RISK AS A BASIS FOR RADIATION PROTECTION

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Discussions on risk in radiation protection go back more than 30 years (1,2) but it was not until Report 26 by the ICRP in 1977 (3) that risk estimates became closely associated with a protection system. Since future protection systems will become more and more dependent on numerical estimates of risk, these estimates and their uncertainties become of critical importance and must constantly be updated as new information becomes available. I shall discuss here some features of the complex subject of somatic risk from ionizing radiation in relation to problems in radiation protection. Others in later plenary lectures will develop other aspects of this question.

SOMATIC RISKS

Somatic risks are distributed in time after each exposure and, for example, when an individual receives a dose of 1 rad of low-LET radiation, he or she is initially at risk of dying from leukemia or later from any one of a wide variety of solid tissue tumors, especially thyroid, breast, lung or bone. A model which attempts to describe the situation is shown in Figure 1.

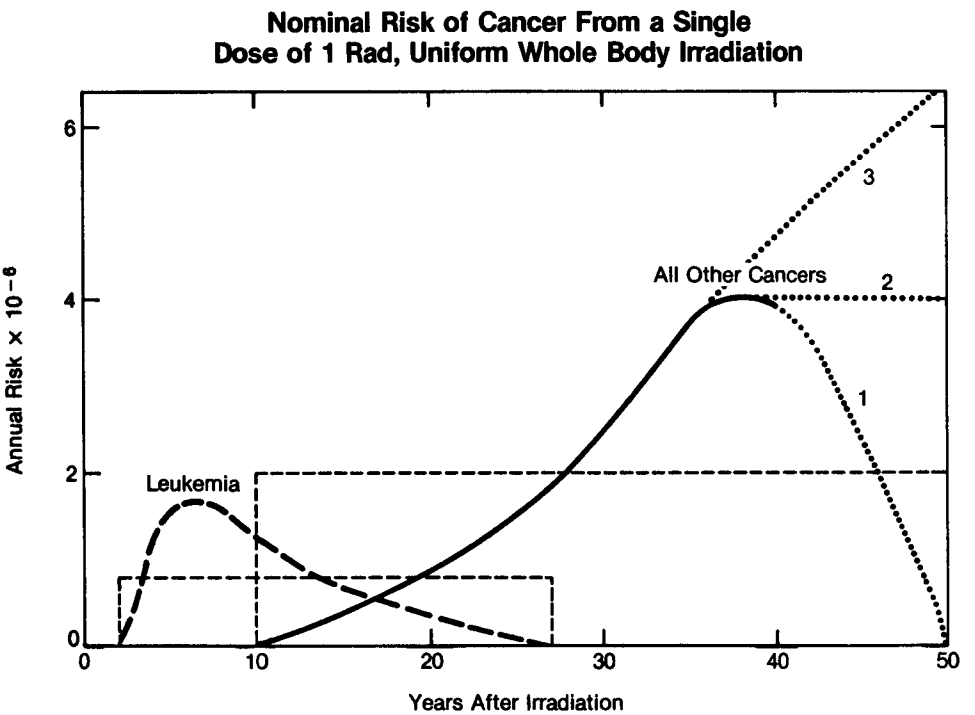

Figure 1

At first, for 2 years, there is no risk. Then the individual is at increasing risk of leukemia up to about 6-8 years, the risk falling slowly thereafter to essentially zero at 27 years. The average annual risk over the period shown dashed is 0.8×10^{-6}/year and the period of risk is 25 years, so that the lifetime risk of mortality from leukemia is 2×10^{-5} per rad. In the case of the solid tumors, we know the exact time relationships less well, especially at later times which are shown dotted. There is no risk in the first 10 years (latent period); then the risk rises slowly. Thereafter the risk may decline (like leukemia) to be over by about the 50th year, curve 1, continue at about the same level, curve 2, or rise steadily, like the natural risk of cancer, curve 3. For simplicity, we shall consider curve 1; the average annual risk is taken to be 2×10^{-6}/year for a period of risk of 40 years (dashed line) or a lifetime risk of solid tissue cancers per rad of 8×10^{-5}. (The actual values of the annual risk, 0.8×10^{-6}/yr for leukemia, 2.0×10^{-6}/yr for solid tumors can easily be adjusted in the model if and when this should be warranted.) The risk of solid tumors, while slower to develop, is 4 times greater than that of leukemia, and the total risk of leukemia and other cancers is 10^{-4} per rad lifetime. Note that for individual solid tumors, e.g., lung and breast, the actual latent periods and periods at risk may differ and latent periods also vary with age.

