Direct Estimates of Low-Level Radiation Risks of Lung Cancer at Two NRC-Compliant Nuclear Installations: Why Are the New Risk Estimates 20 to 200 Times the Old Official Estimates?

IRWIN D.J. BROSS, Ph.D.,* AND DEBORAH L. DRISCOLL, B.A.

*Director of Biostatistics; Roswell Park Memorial Institute, Buffalo, New York

Received July 8, 1981

An official report on the health hazards to nuclear submarine workers at the Portsmouth Naval Shipyard (PNS), who were exposed to low-level ionizing radiation, was based on a casual inspection of the data and not on statistical analyses of the dosage-response relationships. When these analyses are done, serious hazards from lung cancer and other causes of death are shown. As a result of the recent studies on nuclear workers, the new risk estimates have been found to be much higher than the official estimates currently used in setting NRC permissible levels. The official BEIR estimates are about one lung cancer death per year per million persons per rem [5]. The PNS data show 189 lung cancer deaths per year per million persons per rem.

BRIEF HISTORY OF THE PORTSMOUTH NAVAL SHIPYARD STUDY

An unusual aspect of the Portsmouth Naval Shipyard (PNS) study was that all meetings, memos, and other transactions were, by law, put into a public record. Unnecessary repetition of organizational, methodological, and other details of the PNS study can therefore be avoided by a brief outline of its history.

In February 1978, the Center for Disease Control and a subdivision, the National Institute of Occupational Safety and Health (CDC/NIOSH), were given a congressional mandate to carry out the Portsmouth Naval Shipyard study [1]. CDC/NIOSH was instructed to confirm or deny, and in a timely manner, a report by Dr. Thomas Najarian of excess leukemia and cancer among the nuclear submarine workers at PNS. Dr. Najarian subsequently published his report, with co-author, Dr. Theodore Colton, in The Lancet [2]. The House subcommittee, which had heard Dr. Najarian testify, had also heard testimony from Drs. Thomas Mancuso, Karl Z. Morgan, and Irwin Bross, and named these scientists to an Oversight Committee for the PNS study, additional scientists being named later.

This advisory committee received a first draft of a “final report” on the CDC/NIOSH study in September 1980. Several members of the committee objected to two serious omissions in that report. First, the congressional mandate specifically involved the dosage-response relationship between badge dose exposures and leukemia.

Presented at a symposium on Effects on Humans of Exposure to Low Levels of Ionizing Radiation, Yale University School of Medicine, May 14, 1981.

Address reprint requests to: Dr. Irwin D.J. Bross, Director of Biostatistics, Roswell Park Memorial Institute, 666 Elm Street, Buffalo, NY 14263.

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and cancer deaths. The dosage-by-latency tabulations required had been given only for leukemia and a few related causes of death and not for other cancers or other causes of death. Second, no statistical analysis of the dosage-response relationships had been made.

Despite these and other objections, CDC/NIOSH issued its final report in December 1980. Without even notifying the committee, it submitted a much shorter version to The Lancet that was published on January 31, 1981 [3]. On January 26, 1981 (and without knowledge of the publication), Dr. Bross submitted a critique to CDC/NIOSH, "Radiogenic Lung Cancer Among Nuclear Workers at Portsmouth Naval Shipyard" which noted in the public record that:

However this "final report" included only a small part of the Portsmouth Naval Shipyard data that was relevant to the scientific assessment of radiation hazards. . . . The facts in the dosage-by-latency tables that were not in the "final report" flatly contradict the statements made by CDC/NIOSH in the "final report" and to the press. [4]

The primary purpose of this paper is to present the data on lung cancer among the nuclear shipyard workers and the straightforward statistical analyses which demonstrate a strong dosage-response relationship in this data. At an open meeting on March 17, 1981, significant or highly suggestive statistical dosage-response analyses for lung cancer, leukemia, and other causes of death were presented to CDC/NIOSH by Dr. Bross and Dr. Colton. However, CDC/NIOSH refused to retract or correct the conclusion of its final report:

Finally, in PNS radiation workers, we found no positive dosage response relationships between ionizing radiation dose and mortality for any cause reported. [3]

The statement was true at the time it was made. Since the data had only been "eyeballed" and not subjected to proper statistical analysis for dosage-response relationships nothing had been "found."

