A GUIDE TO MSK III RISK ESTIMATES

FOR RADIATION WORKERS

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Glossary

Hanford Data These data describe workers in a reprocessing plant which is situated in Washington State USA and has been in operation since 1944. They are currently the only source of worker-based estimates of cancer risks from low-level radiation.

Low-Level Radiation Includes single or repeated exposure to doses of radiation which are much too small to have obvious (tissue damage) effects. Workers who are repeatedly exposed may have high cumulative doses. These should not be confused with single doses of sufficient strength to have obvious (tissue damage) effects and are a reminder that dose rates may be slow or fast.

Stochastic Effects of Ionizing Radiation Health effects caused by damage to the controlling genes of single cells or mutations. Gene damage may be a forerunner of cancer or genetic defects and a single defective gene may be sufficient to initiate future trouble. Therefore, for stochastic effects of radiation there is no such thing as a dose level below which there could never be any health effects.

Non-Stochastic Effects of Ionizing Radiation Tissue damage or cell death effects of radiation. Though these are typically high dose effects, long-lasting damage to blood forming tissues (marrow aplasia or fibrosis) may be caused by much smaller doses than equivalent damage to other organs. Furthermore, recent work has shown that incomplete recovery from marrow damage (with possible consequences for all causes of death) is relatively common and easily mistaken for complete recovery.

External or Penetrating Radiations These include gamma rays, x-rays and neutrons. Individual monitoring by film badges worn on overalls during working hours is no problem and annual doses should be available for all radiation workers. For external radiation there is virtually no difference between rads (units of absorbed dose) and rems (units of tissue dose equivalents).

Internal Radiation Includes alpha and beta radiation. Requires internal depositions of radioactive substances and is not easily measured. Individual monitoring requires either whole body counts at frequent intervals or periodic testing of urine or other blood fluids (bioassay data) and rads no longer equal rems.

ABCC Atomic Bomb Casualty Commission whose publications are an important source of risk estimates for health effects of low-level radiation. These estimates are all based on persons who were still alive 5 years after the bombing of Hirosima and Nagasaki[1].

ICRP International Commission for Radiation Protection whose most recent recommendations for health risks of radiation workers are contained in ICRP 26[2]. According to these recommendations (i) for badge monitored workers the maximal permissible dose of external radiation is 5 rems per annum; (ii) for internal radiation equivalent dose levels are organ-related and may be much higher than 5 rems per annum; (iii) linear extrapolation of high dose observations should somewhat exaggerate the effects of low doses because the true curve is curvilinear upwards; and (iv) the slower the dose rate the smaller the risk of any delayed effects.

MSK Mancuso, Stewart and Kneale who are authors of a series of papers (based on Hanford workers) with findings which cannot be reconciled with ICRP 26 recommendations.

Nature of the Differences between ICRP Recommendations and MSK Risk Estimates

ICRP 26 recommendations are based on ABCC publications whose conclusions are in reasonably close agreement with the findings for radiotherapy patients[6] and animal experiments. MSK III estimates are based on Hanford data and are in reasonably close agreement with estimates based on in utero to pregnancy x-rays[7] but (1) they are an order of magnitude higher than ICRP 26 recommendations; (2) they imply that linear extrapolation of high dose observations is bound to under-estimate the risks at low dose levels because the true curve is curvilinear downwards, and (3) as a result of the dose response curve obeying the square root law, the risk of delayed (mutational) effects is greater for slow than fast delivery of the radiation (i.e. in the long run a slow dose rate is more dangerous than a fast rate).

Neither Hanford workers nor the children who were x-rayed in utero had any experience of high doses but some A-bomb survivors and all of the radiotherapy patients had doses which were well above the lowest level associated with bone marrow damage. The effects of such damage include loss of immunological competence (with heightened sensitivity to infections) and eventual development of aplastic anaemia. Therefore, the clash between ICRP recommendations and MSK risk estimates could be due to early (marrow damage) effects of high doses preventing full expression of much later (mutational) effects.

