CASE CONTROL STUDY OF LUNG CANCER
IN CIVILIAN EMPLOYEES AT THE
PORTSMOUTH NAVAL SHIPYARD
KITTERY, MAINE

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16. Abstract (Limit: 200 words)
    A case/control study of deaths due to lung cancer in civilian workers at the Portsmouth Naval Shipyard (SIC-3731), Kittery, Maine was conducted. Cases consisted of white males who had worked at the shipyard at some time during the period January 1, 1952, through August 15, 1977, and who died from a malignant neoplasm of the trachea, bronchus, or lung (lung cancer). Three comparison subjects were selected for each case, based on date of birth, date of first employment, and duration of employment. Odds ratios were elevated for radiation exposure history, asbestos (1332214) exposure, and exposure to welding byproducts. There was a statistically significant excess for workers with a cumulative lifetime exposure of at least 1 rem. The odds ratios for combined asbestos and welding exposure histories (as a single factor) were significantly elevated for two of three duration categories. Exposures to asbestos and welding byproducts tended to confound the association between radiation and lung cancer; radiation workers also had a propensity to have been exposed to asbestos and welding byproducts. Introduction of latency periods into the analysis resulted in the odds ratios for radiation exposure becoming smaller, and odds ratios for asbestos and welding byproducts becoming larger. The authors concluded that these results neither support nor exclude an association between radiation exposure and lung cancer mortality at this facility.

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ABSTRACT

Analysis of workers at the Portsmouth Naval Shipyard (PNS) who died of cancer of the bronchus, trachea, or lung (lung cancer) and matched controls, revealed elevated odds ratios for radiation exposure history, asbestos exposure, and exposure to welding by-products. The radiation-related excess was statistically significant for persons whose cumulative lifetime exposure was at least 1.0 rem. When asbestos and welding exposure histories were combined as a single risk factor, the odds ratios for the combination were significantly elevated for two of the three duration-of-exposure categories examined.

Further analysis of the effect of radiation exposure, while controlling for exposures to asbestos and welding fume, produced lower (non-significant) estimates of radiation risk than the uncontrolled analyses at all levels of radiation exposure examined. This reduction implies that radiation workers had a propensity also to be exposed to asbestos and/or welding by-products; those exposures confounded the association between radiation and lung cancer.

An analysis of mortality by latency-induction period provided further evidence that radiation did not significantly contribute to the etiology of lung cancer. Odds ratios for radiation exposure became smaller as latency periods were introduced into the analysis, while those for asbestos/welding exposure tended to increase.

These analyses do not preclude a possible association between radiation exposures at PNS and excess mortality from lung cancer, but neither do they provide evidence in support of such a relationship.

INTRODUCTION

In May 1978, nuclear workers at the Portsmouth Naval Shipyard (PNS), Kittery Maine, were reported by Najarian et al to have experienced a five-fold increase in proportional mortality due to leukemia and a two-fold increase due to all cancers combined.[1] In consequence, the United States House of Representatives' Subcommittee on Health and the Environment requested that the Department of Health and Human Services conduct further epidemiologic studies. The National Institute for Occupational Safety and Health (NIOSH) was directed to conduct this research. A protocol was developed for a retrospective cohort mortality study of the entire shipyard population, and of the radiation workers in particular.[2] In addition, the protocol called for case/control studies to be conducted on specific causes of death in the event that any unusual patterns of mortality were uncovered in the cohort study.

The data from the cohort mortality study did not support the previous findings of increased mortality due to either leukemia or to all cancers combined. Also, no excess mortality from any cause was observed in shipyard workers who had occupational exposure to radiation.[3,4] The principal explanation for the discrepancies between the findings of the NIOSH cohort study and those of the earlier Najarian study appears to have been misclassification of data on radiation exposure histories by the original researchers, resulting from faulty recall of work histories by the next of kin of deceased workers.[5]

Although no overall excess mortality due to cancer at any site was observed in

the NIOSH cohort study, a decision was made to conduct a case/control analysis of deaths due to malignant neoplasms of the trachea, bronchus, and lung (lung cancer). This decision followed the observation that deaths from this cause appeared to have occurred more often than expected for persons who had a cumulative lifetime radiation dosage of at least 1 rem, and who had experienced their initial exposure to radiation at least 15 years prior to death. In that group of workers, 13 deaths from lung cancer were observed versus 6.56 expected (Standardized Mortality Ratio = 198). (see appendix for more detailed backround material on these lung cancer deaths). The significance of this apparent excess should be weighed against the knowledge that there existed no a priori hypothesis postulating that radiation encountered at the shipyard might be responsible for lung cancer. Further, other potential lung carcinogens (e.g. asbestos and by-products of welding) are known to have been present.

Differentiation in a retrospective cohort analysis of radiogenic disease from disease induced by other causes would require the coding of detailed work histories for each of the approximately 25,000 cohort members. The resources required to accurately code this many records would be prohibitive. For this reason a case/control approach was employed; this study required detailed coding of work history for only the lung cancer cases and their matched controls. In addition to its economy, this approach permitted directing more attention to coding accuracy.

This report presents the findings from the NIOSH case/control study of lung cancer deaths at PNS. The work-related exposures evaluated in the analysis

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are radiation, asbestos, and welding by-products. These exposures were examined by dose or by duration of exposure. Also, the potential confounding influences of asbestos and welding by-product exposures were controlled while evaluating the effects of radiation exposure.

Methods

Population:

The study population was defined in the original cohort mortality study[3] as all white males who had worked at PNS at any time from January 1, 1952, until August 15, 1977. From this group, any person with an underlying cause of death due to a malignant neoplasm of the trachea, bronchus, or lung (lung cancer) was considered for the present analysis, to be a "case." Only death certificates in the possession of NIOSH by December 1980 were eligible for consideration. As in the previous cohort analyses, causes of death were coded by a qualified nosologist from death certificate designation.

