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# T A B L E S

## RADIATION EXPOSURES OF HANFORD WORKERS DYING FROM VARIOUS CAUSES

By

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REPOSITORY DOE-FORRESTAL
COLLECTION MARKEY FILES
BOX No. 4 of 6
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23
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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 | (2) |
|---|---|---|---|---|---|---|
| **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~~ 2,179 | 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 | 1,268 | 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-v

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ANNUAL RADIATION DOSES OF EXPOSED MALE CANCERS (CASES)
and NON-CANCERS (CONTROLS)
(iii) Employment Years of Badge Readings

| Employment Years | Number of Positive Readings Cases | Number of Positive Readings Controls | Average Radiation Doses (1) Cases Centirads | Average Radiation Doses (1) Controls Centirads | High Risk Years (2) Cases | High Risk Years (2) Controls |
|---|---|---|---|---|---|---|
| 0 - 1 | 463 | 1,786 | 20.8 | 22.5 | - | 2 |
| 2 - 3 | 475 | 1,747 | 23.4 | 16.8 | 1 | 1 |
| 4 - 5 | 368 | 1,294 | 18.4 | 17.2 | 2 | - |
| 6 - 7 | 321 | 1,164 | 22.5 | 24.1 | - | 2 |
| 8 - 9 | 273 | 985 | 34.4 | 28.3 | 2 | - |
| 10 - 11 | 232 | 811 | 42.0 | 33.2 | 2 | - |
| 12 - 13 | 164 | 528 | 48.6 | 44.5 | 1 | 1 |
| 14 - 15 | 171 | 521 | 55.2 | 47.8 | 2 | - |
| 16 - 17 | 171 | 541 | 47.3 | 45.7 | 1 | 1 |
| 18 - 19 | 144 | 461 | 46.8 | 42.9 | 1 | 1 |
| 20 - 21 | 103 | 294 | 50.6 | 53.5 | 1 | 1 |
| 22 - 23 | 73 | 160 | 40.1 | 31.7 | 2 | - |
| 24 - 25 | 55 | 74 | 21.6 | 19.9 | 2 | - |
| 26 - 28 | 14 | 22 | 14.4 | 16.1 | 1 | 2 |
| TOTALS | 3,027 | 10,388 | 34.7 | 31.7 | 18 | 11 |

(1) ) See footnotes to table 2
(2) )

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TABLE 4

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

(iv) Years Before Death of the Badge Readings

| Years Before Death | Number of Positive Readings Cases | Number of Positive Readings Controls | Average Radiation Dose (1) Cases | Average Radiation Dose (1) Controls | High Risk Years (2) Cases | High Risk Years (2) Controls |
|---|---|---|---|---|---|---|
| | | | Centirads | | | |
| 0 – 1 | 155 | 675 | 27.1 | 27.9 | 1 | 1 |
| 2 – 3 | 244 | 854 | 42.0 | 35.4 | 2 | – |
| 4 – 5 | 273 | 975 | 39.8 | 42.4 | 1 | 1 |
| 6 – 7 | 305 | 1,015 | 37.0 | 39.5 | – | 2 |
| 8 – 9 | 310 | 1,022 | 36.7 | 31.8 | 2 | – |
| 10 – 11 | 283 | 933 | 33.4 | 28.1 | 2 | – |
| 12 – 13 | 244 | 868 | 35.0 | 25.5 | 2 | – |
| 14 – 15 | 257 | 863 | 29.0 | 22.2 | 2 | – |
| 16 – 17 | 239 | 861 | 27.2 | 21.3 | 2 | – |
| 18 – 19 | 220 | 724 | 21.3 | 18.1 | 2 | – |
| 20 – 21 | 186 | 592 | 12.9 | 14.1 | – | 2 |
| 22 – 23 | 143 | 481 | 15.0 | 15.7 | – | 2 |
| 24 – 25 | 111 | 353 | 18.5 | 16.9 | 1 | 1 |
| 26 – 28 | 56 | 172 | 12.5 | 21.8 | – | 3 |
| TOTALS | 3,027 | 10,388 | 27.7 | 25.8 | 17 | 12 |

(1)) See footnotes to table 2
(2))

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TABLE 5

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

(ii) Age at the Time of the Badge Readings (excluding exposures within 5 years of death)

| Age in Years | Number of Positive Readings Cases | Number of Positive Readings Controls | Average Radiation Doses (1) Cases Centirads | Average Radiation Doses (1) Controls Centirads | High Risk Years (2) Cases | High Risk Years (2) Controls |
|---|---|---|---|---|---|---|
| 20 - 22 | 11 | 22 | 28.6 | 13.0 | 2 | 1 |
| 23 - 25 | 21 | 99 | 11.8 | 21.5 | 1 | 2 |
| 26 - 28 | 55 | 172 | 26.3 | 26.3 | 1 | 2 |
| 29 - 31 | 93 | 272 | 22.1 | 30.0 | - | 3 |
| 32 - 34 | 111 | 419 | 14.4 | 30.6 | - | 3 |
| 35 - 37 | 150 | 538 | 19.5 | 23.9 | 1 | 2 |
| 38 - 40 | 160 | 609 | 20.7 | 21.3 | 2 | 1 |
| 41 - 43 | 224 | 665 | 25.7 | 24.7 | 2 | 1 |
| 44 - 46 | 234 | 741 | 28.9 | 26.4 | 2 | 1 |
| 47 - 49 | 253 | 777 | 37.8 | 31.9 | 3 | - |
| 50 - 52 | 281 | 876 | 33.4 | 30.7 | 3 | - |
| 53 - 55 | 265 | 930 | 34.3 | 26.0 | 3 | - |
| 56 - 58 | 235 | 863 | 30.7 | 25.3 | 2 | 1 |
| 59 - 61 | 196 | 708 | 28.3 | 24.7 | 3 | - |
| 62 - 64 | 160 | 527 | 34.1 | 23.7 | 3 | - |
| TOTALS | 2,449 | 8,216 | 26.4 | 25.3 | 28 | 17 |