Evidence in support of this hypothesis has been found in several ABCC publications[7,8]. Therefore, it is unlikely that A-bomb survivor estimates will always be the basis of ICRP recommendations for radiation

workers and almost certain that their place will sooner or later be taken by estimates based on workers. Therefore, all medical and legal advisers to radiation workers should at least know of the existence of Hanford data and know how to apply MSK risk estimates to workers whose records include annual doses of external radiation.

Hanford Data

These data relate to 30,000 operatives from a reprocessing plant which is so highly mechanised that, over a period of more than 30 years (1944-75), individual monitoring for external and internal radiation (by film badges and bioassay tests) only found 15 workers whose doses of external radiation exceeded 5 rads per annum, and 225 workers with even short lived evidence of internal radiation. Therefore, Hanford data should be a reliable source of risk estimates for delayed effects of repeated exposure to very small doses of external radiation.

Deaths of the Hanford workers were ascertained by periodic screening of Social Security numbers for death benefit claims, and later identification of the death certificate of these ex-workers. Therefore, measures of relative risk (which only require comparisons between different dose levels) were more easily obtained than measures of absolute risk (which require comparisons between survey data and national statistics and are only valid if the worker population is a true cross section of the nation). Thus far, only primary causes of death have been used as indicators of radiation health effects. Therefore, there has probably been better recognition of radiation effects for lethal cancers, such as cancers of bone marrow or lung, than cancers with a good prognosis, such as cancers of prostate or skin.

The latest MSK risk estimates were obtained after dividing the workforce into 480 cohorts or groups which were controlled for numerous factors including radiation danger levels for different occupations, and the cancer deaths were divided into two groups (i.e. cancers of tissues which earlier studies had shown were exceptionally radiosensitive so called group A cancers, see table 1) and other or unspecified cancers (Group B).

MSK Estimates of Relative Risk

A statistical analysis which was designed to meet all objections raised by critics of earlier estimates of relative risk (and had several optimal properties) found definite evidence of radiation effects for the group A cancers and showed that they were influenced by the following factors:-

1. Exposure Age The radiation effect increased progessively with age thus making the risk for workers aged 40 years over twice as high as the risk for workers aged 30 years (table 2 and Fig.).

2. Cancer Latency Intervals between cancer induction and death were usually measured in decades but there was a wide spread on either side of the most dangerous interval, (i.e. 25 years, see table 2 and Fig.). Therefore, even a cancer death within 5 years of a radiation exposure has a small chance of being radiation-induced.

3. Dose Response The cancer risk per unit dose showed signs of being greater at low than high dose levels (table 4 and Fig.). Therefore, although a dose of 15 rems might be sufficient to double the normal risk of developing a group A cancer, a three-fold increase in risk would require a dose of 60 rems.

Finally, tables 5 and 6 show the actual dose records of two Hanford workers and the calculations which led to the conclusion that only one of these men was eligible for compensation. In each table the "cancer effective" dose for each working year was obtained by multiplying the actual dose by the appropriate age and latency factors, and the relative risk was then obtained by summing the effective doses for each year (to obtain a cumulative dose) and consulting table 4. For the first worker the effective dose (38.4 rads) was much higher than the actual dose (6.6 rads), and for the second worker it was much lower (0.9 rads and 7.7 rads) and this difference was the result of the first worker being older than the second and not dying until several years after leaving Hanford.