To select an appropriate number of controls per case, power calculations were performed on various arbitrary odds ratios and exposure rates (Table 1). A ratio of 3 controls for each case was found to provide adequate power; there was no appreciable increase in power with more than 3 controls per case. Every member of the cohort, whether alive or dead, was eligible to be selected as a matched "control" for each case, with the exception that if dead, a candidate must not have died of a malignant neoplasm. Each case was compared to every other member of the cohort and evaluated for closeness of match by three criteria: 1) the absolute difference between dates of birth, 2) the absolute difference between dates of first employment, and 3) the absolute difference between the durations of employment (from first date of employment to last date of employment). These three differences were then summed to

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produce a rank. The three candidates with the lowest ranks were matched with
their respective case. When the lowest ranking score was the same for more
than three candidates, the first three candidates encountered (files are
ordered by Social Security Number) were selected. Each control chosen
remained in the pool of eligible candidates to be matched against all other
cases. In the event that the same individual was chosen as a control for more
than one case, he was assigned to that case matching more closely, and a new
candidate was selected for the remaining case.

Although recent methodologic studies[6,7,] suggest that controls should be
selected from the pool of workers at risk at the time the case died, time of
death was not considered in this sampling scheme. By matching on date of
birth, year first employed and duration of employment we assume under the null
hypothesis that the expected proportions of exposed and unexposed controls
would be the same as those of the cases.

Environmental:

The Portsmouth Naval Shipyard (PNS) is a large industrial complex which
employs workers representing a number of trades. These trades include
welding, insulating, pipe fitting, electrical work, rubber work, and
machining. Within any trade, an individual may be a radiation worker.
Regardless of an individual's job classification, if he had ever worked in an
area with potential radiation exposure, he was monitored for such exposure.

For each such individual, radiation doses have been recorded by PNS and are reported as an annual dose.

A study member was considered to be a "radiation worker" if a history of radiation exposure had been maintained by PNS, even if his recorded lifetime cumulative dose was zero. We verified all recorded radiation values by comparing the annual summaries used in the study to the actual source documents (DD 1141 forms) kept in the medical files at PNS. The DD 1141 forms of each case and each control was reviewed for evidence of internal exposures, errors and any unusual exposure or medical disqualification from the radiation program. The results of this audit revealed some errors and unusual exposures, although they were for the most part of no consequence. Among those items were one case which had received 0.106 rem of neutron exposure out of a lifetime cumulative dose of 29.122 rem. Two controls were found to have had neutron exposure (one received 0.022 rem of neutron exposure out of a lifetime cumulative dose of 0.755 rem, the other received 0.084 rem of neutron exposure out of lifetime cumulative dose of 6.006 rem). Errors were found in the radiation histories of three cases and four controls. In the worst instance a case whose lifetime cumulative dose was listed in the annual summary as 39.207 rem in actuality had 0.246 rem as a result of a missing decimal in one year's recorded dose. All of the other errors were less than 1 rem. Overall the error rate in the annual dose summaries was less than 0.5%. The dose files were corrected before analysis.

Unfortunately, no similarly comprehensive industrial hygiene record system describing the types and extent of other individual occupational exposures was

maintained by PNS. Personnel records indicating the specific shops to which
an individual had been assigned, his job classifications and the date of each
change in employment (either a change in shop or job assignment) were,
however, available. Also job descriptions, some limited PNS industrial
hygiene data, and reports of several NIOSH industrial hygiene surveys assisted
in the identification and quantification of occupational exposures at the
shipyard. A more detailed assessment of the occupational environment at PNS
was presented in a previous report.[3]

For each case and each control, a detailed work history was coded. This work
history included data on the beginning and end date of each job held
throughout an employee's entire working career at PNS. Any change in shop
assignment or in job classification was considered to be a job change. Coding
of all job history information was standardized according to a departmental
dictionary which we assembled with the help of PNS staff. This dictionary
assigned a four-digit number to every job held by each case and control. This
four-digit number was made up of a two-digit prefix indicating shop, and a two
digit suffix indicating job classification. In most instances, the same
two-digit job classification code was used for a job classification,
regardless of shop assignment. For example, the welding shop was assigned
prefix 26 while the maintenance shop was assigned the prefix 07. The suffix
for the job of welding was 01 in any shop. Hence, if an individual worked as
a welder in the welding shop, his code was 2601, whereas if he worked as a
welder in the maintenance shop, his code was 0701. This procedure enabled
examination of data by shop, by job classification, or by the combination of
the two.

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Because asbestos, which is a known lung carcinogen, and welding by-products,

which are suspected to contain lung carcinogens, were both present in

abundance at PNS, they were considered to be potentially confounding risk

factors for the development of lung cancer.[8,9] Therefore the shops and

job classifications that were suspected of involving exposure to either

asbestos or welding by-products were identified. These determinations were

based on the available industrial hygiene data. Those shop and job

classifications where asbestos exposure was probable were designated as A1;

when there was potential, but less certain exposure to asbestos, the

designation A2 was assigned. Likewise, where exposures to by-products of

welding were probable, shop and job classifications were designated W1; where

there was only potential exposure, they were designated W2 (Table 2).

Analytical:

A NIOSH case/control computer program, adapted from a University of

North Carolina program, was used to analyze patterns of exposure to radiation,

and to assess various combinations of shop, job classification, and radiation

exposure relative to mortality from respiratory cancer. Odds ratios,

corresponding chi-square values, and 95% confidence intervals were generated

for specific "exposed" shops and jobs, and for exposure to radiation.

Matching was maintained throughout all analyses that generated odds ratios for

exposures within a specified universe, and chi squares were calculated as

described by Mantel and Haenszel for individual exposure variables.[10]

When simultaneous investigation of multiple exposure variables was desired,

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conditional logistic regression was employed.[11] Use of this model allowed estimation of the odds ratio for radiation exposure while simultaneously controlling for exposure to other carcinogens, as well as for possible interactions between them.

