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RADIATION EXPOSURES OF HANFORD WORKERS DYING FROM VARIOUS CAUSES

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Hanford employees who are concerned with the manufacture of radiation products wear radiation badges and records have been systematically kept of the readings since 1944.[1] Combined with suitable epidemiological information these data provide an opportunity to discover whether there is a cancer hazard associated with low level radiation. Linking of the epidemiological information, which includes such factors as sex, date of birth and work history, has been provided by the social security numbers of the workers. These have enabled a follow-up to be maintained to identify any deaths in the monitored population and to obtain death certificates.

Minor errors which accumulate more in the records of currently alive employees, because they have no definite cutoff date, as dead persons do, invalidate strict comparability of the records of live and dead employees. Therefore, in place of waiting until all such errors have been strictly eliminated from the data, the current presentation is based only upon comparisons among various categories of dead employees. These included 3,521 men and 362 women who died between 1944 and 1972 and for whom death certificates were available (table 1).

Analysing the annual proportions exposed and the mean dose per exposure in various ways (including breakdowns by calendar year, years since hire, years before death, and age at exposure) showed that the exposure proportion was systematically higher for the cancers than the other causes of death (table 2, Fig. 1).

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In view of these findings it was decided to: (i) apply a strict statistical test based on the logistic model[2] to the mean doses cumulated in various ways; (ii) quantify the radiation sensitivity by estimating the doubling dose based on the linear model as a working hypothesis. The radiation doses were cumulated to stated periods before death, and the period before death which showed the maximum statistical significance of the difference between the mean dose of a given type of cancer and that of non-cancers (control or standard group) provided an estimate of the latent period of the cancer (tables 3 and 4). By cumulating the radiation doses to stated ages similar estimates of the age of maximum sensitivity to cancer induction were obtained.

By these tests the only cancers showing significant radiation associations were myeloid neoplasms, lung cancer and pancreatic tumors for men and breast cancer for women (table 5). These estimates were checked by forming from them estimates of the excess mortality ratio due to radiation and comparing these ratios with the observed standardized mortality ratio from national statistics (table 6). The only disease showing a marked difference in this validity test check was lung cancer and this may possibly be accounted for by factors such as smoking and other hazards from industrial exposure. Estimates were also made of the actual numbers of radiogenic cancers

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(table 7), with the finding that about 30 cancer deaths (or less than 1% of all deaths) were radiation-induced. Finally, the results also showed that the ages of maximum sensitivity to radiation were at both ends of the life span for adults.

The cancers that were found to be radiosensitive, and their estimated latent periods, agree in general with what is known or suspected of adult cancer aetiology; however, the estimate of doubling dose were lower (i.e., estimated radiosensitivty was greater) than previous studies had led one to suspect. Further analysis to establish the exact shape of the dose-response curve and to study possible interactions and associations with potential promoters of cancer and other factors are clearly necessary, both for this study and in other populations exposed to similar levels of dose.

REFERENCES:

1. Mancuso, T.; Sanders, B.; and Brodsky, A. Proceedings of the 6th Annual Health Physics Society Topical Symposium Vol. III. Study of the Lifetime Health and Mortality Experience of Employees of AEC Contracts. COO-3248-1, 1971.

2. Cox, D.R. Analysis of Binary Data. Methuen, London, 1970.

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FIGURE 1. CALENDAR YEARS OF RADIATION EXPOSURES (MALE DEATHS)

