure using the population of Japan in 1985.
[b] Leukaemia risks were computed using the excess absolute risk model presented in [P33]. This model has a non-linear dose response and the risk varies with time, sex and age at exposure. Projection beyond the current follow-up was based on this model.
[c] Solid tumour risks were computed using linear dose-response models with age-at-exposure and sex-specific relative risks and a 10-year latency period.

Table 33
Standardized mortality ratios for all causes of death and for malignant neoplasms for nuclear energy workers [D10]

Nuclear installation	*Standardized mortality ratios [a] for deaths due to*					
	All causes	*All malignant neoplasms*	*Cancer of digestive system*	*Lung cancer*	*Cancer of lymphatic and haematopoietic system*	*Leukaemia*
United Kingdom						
United Kingdom Atomic Energy Authority	0.76	0.78	0.79 (108)	0.71 (153)	0.98 (38)	1.2 (18)
Sellafield [b]	0.96	0.96	1.07 (132)	0.88 (147)	0.93 (27)	0.83 (10)
United Kingdom Atomic Weapons Establishment [c]	0.73	0.79	0.84 (90)	0.64 (85)	0.48 (11)	0.44 (4)
United States						
United Nuclear	0.83	0.97	0.84 (107)	1.02 (14)	0.88 (4)	1.19 (2)
Pantex	0.72	0.63	0.45 (8)	0.51 (12)	0.89 (7)	1.34 (4)
Rocky Flats [b]	0.63	0.71	0.73 (25)	0.65 (30)	0.64 (9)	0.75 (4)
Portsmouth	0.78	0.96	-	-	0.74 (15)	0.88 (7)
Oak Ridge National Laboratory	0.73	0.80	0.67 (41)	0.75 (59)	1.04 (28)	1.50 (16)
Oak Ridge, Y-12 [d]	1.00	0.96	0.73 (210)	1.23 (324)	0.83 (77)	1.04 (40)
Oak Ridge, Y-12 [e]	0.89	1.01	0.74 (33)	1.36 (89)	0.90 (19)	0.50 (4)
Oak Ridge federal nuclear plants	1.11	1.05	0.80 (490)	1.27 (850)	0.98 (195)	1.13 (92)
Hanford	0.78	0.85	0.86 (310)	0.84 (339)	0.82 (103)	0.71 (36)
Linde Air Products	1.18	1.12	1.38 (27)	1.02 (21)	0.93 (6)	-
Savannah River	0.75	0.74	0.70 (50)	0.83 (83)	0.95 (32)	1.50 (18)
Naval shipyards	0.76	0.99	0.94	1.07	0.82	0.91

[a] Observed deaths in parentheses.
[b] Substantial proportion of radiation workers monitored for plutonium.
[c] Substantial proportion of workers exposed to tritium.
[d] Workers employed 1943-1947.
[e] Workers employed only after 1947.

Table 34
Estimates of excess relative risk per sievert for all cancers and leukaemia from studies of workers in nuclear and related industries [a]
[C34]

Nuclear installation	*Subjects*	*All cancers*			*Leukaemia*			*Other observations*		*Ref.*
		Number of deaths	*Excess relative risk (Sv^{-1})*	*90% CI*	*Number of deaths*	*Excess relative risk (Sv^{-1})*	*90% CI*	*Cancer type*	*Number of deaths*	
Canada										
Atomic Energy of Canada Ltd.	8,977	219 [b]	0.05	-0.68-2.17	4 [c]	19.0	0.14-113			[G3]
United Kingdom										
Atomic Energy Authority	21,545	720 [b]	0.8	-1.0-3.1 [d]	31	-4.2	-5.7-2.6	Uterus Prostate	8 42	[F11]
Atomic Weapons Establishment	9,389	275	7.6	0.4-15.3 [d]	4	-	-	Lung Prostate [e]	85 20	[B5]
Sellafield	10,157	396	-	-	10	*f*	*f*	Bladder Multiple myeloma Lympho-haematopioetic	14 7 27	[S14]
National Registry for Radiation Workers	95,217	1,435	0.47	-0.12-1.2	47 [c]	4.28	0.40-13.6	Thyroid	9	[K20]
United States										
Hanford	36,971	1,413 [b]	-0.0	-0-1.9	44 [c]	-1.1	-0-1.9	Hodgkin's disease Pancreas	19 77	[G16]
Oak Ridge National Laboratory	8,313	346	3.27	1.26-5.3	28	6.38 [g]	-11.2-24	Lung	96	[W21]
Combined [h]	35,933	1,036	-1.0	<0-0.4	42 [c]	<0	<0-3.4	Multiple myeloma	12	[G19]

[a] Doses are lagged by 10 years for cancers and 2 years for leukaemia unless otherwise specified.
[b] Excluding leukaemia.
[c] Excluding chronic lymphocytic leukaemia.
[d] 95% confidence interval.
[e] Only among workers monitored for exposure to radionuclides.
[f] Significant trend.
[g] Doses are not lagged.
[h] Hanford, Oak Ridge National Laboratory and Rocky Flats combined.