It is evident (4) that after continuous irradiation, the annual risk will increase year by year in a somewhat complex way, reaching about 10^{-4}/yr after 50 years at 1 rad/yr, and an accumulated risk of 0.24% eventually rising to 0.5%. If the risk from each dose is actually over after 50 years, all risk will not cease until 50 years after exposures are terminated. Risk will never cease if the risk from a single dose continues indefinitely.

Recently (4), nine different estimates of risk for individual organs made between 1957 and 1982 were compared; they varied by not much more than a factor of 2. Table 1, for example, compares the "best" estimates made by UNSCEAR 1977 (5), ICRP 1977 (3) and BEIR 1980 (6) with a more recent NCRP appraisal (7) which includes the latest Japanese data (8). Actually, each of the reports gave ranges

Table 1
ABSOLUTE RISK ESTIMATES (LIFETIME)
(MORTALITY X 10^{-6}/RAD)

	UNSCEAR 1977	ICRP 1977	BEIR 1980	NCRP 1983
Leukemia	20	20	25	20
Thyroid	10	5	~ 5	5
Breast	(50)	AVG 25	20	20
Lung	25	20	25	25
All Others	40	50	35	50
	95-145	125	110	120

NCRP Figures are Based on Appraisal of All Earlier Data plus Kato and Schull 1982.

and in particular the BEIR committee gave various other estimates based on other projection and extrapolation models.

In addition to the uncertainties associated with the small numbers involved in each tumor endpoint, the estimates depend on many other factors, some of which are not well known or understood. I have already published some comments about them (9,10,11), and I will make only a few points here.

Japanese Data, Leukemia and Solid Tumors

The total risk was taken to be 5 x leukemia risk (5). The lifetime leukemia risk at 2 x 10^{-3} Sv^{-1} is probably known to within about a factor of 3. The ratio 5, once thought to be only about 2 (in the 1950's) was first cited as 5 by NCRP in 1971 (2). Even as the data from Japan continues to accumulate more and more solid tumors (but no more leukemias), the projected number of 5 still seems to be a conservative ratio since to date there are ~ 90 leukemias and about 160 solid tumors, a ratio of about 1.8. However, the solid tumors in the last 4-year period rose sharply (8), and the next periods of data accumulation in the Japanese will be critical. The value of the ratio is supported by other sources, not useful for quantitative risk estimates because of poor dosimetry, but useful for ratios, such as the U.S. and the British radiologists, studies of pelvic irradiation, and the treatment of spondylitis with x rays.

Japanese Dosimetry

Estimates of the doses received by the Japanese survivors of the A-bombs were made in 1950, 1957 and 1965 (12). Recently, as a result mainly of new spectral information on the radiations believed to have issued from the weapons and some new transport calculation techniques, revisions in the doses have been proposed (13). The proposed changes at Nagasaki are minor but those at Hiroshima may decrease the neutron dose by about x 10 and increase the gamma dose by about x 4. A multilaboratory program now in progress is likely to confirm the LLNL estimates, at least approximately. Some changes in structural shielding and organ shielding estimates must still be taken into account. An extensive program of actual measurement of the dose--by activation techniques for the neutrons, and by thermoluminescence in roof tiles for the gamma rays is planned in both Japanese and U.S. laboratories (14). This may provide a real measurement estimate of the doses to confirm or challenge the calculations. The effect of the changes on risk estimates is not expected to be large, the effects at Hiroshima previously thought to be due to neutrons now being attributed to the increased γ rays. It will be surprising if, in the end, our estimates of γ risk change by as much as x 2 (15). (If risk estimates are based on sources other than the bombs only, the estimates rise by about 50-100% (4,16), well within the uncertainties expected.) The new proposed dosimetry brings the data for the two cities into better agreement for some biological endpoints, such as leukemia (17,15).

Absolute and Relative Risk

The risks quoted above are based on the absolute risk model. BEIR 1980 gave estimates based on each model and in some cases relative risks are 2 to 3 times greater than the corresponding absolute risk. Relative risk seems to have been a more useful predictor of

effects in the Japanese than absolute risk, at least for two age groups (18). Relative risk may not be so useful for comparing organ risks or for constructing protection systems based on comparative organ risk such as that of ICRP (3).