QUALITATIVE RESULTS OF THE PORTSMOUTH NAVAL SHIPYARD STUDY

After receiving a complete set of tables from CDC/NIOSH in December 1980, the first table considered by Dr. Bross was the one for lung cancer. As is well known (and as was noted and referenced in the published CDC/NIOSH report), lung cancer is radiogenic [3]. The effects tend to become detectable after about 15 years. In his letter to Dr. Bross of March 4, Dr. Robbins, then the NIOSH director, stated that "the report reserves judgment . . . because of the small cohort size and short latency experienced by most of the cohort relative to the cohort size and latency periods necessary to study organ cancers." This statement is consistent with a 15-or-more-year latent period (but it is not consistent with a latent period of 10 years or less).

Table 1 shows the data on which the first analysis was performed. This data was abstracted from the full CDC/NIOSH "dosage × latency" table (81 cases) considering only those cases with a latent period of over 15 years and by consolidating dosage categories under 0.5 rem. Dr. Karl Z. Morgan discussed this consolidation in detail at the March 17 meeting. As he showed, it is almost meaningless from a do-
TABLE 1
Observed and Expected Deaths from Lung Cancer by Radiation Exposure for Workers at the Portsmouth Naval Shipyard. Standardized Mortality Ratios (SMR) and Incremental SMRs (ΔSMR) are also shown.

| Radiation Exposure (in Rem) | 0.001– 0.500– 1.00– 5.00– 15.0+ |
|----------------------------|----------------------------------|
| Observed Deaths            | 3 3 6 4 3                        |
| Expected Deaths            | 7.40 1.67 3.69 1.80 1.07          |
| SMR                        | 0.41 1.80 1.63 2.22 2.80          |
| ΔSMR                       | -0.59 0.80 0.63 1.22 1.80         |

From the observations and expectations the Standardized Mortality Ratio (SMR) and the incremental SMR (ΔSMR) can be calculated as measures of radiation effects. If a simple linear mathematical model is used, the incremental SMR would be simply proportional to dosage. This result is derived in Appendix I.

Note that if the higher doses (more than 1 rem) are combined, the expected numbers are similar to those at the lower doses (less than 0.5 rem). The expectations are 6.56 and 7.40, respectively. Therefore, the observed deaths can be directly compared in a very simple way. There were 13 deaths observed at the higher dose and three deaths observed at the lower dose—a striking difference that should have been found even by "eyeballing." This difference is statistically significant (5 percent) by the Sign Test.

The simplest measure of potential radiation effects at a given dose is the ratio of the observed number of deaths to the number expected, the SMR. Under the null hypothesis that there is no radiation effect (i.e., the assumption to be tested), the SMR should be unity. This makes possible another comparison of the "higher" and "lower" dosage categories. This can be done most directly by calculating a statistic which will have approximately a unit normal distribution (mean zero and variance

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TABLE 1A
Calculation of the Risk of Lung Cancer in BEIR Units from the Portsmouth Naval Shipyard Data (exposure ≥ 1 rem)

| Basic Data |
|------------|
| Excess deaths from lung cancer = 6.44 |
| Average lifetime dose (in rem) = 7.70 |
| Person years = 4,423 |

| Calculation |
|-------------|
| Units are deaths per million per year (10^6/year) |
| 6.44 deaths × 10^6 |
| 4,423 person years × 7.7 rem = 189 deaths per 10^6/year/rem |
An Elementary Significance Test for The PNS Lung Cancer Data

| SMR for 1+ rem | 1.982 |
| SMR for under 0.5 rem | 0.405 |
| Difference | 1.577 |

Variance of \( \frac{O}{E} = \frac{1}{E^2} \)

Variance of difference = \( \frac{1}{7.40} + \frac{1}{6.56} = 0.2875 \)

S.E. of difference ≤ \( \sqrt{0.2875} = 0.536 \)

\[ \frac{\text{Difference}}{\text{S.E. of difference}} = \frac{1.577}{0.536} = 2.94^{**} \]