References

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2. ICRP Publication 26, Radiation Protection, Recommendations of the International Commission on Radiological Protection.
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6. Smith, P. & Doll, R. Mortality Among Patients with Ankylosing Spondylitis after a Single Course with X-rays. Brit. Med. J. 1, 1982, 449-460.
7. Stewart, A.M. Delayed Effects of A-bomb Radiation : A Review of Recent Mortality Rates and Risk Estimates for Five-year Survivors. J. of Epid. and Comm. Health, 36, June 1982, no.2, 80-86.
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Table 1

List of Cancers of Radiosensitive Tissues[1]

Tissues	ICD Nos. (8th Revision)
Pharynx	146 - 149
Bronchus and lung	162 ; 163
Stomach	151
Large Intestine	153
Pancreas	157
Breast	174
Bone Marrow[2]	203 ; 205
Other Haemopoetic[3]	200 - 202 ; 206 - 207
Thyroid	193

(1) see ICRP 14 also MSK III

(2) Includes Myeloma (203) and Myeloid leukaemia (205)

(3) Includes Lymphosarcoma (200), Hodgkins disease (201) and other or unspecified leukaemias (206-7)

Exposure Age Factor

(see table 2)

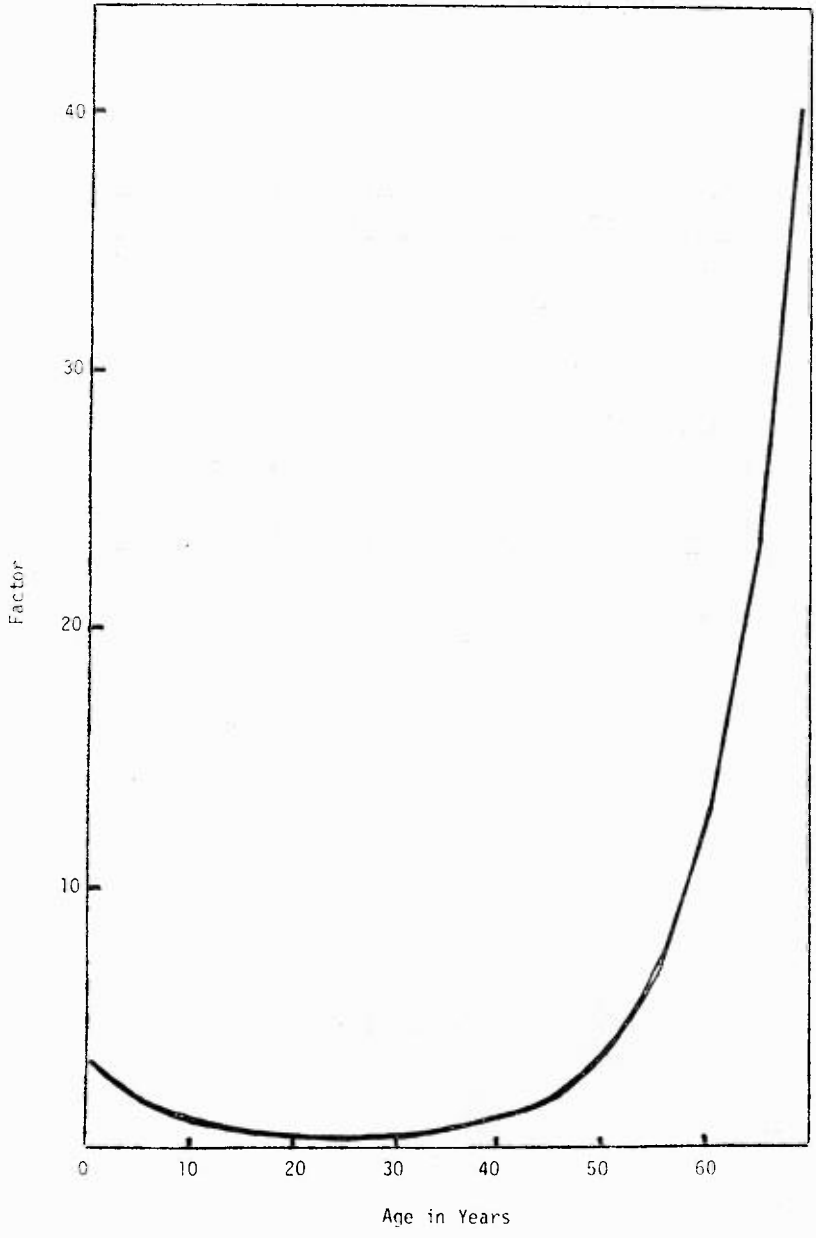

Table 2

Exposure Age Factor (1)