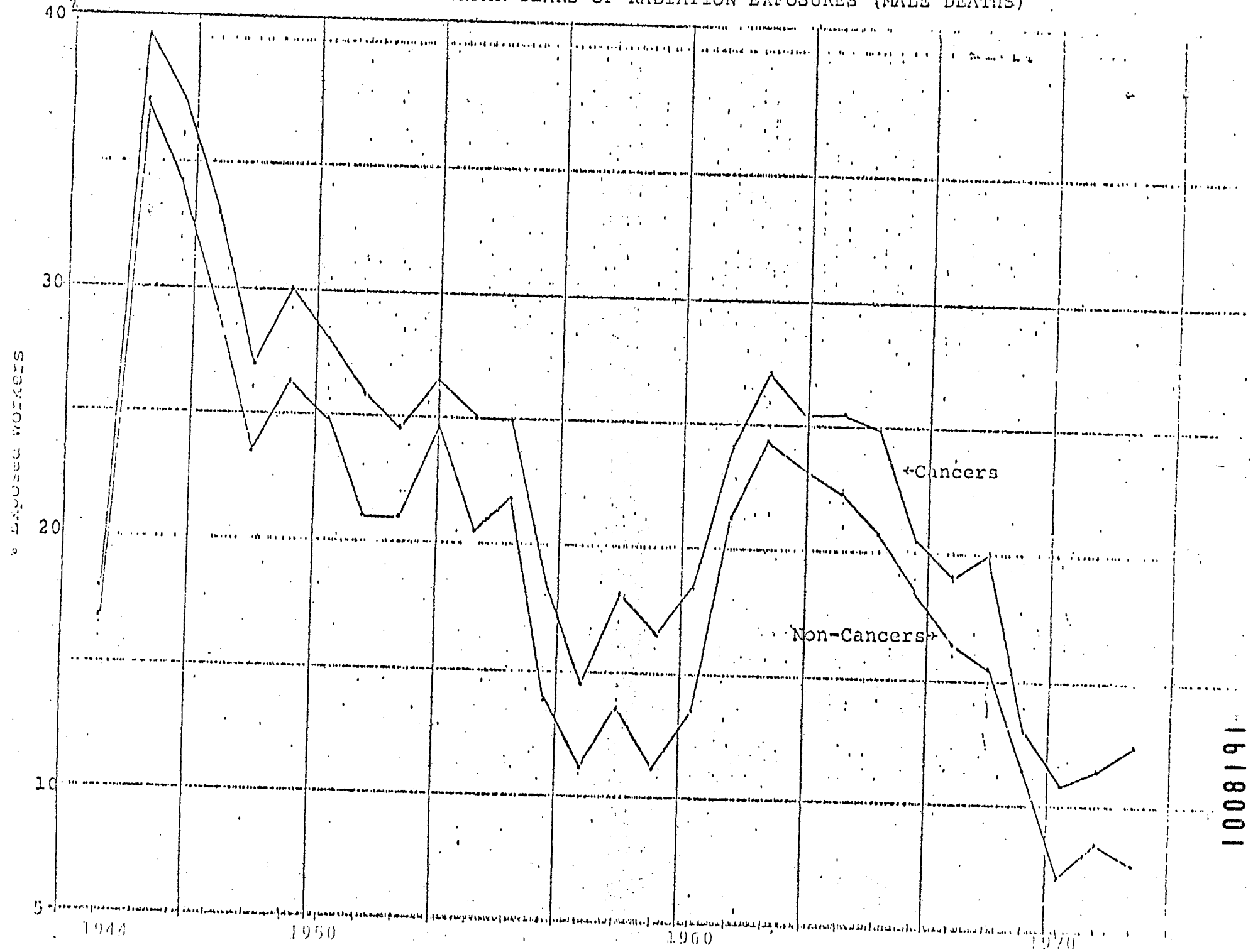

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TABLE 1

MONITORED POPULATION OF HANFORD WORKERS

Certified Deaths of Male and Female Workers, 1944-1972

Certified Deaths	Cases No.	External Radiation Exposed Workers No.	Total Dose Centirads	Exposed Workers %	Average Doses (1) Centirads	Average Doses (2) Centirads
Males:						
Cancers	670	441	90,514	65.8	205	135
Non-Cancers	2,851	1,739	291,123	61.0	167	102
All Causes	3,521	2,180	381,637	61.9	175	108
Females:						
Cancers	111	32	4,430	28.8	138	40
Non-Cancers	251	76	5,285	30.3	70	21
All Causes	362	108	9,715	29.8	90	27

(1) = radiation doses of exposed workers

(2) = radiation doses of all workers

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TABLE 2

ANNUAL RADIATION DOSES OF EXPOSED MALE CANCERS (CASES) and NON-CANCERS (CONTROLS)

(i) Calendar Years of Badge Readings

Calendar Yrs.	Number Positive Readings Cases	Number Positive Readings Controls	Average (1) Radiation Doses Cases Centirads	Average (1) Radiation Doses Controls Centirads	High (2) Risk Years Cases	High (2) Risk Years Controls
1944-1945	237	901	22.0	21.4	1	1
1946-1947	333	1,258	12.0	13.1	–	2
1948-1949	325	1,149	8.6	8.4	1	1
1950-1951	311	1,104	12.4	12.8	–	2
1952-1953	304	1,119	22.1	20.2	2	–
1954-1955	288	1,009	28.5	23.0	2	–
1956-1957	185	568	42.1	41.8	–	2
1958-1959	183	528	53.9	51.8	2	–
1960-1961	203	660	53.6	46.1	2	–
1962-1963	227	788	47.3	43.2	2	–
1964-1965	184	599	63.5	60.6	1	1
1966-1967	130	396	44.3	42.8	2	–
1968-1969	85	223	40.2	42.4	1	1
1970-1972	32	76	36.5	17.7	2	1
TOTALS	3,027	10,388	34.8	31.8	18	11

(1) Average dose per exposed worker standardized for number of exposed workers in each year.