Critical Values are 1.96 (5%) and 2.57 (1%)

unity). The details are shown in Table 1B. The difference between the SMRs, \(13/6.56 = 1.982\) for the “higher” exposures and \(3/7.40 = 0.405\) for the “lower” exposures is \(1.982 - 0.405 = 1.577\). Then dividing by the standard error of the difference, a unit normal test statistic is obtained. The standard assumption that the deaths follow a Poisson distribution can be made. This means that the variance of the observed number of deaths will be equal to its expectation under the null hypothesis. The variance of the SMRs is the reciprocal of the expectation since:

\[ \text{Variance} \frac{O}{E} = \frac{1}{E^2} \]

\[ \text{Variance} \frac{E}{E^2} = \frac{1}{E} \]

Hence, the variance of the difference is the sum of two variances:

\[ \text{Variance of difference} = \frac{1}{7.40} + \frac{1}{6.56} = 0.2875 \]

The standard error is the square root of 0.2875, or 0.536. When the difference is divided by its standard error, the result is 2.94. A value of 1.96 would be needed for the 5 percent probability level and 2.57 for the 1 percent level so the results here are highly significant.

No critical assumptions are made in either of the simple methods used to obtain this result. Therefore, it is hard to deny the conclusion that the excess lung cancers at higher doses cannot be explained away by chance or sampling variation. Hence, they represent some kind of real effect.

These results do not contradict the CDC/NIOSH statement that “cancer rates among the shipyard workers were normal or lower than normal compared to the overall population.” Of the 98,223 person-years in the series, only 4,423 person-years involve more than 1 rem of lifetime exposure and 15 years of latency. When CDC/NIOSH diluted this 4.5 percent of relevant person-years with 95.5 percent irrelevant person-years, nothing was likely to be “found” even if lung cancer was strongly radiogenic. It was an incompetent way to examine this data for radiation effects.
RADIATION RISKS OF LUNG CANCER UNDER ALARA STANDARDS

CONTRAST OF NEW AND OLD RISK ESTIMATES

If a linear relationship between dose and response is assumed for interpolation—a much weaker assumption than linear extrapolation—it can be shown (see Appendix I) that there should be a direct proportionality between the radiation dose and the increment SMR. The slope of the curve is the reciprocal of the doubling dose. An analysis of the data using simple linear regression is shown in Fig. 1. The response variable (Y), the incremental SMR in Table 1, is plotted against the mid-dose for the radiation categories. The regression line through the origin is also shown. The slope of this line is 0.081. The reciprocal of this, the doubling dose, is 12.3 rem. Even here there is some question about linearity but, on this assumption, the doubling dose for lung cancer is around 12 rem.

Although the role of susceptible subgroups will be considered later, Fig. 1 suggests that some persons are vulnerable to doses as low as 1 rem and this may be one reason for the departure from linearity. Note that departures from linearity can only reduce the statistical significance of the linear analysis, but that the slope is nevertheless significant at the 5 percent level.

The official BEIR estimates are in the vicinity of one lung cancer death per year per million persons per rem [5]. Since the 1980 BEIR report used much the same data as the original 1972, this extrapolative estimate has not changed. The corresponding direct estimate can be obtained by considering workers in Table 1 who were exposed to 1 rem lifetime dose or more. The procedure is shown in Table 1A. There are 13 deaths. Using U.S. vital statistics to adjust for age, CDC/NIOSH

![Graph](image)

FIG. 1. Excess Lung Cancer (ΔSMR) by Lifetime Radiation Dose (in Rem) for Radiation-Exposed Workers at Portsmouth Naval Shipyard (Broken line = data points; Solid line = fitted regression line).
calculations indicate that 6.56 deaths would be expected. Hence, there are 6.44 excess deaths. The 6.44 excess deaths come from 4,423 person-years and an average lifetime dosage of approximately 7.7 rem. Hence, to have the same units as the BEIR estimate [5], we must divide 6.44 by 4,423, divide again by 7.7, and multiply by 1,000,000. This gives 189 lung cancer deaths per year per million persons per rem. This is over 100 times the official estimates and completely changes the picture both for protection of workers from radiation-induced lung cancer and for compensation.