Standard Age (1.0) = 40 years

Exposure age in years	Age Factor	Exposure age in years	Age Factor	Exposure age in years	Age Factor	Exposure age in years	Age Factor
0	3.10	20	0.25	40	1.00	60	12.5
1	2.70	21	0.22	41	1.13	61	14.0
2	2.40	22	0.20	42	1.30	62	16.0
3	2.12	23	0.17	43	1.48	63	18.2
4	1.87	24	0.15	44	1.65	64	21.0
5	1.65	25	0.16	45	1.87	65	23.3
6	1.48	26	0.17	46	2.12	66	26.7
7	1.30	27	0.20	47	2.40	67	31.0
8	1.13	28	0.22	48	2.70	68	35.0
9	1.00	29	0.25	49	3.10	69	39.5
10	0.90	30	0.29	50	3.49		
11	0.80	31	0.33	51	3.90		
12	0.74	32	0.38	52	4.40		
13	0.62	33	0.43	53	5.01		
14	0.54	34	0.49	54	5.70		
15	0.49	35	0.54	55	6.52		
16	0.43	36	0.62	56	7.71		
17	0.38	37	0.74	57	8.60		
18	0.33	38	0.80	58	10.00		
19	0.29	39	0.90	59	11.10		

(1) Only of relevance if a worker subsequently develops one of the cancers in Table 1.

Latency Factor

(see table 3)