(1) ) see footnotes to table 2
(2)

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TABLE 6

CERTIFIED CAUSES OF DEATH
EXPOSED WORKERS AND RADIATION DOSES

| Diagnostic Categories | Cases | Exposed Workers | Radiation Doses (1) (1) | Radiation Doses (1) (2) |
|---|---|---|---|---|
| | Nos. | % | Centirads | |
| **Males:** | | | | |
| Neoplasms | 680 | 65.5 | 204 | 133 |
| Cardiovascular Diseases | 1,839 | 62.4 | 166 | 103 |
| Respiratory Diseases | 192 | 55.2 | 135 | 75 |
| Digestive Disorders | 139 | 59.9 | 190 | 114 |
| Accidents | 450 | 60.5 | 192 | 116 |
| Other Causes | 221 | 62.0 | 136 | 84 |
| **Females:** | | | | |
| Breast Cancer | 28 | 25.9 | 241 | 62 |
| Other Neoplasms | 83 | 30.0 | 183 | 33 |
| Cardiovascular Diseases | 124 | 29.8 | 100 | 30 |
| Accidents | 55 | 29.1 | 40 | 12 |
| Other Causes | 72 | 31.9 | 42 | 13 |
| All Causes of Death — Males | 3,521 | 62.0 | 175 | 103 |
| All Causes of Death — Females | 362 | 29.8 | 90 | 27 |

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(1) See footnote to table 1.

TABLE 7

CANCER DEATHS OF MALE WORKERS - EXPOSED WORKERS and RADIATION DOSES BY CANCER CELL TYPES

| Main Categories | Cell Types (ICD Nos.) | Deaths No. | Exposed Workers | Average Radiation Doses (1) | (2) |
|---|---|---|---|---|---|
| | | | | Centi- | |
| | Large Intestine (151) | 61 | 80.3 | 168 | 135 |
| | Pancreas (157) | 49 | 63.3 | 416 | 263 |
| Solid Tumors (140-199) | Lungs (160-3) | 192 | 67.2 | 205 | 169 |
| | Kidney (189) | 21 | 66.7 | 281 | 187 |
| | Brain (191) | 18 | 61.0 | 360 | 180 |
| | Residue | 265 | 60.0 | 94 | 56 |
| | Myeloma (203) | 11 | 81.8 | 948 | 775 |
| RES Neoplasms (200-209) | Myeloid Leukemia (205) | 11 | 54.5 | 223 | 123 |
| | Lymphatic neoplasms (200-1; 204) | 33 | 81.8 | 148 | 121 |
| | Residue (202;206-9) | 9 | 66.7 | 34 | 22 |

(1) See footnote to Table 1

TABLE 8

/C

CUMULATIVE RADIATION DOSES OF MALES AT STATED INTERVALS BEFORE DEATH

(1) NON-CANCER DEATHS

Mean Cumulative Radiation Dose in Centirads

| Year Before Death | 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 | 38.2 |
| 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 | 2,851 | 1,839 | 450 | 562 |

(1) Standard group.

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TABLE 9

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 11

CUMULATIVE RADIATION DOSES OF MALES AT STATED INTERVALS BEFORE DEATH

(A. RES NEOPLASMS

| Years Before Death | Mean Cumulative Radiation Doses in Centirads (1) | | |
|---|---|---|---|
| | All RES Neoplasms (200-209) | Myeloid Neoplasms (203; 205) | Lymphatic and Reticular Neoplasms (200-2; 204; 206-9) |
| 28 | 0.7 | 1.0 | 0.0 |
| 26 | 24.6 | 3.0 | 57.0+ |
| 24 | 14.3 | 4.2 | 26.4 |
| 22 | 23.1 | 19.0 | 26.7 |
| 20 | 33.0 | 37.6 | 29.1 |
| 18 | 52.2* | 53.1 | 51.1 |
| 16 | 83.0** | 121.6*** | 50.5 |
| 14 | 105.2** | 180.5*** | 54.0 |
| 12 | 125.0** | 231.1*** | 60.7 |
| 10 | 154.0**+ | 310.2*** | 63.4 |
| 8 | 173.4** | 401.4***+ | 62.3 |
| 6 | 194.5* | 446.9*** | 65.0 |
| 4 | 200.9* | 438.5*** | 72.9 |
| 2 | 215.2* | 468.1*** | 90.3 |
| 0 | 223.1* | 469.2*** | 100.1 |
| Number of Deaths | 64 | 22 | 42 |

(1) See footnotes to Table 9.

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TABLE 11

CUMULATIVE RADIATION DOSES OF MALES AT STATED INTERVALS BEFORE DEATH

(4) RES NEOPLASMS

| Years Before Death | Mean Cumulative Radiation Doses in Centirads (1) All RES Neoplasms (200-209) | Myeloid Neoplasms (203; 205) | Lymphatic and Reticular Neoplasms (200-2; 204; 206-9) |
|---|---|---|---|
| 28 | 0.7 | 1.0 | 0.0 |
| 26 | 24.6 | 3.0 | 57.0+ |
| 24 | 14.3 | 4.2 | 26.4 |
| 22 | 23.1 | 19.0 | 26.7 |
| 20 | 33.0 | 37.6 | 29.1 |
| 18 | 52.2* | 53.1 | 51.1 |
| 16 | 83.0** | 121.6*** | 50.5 |
| 14 | 105.2** | 180.5*** | 54.0 |
| 12 | 126.0** | 231.1*** | 60.7 |
| 10 | 154.0**+ | 310.2*** | 63.4 |
| 8 | 175.4** | 401.4***+ | 62.3 |
| 6 | 194.5* | 446.9*** | 65.0 |
| 4 | 200.9* | 438.5*** | 72.9 |
| 2 | 216.2* | 468.1*** | 90.3 |
| 0 | 223.1* | 469.2*** | 100.1 |
| Number of Deaths | 64 | 22 | 42 |

(1) See footnotes to Table 9.