Analyses were performed for all "radiation workers" combined (regardless of amount of exposure) as well as separately for each of the following cumulative lifetime exposure categories: 0.0 rem, 0.001 to 0.999 rem, and for those who had attained equal to or greater than 1.00 rem. (This last category roughly corresponds to the dose category in which the elevated number of lung cancers had been observed in the cohort study)

Death from lung cancer is generally believed to require a long latency period subsequent to the initiating exposure. Accordingly, analyses were performed in which 5, 10, 15, and 20 years were subtracted from the date of death of each case and the resultant dates used as the terminal work history date for each individual in the matched set. This "lagging" of work histories eliminates from consideration exposures to radiation and to asbestos and/or welding which may not have had sufficient latency to be of etiologic importance.

RESULTS

Four hundred and five persons were identified in the PNS population as having

died from malignant neoplasms of the trachea, bronchus, or lung (lung

cancer). For those cases we selected 1215 controls (three for each case).

The mean ages at date first employed, at date last employed, mean lengths of

employment, dates of birth, dates first employed, and dates last employed,

were determined for cases and controls (Table 3). Comparisons of these means

are an indication of the closeness of the matching.

Of the cases, 121 had radiation histories maintained by PNS. Of the controls,

330 had radiation histories. The radiation exposures experienced by the 1620

study subjects are summarized in Tables 4 and 5a-c.

Radiation

Lung cancer cases were found to have an odds ratio of 1.23 (95% confidence

interval (C.I.) = 0.91-1.67) for ever having had a radiation history

(Table 6). Although not significantly different from 1.0, this odds ratio is

higher than the risk of death from lung cancer in radiation workers seen in

the previous cohort analysis. This finding suggests that radiation work at

PNS might in some way be associated with mortality due to lung cancer.

Restricting the analysis to a comparison of those workers whose cumulative

lifetime radiation dose was 0.0 rem, and to those with between 0.001 and 0.999

rem compared to those with no recorded dose, did not appreciably change the

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odds ratio (OR 1.17; C.I. 0.68–2.04 and OR 1.11; C.I. 0.77–1.61,

respectively). However, restricting the analysis to a comparison of those

workers who had a cumulative lifetime radiation exposure of 1.00 rem or

greater with those with no recorded dose yielded a statistically significant

odds ratio of 1.64 (C.I. 1.03–2.62).

Asbestos

Asbestos exposure was an obvious factor to consider when evaluating lung

cancer mortality in a shipyard population.[8] Lung cancer cases were found

to have an odds ratio of 1.24 for ever having worked in an A1-classified job

(probable exposure to asbestos) (C.I. 0.92–1.68)(Table 7a). When a

requirement was imposed for a minimum of 5 years of exposure, the odds ratio

increased to 1.53 (C.I. 0.99–2.36), and with a minimum requirement of 10 years

of exposure, the odds ratio was 1.61 (C.I. 0.94–2.75). Although none of these

elevated odds ratios are statistically significant, possibly due to the small

number of cases in the latter categories, a progressive increase in odds

ratios with increasing duration of exposure is apparent.

A history of having ever worked in either an A1- or A2-classified job

(probable or potential exposure to asbestos) yielded an odds ratio of 1.25

(C.I. 0.99–1.58) (Table 7b). With a minimum requirement of 5 years exposure

in an A1- or A2- job, the odds ratio increased to 1.31 (C.I. 0.97–1.78).

However, when a 10-year minimum requirement was imposed, the odds ratio

decreased to 1.18 (C.I. 0.83–1.69).

Almost all employees of shop 56 (Pipe Shop) were classified as either A1 or A2 exposed. Odds ratios for ever having worked in shop 56, for working a minimum of 5 years, and for working a minimum of 10 years were calculated (Table 7c). All of these odds ratios were significantly elevated, and they increased from 1.43 (C.I. 1.03-2.00), for having ever worked in shop 56 to 1.83 (C.I. 1.14-2.95) for persons with at least 5 years experience in the shop, and to 1.99 (C.I. 1.10-3.58) for persons with at least 10 years experience.

Welding

Occupational exposures to the by-products of welding activity also have been associated with an increased risk of lung cancer.[9] Although some odds ratios for exposure to welding by-products were elevated in this analysis, statistical significance was not demonstrated for any W1-classified job (probable exposure to welding by-products)(Tables 8a-c). The odds ratio for ever having worked in a W1-classified job was 1.13 (C.I. 0.76-1.68)(Table 8a). Odds ratios for minimum exposure times of 5 and 10 years are 1.20 (C.I. 0.74-1.92) and 0.93 (C.I. 0.50-1.72), respectively.

Some significantly elevated odds ratios were present for working in either a W1- or W2-classified job (probable or potential exposure to welding by-products)(Table 8b). The odds ratio for ever having worked in a W1- or W2-job was 1.46 (C.I. 1.17-1.83), that for working a minimum of 5 years 1.41 (C.I. 1.06-1.87), and that for a minimum of 10 years, 1.24 (C.I. 0.89-1.74).

Almost all individuals assigned to shop 26 (Welding Shop) were involved in welding. Odds ratios for ever having worked in shop 26, for working a minimum of 5 years, and for working a minimum of 10 years are 1.13, 1.16, and 0.83 respectively (Table 8c). None of these ratios were statistically significant.