(2) Number of years with higher rates for cases than controls or vice-versa

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TABLE 3

CUMULATIVE RADIATION DOSES OF MALES AT STATED INTERVALS BEFORE DEATH

(1) NON-CANCER DEATHS

Year Before Death	Mean Cumulative Radiation Dose in Centirads			
	All Non-Cancer Deaths (1)	Cardiovascular Diseases	Accidents	Other Causes
28	3.2	3.4	0.0	3.2
26	15.8	15.3	7.1	19.2
24	19.4	17.4	10.9	28.2
22	22.4	20.6	18.3	29.4
20	24.1	22.7	20.0	30.7
18	29.0	27.9	23.5	35.1
16	35.2	24.8	32.3	38.1
14	41.3	41.3	37.1	43.2
12	48.2	48.9	44.3	47.9
10	56.6	57.2	54.8	55.5
8	67.3	68.0	64.4	66.6
6	80.0	81.6	76.4	76.7
4	92.6	94.6	91.0	86.6
2	100.9	104.0	100.5	90.7
0	106.0	110.9	101.4	93.2
Number of Deaths ~~3,521~~ 2851		1,839 450 562 2,851	450	562

(1) Standard group.

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TABLE 4

CUMULATIVE RADIATION DOSES OF MALES AT STATED INTERVALS BEFORE DEATH

(2) CANCER DEATHS

Years Before Death	Mean Cumulative Radiation Dose in Centirads[1]		
	All Cancers	Solid Tumors	RES Neoplasms
28	1.9	2.2	0.7
26	12.5	11.5	24.6
24	18.9	19.3	14.3
22	22.7	22.7	23.1
20	25.2	24.5	33.0
18	34.0	32.3	52.2 *
16	44.3	40.6	83.0 **
14	54.3 *	49.1	105.2 ** +
12	65.0 * +	58.8 +	126.0 **
10	76.7 *	69.1	154.0 **
8	90.4 *	81.7	175.4 **
6	104.2	95.0	194.5 *
4	116.6	107.7	200.9 *
2	129.0	119.6	216.2 *
0	134.4	125.0	223.1 *
Number of Deaths	670	606	64

(1) Figures in italics (underlined) significantly different from the standard group (see Table 8)

Levels of significance * $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

\+ radiation dose that compared most unfavourably with the standard dose.

TABLE # 5

ESTIMATED DOUBLING DOSES AND LATENT PERIOD FOR CANCERS WITH DEFINITE RADIATION ASSOCIATIONS

Diagnostic Categories	Sex	Estimates (1) Doubling Dose In Rads	Estimates (1) Latent Period Years	Proportional Representation A %	Proportional Representation B %
Myeloid Neoplasms	M	1.8 – 2.6	8	3.3 (34.4)*	1.9 (18.4)*
Breast Cancer	F	2.9 – 7.7	21	24.3	20.5
Pancreas	M	5.0 – 7.4	10	7.3	5.8
Lung	M	6.1 – 10.6	14	27.8	10.9

(1) Based on pre-death years showing exceptionally high differences between the observed and expected radiation doses and having at least 20 individuals (see text).

(A) Proportion of cancer deaths in the study population

(B) Proportion in the age adjusted death rates for U.S. whites (1950-67) (6)

(*) Proportion of RES neoplasms.

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STANDARDIZED MORTALITY RATIOS FOR CANCERS WITH DEFINITE RADIATION ASSOCIATIONS

EXPECTED AND ESTIMATED RATIOS[1]

CANCERS WITH DEFINIE RADIATION ASSOCIATIONS	SEX	S.M.Rs. EXPECTED	S.M.Rs. ESTIMATED
MYELOID NEOPLASMS	M	176	179
BREAST CANCER	F	124	127
PANCREAS	M	127	114
LUNG	M	314	107

(1) Expected based on National Statistics
Estimated based on radiation doses of Hanford workers (see Text)

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TABLE 7

RADIATION-INDUCED CASES AS PROPORTIONS OF VARIOUS CAUSES OF DEATH

Diagnostic Categories	All Cases Exposed Nos.	All Cases Not Exposed Nos.	Estimated Radiogenic Cancers All Cases Nos.	Estimated Radiogenic Cancers Exposed Cases %
Males:				
Myeloid Neoplasms	15	7	9.5	63.3
Pancreatic Tumors	31	18	6.1	19.7
Lung Cancer	129	63	12.1	9.4
All RES Neoplasms	43	16	10.6	22.1
All Cancers	441	229	23.5	5.3
All Deaths	2,138	1,342	23.5	1.1
Females:				
Breast Cancer	8	20	5.9	84.3
All Cancers	32	79	4.2	13.1
All Deaths	108	254	4.2	3.9
TOTALS	2,227	1,596	27.7	1.2

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