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TABLE 12

CUMULATIVE RADIATION DOSES OF FEMALES AT STATED INTERVALS BEFORE DEATH

(1. BREAST CANCERS AND OTHER CANCERS

Mean Cumulative Radiation Dose in Centirads

| Years Before Death | Non-Cancer Deaths (1) | Breast Cancer (174) | Other G.U. Cancers (180-189) | Other Cancers |
|---|---|---|---|---|
| 26 | 3.4 | 27.0* | 0.0 | 0.0 |
| 24 | 6.4 | 25.7* | 0.0 | 0.0 |
| 22 | 6.0 | 24.3*+ | 0.0 | 4.9 |
| 20 | 7.5 | 19.2 | 0.0 | 4.5 |
| 18 | 8.5 | 13.7 | 0.0 | 7.6 |
| 16 | 10.3 | 12.9 | 0.4 | 10.8 |
| 14 | 11.4 | 12.4 | 0.8 | 13.9 |
| 12 | 13.7 | 16.5 | 13.1 | 17.9 |
| 10 | 16.3 | 22.7 | 16.1 | 23.9+ |
| 8 | 17.8 | 40.6 | 15.4 | 26.3 |
| 6 | 19.8 | 52.6 | 15.0 | 27.3 |
| 4 | 20.6 | 60.0 | 13.3 | 32.9 |
| 2 | 21.7 | 61.0 | 14.8 | 36.3 |
| 0 | 22.3 | 61.6 | 16.9 | 39.7 |
| Number of Deaths | 251 | 28 | 26 | 57 |

(1) Standard group. Figures in italics (underlined) were significantly different from standard.

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

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# CUMULATIVE RADIATION DOSES FOR MEN AT STATED AGES
## ALL RES NEOPLASMS AND SOLID TUMORS WITH HIGH RADIATION DOSES

| Exposure Age in Years | Mean Cumulative Radiation Doses in Centirads: Non-Cancer Deaths (1) | All RES Neoplasms | t values | Six Solid Tumors (2) | t values |
|---|---|---|---|---|---|
| 21 | 8.0 | 0.0 | - 0.3 | 39.3 | + 2.3 * |
| 24 | 13.4 | 11.3 | - 0.1 | 40.2 | + 2.1 * |
| 27 | 31.4 | 23.8 | - 0.2 | 41.2 | + 0.6 |
| 30 | 37.6 | 36.6 | - 0.1 | 40.3 | + 0.1 |
| 33 | 43.5 | 32.0 | - 0.4 | 39.0 | - 0.3 |
| 36 | 52.2 | 38.0 | - 0.4 | 41.0 | - 0.6 |
| 39 | 57.9 | 37.1 | - 0.5 | 43.1 | - 0.7 |
| 42 | 56.9 | 45.4 | - 0.3 | 51.3 | - 0.3 |
| 45 | 59.0 | 68.1 | + 0.3 | 62.6 | + 0.3 |
| 48 | 63.7 | 88.0 | + 0.7 | 86.0 | + 1.5 |
| 51 | 74.0 | 143.5 | + 1.5 | 110.4 | + 2.1 * |
| 54 | 81.4 | 202.2 | + 2.1 * | 136.5 | + 2.7 * |
| 57 | 83.7 | 244.4 | + 2.5 * | 170.3 | + 3.6 ** |
| 60 | 80.1 | 180.5 | + 1.6 | 130.0 | + 2.1 * |
| 63 | 77.7 | 328.0 | + 3.7 ** | 126.9 | + 1.9 |
| 66 | 66.9 | 525.2 | + 6.3 *** | 137.8 | + 2.5 * |
| 69 | 51.1 | 566.1 | + 7.9 *** | 78.5 | + 0.8 |
| 72 | 42.8 | 701.1 | + 9.9 *** | 98.0 | + 2.7 * |
| 75 | 36.3 | 45.3 | + 0.1 | 97.7 | + 2.8 * |

(1) Standard group (see Fig. 5)

(2) Large intestine, pancreas, kidney, brain and lung (see Table 7)

CUMULATIVE RADIATION DOSES FOR MEN AT STATED AGES
ALL RES NEOPLASMS AND SOLID TUMORS WITH HIGH RADIATION DOSES

| Exposure Age in Years | Mean Cumulative Radiation Doses in Centirads: Non-Cancer Deaths (1) | All RES Neoplasms | t values | Six Solid Tumors (2) | t values |
|---|---|---|---|---|---|
| 21 | 8.0 | 0.0 | - 0.3 | 39.3 | + 2.3 * |
| 24 | 13.4 | 11.3 | - 0.1 | 40.2 | + 2.1 * |
| 27 | 31.4 | 23.8 | - 0.2 | 41.2 | + 0.6 |
| 30 | 37.6 | 36.6 | - 0.1 | 40.3 | + 0.1 |
| 33 | 43.5 | 32.0 | - 0.4 | 39.0 | - 0.3 |
| 36 | 52.2 | 38.0 | - 0.4 | 41.0 | - 0.6 |
| 39 | 57.9 | 37.1 | - 0.5 | 43.1 | - 0.7 |
| 42 | 56.9 | 45.4 | - 0.3 | 51.3 | - 0.3 |
| 45 | 59.0 | 68.1 | + 0.3 | 62.6 | + 0.3 |
| 48 | 63.7 | 88.0 | + 0.7 | 86.0 | + 1.5 |
| 51 | 74.0 | 143.5 | + 1.5 | 110.4 | + 2.1 * |
| 54 | 81.4 | 202.2 | + 2.1 * | 136.5 | + 2.7 * |
| 57 | 83.7 | 244.4 | + 2.5 * | 170.3 | + 3.6 ** |
| 60 | 80.1 | 180.5 | + 1.6 | 130.0 | + 2.1 * |
| 63 | 77.7 | 328.0 | + 3.7 ** | 126.9 | + 1.9 |
| 66 | 66.5 | 525.2 | + 6.3 *** | 137.8 | + 2.5 * |
| 69 | 51.1 | 566.1 | + 7.9 *** | 78.5 | + 0.8 |
| 72 | 42.8 | 701.1 | + 9.9 *** | 98.0 | + 2.7 * |
| 75 | 36.3 | 45.3 | + 0.1 | 97.7 | + 2.8 * |