Asbestos and Welding Combination

Because of considerable overlap of study subjects among the categories of asbestos exposure, welding exposure, and assignment to welding and pipe shops, it is not readily apparent which exposure, or interaction of exposures, might account for the elevated odds ratios. To facilitate the present evaluation, asbestos and welding classified jobs were therefore combined and treated as one exposure (henceforth referred to as category AW). Lung cancer odds ratios are presented for this combined category in Table 9. For ever having had any experience in an AW-job, the odds ratio was 1.43 (C.I. 1.12-1.81). With a 5-year minimum exposure requirement, the odds ratio becomes 1.50 (C.I. 1.11-2.04), and for working a minimum of 10 years, the odds ratio was 1.38 (C.I. 0.97-1.98)

Radiation and Possible Confounders

To determine if the elevated odds ratios associated with radiation exposure were attributable to radiation exposure itself, or if they resulted from an association between radiation and exposure to other carcinogens at PNS, we

controlled for category AW exposure by using conditional logistic regression[11] with both exposure variables in the model. Odds ratios and 95% confidence intervals were calculated for ever having a radiation history, and subsequently for the categories corresponding to cumulative radiation history of 0.0 rem, 0.001 to 0.999 rem, and equal to or greater than 1.00 rem, all corrected for AW. In addition, possible interaction between radiation exposure and AW exposure was tested using the conditional logistic model. This model revealed no statistically significant interaction between these exposures. The interaction term was then removed from the model before exposure odds ratios were estimated. The estimated odds ratio for ever having a history of radiation (OR 1.17; C.I. 0.84-1.61), for a dose of 0.0 rem (OR 1.13; C.I. 0.65-1.97), for doses of 0.001-0.999 rem (OR 1.07; C.I. 0.74-1.55) and for doses equal to or greater than 1.00 rem (OR 1.50; C.I. 0.94-2.41) were all non-significant (Table 10), although the last category was associated with a higher odds ratio as compared to the preceding categories. The odds ratio for AW exposure (with radiation exposure in the model) was significant (OR 1.41; C.I. 1.09-1.89).

To assess further the suggestion of a higher risk of lung cancer with increased cumulative exposure to radiation (although not statistically significant), the possibility of a dose-response relationship was investigated. Several models were fit to characterize the shape and significance of any potential dose-response curve. The probability of death from lung cancer was modeled as a function of DOSE, DOSE + DOSE^2, and the natural log of DOSE. All three models were non-significant, with the best fit achieved by the log DOSE model.

Effect of Lagging Exposures

Meaningful analysis of lung cancer needs to take into account the induction-latency period for disease. Since the exact latency period for radiation induced cancer following prolonged exposure is unknown, exposure was lagged 5, 10, 15, and 20 years from the death of the case. In this analysis, the odds ratios are never significant for exposure to any amount of radiation at any of the lag periods examined (Table 11). In general, the odds ratios for radiation tend to become smaller as the lag intervals become larger, suggesting that there is little effect from radiation exposure. However, the very wide confidence intervals for the larger lag periods demonstrate that few workers in this population had radiation exposure 15 or more years prior to the death of the case. In contrast, all of the odds ratios for asbestos/welding exposure remain significantly elevated across all lag periods. In fact, the odds ratios increase relative to the non-lagged analysis through the 5 and 10 year lag periods before leveling off through the 15 and 20 year lag periods.

DISCUSSION

In this case/control study of 405 lung cancer deaths at PNS, odds ratios for
exposure to radiation were elevated, whether exposure was defined as (1) any
recorded radiation history, (2) measured cumulative exposure of 0.0 rem,
(3) cumulative exposure to 0.001 to 0.999 rem, or (4) cumulative exposure to
at least 1.00 rem. The increase was statistically significant for the highest
exposure group when exposure to other lung carcinogens was not considered.
This finding was not unexpected, because the group with more than 1.00 rem of
radiation exposure was very similar to the group identified previously in the
retrospective cohort mortality study as having excess risk of mortality from
lung cancer. The observation of an elevated odds ratio in this group does
more therefore to confirm the results of the SMR study than it does to
establish radiation as a factor in the development of lung cancer in workers
at PNS. Nevertheless, this observed excess suggests a relationship between
radiation exposure and lung cancer, either because radiation itself is a
causative agent, or because of a close association between radiation and other
carcinogenic exposures at PNS, such as asbestos and welding by-products.

Further analyses to evaluate these etiologic possibilities were performed on
the lung cancer cases. They revealed increased odds of having worked in areas
where asbestos and/or welding by-products were believed to be present (Table
10 and 11). However, separating the effects of welding and asbestos exposures
was not possible because most individuals with exposure to one also had
exposure to the other. Analysis of the group with the greatest exposures to
asbestos, (shop 56 workers) supports the notion that asbestos is responsible

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for some of the lung cancer risk. (i.e. the most highly significant odds
ratios were seen for this group).

Because exposures to asbestos and to welding by-products were, in some
instances, both significantly associated with mortality from lung cancer,
attempts were made to consider the potential confounding effect of these
combined exposures upon the association between radiation exposure and lung
cancer. When this analysis was done, odds ratios for radiation exposure
decreased for all dose categories examined. Thus, the hypothesis that
radiation exposure accounted for the observed excess in mortality due to lung
cancer could not be substantiated. Instead, it appears that exposures to
asbestos and/or welding by-products were largely responsible for the excess
cancer risk, and served as confounders in the association between radiation
and lung cancer.

In evaluating these findings it is important to consider the potential for
error which existed in the designation of various shop and job classifications
as having asbestos or welding by-products exposure. In large part these
designations were subjective determinations based upon our impression
following examination of the sparse industrial hygiene data at PNS,
supplemented by our field surveys and discussions with PNS personnel. Most
asbestos exposure in this study population occurred in the past, prior to
efforts by PNS to greatly curtail such exposures. Misclassification error may
account for the slightly lower odds ratios seen for persons designated as
exposed to asbestos, compared to persons who worked in the Pipe Shop (shop 56)
where there exists a higher probability of asbestos exposure. However, the

fact that the differences in odds ratios were not great between these two groups suggests that classification was fairly accurate.