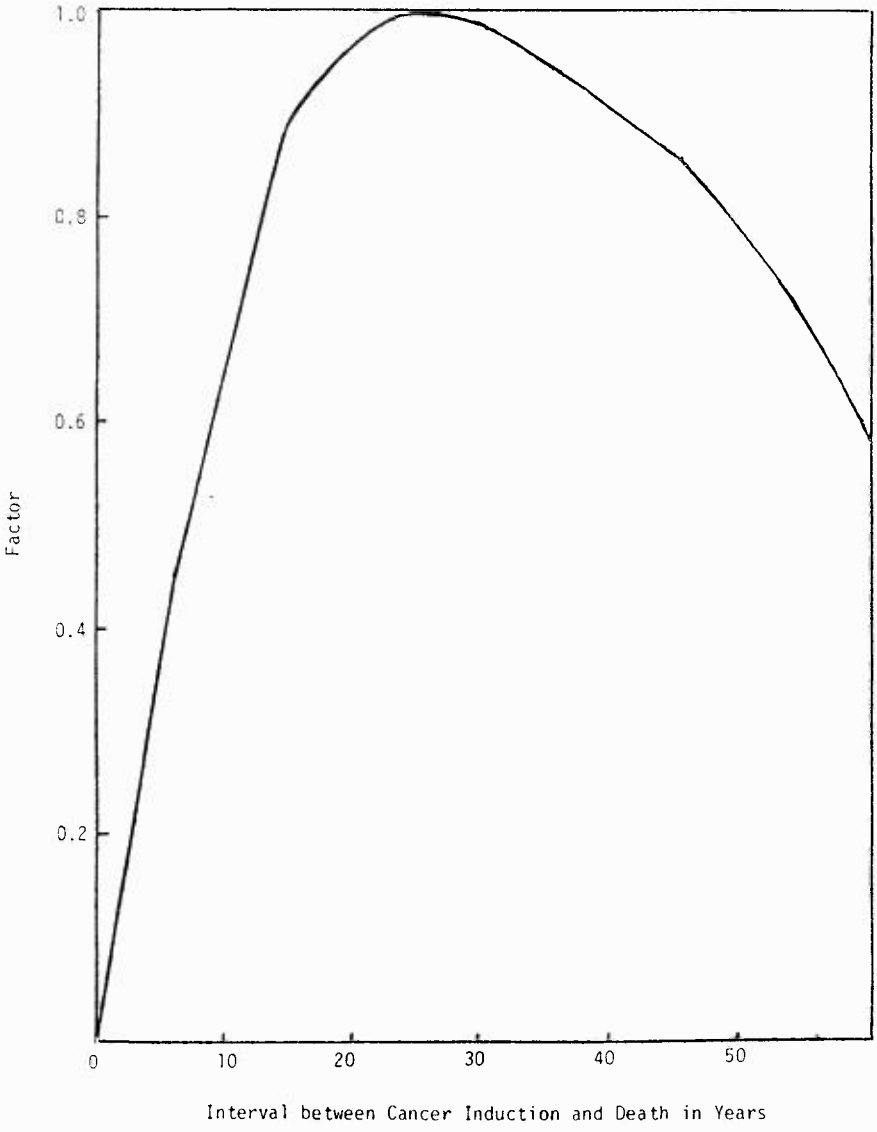

Table 3

Latency Factor[1]

(Interval between Cancer Induction and Death)

Standard Pre-death Period (1.0) = 25 years

Pre-death years	Latency Factor	Pre-death years	Latency Factor	Pre-death years	Latency Factor
0	0.00	20	0.97	40	0.89
1	0.10	21	0.98	41	0.88
2	0.20	22	0.99	42	0.87
3	0.29	23	0.99	43	0.86
4	0.37	24	1.00	44	0.84
5	0.44	25	1.00	45	0.83
6	0.51	26	1.00	46	0.81
7	0.56	27	0.99	47	0.79
8	0.62	28	0.99	48	0.78
9	0.68	29	0.99	49	0.76
10	0.73	30	0.98	50	0.76
11	0.77	31	0.98	51	0.74
12	0.81	32	0.97	52	0.73
13	0.83	33	0.96	53	0.70
14	0.86	34	0.95	54	0.69
15	0.88	35	0.94	55	0.68
16	0.90	36	0.93	56	0.67
17	0.93	37	0.92	57	0.64
18	0.94	38	0.90	58	0.63
19	0.96	39	0.89	59	0.61

(1) see footnote to Table 2

Dose Response Factor

(see table 4)