(1) Standard group (see Fig. 5)

(2) Large intestine, pancreas, kidney, brain and lung (see Table 7)

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TABLE 14

# 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 DEFINITE 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)

TABLE 16

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 | 48 | 16 | 10.6 | 22.1 |
| All Cancers | 441 | 229 | 23.5 | 5.3 |
| All Deaths | 2,179 | 1,342 | 23.5 | 1.1 |
| Females: | | | | |
| Breast Cancer | 7 | 20 | 5.9 | 84.3 |
| All Cancers | 32 | 79 | 4.2 | 13.1 |
| All Deaths | 108 | 254 | 4.2 | 3.9 |
| TOTALS | 2,287 | 1,596 | 27.7 | 1.2 |

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TABLE 16

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 | 19 | 6.1 | 19.7 |
| Lung Cancer | 129 | 63 | 12.1 | 9.4 |
| All RES Neoplasms | 48 | 16 | 10.6 | 22.1 |
| All Cancers | 441 | 229 | 23.5 | 5.3 |
| All Deaths | 2,179 | 1,342 | 23.5 | 1.1 |
| **Females:** | | | | |
| Breast Cancer | 7 | 20 | 5.9 | 84.3 |
| All Cancers | 32 | 79 | 4.2 | 13.1 |
| All Deaths | 108 | 254 | 4.2 | 3.9 |
| TOTALS | 2,287 | 1,596 | 27.7 | 1.2 |