Misclassification may also have resulted from errors made in the reconstruction and classification of work history data. Personnel records were not maintained by PNS for the purpose of conducting epidemiologic studies. Many of the records were very old (going back to the beginning of the century) and at times somewhat vague in their description. We (aided by PNS personnel) had to reconstruct work histories on all 1620 cases and controls. Occasionally this process included classification of persons into shop and job classification categories entitled "unknown". Coding of shops did not present so large a problem as did the coding of specific job classifications, as shops almost always were represented as a numeric code, whereas job classifications were sometimes described by short narratives. While it is impossible to determine either the extent or severity of this misclassification, it is believed that because the coders were never aware of whether they were coding a case or control, and because strict rules of coding were in force, error was both minimal and random in nature.

The same possibility of misclassification does not apply to radiation exposures, where there exists a relatively high degree of confidence in the data. Therefore, the estimated odds ratios for radiation exposures are highly reliable.

In addition to problems in Shop and job classifications, there are other areas where error could have influenced the results of the comparisons made in this

study. One source of possible error is in the selection of controls. Individuals who were deceased, but whose death certificates were not obtained by December 1980 were permitted to be included in the control population. The potential exists therefore that persons who had died of lung cancer could have been counted among the controls rather than the cases. Further, because we had no criterion stipulating that potential controls be deceased, living individuals who might eventually succumb to lung cancer also have been counted among the controls. In an attempt to address this possibility, we conducted an analysis that restricted the study population by requiring the control to survive the case, and by terminating all exposure within the matched set at the date of death of the case. Following these restrictions, the size of the study population 1307 persons; 387 cases and 920 controls. This procedure also permitted analysis of the incidence of lung cancer over time. Odds ratios for radiation categories 0.0 rem (OR 1.15), 0.001 to 0.999 rem (OR 1.09), and for equal to or greater than 1.00 rem (OR 1.56), still yielded no statistically significant increases (p = 0.65, 0.66, and 0.08, respectively) in this analysis. The odds ratio for asbestos/welding exposure continued, however, to show a statistically significant increase (OR 1.40; p 0.013).

Also it should be noted that radiation exposure has not existed in this population for as many years as have exposures to asbestos and welding; therefore the results presented are valid only up to the present time and my conceivably change with the accumulation of additional latency. Exposure to radiation over many additional years in this population remains unevaluated.

Another possible source of error in this study is the lack of of smoking

histories. Because no smoking histories were available, the assumption implicit in these analyses is that the proportion of smokers and the amount of cigarettes smoked is similar in cases and controls.

Finally, power calculations conducted at the beginning of this investigation were designed to aid in the selection of an adequate number of controls for optimum study size. The lowest odds ratio considered was 1.5. Odds ratios of less than 1.5 have associated powers that are far lower (Table 12). For instance, the power of this study to detect a true relative risk of 1.3 was only 56%. The power to detect a true relative risk of 1.2 was only 31%. Therefore, due to the size of this study, it is possible that elevated risk could exist but could not be statistically detected.

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TABLE 1

POWER CONSIDERATIONS: OPTIMUM NUMBER OF CONTROLS FOR PNS CASE/CONTROL STUDY

Odds Ratio	Exposure Rate = 33% in Controls % power for 4,3,2,1:1 Controls	Relative Risk	Exposure Rate = 20% in Controls % power for 4,3,2,1:1 Controls	Relative Risk	Exposure Rate = 10% in Controls % power for 4,3,2,1:1 Controls
1.5	97, 96, 94, 87	1.5	93, 91, 88, 78	1.5	78, 75, 71, 59
2	99, 99, 99, 99	2	99, 99, 99, 99	2	99, 99, 99, 96

TABLE 2
SHOPS AND JOB CLASSIFICATIONS IDENTIFIED WITH HAVING
ASBESTOS OR WELDING EXPOSURE

A1
(probable asbestos exposure)

0306 UTILITIES/POWER PLANT - pipefitter
0606 CENTRAL TOOL - pipefitter
0706 MAINTENANCE - pipefitter, plumber
0707 MAINTENANCE - insulator, pipe coverer
0732 MAINTENANCE - rigger
5606 PIPE - pipefitter, coppersmith, plumber
5607 PIPE - insulator, pipe coverer
5609 PIPE - laborer
9906 TEMPORARY SERVICES - pipefitter

A2
(potential asbestos exposure)

0238 TRANSPORTATION - equipment mechanic
0701 MAINTENANCE - welder
0901 SUPPLY - flame cutter (welder)
1110 SHIPFITTER - shipfitter
1111 SHIPFITTER - caulker & chipper, driller
1729 SHEETMETAL - sheetmetal worker
2600 WELDING - supervisor
2601 WELDING - welder
2602 WELDING - laborer
3101 INSIDE MACHINE - welder
5600 PIPE - supervisor
7232 RIGGERS & LABORERS - riggers

W1
(probable welding by-products exposure)

0701 MAINTENANCE - welder
0901 SUPPLY - flame cutter
2601 WELDING - welder
2602 WELDING - laborer
3101 INSIDE MACHINE - welder

W2
(potential welding by-products exposure)

0306 UTILITIES/POWER PLANT - pipefitter
0606 CENTRAL TOOL - pipefitter
0706 MAINTENANCE - pipefitter, plumber
0708 MAINTENANCE - air condition mechanic
0732 MAINTENANCE - rigger
1110 SHIPFITTER - shipfitter
1111 SHIPFITTER - caulker and chipper, driller
1729 SHEETMETAL - sheetmetal worker
2600 WELDING - supervisor
3826 OUTSIDE MACHINE -machinist
5606 PIPE - pipefitter, coppersmith, plumber
5607 PIPE - insulator, pipe coverer
5608 PIPE - air condition mechanic
5609 PIPE - laborer
9906 TEMPORARY SERVICES - pipefitter

