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ORIGINAL ARTICLE: ASSESSMENT

Estimates of Uranium and Nuclear Radiation Casualties Attributable to Activities since 1945

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Estimates are presented of the total number of cases of malignant disease and of damage to offspring attributable to environmental or occupational exposure to low-level radiation produced by nuclear weapon tests and the nuclear industries.

KEYWORDS Nuclear weapon tests Nuclear power Long-term radiation effects

Introduction

The dropping of the atomic bombs on Hiroshima and Nagasaki in 1945 initiated an unprecedented arms race, which has escalated dramatically over the last 40 years. Theological, medical, philosophical and legal discussions of this frightening phenomenon have focused on the negative human consequences of the use of such an excessively destructive means for obtaining any goals, even self-defence or freedom. Much less can threatening the use of nuclear weapons in order to establish some world government based on a monopoly of such violence be justified. The *use* of nuclear weapons is not only self-destructive, but is also destructive of all the goals which they purport to preserve.[1]

The question of the legal and human acceptability of deterrence, i.e. the production, deployment and threatened defensive use of nuclear weapons, has been less clearly dealt with in the literature. Seemingly this is because production and possession of these weapons have been perceived to be 'harmless'. One does not normally condemn production or possession of a knife or hatchet as evil. In fact they are socially redeemed by being put to good uses, such as cutting bread or splitting wood for a fire. The nuclear-weapon nations have attempted an analogous move, creating a 'peaceful atom programme' which uses the fissioning of the uranium atom (a necessary part of the weapons cycle since it produces the plutonium) to boil water for generating electricity. This peaceful atom industry has been supported financially by governments and given intellectual support from the community of physicists and engineers. It has been widely advertised as a safe, cheap and efficient way to produce electricity.

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By averaging the dose of ionizing radiation, which the public and workers receive from the routine pollution released by the industry, over nations, regions or even the global community, the individual price paid in terms of health damage may seem small. It underemphasizes personal costs since pollution is not uniformly distributed. However, the total number of casualties does depend on the population dose, i.e. number of persons exposed multiplied by the average exposure, although the occurrence of casualties will be higher in a sub-population receiving higher than average dose. It is necessary to assume military-related exposure figures from the reported commercial nuclear experience since the military nuclear production industry is generally unreported in public literature.

I hope to demonstrate not only that the rates of deaths and injuries caused by the production and testing of nuclear weapons and production of nuclear power are high, but also that these rates exceed the death and injury rates caused by other hazardous industries tolerated in the first world. The usual criteria for the acceptability of an industry are: not more than one death per 10 000 workers per year, and not more than one death per million persons in the general public per year. These criteria appear to be exceeded by the nuclear industry.

If the average nuclear worker is exposed to only 20% of the recommended permissible occupational dose, i.e. to 1 rem per year, my estimate predicts 4 to 16 cancers (including leukaemia and other malignancies) per 10 000 workers per year.[2] For a dose of 1 rem, the International Commission on Radiological Protection (ICRP) prior to 1984 estimated about 1.25 cancer fatalities per 10 000 workers but has most recently admitted the number may be as high as 6. The US National Academy of Sciences' Biological Effects of Ionizing Radiation (BEIR III) Committee estimates this at about 10 cancer per 10 000 workers per year. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1977) still uses an estimate of one cancer deaths.

In addition to cancers, there could be genetic damage to some of the workers' children and some industrial accidents causing non-radiation related fatalities.

Assuming that the general public receives from the industry no more, on average, than 2% of the radiation exposure internationally recommended as 'permissible' from man-made sources (excluding medical), i.e. 0.01 rem per year, some 5–16 cancers per million people may be caused annually.[2] Again, ICRP prior to 1984 gave 1.25 and now appears to be saying six cancers. The BEIR III calculates about 10 cancer and UNSCEAR 1977 estimates one cancer. Even if some of these cancers responded to treatment or only indirectly caused death, fatalities would most likely exceed the 'one death per million persons per year' guideline.

Clearly the magnitude of the health damage caused by the production of nuclear weapons and nuclear power could be unusually large relative to other hazardous industries. Given randomly occurring accidents, 'abnormal incidents' or poor management of nuclear plants causing worker average

exposures to exceed 20% of the permitted maximum or the general public exposures to exceed 2% of their legally permissible level, the number of fatalities will be still higher. Until health records are properly kept and audited, such casualties and deaths are unlikely to be documented and the incidence may be masked by local variance in cancer and birth defect rates. Moreover, victims will have difficulty in establishing the cause of their suffering.