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

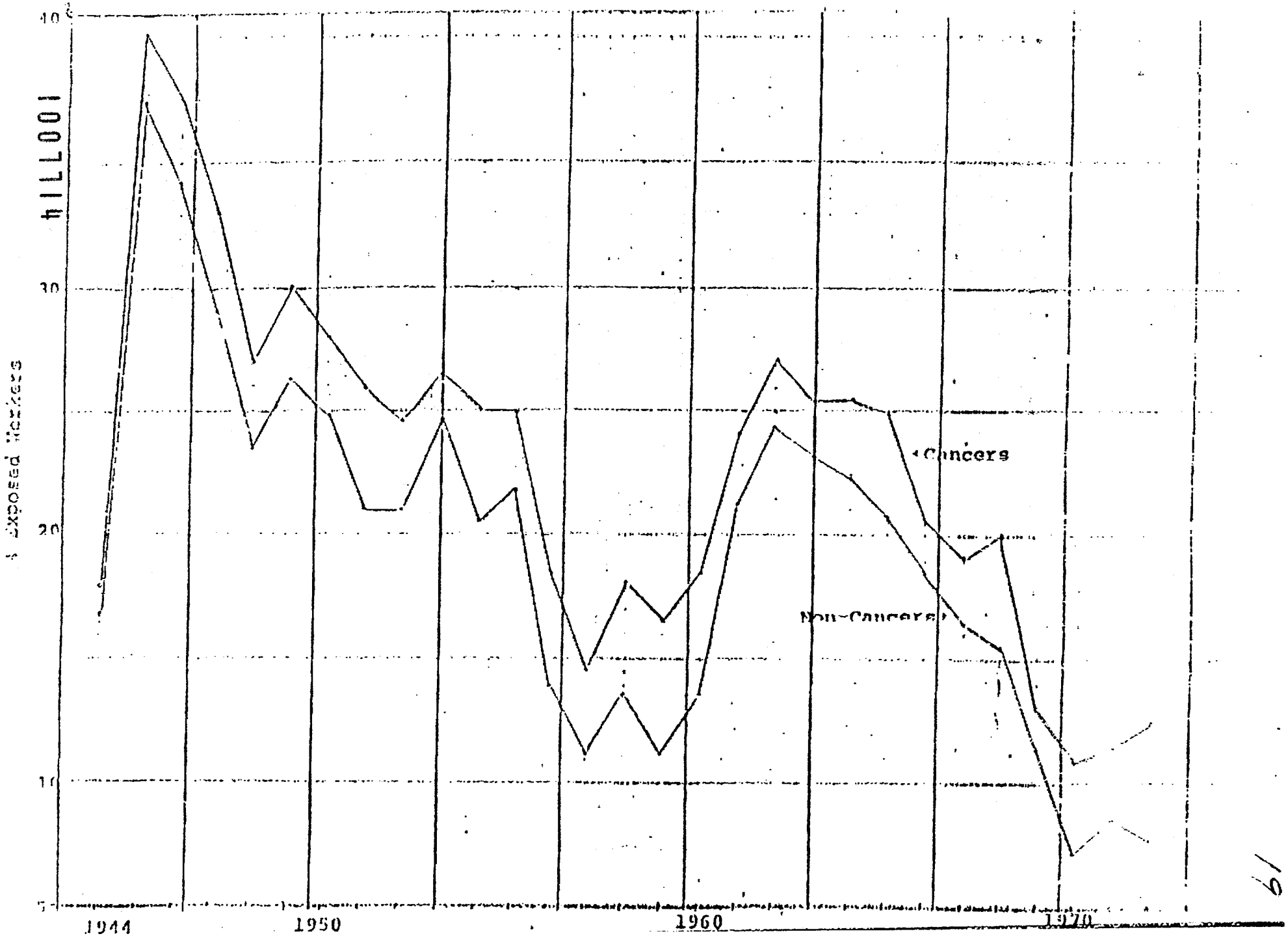


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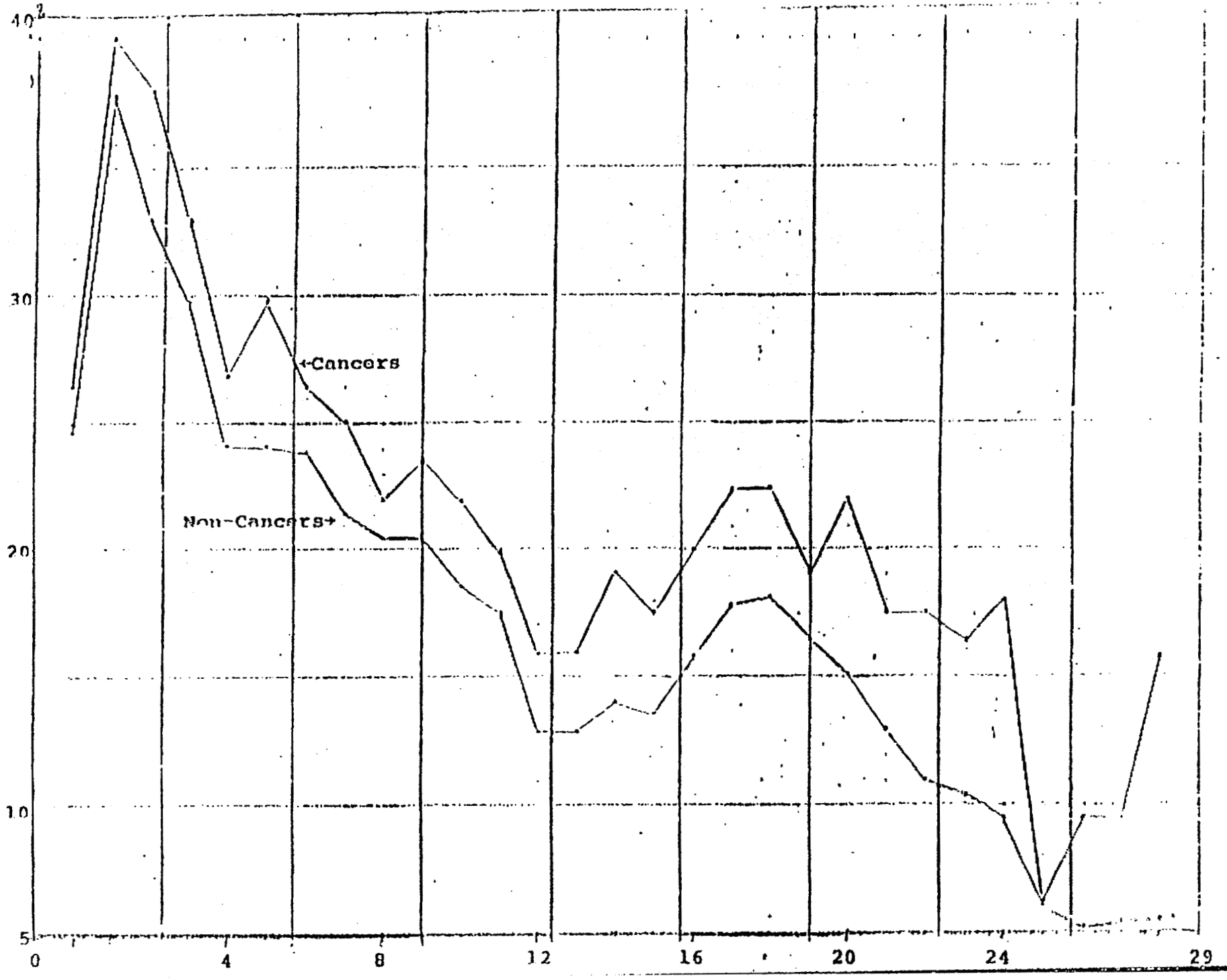
FIGURE 2. RADIATION EXPOSURES BY DURATION OF EMPLOYMENT (MALE DEATHS)