The respective merits of absolute and relative risk models will undoubtedly be better understood when the accumulation of data in the Japanese is more mature. Obviously, the two models have different mechanistic implications.

Incidence vs. Mortality

Mortality information has until recently been more reliable than incidence data. As incidence data improve, they may assume greater importance because of their more direct applicability for dose-effect models and their possible significance philosophically. The relationship between induced and fatal cancers varies with site but may be about x 2 higher overall.

In spite of these and many other uncertainties, the estimates of risk given in Table 1 seem sound, though surprises are always possible because our data at low doses is still so unfirm. However, until the cancers other than leukemia in the Japanese become clear (one or two more data cycles at least) and the dosimetry re-evaluation is complete, higher total risk estimates even for low-LET radiation cannot be discounted.

RISK AND RADIATION PROTECTION LEVELS

Radiation protection levels for workers, for the public and for emergencies have been in existence for some time; they were developed without risk as a base and have served our society well, so far. How then, does one relate a knowledge of risk to judgments about protection levels? One way is to simply consider the risks associated with the levels and compare these with other appropriate circumstances.

Occupational

We can derive from the model of Figure 1 (4) that exposure continuously at 1 rad/yr will result after 50 years in an annual risk of 10^{-4}/yr and an accumulated risk of 0.24% (eventually 0.5%). Also, comparison with fatal accident rates in industry indicates that we should aim to maintain the average risk to workers below 10^{-4}/yr in order to compare favorably with the "safer" industries (4,7).

Actual exposures in occupational circumstances in the USA for different worker groups are shown in Table 2. They involve nominally 1,357,000 workers to an average exposure of 110 mrem. For those actually exposed, 610,000, the average is 250 mrem, corresponding to an annual risk eventually of 0.25 x 10^{-4}/yr and a lifetime risk (eventually) of about 0.125%.

While the average level may be satisfactory, some few workers could be consistently close to the maximum annual limit. At 5 rem/yr for 50 years (age 18-68), 250 rems is theoretically possible, an annual risk of 5 x10^{-4}/yr and a total risk after 50 years of 1.2%

Table 2
OCCUPATIONAL EXPOSURE SUMMARY
(1980)

	No. of Workers		Mean Exposure mrem		Collective Dose
	Total	Exposed	Total	Exposed	(person-rem)
Medicine	477,500	218,600	70	150	32,600
Industry	371,800	196,700	120	230	46,200
Nuclear Fuel Cycle	148,100	82,900	390	700	57,700
Government	178,600	56,300	60	200	11,100
Misc.	181,100	53,400	40	140	7,900
All Workers	1,357,100	612,900	110	250	155,500

rising to a maximum of 2.5% lifetime. This is high compared with a natural rate of dying of cancer of 16-20%. This risk could be avoided by either a lifetime limit of say 100 rems or perhaps better 2(N-18) rems where N is the age in years. This would keep the flexibility of the NCRP age proration formula, limit the exposure of the youngest workers, limit the overall risk to no more than 1% and reduce the magnitude of the changes in organ dose levels permitted by the ICRP system. NCRP is giving consideration to this at present. In other respects, the exposure of workers seems reasonable and on the average decreasing with time, so that ALARA seems to be working.

High LET Radiation

An important subset of the occupationally exposed are those relatively few individuals, potentially or actually exposed to high LET radiations such as neutrons. NCRP issued a statement in February 1980 (19) warning that neutrons may be somewhat more hazardous relative to x and γ rays than previously thought. This view was based mainly on the effects attributed to neutrons at Hiroshima, based on the T65 dosimetry, but also on the increasing awareness of laboratory studies indicating RBE's higher than the quality factor (of 10) for fission neutrons. Subsequent dosimetric information has essentially removed the neutrons from the scene at Hiroshima, but laboratory studies have continued to indicate RBE values higher than 10 at low doses. The RBE values may depend on endpoint and an average may be in the 30-50 range (20). The situation, as indicated in the NCRP statement, may not be as drastic as these RBE's imply because measurement on the body may tend to overestimate the actual whole-body dose substantially. Nevertheless, it seems that revisions in the quality factor should be in prospect when adequate data is available and a comprehensive study of the problem can be completed.