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TABLE 3

DISTRIBUTIONS OF AGES AND CALENDAR TIMES AMONG CASES AND CONTROLS

	405 cases	1215 matched controls
AGE AT DATE FIRST EMPLOYED mean	37.02	37.07
AGE AT DATE LAST EMPLOYED (or August 15, 1977) mean	55.29	55.32
LENGTH OF EMPLOYMENT mean	14.07	14.41
DATE OF BIRTH mean	1906.25	1906.23
DATE FIRST EMPLOYED mean	1943.31	1943.30
DATE LAST EMPLOYED mean	1961.53	1961.55

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TABLE 4
DISTRIBUTION OF RADIATION EXPOSURE AMONG CASES AND CONTROLS
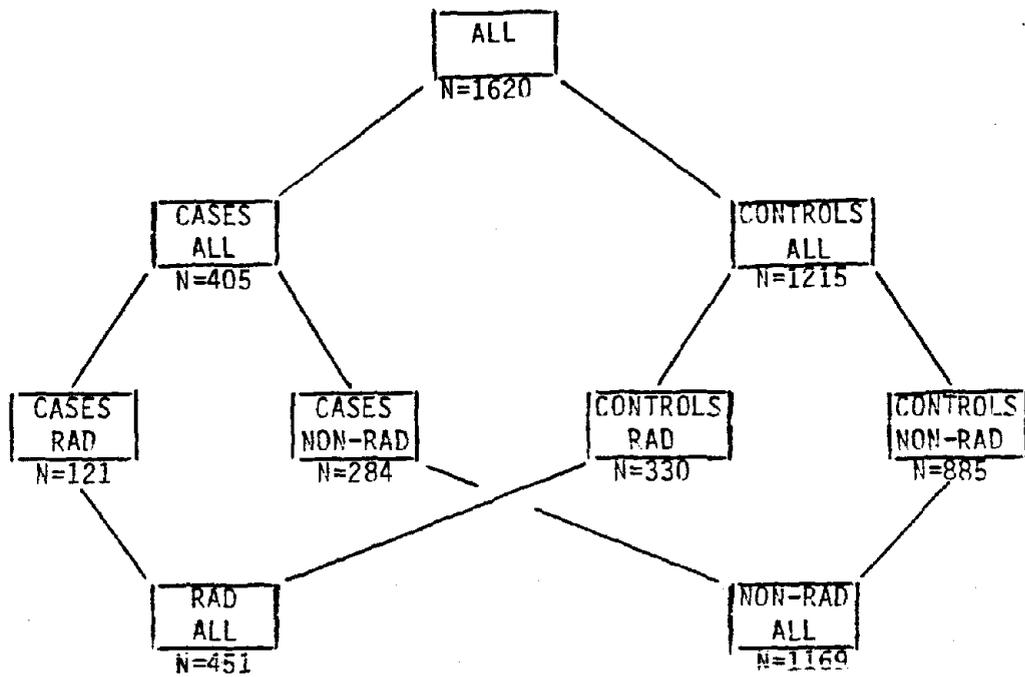
TABLE 5a

DISTRIBUTION OF RADIATION EXPOSURE AMONG 405 CASES

Radiation History	Frequency	Cumulative Frequency	Cumulative Frequency of Exposed
No History	284	284	–
0.0	21	305	21
0.001–0.029	14	319	35
0.030–0.099	19	338	54
0.100–0.499	14	352	68
0.500–0.999	15	367	83
1.000–4.999	25	392	108
5.000–14.999	8	400	116
15.00 & over	5	405	121

TABLE 5b

DISTRIBUTION OF RADIATION EXPOSURE AMONG 1215 CONTROLS

Radiation History	Frequency	Cumulative Frequency	Cumulative Frequency of Exposed
No History	885	885	—
0.0	60	945	60
0.001-0.029	40	985	100
0.030-0.099	44	1029	144
0.100-0.499	77	1106	221
0.500-0.999	29	1135	250
1.000-4.999	47	1182	297
5.000-14.999	20	1202	317
15.00 & over	13	1215	330

TABLE 5c

DISTRIBUTION OF RADIATION EXPOSURE AMONG 1620 CASES AND CONTROLS

Radiation History	Frequency	Cumulative Frequency	Cumulative Frequency of Exposed
No History	1169	1169	–
0.0	81	1250	81
0.001-0.029	54	1304	135
0.030-0.099	63	1367	198
0.100-0.499	91	1458	289
0.500-0.999	44	1502	333
1.000-4.999	72	1574	405
5.000-14.999	28	1602	433
15.00 & over	18	1620	451

TABLE 6

MATCHED STATISTICS FOR LUNG CANCER, VARIOUS RADIATION EXPOSURES

exposed cases	exposed controls	matched odds ratios	matched chi square	confidence interval
Any History of Radiation				
121	330	1.23	1.75	0.91 - 1.67
Cumulative Radiation Exposure equal to 0.0 Rem				
21	60	1.17	0.32	0.68 - 2.04
Cumulative Radiation Exposure of 0.001 to 0.999 Rem				
62	190	1.11	0.33	0.77 - 1.61
Cumulative Radiation Exposure Equal to or Greater Than 1.0 Rem				
38	80	1.64	4.33	1.03 - 2.62

TABLE 7a
MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = Asbestos 1

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	71	1215	178	1.24	2.03	0.92 - 1.68
minimum 5 years	366	35	1016	68	1.53	3.71	0.99 - 2.36
minimum 10 years	355	24	960	42	1.61	3.02	0.94 - 2.75

TABLE 7b
MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = Asbestos 1 and 2

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	213	1215	576	1.25	3.66	0.99 - 1.58
minimum 5 years	297	111	735	242	1.31	3.03	0.97 - 1.78
minimum 10 years	259	73	582	146	1.18	0.86	0.83 - 1.69