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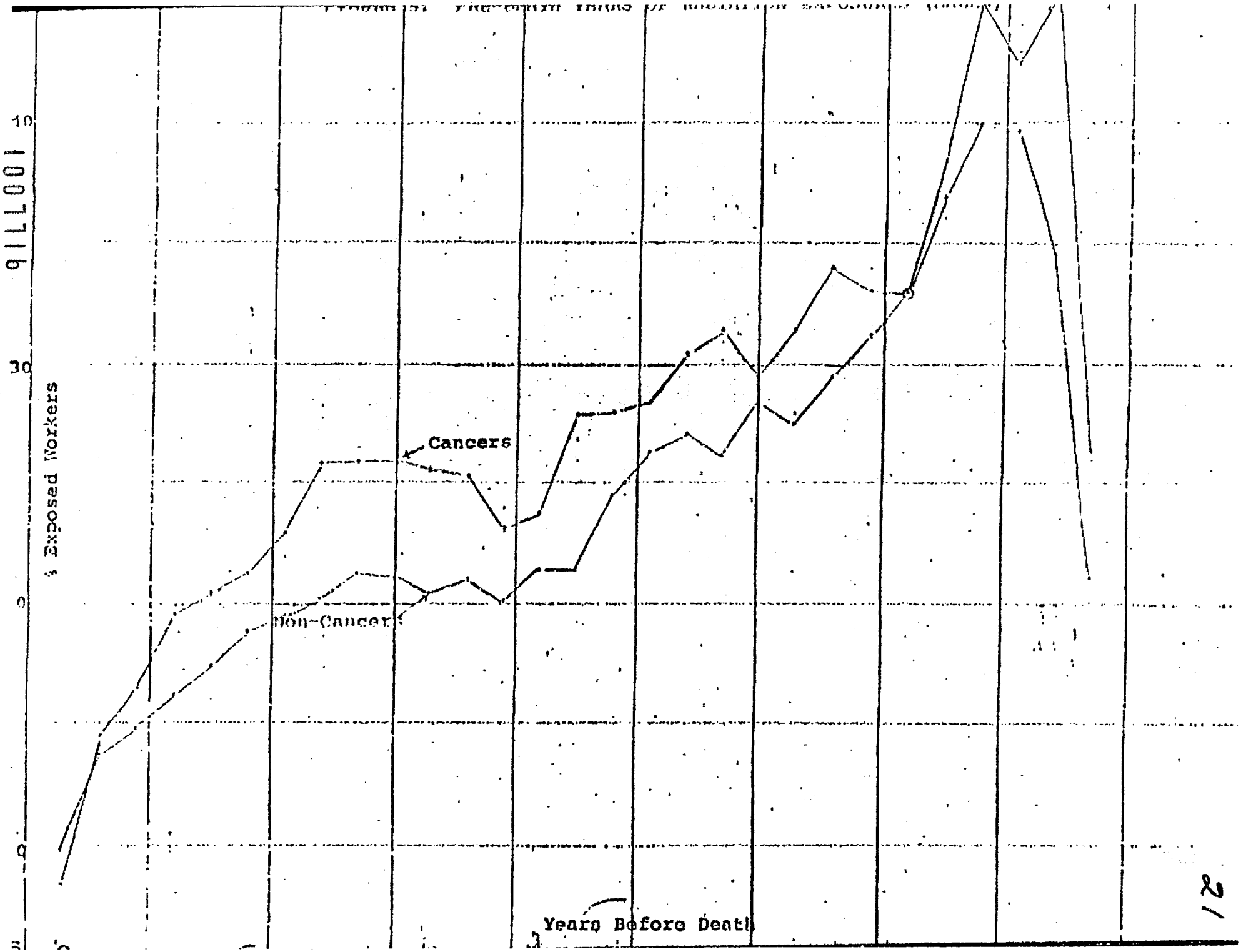
% Exposed Workers
10
30
0
Cancers
Non-Cancers
Years Before Death

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FIGURE 4. EXPOSURE AGES OF MALE DEATHS