Public

Some of the sources of exposure to the public yielding the largest population detriment are shown in Table 3. The limit for individual members of the public, 0.5 rem/yr, results in an average

Table 3
POPULATION DETRIMENT FROM DIFFERENT RADIATION EXPOSURE CIRCUMSTANCES

SOURCE	AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT	# PEOPLE	ANNUAL COLLECTIVE EFFECTIVE DOSE EQUIVALENT
BACKGROUND OTHER THAN RADON	1 mSv	240×10^6	240×10^3 Person-Sv
RADON - AVERAGE BACKGROUND (0.2 WLM/YR)	2 mSv	240×10^6	480×10^3 Person-Sv
- MOST HIGHLY EXPOSED AT >2 WLM/YR	20 mSv+	0.33×10^6	6.6×10^3 Person-Sv
MEDICAL EXPOSURES	0.9 mSv	240×10^6	220×10^3 Person-Sv
OCCUPATIONAL	2.5 mSv	1.36×10^6	1.55×10^3 Person-Sv

"expected" level to the public (3) of 0.05 rem/yr. Associated with this is a maximum risk of 0.5×10^{-5}/yr and an accumulated risk of 1.2×10^{-4}. Background to the whole body (excluding radon) gives rise to an annual risk, at the average level of 0.1 rem/yr, of 10^{-5}/yr after 50 years and a total accumulated risk of 0.024% in 50 years or possibly up to about 0.05% lifetime. Radon exposure to the lungs is an additional factor. The effective dose equivalent from the average radon background level of 0.2 WLM/yr in the USA is estimated to be 0.2 rem/yr, i.e., the risk of lung tumors from the radon background is twice as great as the risk of all cancers from other background sources. Furthermore, the maximum levels of radon can reach above 10 times the average, i.e., 2 WLM/yr, which is the NCRP's proposed limit for remedial action, and at this level the annual risk reaches 2×10^{-4}/yr and the total risk about 1% lifetime.

While these levels are experienced by relatively few people, estimated at about 330,000 persons above 2 WLM/yr, the collective dose is substantially more than that involved in exposures to the radiation work force. Furthermore, the information we have is based on a limited data base and more data are needed to determine whether the problem is more or less serious than we currently believe.

Emergency Levels

Formerly, levels were promulgated for working circumstances involving, for example, emergency situations arising from accidents. Recommended levels (2) for emergencies were 100 rem lifesaving and 25 rem non-lifesaving. Neither NCRP nor ICRP now recommend an emergency level, and they suggest the use of volunteers. The former numbers are useful as guides, perhaps in public as well as occupational circumstances. At 100 rem, the risk of acute effects is small but the cancer risk will follow Figure 1 and continue for 50 years, reaching a maximum annual risk of perhaps 10×10^{-4}/yr and a 50-year risk (also the lifetime risk) of 2.5×10^{-2}. (The risk coefficient to be associated with 100 rem is that associated with higher doses and dose rates viz 5×10^{-5} for leukemia x 5 for all cancers, not the 2×10^{-5} for leukemia used at low doses.)

For 25 rems, the situation is equivocal; the dose is neither high nor low, thus the base leukemia risk coefficient is between 2 and 5 x 10^{-5}, and the total risk is between 2.5 and 6 x 10^{-3} lifetime.

Space

Since 1970 radiation exposures to individuals on missions in space has been limited by the recommendations of the Space Science Board (13). These include a lifetime limit of 400 rems which would probably be received in smaller amounts per mission. Thus, the risk is probably between 4 and 10 x 10^{-2}, i.e. 4-10% lifetime, a rather considerable addition to the normal risk of cancer. Even so, the annual risk, which may be about 0.5% over a 20-year period, may not be large compared with other risks the astronauts face. Further study of space radiation hazards seems warranted (21).

CONCLUSIONS

An examination of the risks associated with current protection levels seems to indicate that occupationally, the average exposures are satisfactory, but that some additional limitation may be necessary for exposures close to the limit and NCRP is considering this. Further consideration needs to be given to exposures to high LET radiation since RBEs may require adjustments in the quality factor. Public: Exposures to man-made sources are generally small compared with those from natural background, only medical procedures being close to the same range. The most important source of exposure in many countries is radon and both ICRP and NCRP have drawn attention to this and proposed similar action levels. Emergency situations and space radiation activities are special circumstances involving relatively few people and higher risks of other kinds, so different judgments need to be employed.

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