TABLE 7c
MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = Shop 56 (Pipe Shop)

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	59	1215	131	1.43	4.46	1.03 - 2.00
minimum 5 years	375	31	1066	53	1.83	6.34	1.14 - 2.95
minimum 10 years	365	21	1019	33	1.99	5.23	1.10 - 3.58

TABLE 8a
MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = Welding 1

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	41	1215	111	1.13	0.38	0.76 - 1.68
minimum 5 years	392	28	1143	71	1.20	0.55	0.74 - 1.92
minimum 10 years	380	16	1089	49	0.93	0.05	0.50 - 1.72

TABLE 8b
MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = Welding 1 and 2

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	236	1215	597	1.46	10.80	1.17 - 1.83
minimum 5 years	310	143	780	310	1.41	5.67	1.06 - 1.87
minimum 10 years	256	91	585	190	1.24	1.61	0.89 - 1.74

TABLE 8c
MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = Shop 26 (Welding Shop)

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	41	1215	111	1.13	0.38	0.76 - 1.68
minimum 5 years	392	28	1145	73	1.16	0.40	0.73 - 1.86
minimum 10 years	380	16	1094	54	0.83	0.33	0.46 - 1.53

TABLE 9

MATCHED STATISTICS FOR LUNG CANCER, RISK FACTOR = All Asbestos and Welding (AW)

amount exposure	total cases	exposed cases	total controls	exposed controls	matched odds ratios	matched chi square	95% confidence intervals
ever exposed	405	267	1215	706	1.43	8.55	1.12 - 1.81
minimum 5 years	283	152	687	317	1.50	6.85	1.11 - 2.04
minimum 10 years	226	96	487	181	1.38	3.15	0.97 - 1.98

TABLE 10

CONDITIONAL LOGISTIC REGRESSION FOR LUNG CANCER WITH VARIABLES
RADIATION EXPOSURE AND AW EXPOSURE CONTAINED IN THE MODEL

Exposure	Odds Ratio	95% Confidence interval
Any history of radiation exposure	1.17	0.84 - 1.61
Cumulative radiation = 0.0 rem	1.13	0.65 - 1.97
Cumulative radiation = 0.001 - 0.999 rem	1.07	0.74 - 1.55
Cumulative radiation = 1.00 rem or greater	1.50	0.94 - 2.41
Exposure to AW	1.41	1.09 - 1.89

TABLE 11

CONDITIONAL LOGISTIC REGRESSION FOR LUNG CANCER WITH VARIABLES
RADIATION EXPOSURE AND AN EXPOSURE CONTAINED IN THE MODEL
LAGGED 0 TO 20 YEARS BY 5 YEAR INTERVALS

	Lag Period				
Exposure	0 years OR (C.I.)	5 years OR (C.I.)	10 years OR (C.I.)	15 years OR (C.I.)	20 years OR (C.I.)
0.0 rem	1.13 (0.65-1.97)	0.75 (0.39-1.45)	0.84 (0.43-1.67)	1.83 (0.83-4.02)	0.001 (-----)
0.001 - 0.999 rem	1.07 (0.74-1.55)	0.88 (0.59-1.29)	0.84 (0.54-1.32)	1.69 (0.98-2.93)	1.62 (0.56-4.65)
1.00 rem or greater	1.50 (0.94-2.41)	1.29 (0.79-2.11)	1.12 (0.63-2.00)	1.15 (0.53-2.49)	0.38 (0.05-3.11)
asbestos/ welding	1.41 (1.09-1.89)	1.47 (1.14-1.89)	1.60 (1.24-2.07)	1.58 (1.21-2.05)	1.62 (1.22-2.15)

TABLE 12
POWER CURVE FOR INCREASING RELATIVE RISK
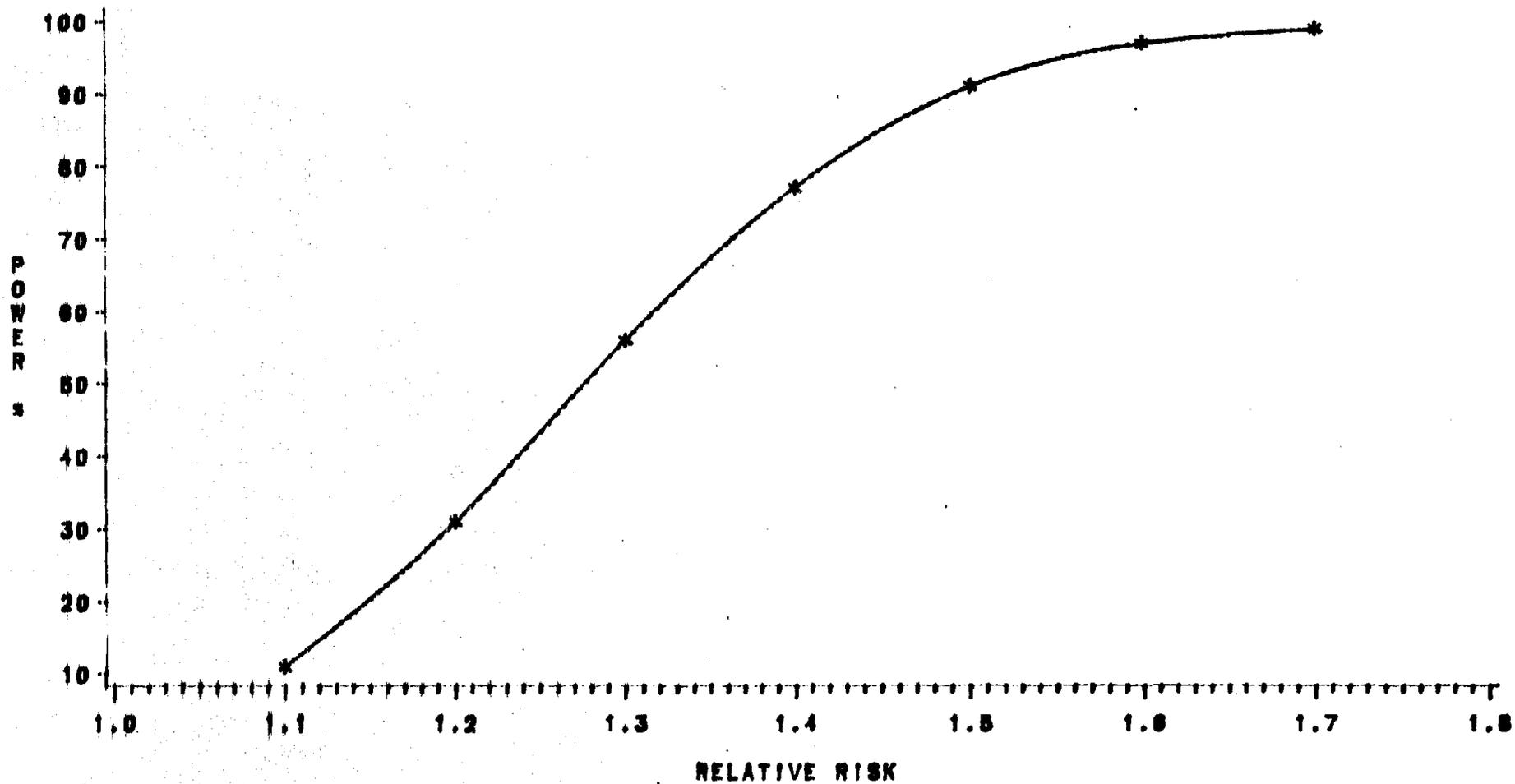
POWER CALCULATED FOR ANALYSIS OF DICHOTOMOUS VARIATES