Table 35
Risk estimates for all cancer and leukaemia (excluding chronic lymphocytic leukaemia) from occupational studies and survivors of the atomic bombings in Japan

Study	*Excess relative risk (Sv^{-1})* [a]
All cancer	
United Kingdom [K20] National Registry for Radiation Workers [b]	0.47 (-0.12-1.20)
United States [G17] Hanford, Oak Ridge National Laboratory and Rocky Flats combined [c]	-1.0 (<0-0.4)
United Kingdom and United States combined [K21]	0.23 (<0-0.83)
Survivors of atomic bombings in Japan [d] Males only, exposed over age 20 years 1950-1970 (linear relative risk model, RBE = 10)	0.33 (0.11-0.60)
Leukaemia (excluding chronic lymphocytic leukaemia)	
United Kingdom [K20] National Registry for Radiation Workers [b]	4.3 (0.40-13.6)
United States [G17] Hanford, Oak Ridge National Laboratory and Rocky Flats combined [c]	<0 [e] (<0-3.4)
United Kingdom and United States combined [K21]	1.7 (<0-5.9)
Survivors of atomic bombings in Japan [d] [R23] Males only exposed over age 20 years 1950-1970 (linear-quadratic relative risk model, RBE = 10)	6.2 (2.7-13.8)

[a] Estimates for occupational studies based on a linear relative risk model. Doses lagged for 10 years (all cancer) or 2 years (leukaemia). 90% CI in parentheses.
[b] Based on monitored workers at sites operated by British Nuclear Fuels (including Sellafield), Ministry of Defence, United Kingdom Atomic Energy Authority and Nuclear Electric.
[c] Based on monitored white males employed at least six months at the Hanford site, Oak Ridge National Laboratory or at the Rocky Flats nuclear weapons plant.
[d] No low-dose-rate reduction factor has been included.
[e] Likelihood maximized at a value that would have led to negative excess relative risks.

Table 36
Comparison of risk estimates for mortality in survivors of atomic bombings in Japan and nuclear workers in the United Kingdom and in the United States

Group	*Size of cohort*	*Person-years*	*Collective dose (man Sv)*	*Average dose (mSv)*	*Excess relative risk (Sv^{-1})* [a]		*Lifetime risks (% Sv^{-1})* [a]	
					All cancer	*Leukaemia*	*All cancer*	*Leukaemia*
Survivors of atomic bombings [S7]	75,991	2,185,000	10,500	251	0.39 (0.32-0.46)	5.2 (3.8-7.1)	4 [b] (3-5)	0.4 [b] (0.3-0.55)
Nuclear workers in the United Kingdom [K20]	95,217	1,218,000	3,198	34	0.47 (-0.12-1.20)	4.3 (0.40-13.6)	10 (<0-26)	0.76 (0.07-2.4)
Nuclear workers in the United States [G17]	35,933	705,000	1,140	32	-0.99 (-1.6-0.38)	<-1.5 (<-1.5-3.4)	<0 (<0-8.2)	<0 (<0-0.60)

[a] 90% CI in parentheses.
[b] Based on ICRP [I10] with low-dose-rate reduction factor of 2.

Table 37
Cancer mortality among workers at the Mayak nuclear plant [a]
[N4]

Employees at	*Percentage of deaths from cancer for total gamma dose*	
	<1.0 Sv	*>1.0 Sv*
Facility A	5.7 ± 0.6	9.4 ± 1.2
Facility B	4.3 ± 0.4	8.1 ± 0.6
Both facilities	4.8 ± 0.4	8.4 ± 0.5

[a] Employees who started work before 1958.

Table 38
Cancer mortality among male workers at the Mayak reactors and reprocessing plant
[K23]

	Reactor workers		*Reprocessing plant workers*	
	1949-1953	*1954-1958*	*1949-1953*	*1954-1958*
Average cumulative gamma dose (Sv)	1.22	4.92	2.45	7.16
Number of workers with film badge record	1,286	509	1,812	1,479
Person-years (to 31 December 1989)	45,947	15,730	61,649	44,464
All cancer				
Observed	101	19	197	55
Expected	126.4	26.3	153.2	61.3
Observed/expected [a]	0.80 (0.7-0.9)	0.72 (0.4-1.1)	1.28 (1.1-1.4)	0.9 (0.7-1.1)
Leukaemia				
Observed	6	2	25	6
Expected	5.68	1.41	7.11	3.59
Observed/expected [a]	1.06 (0.5-2.1)	1.42 (0.3-4.5)	3.52 (2.4-4.4)	1.67 (0.7-3.3)

[a] 95% CI in parentheses.

Table 39
Lung cancer deaths in workers at the Mayak radiochemical plant
[H17]

Cumulative equivalent dose in lungs (Sv)	*Number of workers*	*Observed cases*	*Expected cases*
0-0.25	470	0	2.1
0.26-1.00	607	4	6.2
1.01-4.0	929	19	16.2
>4.00	340	22	8.1
All cases	2,346	45	32.6