Methodology

Estimates of the health effects of the nuclear commercial and weapon industries and nuclear weapon tests are based on dose estimates in United Nations documents, which are derived from industry self-reporting. Risk estimates are given in my *Handbook for Estimating Health Effects from Exposure to Ionizing Radiation*.[2] These rely in part on atomic bomb studies in Hiroshima, and are expected to be revised upward. From Dr Edward Radford, who directed the US atomic bomb study revision and who was also Chairperson of BEIR III, I learned that the expected numbers of cancers per rad based on atomic survivor data will be about doubled (Personal Communication, 10 April 1985). As these new estimates are not yet available, my more conservative estimates will be used here.

I have calculated the collective radiation dose from nuclear weapon testing from UN data by multiplying the average dose by the global population figure.

As there are no public reports available on the nuclear weapon industry, I have assumed that it is equal in size to the strictly peaceful commercial nuclear industry.

Using the nuclear commercial industry reported numbers, the UN has derived estimates of the worker and general public exposures from the uranium support industries for each MWe of electricity generated. The support industries include uranium mining, milling, transportation and fuel rod fabrication. A British figure for reprocessing is also available.

The commercial reactors in Britain, France and the Soviet Union are presumably all dedicated to weapons since these countries engage in plutonium separation for either breeder reactors (which produce still more plutonium) or direct weapon manufacture. In the USA, commercial fuel rods were reprocessed for military use until 1972, the closing of the West Valley reprocessing plant. At present the fuel rods are being stored on the nuclear reactor sites, waiting for the completion of the new Purex Plant on the Handford Reservation in Washington State. They may then be used for the nuclear weapon programme, as an executive order by the President could override the current Nuclear Regulatory Commission prohibition.

Nuclear News of May 1984 lists 346 operating commercial nuclear generators each with capacity greater than 30 MWe, providing a combined global 230 000 MWe capacity. The planned 182 nuclear reactors are expected to add about 173 000 more MWe power in the near future. The list includes

many generators dedicated to both the commercial and military programmes. In addition to reactors listed by *Nuclear News*, there are so-called weapon reactors with no commercial function, reactors on submarines and naval vessels, training reactors for military personnel, and research reactors for research and training of unversity students. In the analysis I assumed that the non-reported nuclear weapon reactors had approximately the same MWe capacity as the strictly peaceful reactors. Those reactors considered 'strictly peaceful' make up about 30% of the reported commercial industry, therefore the hidden nuclear weapon industry was assumed to increase total global MWe by 30%.

Nuclear reactors seldom run at their potential capacity. In order to estimate more closely the actual operating experience, an assumption that reactors operate at 70% capacity was added. This adds a large degree of conservatism to the health estimates since reduced operation time for reactors frequently reflects shut-down for repairs often necessitated by abnormal releases of radiation. Moreover, the reactor start-up process releases more radioactive material than would be released in a comparable time period of smooth operation. Radiation exposures from leaks or start-up are not included.

UN estimates of absorbed radiation dose in rad by the public and by nuclear workers from the reactor industry and its support services were converted to dose equivalent by multiplying the dose in rad by the appropriate quality factor: 1 for external sources of radiation and for internal beta radiation, except from tritium for which I have used 1.8; and 20 for internal alpha emitters such as plutonium.

The *Handbook* was used to estimate the health effects per million person-rem. The main categories of effects are cancers and damage to offspring—genetic effects, infertility, intrauterine and infant mortality, and congenital malformations and disease.

The cancer estimates used in the *Handbook* were derived for North Americans, i.e. 549 to 1648 cancers per million person-rem dose[2] (from Table 9, p. 16).

In estimating the detriment to offspring globally, the numbers derived for the North American and European population were doubled. The crude birth rate for North America between 1975 and 1980 was 15.3 per 1000; for Europe it was 14.5 per 1000. For the same time interval the global average crude birth rate was 28.0 per 1000. The expected number of offspring and the number of women pregnant at any given time globally would be double those numbers used in the *Handbook*. The following estimates of damage to offspring of the global population per million person-rem were used: 1000 to 50 000 genetic diseases per generation at equilibrium; 4200 less offspring surviving to age 1 year; 18–22 congenital malformations; and about 4000 non-stochastic effects such as lower birth weight and mental or physical retardation[2] (from Table 43, p. 75). These latter effects reflect cumulative damage to the gene pool and affect human survival in the future.[4]

One other methodological question needs to be mentioned. Both for immediate, external radiation and for radioactive chemicals taken into the

body and incorporated into tissues such as the thyroid, muscle or bone, where the dose may be delivered over a period of days, months, years or a lifetime.[3] I have used the 50-year effective dose equivalent, allowing for the longest possibility for delivery of the dose. The 50-year effective dose equivalent may actually be received in a few days or over a lifetime. The radiation dose received by an individual in any 1 year is a combination of new exposure and the continued exposure to radioactive chemicals previously incorporated into the body. Using each year's 50-year dose equivalent eliminates the complication of calculating new and cumulative doses each year.