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Appendix

Lung Cancer Deaths

In December 1980, a report entitled "Epidemiologic Study of Civilian Employees at the Portsmouth Naval Shipyard" was issued by the National Institute for Occupational Safety and Health. This report described the mortality experience of 24,545 persons who had worked at the Portsmouth Naval Shipyard between 1952 and 1977. The study had been initiated because of a report of excess leukemia deaths among former nuclear workers at the facility. Contained in the report were detailed analyses of the deaths due to hematopoietic malignancies, as well as from all malignant neoplasms combined. These analyses included stratification of observed and expected numbers of deaths by latency and duration of employment. For 7,615 radiation workers, further stratification by lifetime cumulative radiation dose was presented. In addition, overall observed and expected numbers of deaths for 83 specific causes were reported. Detailed stratification by dose and latency did not appear in the report for all 83 causes of death, because of concerns over the meaning of associations found during multiple comparisons without benefit of a priori hypotheses. They were, however, calculated as part of the computer program that generated the overall figures.

The 1980 paper reported that 81 deaths had occurred within the death category of malignant neoplasms of the trachea, bronchus, and lung (lung cancer), while 76.23 were expected (SMR = 106). This excess of overall lung cancer mortality was not statistically significant (95% confidence interval = 84-132). However, when the detailed computer reports of observed and expected deaths stratified by dose and latency were examined, and only those person-years at-risk which occurred after 15 years of latency and after a minimum of 0.5-rem exposure were considered, a more definite excess of lung cancer was apparent (16 observed cases vs. 8.23; SMR = 1.94). However, because this excess is dependent upon the selection of these particular dose and latency parameters which were chosen a posteriori to find the maximum value of the observed to expected ratio, the possibility that chance was responsible for the excess must seriously be considered. Further, the affect of exposures to carcinogens other than radiation was not evaluated in the cohort study, even though such exposures were known to exist.

A detailed table of the observed and expected numbers of deaths due to lung cancer follows. This table is similar to the ones presented in the 1980 report that described the mortality for hematopoietic malignancies. There have been two additional lung cancer deaths found since the 1980 analyses, making the total number of lung cancer deaths 83.

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OBSERVED AND EXPECTED DEATHS FOR LUNG CANCER
AMONG 7,615 WHITE MALES WITH RECORDED LIFETIME DOSE ≥ 0.001 REM
BY CUMULATIVE DOSE (DOSE) AND BY TIME SINCE
INITIAL RADIATION EXPOSURE ≥ 0.001 REM (LATENCY)

|OBSERVED|
|EXPECTED|

DOSE

LATENCY	0.001 – 0.030	0.030 – 0.100	0.100 – 0.500	0.500 – 1.00	1.00 – 5.00	5.00 – 15.00	15.00 & OVER	TOTAL*
1DAY –	0	0	0	0	0	0	0	0
1YR	1.0	0.4	0.3	0.1	0.1	0.0	0.0	1.0
1YR –	1	2	2	3	1	0	0	9
3YRS	1.2	1.3	1.3	0.4	0.7	0.1	0.0	5.0
3YRS –	1	2	0	0	1	1	0	5
5YRS	1.2	1.4	1.7	0.6	1.0	0.3	0.0	6.3
5YRS –	5	5	5	2	5	3	0	25
10YRS	3.1	4.1	6.2	2.4	4.2	1.7	0.4	22.2
10YRS –	3	6	3	6	5	0	1	24
15YRS	2.8	3.5	6.6	3.1	5.6	2.5	1.2	25.4
15YRS –	1	1	2	3	6	4	3	20
20YRS	1.7	1.7	3.4	1.6	3.4	1.7	1.0	14.5
20YRS	0	0	0	0	0	0	0	0
& OVER	0.2	0.2	0.2	0.1	0.3	0.1	0.1	1.3
	11	16	12	14	18	8	4	83
TOTAL*	11.2	12.7	19.8	8.3	15.4	6.5	2.7	76.6

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*totals may not add up because of rounding