Might the excess PNS lung cancer be due to lifestyle or hazards of the workplace other than radiation? This question can be answered by considering the radiation-exposed workers with less than 0.5 rem exposure in Table 1. Here 7.40 deaths were expected and if lifestyle or workplace hazard were doubling the risks there should be about 15 deaths. Actually, there are only three deaths from lung cancer in this series. Apparently, the “healthy worker” bias due to the stringent standards used in selecting and clearing the nuclear workers overrides lifestyle or factors other than radiation exposures.

How can the striking differences between the direct estimate from the PNS data and the official estimates of lung cancer risks be explained? The probable scientific reason for this discrepancy is that a small proportion of the population has pre-existing genetic damage that renders it extremely vulnerable to low-level ionizing radiation [6,7].

Note that the PNS workers received much less than the 5 rem per year currently permitted by the Nuclear Regulatory Commission—actually receiving only about 0.5 rem per year [3]. Yet this was enough to greatly increase their risk of lung cancer. Whereas most of the excess PNS lung cancer deaths are probably from this susceptible subgroup, in the high-dose studies this group would become relatively unimportant in the total deaths. However, in setting standards to protect nuclear workers, it is this subgroup which has to be protected.

The role of the susceptible subgroups was pointed out in 1972 to the original BEIR commission [8]. These susceptibles were not considered in the new 1980 BEIR estimate [9]. However, their role is crucial for both a scientific and a public health understanding of the health hazards of low-level ionizing radiation.

Now, let us consider briefly the inevitable question: Why does the new PNS data show excess risk of lung cancer when the older data for the workers at the Hanford Reprocessing Plant in Washington State is said to show no lung cancer relationship?

There are two answers to this question, one historical and one current. The historical answer is that when Dr. Thomas Mancuso and his co-workers, Dr. Alice Stewart and Mr. George Kneale, originally analyzed the Hanford data they did find excess lung cancer and a doubling dose for lung cancer of about 10 rem, similar to the corresponding estimate for the shipyard workers [10]. Later Hanford analyses made by Dr. Ethel Gilbert and Dr. Sidney Marks at Battelle West [11] did not find the lung cancer relationship.

Dr. Gilbert kindly provided reprints of her original report [11] and a brief update [12] covering the years of Hanford experience after the 1974 cutoff and through 1977. Using these reports, the data table shown in Table 2 was constructed for the Hanford workers who died of lung cancer in 1975–1977. It is not possible to make the PNS data tables and the Hanford tables exactly comparable because, for example, the Hanford data tables have the lowest dosage category as under 2 rem whereas the PNS uses under 0.5 rem. In the PNS data, effects for leukemia, lung cancer, and other causes appear in the range from 0.5 rem to 2 rem. The dose-response relation-
TABLE 2
Observed and Expected Deaths from Lung Cancer by Radiation Exposure for Workers at Hanford Reprocessing Plant. Standardized Mortality Ratios (SMR) and Incremental SMRs (ΔSMR) are also shown. (1977 – 1974)

| Radiation Exposure (in Rem) | 0-2 | 2-5 | 5-15 | 15+ |
|----------------------------|-----|-----|------|-----|
| Observed Deaths            | 13  | 10  | 6    | 3   |
| Expected Deaths            | 19.1| 5.9 | 3.6  | 3.4 |
| SMR                        | 0.68| 1.69| 1.67 | 0.88|
| ΔSMR                       | -0.32| 0.69| 0.67 | -0.12|

ships may be somewhat obscured in the Battelle baseline series because of this 2 rem choice.

As can be seen from Table 2, the Hanford data for 1975–1977 which is the data with comparable latency to the over-15 years’ latency used for PNS, tends to confirm the PNS results although the effects are not quite as clear. There is an anomalous point in the data for exposures over 15 rem, but there are some technical problems in this dosage category that appear also in the PNS data. For example, administrative doses can result in spurious high exposures.

An independent direct estimate of lung cancer risks from the Hanford series is shown in Table 2A. It is a third of the PNS estimate but many times the official BEIR estimate of one per million. None of these estimates, including BEIR estimates, are very precise. All such numbers should be read as orders of magnitude rather than literally. What can be said with assurance is that the direct estimates of risk to nuclear workers are two logarithmic orders of magnitude greater than the official risks. When the actual risks are 100 times greater, the cost-benefit calculations or permissible levels or environmental impact statements based on the official estimates cannot protect the health and safety of workers or the public.