In this analysis the number of cancers expected eventually to develop into clinically detectable disease, and the cellular damage expected actually to result in a deformed or diseased child, are counted.[4] Where some damage is assigned to the time prior to and some after the year 2000, it is based on general bioavailability of the pollutant given no extraordinary human intervention (satisfactory isolation of uranium mining and milling waste could, for example, reduce the future damage to humans and to the environment), and relates to time of cancer initiation (time of exposure to the cancer-causing material), not the time of clinical diagnosis.

As stated above, it is expected that the cancer estimates will be doubled after the release of the re-analysis of the Hiroshima data by the US National Academy of Sciences.

Findings

I. *Nuclear weapon testing—1946 to 1976*

The 1977 UNSCEAR report to the UN General Assembly provides in its Table 26 of Annex C estimates of the average dose commitments from radionuclides produced in all nuclear weapon tests carried out prior to 1976. These doses in mrad converted to mrem to the year 2000 are shown in Table 1. The quality factor of 1 was used for external radiation and internal gamma radiation, 1.8 for internal radiation from ^{3}H (tritium), and 20 for internal alpha radiation from plutonium. This gives approximate doses per person of 0.1 rem to gonads and 0.2 rem to whole body (bone marrow, bone lining cells and lungs). For a world population in 1975 of 4.033×10^{9} (UN figure), the collective gonadal dose is approximately 0.1 rem $\times$ 4×10^{9} persons = 4×10^{8} person-rem. My estimates[2] of the effects of this collective dose are:

Genetic diseases:	400 000 to 20 000 000
Offspring mortality:	1 680 000
Congenital malformations:	7200 to 8800

The number of low birth weight infants, or those with mental or physical retardation, may be as high as 1.6 million.

For the whole body collective dose of 0.2 rem $\times$ 4×10^{9} persons = 8×10^{8} person-rem, my estimate of cancers is 400 000 to 1 300 000.

Table 1. Dose commitment from radionuclides produced in all nuclear tests carried out before 1976. In mrem, to the year 2000 (from UNSCEAR 1977 Table 26 of Annex C)

Source of radiation	Average dose to world population in mrem			
	Gonads	Bone marrow	Bone lining	Lung
External				
Short lived radionuclides	30	30	30	30
^{137}Cs	38	38	38	38
Internal				
^{3}H	3.6	3.6	3.6	3.6
^{14}C	7	32	29	9
^{54}Mn	—	—	—	1
^{55}Fe	0.7	0.4	0.7	0.7
^{90}Sr	—	52	71	—
^{89}Sr	—	0.3	—	—
^{106}Ru	—	—	—	24
^{137}Cs	17	17	17	17
^{144}Ce	—	—	—	38
^{239}Pu	—	—	18	18
Total*	96	173	207	179

*Rounded to nearest whole number

Table 2. Reported nuclear reactor operations in MWe, 1958–1984*

Year	MWe at the end of period (at 70%)	Estimated average annual MWe during period
1943–57	1968	984
1958–64	4133	3050
1965–69	10 879	7506
1970–74	40 718	25 798
1975–79	85 644	63 181
1980–84	162 700	124 172
Sub-total	162 700	—
Planned and under construction	283 855 (to year 2000)	233 278 (to year 2000)
Total at year 2000	283 855	

*The 1958 estimates were extended back to 1943 to cover the unreported nuclear reactors totally dedicated to weapon production. Aside from this extension, this table summarizes the *Nuclear News* (Feb. 1984) report on the size of the global commercial nuclear industry. The figures after 1958 need to be multiplied by 1.3 to approximate the size of the total nuclear industry.