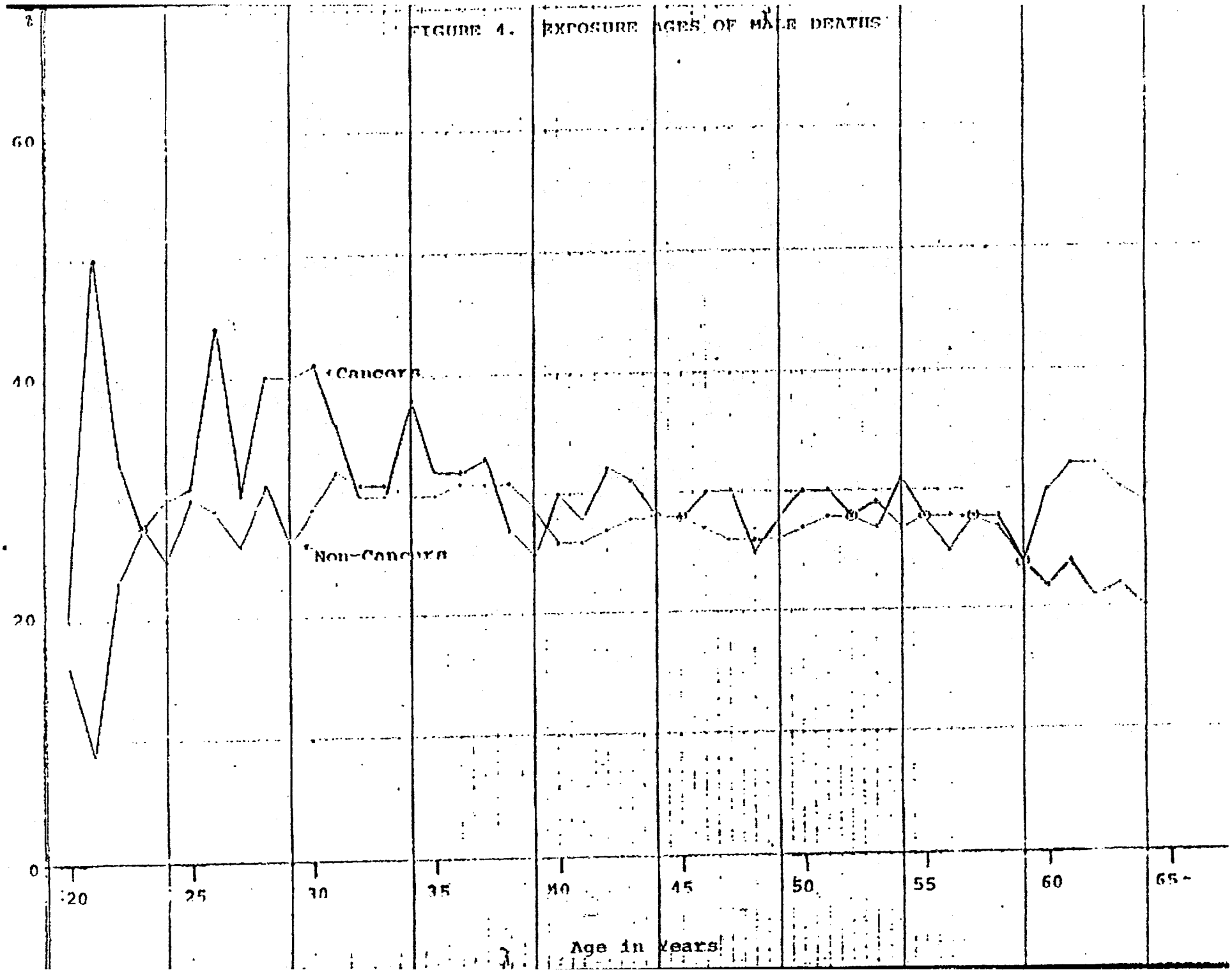


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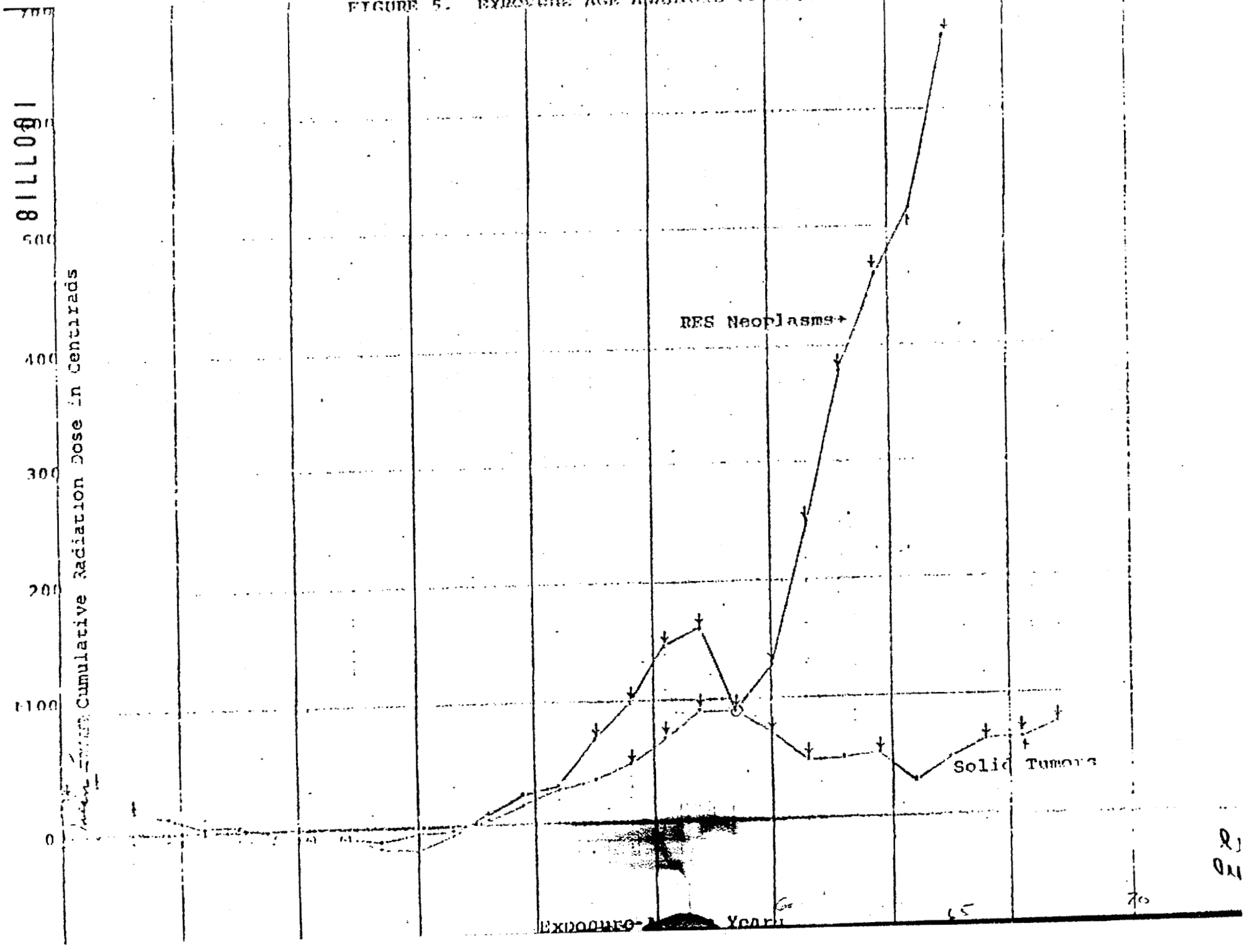
FIGURE 5. EXPOSURE AGE ANALYSIS OF RADIATION DOSES