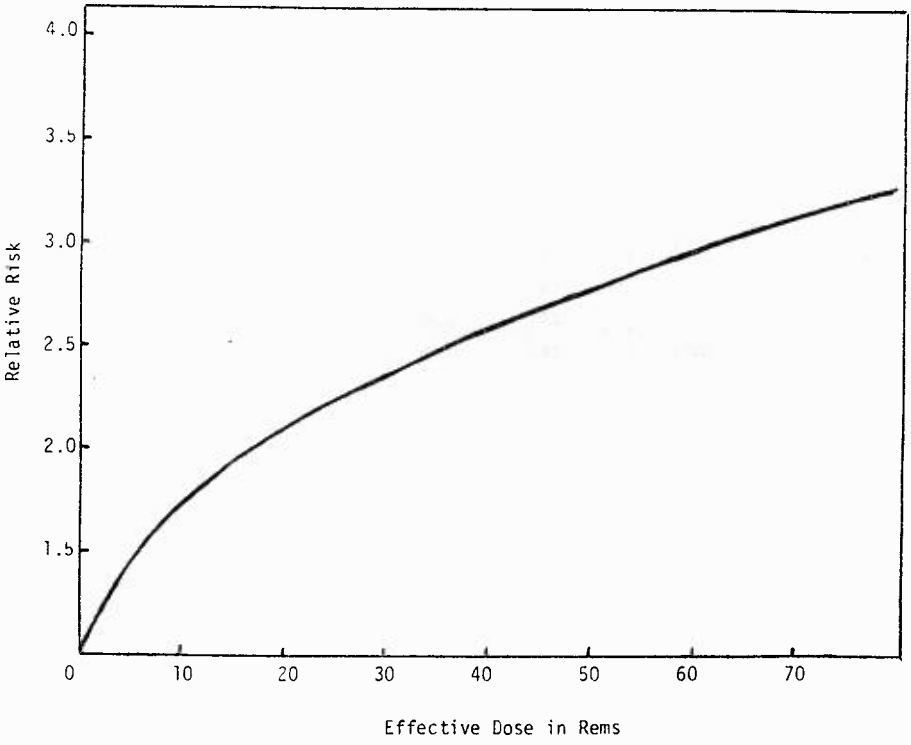

Table 4

Dose Response Factor

Doubling Dose (RR = 2.0) = 15 rads

E.D.[1]	R.R.[2]	E.D.	R.R.	E.D.	R.R.	E.D.	R.R.
1	1.26	20	2.15	40	2.63	60	3.00
2	1.37						
3	1.45	22	2.20	42	2.67	62	3.04
4	1.52						
5	1.58	24	2.27	44	2.71	64	3.06
6	1.63						
7	1.68	26	2.32	46	2.75	66	3.09
8	1.73						
9	1.77	28	2.37	48	2.79	68	3.13
10	1.82						
11	1.86	30	2.41	50	2.83	70	3.16
12	1.89						
13	1.93	32	2.46	52	2.86	80	3.31
14	1.96						
15	2.00	34	2.50	54	2.90	90	3.45
16	2.03						
17	2.06	36	2.55	56	2.93	100	3.58
18	2.10						
19	2.13	38	2.59	58	2.97		

(1) E.D. = Effective Dose in rems;

R.R. = Relative Risk (see Table 5)

Table 5

First Hanford Worker

Dates

Birth 3.4.97
Hire 23.10.47
Death 4.6.69

Cause of death: Lung Cancer (ICD no. 162)

Years	Age	Pre-death years	Dose (millirad)	Factors Age[1]	Factors Latency[2]	Effective Dose	Relative Risk[3]
1947	50	22	-	-	-	-	-
1948	51	21	250	3.9	0.98	965	-
1949	52	20	50	4.4	0.97	213	-
1950	53	19	1240	5.0	0.96	5952	-
1951	54	18	1480	5.7	0.94	7930	-
1952	55	17	1750	6.5	0.93	10579	-
1953	56	16	930	7.7	0.90	6445	-
1954	57	15	380	8.6	0.88	2876	-
1955	58	14	240	10.0	0.86	2064	-
1956	59	13	60	11.1	0.83	553	-
1957	60	12	40	12.5	0.81	405	-
1958	61	11	200	14.0	0.77	216	-
1959	62	10	20	16.0	0.73	234	-
1960	63	9	-	-	-	-	-
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1969	72	0	$\sum$ 6640	-	-	$\sum$ 38432	2.59

(1) see table 2 and Fig. 1
(2) " " 3 and Fig. 2
(3) " " 4 and Fig. 3.

Table 6

Second Hanford Worker

Dates

Birth 22.7.25
Hire 18.8.53
Death 21.3.61

Cause of death: Large Intestine Cancer (ICD no. 153)

Years	Age	Pre-death Years	Dose (millirad)	Factors Age[1]	Factors Latency[2]	Effective Dose	Relative Risk
1953	28	8	-	-	-	-	-
1954	29	7	190	0.25	0.56	27	-
1955	30	6	70	0.29	0.51	10	-
1956	31	5	1050	0.33	0.44	152	-
1957	32	4	1220	0.38	0.37	172	-
1958	33	3	1830	0.43	0.29	228	-
1959	34	2	1970	0.49	0.20	193	-
1960	35	1	1250	0.54	0.10	68	-
1961	36	0	70	0.62	0.00	0	-
			$\sum$ 7650			$\sum$ 850	<1.26