DISCUSSION OF RISK ESTIMATES

Time is now running out for the official interagency policy that low-level ionizing radiation is "harmless" and for the risk estimates that support this policy. The reason

TABLE 2A
Calculation of the Risk of Lung Cancer in BEIR Units from the Hanford Data (exposure ≥ 2 rem)

| Basic Data         |
|--------------------|
| Excess deaths from lung cancer = 6.10 |
| Average lifetime dose (in rem) = 6.70 |
| Person years = 14,027 |

| Calculation         |
|--------------------|
| Units are deaths per million per year (10⁶/year) |
| 6.1 deaths × 10⁶   |
| 14,027 person years × 6.7 rem |
| = 65 deaths per 10⁶/year |
for this is that during the "harmless" era there were many unnecessary and avoidable exposures to low-level radiation. In addition to those at Hanford and Portsmouth, there were the nuclear weapons tests affecting both servicemen and civilians and exposures to medical X-rays (see Appendix II). Since the 15-year latent period has now elapsed, the leukemia, lung cancer, and other diseases caused by the low-level radiation are now showing up even in the studies carried out by the federal agencies.

To estimate the actual radiation risks from the data that are coming out of the newer studies is not especially difficult but does require some competence in the biostatistical analysis of dose-response data. When the Tri-State Survey Data on diagnostic X-rays was analyzed in the RPMI Biostatistics Department, it required a sophisticated analysis using a mathematical model to obtain the estimate of about 5 rem as the doubling dose for myeloid leukemia in men that was reported in 1979 [13]. However, only simple arithmetic of the kind used for the Portsmouth analysis was required to confirm this estimate using the Center for Disease Control of servicemen at the Big Smoky tests [14] or the Portsmouth data.

The 5-rem doubling dose for leukemia, now twice confirmed by independent studies reported by federal agencies, is very different from the official estimate in the interagency report [15] of well over 100 rem. This again suggests the actual risks are more than 20 times the official ones. Indeed, there are now more than 30 studies (see Appendix II) where the data show positive relationships in human populations exposed to low-level ionizing radiation, results which would be statistically impossible if the official estimates were correct.

Official agencies refuse to use the new data for BEIR and other radiation risk estimates because they say that the older data (such as the Japanese A-bomb data) is the "best available" but there is no biostatistical warrant for this claim. Chart A contrasts the general nature of the new data (e.g., at Portsmouth Naval Shipyard and Hanford) with the older data (e.g., A-bomb data). From a scientific standpoint a population of healthy workers who have never been exposed to high doses of radiation is much more informative than a population of sick persons or survivors of the A-bomb who may have been exposed to hundreds of rem. Again, continuous and concurrent dosimetry for monitoring nuclear workers is far superior to retrospective dosimetry that is based on assumptions which are now in serious question. Finally, good statistical practice says that you never extrapolate far beyond the range of the data when good data in the right range is available.

This is not a criticism of the original 1972 BEIR report [5]. At that time it made sense to use the high-dose data and linear extrapolation because this was the only way that risk estimates at low doses could be made. However, with the much better data and direct risk estimates available in 1981, scientific evaluation of radiation risks would replace the obsolete older estimates by the newer ones. That this did not happen in the latest BEIR report suggests that official estimates are no longer a scientific product but rather a political one.

For radiation technologies, as for other hazardous technologies, biostatistical-epidemiological studies such as the PNS study become bogged down in real or manufactured "controversies" involving methodological issues, "interpretations," philosophical questions of causality.