II. *Nuclear power and support industries*

Table 2, derived from *Nuclear News*, February 1984, shows the gradual growth of the nuclear industry. Since the 'strictly peaceful industry' is estimated as 32% by number and 29% by MWe capacity of the total reported nuclear industry, these average figures for each time interval except the first should be multiplied by 1.3 to approximate an estimate of the total nuclear industry (the weapon industry plus the reported commercial sector).

Table 29 in UNSCEAR 1977 gives collective dose commitments to the general public from the entire fuel cycle, including uranium mining and milling in 'man-rad' per MWe produced per year. Based on this, Table 3 gives the person-rem doses per MWe generating capacity of nuclear reactors per year, together with the accumulated radiation doses to the public to the year 2000 based on 1984 commercial nuclear industry projections.

Health effects to offspring due to radiation dose to parents from nuclear reactor operation and its support industries can be estimated in relation to the 2.1 million (0.4 plus 1.7 million) person-rem dose to gonads (1943–1985). The dose commitment to offspring including planned industry expansion would be 8.4 million (1.7 plus 6.7 million) person-rem.

To extend these calculations to include the hidden nuclear weapon

Table 3. Estimated dose commitment to the general public from nuclear reactors and support industries, 1943 to 2000 (from Table 2 and UNSCEAR 1977 Table 29 of Annex D)

Years	Average annual MWe during period	No. of years	Estimated dose in person-rem: To gonads, Local/ regional	To gonads, Global	To whole body, Local/ regional	To whole body, Global
1943–57	984	15	5756	22 140	7528	56 088
1958–64	3050	7	8326	32 025	10 888	81 130
1965–69	7506	5	14 637	56 295	19 140	142 614
1970–74	25 798	5	50 306	193 485	65 785	490 162
1975–79	63 181	5	123 203	473 857	161 112	1 200 439
1980–84	124 172	5	242 135	931 290	316 639	2 359 268
Sub-total	—	42	About 0.4 million	About 1.7 million	About 0.6 million	About 4.3 million
Planned or under construction	223 278* (to year 2000)	15	About 1.3 million	About 5.0 million	About 1.7 million	About 12.7 million
Total to year 2000	—	—	About 1.7 million	About 6.7 million	About 2.3 million	About 17.0 million

*Note: Although it may be argued that some of the earlier reactors will have been closed down by this time, their support industries continue to pollute the environment even after shut-down. Moreover, reactors with output less than 30 MWe annually are omitted from this table, adding a further measure of conservatism to offset close down.

industries one should multiply the following by 1.3. My estimates[2] of the effects on offspring are:

	To 1985	To 2000
Genetic diseases:	2100 to 105 000	8400 to 420 000
Offspring mortality:	8820	35 300
Congenital malformations:	38 to 46	151 to 185

The numbers of low birth weight, mentally or physically retarded infants could be 8400 to year 1985, with an eventual increase to 33 600.

My cancer estimates[2] are based on the combined local/regional and global person-rem doses: 4.9 million (0.6 plus 4.3 million) person-rem to year 1985, and 19.3 million (2.3 plus 17.0 million) person-rem to year 2000, as given in Table 3. The number of cancers in the general population attributable to nuclear reactors and their support industries I estimate to be:

To 1985	To 2000
2700 to 8080	10 600 to 31 800

Total estimates, including weapon nuclear industries by multiplying by 1.3, are:

To 1985	To 2000
3500 to 10 500	13 800 to 41 300

Nuclear reactor accidents have not been included in these estimates.

III. *Nuclear workers*

Nuclear reactor operation involves radiation exposure for uranium and nuclear workers. Table 45 of UNSCEAR 1977 estimates 4 'man-rad' worker exposure for every MWe energy produced per year. Using the MWe production figures in Table 2, Table 4 gives estimated dose commitment to workers from the nuclear industries. It was assumed that the dose to gonads for workers is 3 person-rem per MWe per year, about 75% of the whole body dose. The estimates of MWe averaged after 1958 were multiplied by 1.3 to include both commercial and weapon nuclear industries.

Workers involved in actual weapon production, as distinct from the production of weapons material, and military and civilian workers at nuclear test sites were not included in the estimates, since their exposure is not reported.