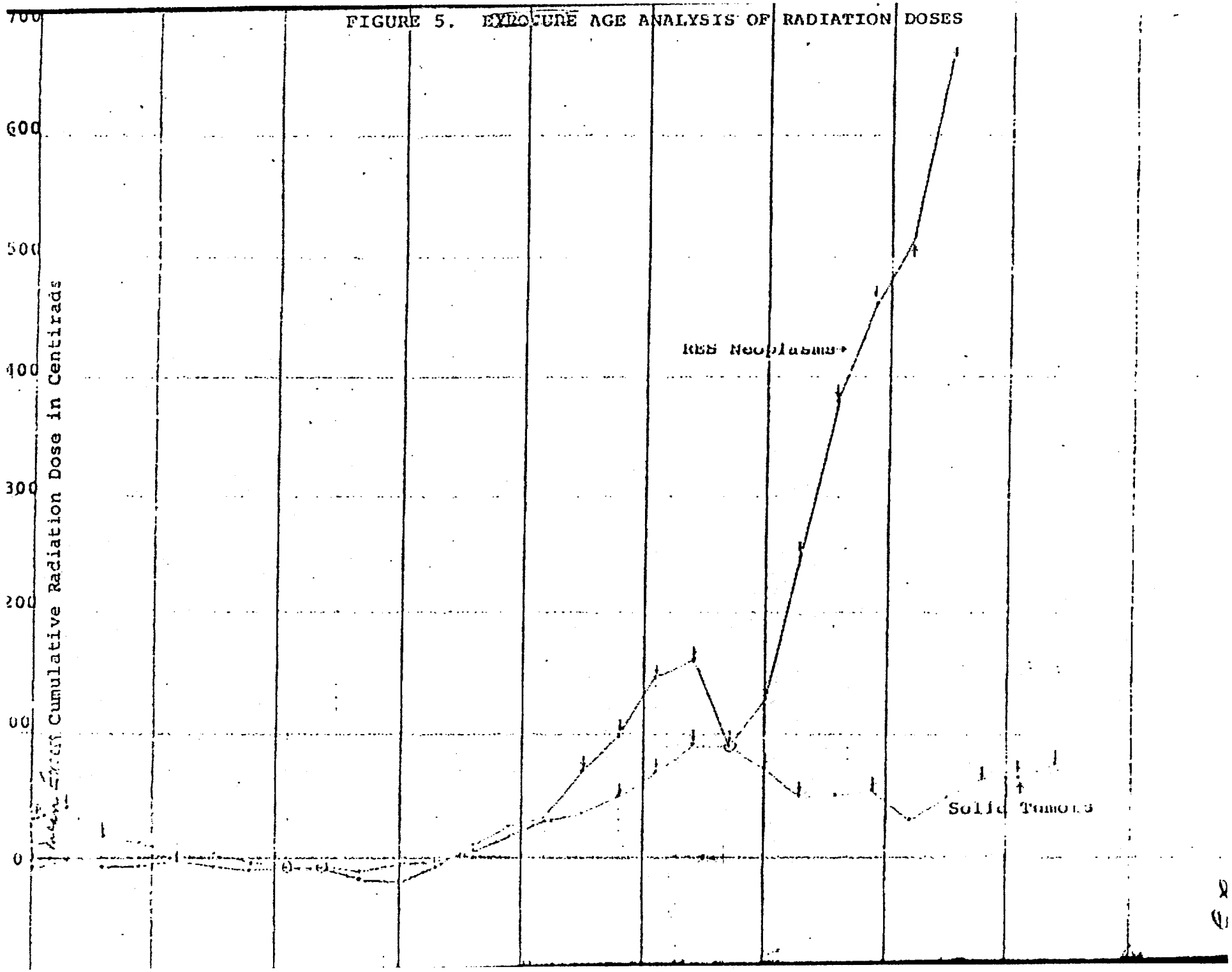


Methodology

In the source data the stimulus (i.e., radiation dose) was continuously variable and the observed response (i.e., the development of a cancer) was a strictly an "all or nothing" or binary response. Furthermore, the most plausible alternative to the null hypothesis of low level radiation having no carcinogenic effects, is that the dose-response relationship is either linear or at least monotonically increasing. Therefore, the most appropriate statistical model was the logistic or log-linear one which states that the logarithm of the probability of developing a cancer is linearly related to the radiation dose over a suitable range of dose.[2]

Under the assumptions of this model the most powerful test of the null hypothesis was the permutation test of the difference of the mean doses between persons developing cancer and the whole population (i.e., all deaths). This was

FIGURE 5. EXPOSURE AGE ANALYSIS OF RADIATION DOSES

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I. Let $N$ = Size of whole population

$n$ = Size of sub-population developing cancer

$R$ = Average value of radiation dose in whole population

$r$ = Average value of radiation dose in sub-population developing cancer

$S$ = Average value of squared dose in whole population.

Then, the estimate of variance in whole population $(V) = \frac{N}{(N-1)}(S-R^2)$ and $t = (r-R)/\sqrt{V\left(\frac{1}{n} - \frac{1}{N}\right)}$ where this statistic is approximately distributed as a t statistic with (n-1) degrees of freedom for testing the null hypothesis.

II. If the null hypothesis is rejected - as a result of t exceeding a critical value of approximately 2.0 - a quantitative estimate of radiation sensitivity is required and can be obtained in the following way: Let D equal the quantity of radiation which is just sufficient to increase the risk of cancer death to double its normal value (doubling dose). Then the expected value of $r = \frac{R + S/D}{1 + R/D}$. By solving this equation with the observed value of r one can obtain an estimate of D for any cancer with definite radiation associations.

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III. Finally, by applying these formulas to radiation doses cumulated up to a given age (or pre-death period,, one should be able to recognize (by the t values) both the age of maximum sensitivity to cancer induction and the commonest interval between initiation and death. This second application of the formulas (which is needed to measure cancer latent periods) is subject to a slight bias due to different cancers having differing mean ages at death but, in practice, this is unlikely to an important source of error.

Reference 2. Cox D.R. (1970) The Analysis of Binary Data, Methuen London.

Formula for estimating $EMR = 1 + \frac{R}{C}$

Rush: ~~PSG.~~

NRC follow up

Nucl. Med - ORNL interaction, direction

~~Manuscript~~

~~IAEA - Acc. Center~~ . BNL - another center

~~DTPA - inventory~~ - IND - Utah (Leong)

~~Accident files from Cunningham~~

BNL - industrial medicine

Riley - site visit

PERF

epid. contracts

FDA - reply

→ WBC

DTPA ⁝ [redacted]

IAEA Symp Diagnosis and Treatment —
8-12 Dec 75

Anxiety - WBC - Phil Dean

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