Perhaps the best hope is to invoke the "Primacy Principle":

In dealing with potentially hazardous technologies, the benefit of the doubt must go to the public and not to the technology.
CHART A  
Comparison of the New Data on the Portsmouth Shipyard Workers with the Data Used in Official Reports (Interagency, BEIR, ICRP, etc.)

| Characteristics of the Data                  | PNS Data                                      | Official Reports                                      |
|----------------------------------------------|-----------------------------------------------|------------------------------------------------------|
| Who are the persons under study?             | Nuclear workers under normal working conditions | Survivors of an A-bomb or persons with grave disease requiring therapeutic X-ray |
| What are the dosages of ionizing radiation?  | Low-level radiation directly pertinent to occupational exposure standards | Dosages in most subjects of well over 100 rem |
| What is the quality of the dosimetry for persons under study? | Continuous concurrent monitoring of the exposures with recording of dates, doses, etc., for each individual | Retrospective estimates of exposures without adequate crosschecks or control of the dosimetry |
| What is the quality of the follow-up of the persons under study? | Virtually complete (98%) with full death certificate and other information | Incomplete and often inadequate follow-up and poor quality of information on individuals |
| What was the quality of the information used for comparisons? | Nosology review enabled use of age-sex-race-cause specific U.S. rates | Pick-up or biased comparison series (e.g., in some A-bomb comparisons, persons exposed up to 10 rem are used as controls) |
| What assumptions were necessary for estimates of doubling dose or other quantitative measures of health effects? | Estimates can be made directly without any strong assumptions | Estimates require assumption of dubious "linear" or other hypotheses and are merely guesswork |
In practical terms this means that the critics of a technology must present a sound _prima facie_ case on the hazard and after this the burden of proof shifts to the proponents to show that the technology is safe.

Consider the 5-rem-per-year exposure that the Nuclear Regulatory Commission currently allows for nuclear workers such as those at PNS. The present report and other cited studies show that the doubling doses for lung cancer or leukemia are in the dosage range that is currently permitted annually. There is now much more than a _prima facie_ case that NRC permits doses of radiation that are dangerous—a dose that doubles the risk of a fatal disease is a serious public health hazard. By the Primacy Principle it should now be up to the proponents of such exposures to prove that they are safe. Failure to do this should settle the argument and lead to the reduction of the permissible dose below 0.5 rem per year (as was proposed at the 1978 congressional hearing) [1].

**APPENDIX I**

For a given individual, the probability of dying from lung cancer in a given person-year can be expressed algebraically as a function of a baseline risk for a white male of his age, $R(z)$, and the radiation dose ($X$). If the dosage-response curve is linear and the reciprocal of the doubling dose is $U$, then:

$$ P = R(z) \left(1 + UX\right) \tag{1} $$

The expectation ($E$) of the observed number ($O$) in a given dosage category can be obtained from equation [1] by summing over age-specific person-years within the category. If there is no radiation effect ($U = 0$ and the doubling dose is infinite), and if the rates from national vital statistics are used for $R(z)$, then the expectation under this null hypothesis ($E_o$) would be equal to the "expected" number in the CDC/NIOSH tables. If $U$ is a positive quantity and if the mid-dose for a dosage category is taken as the exposure for all persons in the category, the summation is taken as the exposure for all persons in the category, the summation leads to a non-null expectation ($E_1$) which is simply related to the null expectation ($E_o$) by:

$$ E_1 = E_o \left(1 + UX\right) \tag{2} $$

A commonly used statistic in this kind of contingency table is the Standardized Mortality Ratio (SMR) which is defined as the ratio of the "observed" number ($O$) to the null expectation ($E_o$), $O/E_o$. The SMR will be unity if there are no effects. Hence, another measure of effect is the incremental SMR ($\Delta$SMR) which is $\text{SMR} - 1$. From equation [2] it follows that the expected value of the incremental SMR is simply proportional to the inverse of the doubling dose ($U$):

$$ E \frac{O}{E_o} - 1 = E(0) \frac{E(O)}{E_o} - 1 = E_o \frac{(1 + UX)}{E_o} - 1 = UX \tag{3} $$

Hence, if the incremental relative risks are fitted by a straight line which goes through the origin (0, 0) of a graph of $Y = \Delta$SMR against dosage $X$, the slope of this line will give an estimate of $U$. Its reciprocal estimates the doubling dose.

**APPENDIX II**

Biostatistical Studies of Populations Exposed to Low-Level Ionizing Radiation
Where Positive Health Effects Appear in the Data (By Type of Exposure)
Medical X-Ray

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