As occupational exposure is chiefly to men, congenital malformations do not occur. In this analysis of damage to offspring it was assumed[2] that the fathers' exposures would be the source of about half the expected number of other effects. My estimates[2] of damage to children of these workers are:

	To 1985	To 2000
Genetic diseases:	2000 to 100 000	8500 to 425 000
Mortality:	8400	35 700

Table 4. Estimated dose commitment to workers from nculear weapon and nuclear power support industries, 1943 to 2000 (from Table 2 and UNSCEAR 1977 Table 45 of Annex D)

Years	Av. MWe annually period during	No. of years	Estimated dose in person-rem	
			To gonads	To whole body
1943–57	984	15	44 280	59 040
1958–64	3970	7	83 000	111 000
1965–69	9760	5	146 000	195 000
1970–74	33 500	5	503 000	671 000
1975–79	82 100	5	1 230 000	1 640 000
1980–84	161 000	5	2 420 000	3 230 000
Sub-total	—	42	About 4.0 million	About 5.9 million
Planned or under construction	290 000	15	About 13.0 million	About 17.4 million
Total to year 2000	—	—	About 17.0 million	About 23.3 million

For 1958 and beyond, the values in Table 2 were multiplied by 1.3 to include both weapon and commercial nuclear industries.

The corresponding estimates at these years for low birth weight, mentally or physically retarded children are 8000 and 34 000.
My estimates[2] of cancers in the workers are:

To 1985	To 2000
3240 to 9720	12 800 to 38 400

IV *Beyond the year 2000*

On the UN assumption that the carbon-14 already released by weapon testing prior to 1976 is the only radionuclide of consequence beyond the year 2000 (UNSCEAR 1977), an estimated additional 0.12 rem to gonads and 0.455 rem to whole body to the global population would be delivered over 8300 years. Assuming for the calculation that the size of the world population and the crude birth rate remain stable after the year 2000, this carbon-14 would cause an additional 0.12 rem × 6199 million people = 744 million person-rem gonadal dose and 0.455 rem × 6199 million people = 2820 million person-rem whole body dose.

My estimates[2] of the future effects from these dose commitments are:

Damage to future offspring:
Genetic diseases: 744 000 to 37 200 000
Offspring mortality: 3 120 000
Congenital malformations: 13 400 to 16 400

There may be as many as 3 000 000 low birth weight, mentally or physically retarded children.

Future cancers: 1 550 000 to 4 650 000

Conclusion

Additionally, in future time, there could be an incalculable number of additional cancers and birth defects due to uranium mining and milling, debris and radioactive waste.

The total of all these health effects is staggering and it is only because the casualties and deaths are spread out both geographically and in time that we fail to notice them. In areas where the casualties are most concentrated, as for example the Marshall Islands, Utah, Namibia, Elliot Lake (Canada), and other uranium or nuclear-polluted areas, the victims have little political voice.

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Rosalie Bertell obtained her PhD in biometrics in 1966 and was Senior Cancer Research Scientist at Roswell Park Memorial Institute, Buffalo, 1969–1978. She has numerous publications on environmental health and peace subjects. Dr Bertell, well-known inter-nationally for her campaigning against the dangers of nuclear technology, won a Right Livelihood Award (the 'Alternative Nobel Prize') in 1986 for her work on the effects of low-level radiation. She is a member of the Order of Grey Nuns.

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LETTERS TO THE EDITORS

Nuclear radiation casualties

I should like to comment on a point in my article 'Estimates of Uranium and Nuclear Radiation Casualties Attributable to Activities since 1945' (*Med War* 1988; 4: 27–36) which could be a source of confusion for the reader.

Estimates of cancers per person-rem exposure to ionizing radiation are complicated by the nuclear industry's choice to count cancer fatalities (a number which varies with availability of medical care and survival rate for the infectious diseases or stress connected with cancer development), and my medical orientation towards counting cancer incidence. This is reflected in the numbers which I quoted in my article per person-rem exposure: the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) use respectively 125 and 100 cancer fatalities per million person-rem exposure. The US National Academy of Science Committee on the Biological Effects of Ionizing Radiation (BEIR) gives both cancer incidence and cancer death estimates. I used the cancer incidence rates derived from the BEIR table of *absolute risk* estimates by cancer site and age at time of exposure for 11 to 30 years after exposure. These incidence rates are doubled to respect host vulnerability, i.e. the *relative risk* estimates, and increased to include the leukaemia and bone cancers which appear within 3 to 5 years of exposure and also those cancers appearing more than 30 years after exposure. One thousand cancers per million person-rem is a rough estimate from this source. My estimate of 549 to 1648 is derived from cancer incidence rates as reported in peer reviewed literature. I used the word 'casualty' rather than fatality to indicate the magnitude of incidence rate for cancer and congenital effects, not all of which are first cause of death.

I should like to take this opportunity to update your readers on my Institute's new address, which is as given below.

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